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Contents

SCAR Working Group on Geodesy and Geographic Information

Report of the Thrid SCAR Antarctic Geodesy Symposium,	
St Petersburg, Russia, 18–20 July, 2001	1
Appendices	69



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SCIENTIFIC COMMITTEE ON ANTARCTIC RESEARCH

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SCIENTIFIC COMMITTEE ON ANTARCTIC RESEARCH

SCAR Report

No 21, January 2002

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69

1

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CONTENTS

INTRODUCTION

.

PAPERS PRESENTED AT THE SYMPOSIUM	
The Response of Polar Ionosphere to a Magnetic Storm Obtained from GPS Observations	
Baran, Wielgosz, Cisak, Shagimuratov:	1
Analysis of Regional Geoid Estimation in Victoria Land	
Barzaghi, Borghi, Capra, Gandolfi:	6
VLNDEF Project for Crustal Deformation Control of Northern Victoria Land	
Capra, Gandolfi, Mancini, Sarti, Vittuari:	8
The SCAR GPS Campaigns in the ITRF2000	
Dietrich, Rülke:	10
The International GPS Service (IGS) Ionosphere Working Group Activities	
Feltens, Iono:	12
Outline of the GIS of the Antarctic Environment	
Klepikov:	16
Upgrades to the Australian Antarctic Geodetic Network, 2000/2001	
Johnston, Digney, Manning:	19
GPS connections at Antarctic Tide Gauge Bench Marks in 2000/2001 Summer	
Manning, Johnston, Digney:	25
SCAR Geodesy in Antarctica	
Manning:	30
Extension of the Antarctic Geodetic Network in Grove Mountains	
Johnston, Digney, Manning:	34
Connections between Geodetic Networks in the Larsemann Hills 2000/2001	
Johnston, Digney, Manning:	38
Application of the NMD-GA Online GPS Processing System (AUSPOS) to Antarctica	
Dawson, Govind, Manning:	42
Influence of Ionosphere in Arctic and Antarctic Regions on GPS Positioning Precision	
Krankowski, Baran, Shagimuratov, Cisak:	49
On Determination Precision of Tropospheric Delay at the Antarctic Coast Stations	
Zablotskyj:	53
Contribution of Data from Polar Regions to the Investigation of Short Term	
Geodynamics. First results and Perspectives	
Krynski, Zanimonskiy:	56
East Antarctica Coverage GIS Project	
Yuskevitch	61
SLIDE PRESENTATIONS	
Summarizing Information to Update the SCAR-GGI Permanent Tide Gauge Observatory	
Sites, Antarctica	
Shibuya:	66
APPENDICES	
1. List of Participants	69
2. Symposium Program	70
3. List of Papers	72

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Report of the

THIRD ANTARCTIC GEODESY SYMPOSIUM 2001

St Petersburg, Russia, 18–20 July 2001

INTRODUCTION

This SCAR Antarctic Geodesy Symposium (AGS'01) was the third inter-period symposium arranged by the Working Group on Geodesy and Geographic Information as a contribution to the GIANT program. It was hosted by Aerogeodezia, at the Arctic and Antarctic Research Institute, St Petersburg. Fourteen people participated in the symposium which included representatives from seven SCAR countries (see Appendix 1).

The program contained presentations on recent history of Russian geodetic activities in Antarctica and reports on active research in Antarctica. A particularly notable presentation was made by Professor Reinhard Dietrich on the inclusion of results from the SCAR GPS surveys in the International Terrestrial Reference Frame (ITRF 2000) of the International Earth Rotation Service. A new area of research was the research project headed by Dr Cisak, on the influence of the atmosphere on precise GPS observations related to Antarctica. Australia presented details of an impressive on-line GPS processing service as a new tool for application in Antarctica. Extended discussion on methods for calibration of tide gauges followed the presentation by Dr Kazou Shibuya on Antarctic tide gauges. Current field activities in Antarctica were highlighted by Australia, Italy, Japan, Germany and USA. Feedback on the ANTEC, and the WG-GGI Geographic Information meetings, was given by several participants, who had attended these meetings held in the previous week in Siena.

A joint reception was hosted by AARI for the symposium attendees together with representatives from the separately held ATCM meeting. This reception was followed by a technical tour of the facilities at AARI including the Otto Schmidt Research Centre in the Institute. Presentations on the second day were followed up by technical tours to the Arctic and Antarctic Museum and inspection of the impressive facilities of the Aerogeodezia business enterprise.

The excellent symposium was by hosted by Dr Alexander Yuskevitch of Aerogeodezia utilising AARI facilities and continued the successful series of inter-period technical geodesy symposia. Most participants provided final versions or summaries of their presentations and these are published in this report

John Manning Chief Officer

The Response of Polar Ionosphere to a Magnetic Storm Obtained from GPS Observations

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Abstract

GPS measurements at IGS network were used to study the ionospheric effects of September 12th-16th, 1999 magnetic storm on Arctic and Antarctic regions. The GPS data from more than 60 stations of EPN (EUREF Permanent Network) were applied to create Total Electron Content (TEC) maps over Europe. The dense GPS network in Europe enabled to release TEC maps with high spatial and temporal resolution. 15 minutes averages of TEC values were taken to produce TEC maps. The storm consisted of the positive as well as the negative phase. The positive effect took place during the first day of the storm. A short daytime enhancement of TEC was observed at all latitudes. The maximum enhancement reached a factor of 1.3-1.5. On the second and third days the negative phase of the storm appeared. The decrease of TEC was registered regardless of time of a day and exceeded 70% relative to the quiet days. On September 15th and 16th once again an essential daytime enhancement of TEC was observed.

The complex nature of the ionospheric storm was related to the features of development of magnetic storm. We found out that during the storm the large and mediumscale irregularities occurred in the high-latitude ionosphere. The multi-stations technique was used to create TEC maps and it was successful in particular to study the midiatitude ionospheric trough. We also found out that the essential changes of TEC registered in the auroral and subauroral ionosphere were attributed to the effect of the trough. Data on dynamics of the trough in dependence on geomagnetic activity is presented. The horizontal gradients in the ionosphere during the disturbances were pronounced. These gradients may have an impact on ambiguity resolution while processing GPS data.

1. Introduction

Nowadays GPS measurements are commonly used to investigate the structure and dynamics of the ionosphere. Recently, several authors have applied the GPS network data to study an occurrence of TEC during a storm (Ho et al., 1998; Musman et al., 1998; Jakowski et al., 1999; Baran et al., 2001). Those studies basically concern analyses of winter events during solar minimum. It is known, that the ionospheric effects of a storm essentially depend on the season (Fuller-Rowel and Codrescu, 1996). Here we present data on the ionospheric response to a September 1999 storm. The paper stresses especially on the response of TEC in polar and subauroral regions of the ionosphere. The data of Arctic and Antarctic GPS stations were used for analysis of ionospheric TEC behaviour during the storm. The detail picture of development of the storm in TEC was obtained for European sector by producing TEC maps. The dense network of GPS stations in Europe enabled to conduct TEC measurements with high temporal and spatial resolution and find out the dramatically changes of TEC during the storm. The reasons for these phenomena is discussed.

2. Geomagnetic Conditions

September 1999 included a few magnetic active periods. We shall discuss the intensive disturbances of 12-16 September. The variations of Kp and Dst indices are presented in Fig.1. The sudden commencement of storm occurred September 12th at 04 UT. The maximum sum of Kp reached 39 on September 13th. The storm consisted of series of intensive geomagnetic bays.





Figure 1. Kp and Dst variations during September 11th - 16th, 1999

3. Data Source

The GPS measurements collected at the stations of IGS and EPN networks were used in this study. The EUREF Permanent Network observations were used to produce TEC maps. Data from more than 60 European GPS stations were processed (Fig.2).



Figure 2. Map of stations used in this paper

4. Estimation Technique

When estimating TEC from GPS observations the ionosphere was approximated by a spherical shell at fixed height of 350 km above the Earth surface. The simple geomagnetic factor was used to convert the slant TEC into a vertical one. The high precision phase measurements were used when processing GPS observations. The phase ambiguities were removed by fitting phase measurements to code data collected along individual satellite pass. After pre-processing the phase measurements contained an instrumental bias only. The absolute TEC and the instrumental bias were estimated using the single site algorithm (Baran et al., 1997). The biases were determined for every individual stations using GPS measurements of all satellite passes over site in 24-hour period. The diurnal variations of TEC over site and biases for all satellites were simultaneously estimated. After the technique had been run on all stations the instrumental biases were removed in all satellite passes. Using this procedure the absolute line of sight TEC for all satellite-receiver paths were calculated.

To solve the spatial and temporal variations of TEC in GPS data and to produce TEC maps the measurements were fitted to a spherical harmonic expansion in F and Q. The coordinate system used is geographic latitude (F) and longitude (Q). Only TEC observations with elevation angles above 20 ∞ were used in the fits. The spherical harmonic expansion was truncated to the order and degree of 16.

The accuracy of TEC maps depends on spatial gaps in TEC data (Manucci *et al.*, 1998). The large number of GPS stations in Europe provide a good coverage for GPS data and enable to get high accuracy TEC maps with an error at the level of 0.5 - 2TECU. Fig. 3 shows the shell coverage for data arcs of 15 min. length. The adequate shell coverage yields a reasonable surface harmonic fit and provides TEC spatial resolution of 100-200km with time resolution of 15 min.

In order to clearly identify the ionospheric changes during the storm the percentage change of storm-time TEC relative to TEC maps for quiet conditions was computed. To obtain the quiet time data we averaged 5 magnetically quiet days of TEC measurements. The maps over Europe in this case were produced every 15 minutes. To discuss the storm behaviour in detail, various temporal and spatial TEC profiles were obtained from TEC maps. All TEC data was presented in TEC units (1TECU = 10^{16} el/m²).

5. Diurnal Variations of TEC

General idea of storm development can be seen in dayby-day diurnal variations of TEC. Fig. 4 shows the example of TEC variations over two stations of northern and southern hemispheres during the storm. The TEC behaviour at KIRU, VAAS and SYOG stations is very similar. On the first day of the storm the positive effect took place. The short time increase of TEC was observed near local noon. On the second and third days the negative phase of the storm was developed. The main feature of the storm under consideration is a significant positive effect during daytime on 15 and 16 September. This series of TEC enhancement is probably related to the feature of development of magnetic storm, which included the sequence of magnetic bays (Fig.1).

It is interesting that at VESL station the storm effect is weakly pronounced. It can be seen that at VESL the absolute level of TEC is lower than at higher latitude SYOG station. It appears that VESL was located near the ionospheric trough. In the trough the TEC is minimal and it is increasing in direction of both the equator and the pole. Unfortunately the longitudinal arrangement of Antarctic stations does not represent the latitudinal distribution of TEC in Antarctic area and does not enable to determine the latitudinal location of trough. Difference in behaviour of TEC at SYOG and VESL can partially be attributed to the longitudinal effect of storm development.



Fig.3. Spatial coverage by data provided by GPS network at arc of 15

REPORT OF THE THIRD SCAR ANTARCTIC GEODESY SYMPOSIUM



Figure 4. Diurnal variation of TEC during 11-16 September 1999 (solid curves) with median values (dots). The geomagnetic coordinates are given in the figure.

6. Spatial Variations of TEC During Storm

The fine spatial structure of the ionosphere is well traced in GPS phase observable on individual satellite passes. Fig. 5 demonstrates the variations of TEC along single satellites tracks on quiet day of September 11th (SKp=16) and on disturbed day of September 12th (SKp=31). Because the orbital revolution period Of GPS satellite is 12h of sidereal time the track repeats on successive days except the satellites arrive 4 minutes earlier each day. In Fig. 5 one can see that during storm the auroral and subauroral ionosphere was essentially modified. The large and medium scale structures with deep changes of TEC developed after noon during the storm in the Northern and Southern hemispheres.

The behaviour of TEC at stations spaced out on 300-500 km is also different. It is evident that spatial correlation of TEC during the storm deteriorated. The large scale ionospheric structure we attributed to the occurrence of the main ionospheric trough, which during storm was lowering towards the equator. The storm-time horizontal gradient in ionosphere also increased. The severe ionospheric conditions, which occurred during the storm, can prevent ambiguity resolution and influence on accuracy of GPS positioning (Wanninger, 1993).



Figure 5. Time variations of TEC along individual satellite passes on quiet day 11 (solid curve) and disturbed day 12 (dots) September 1999. The location of the satellite traces on ionospheric height are also presented (crosses)

7. Storm-time TEC Distribution over Europe

The temporal evaluation of TEC distribution over Europe on the first disturbed day i.e. on September 12th is presented in Fig. 6 via the series of TEC maps. When producing the maps we used 15-min averaged TEC data. This provides analysis of ionospheric response to the storm in detail. The presence of the trough is the significant feature of latitudinal variations. In Fig. 6 one can see that the trough occurred at the east and after that moved to the west. As compared to quiet geomagnetic conditions the daytime ionization enhanced at high latitudes and after that moved to low latitudes. The enhancement of TEC amounted to 30-50% at high latitudes; towards the equator the percentage deviation have increased to 60-80%. The positive effect in TEC lasted till 15-16 UT and then the negative phase of the storm started.



Figure 6. TEC maps over Europe in geographic coordinates for post noon sector of 12 September

In Fig. 4 one can see the marked surge in diurnal variations of TEC near the noon on September 12th. The analysis of diurnal variations of TEC at different latitudes showed that the surge moved towards the equator. The surge at the lower latitudes appeared about 2-3 hours later. TEC maps with 15min interval enabled to obtain the picture of TEC perturbation related with this surge in detail. Fig. 7 demonstrates the temporal evaluation of latitudinal profiles of TEC deviation. Here one can see as the large-scale wavelike perturbation moved towards the equator. It is interesting that the amplitude of the perturbations increased with time. The perturbance is associated with a large-scale travelling disturbance (TID) that have latitudinal scale of about 1500-2000km. Time delay of wave surge corresponds to a propagation velocity of the perturbation, i.e. to about 200ms ¹. The velocity is lower than the TID velocity of winter storm of January 10th, 1997 (Jakowski et al., 1999).

During September 13th and 14th the negative phase of the storm in TEC distribution over Europe took place. The latitudinal profiles of the percentage TEC deviation (from averaged quiet values) on September 13th and 14th at longitude of 20[∞] E are presented in Fig.8. The daytime depressions exceeded 50% during September 13th and 30%



Figure 8. Latitudinal profiles of percentage TEC changes relative to the quiet time for 13 September (left panel) and 14 September (right) at different hours. The zero level is shown for each curve



Figure 7. The 15 min latitude profiles of percentage TEC changes relative to the quiet time for period of 11:45-13:15 UT, 12 September 1999. The zero level is shown for each curve

during September 14th. There are interesting strong variations of percentage deviation of TEC on latitude in evening/night sector. The effects we attribute to the difference in location of the trough for disturbed and quiet geomagnetic conditions. For September 13th the negative effects were more pronounced at latitudes over $30 \approx 55 \approx N$. At the same time on September 14th the depression of TEC was observed at all latitudes under consideration.

It is worth to note the longitudinal dependence in development of the storm at midlatitudes during September 13th. At longitudes over 20∞E the positive effect while at longitudes under 20∞E the negative effect were detected. Such behaviour of TEC gives an evidence of the regional feature in development of the storm (Cander and Mihajlovic, 1998).

The feature of the storm is the occurrence of the daytime positive effect on a recovery stage of the storm on September 15^{th} and 16^{th} (Fig. 9). The attention shall be paid to time shift of percentage deviation maximum when going from high to lower latitudes. The maximum at the lower latitudes appeared about 2-3 hours later. At high latitudes the duration of the positive effect was about 3-4 hours. After 12 UT at latitude of 70∞ N the negative effect took place on September 15^{th} as well as on 16^{th} . At all



Figure 9. Diurnal profiles of percentage TEC changes relative to the quiet time for 15 September (left panel) and 16 September (right) at different latitudes (40∞ , 50∞ , 60∞ , 70∞ N). The zero level is shown for each curve

latitudes the positive effect was observed only in daytime. During night at high latitudes the negative effect took place on September 15^{ch} and 16^{ch} .

8. Storm-time Dynamics of the Ionospheric Trough

The temporal variation of TEC for individual satellite passes (Fig.5) and TEC maps (Fig.6) demonstrate the trough-like structures in behaviour of TEC. The occurrence of the trough in latitudinal profiles of TEC is presented in Fig. 10 for quiet and disturbed days. For quiet geomagnetic conditions the trough-like structure was observed after 19 UT. The ratio of TEC at polar wall to bottom of the trough was less than 2, the equatorward wall is weakly pronounced. For disturbed day (September 12th) the trough started after 15 UT (16:30 LT). The depth of the trough increased. Both walls of the trough were particularly pronounced. For September 13th equatorward wall was well pronounced and the polar one was weak. The ratio of TEC at equatorward wall to bottom amounted to the factor of 3-4. The value of TEC at the bottom of the trough made up only 3 TECU. The equatorward displacement of the trough is well detected during the disturbance. Location of the trough was also shifted to the equator. As the whole, the trough underwent substantial changes during the disturbance.

Summary

The behaviour of TEC during the equinox storm is very complex and includes many interacting ionospheric effects. Storm-time response of TEC depends on latitude, longitude, local time and it is specified by features of development of magnetic storm such as:

- Irregularities with a wide range of scale sizes, that developed during the storm in the ionosphere caused deep variation of TEC. As a consequence the spatial correlation of TEC was deteriorated.
- Large scale TID with amplitudes over 20% higher relative of quiet time occurred during the disturbance.
- Structure of the polar ionosphere was essentially controlled by the ionospheric trough. The location and depth of the trough depends on the local time, magnetic activity, and season.
- Horizontal gradients in the ionosphere also severely increased during the storm. Maximal latitudinal gradients of TEC occurred at polar and equator walls of the trough.

Acknowledgements

The authors are grateful to IGS community and WDC-C1 for the GPS data. Research was conducted within the project No 8T12E04520 supported by Polish National Committee for Scientific Research.



Figure 10. The dynamics of latitude profiles at post-noon sector for quiet day (left panel) and disturbed days September 12th and 13th (central and right panel)

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Analysis of Regional Geoid Estimation in Victoria Land

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Introduction

Improvement in knowledge of Antarctic Geoid is currently one of the main purposes of the international scientific community. This is a difficult task due to the lack of gravimetric observations directly connected to the particular characteristics (climatic and hazardous) of the Antarctic continent. Each nation still owns gravimetric and geodetic data on non-public databases and it is partly because of this that it is quite difficult to obtain reliable geoid estimates. In order to define a project for the estimation of a high precision Geoid, the international scientific community needs a global geodetic and gravimetric database for the Antarctic continent (Capra & Gandolfi 2001).

The actual situation in geoid knowledge in Antarctica can be summarized in the following points:



Figure 1 - Investigated area

Moreover the effectiveness in gravity data reduction of available global geopotential models, ice thickness and digital terrain model data in the coastal area of Victoria Land (85 < j < -65; 130 < l < 181) was tested. This analysis allows us to point out some constraints on the possible high-resolution geoid computation (Fig. 2).

One of the main problems is the recovery of gravimetric data from the scientific community. In particular, the historical data as a lot of information about the survey characteristics has been lost.

Ice surface topography has been taken from BEDMAP, the cartography from ADD (Antarctic Digital Database), the ice density mean values from literature, and Airborne Gravity data regarding the Northern part of Victoria Land has been provided from Reitmayr *et al.* (1963 - 1995) (USG: A.P. Crary (1963), BEN: S.B. Smithson (1972),

- a precise geoid (<1 m precision) is not available at the moment;
- some discrepancies (more than 1m) between observed values and OSU91A and EGM96 are present;
- a relatively poor distribution of geodetic and geophysical data, overall gravity data is present.

Taking into account the state of art, some preliminary analysis has to be made in order to evaluate the possibility of estimating a really high precision geoid of Antarctica.

The impact of global model and observed data on highresolution geoid estimation in a coastal area of Victoria Land, Antarctica was performed and some preliminary analysis for verifying data compatibility and reliability were made (Fig. 1).



ROB: E.S. Robinson & J.F. Splettstoesser (1984)). The EGM96 and the GPM98CR global models have been chosen for reducing the gravity data.

Statistics of the gravity data set

In order to check the quality of the available data, some preliminary statistical test has been performed. As for the gravity data, the most significant results are listed in Table 1

The geopotential model EGM96 were computed up to degree 360 while the geopotential model GPM98CR (Wenzel, 1998) to degree 720. These are very poor results that are naturally confirmed by a campaign-based analysis that is described in Table 2. The table also indicates that only few campaigns show an efficient reduction using EGM96 geopotential model.



Figure 2. The ice thickness (a) and gravity data measurements (b) performed by different groups in Antarctica

The reasons for this behaviour are quite difficult to find both for the unreliability of the global models in the Antarctic continent and for the poor description of the gravimetric survey.

In Table 3 a test on the reduction of the masses above sea level is reported (no bathymetric information are taken into account).

Conclusions and future perspectives

Geodetic and gravimetric data collection was carried out

and a test to check available gravity data for geoid computation was done. A very poor efficiency of the used global potential models in reducing the existing gravity data was proved. Moreover the correlation between ice thickness/DTM data and gravity appears to be not sufficient for a reliable data reduction.

In the future, a deeper investigation into the different data sets will be necessary in order to verify data compatibility before starting any kind of geoid estimation.

	Points	Mean	σ	Min	Max
ΔgFA	1636	-16.47	49.02	-156.50	230.20
ΔgB	1636	-73.16	60.24	-307.80	112.00
ΔgFA - ΔgEGM96	1636	-0.85	46.66	-236.73	204.14
ΔgFA - ΔgPM98CR	1636	2.74	43.76	-209.46	199.64

Table 1 - Statistics of the gravity data set (values in mGal)

		ΔgFA		ΔgB		ΔgFA - ΔgEGM96	
Campaign	Points	Mean	σ	Mean	σ	Mean	σ
ACC	43	-37.0	-25.3	-117.9	24.8	-20.8	32.0
ACI	32	-29.0	37.9	-121.9	56.0	6.26	33.9
ACR	50	-35.6	39.3	-128.6	55.7	-17.9	42.3
BEN	736	-31.1	42.7	-51.4	48.7	-11.6	38.9
BRN	34	1 5.9	17.7	-137.1	11.3	46.6	23.0
DRY	27	-28.9	35.7	-112.9	71.5	3.5	42.3
DUE	92	58.6	64.4	- 106. 1	80.3	26.0	39.6
G07	95	-101.9	81.2	-57.0	65.3	-4.1	73.7
GON	37	-36.2	52.3	-34.7	-120.6	-114.1	76.0
KI1	61	36.1	48.8	-31.6	54.2	25.0	61.5
ROB	66	1.0	49.8	-96.2	60.6	10.5	44.7
USG	363	-9.6	31.2	-106.1	47.4	19.4	13.4
	1			1			

Table 2 Statistics of the gravity data set for each gravimetric campaign (values in mGal) (<u>Blue colour</u>: campaign with an efficient reduction using the geopotential model EGM96)

	Points	Mean	σ	Min	Max	
ΔgFA	1636	-16.47	49.02	-156.50	230.20	_
ΔgFA - ΔgTC	1636	-87.47	71.03	-391.96	190.11	

Table 3 Summary of the statistics on the reduction of the masses above sea level (values in mGal)

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VLNDEF Project for Crustal Deformation Control of Northern Victoria Land

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The VLNDEF (Victoria Land Network for DEFormation control) program was developed with the aim of extending northward and southward the existing GPS network for crustal deformation control of Victoria Land.



During 1999-2000 and 2000-2001 Italian expeditions in Antarctica completely surveyed, for the first time, a network characterised by 25 stations, spanning an area of 800 km northward and 300 km westward, covering the area from Terra Nova Bay (TNB) to Pacific Ocean Oates Coast. There was an average distance of 70-80 km between stations (Fig 1). Because of some rather long baselines, the session duration was not less than 40 hours (15 sec. sampling rate) and the network coordinates were emanated from the GPS permanent stations of Terra Nova Bay Station (TNB1).

The VLNDEF project was conducted within the activity of GIANT (Geodetic Infrastructure of Antarctica) SCAR (Scientific Committee on Antarctic Research) Program. GIANT has being developed for several years with the aim of studying the infrastructure and the geodynamics of Antarctica through the analysis of different geophysical and geodetic sources: GPS (SCAR GPS Epoch campaigns) and permanent tracking stations, DORIS, Gravimetry, VLBI, remote sensing and tide gauges. Moreover, the geodetic activities are coordinated and finalised within the actions of ANTEC (ANTarctic NeoTECtonics) SCAR Group of Specialists. Within the international research for the control of Antarctic crustal deformation, the VLNDEF network was connected to the Transantarctic Mountains Deformation (TAMDEF) network.

Figure 1. VLNDEF points distribution

The VLNDEF network includes two geodetic networks previously installed around Terra Nova Bay, Italian base in Antarctica: a geodetic reference network; and a network for deformation control of Mt.Melbourne. The networks were surveyed four times with GPS techniques (Al Bayari *et al.*, 1996, Capra A. *et al.*, 1997, 2000).

The VLNDEF network geometry is based on the local morphology as the faulting system. The station location was planned using the tectonic map of Salvini (Salvini F. et al., 1997), which shows the distribution of faults accepted from scientific community, and using USGS maps (1:250 000 scale).

First Campaign Results

GPS data have been processed using Bernese version 4.2 and GIPSY – OASIS II (rel. 2.6.1) software. The complete data-set is made up by almost twenty sessions, half of which are 24 hours long while the others are 12 hour sessions.

Bernese data processing

The solution has been obtained adopting the IGS precise ephemeris and solving ambiguities with the QIF (Quasi lono Free) method followed by the L3 (Iono-free) solution of the baselines. Ambiguities are pre-eliminated and not included in the baseline estimation procedures. The network has been fixed to the TNB1 station using as a reference coordinates the ITRF97 values available from the processing of the SCAR GPS data. The tropospheric delay is being modelled using Saastamoinen standard formula estimating a correction every two hours to its a priori values. Gradients for an azimuthally non-symmetric atmosphere have been taken into account and used in the processing procedure.

GIPSY data processing

The complete dataset has been analysed using the most recent version of GIPSY-OASIS II (release 2.6.1). The software uses undifferenced observations using both phase and code observables. GIPSY uses a Square Root Information Filter (SRIF) which is a modified Kalman filter where parameters have been estimated every 300 seconds. All sessions have been processed following a free network approach with fiducial orbits created at JPL. The troposphere has been modelled using Saastamoinen formula and Niell mapping function. Zenith delays a priori values have been corrected in the estimation process. Azimuth troposphere gradients have also been estimated.

The mean value of Helmert transformation between the two solutions is about at 1 cm level. The results did not show large differences, when compared to the accuracy of the technique, in terms of internal consistency and coordinates values. It seems that the different statistical approach and computational algorithms that the two types of software used did not influence the solutions. It is important to point out that coordinates evaluated with GIPSY for TNB1 (the GPS permanent station in Terra Nova Bay) are not significantly different from those computed in SCAR GPS Epoch campaigns and expressed in ITRF97. It therefore seems that fixing ITRF97 coordinates for TNB1 when processing data with Bernese did not introduce remarkable constraints in network solution.

It was decided to use current ITRF emanation coordinates of TNB1 for VLNDEF network for successive network repetition for crustal deformation investigation.

Conclusions

The VLNDEF project started in 1999-2000, during the XV Italian expedition in Antarctica, when a network of 21 stations has been materialised and measured. In the following 2000-2001 expedition 5 more markers have been installed and measured with the aim to realise a southward expansion of the network.

Network solutions made by Bernese and GIPSY for 21 VLNDEF stations show good internal consistency and repeatability and are not significantly different in terms of internal consistency and coordinates values. It has been decided to assume the network's coordinates emanation from TNB1 (ITRF97 solution) for successive campaigns for the deformation control.

In a near future we want to examine the connection between VLNDEF and TAMDEF networks and with SCAR GPS Epoch solutions. It will be opportune to take into account the possible constraints introduced by the use of ITRF fixed coordinates for more then one GPS tracking stations, whose coordinates are derived form international net solutions (IGS, SCAR GPS Epoch, etc).

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The SCAR GPS Campaigns in the ITRF2000

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The realization of the International Terrestrial Reference Frame (ITRF) is an important goal of the international geodetic community. Observations of satellites of the Global Positioning System (GPS) are thereby a major contribution. Data acquired during the SCAR GPS Campaigns represent valuable input for this pupose, which has been described in detail (Dietrich. 2001). It has been demonstrated, that also for Antarctica accuracies in the Icmlevel have been achieved, and the results include the tectonic mc tions of Antarctic GPS sites (Dietrich *et al.*, 2001).

Regional densifications were accepted for the realization of the ITRF2000 for the first time. As a regional densification solution for Antarctica all GPS data from 1995 to 1999 have been reprocessed with the Bernese GPS Software, Version 4.2 and forwarded as a SINEX file to the ITRS Centre of the IERS, Paris.

As a result, all Antarctic GPS stations, which provided data, are now included in the official ITRF2000 solution, which is available in the Internet (Altamimi, 2001). Table 1 shows the ITRF2000 coordinates and rates. The station distribution and horizontal motion rates are displayed in Figure 1. Thanks are directed to all participants of the SCAR GPS Campaigns.

We strongly recommend that all users of GPS in Antarctica refer to the official ITRF2000 coordinates.

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Figure 1: Station distribution and horizontal motion rates of Antarctic GPS stations within ITRF2000

REPORT OF THE THIRD SCAR ANTARCTIC GEODESY SYMPOSIUM

Station name	X	Y	Z	V _x	V,	V,
	[m]	[m]	[m]	[mm/a]	[mm/	[mm/a]
					<u>a]</u>	
ART1 66017M001	1541244.8804	-2555205.1061	-5618168.9943	13.3	-8.7	7.4
BEL1 66018M001	1105999.5362	-763743.1799	-6214256.1147	21.3	-0.2	-31.7
BELG 66018M002	1106002.2977	-763742.2090	-6214255.8014	21.3	-0.2	-31.7
CAS1 66011M001	-901776.1617	2409383.4187	-5816748.4196	0.1	-7.7	-7.3
DAL1 66019M001	1548376.2484	-2544409.3161	-5621096.3554	13.6	-7.5	4.9
DALL 66019M002	1549109.8420	-2544290.0568	-5620947.1822	13.6	-7.5	4.9
DAV1 66010M001	486854.5477	2285099.3019	-5914955.6832	0.8	-3.2	-5.7
DUMI 91501M001	-1940883.7791	1628483.3531	-5833718.0175	-1.5	-13.9	-2.4
ELE1 66021M001	1723594.8003	-2520204.0306	-5581225.2206	12.8	7.7	4.6
ESP1 66022M001	1560034.3767	-2401882.7248	-5679859.9970	19.1	-3.3	-4.8
FOR1 66023M001	2061522.3573	431615.7175	-6000314.4990	8.1	0.8	-5.6
FOR2 66023M002	2061809.1388	432116.1152	-6000155.3574	8.1	0.8	-5.6
FOS1 66024M001	757185.4670	-1904739.7270	-6019724.3107	15.8	-4.8	2.7
GRW1 66012M001	1536965.6501	-2554125.2502	-5619825.2676	16.6	-10.8	0.9
KERG 91201M002	1406337.3357	3918161.0996	-4816167.3549	-5.3	2.8	-5.8
MAIT 66028M001	2063437.6463	428659.4380	- 5999849.1166	8.1	0.8	-5.6
MAR1 66029M001	1527541.6468	-2321657.4747	-5721839.9756	17.6	-3.7	-6.1
MAW1 66004M001	1111287.1660	2168911.2787	- 5874493.5948	1.4	-2.3	-3.6
MCMU 66001M003 B	-1311703.2498	310815.1042	-6213255.1246	8.8	-12.0	-3.3
NOT1 66031M001	1451912.1204	-2436397.9268	-5693758.6311	17.1	-4.5	-3.5
OHG1 66008M003	1525852.2494	-2432401.8360	-5676185.0061	19.3	-3.7	-3.9
OHIG 66008M001	1525872.4801	-2432481.3040	-5676146.0816	19.3	-3.7	-3.9
PAL1 66005M001	1192924.6603	-2450915.5819	-5747042.5510	16.5	-5.2	2.9
PALM 66005M002	1192671.7725	-2450887.5812	- 5747096.0449	16.5	-5.2	2.9
PRA1 66033M001	1493161.9747	-2550156.7342	- 5633379.0772	14.0	-10.6	2.1
ROT1 66007M001	909255.1005	-2264721.3343	-5873063.0174	15.4	-2.5	2.0
SIG1 30607M001	2189251.3766	-2235016.4127	- 5539523.6429	14.1	-2.6	0.8
SMR1 66034M001	927077.5077	-2195046.5033	- 5896519.2639	16.0	-4.9	3.9
SPR1 66035M001	1342651.5903	-2427390.4579	-5724115.4923	16.3	-4.6	-1.4
SYOG 66006S002	1766207.8409	1460290.3502	-5932297.6797	3.8	-1.5	-1.5
TNB1 66036M001	-1623858.4728	462478.1939	-6130048.9421	5.8	-12.4	-12.2
VESL 66009M001	2009329.7131	-99741.4738	-6033158.4722	10.2	1.8	4.8
ZHON 66030M001	531102.2103	2190269.9476	- 5946719.1420	-0.9	-2.0	5.6

Table 1: Coordinate solution of ITRF2000, epoch 1997.0 and velocity solution for Antarctic GPS sites (from (Altamimi, 2001)).

The International GPS Service (IGS) Ionosphere Working Group Activities

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Abstract

The International GPS Service (IGS) Ionosphere Working Group (Iono_WG) has been active since June 1998. The working group's main task is the routine provision of ionosphere Total Electron Content (TEC) maps with a 2hour time resolution and of daily sets of GPS satellite and receiver hardware delays (DCBs). The computation of these TEC maps and hardware delays sets is based on the routine evaluation of GPS dual-frequency tracking data recorded with the global IGS tracking network. Currently five IGS Ionosphere Associate Analysis Centers (IAACs) cooperate in the Iono_WG activities.

In the medium- and long-term, the working group intends to develop more sophisticated ionosphere models and to realise near-real-time availability of IGS ionosphere products.

Beyond the routine provision of ionosphere products, the Iono_WG intends to support the ionosphere community also with other activities, e.g. by using the IGS global tracking network and capabilities to run high-rate data campaigns during events being of special relevance for the ionosphere. A first such campaign was organised during the total solar eclipse on 11 August 1999, and a solar maximum campaign, called "HIRAC/Solarmax", did run from 23 to 29 April 2001. The intent of such campaigns is to establish high-rate tracking databases for ionosphere scientists and other interested researchers, which can be the subject of ionospheric analyses over the years. The highrate data are made available through the Crustal Dynamics Data Information System (CDDIS) IGS Global Data Centre.

It is the intent of this presentation to give an overview over the Iono_WG activities, also with regard to possible common interests of the Iono_WG and SCAR/WG-GGI.

1 Introduction

The Working Group started its routine activities in June 1998: Several so called Ionosphere Associate Analysis Centres (IAACs) provide per day twelve global TEC maps with a 2-hours time resolution and a daily set of GPS satellite DCBs in IONEX format files (Schaer *et al.*, 1997). The routine provision of daily ground station DCBs is under preparation. Currently five IAACs contribute with ionosphere products:

- CODE, Center for Orbit Determination in Europe, Astronomical Institute, University of Berne, Switzerland.
- ESOC, European Space Operations Centre of ESA, Darmstadt, Germany.
- JPL, Jet Propulsion Laboratory, Pasadena, California, U.S.A.
- NRCan, National Resources Canada, Ottawa, Ontario, Canada.
- UPC, Polytechnical University of Catalonia, Barcelona, Spain.

The mathematical approaches used by the distinct IAACs to establish their TEC maps are quite different. Details about the individual IAACs modelling can be found in e.g. (Schaer 1999; Feltens, 1998; Mannucci *et al.*, 1998; Gao *et al.*; Hernandez-Pajares M. *et al.*, 1999).

2 Main Activity

Once a week the ionosphere products from the different IAACs are compared at the Ionosphere Associate Comparison Center (IACC) at ESOC. These comparisons are based on a preliminary version of a dedicated comparison/combination algorithm, being based on weighted and unweighted means. Analyses of the residuals of the different IAACs TEC maps with respect to the outcoming "mean" TEC maps allow for the establishment of statistics about the IAACs TEC maps agreement. The same procedure is principally also done for the DCBs.

However, as already mentioned above, the IAACs use very different approaches to establish their TEC maps, which results in very different temporal and spatial resolutions. These circumstances reflect also in the comparison results; the weighting scheme in the comparison algorithm must be improved. Software

REPORT OF THE THIRD SCAR ANTARCTIC GEODESY SYMPOSIUM

upgrades for an improved weighting scheme are currently under work. The new weighting scheme for the comparison/combination algorithm will use the output of two self-consistency methods proposed by NRCan and UPC (Heroux, 1999; Hernandez-Pajares, 2000). Both methods are in principle based on the analysis of residuals resulting from the comparison of directly from GPSobservables derived TEC values with corresponding TEC values interpolated from the IAACs TEC maps, in order to assess the quality of the distinct IAACs TEC maps. This is done with GPS data collected at ground stations equally distributed in a global geographic grid in order to achieve geographic-dependent weighting.

Beyond that, the Iono_WG intends to perform other kinds of validation, which are in short:

- Comparison of IAACs models vertical TEC values with TEC values derived from TOPEX (and Envisat, once launched) altimeter data.
- Validation with ionosondes data.

- Validation by verifying the different IAACs models ability to adapt to International Reference Ionosphere (IRI) TEC values. - The IRI is considered in this test simply as a pure mathematical reference.
- Analyses of ERS/Envisat orbit determination statistics resulting from the usage of the different IAACsmodels for correcting ionospheric delays.

As an example of results obtained with the preliminary comparison algorithm, Figure 1 shows the sequence "mean" TEC maps of 28 March 2000, a day during a period in the current solar maximum, when the TEC level was very high.

The other important subject of comparisons are the DCBs. When directly comparing the DCB-series of the different IAACs, one can see an overall agreement in the order of about 0.3 ns. According to a presentation of S. Schaer at the IGS Workshop, 27 - 29 September 2000, Washington, mean IAAC satellite DCB series show an agreement of about 0.1 ns, while the day-by-day variations are significantly higher.



Figure 1: The IGS "weighted mean" TEC maps of 28 March 2000 in [TECU] (1st row: 1^h, 3^h, 5^h, 7^h; 2nd row: 9^h, 11^h, 13^h, 15^h; 3nd row: 17ⁿ, 19^h, 21^h, 23^h).

3 Special Activities

On the occasion of the solar eclipse on 11 August 1999 the Iono_WG organized and coordinated a special observation campaign. This event was a unique opportunity to demonstrate the power of the GPS technique in monitoring the ionospheric ionization. As the zone of totality crossed Europe, the rather dense portion of the IGS network provided excellent conditions for monitoring the eclipse. Around 60 IGS ground stations along the eclipse path from North America over Europe to the Middle East recorded on that day highrate dual-frequency GPS-data (1 sec resp. 3 sec). These solar eclipse data were archived at the Crustal Dynamics Data Information System (CDDIS) NASA/GSFC U.S.A. and can be accessed for analyses via anonymous ftp at cddisa.gsfc.nasa.gov in directory /gps/99eclipse (Feltens and Noll, 1999).

Figure 2 presents an example for the detection of Travelling Ionospheric Disturbances (TIDs) from highrate GPS measurements at two Swedish stations, recorded during the solar eclipse on 11 August 1999. See also Jakowski *et al.*, 1999a and Jakowski *et al.*, 1999b for the Solar Eclipse Campaign.

The current solar maximum represents another unique chance to establish such a high-rate tracking database for ionosphere analyses. The two regions of major interest are in this case: 1) the polar regions and 2) low latitudes including



Figure 2: Travelling Ionospheric Disturbances (TIDs) detected from high-rate GPS data at two Swedish stations on 11 August 1999

the crest regions at both sides of the geomagnetic equator.

The "HIRAC/SolarMax" campaign was thus organized by the Iono_WG and lasted from 23 - 29 April 2001. On 26 April a large solar flare was observed which impacted the ionosphere on 28 April. A list of the stations and a map (Figure 3) can be accessed as .pdf files via

ftp://cddisa.gsfc.nasa.gov/pub/gps/01solarmax/solarmax_table.pdf ftp://cddisa.gsfc.nasa.gov/pub/gps/01solarmax/solarmax_map.pdf



Figure 3: Global Map of IGS stations which were proposed to participate at the "HIRAC/SolarMax" campaign. Of these stations over 100 delivered their data to the CDDIS so far.

In order to obtain a comprehensive view of the geomagnetic and ionospheric state, the IGS activity within HIRAC/SolarMax was coordinated with other ionospheric observation programs or measurement campaigns, especially with the European action COST 271: "Effects of the upper atmosphere on terrestrial and earth-space communications". More than 20 people participating in COST 271 have supported this campaign by a number of coordinated and well-qualified observations. In particular the global ionosphere impact on signal propagation in space based communication and navigation systems shall be studied. These coordinated measurements included:

- Vertical Sounding,
- GPS based TEC monitoring over Europe,
- NNSS measurements along tomography chains,
- Geomagnetic Activity,
- · Electric field measurements,
- EISCAT,
- Space based GPS onboard CHAMP,
- HF Radar measurements.

The high-rate GPS and GLONASS data are also archived at the CDDIS and are available through anonymous ftp at *ftp://cddisa.gsfc.nasa.gov* in directory / *gps/01solarmax* (Feltens, Jakowski and Noll, 2001). The high-rate tracking data of more than 100 IGS stations were delivered to the CDDIS so far (status at 18 June 2001). Similar campaigns are also planned for the future.

4 Possible Involvement of the IONO_WG into SCAR/WG-GGI Activities

Ionospheric behaviour is often a complicated one, especially around the equator and over the polar regions this was also the main reason why the HIRAC/SolarMax campaign was initiated. The Iono_WG has thus a vital interest to become involved into activities like Antarctic research. Generally the IGS could contribute to the Antarctic research activities with high-rate GPS tracking data, since quite a lot of IGS sites are located in the Antarctica, and many of these sites are already involved into the SCAR/WG-GGI activities. The IGS Iono_WG could especially contribute with routine TEC information over the Antarctic region. Dedicated tracking campaigns, similar to HIRAC/SolarMax, could be organised to get a better understanding of high atmosphere behaviour over the Antarctica. The Iono_WG could also use its contacts to the ionosphere community to encourage ionosphere people to contribute with other non-GPS data to such campaigns too. Further fields of cooperation might be possible.

5 Conclusions and Look into the Future

The IGS Ionosphere Working (Iono_WG) commenced its activities in June 1998. Main task is the routine establishment and provision of ionosphere products using IGS global GPS tracking data. The world wide IGS GPS and GLONASS ground stations network (about 180 sites) provides the unique opportunity for a global ionosphere monitoring on routine base. Currently five Ionosphere Associate Analysis Centers (IAACs) contribute to this routine processing. Once the current comparison/ combination algorithm is upgraded with a new weighting scheme, the Iono_WG intends to start with the routine delivery of an official IGS ionosphere product.

The next important task will be a significant reduction of the time interval between the recording of the GPS observables and the delivery of ionosphere products derived from these GPS data; currently these are 11 days.

In the medium and long-term the Iono_WG models shall be extended and improved, e.g. with regard to special models for certain regional and local areas (e.g. for the Antarctica), or at the IAACs the development of more complex mathematical ionosphere models. Final target should then be an independent IGS ionosphere model.

With regard to the SCAR/WG-GGI activities, it could be of benefit for the Iono_WG also to become involved in Antarctic research.

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Outline of the GIS of the Antarctic Environment at the Arctic and Antarctic Research Institute, St.-Petersburg, Russia

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The Geographic Information System of the Antarctic Environment (hereafter GIS "Antarctic Environment") is developing in the Arctic and Antarctic Research Institute (AARI) in the framework of subprogram "Study of the Antarctic" of Federal Program "World Ocean". GIS "Antarctic Environment" project is planned for 1999-2007.

The main goal of the project is historical data rescue and the preparation of a modern quality-controlled set of data on the Antarctic environment. Main tasks of the work are:

- digitization of manuscript data;
- reformatting of data stored in electronic form to the international data exchange formats;
- data quality control.

The main functions of GIS "Antarctic Environment" are:

- data organization under the control of reliable modern distributed Relational Data Base Management Systems (RDBMS);
- the storage of information on modern special devices with maintenance of corresponding data formats and documentation;
- data analyses, data processing and interpretation for the support of research activities in the Antarctic including remote data requests and transfers.

The system can be divided into three parts:

- distributed different thematic data bases;
- GIS-server with corresponding server/client applications;
- Web-server with it's applications.

The main system's module is the cartographic server, which combines different features of this 3 technologies and supplies users with friendly and reliable interface, supported with well-known Web browsers, such as Internet Explorer or Netscape Navigator. Different ways of GIS and Web technologies matching have been reviewed to make the reasonable choice for Intra/Internet scale cartographic server realization. Commercial and Open source software products for project development have been discussed. We use two platforms: first is based on commercial software (Win2000 Server, Oracle RDBMS, GIS ARC/INFO) and second is based on Open Source software (Linux, Grass, PostgreSQL, Apache Web-server).

Different types of information will be stored in the GIS "Antarctic Environment": digital data, hard copy maps, text information, illustrations (photo and drawings), satellite images, model results. Information will be divided into several sections: meteorology, oceanography, magnetosphere and ionosphere geophysics, sea ice, continental ice sheet, biology, geology and Russian Antarctic Expedition activity.

The AARI efforts are mainly focused now on development of the Antarctic atmosphere and ocean digital data bases as parts of GIS "Antarctic Environment": Steps of work with meteorology and oceanography data are the next:

- data rescue and digitization;
- data checking (visual comparison with the original data reports);
- preliminary quality control (search of obvious errors and theirs rejection and correction);
- expert quality control (search of questionable values and marking by flags, expert quality control of all questionable values, development computer algorithms for the quality control).

At the moment:

- the general project of GIS "Antarctic Environment" has been developed; a test version of the GIS, based on digital oceanography data, has been created (Figs. 1 and 2);
- 2 special Windows95/98/NT interface programs for RDBMS have been developed and
- 3 the interface programs for RDBMS have been developed.

Some Antarctic atmosphere data (Tables 1, 2 and 3) are already available via the Internet, at (http://www.aari.nw.ru/).

REPORT OF THE THIRD SCAR ANTARCTIC GEODESY SYMPOSIUM



Figure 1. Distribution of the number of observations with measured parameters from the AARI Antarctic oceanography database (The database contains physical and chemical oceanography data at nearly 40 thousand stations made during 1924 - 2000 in the Southern ocean)

Number of stations



Figure 2. Utilization of user's interface of the oceanography module of the Antarctic GIS for data visualization

17

SCAR WORKING GROUP ON GEODESY AND GEOGRAPHIC INFORMATION

Station	PC - index*	Riometric data	Magnetic field variation	Comments
Vostok	1998-2001	1998-2001		PC-index data are presented in AARI Internet site as current one-minute values in near real time.
Mirny		1999-2001	1995-2001	
Novolazarevskaya			2000-2001	

Table 1. Russian Antarctic magnetosphere and ionosphere geophysics data and parameters available via Internet. (*The PC index is an index to monitor the polar cap magnetic activity which is mainly caused by changes in the Inter-planet magnetic field southward component and solar wind velocity).

Station	Geopotential height (H)	Temperature (T)	Wind speed (V)	Comments
Bellingshausen	1969-1996	1969-1996	1969-1996	H, T and V data are
Mirny	1978-2000	1978-2000	1978-2000	presented in Internet as current mean monthly values
Leningradskaya	1983-1991	1983-1991	1983-1991	at st andard pressure levels
Novolazarevskaya	1978-2000	1978-2000	1978-2000	after statistical control.
Vostok	1980-1992	1980-1992	1980-1992	
Molodezhnaya	1978-1998	1980-1998	1980-1980	

Table 2. Russian Antarctic upper atmosphere balloon sounding data set available via Internet

Station	MSLP	Pst	Ts	Vs	Humidity	Cloudiness	Comments
Bellingshausen	1968-2001	1968-2001	1968-2001	1968-2001	1968-2000	1968-2000	 MSLP, Pst, Ts and Vs data are presented in Internet as current mean monthly values. Ts data are presented in Internet as mean seasonal and annual values after full climatological control.
Mimy	1956-2000	1956-2000	1956-2001	1956-2000			As in point 1 and 2 (see above)
Leningradskaya	1987-1991	1987-1991	1987-1991	1987-1991			As in point 1 (see above)
Novolazarevskaya	1961-2000	1961-2000	1961-2001	1961-2000			As in point 1 and 2 (see above)
Vostok	1987-2000	1987-2000	1958-2000	1987-2000			As in point 1 (see above)
Molodezhnaya	1987-1999	1987-1999	1963-1999	1987-1999			As in point 1 (see above)
Oazis		1957-1958					
Komsomolskaya	•	1956-1957					

Table 3. Russian Antarctic meteorological measurements data set available via Internet. (MSLP – mean sea level pressure, Pst – atmospheric pressure at station level, Ts – surface air temperature, Vs – wind speed at 10 m level).

Upgrades to the Australian Antarctic Geodetic Network, 2000/2001

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1. Introduction

The Australian Antarctic Geodetic Network (AAGN) consists of a series of geodetic control marks placed on solid rock outcrops throughout the Australian Antarctic Territory. The majority of these marks were established placed using terrestrial-surveying techniques from 1965 to 1976. In previous years a number of astro fixes had been observed as control for reconnaissance mapping.

The terrestrial based AAGN was established to support mapping and other geographically dependant sciences in the Australian Antarctic Territory. It consists of survey marks placed typically on mountaintops in solid exposed rock locations. The network was extended south from Mawson station into the northern Prince Charles Mountain's (PCM's) using loops of angles and distances using second order Australian geodetic survey techniques from 1965 to 1970. The network was later extended (in the 1970's) into the southern PCM's and across to Davis via the eastern Amery and Manning Nunataks (Fig.1). The network extended as far south as Wilson Bluff with a number of rock outcrops intersected including Mt Komsomolsky, the most southerly exposed rock site.

In recent years satellite positioning technology, firstly Doppler NAVSTAR techniques and then the Global Positioning System (GPS) has been used to strengthen the main Terrestrial geodetic network. These techniques enabled connections over intercontinental distances with far greater accuracy and without the need for intervisibility between sites (Fig.2).

The use of space geodetic techniques has gradually increased since the first Pageos experiment in 1969 where stations at Mawson and Casey were used to determine coordinates in a global reference frame.



Figure 1. The Lambert Amery basin in East Antarctica

Later the TRANSIT Doppler system was widely used to strengthen the network at a greater density. From 1990 onwards the Global Positioning System has been the primary tool for geodetic surveying in the Antarctic network. Originally it was used in an exclusively base-



line mode over relatively short distances, which resulted in significant improvement to the existing network, and more importantly allowed the establishment of new stations in far less time than was achievable historically.



Figure 2. Classical terrestrial methods of surveying used in the terrestrial geodetic network.

2. Recent Survey Work

In late 1993 Continuous GPS (CGPS) installations were established at Casey, Davis, Mawson and Macquarie Island. Data from these CGPS sites is transferred back to Australia for distribution to the international community, in particular the International GPS service (IGS). Data from these sites is processed by the IGS analysis centres to determine coordinates for the station in the latest International Terrestrial Reference Frame (Currently ITRF2000). The AAGN is constrained to the ITRF coordinates for these three stations and adjusted using Least squares techniques, thus propagating ITRF2000 coordinates through the network.

In 1997 AUSLIG undertook the first major GPS campaign in a number of years to upgrade the AAGN. It concentrated on the southern PCM's where the propagation of errors from the coastal CGPS sites was expected to be greatest (Fig.3).

The data from this GPS campaign was processed and the resultant coordinates in ITRF96 were included in the Least square adjustment of the AAGN. These GPS coordinates had a profound effect on the network, causing a several hundred-metre adjustment to some isolated sites, particularly toward the south western portion of the network. As a result it was decided to continue to strengthen the network whenever possible by observing further GPS data on existing network sites.

3. Current Survey Activity in 2000/2001 Season

In the 2000/2001 summer field season the focus of NMD-GA activities as apart of the ANARE activities were focussed on:

- · Extending the network into the Grove mountains
- strengthening the long traverse down the eastern side of the Amery ice shelf. (See Figure 4).



Figure 3. Recent GPS observations taken in the southern PCM's to strenghen the geodetic network

REPORT OF THE THIRD SCAR ANTARCTIC GEODESY SYMPOSIUM



Figure 4: Locations of GPS Observations 2000/2001 Season

The following sections detail the observations undertaken.

- The first objective was to locate and obtain geodetic quality GPS observations on existing geodetic sites in the Grove Mountains and extend the network into the centre of the Grove Mountains by establishing a new GPS sites in the vicinity of Mt Harding. These tasks were partially completed during the season and are form the basis of a separate paper presented during AGS01 symposium (Johnston *et al*, 2001).
- The second objective was improving the long single line geodetic traverse- from Blundell Peak in the Larsemann Hills to Blustery Peak in the PCM's. This

long traverse included very little observational redundancy, being a single line traverse. Yet its proximity being adjacent to the scientifically active Amery Ice Shelf required the determination of accurate station coordinates on rock as reference sites. To strengthen the traverse, GPS observations were taken at four existing sites on the traverse :

- Landing Bluff;
- Mt Caroline Mikkelsen;
- Corry Rocks; and
- Rubeli Bluff.

The work undertaken at each site is described overleaf.

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Figure 5.1 Landing Bluff monuments. (NMS138 in foreground. AUS042 is in the background. AUS305 covered with radome).

3.1 Landing Bluff (AUS305)

Landing Bluff is a fundamental site in the Australian Antarctic Geodetic Network, first established in the 1967/ 68 survey. Three survey marks now exist at this site (Fig. 5.1). The first is a Russian brass plaque set in the original NMS138 drill hole placed by ANARE surveyors from the Australian Division of National Mapping in 1968. This plaque is the primary monument at Landing Bluff and now has an empty Im high gas bottle standing directly over it. The second monument is AUS042, which consists of a stainless steel bolt drilled in to bedrock (placed by AUSLIG, 1991). The final monument is the antenna mount (AUS305) for the Australian National University's CGPS site, which was constructed in 1999. These three sites have all been observed at different times for varying purposes, but were never actually connected to each other.

GPS observations were taken at both AUSLIG monuments (DOYs 347, 348 and 349 2000) and have been processed along with data from the ANU installation. The details of this GPS occupation can be found in Table 1. This connection was subsequently included in the new adjustment (ANT2001).

Site	DOY	Date	Start	Finish	Vert Antenna Height (m)	Antenna Type
136E Mt Caroline	17	17/1/2001	4:51:30	23:59:30	1.1325	ASH700936E
Mikkelsen	18	18/1/2001	0:00:00	23:59:30	1.1325	ASH700936E
	19	19/1/2001	0:00:00	8:50:30	1.1325	ASH700936E
1422 Corry Rocks	17	17/1/2001	6:49:00	23:59:30	1.2520	ASH700718B
	18	18/1/2001	0:00:00	11:10:30	1.2520	ASH700718B
	19	19/1/2001	0:00:00	23:59:30	1.2520	ASH700718B
	20	20/1/2001	0:00:00	23:59:30	1.2520	ASH700718B
	21	21/1/2001	0:00:00	8:52:30	1.2520	ASH700718B
A042 Landing Bluff	347	12/12/2000	4:39:00	23:59:30	1.2884	ASH700936E
	348	13/12/2000	0:00:00	23:59:30	1.2884	ASH700936E
	349	14/12/2000	0:00:00	23:59:30	1.2884	ASH700936E
N138 Landing Bluff	347	12/12/2000	5:17:30	22:01:00	1.3086	ASH700936E
N143 Rubeli Bluff	17	17/1/2001	10:30:30	23:59:30	2.500	ASH700936E
	18	18/1/2001	0:00:00	23:59:30	2.500	ASH700936E
	19	19/1/2001	0:00:00	23:59:30	2.500	ASH700936E
	20	20/1/2001	0:00:00	17:15:30	2.500	ASH700936E

Table 1 Summary of GPS observations for AAGN upgrade.



Figure 5.2 Mt Caroline Mikkelsen - 2.5 Metre Steel Cairn and Station Eccentric mark (NMS 136)

3.2 Mt Caroline Mikkelsen (NMS 136E)

The site at Mount Caroline Mikkelsen forms the top mark in traverse down the eastern side of the Amery Ice shelf. It was established in 1967/68 and reoccupied the following year when the station monument was built. It is the connecting mark between Blundell Peak in the Larsemann Hills and the Eastern Amery. Previous to the data collected in the 2000/2001 season, there were only terrestrial observations made to this geodetic control point.

A rock filled 2.5 metre steel pipe surmounts the station mark at Mount Caroline Mikkelsen. The eccentric mark, which was used for the GPS observations, consisted of a 6 inch rock piton (Fig. 5.2).

GPS data was collected for over 48 hours on the eccentric mark, details of which can be found in Table 1. Resultant positions are included in Table 2.

SITE	Name	Latitude	Longitude	Ellipsoidal Height (m)
AUS042	AUS042	S 69° 44' 32.23501"	E 73° 42 37.56993"	139.638
AUS305	LDBF	S 69° 44' 32.25112"	E 73° 42 37.40090"	133.187
NMS 136E	Mt Caroline EC	S 69° 45' 10.19959"	E 74° 23 54.38701"	249.977
NMS 143	RUBELI BLUFF	S 70° 28' 39.20983"	E 72° 26 32.94741"	237.488
NMS 142E2	Corry R ECCE 2	S 70° 17' 46.95769"	E 71° 46 30.21113"	239.835
NMS 138	LANDING BLUFF	S 69° 44' 32.14039"	E 73° 42 36.94688"	133.987

Table 2 - Coordinate results for AAGN upgrade shown in terms of ITRF2000 @2000.

3.3 Rubeli Bluff (NMS 143)

The Rubeli Bluff mark (NMS 143) located in the Reinbolt Hills is an integral part of the Eastern Amery Traverse. Rubeli Bluff was the final position occupied in the 1967/ 68 summer geodetic traverse and was used again to continue the traverse next season 1968/69.

Unfortunately the station eccentric mark which consisted of a 6 inch piton approximate 6.2 metres online from the station mark to Corry Rocks NMS 142 was not found. The station mark could also not be used due to the large 1.8 metre stone cairn built over it (Fig 5.3). Therefore the GPS antenna was set up over the top of the cairn on the assumption that it was concentrically built over the station mark. The height of the antenna was approximately 2.4 metres above the ground mark. A total of 3 days GPS observations were made at Rubeli Bluff, the resultant positions are included in Table 2.



Figure 5.3 Rock Caim Over Station Mark - Rubeli Bluff NMS 143

3.4 Corry Rocks (NMS 142)

Corry Rocks is a rock outcrop located at the northern end of the ice covered Gillock Island. The station forms part of the east Amery traverse section which extends from the Larsemann Hills to the PCM's. The station was established in 1968, and was revisited in 1991, when an additional station eccentric mark was placed. This new mark NMS 142 ECCE 2, consisted of an expansion bolt set in rock (Fig 5.4). GPS data was collected on this mark during the visit in 1991.



Figure 5.4 NMS 142 ECCE 2 - With rock caim over station mark in the background.

The baselines between these stations and Davis and Mawson were included in the Antarctic adjustment (ANT2001) along with data collected by the University of Tasmania in 1998 at New Year Nunatak, AUS037T (Fox Ridge) and AUS072 (Else Platform) in the PCMs. A summary of the data observed in 2000/2001 can be found in Table 1 and the results found in Table 2. The resultant coordinates were derived from processing the data using the Bernese precision processing software. The results of the processing were then used to undertake a least squares adjustment using NEWGAN software, constraining the ITRF 2000 coordinates of the three ARGN at epoch 2000.0.

4. Conclusion

Four original stations on the east Amery geodetic traverse were successfully reoccupied with GPS observations. The result enabled the network to be considerably strengthened and a new network adjustment carried out in the IRTF2000 reference frame.

In the future the AAGN will continue to be upgraded by observing geodetic quality GPS in keys areas throughout the network when logistic support is available. These areas include:

- Southern Prince Charles Mountains
- Enderby Land
- Grove Mountains
- Commonwealth Bay
- Trans-Antarctic Mountains

The network will also be further strengthened by long occupation GPS observations in the Grove Mountains and Southern PCM's. The high precision results will also be extremely useful for constraining the adjustment of the AAGN and results from these long occupation observation campaigns will contribute to eustatic studies and evaluation of the dynamics of the Lambert rift.

The integration of geodetic networks and Continuous GPS sites operated by other nations and other scientific researchers will also strengthen the AAGN.

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GPS connections at Antarctic Tide Gauge Bench Marks in 2000/2001 summer

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Introduction

Increasingly climate change scientists are focusing their effort towards Antarctica in an attempt to gain a better understanding of the changes in global climate. One indicator of change being monitored is that of Southern Ocean dynamics in particular changes in absolute sea level. Australia's contribution to this research at present consists of a network of tide gauges located in East Antarctica including each of the Australian stations and Macquarie Island (Fig.1). To monitor the network and facilitate the distinction between absolute and relative sea level changes by accounting for vertical uplift, the National Mapping Division, Geoscience (NMD-GA formerly AUSLIG) uses a continuous GPS base receiver at each of the manned stations.

The Australian Antarctic Division (AAD) maintains installation and system calibration for the Australian Antarctic tide gauge network at its manned stations. This network provides not only valuable data in terms of sea level change but is also important for tidal studies including tidal predictions for shipping and also height datums for mapping and charting.

Background

The first Australian tide gauge in Antarctica was established during the Australian Antarctic Expedition of



These activities included those of the first wintering party at Mawson Station in 1954, where the surveyor and Station Leader, Bob Dovers, established a tide board and associated benchmark in order to determine MSL for the station and surrounding survey control. It was a similar situation at the other stations, such as Casey, where the United States established Mean Sea Level at the old Wilkes station in 1957, by conducting a series of timed water measurements, connecting to an onshore benchmark.

In the 1970s renewed efforts were made to more accurately determine MSL, and therefore provide an improved height datum to base geodetic survey control. The technique utilised was to install bottom mounted pressure tide gauges, and then observe and record tidal heights on a tide pole located near the gauge. By comparing the tidal height as recorded by the gauge with those of the



tide pole, the zero of the gauge was able to be determined in relation to the tide pole zero. MSL was then transferred to a nearby benchmark by levelling between the mark and the zero of the tide pole. In some cases MSL was recalculated over a period of several years. An example of this is Davis Station, where 3 separate determinations of MSL were made between 1979 and 1983, with differences in these values of the TGBMs in the order of one metre.

Figure 1: Australian tide gauge sites in the Southern Ocean

Recent Activities

Although the ad hoc nature of determining MSL at the time provided useful information for a number of applications including height datum control for mapping and charting, there was no program that provided continuous data for the research into long-term sea level rise. In 1991, AAD, in collaboration with AUSLIG and the National Tidal Facility embarked on a program to install tide gauges at the manned stations in East Antarctica and on sub Antarctic Islands of the Southern Ocean. A two-phase approach was adopted, allowing gauges to be immediately deployed, while investigating better designs for permanent installations.

The first of the new gauges was deployed at Mawson in 1992, which was followed by Davis and Casey in 1993.



Figure 2: Permanent GPS marker at Mawson Station (AUS064)

GPS and Tide Gauge Bench Marks

NMD-GA through its Australian Regional GPS Network (ARGN), also provides support to the tide gauge network in Antarctica and Macquarie Island by operating continuous GPS receivers at those sites which are part of the International GPS Service (IGS), see Fig.2. The data from these sites and subsequent analysis by IGS global analysis centres provide a time series of both horizontal and vertical motion of the land at those sites.

To relate any vertical land motion detected from GPS to sea level, an accurate height connection must be made between the tide gauge and the GPS. To achieve this, coastal Tide Gauge Bench Marks (TGBMs) located as close as possible to the tide gauge are used. These are then connected to the actual tide gauge readings by water level calibration. A network of these bench marks are usually established, thus enabling the relative height history of the marks to be examined, indicating any significant local subsidence or stability problems with the marks.

Over the last decade concerted efforts have been made to ensure that the connection between the TGBMs and the GPS reference mark has been completed each summer season (Fig. 3). Typically the work has involved the use All three of these gauges are freestanding bottom mounted pressure gauges. The gauge at Macquarie Island, was established in 1993, and is a shore mounted precision Aquatrak acoustic type gauge installed in a sloping hole drilled through the rock. This is supported by a bottom mounted pressure gauge. Although the bottom-mounted gauges have been supplying data for over 8 years, they remain problematic, particularly in terms of power and effective communications in an ice environment. Therefore efforts have been made to find more suitable locations to install precision shore mounted gauges at Australian Antarctic Stations, whilst research also continues into more effective ways of retrieving data from the bottom mounted gauge, such as the use of radio transmitters (Australian Antarctic Division 2001).



Figure 3: Attempting to transfer MSL from the Tide Gauge at Davis to the TGBM

of orthometric levelling to complete the connection, and also on some occasions the use of GPS to derive ellipsoidal heights on TGBMs.

The determination and monitoring of ellipsoidal height at these benchmarks by GPS surveys, as required by the Global Sea Level Observing System (GLOSS), enables the true monitoring of sea level as the ellipsoidal heights are then fixed within a global reference frame, whereas the orthometric levelling can only detect local change in benchmark heights relative to other monuments.

GPS – TGBM Vertical Connection Results

During the summer season of 2000/2001, height connections were made to the TGBM from the GPS mark at both Mawson and Davis Stations by both differential GPS and orthometric levelling. The aim of these connections was to define the relative height differences between each of the Tide Gauge Benchmarks and the Permanent GPS, and to establish an ellipsoidal value at the tide gauge benchmarks. As previously mentioned this connection provides important data for monitoring long-term sea level change at sites in the Southern Ocean. This connection also helps to better understand the separation relationship between MSL and derived ellipsoidal heights from GPS. The methods used to measure the height differences included the use of GPS at the TGBM to derive ellipsoidal height differences and a new terrestrial technique known as EDM-Height Traversing "Leap Frogging") to determine orthometric heights (Rueger and Brunner, 1982). This method is a variant of the common technique of spirit levelling, where the differences in height between change points are determined using observations of zenith angles and slope distances. (ICSM 2000). By adopting this method the systematic errors, such as thermal expansion, which can effect optical levelling are eliminated. The "Leap-Frog" method utilised a Leica TC2003 Total Station and a single fixed height survey rod and reflector, which was set over each change point for both Back-sight and Fore-sight observations.

Tables 1 and 2, and Figures 4 to 6 summarise the results from the 2000/2001 season with normal orthometric levelling comparisons from other seasons. Typically the

comparisons with other years are at the 3-5 mm level, however the results from some years do not compare extremely well, and suggests that there may be gross errors in some of the previous levelling work.

The techniques used in the 2000/2001 survey have demonstrated the ability to achieve very high measurement accuracies, which are paramount given that scientists are trying to detect the vertical velocity of the underlying bedrock eg Bevis *et al.* (2001), with an accuracy of better than 1mm/yr

Mawson Station

Table 1 summarises the results from orthometric levelling at Mawson Station from years 1995 to 2001. The table includes the GPS mark (AUS064), TGBM (AUS258) network and adopted vertical datum point for Mawson Station (ISTS051). The route taken for the levelling work at Mawson during the 2000/201 season is shown in Figure 4



Figure 4: Route of levelling at Mawson Station.

Year Station	2000/2001	1998/99	1997/98	1996/97	1995/96
AUS301	1.835		1.835		
AUS258* (TGBM)	1.411	1.411	1.409	1.415	1.413
AU\$300	2.133	2.133	2.132		
ISTS051 RM4	9.588	9.591		9.588	
ISTS051#	9.792			9.792	9.792
AUS064 (GPS mark)	32.446		32.433	32.450	32.490

Note:# Adopted vertical datum for local survey network at Mawson Station

* Current TGBM, used to connect to transfer height from tide gauge

Table 1 - Comparison of Mawson levelling results. All heights are shown in metres.



Figure 5 Fixed Height Rod used for EDM Height Traversing (Under GPS Antenna)



Figure 6 Total Station used for EDM Height Traversing

Davis Station

The results of level connection between the TGBM at Davis Station (AUS184) and the GPS mark (AUS099) are shown in Table 2, other significant marks are also

shown, including: NMVS4 (former Australian National Mapping TGBM), AUS303, D5, D3, Met. BM. The values derived from the levelling work are based on a 1983 MSL height determination for NMV/S/4.

Year Station	2000/2001	1999/2000	1998/99	1996/97	1994/95
AUS186	4.7202	4,7202	4.720	4.732	4.7140
AUS303	15.4995	15.500	15.508		
D5	19.9195			19.922	
D3	23.0843	23.087	23.101	23.088	
NMV/S/4	2.1790		2.179	2.179	2.1790
MET BM	18.4013			18.3994	18.4000
AUS099	27.8686	27.868		27.869	27.8659

All heights shown in metres.

Table 2 Davis levelling results with a comparison to previous surveys.



Figure 7: Route of levelling at Davis Station.

GPS Height Connections

During the 2000/2001 season four TGBMs were observed using quality geodetic GPS observations: AUS258 at Mawson, AUS186 and NMVS4 at Davis and AUS334 in the Larsemann Hills. AUS258, AUS186 and AUS334 currently have high precision tide gauges operating adjacent to them. The downloading and connection of these tide gauges to the TGBMs is not NMD-GAs responsibility, that component of the project is the responsibility of AAD. Table 3 lists the resulting coordinate results for the four marks mentioned. Table 4 shows the comparison of the GPS height differences and orthometric levelling from the 2000/2001 summer season. The comparison shows very good agreement, with the largest discrepancy being of the order of 17 mm from the derived orthometric height at Mawson. The derived orthometric height is obtained by combining the height differences from the GPS with the modelled geoid difference from the EGM96 global geopotential model (DH_{derived} = Dh_{GPS} - DN_{geoid}). In the above case DN_{geoid} is typically in the order of 10mm.

Site	Latitude	Longitude	Ellipsoid al height (m)
AUS258 Mawson	-67° 36' 00.54494"	62° 52' 22.69653''	28.094
AUS186 Davis	-68° 34' 20.59889"	77° 58' 05.63094''	21.265
NMVS4 Davis	-68° 34' 33.92218"	77° 57 '48.96975"	18.724
AUS334 Larsemann Hills	-69 23' 01.16875"	76° 22' 20.61154''	17.162

Table 3 Coordinates for the TGBMs shown in terms of ITRF2000 @2000

Conclusions and Future Activities

The work completed by NMD-GA during the summer 2000/2001 forms an integral part of the Southern Ocean sea level monitoring, by providing a height connection between the TGBM and GPS. GPS observations on the TGBM have also allowed ellipsoidal heights to be determined, providing the separation of absolute sea surface change from relative motion.

The techniques used in the summer 2000/2001 season have proved to be an effective and efficient method of determining height differences between the fundamental marks. This work however needs to be continued on an ongoing basis to allow constant monitoring of these marks to detect any differential vertical movement.

NMD-GA is committed to ensuring the continual operation of its network of permanent GPS receivers in the Australian Antarctic Territory. In particular its support of the Southern Ocean sea level monitoring program. Future years may provide an extension of this network to other areas within the AAT, providing important data to otherwise remote areas.

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Year	2000/2001 Height		
Baseline	Difference (m)		
Mawson Station			
AUS064-AUS258(- h GPS)	31.042		
AUS064-AUS258(- H derived)	31.052		
AUS064-AUS258(- H levelled)	31.035		
Difference	0.017		
Davis Station			
AUS099-AUS186(v h GPS)	23.151		
AUS099-AUS186(- H derived)	23.151		
AUS099-AUS186(- H levelled)	23.148		
Difference	0.003		
AUS099-NMVS4(🕶 h GPS)	25.682		
AUS099-NMVS4(- H derived)	25.692		
AUS099-NMVS4(- H levelled)	25.689		
Difference	0.003		

Table 4 A comparison of GPS Heighting and Orthometric levelling between the ARGN mark and the TGBM.

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SCAR Geodesy in Antarctica

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Background

The Scientific Committee on Antarctic Research (SCAR) was formed at The Hague in February 1958. It evolved from the Special Committee on Antarctic Research established by the International Council for Science (ICSU) to co-ordinate the scientific research of the twelve nations active in Antarctica during the IGY, the International Geophysical Year in 1957-58.

The main activity of SCAR has been to provide a forum for scientists of all countries with research activities in the Antarctic to discuss their field activities and promote cooperation and collaboration in scientific research amongst Antarctic Treaty Nations. The surveying and mapping activities of SCAR are coordinated through its Working Group on Geodesy and Geographic Information - WG-GGI (http://www.scar-ggi.org.au/).

From its inception the WG-GGI working group encouraged standardised mapping of the Antarctic continent and established a set of recommendations and standing resolutions as mapping standards. Initially it recommended the use of the Hayford 1924 International spheroid as the basis for mapping projections and positional computations. The initial role of Geodesy within the SCAR WG-GGI evolved from the provision of control for exploration and mapping to the establishment of a single geodetic reference frame for all Antarctic spatial data. Utilising space geodesy techniques it is possible to monitor the internal tectonic motion of the continent and its linkage to other Gowanaland fragments.

The operational aspects of the WG-GGI were structurally reviewed during XXII SCAR in 1992 resulting in a changed focus on mapping standards and individual national activities, to a theme based structure with identified project responsibilities. Since that time the overall program has further evolved into two major umbrella streams:

- Geodetic Infrastructure of Antarctica (GIANT) Program
- Geographic Information Program

There are eight projects in the GIANT Program and nine projects in the Geographic Information Program.

At the XXVI SCAR meeting in Tokyo in 2000 an Outreach Program was added to the Working Group structure. There are four projects in this new Program, which are:

- Website Maintenance;
- Publications;
- · Liaison; and
- Meetings

The use of Space Geodesy in Antarctica

In the second half of the 20th century the positioning of geographic features on the Antarctic continent and measurement of baselines to other continental land masses was still only achievable from astronomic observations or local trigonometric surveys within Antarctica. Triangulation chains were difficult to establish due to the need for multi station visibility for angles. The networks, which were established, were usually limited to the immediate vicinity of the base stations, or as small area triangulations based on isolated celestial fixes. It was usually impossible to connect these triangulations by terrestrial survey.

In the early sixties microwave electronic distance measuring equipment (EDM) was introduced to the Antarctic continent, which enabled trilaterations, and large traversing loops rather than pure triangulation to be undertaken, producing systematic but still isolated geodetic networks.

The first application of space geodesy to address this problem and to determine the coordinates of some Antarctic stations in a global reference frame was commenced in 1969 when the global astro-triangulation PAGEOS program occupied Antarctic sites at McMurdo, Mawson, Palmer and Casey. In the early 1970s satellite based microwave positioning proved more useable and firstly Tranet Doppler and then GPS became available on global scale (Manning *et al*, 1990). The development of positional accuracies achievable from the different geodetic techniques is summarised in Table 1 below.

The SCAR GPS Projects

The early Antarctic space geodesy programs were the initiatives of individual countries as part of extensive global programs, and no coordinated international geodetic program existed on the Antarctic continent. In 1976 the SCAR WG-GGI began to look at the possibility of linking the individual national geodetic networks by Doppler techniques and work commenced on gathering the extent of each nations geodetic networks with view to a joint approach. However, due to logistic limitations no overall plan was implemented to link the individual networks.

In the late 1980's GPS emerged as a geodetic tool with a potential for Antarctic applications. The XX SCAR meeting, in Hobart, in 1988 endorsed a proposal by Australia to test the developing GPS technique for mapping control and Geodesy applications in monitoring crustal motion. This pilot study was undertaken in two phases: Feasibility observations January 1990 Test observations in January 1991.

REPORT OF THE THIRD SCAR ANTARCTIC GEODESY SYMPOSIUM

Technique	Positional Uncertainty
Positional Astronomy	+- 200metres
Satellite/Stellar photography (PAGEOS)	10 metres
TRANET Doppler	3-5 metres
GPS	1-2 metre
VLBI	1 decimetre
GPS	1 decimetre
GPS	centimetres
	TechniquePositional AstronomySatellite/Stellar photography (PAGEOS)TRANET DopplerGPSVLBIGPSGPSGPS

Table 1: Development of positional accuracy of Antarctic sites

Despite problems encountered the trial clearly showed that baseline accuracies in the order of one metre over intercontinental distances were possible even with the low number of GPS satellite available at the time (Govind *et al* 1990).

With the success of these pilot studies the WG-GGI started an ongoing series of summer GPS epoch surveys headed by Prof Reinhard Dietrich from Germany (Dietrich *et al*, 2001). All data is archived at the University of Dresden (dietrich@ipg.geo.tu-dresden.de) and can be viewed at: www.tu-dresden.de/ipg/SCARGPS/ database.html

Despite their success, the GPS campaigns were logistically costly and it was difficult to arrange occupation of all sites at the same time being subject to different logistic arrangements. Consequently in 1993 six permanent GPS sites were installed to provide fundamental fiducial stations to link epoch surveys together.

This was a significant technological advance as it provided a potential continuous time series of observations and a network of key sites which can then be used as a



Figure 1: Permanent GPS stations in Antarctica

control framework for subsequent temporary occupations at different times. In 1994 three more permanent GPS trackers were installed.

Since that time Permanent trackers contributing continuous data to IGS have been established at SANAE, in 1999, and other annual down load GPS base stations are operating at Terra Nova Bay, Maitri, Dumont d'Urville and Zhong Shan. Deployment of GPS equipment at unattended remote Antarctic localities for regional densification of geodetic infrastructure is under construction which requires remote power input and regular data retrieval. This technology needs further development.

The Geodetic Infrastructure of Antarctica (GIANT) Program

In 1992 it was decided to develop a coordinated network of GPS geodetic stations using available surveys together with collocation of other techniques such as VLBI, Absolute Gravity, DORIS and tide gauges. This was collectively identified as the Geodetic Infrastructure for Antarctica (GIANT) program - as described in WG-GGI web site http://www.scar-ggi.org.au/geodesy/giant.htm

The ongoing GIANT program objectives are to:

- Provide a common geographic reference system for all Antarctic scientists and operators.
- Contribute to global geodesy for the study of the physical processes of the earth and the maintenance of the precise terrestrial reference frame
- Provide information for monitoring the horizontal and vertical motion of the Antarctic.

Major projects of the Program are:

- Permanent Geodetic Observatories;
- Crustal Deformation Network;
- Physical Geodesy;
- Geodetic Control Database;
- Tide Gauge Data;
- Atmospheric Impact on GPS Observations in Antarctica;
- Remote Geodetic Observatories; and
- New Geodetic Satellite Missions
The status and progress reports of these projects are discussed annually. Details of the most recent WG / GIANT meetings in both Siena, Italy and St. Petersburg, Russia can be found at <http://www.scar-ggi.org.au/meetings/prevmeet.htm>.

The techniques covered by the Permanent Geodetic Observatories project are:

- Continuous GPS
 - DORIS
 - VLBI
- Tide gauges
- Absolute Gravity
- PRARE
- GLONASS

The status of the elements listed above is shown on the Permanent Observatories web page at <u>http://www.scar-ggi.org.au/geodesy/perm_ob/sites.htm</u>

Current Status of the Geoid

Another element of the Physical Geodesy project of the GIANT program is the computation of an Antarctic Geoid to provide the connection from ellipsoidal heights, (such as from GPS heights) and heights above sea level. Australia produced early versions of the Antarctic Geoid based on GEM and OSU gravity data sets, which are available on the NMD-GA web site <u>http://www.auslig.gov.au/geodesy/</u><u>antarc/antgeoid.htm</u>. An accurate definition of the geoid in Antarctica continues to be hampered severely constrained by the scarcity of gravity information, especially across the inland of the continent.

In 1996 NIMA produced a new global Gravity data model as EGM96, however it still suffers from lack of gravity coverage in Antarctica. A grid of geoidal separation values that can be used to interpolate a separation value for any location south of 60 degrees latitude are available on the WG-GGI webs site for individual interpolation.

The gathering of geophysical data to improve the Antarctic Geoid is a major undertaking and is being undertaken cooperatively with other groups through the newly formed SCAR Group of Specialists on Antarctic Neotectonics (ANTEC) and the associated BEDMAP, ADGRAV and RAMP projects.

ANTEC

ANTEC was established following the SCAR XXV meeting in Concepcion, Chile in 1998. The objectives of ANTEC are intertwined with the need for a precise geodetic network over Antarctica, calling for the establishment of remotely operated sites away from the manned coastal stations and the integration with other Geodetic techniques. The GIANT program has three representatives on this Group of Specialists. More information about ANTEC can be found at: http:// www.scar-ggi.org.au/geodesy/antec/antec.htm>

ITRF

Antarctica is important in global geodesy. Global Geodesy models have heavily relied on observations from Northern Hemisphere sites and the results do not always fit the Southern Hemisphere or represent the best global picture. Antarctic geodetic observatories provide data to rectify this imbalance with some continuous GPS sites using satellite data retrieval to make their data available to the global data base of the International GPS Service (IGS) on a daily basis.

The continuous GPS sites in Antarctica have been used in ITRF 2000 primary determinations (Altimimi 2001) and the epoch surveys have also been provided as an input by Dietrich (2001) as densification of the official IERS reference frame. This results in a network of official published IERS coordinates (with velocities) for Antarctic rock sites which can be used by any scientists as the basis for positions that are well defined in the Global reference frame

Velocities for Antarctic ITRF sites are given in Table 2 and Figure 2.

ID	LATv	LONv	HGTv
7400	0.0163	0.0189	0.0047
ART1	0.0161	0.0068	0.0001
BEL1	0.0105	0.0119	0.0347
BELG	0.0105	0.0119	0.0347
BRAZ	0.0125	-0.0039	0.0016
CAS1	-0.0096	0.0026	0.0037
DAL1	0.0142	0.0077	0.0019
DALL	0.0142	0.0077	0.0019
DAV1	-0.0048	-0.0015	0.0043
DUMI	-0.0081	0.0116	-0.0009
ELE I	0.0141	0.0062	0.0024
ESP1	0.0097	0.0142	0.0102
FOR1	0.0058	-0.0009	0.0079
FOR2	0.0058	-0.0009	0.0079
FOSI	0.0107	0.0129	0.0007
GOUG	0.0185	0.0202	-0.0017
GRW1	0.0162	0.0086	0.0075
KERG	-0.0031	0.0060	0.0050
KOUR	0.0120	-0.0045	0.0026
LPGS	0.0114	-0.0017	0.0011
MAC1	0.0304	-0.0108	0.0001

Table 2 Positions and velocities for Antarctic ITRF sites



Figure 2 Velocities for Antarctic ITRF sites

Conclusion

There has been considerable international cooperation in Antarctic Geodesy since SCAR was formed in 1958. The principal coordinating mechanism has been the SCAR working group on Geodesy and Geographic Information and recently thorough its GIANT sub program. The GIANT program is ambitious with many problems of real time intercontinental data communication, from base stations and placement of receivers in remote localities, but progress is being made.

A number of permanent GPS receivers have been installed in Antarctica over the past five years and data is increasingly being retrieved by satellite transmission from these sites. This fiducial network of GPS points augmented by VLBI and other technique forms the basis for an integrated geodetic infrastructure as the basis for all scientific spatial data within a single global reference frame. Ready on-line access to data and results is an objective of the program and details are kept up to date on the WG-GGI web site through the WG-GGI Outreach program.

Geodetic observatory sites in Antarctica are of ongoing importance to global geodesy especially in the determinations of precise orbits and the integration of different observational techniques. These sites have been complimented by summer epoch campaigns to densify the ITRF network across Antarctica with specific regional projects in the Antarctic Peninsula and McMurdo Sound

The application of space geodesy now offers tools to

undertake a more comprehensive study of crustal movements within Antarctica and in relation to other fragments of the ancient Gondwanaland. The monitoring of surface geodynamics and the provision of results can make a significant contribution to the work of other Antarctic earth scientists such as is the case with newly formed ANTEC group of specialists concerned with developing a better understanding of the crustal dynamics of Antarctica.

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Extension of the Australian Antarctic Geodetic Network in Grove Mountains

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1. Background

The Grove Mountains consist of a scattered group of mountains and nunataks extending over an area 65 by 30 km in extent. They are located in Princess Elizabeth land in East Antarctica centred at 76° east 70° south, some 200 kilometres inland and 160km east of the Mawson Escarpment.

The area of the Grove Mountains has attracted very few visitors; it was first sighted and photographed from the air by ANARE Beaver aircraft operating out of Mawson in the 1950s. The initial ground visit was made

in November 1958 by ANARE surveyor Knuckey and geologist Macleod (AUSLIG, 1998) (Fig. 1). This was followed by ANARE visits in the 1972 and 1974 summer seasons, at a time when visits were also made by the Soviet expeditions based at Druzhnaya.

The Grove Mountains have now become an area of renewed interest for both Russian and Chinese scientists, with both countries active in the region in recent years. A ground party from the Chinese Antarctic Research expedition CHINARE spent an extended period there during the summers of 1998/1999 and 1999/2000. These expeditions used ground vehicles and

2. Geodetic Surveys 2000/2001 in the Grove Mountains

ANARE undertook geodetic survey work in the region in the summer 2000/2001. Initially it was planned to fly into the Grove Mountains from Davis wintering station on four separate days, allowing enough time to complete all the intended work. However owing to the harsh flying conditions encountered there was only time for two visits during the 2000 / 2001 summer season.

Although only two trips were made into the Grove Mountains a number of outcomes were achieved they included:



Figure 1. ANARE Surveyor Knuckey performing astronomical observations near Mt Harding in the Grove mountains 9 November 1958.

personnel in an over-snow glaciological traverse to the Grove Mountains from their winter base at Zhong Shan in the Larsemann Hills, 300 km to the north. The Chinese expedition was part of a larger plan to traverse from the Larsemann Hills to Dome Argus (a further 600km inland from the Grove Mountains). Their work in the Grove Mountains consisted mainly of geological research, which also included some large-scale mapping. A Russian expedition undertook an airborne geophysical survey to the north of the Grove Mountains during the previous season.

- Establishment of a new geodynamic survey monument in the vicinity of Mount Harding, to strengthen the Antarctic geodetic network, and also assist with long term monitoring of crustal motion in Antarctica.
- Several days of GPS data collected on the existing geodetic network point at Austin Nunatak – 60km to the West of Mount Harding
- Search for two existing CHINARE geodetic control points established near Mount Harding and Zakharoff Ridge.

2.1 A Permanent Geodynamic Mark for the Grove Mountains: AUS 351

A new permanent geodetic quality mark was established on a nunatak to the South West of Mount Harding. The mark, AUS 351 was located on a flat ledge at the northern end of the nunatak approximately 50 metres above the ice level. AUS351 consisted of a 150 mm stainless steel plate, with a centred 5/8" spigot. See Figures 2 and 3 below.

The site for the new mark was chosen due to its close proximity to Mount Harding, the availability of solid bedrock and its accessibility. The mark is accessible by landing on the ice below and climbing up to the ledge above, typically the climb takes up to 20 minutes. There is sufficient space on the ice to allow landing by both fixed wing and rotary aircraft. Ice conditions were very firm, with small amounts of drift snow visible.

In terms of weather, dimples in the ice, large wind scours around rock outcrops and conditions experienced over

the two trips indicated that the Groves was a high wind region with strong winds predominantly from the South-East.

To enable a long GPS observation period solar panels were used to maintain battery charge for the receiver. The receiver was also housed in an insulated aluminium warm box to keep the equipment from freezing.

As indicated above two visits were made to AUS351 during the 2000/2001 summer. The geodynamic type mark was partially installed during the first trip (29th December 2000), but the resin did not set correctly. This mark was subsequently reset on the second visit (11 January). Therefore the site referred to as AUS351E is this mark prior to it being reset. Both AUS351E and AUS351 were placed in the same hole however AUS351 is somewhat lower (approximately a decimetre). The second visit, shortly after the New Year also enabled the Ashtech GPS receiver to be reset as it had stopped logging due to an end of year changeover problem.



Figure 2. Location of AUS351 - Looking North to Mount Harding



Figure 3. Photo of AUS351 Station Mark and GPS Choke Ring Antenna

SCAR WORKING GROUP ON GEODESY AND GEOGRAPHIC INFORMATION

Continual bad flying conditions between Davis Station and the Grove Mountains meant a third and final trip to the area was not possible. Thus only the original small amount of data (2 days) was collected from AUS351E as in Table 1. The remaining 2 weeks data and all equipment remains on site and will be retrieved next season.

Data from AUS351E have been processed using the Bernese processing software. The data were processed using IGS precise ephemerides in the ITRF 2000 Reference Frame, at epoch 2000.0 the results are shown below in Table 2.



Figure 4. Solar Panel and GPS warm box set up at AUS 351

Site	DOY	Date	Start	Finish	Vert Antenna Height (m)	Antenna Type
NM50 Austin NTK	364	29/12/2000	7:25:30	23:59:30	0.7879	ASH700718B
	365	30/12/2000	0:00:00	9:53:00	0.7879	ASH700718B
351E Groves	364	29/12/2000	9:50:30	23:59:30	0.0000	ASH700936E
	365	30/12/2000	0:00:00	23:59:30	0.0000	ASH700936E
	366	31/12/2000	0:00:00	23:59:30	0.0000	ASH700936E

Table 2 Coordinate for AUS351E shown in terms of ITRF2000 @2000.

SITE	AUS351E - Grove Mountains
Latitude	-72° 54' 29.17479"
Longitude	74° 54' 36.43606''
Ellipsoidal Height (m)	1891.289

Table 1 Summary of GPS observations for Grove Mountains Network.

SITE	NMS 50 AUSTIN Nunatak
Latitude	-72° 56' 11.50546"
Longitude	73° 21' 36.88113"
Ellipsoidal Height (m)	1639.637

Table 3 Coordinates for NMS 50 - AUSTIN Nunatak shown in terms of ITRF2000 @2000.

2.2 Austin Nunatak (NMS 50)

Austin Nunatak was the terminal geodetic station in the 1974 ANARE geodetic network traverse from the Mawson Escarpment to the Grove Mountains. Azimuth observations from Austin Nunatak were closed out at the spire of Mason Peak.

The survey mark at Austin Nunatak is located on a flat ledge adjacent to the high point and consists of a rock piton with aluminium tag. The station mark was located in good condition, and all eccentric marks found.

Two-days of GPS data was observed at the Austin Nunatak station mark, NMS 50, and was initially processed using NMD-GA's on-line processing software using IGS precise ephemerides in the ITRF 1997 Reference Frame. All coordinates refer to a mean epoch of the observation data. The final results were recalculated in ITRF2000 results are shown below in Table 3.



Figure 5. Photo of Austin Nunatak (NMS 50) and looking East to the Grove Mounatins

2.3 CHINARE Geodetic Control

As discussed previously, CHINARE spent two full summers in the Grove Mountains conducting geological research, culminating in the publication of a 1:25 000 scale topographic map (CACSM 2001). As part of their research, two geodetic control points were established and GPS data observed at each point. The coordinates supplied for the points are listed in Table 4 (Wang, 2000). MG8 was described as being a steel rod, 1.8m above ground surface, cemented into a drill hole in rock near Zakharoff Ridge. MG9 is a steel rod 0.5m high, cemented into a drill hole in rock on the south-eastern side of Mount Harding.

Site	Latitude	Longitude	Height
MG8	\$72 53' 00.76"	75 04' 52.43"	2147.0m
MG9	\$72 54' 36.95"	75 09' 27.47"	2160.0m

Table 4. CHINARE marks in the Grove Mountains

An attempt was made to find the marks, which were described as steel rods set in bedrock. However at the supplied coordinates, bamboo canes driven into the snow were discovered. Using a hand-held GPS on the ground to navigate, the cane near Mt Harding located on the snow bank was some 150 metres from rock. From the air the other site at Zakharoff Ridge appeared to also be a bamboo cane on snow in the vicinity of some fuel drums.

4. Conclusion

The geodynamic mark established in the vicinity of the Grove Mountains is suitable for reoccupation without any possibility of GPS antenna height or centring errors. As such, it is ideal for postglacial rebound and tectonic research relating to the Lambert Rift. Data will be gathered at every opportunity to contribute to this study.

Additionally, establishment of supplementary points in the Grove Mountains will be undertaken as the opportunity arises. The connection of the existing CHINARE marks to the new Australian mark is also of considerable importance, particularly for joint unification of Antarctic geodetic networks in the region.

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Connections between Geodetic Networks in the Larsemann Hills 2000/2001

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Background

Larsemann Hills is a coastal region of 50 x 30 kms of exposed rock, lakes and low rolling hills located on the Lars Christensen Coast, Princess Elizabeth Land in East Antarctica. It is an area of ongoing science activity and environmental monitoring. Currently Australian, Chinese and Russian bases exist within a five kilometre radius of each other. All three nations have created independent survey networks in the area for their own purposes. CHINARE has established a continuous GPS tracker at their fundamental pillar in 1999 in support of inland glaciology activities. There is a Russian fundamental pillar and ground marks as well as ANARE marks established using terrestrial and space based techniques.

Although first sighted during the Christensen Norwegian expeditions of the 1930's, the first ground visit was made by ANARE surveyor Fisher and geologist Stinear in August 1957. They landed by Beaver aircraft on the sea ice and observed an astrofix on Sigdoy (now Fisher Island) and examined the geology of the nearby area. This was the first ground control point in the area for mapping from aerial photography. The Soviet Antarctic Expedition (SAE) visited the area for geological survey soon after in the 1957/58 summer season. Since that time a series of ongoing visits have been made by ANARE field parties for scientific investigation.

In 1968 an ANARE geodetic station was established on Blundell Peak, a high point in the Larsemann Hills as the start of a Tellurometer traverse. The following summer this point was reoccupied and surveys were extended easterly and westerly to complete a continuous line of geodetic trig points between Mawson and Davis stations.

In 1986/87 summer a SAE base, Progress 1, was established on the Broknes peninsula and an ANARE summer field base, Law Base, was established nearby. In early 1989 a wintering station was established by the Chinese National Antarctic Expedition (CHINARE) named Zhong Shan. A new SAE station, Progress 2, replaced Progress 1 in the winter of 1989 at a site more convenient for shipping resupply.

Mapping

The area was first mapped from the Christensen aerial photography of the 1030s in the Hansen series of reconnaissance charts released from 1946. This small scale mapping was continued with the aerial photographs of the United States Navy Antarctic Expedition (Operation Highjump) acquired 1946-47 summer. More detailed exploration of the coast and small scale mapping continued by both ANARE and SAE from the late 1950s. SAE published some of its information in the Atlas of Antarktiki in 1964 and a 1:100 000 scale topographic map "Larsemann Hills", R43-57,58 was published in 1980, using aerial photography flown in 1974, the map was based on the Krasovsky ellipsoid..

The first large scale map was published by AUSLIG for ANARE in 1989. It was a 1:25,000 scale SPOT Image map which was later upgraded with official names and reprinted with a topographic line map on the obverse in 1990. The map was based on geodetic control from field surveys undertaken from 1969 to 1988. The SPOT image used was acquired on 19 February 1988 while the line map was photogrammetrically plotted from ANARE photography previously flown in 1957 and 1961. The WGS84 coordinate system was used and the projection was Transverse Mercator.

China published a 1:10 000 scale topographic mapping in 3 sheets using the WGS72 coordinate system with a Gauss-Kruger projection. It was based on helicopter small format aerial photography, with field control survey from 1989 to 1992.. The map was compiled in September 1992 and printed in July 1993 by the Wuhan Technical University of Surveying and Mapping Press.

Geodetic Networks

Resolution 5 of the Geodesy and Geographic Information Working Group Report (www.scar-ggi.org.au/tokyo/ scar_rpt.pdf) to the XXVI Scientific Committee on Antarctic Research (SCAR) meeting in July 2000, was aimed at that unification of geodetic and mapping datums throughout Antarctica by the year 2001. This would allow the most effective means of integrating spatial information between Antarctic countries. The basis for AntGD2000 (the name chosen for the unified datum) would be the International Terrestrial Reference Frame 2000 (ITRF2000 @ 2000).

As a contribution to this objective of a unification of geodetic networks, ANARE surveyors undertook geodesy observations in the Larsemann Hills in the summer 2000/ 2001 to connect three local, but separate, geodetic networks. In this work a series of Australian, Chinese and Russian survey control points were connected to the International Terrestrial Reference Frame by geodetic quality GPS observations. Thirteen existing Larsemann Hills points were occupied, details of the data observation schedule is given in Table 1.

REPORT OF THE THIRD SCAR ANTARCTIC GEODESY SYMPOSIUM

						
Site	DOY	Date	Start	Finish	Vert Antenna Height (m)	Antenna Type
AUS334 (TGBM)	20	20/1/2001	5:29:30	23:59:30	1.0819	AOADM_T
	21	21/1/2001	0:00:00	2:42:30	1.0819	AOADM_T
ZI JIN PEAK	27	27/1/2001	8:06:30	23:59:30	0.9110	ASH700936E
	28	28/1/2001	0:00:00	5:49:00	0.9110	ASH700936E
WO LONG BEACH	21	21/1/2001	7:54:30	23:59:30	0.970	AOADM_T
ORIGIN CHINESE	23	23/1/2001	6:32:00	23:59:30	0.0040	ASH700936E
	24	24/1/2001	0:00:00	11:59:00	0.0040	ASH700936E
	25	25/1/2001	7:11:30	16:20:00	0.0040	ASH700936E
	26	26/1/2001	6:10:30	23:59:30	0.0040	ASH700936E
	27	27/1/2001	0:00:00	4:28:30	0.0040	ASH700936E
NMS 278	19	19/1/2001	10:38:00	23:59:30	0.0000	ASH700936E
	20	20/1/2001	0:00:00	23:59:30	0.0000	ASH700936E
	21	21/1/2001	0:00:00	23:59:30	0.0000	ASH700936E
	22	22/1/2001	0:00:00	0:31:00	0.0000	ASH700936E
RUSSIA 01	28	28/1/2001	6:11:30	23:59:30	1.2995	AOADM_T
	29	29/1/2001	0:00:00	2:39:30	1.2995	AOADM_T
ORIGIN RUSSIA	28	28/1/2001	6:49:00	23:59:30	0.0860	ASH700936E
	29	29/1/2001	0:00:00	14:01:30	0.0860	ASH700936E
THREE MAN PEAK	29	29/1/2001	10:16:00	23:59:30	1.3964	AOADM_T
V5	29	29/1/2001	15:19:30	23:59:30	0.7595	ASH700936E
	30	30/1/2001	0:00:00	12:02:30	0.7595	ASH700936E
WEATHER PEAK	22	22/1/2001	7:46:00	23:59:30	0.8344	ASH700936E
	23	23/1/2001	0:00:00	5:34:00	0.8344	ASH700936E
WU YAN GANG	27	27/1/2001	12:23:30	23:59:30	0.9263	AOADM_T
	28	28/1/2001	0:00:00	3:46:30	0.9263	AOADM_T
TGBM CHINESE	23	23/1/2001	5:54:00	20:09:30	1.1113	AOADM_T
	25	25/1/2001	7:16:30	23:59:30	1.1113	AOADM_T
	26	26/1/2001	0:00:00	23:59:30	1.1113	AOADM_T
	27	27/1/2001	0:00:00	23:59:30	1.1113	AOADM_T

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Table 1. Summary of ANARE GPS observation in the Larsemann Hill 2001/2002

SCAR WORKING GROUP ON GEODESY AND GEOGRAPHIC INFORMATION

Coordinate values for the Chines and the three Russian sites were provided by the Chinese Antarctic Mapping Centre in Wuhan (Wang 2000). No direct values for the Russian sites occupied or other ground marks, were supplied by Russia. The original coordinates and the datum details are still unknown.

The GPS baselines were processed using the Bernese precision processing software. All observations were adjusted using NEWGAN, a terrestrial adjustment software, holding the ITRF 2000 coordinates of the three Australian marks fixed. The results are listed in Tables 2 and 5. Using these coordinates and those supplied by the Chinese for the same marks an attempt at deriving 7 parameter transformation parameters was undertaken. This process requires both data sets to be homogenous but this was not the case and the technique could not be utilised. Alternatively a mean block shift for the section of the Larsemann Hills was calculated and the residuals from this block shift are shown in Table 3. Figure 1 indicates the magnitude and orientation of the resultant block shift vectors for each common station.

One of the thirteen sites occupied was the tide gauge benchmark (AUS334) for the Australian tide gauge on Nella Fjord. The Chinese Wo Long Beach Benchmark at Zhong Shan was also connected as this benchmark is the source of the Zhong Shan height datum, which was based on previous tide board readings.

Site	Lat	Long	Ellipsoidal Height (m)
Origin China	-69° 22' 28.48408''	76 22' 23.11836"	44.070
Zi Jin Peak	-69° 22' 32.65189"	76 22 12.93128"	68.082
Weather Peak	-69° 22' 18.84040''	76 22' 07.41206"	41.799
Wu yan gang	-69° 22' 20.72896''	76 21' 50.61894"	32.169
Wo Long Beach	-69° 22' 23.93179"	76 22' 40.68004''	24.888
RUSSIA 01	-69 22' 30.37254"	76 22' 22.95979"	46.609
Origin Russia	-69° 22' 51.04930"	76 23' 11.57155"	65.260
Three Man Peak	-69° 22' 49.27987"	76 17' 41.22551"	148.422
V5	-69° 24' 01.46181"	76 23' 48.85600"	78.715

Table 2. Coordinate Values for marks in terms of ITRF2000 @ 2000.

Site	Lat	Long	Ellipsoidal Height (m)
Origin China	-69° 22' 28.34495"	76 22' 22.43440"	45.760
Zi Jin Peak	-69° 22' 32.51232"	76 22' 12.24484''	69.760
Weather Peak	-69° 22' 18.70116''	76 22' 06.72946''	43.460
Wu yan gang	-69° 22' 20.58960''	76 21' 49.93527"	33.950
Wo Long Beach	-69° 22' 23.79299"	76 22' 39.99790''	26.560
RUSSIA 01	-69° 22' 30.23345''	76 22' 22.27598"	48.260
Origin Russia	-69° 22' 50.91228"	76 23' 10.87871"	66.970
Three Man Peak	-69° 22' 49.13866"	76 17' 40.53336"	150.130
V5	-69° 24' 01.32594"	76 23' 48.16219"	80.390

Table 3. Coordinate Values adopted by the Chinese as indicated by the ellipsoidal parameters for NSWC9Z2

Site	Diff Lat (m)	Res Lat (m)	Diff Long (m)	Res Long (m)	Bearing	Vector (m
Origin China	1.520	0.004	-21.194	-0.006	303.1	0.007
Zi Jin Peak	1.525	0.009	-21.271	-0.083	276.0	0.083
Weather Peak	1.521	0.005	-21.152	0.036	81.9	0.036
Wu Yan Gang	1.522	0.006	-21.185	0.003	24.2	0.007
Wo Long Beach	1,516	0.000	-21.138	0.050	89.6	0.050
RUSSIA 01	1.520	0.004	-21.189	-0.001	337.9	0.004
Origin Russia	1.497	-0.019	-21.469	-0.281	266.1	0.282
Three Man Peak	1.543	0.027	-21.448	-0.260	275.9	0.261
V5	1.484	-0.032	-21.499	-0.311	264.2	0.313
Mean	1.516		-21.188			

Table 4. Tabulated differences between the two systems at the marks listed. Residuals shown are after the mean block shift has been removed.



Figure 1. Block Shift Residual Vectors for Russian and Chinese Stations

Site	Lat	Long	Ellipsoidal Height (m)
C1	-69° 23' 31.207325''	76° 22' 44.580448''	130.367
NMVS 278	-69° 23' 21.178831''	76° 22' 50.762353"	80.058
AUS334 (TGBM)	-69° 23' 01.168748"	76° 22' 20.611541''	17.162
ZHON CGPS	-69° 22' 15. 786090"	76° 22' 11.460246"	40.707
TGBM Chinese	-69° 22' 23.195421"	76° 22' 42.134833"	21.920

Table 5. Coordinate Values for additional Larsemann Hills marks in terms of ITRF2000 @ 2000

Conclusion

In 2000/2001 a field survey was undertaken to produce a combined geodetic network over the Larsemann Hills by GPS observations connecting the ANARE and CHINARE marks in Broknes Peninsula in the eastern part of the Larsemann Hills area. The results were calculated in ITRF2000 at January 2001 epoch and are being made available through SCAR WG-GGI web site (www.scarggi.org.au). These connections provide an initial understanding of the transformation parameters needed to combine spatial data based on the three different Geodetic datums in the area.

The first results of the field survey indicate that the transformation parameters developed for spatial data integration are only suitable at the half metre level of accuracy. This could be improved by readjusting the Chinese terrestrial network to be more homogeneous by holding the ITRF positions fixed. This would produce greater accuracy for a GIS based on combined data. Transformation parameters for application to the Russian mapping and related spatial information need further investigation but a initial block shift relating to the comparison of the coordinates at the Russian fundamental survey pillar should be possible.

The extension of this survey into the rest of the Larsemann Hills area and into the surrounding geodetic networks, along the Ingrid Christensen coast, will improve the understanding of the relationship between the Australia and Russian adopted datums. To date no coordinate values have been obtained from the Russian authorities for marks installed by them. The sharing of this information would enhance this process as a base for a future combined GIS for environmental monitoring purposes.

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Application of the NMD-GA Online GPS Processing System (AUSPOS) to Antarctica

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Abstract

The Australian Surveying and Land Information Group's Online GPS Processing Service (AUSPOS) provides users with the facility to submit via the Internet, dual frequency geodetic quality GPS RINEX data observed in a 'static' mode and receive rapid turn-around precise coordinates. The service is free and provides ITRF coordinates worldwide, it is available for use in Antarctica. This Internet service takes advantage of both the International GPS Service (IGS) product range and the IGS GPS network and works with GPS data collected anywhere on Earth. Aspects of the design, implementation, usage and future plans of this system are reviewed.

The AUSPOS system can be found at http:// www.auslig.gov.au/geodesy/sgc/wwwgps.htm.

Introduction

Increasingly spatial information scientists are turning to the Internet as a tool to aid their activities. The field of high precision geodetic GPS is well represented on the Internet with many scientific, private sector and national geodetic agencies maintaining useful and informative geodetic GPS related web pages. Geoscience Australia's National Mapping Division NMD-GA is one such agency, (GA, 2001), see http://www.auslig.gov.au. NMD-GA



Figure 1. The Australian Regional GPS Network (ARGN). Consisting of 15 dual frequency geodetic quality GPS receivers tracking continuously

provides fundamental geographic information to support spatial data infrastructure applications. As the national body for Geodesy in Australia it is responsible for the national level geodetic infrastructure throughout Australia and its territories. As part of this role NMD-GA maintains a network of permanent GPS receivers throughout both Australia and the Australian Antarctic Territory (AAT). This GPS network shown in Figure 1, makes an important contribution to the national GPS infrastructure and further contributes to the international GPS community through the International GPS Service (IGS). NMD-GA is an IGS Regional Network Associate Analysis Centre (RNAAC) and routinely submits analysis products for combination with other IGS contributors.

As high precision global geodetic GPS technology has evolved, processing and analysis software has become more sophisticated and in general more automated. This development has now seen the implementation of Internet based geodetic GPS processing services, the first being NASA Jet Propulsion Laboratory's Auto-GIPSY Service (JPL, 2001) and later the Scrippts Orbit and Permanent Array Centre (SOPAC) coordinate generator (SOPAC, 2001).

In Australia these International GPS Processing Services were being widely used by the geodetic GPS community. It was at this time that the potential for user confusion between the International Terrestrial Reference Frame (ITRF), as provided by these International GPS processing services and the Australian national datum, GDA94 was recognised.

Since GDA94 was based on the ITRF92 at a fixed epoch of 1994 (ICSM, 2001) the latest ITRF coordinates produced were becoming substantially offset after a period of six years. This difference is due largely to the tectonic motion of the Australian plate as shown in Figure 2. Coordinate differences between GDA94 and the ITRF in 2001 are approximately 0.5 metres in magnitude.

NMD-GA traditionally has offered a GPS processing service to its clients in the national interest such as aviation, defence and other federal and state government agencies. For this processing GPS data was generally received on various digital media, including CDROM, floppy disks and email attachments. Customer service then relied on a hand-on-process and as such was not necessarily meeting the needs of the NMD-GA clients. Clients were increasingly requiring a 24 hour x 7 day a week access to a precise GPS processing service.

In this context in early 2000 a decision at NMD-GA was made to develop a 24 hour a day online web based GPS processing service that would provide users with access to GDA94 based coordinates for Australian users, and ITRF for International users. After several months of development the service was officially released on the 11th November 2000. This service is known as the NMD-GA Online GPS Processing Service or AUSPOS and has now been in continuous operation for over 12 months. It is accessible via the NMD-GA web site at www.auslig.gov.au.



Figure 2. Tectonic motion of the Australian land-mass. Tectonic velocity associated with the Australian land mass tends to the North East at approximately 70 mm/yr. Source. IGS cumulative solution, IGS-1P20.SNX (IGS, 2001)

The AUSPOS System

AUSPOS was designed and implemented with the following features and design goals;

- an easy to use web page interface;

applicable anywhere on Earth; and

GDA94 compliant for Australian users, ITRF elsewhere. Full details of the implemented system are given in Dawson et al (2001) Table 1 shows a breakdown of each of these software components or modules.

The AUSPOS design facilitates it use for a variety of applications in Antarctica (see Figure 3), including;

dual frequency geodetic GPS data processing capability; standard web-browser direct upload or ftp; highest quality global GPS processing standards; 24 hour x 7 days a week service; rapid processing turnaround, < 15 minutes/file; results returned by email and ftp server;	 DGPS reference station positioning remote GPS station positioning; ultra-long baseline positioning; GPS connections to IGS stations; Quick check of observational data high accuracy positioning; and
Software Component	Description and Purpose
 gps.cgi → PERL CGI script → located at www.auslig.gov.au Cosmgps_server → C language software → located inside the AUSLIG firewall 	 web interface uploads data collects GPS antenna height and type reports GPS processing status GPS job processing controller interfaces to web application interfaces to MicroCosm suite processing job queue user data quality checking user data preparation IGS data collection report GPS processing status PDF report generation email distribution
MicroCosm	orbit and geodetic parameter estimation
→ Fortran software	→ GPS data processing
→ located inside the AUSLIG firewall	→ receiver clock estimation
	→ least squares parameter estimation

Table 1. The AUSPOS software components (AUSLIG now known as NMD-GA)

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Figure 3. GPS at work in a remote Antarctic location

• GPS network quality control.

Figure 4 shows the AUSPOS web page interface. Users can directly submit or upload GPS RINEX data to NMD-GA where it is processed and results returned by email and

anonymous ftp. The AUSPOS web site includes a step by step user guide, frequently asked questions, new feature and bug reports, and regularly updated user analysis and user location maps.

Figure 5 shows the AUSPOS usage to July 2001 and

AUSLIG - Geodesy - Microsoft Internet Explorer	
Ello Edit Yow Favorites Icols Help	27
· + + Ø ② ② G. G. C. Ø Par- Ø Back, Eprvard: Stop Refinant Home Search Fevorites History Mai Print	
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AUSTRALIA'S NATIONAL MAPPING AGENCY	E 177
I PRODUCTS PROGRAMS I INTERACTIVE CCCD SPATIAL DATA INFRASTRUCTURE ABOUT AUSLIG PUBLICATIONS	O STARCH
GEODESY GEODEST & GPS	
GOA AUSLIG Online GPS Processing Service	- AUSLIG
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Figure 4. The AUSPOS web interface

includes GPS observations collected by several groups working in the Antarctic.

NMD-GA contributes data and analysis products to IGS from 15 NMD-GA GPS base stations, which includes three Antarctic sites. as shown in Figure 1, that are located across Australia and its offshore territories. AUSPOS was designed to exploit both the IGS product range and the IGS global GPS network. The full IGS tracking network consists of over 200 permanent GPS sites as shown in Figure 6. AUSPOS positioning is by differential GPS to several IGS stations using IGS precise orbits, Earth Orientation Parameters, atmospheric and other highquality GPS data products (IGS, 2001) together with ITRF station coordinates and velocity parameters.

The International Terrestrial Reference Frame (ITRF) produced by the International Earth Rotation Service (IERS) is a realisation of an ideal reference system. The frames produced by IERS as realizations of International Terrestrial Reference System (ITRS) are named International Terrestrial Reference Frames (ITRF) (IERS, 2001). The IGS undertake their own realisation of the ITRF using analysis results from the IGS community. The IGS cumulative solution (IGS-SSC) is one such solution and is currently aligned to the ITRF97 reference frame. AUSPOS undertakes all computations using the IGS cumulative solution as its reference frame.

Within Australia results are provided in the GDA datum fixed at an epoch of 1 January 1994. A seven parameter transformation is applied from the latest IGS-SSC to the observation epoch mapped to the GDA coordinates at the Australian IGS sites.



Figure 5. Location of AUSPOS data requests from July 2000 to July 2001



Figure 6. The International GPS Service (IGS) network of permanent GPS stations (IGS, 2001)

Feature/function	Description
Observations	RINE X dual frequency GPS code and carrier phase.
	User GPS navigation data is not required.
Data quantity	Minimum of 1 hour, recommended minimum of 6 hours
Multiple files submission	Maximum of 7 user files per submission
Compression	UNIX, ZIP, Hatanaka formats only
Orbit and Earth	IGS precise, ultra-rapid, rapid, final
Orientation	
Observations used	Double difference carrier phase
Reference frame	IGS-SSC (nominally ITRF97 at present),
	GDA94 for Australia
Geoid	Heights above the geoid are supplied within Australia using AUSGeoid98 (Johnston and Featherstone, 1998).
# IGS stations used	3
Results quality	<10mm horizontal <20mm vertical with 6 hours of data
Antenna phase centre	IGS or NGS models
Report delivery	Email and anonymous fip
Report format	ADOBE PDF

Table 2. AUSPOS feature and function summary

AUSPOS Features

The AUSPOS features and functions are summarised in Table 2.

AUSPOS System Modelling and Analysis

AUSPOS GPS processing is undertaken in accordance with the International Earth Rotation Service computation standards and is summarised in Tables 3, 4 and 5. Within the computation module AUSPOS uses the MicroCosm software suite (Martin, 2000) which is a full implementation of the IERS96 computations standards (McCarthy, 1996). MicroCosm has been used at NMD-GA for geodetic orbit determinations and parameter estimation for not only GPS but Satellite Laser Ranging (SLR) and Doppler Orbitography and Radio Positioning Integrated by Satellite (DORIS) (Govind *et al*, 1999).

Component	Description
Observable	Carrier phase. Pseudo-range for receiver clocks only. 20° Elevation cut-
	off. 30 second sampling rate
Ionosphere	Ionosphere corrected L1 double difference
Troposphere	Mulified Hopfield (Goad, 1974)

Table 3. AUSPOS observation Modelling

Component	Description
Earth's Gravitational (Static) Potential	EGM96 – degree and order 12
Solid Earth Tides (Dynamic) Potential	Love Model
Ocean Tide (Dynamic) Potential	Christodoulidis
Third Body Perturbations	Sun, Moon and Planets. Values for physical constants
	AU, Moon/Earth mass ratio, GM from JPL DE403
	Planetary Ephemeris.
Direct Solar Radiation Pressure	ROCK
Centre of Mass Correction / Attitude	Observation Correction applied

Table 4. AUSPOS Orbit Modelling

Omponent	Description
Precession	IAU76/IERS96 (McCarthy 1996).
Nutation	IAU80/IERS96 (including epsilon and psi corrections) (IERS,
	1996). Sine terms added to accumulated precession and nutation
	in right ascension as in IERS TN 21, p. 21 (McCarthy, 1996).
Geodesic Nutation	As in IERS TN 21, p.37 (McCarthy, 1996)
Polar Motion	CO4 – apriori (IERS, 2001)
Earth Rotation (UT1)	CO4 – apriori (IERS, 2001)
Daily/sub-daily tidal corrections	Applied
to X,Y and UT l	
Plate Motion	GS cumulative solution (IGS, 2001)
Planetary and Lunar Ephemeris	JPL DE403
Station Displacement	
Solid earth Tide	Williamson and Diamante (1972) + Wahr (1980) for the
Loading	frequency dependent elastic response of the Earth's fluid interior.
Oman Tide Loading	Not applied
Pole Tide	Applied
Atmospheric Loading	Not applied
Reference Frame	GS-SSC cumulative solution (IGS, 2001)

Table 5. AUSPOS station position modelling and reference frame modelling

Antarctic Applications

For applications outside Australia such as for Antarctica, results are provided directly in ITRF without the need to apply transformation parameters to a local datum. In Antarctica AUSPOS uses the existing IGS sites to compute a baseline from the three closest GPS sites, typically 1000 to 3500 km. Typical speeds (depending on Internet connection rate) and accuracy expected of system are

6 hour file

- results delivered in about 3 minutes
- 20 mm horizontal, 50 mm vertical

24 hour file

- results delivered in about 15 minutes
- <10mm horizontal and 10-20 mm vertical

An indicative measure of the AUSPOS accuracy versus observation length is shown in Figure 7.

Emailed results (in PDF format) for a typical site in East Antarctica can be seen in Figures 8 and 9.

1 User and IGS GPS Dat	User and IGS GI	PS Da	ta
------------------------	-----------------	-------	----

All antenna heights refer to the vertical distance from the Ground Mark to the Antennna Reference Point (ARP).

User File	Antenna Type	Antenna Height (m)	Start Time	End Time
He603640.00a	AS#7007168	0.7879	2000-12-29 07:24 59	2000-12-29 23 59:59
Ma503650.00a	ASH7007188	0.7879	2000-12-30 00:00:00	2000-12-30 09 54 00
	A CONTRACT OF A			
			- · · ·	
10-5-5	9.9			e e e



Figure 1: Global View – submitted GPS station(s) and nearby IGS GPS stations used in the processing: triangle(s) represent submitted user data; circle(s) represent the nearest available IGS stations





2 Processing Summary

Date	IGS Data	User Data	Orbit Type
2000-12-29	davi navi syog	Hin60	IGS Final
2000-12-30	davl mavl syog	NetSO	IGS Final

3 Computed Coordinates (ITRF97)

All computed coordinates are based on the IGS realisation of the ITRF97 reference frame, provided by the IGS commulative solution. All the given ITRF97 coordinates refer to a mean epoch of the site observation data. All coordinates refer to the Ground Mark.

3.1 Cartesian (ITRF97)

RM2

		X(82)	*(#)	2(2)	1110-974
	dav1	486854.554	2286099.294	-5914956.737	2000/12/30
	maw 1	1111287.177	2168911.275	~5874493.640	2000/12/30
	ayog	1766207.863	1460290.352	-5932297.721	2000/12/30
	Na50	537706.965	1799141.542	-6076735.061	2000/12/30
3	Na50	0.007	0.019	0.009	

*/-

3.2 Geodetic, GR580 Ellipsoid, ITRF97

		Latitude(DMS)	Longit	ude(DMS)	Height(m)	
	davî	-68-34 -38.3624	77 58	21.4087	44.451	2000/12/30
	may 1	-67-36 -17,1595	62 62	14.5762	59.180	2000/12/30
	eyog	-69 0 -25.0466	39 36	1.4782	50.041	2000/12/30
	Nm50	-72-56 -11.5052	73 21	36.0611	1639,737	2000/12/30
15	Net50	0.014 #	P .	0.012 #	0.013	-

4 Solution Information

o validate your solution you should check the :-

- i. Antenna Reference Point (ARP) to Ground Mark records;
- ii. Apriori Coordinate Updates, valid range is 0 000 75:000 m; and
- iii. Coordinate Precision, valid range is 0.001 0.025 m.
- iv. Root Mean Square (RMS), valid range is 0.0005 0.0250 m; and
- v. % Observations Deleted, valid range is 0 25 %:

4.1 ARP to Ground Mark, per day

All heights refer to the vertical distance from the Ground Mark to the Antenna Reference Point (ARP). The Antenna Offsets refer to the vertical distance from the ARP to the L1 phase centre.

	Height(a)	Ant	enne Offse	ta(m)	
Station	Up	East	Borth	Up	yyyy/m/dd
Nm50	0.7879	0.0010	0.0034	0.0873	2000/12/29
Nm50	0.7879	0.0010	0.0034	0.0873	2000/12/30

Figure 8. Pages 2 and 3 from a typical AUSPOS report

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4.2	Aprior	i Coordin	ate Up	dates	- Cartesi	an, per day	
			dI(m)		dY(a)	dZ(m)	
	Mas0		0.094		0.257	-0.886	2000/12/29
	Hz.50		0.080		0.291	-0.904	2000/12/30
4.3	Coord	inate Pre	cision -	Carte	esian, per	day	
	1 Signa	a	sX(m)		sY(m)	#2(m)	
	Nm50		0.005		0.011	0.011	2000/12/29
	Nm50		0.006		0.006	0.012	2000/12/30
4.4	Coord	inate Valı	re - Ca	rtesia	n, ITRF9	7, per day	
			X(m)		Y(m)	Z(m)	ITRF970
	Nm50	53770	6.970	1799	141.517	-6076735.053	2000/12/29
	₩250	53770	6.956	1799	141.551	-6076735.071	2000/12/30
4.5	Geode	tic, GRS8	IO Ellip	soid, l	TRF97.	per day	
						Ellipsoida	1
		Latitude	(DMS)	Longi	tude(DMS)	Height(m)	
	Nm50	-72-56 -11	. 5058	73 21	36.8797	1639.723	2000/12/29
	Nm50	-72-56 -11	. 5051	73 21	36,8822	1639.748	2000/12/30
4.6	RMS,	Observat	ions, D)eletio	ns per da	ıy	
	Data	RMS (m)	# Obser	vations	X Obs. Del	eted Date	
	dev1	0.0200	104	02	5 %	2000-12-2	9
	mawi	0.0194	981	B9	1 4 X	2000-12-2	9

Figure 9. Pages 4 and 5 from a typical AUSPOS report

18 1

13.3

2000-12-30

2000-12-30

2000-12-30

Conclusion

0.0214

0.0100

0.0118

28343

41130

5354

14678

The AUSPOS system is a very useful tool for Antarctic applications despite the current paucity of IGS stations across the continent whereby coordinates at the centimetre level can be determined where there is Internet access even at remote locations. Values are provided in a short time from be return by e-mail. The length of observation time and the quality of the data however determine the quality of results. Users should consider using at least six hours of data and several days observation is encouraged to provide an evaluation of accuracy rather than precision.

This is a very powerful and useable tool that is provided as a free service worldwide, user details can be found at http://www.auslig.gov.au/geodesy/sgc/ wwwgps.htm.

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A GPS Computation Standards

A.1 Measurement Modelling

	ionosphere corrected L1 double difference carrier phase,
	Fruedo-range only used for receiver CRICk estimation,
1	Elevation cut-off ZU",
	Sampling rate 30 seconds.
	Weighting 1.0cm for double difference.
Troposphere	Modified Hopfield
Preprocessing	Receiver clocks estimated using pseudo-range information
Satellite center of mass correction	Block Fx.y.z: 0.2100, 0.0000, 0.8540 m
	Bloch II/IIA x,y.z: 0.2794, 0.0000, 0.9519 m
Satellite Antenna Phase centre calibration	Not applied
Ground Antenna phase centre calibrations	Elevation-dependent phase centre corrections are applied
	according to the model IG501, the NGS antenna calibra-
	tions are used when the antenna used is not a recognised
	IGS type. The corrections are given relative to the Dorne
	Margolin T antenna.
Atmospheric Orag	Jachhia Model
Centre of Mass Correction / Attitude	Nd
A 2 Orbit Modelline	
B	
Earth's Gravitational (Static) Potential	EGN96 - degree and order 12
Model	l
Solid Earth Tides (Dynamic) Potential	Love Model
Ocean Tide (Dynamic) Potential	Christodoulidis
Third Body Perturbations	Sun, Moon and Planets
	Values for physical constants - AU, Moon/Earth mass ratio,
	GM(moon, sun and planets) from JPL DE403 Planetary
	GM(moon, sun and planets) from JPL DE403 Planetary Ephameria
Direct Solar Radiation Pressure	GM(moon, sun and planets) from JPL DE403 Planetary Ephameris. Rock
Direct Solar Radiation Pressure	GM(moon, sun and planets) from JPL DE403 Planetary Ephemeris. Rock
Direct Solar Radiation Pressure	(SM(moon, un and planets) from JPL DE403 Planetary Ephemeria. Rock and Reference Frame
Direct Solar Radiation Pressure A.3 Station Position Modelling	(OM(moon, sun and planets) from JPL DE403 Planetary Ephemeria Rock and Reference Frame
Direct Solar Radiation Pressure A.3 Station Position Modelling Procession	GM(moon, sun and planets) from JPL DE403 Planetary Ephanneris. Rock and Reference Frame IAUT0/IER596
Direct Solar Radiation Pressure A.3 Station Position Modelling Precession Nutsion	(GM(moon, sun and planets) from JPL DE403 Planetary Ephemoria. Rock and Reference Frame IAU76/IER596 IAU76/IER596 (including spillon and pill corrections)
Direct Solar Radiation Pressure A.3 Station Position Modelling Precession Nutation Suite terms added to accumulated precession	CM(moon, sun and planets) from JPL DE403 Planetary Ephannesis. Rock and Reference Frame IAU76/IER596 Including applion and pil corrections) As in IER5 TN 21.0. 21
Direct Solar Radiation Pressure A.3 Station Position Modelling Precession Nutation Sine terms added to accumulated precession and nutation in Right Accumion	(GM(moon, sun and planets) from JPL DE403 Planetary Rock and Reference Frame (AU70/JER596 (AU20/JER596 (including apsilon and psi corrections) As in IER5 TN 21, p. 21
Direct Solar Radiation Pressure A.3 Station Position Modelling Precession Nutation Sina terms added to accumulated precession and nutation in Right Ascension Geodesic Nutation	CM(moon, sun and planets) from JPL DE403 Planetary Ephanners, Rock and Reference Frame IAU76/IER596 IAU30/IER596 including applion and pol corrections) As in IER5 TN 32. p. 21 As in IER5 TN 32. P. 37
Direct Solar Radiation Pressure A.3 Station Position Modelling Precession Nutation Sina terms added to accumulated precession and nutation in Right Accession Geodesic Nutation Polar Motion	CM(moon, sun and planets) from JPL DE403 Planetary Ephannesis. Rock and Reference Frame IAU70/IERS96 (including spuilon and pui corrections) As in IERS TN 21, p. 21 As in IERS TN 21, P. 37 IGS Earth Orientation Parameters (Ultra rapid, Rapid, Fr.
Direct Solar Radiation Pressure A.3 Station Position Modelling Precession Nutation Sina terms added to accumulated precession and nutation in Right Accession Geodesic Nutation Polar Motion	CM(moon, sun and planets) from JPL DE403 Planetary Ephanneris. Rock And Reference Frame IAU76/IER596 IAU80/IER596 (including applion and pri corrections) As in IER5 TN 21, p. 21 As in IER5 TN 21, P. 37 IGS Earth Orientation Parameters (Ultra capid, Rapid, Fin Ial), aprice
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Influence of Ionosphere in Arctic and Antarctic Regions on GPS Positioning Precision

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Abstract

Results of analysis of the influence of ionosphere over the Arctic and Antarctic regions on positioning precision are presented in the paper. The analysis relies on studying repeatability of vectors' co-ordinates. Vectors of different length (130km - 3500km) were investigated during the quiet and disturbed ionosphere (ionospheric storms). The GPS observations from following periods of the ionospheric storms: 15-18 February, 11-16 September, 27-30 September and 10-15 October 1999, were analysed. The IGS and SCAR permanent observations from Onsala (57°N, 12°E), Kootwijk (52°N, 6°E), Kiruna (67,8°N, 20,9°E), Metsahovi (60°N, 24°E), Tromso (69,6°N, 18,9°E), O'Higgins (-63°N, 302°E), Davis (-68°N, 78°E), Mawson (-68°N, 63°E), East Ongle Island (-69°N, 40°E) and Arctowski (-62°N, 58°W) were taken for analysis. Bernese ver.4.2 software was used for the analysis of observational data of the eight and twelve-hour sessions. Results were referred to those obtained from 24-hours sessions from periods of the quiet ionosphere.

Strong correlation between TEC changes and all vector components were obtained. The changing conditions of ionosphere mostly affect height component. The height differences obtained from the quiet and disturbed ionosphere reach a few dozen millimeters even for 130km long vectors.

Introduction

To determine the ionospheric TEC, a geometry-free linear combination is used. It contains the ionospheric delay and the ambiguities for phase measurements and equipment biases for code measurements.

The relationship between ionospheric delay and the TEC, and difference between dual-frequency code (P) and phase (F) measurements may be written (Baran *et al*,

$$\Delta P[m] = M \ ?TEC / \cos z + A_p + \varepsilon_p$$

$$\Delta \Phi[m] = M \ ?TEC / \cos z + A_{\Phi} + \varepsilon_{\Phi}$$

1997):

Here TEC is the vertical electron content, M is a scale factor, \mathcal{E}_p , \mathcal{E}_{Φ} are noise terms, A_p and AF are equipment biases (AF contains the phase ambiguity), z is the zenith angle of the ray at the sub-ionospheric point.

TEC Variations during Storm

The magnetic storm under consideration occurred on 27-29 September 1999. Diurnal values of TEC on 27-30 September 1999 for every single station were estimated. Diurnal variations at different sites are given in Fig.1. At the first day of the storm i.e. 27 September, a significant TEC increase took place. The positive effect of storm during daytime occurred at all sites. On the second day of storm the negative phase only for the high-latitude station Thule was found. On the others stations the positive disturbance lasted through the storm.

Studying of the repeatability of the coordinates and the length of the vector during the ionospheric storms. Analysis relied on studying of repeatability of the coordinates and the length of the vectors connecting Onsala with Metsahovi, Hoefn, Thule, Kiruna, Ny-Alesund, Reykjavik and Tromso stations, Davis with Mawson and Casey stations and O'Higgins with Arctowski station. Coordinates of the Onsala, Davis and O'Higgins stations were fixed. The distances of all mentioned above stations to Onsala, Davis and O'Higgins respectively are given in Table 1.

Three periods of the ionospheric storms from 15 - 18February, 11 - 16 September, 27 - 30 September and 10 - 15 October of 1999 were analysed. Bernese v.4.2 software was used for the analysis of observational data of the six, eight and twelve-hours sessions. Results were referred to those obtained from 24-hours sessions.

In Figures 2-7 the examples of oscillations in DN, DE and DU for chosen vectors are shown. On February 16th and on September 27th, 1999, during maximum of ionospheric storm one can see the extreme in determined components.

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Figure 1 Space-time occurrence of storm in Total Electron Content during 27-30 September 1999(TEC given in 10¹⁶ el/m²)

Station	Distance (km)	Station	Distance (km)
	ONS	ALA	
Metsahovi	784	Reykjavik	1956
Kiruna	1250	Ny-Alesund	2387
Tromso	1406	Thule	3622
Hoefn	1640		
	DA	VIS	
Mawson	636	Casey	1397
	O'HIC	GGINS	
Arctowski	132		

Table 1. The lengths of vectors



Figure 2. Day-to-day changes of North, East and Up components obtained from 24-hours sessions for Metsahovi station and changes of Onsala-Metsahovi vector length



Figure 3. Day-to-day changes of North, East and Up components obtained from 12-hours sessions for Metsahovi station and changes of Onsala-Metsahovi vector length

The best repeatability was achieved for 24-hours sessions. For Onsala-Metsahovi vector, shown in Fig. 2, maximum discrepancies amount to: DN=5mm, DE=13mm and DU=20mm. Variations vector length reached 12mm.

When ionosphere is quiet (TEC amounts to 2-7 TECU)





Figure 4. Day-to-day changes of North, East and Up components obtained from 8-hours sessions for Metsahovi station and changes of Onsala-Metsahovi vector length

As one can see in Fig. 4, the highest influence of ionosphere was observed during processing observations carried out between 08^{00} - 16^{00} , when TEC showed largest changes. During ionospheric storm (27 and 28 September) TEC values changed from 6 to 23 TECU for Metsahovi station (Fig. 1). One can also see the largest changes for DU component. Day-to-day changes reached 32mm in DU, and 19 mm in the vector length (Fig. 3).

Mentioned above analyses showed, that influence of

ionospheric storms can be observed for vectors longer then 650 km. However, period of ionospheric storm between 15 and 18 February 1999, showed the occurrence of unfavorable influence of ionospheric storms on analysed components even for length of vector 132 km (O'Higgins-Arctowski). The highest discrepancies amounted for DU component too. Day-to-day changes (using observations carried out between 06^{00} - 12^{00}) amounted to 220 mm in DU, and 14mm for the vector length (Figures 5-7).



Figure 5. Day-to-day changes of North, East and Up components obtained from 24-hours sessions for Arctowski station and changes of O'Higgins-Arctowski vector length



Figure 6. 5 Day-to-day changes of North, East and Up components obtained from 12-hours sessions for Arctowski station and changes of O'Higgins-Arctowski vector length



Figure 7. 5 Day-to-day changes of North, East and Up components obtained from 6-hours sessions for Arctowski station and changes of of O'Higgins-Arctowski vector length

Conclusions

The ionosphere in Arctic and Antarctic regions has considerable influence on the accuracy determination of the vectors.

The periods of the increased ionospheric activity were analysed. Strong correlation between TEC changes and North, East and Up vector components were obtained.

The changing conditions of ionosphere mostly affect height component. The height differences obtained from the quiet and disturbed ionosphere reach a few dozen of millimeters even for 132km long vector (O'Higgins-Arctowski).

Because of the great dynamics of the TEC during the ionospheric storms the special attention should be paid to the vector co-ordinates obtained from semidiurnal GPS sessions.

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On Determination Precision of Tropospheric Delay at the Antarctic Coast Stations

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Abstract

The paper studies some peculiarities of the determination of zenith tropospheric delay in the Antarctic coastal zone. There are shown the values of the dry and wet components of zenith tropospheric delay obtained by an integration of the average monthly radiosonde data at several polar stations. Determination analysis of the dry and wet components is adduced on the basis of the twice per day aerological soundings carried out during January at Mirnyj station. The accuracy estimation was carried out for zenith tropospheric delay determination by the Saastamoinen and Hopfield models and by author proposed ones.

1. Introduction

At present GPS observations find a wide use for solution a lot of diverse scientific and real-world problems in Polar Regions and first of all in Antarctica. Taking into consideration that the network of GPS permanent stations is in progress in Antarctica and the yearly 20- day's GPS campaigns acquire more and more prevalence at many Antarctic stations it becomes evident that problem of detail investigation of the atmospheric influence peculiarities on the results of such observations is exceptionally topical in this region. Therefore a study of atmospheric effects on the results of GPS measurements should be carry out not only on a global or regional scale but also on a local one (at individual permanent GPS stations).

Determination of zenith tropospheric delay and its 2. components by integration of refractivity

Total tropospheric delay is expressed as:

$$d_{trop} = d_d^{z} ?m_d + d_w^{z} ?m_w, \quad (1)$$

where d_d^z and d_w^z are zenith dry and wet components respectively; m_d , m_w are mapping functions of zenith tropospheric delay components at zenith angles $Z > 0 \infty$. Total zenith tropospheric delay from radiosonde data is determined by numerical integration of the N_d and N_w refractivities:

$$d_{trop}^{z} = d_{d}^{z} + d_{w}^{z} = 10^{-6} {}^{H_{a}} N_{d} dH + 10^{-6} {}^{H_{a}} N_{w} dH,$$
(2)

Expressions for the dry and wet refractivities are the following: Ρ.

$$N_{d} = K_{1} \frac{d}{T}, \quad (3)$$
$$N_{w} = K_{2} \frac{e}{T} + K_{3} \frac{e}{T^{2}}, \quad (4)$$

where K_1, K_2, K_3 are refractivity constants; $P_d = P - e$ is partial pressure due to dry air; T is air absolute temperature; e is partial pressure of water vapour.

With the aim to show an evidence of the values of dry and wet components of zenith tropospheric delay we used the average monthly radiosonde data for two seasons at few polar stations. The quantities d_d and d_w were obtained by means of numerical integration (Table 1).

It should be noted that available data represent the air humidity at the isobaric surface equal to 100 hPa at Mirnyj and Heys Isle stations and only to 300 hPa at Academic Vernadskyj station. Taking into account the air humidity in the atmospheric layer 300 - 100 hPa the contribution to the wet component by Mirnyj station data introduces a quantity equal on average to 3 mm in summer and just 0.3 mm in winter.

Station	Н	Summer			Winter			
	km	Month	d_d	d_w	Month	d_d	d_w	
Vostok	3.49	December	1441	7	July	1427	1	
Mirnyj	0.04	January	2242	50	July	2233	23	
Academic Vernadskyj	0.01	January	2245	72	August	2259	38	
Heys Isle (North Arctic)	0.02	July	2301	100	January	2307	16	

Table 1. Dry and wet components (mm) obtained by the average monthly radiosonde data at the polar stations

On average in the Antarctic coastal zone and in North Arctic the value of wet component makes up 3+4% of the total value in summer and 1+2% in winter. At Vostok station the value d_d forms only ~ 65% of corresponding delay in comparison with other Antarctic coast stations. That is caused by the great elevation of this station above sea level. The wet component is very small here as the atmospheric air is close to dry one especially in winter.

3. Determination of the zenith tropospheric delay components by analytical models

A modern software for GPS data processing contains usually several models for the determination of tropospheric delay. For example the GeoGenius2000 programme contains 7 of such models including the Saastamoinen model, Hopfield classical one, two Hopfield modified models and others. So a user has a possibility to fit that or other model appropriate in the best way to the atmosphere structure in an observations area (having in view some regional average yearly model or seasonal one).

Our investigations concerning this question have been realised on the basis of the twice per day (at 6 and 18 o'clock of the local mean time) aerological soundings carried out during one summer month (January) at Mirnyj station (Proceedings of SAE, 1963). Since the Saastamoinen and Hopfield models are the most widely used we adduce here the illustrations and analysis of the dry and wet components obtained by these models. Figures 1 and 2 show the graphs of differences Δd_d^z and Δd_w^z

between dry and wet components of zenith tropospheric delay calculated by the radiosonde data and corresponding components by the Saastamoinen (top line) and Hopfield (bottom line) models for 6 o'clock in the morning.

It should be noted that the air humidity effect was allowed only for the upper boundary of troposphere.

As is obvious the results obtained by the Saastamoinen and Hopfield analytical models have approximately the same accuracy. However there is a steady displacement between both dry and wet components calculated by these models. So it averages 7 and 11 mm for dry and wet components at 6 o'clock and 7 and 15 mm at 18 o'clock.

The similar displacements of Δd_w values take place also for Ifadis, Baby, Chao, Berman and Askne and Nordius models (Zablotskyj, 2000). Expressions for these models are borrowed mainly from the monograph (Mendes, 1999).

The same interdiurnal variations of dry and wet components obtained by the Saastamoinen and Hopfield models as well as by other analytical models. We have interpreted this in the following way: a majority of analytical models are founded either on standard atmospheric models or on other averaged atmospheric models obtained mainly for middle latitudes of the Northern Hemisphere.



4. Development of atmospheric models for the Antarctic coastal zone

Proposals concerning atmospheric models for determination of the tropospheric delay are founded on the basis of twice per day aerological soundings carried out in January at Mirnyj station (see Table 2). As is obvious from the temperature characteristics, the morning period essentially differs from evening one. It is typical for the medium latitudes as well. Therefore, an approach to development of the atmospheric model for the summer period at Mirnyj station was followed.

Time	air temperature, °		air pressure, hPa			vapour pressure, hPa			
	aver.	max	min	aver.	max	min	aver.	max	min
6 ^h	-5,2	-1,6	-10,2	986,9	1003	969	3,2	5,2	2,0
18 ^h	-1,3	+3,8	-6,2	986,6	1003	969	4,3	6,0	2,6

Table 2. Main characteristics of the surface meteorological parameters at Mirryj station (January)

5. Reconstruction of temperature vertical profiles

For each day of January we picked out the temperature data on the standard high-levels from Earth's surface to 25 km for 6 and 18 o'clock separately. The vertical temperature gradients had been determined by average values of temperatures and then they were averaged for corresponding atmospheric layers (see Table 3). The data of average monthly temperatures in stratosphere and mesosphere of the Southern Hemisphere calculated the temperature gradients in layers from 25 to 80 km.

By means of the γ_t values and measured surface temperatures the vertical temperature profiles were constructed for the morning and evening moments of separate soundings for the different dates.

Time	Gradient	Boundaries of the atmospheric layers, km								
		0,03-0,2	0,2-0,5	0,5-1	1-3	3-8	8-9	9-12	12-20	20-25
6 ^h	Υı	0.53	2.30	3.98	5.40	5.94	1.93	-2.25	-0.55	-0.10
18 ^h	Ŷı	6.18	6.70	6.32	5.42	5.87	2.00	-2.09	-0.66	-0.10
6 ^h	Ύμ	5.5	5.0	4.5	2.4	2.8	-	-	-	-
18 ^h	Yu	5.5	10.1	8.2	3.3	2.0	-	-	-	-

Table 3. Averaged vertical gradients of temperature (γ_{μ}° C/km) and relative humidity (γ_{μ} , %/km) in January at Mirnyj station

The well-known formula was used for calculation of the atmospheric pressure:

$$D_2 = D_1 ? \exp{-\frac{g_m (H_2 - H_1)}{R_d ? T_m}}.$$
 (5)

where P_2 and P_1 are atmospheric pressures on the altitude levels H_2 and H_1 respectively; g_m is gravity acceleration at the centre of gravity of the air column; P_0 is specific gas constant for dry air; $T_m = (T_1 + T_2)/2$ is average absolute temperature of the vertical air column $(H_2 - H_1)$.

For construction of water vapour vertical profile we propose the following expression:

$$e_2 = e_1 ? \frac{T_2}{T_1} ? \exp(-0.06 ? \gamma_1 ? h - 0.15 ? h),$$
 (6)

where e_2 and e_1 , T_2 and T_1 are the water vapour pressure (hPa) and absolute temperature at the altitudes H_2 and H_1 ; $h = H_2 - H_1$. The constant coefficients 0.06 and 0.15 were obtained from the twice per day aerological soundings at 6 and 18 o'clock during January at Mirnyj station. Hereinafter the vertical humidity profiles were calculated by means of this formula. It should be noted that a somewhat like approach to the determination of vertical distribution of water vapour in the Arctic atmosphere has been executed earlier (Bazlova, 1966). An another approach for construction of the water vapour vertical profile is based on the following. By the surface relative humidity and its vertical gradients (see Table 3) the vertical profile of relative humidity is calculated at all altitudes of a given vertical profile. Simultaneously, the values of water vapour pressure are determined.

For comparison of determination accuracy of the zenith tropospheric delay components obtained by Saastamoinen model and our two ones 19 aerological profiles were picked out for 6 o'clock in the morning. The mean differences Δd_d^z and Δd_w^z and mean square errors of individual differences were obtained by mentioned models (see Table 4)

It is seen from mean differences and from mean square errors as well, the results obtained with our models are a little bit better than ones with Saastamoinen model. It is so especially for the wet component of zenith tropospheric delay. In our opinion the proposed approach is effective and, therefore, it should be tested with aerological sounding data at other Antarctic coast stations.

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Model (SA)		Мо	odel 1	Model 2		
Δd_d	Δd_{w}	Δd_d	Δd_w	Δd_w		
		Mean differen	ice, mm			
2.0	6.6	0.4	-0.4	-1.8		
	Mean square	error of indiv	idual difference	e, mm		
3.6	8.4	2.9	5.8	7.0		

Table 4. Mean differences of dry and wet components and mean square errors of individual differences

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Contribution of Data from Polar Regions to the Investigation of Short Term Geodynamics. First Results and Perspectives

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Abstract

Perfection of technology and appropriate procedures of geodetic measurements makes it possible to detect and investigate short term regular geodynamic processes in time scale from several hours to several days. Also an increasing need for near real time precise satellite positioning requires to investigate short time variations of station co-ordinates geometrically derived from GPS data. Time series of investigated components of the vectors defined by permanent GPS stations and obtained using bernese software show a distinguished periodic behaviour with periods of 24 hours, 12 hours and shorter ones. Regularity of these variations occur at different levels for the vectors investigated.

An attempt to separate periodic biases into three groups depending on ground segment (receiver, antenna, software and site stability), space segment (orbits and satellites configuration) and environmental segment (troposphere and ionosphere models) was undertaken. It requires an extensive analysis of GPS, gravity and meteo data from the stations located in different regions. The comparative analysis of heterogeneous geodetic, geophysical and meteo data that are affected by the Earth rotation can contribute to the development of short term geodynamics by complementing the knowledge on the interrelations within a range of geophysical and meteorological phenomena. In particular, research on the separation of environmental segment requires data from polar regions due to specifics in the diurnal and sub-diurnal atmospheric variations at high latitudes. Recently obtained results are discussed in the paper.

1. Introduction

GPS positioning with centimetre accuracy requires long observation campaigns on wide spread network of points followed by a laborious data processing. The increase of the length of observing session results in the increase of the number of degrees of freedom and decrease of solution error. That error can additionally be reduced by including it into the solution data collected at the other stations of the network. Twenty four hour long observing sessions are considered as shortest in such calculations. Frequently the station co-ordinates are obtained by averaging solutions from a few consecutive days. The use of sessions lasting as long as 24 hour in processing high precision GPS data is not really constrained by redundancy requirements but it is driven by the need of smoothing the solution through removing from it the nonmodelled systematic effects of periodic character. Such an approach concerns also a single vector precise determination from GPS data. Although vectors of 100 km length can already be resolved with fixed ambiguities and high internal precision from a few hour long GPS observing session, the variations of time series of such solutions noticeably exceed the estimated precision of individual solutions.

Research on variability of vector solutions obtained from short GPS observing sessions with use of data collected at Polish permanent stations of the IGS and EUREF networks was initiated in 1999 at the Institute of Geodesy and Cartography, Warsaw. For BOGO-JOZE vector (42 km length) computed with GPPS software using 4h long sessions covering 25 days, the variations in north (N), east (E), up (U) components and vector length (D) did not exceed 5 cm, 10 cm, 10 cm and 4 cm, respectively (Krynski and Cisak, 2000). Calculation of the same vector with Bernese software provided variations in N, E, U components and in D within 1 cm, 1 cm, 4 cm and 1 cm intervals, respectively (Krynski et al., 1999). In both time series of solutions generated using different software packages the distinct periodic terms with 12h and 24 h periods occur. Variability of coordinates of JOZE IGS/ EUREF permanent GPS station obtained from processing with bernese software 1h observing sessions over 22 days at 29 stations of EUREF network was analysed (Bogusz et al., 2000). Variations within 1 cm, 1 cm and 2.5 cm were obtained for N, E and U components, respectively and a distinct periodicity of 12 hour and 24 hour periods was indicated.

2. Permanent GPS station's data analysis

Time series of vector solutions obtained using data from BOGO, JOZE and LAMA permanent GPS stations of EUREF network were analysed. All three stations are situated on approximately the same meridian. Data from 21 days (260-280 DOY 1999) was processed using Bernese 4.2 software for the vectors BOGO-JOZE, JOZE-LAMA and LAMA-BOGO forming a triangle. The vectors calculated from 4h observing sessions with 75% overlap. i.e. the beginning of next session were shifted by 1 hour with respect to the beginning of the previous one. Variations in the obtained time series of solutions are distinctly regular. Spectral analysis of time series of the solutions shows the evidence of diurnal and semi-diurnal periodic terms (Zanimonskiy and Krynski, 2000). Further, a time series of triangle closure was calculated for each vector component. A variation in those series does not seem to be regular. Their magnitules are, however smaller than those in respective components of individual vectors. The amplitude of the variations in vertical component is the largest. Time series for vertical component of BOGO-JOZE vector as well as the respective time series derived from the combination of two vectors remaining in the triangle are shown in Figure 1.

Three curves in Figure 1 remarkably match to each other. The closeness of the curves indicates that in the solutions based on a few hour long observing sessions there exist systematic effects that were not removed from the data. Moreover, it also indicates that these effects distinctly dominate over random errors of observations in the estimated vector components. Thus, variations in the analysed time series are mainly due to effect of nonmodelled biases. Simultaneously rough estimate of random errors corresponds quite well with the estimates provided in the process of individual vector computation.

Most distinguished regularity in time series of obtained vector components corresponds to daily Pblocks of solutions. Such blocks of solutions for the length of BOGO-JOZE vector for 5 consecutive days are given in Figure 2.



Figure 1. Variations in vertical component of BOGO-JOZE vector, of same vector calculated as the sum of two vectors remaining in the triangle; as well as of the average of two previous solutions

Considering diurnal regularity of variations of vector components the average solution for each hour of the day over 21 days was computed for each component of three vectors analysed. Close agreement in the variations of the corresponding components of the vectors was obtained. Figures 3 and 4 show the variations in vertical component and vector length, respectively.

Averaged variations obtained for BOGO-JOZE, JOZE-LAMA and LAMA-BOGO vectors that form a prolate triangle are very similar to each other in corresponding co-ordinates. Most distinguished similarity with simultaneously largest dispersion of solutions took place for the vectors BOGO-JOZE (42 km) and LAMA-JOZE (201 km), i.e. vectors with JOZE as a common station. It was found that the number of GPS satellites tracked at JOZE was frequently smaller than that at BOGO and LAMA. It resulted in weaker solution of the vectors containing JOZE and in consequence larger variations in time series of resolved co-ordinates.



Figure 3. Averaged variations in vertical component

Observed variations in time series of vector components determined from GPS data besides random errors of observations consist of resultant of multiple effects caused by deficiency of the models applied. Resulting biases come from different sources. They can be classified in three groups: ground segment (receiver, antenna, software and site stability), space segment (orbits and satellite configuration) and environmental segment (troposphere and ionosphere models). Separation of the individual biases and adequate observation modelling would enable more accurate determination of vector components from much shorter than 24h sessions of GPS data

3. Analysis of GPS data from mini-network at Borowa Gora

In the solutions obtained for a hundred metre long vectors the effects of orbital biases as well as biases due to ionosphere and troposphere are negligible. The solutions for such short vectors obtained from sufficiently long GPS observing sessions are thus affected by satellite configuration bias (including multipath) as well as biases related to ground segment.



Figure 2. Diurnal regularity of variations of the length of BOGO-JOZE vector



Figure 4. Averaged variations in vector length

GPS observations were conducted at four close to each other stations at Borowa Gora Geodetic-Geophysical Observatory for 5 consecutive days in 2000. Stations 217, OR3 i 3230 are the eccentric points for BOGO permanent GPS station (Figure 5).

GPS data collected at the points of mini-network (Figure 5) was processed using PINNACLE software. The vectors were calculated from 1h sessions with 67% overlap, i.e. the beginning of next session was shifted by 20m with respect to the beginning of the previous one. Time series for the components of 6 vectors in the network were obtained. As expected, the agreement in the variations between daily blocks for each component of the vectors was much better than in case of long vectors. The solutions for vertical component of BOGO-217 (107 m) vector over three consecutive days are shown in Figure 6. Time series for the same component of BOGO-217 vector calculated from a combination of BOGO-3230 i 3230-217 vectors is given in Figure 7.

Similarly the solutions for the length of BOGO-217 (107 m) vector over three consecutive days are shown in Figure 8.



Figure 5. Test mini-network at Borowa Gora Geodetic-Geophysical Observatory



Figure 7. Diurnal regularity of variations of vertical component of BOGO-217 vector calculated as a combination of BOGO-3230 and 3230-217 vectors (1h sessions with 20m shift)

The diurnal variations of short vector components (e.g. Figure 6, Figure 8) as well as of triangle closure (Figure 7) is much more regular than those for long vectors (e.g Figure 2). It is not surprising since in case of short vectors lots of biases differentiate to a negligible level. Variations of short vector components (Figure 6, Figure 8) seem to be chaotic. One can notice in them, however, periodic biases due to multipath and antenna phase centre.

In order to get higher resolution of time series for variations of vector solutions, BOGO-217 vector was calculated from 1h sessions with 98% overlap, i.e. the beginning of next session was shifted by 1m with respect to the beginning of the previous one, over 4h of 273 DOY 2000. The results obtained for vertical component and for vector length on the background of the respective previously discussed more sparse solutions are given in Figure 9 and Figure 10.

Variations in the solutions for vertical component and the length of the vector shown in Figures 9 and 10, respectively, similarly to the other vector components, reflect the effect of satellite configuration. This effect



Figure 6. Diurnal regularity of variations of vertical component of BOGO-217 vector (1h sessions with 20m shift)



Figure 8. Diurnal regularity of variations of the length of BOGO-217 vector (1h sessions with 20m shift)

affects the solutions through geometry, quality of ambiguity solution, multipath and antenna phase centre.

The solutions presented in Figures 9 and 10 are obtained from processing GPS data covering120 epochs (30s sampling rate). Since the data used for two consecutive solutions differ by 4 epochs only (1m shift) one could expect smooth variations in calculated vector components. In both figures, however, sudden jumps and peaks occur. They correspond to a case when satellite configuration changes (new satellite is getting observed or/and one of the observed satellites descended below the horizon) between two consecutive observing sessions processed. Sudden changes in N, E, U vector components and D vector length reached 1mm, 1mm, 2mm and 1mm, respectively. They also take place when the same configuration of satellites is observed but the pairs of satellites chosen to form double differences in two consecutive solutions do not match. Jumps at the level of 2mm, 1mm, 5mm and 2mm in N, E, U vector components and D vector length, respectively, occurred.



Figure 9. Regularity of variations of vertical component of BOGO-217 vector (1h sessions)

4. Specifics of GPS data from polar regions in separation of biases in vector determination

Biases that affect vector solutions from short GPS observing sessions in polar regions can also be classified as the effect of ground segment, space segment and environmental segment. Biases due to ground segment in the solutions from polar regions are expected to represent the same behaviour as the ones in medium latitudes. The substantial difference between the variations in GPS solutions in those two geographical regions occurs in the biases due to space segment, i.e. satellite configuration as well as due to environmental segment.

Distribution of tracked GPS satellites in polar region, due to high latitude, is much less homogeneous than at medium latitudes. Thus, besides 12h and 24h periodic variations in GPS solutions a bias due to satellite distribution heterogeneity is expected to occur. The effects of satellite configuration can be investigated by analysing short and medium length vectors obtained from short GPS observing sessions.

At medium latitudes both troposphere and ionosphere biases consist of a distinguished diurnal periodic component with seasonal influence. At high latitudes the effects of Earth rotation on biases in GPS solutions seasonally decrease to the level of negligibility. Therefore periodicity of the environmental bias in polar region is expected to seasonally practically vanish. This unique situation that occurs in polar regions gives an opportunity to better separate environmental biases. Analysis of GPS time series over different seasons together with meteo data will allow to separate the tropospheric bias what further would lead to the extraction of ionospheric bias.

5. Conclusions

Vector components are determined at a sub-centimetre level of accuracy from at least 24h long GPS observing sessions. Shortening observing session leads to the increase of dispersion of results and to lowering their accuracy.

A distinct regularity with daily cycle for the solutions of vector components is noted. Daily blocks of solutions for short vectors almost perfectly coincide. For long vectors daily blocks of solutions also match very well.



Figure 10. Regularity of variations of the length of BOGO-217 vector (1h sessions)

They are, however, additionally disturbed with biases caused by imperfection of ionosphere and troposphere models as well as satellite orbit models.

The analysis indicates the need of further research on daily regularity of the vector solutions obtained from GPS data and on improvement of ionosphere and troposphere models in order to achieve sub-centimetre accuracy in vector determination from short GPS observing sessions. In such a research an important role plays an analysis of GPS data from polar regions, mainly due to specifics of environmental segment.

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East Antarctica Coverage GIS Project

Alexander Yuskevitch

The beginning of the Antarctic mapping coincides with its discovery by the first Russian Antarctic expedition led by F. Bellingshausen and M. Lazarev when in 1820 our countrymen approached a coast of the Antarctic shelf glacier and for the first time carried out its sea inventory. Since 1956 when a stage of the intensive and detailed exploration of the "Sixth Continent" began, our country has been yearly organizing expeditions to Antarctica. The history knows 34 Soviet and 10 Russian Antarctic expeditions altogether. There were founded more than 30 permanent stations to carry out the exploration and research. Russian specialists have made a significant contribution to realize the combined exploration and research of Antarctica in the fields of geography, geology, glaciology, climatology and so on. A great amount of the work has been done by organizations of the Geological Ministry such as a State Enterprise "Sevmorgeo", Arctic Geology Research Institute, organizations of the Hydrometeorogical Service including the Arctic and Antarctic Institute, some Institutes of the Academy of Sciences: Institutes of Geography, Glaciology, Space Exploration, Oceanography and others.

The year of 1966 was marked by a publication of a twovolume Atlas of Antarctica. The Atlas contained a detailed description of the Continent made on the base of the combined exploration and research carried out up





Legend.

S - cosmic base

 $S_1 S_2, S_3 - cosmic base sections$

 $H_{1}^{-1}, H_{2}^{-2}, H_{3}^{-3}$ – line crossing points of base radio stations $H_{1}^{-1}, H_{2}^{-1}, H_{3}^{-1}$ – elevations of base radio stations crossing points

H , H , H , H_a - elevations of base radio station

to the moment. We can call the Atlas produced together with the specialists of the Main Administration of Geodesy and Cartography as a "Cartographic Encyclopedia of Antarctica".

Specialists of the State Aerogeodetic Enterprise "Aerogeodeziya" have been taking part in the Antarctic expeditions since 1970. The completion survey, topographical mapping and gravimetrical determination have been done during the past years.

A complex of the work to conduct completion geodetic survey for a subsequent mapping of Antarctica consisted of the following principal stages:

- cosmic base measurement between Molodezhnaya and Novolazarevskaya stations with a radiogeodetic system.
- base definition for the radiogeodetic system standardization.
- geodetic chain coordinates setting by adjusting lineangle networks, trilateration networks and by applying an astronomical method.

The cosmic base measurement was carried out to scale radiogeodetic networks. The base was defined between Vecherniaya (10 km from the Molodezhnaya station) and Zenith (5 km from the Novolazarevskaya station) points. An on-board radio range finder (RDS) was used as the radiogeodetic equipment.

The base 1.37 thousand-km long was divided into three parts: Vecherniaya - Larsen, Larsen - Boduen, Boduen -Zenith (see Figure 1). A determination of courses was done applying a method of line crossing to an accuracy of 0.3 m. Elevations were controlled using a method of radioaltimeter leveling to an accuracy of 2-3 m.

The executed work to measure the cosmic base was unique not only for Antarctica, but also in the world practice.

The base determination for the RDS standardization was performed between the Molodezhnaya - Vecherniaya points adjusting a line-angle network of 6 points. There were measured 13 lines and 20 angles. The base was measured with an error of 1:500 000.

The geodetic chain coordinates setting was done adjusting the line-angle networks, trilateration networks and applying the astronomical method.

In Figure 2 you can see as an example a trilateration network subsequently used for topographic mapping at scale 1:200 000 within 80 thousand km² in the area of the Druzhnaya Antarctic station. The network consisted of 4 triangles, 6 points and 9 sides. Astronomical fixed point coordinates were plotted according to a third-order program. The sides of the trilateration network were measured partly with a light range finder "Quartz", partly transiting internal lines of base radio stations RDS.

A total area covered by the State Aerogeodetic Enterprise "Aerogeodeziya" in Antarctica came to more than 500 thousand km². The following plotting scales were used: 1:100 000 and 1:200 000. Maps were plotted by means of aerial cartographic photography applying a stereographic method. A horizontal bridging was done with the radiogeodetic system RDS (see Figure 2). Fig. 2

RDS aerial photography diagram



Elevations were controlled with a method of radar measurement.

Plane coordinates and elevations of aerial photographs served as initial data for the photography bridging with a method of numerical stereo triangulation. A stereo compilation of the relief was performed on multi-purpose apparatus SD and SPR, and also for mountain areas on stereocomparagraphs STD. The map preparation was done in the Gauss projection. A range of the elevations was given beginning from the Southern Ocean level.

Over the period from 1970 there were produced ~ 80 map

sheets at scale 1:100 000 and \sim 100 map sheets at scale 1:200 000. The maps produced were highly praised, at home and abroad, for their accuracy and the wealth of information displayed.

Beginning from 1985 specialists of the SAE "Aerogeodeziya" did the unique work to produce specialized maps of Antarctica by means of the radar survey. The survey was conducted at scales 1:500 000 and 1:1 000 000 from the planes IL-14 and IL-18. A horizontal bridging was carried out with the Doppler system DISS, and elevation referencing was done applying the methods of aerolevelling and barolevelling.

The greatest thickness of ice under the radar sensing came to 2.3 km. The ice-thickness measurement error came to 18.7 m.

Beginning from 1975 specialists of the Enterprise got down to a large-scale topographic mapping – to plot topographical plans at scales $1:2\ 000$ and $1:10\ 000$ for the territory of some Antarctic stations.

Up to 1970 the Antarctic territory was studied rather inadequately in a gravimetric sense. Specialists from different countries determined only 7 gravity bases, gravitational force values of which were directly related to the points of the universal gravimetric network. Observations at those points were carried out with pendulum type gravimeters, an accuracy of the gravitational force value definition came to ~ 0.5 mGal. The most significant and important amounts of the gravimetrical survey in Antarctica were surveys conducted by the SAE "Aerogeodeziya" in the period from 1975 to 1990. Totally 10 first-order gravity bases were founded and determined on the territories of the Russian Antarctic stations. Pendulum type apparatus OVM and "Agate" developed at the Central Research Institute of Geodesy, Aerial Photography and Cartography were used to define gravitational force values.

An accuracy of the gravitational force value definition proved to be equal to 0,25 mGal.

The adjusted gravimetric network served as a base for the gravimetrical survey at scale 1:1 000 000. Such kind of survey was conducted on the territory equal to 34,5 thousand km². Over 350 points were located in total. A density of the survey came to 1 point for 100 km². A horizontal bridging of the points was done applying the astronomical method to an accuracy of m ϕ =3" (~ 100 m), m λ =35" (~ 250 m).

It is necessary to mention about an extensive application of the most perspective and high-productive at that moment technical instruments and methods when conducting topographic, geodetic and gravimetrical surveys. This fact ensured a high accuracy and effectiveness of mapping of the corresponding Antarctic territories.

PRINCIPAL REQUIREMENTS TO THE GIS

The GIS is to meet the following principal requirements:

- effectiveness of input/output of necessary graphic, digital and type matter data on surveying and map coverage of the territory;
- data completeness and reliability;
- applying of a principle of data input and processing by layers;
- availability of ne cessary service forms amd records, technical manuals regulating the GIS handling;
- availability of up-to-date software and its description (user's manual);
- possibility to gain access to the GIS functional through communication channels: e-mail, Internet,

Slide 1

Nowadays it is essential to speed up the work to map Antarctica. By order of Roscartographiya (Federal Service of Geodesy and Cartography of the Russian Federation) the SAE "Aerogeodeziya" has drawn up a program consisting of the following measures:

- applying a GPS-method of coordinates setting when adjusting geodetic networks;
- production of digital topographic maps of Antarctica;
- plotting and revision of topographical plans for the Russian Antarctic stations;
- Antarctic surveying and map coverage GIS development.

The last matter is of international significance and therefore it is quite topical.

In 2000 at the SCAR WG-GGI meeting in Tokyo it was decided to develop a surveying and map coverage GIS for the territory of East Antarctica basing upon data provided by Australia, China and Russia.

It is proposed to develop the GIS for the territory limited by corners with the following coordinates:

-	В	L
1	76°	36°
2	64°	36°
3	64°	108°
4	76°	108°

A number of the following Antarctic stations are located on this territory and not far from it:

Mawson, Wilks (Australia); Zhongshan (China);

Molodezhnaya, Progress, Mirny (Russia); Syowa (Japan).

The GIS is destined for:

- collection, storage, updating, output of data on the surveying and map coverage of the territory;
- ensuring design, bridging, extension and renewal of geodetic networks;
- ensuring GPS-location of outstanding points, aerial photography, subsequent topographic mapping of the territory;
- carrying out the work on a subject mapping of the territory;
- ensuring the work requiring an availability of the surveying and map coverage of the territory.

In slide 1 you can see an expected composition of data to be included in the GIS, and in slide 2 – principal requirements to the GIS.

As a result of the correspondence between Surveying Offices of Australia, China and Russia (represented by the SAE "Aerogeodeziya") there have been brought up some proposals to develop a surveying coverage GIS for the territory of East Antarctica.

In slides 3 and 4 you can see a Project 1 and Project 2 of the Australian side. In slide 5 some proposals of the Australian Antarctic Division are given.

In slide 6 the proposals of China are presented.

GIS DATA

The East Antarctica coverage GIS consists of the following data:

- 1. Geodetic control data:
 - coordinates and elevations system;
 - point name;
 - geodetic, plane rectangular coordinates and point elevation;
 - point centre and mark type;
 - coordinates and point elevations setting method;
 - point location outline;
 - organization the work performer;
 - date of the work carrying out.

2. Cartographic documents:

- general information on the East Antarctic topographic mapping (ellipsoid, map projection, map and plan numbering system, and so on.);
- for every available map or plan sheet: scale, number, method of plotting, organization – the work doer, dates of plotting and edition and so on.).

Slide 2

From the Russian side the following data on the East Antarctic surveying and map coverage can be tentatively put in the GIS-project.

Project 1 (Larsemann Hills Area)

- first-order astronomical fixed point 1 point;
- topographic map at scale 1:1 000 000 2 sheets;
- topographic plan at scale 1:2 000 for the territory of the Progress Antarctic station and a runway.

Project 2

From the Molodezhnaya station to the Progress station (inclusive)

- first-order astronomical fixed points 3 points;
- completion geodetic survey (thinned out);
- topographic map at scale 1:1 000 000 4 sheets;
- topographic map at scale 1:200 000 70 sheets;
- topographic map at scale 1:100 000 56 sheets;
- topographic plans at scales 1:10 000 and 1:2 000 for the territory of the Progress and Molodezhnaya Antarctic stations and runways.

EAST ANTARCTICA COVERAGE GIS PROJECT PROPOSALS OF AUSTRALIA

Project 1

1. Identify Russian and Australian:

- coordinates system in the Larsemann Hills region;
- survey control in the Larsemann Hills region;
- datums used for GIS in the Larsemann Hills;
- aerial photography;
- geophysical information for the surrounding area.

2. Once the data sets were identified:

- complete the topographic mapping from aerial photography of the Larsemann Hills in 2001/2002. (The aerial photography was flown in 1998. The ground control - in the 2000/2001 season);
- comple data of the Larsemann Hills from both Australian and Russian sources;
- integrate data into the GIS.

Slide 3

SCAR WORKING GROUP ON GEODESY AND GEOGRAPHIC INFORMATION

EAST ANTARCTICA COVERAGE GIS PROJECT PROPOSALS OF AUSTRALIA Project 2 1. Extention of the Russian and Australian survey control between the Molodezhnaya and Mirry stations. 2. Identify if there are common control points. 3. Format that the data is currently in - hard or digital copy. Work required to bring the two data sets (Russian and Australian) into a joint reference datum. The project 2 must be co-ordinated with some agencies and organizations of Australia and Russia. Slide 4 EAST ANTARCTICA COVERAGE GIS PROJECT PROPOSALS OF AUSTRALIA Proposed work by the Australian Antarctic Division (AAD); Production of a Spatial Data Model which is acceptable to all parties. This is being produced by the Australian Antarctic Division for the SCAR Working Group on Geodesy and Geographic Information. Photogrammetric plotting of the area to the east of the Broknes Peninsula - Stornes Peninsula, Fisher Island and outer islands 3. Integration of new topographic data with Broknes Peninsula data. 4. Maps for Inclusion in the Larsemann Hills ASMA 5. Hydrographic surveying of the approaches to the Larsemann Hills. 6. Incorporate existing scientific data (geomorphology, geology, flora and auna) into the GIS of the Larsem n Hills Maps showing multiple names for features – Norwegian, Russian, Chinese and Australian names. 8. Integrate Russian, Chinese and Australian geodetic and survey data. 9. Incorporate topographic and other GIS data from Russia and China into ie. P roduction of a chart for the approaches to the Larsemann Hills. Slide 5 EAST ANTARCTICA COVERAGE GIS PROJECT PROPOSALS OF CHINA The following data can be included in the GIS-project:

- data of geodetic control points on Larsemann Hills;
- topographic map with the scale of 1:10,000 on Larsemann Hills;

- topographic map with the scale of 1:100,000 derived from colorful satellits images in Zhong Shan Station:

- topographic map of Grove Mtns. With the scale of 1:25,000 and 10,000; - GPS control points along the 1,100 km traverse route from Zhong Shan Station to Dome-A.

Some advice on how to create Eastern Antarctica Geographic Information System based on Internet:

- The Mapinfo MIF/MID .MGE .Arc/Info Coverage . ArcView Shape file and GeoStar data format can be directly accessed in the existing system, therefore, you must transfer the others data format into the above data format
- The geodetic control point and topographic point must have meta data, that is, the reference of spatial data, such as projection, projection parameters, scale and etc.
- In order to seamless pan on the map, you'd better adopt the same scale In the single layer
- You can create hyperlink between maps which have different scales , thus you can call the sub map from the sup map.

Slide 6

From the Progress station to the Mirny station

- first-order astronomical fixed points 2 points; 0
- ۰ topographic map at scale 1:1 000 000 - 2 sheets:
- ٥ topographic plan at scale 1:2 000 for the territory of the Mirny Antarctic station and a runway.

A diagram of the available Russian topographic maps for the territory of East Antarctica included in the GIS-project is given in slide 7.

Main principles of the GIS development are as follows:

- GIS detail design working out co-ordinated by the • Australian, Chinese and Russian sides;
- subsequent bridging of the geodetic networks; o
- identification of common points of the geodetic ٥ networks of Australia, China and Russia;
- conversion of available paper topographic maps and plans into digital ones;
- continuation of the topographic mapping (mainly in the digital form) of the East Antarctic territory by the Geodetic Offices of Australia, China and Russia;
- selection and usage of modern technical instruments • and GIS software;
- collection of graphic, digital and type matter data on • the surveying and map coverage of the territory;
- input of the collected data into the GIS; •
- processing, analysis, correction, editing, updating and monitoring of data put in the GIS;
- drawing up of the GIS functioning technical manuals ٥ in languages of countries going to use the GIS;
- personnel instruction in working with the GIS.

In our view the GIS is to ensure offering the following typical services:

- input of graphic, digital and type matter data on the 0 surveying and map coverage of the territory, data accumulation on input mediums;
- prolonged and guaranteed data storage and regulated 0 access to it basing on the corresponding powers;
- data processing including data analysis, correction, ۰ editing, updating and monitoring, possibility to modify data forms, measures of parameters, formats of the three-dimensional simulation and etc.;
- output of data on the surveying and map coverage of ۰ the territory in various forms: graphic, digital, and type matter ones, and in standardized shapes: maps, plans, diagrams, outlines, plots, tables, type matters and others.

A schematic diagram of the East Antarctic surveying and map coverage GIS is given in slide 8.

1. Collection of data on the surveying and map coverage of the territory is carried out in the graphic, digital and type matter forms. Currently available lists of coordinates, technical reports, topographic and subject maps and plans at different scales, technical publications serve as data sources. Moreover, the data collection is performed when conducting direct measurements and ground observation of the territory.

2. Data input, accumulation and storage are carried out parallel to its processing. The data input is done by layers

REPORT OF THE THIRD SCAR ANTARCTIC GEODESY SYMPOSIUM



Slide 7

by means of scanning, source material digitizing or directly from the control desk. A data bank presenting itself as a system including an accumulated data stock (databases and a software ensuring data handling - database control system - SUBD) serves as a data accumulation and storage process support. The data bank also consists of a subject code classifier, conventional signs and types library, patterns of sheet division and their marginal representation, specimen standard documents, tables, forms and so on. Optical disks - CD-ROM - mainly serve as input mediums.

3. Data processing consists of: converting, analysis, correction, editing, updating and monitoring.

Converting is a data conversion process from the vector form into the raster one and vice versa, from one data form into another. When making the data analysis an accuracy of the received parameters is evaluated, three-dimensional simulation is done and so on. The data correction, editing and updating are performed using a technology analogous to the one applied when entering data. Monitoring is a process of available data maintenance at the modern level that requires its continuous correction, editing and updating.

4. Data output is done in the graphic, digital and type matter forms, and also in various combinations of these forms. It is possible to display data, print it out, load into a plotter, save on optical disks - CD-ROM.

The GIS-project is to meet modern hardware, software and information control requirements.

Hardware - personal computers with a maximum on-line storage and the highest speed, accessory devices: printers, plotters, scanners, and digitizers with the highest resolution, greatest format and highest precision.

Software - international GIS programs: Arc/Info, Map/Info, GRASS, INTERGRAPH, AutoCAD and others. Program languages are as follows: C++, Java, Delphi, Map Basic and so on.

Information control - service forms and records, and technical manuals including the GIS user's manual in languages of countries going to use the system.

On condition that the GIS-project is successfully coordinated by the countries-performers, a first phase of the GIS will be put into operation approximately in the period of 2003 - 2004.

Summarizing Information to Update the SCAR-GGI Permanent Tide Gauge Observatory Sites, Antarctica

Kazuo Shibuya and Shigeru Aoki National Institute of Polar Research

Other references are;

Summarizing Information to Update the SCAR-GGI Permanent Tide **Gauge Observatory Sites, Antarctica**

Kazuo Shibuya and Shigeru Aoki National Institute of Polar Research, Japan

presented at the AGS'01 Meeting at St. Petersburg 15-22 July, 2001

Story

- Occupation records
- ITRF coordinates
- Instrument
- Calibration

Slide 1

At the AGS'01 Meeting (St. Petersburg) during 15-22 of July 2001, we presented a summary report on the information to update the SCAR-GGI permanent tide gauge observatory sites, Antarctica (http://www.scarggi.org.au/geodesy/perm-ob/tide/tide.htm). Our presentation consists of 4 items and this is the explanatory text of our presentation at the symposium, where slide 1 shows the cover slide of our presentation.

We remind the task of GIANT Program Summary 2000-2002 for the Program 5. Tide Gauge Data, at the XXVI SCAR Meeting of 10-14 July 2000, Tokyo, Japan.

GOAL: To consolidate the collection of and access to Antarctic tide gauge information Activitie

- er information on history of establishment and operation of Antarctic tide gauges
- Research and list all permanent and significant tide gauges established for hydrographic information and scientific studies
- List all known sea level determinations, dates and accuracy estimates for all significant tide gauge
- signmeant the gauge Identify benchmark values and connections to GPS observations sites Facilitate index data into the Geodetic data base
- Facilitate the delivery of data to the Southern Ocean Sea Level Centre (SOSLC)
- Post meta data on web 2002 2004 (Facilitate guidelines on establishment and calibrating on bottom mounted and acoustic type gauges in Antarctic conditions)

Slide 2 reminds us the task of the Program 5. There were 8 listed activities to consolidate the collection of and access to Antarctic tide gauge information. As a first step, we searched and summarized the SCAR national reports from each country in the NIPR library. This is available from the GGI web page listed above and we would request that each participating country correct/add/review, and complete it for their country

Bibliography about sea level variations from the Report to SCAR

JAPAN

Hourly tidal observation data from each Japanese Antarctic Research Expedition were published by the JARE Data Reports Oceanography Series.

The most recent one is:

Oikawa, K., and Iwamoto, K. (1999): Oceanographic data of the 38th Japanese Antarctic Research Expedition from November 1996 to March 1997, JARE Data Rep. No. 246 (Oceanography 21), 50pp, National Institute of Polar Research, Tokyo.

Tidal data from JARE-21 through JARE-37 are available.

Slide 3

- Odamski, M., Michida, Y., Noguchi, I., Iwanzga, Y., Ikeda, S., and Iwamoto, K.. (1991):Mean sea level observed at Syowa Station, East Antarctica. Proc. NIPR Symp. Antarct.Geosci., 5, 20-28.
- Nagata, Y., Kawamiya, M., Michida, Y. and Odamaki, M. (1993): Seasonal variations of the sea level at Syowa Station, Antarctica. Proc. NIPR Symp. Polar Meteorol. Giaciol., 7, 60-72.

ci, M., Oikawa, K., Masuyama, A. and Namiki, S. (1999): Tidal observation results around Syowa Station, Antarctica, paper presented at the 19th NIPR Symposium on Antarctic Geosciences, Tokyo, October 14-15, 1999 (abstract only in Japanese). Odamaki, M., Tidal

Aoki, S., Ozawa, T., Doi, K. and Shibuya, K. (2000): GPS ob of the sea level variation in Lutzow-Holm Bay, A Geophys. Res. Lett., 27, 22 Antarctica. 2285-2288.

Aoki, S., Shibuya, K., Masuyama, A., Ozawa, T. and Doi, K. (2001 accepted): Seasonal variations of sea level and bottom pressure detected by GPS and pressure gauge in Lutzow-Holm Bay, Antarctica. J. Oceanogr. Slide 4

Slides 3 and 4, for example, summarize the bibliography of the Japanese activity on sea level observations. Raw data were being published by the JARE Data Reports Oceanography Series (Slide 3). The reports are available from the NIPR Library on request. Several references on scientific papers are also listed (Slide 4). It is noted that the FD contains similar information from each country.

Accessible Sea Level Variation Time-Series Data via Internet



Faraday / Vernadsky Station --- ACCLAIM programme http://www.pol.ac.uk/psmsl/acclaim.info.html http://www.pol.ac.uk/psmsl/phase2

Mawson, Davis, Casey Station http://www.ntf.flinders.edu.au

GLOSS http://www.pol.ac.uk/psmsl/programmes/gloss.info.html CSR Global mean sea level results

http://www.csr.utexas.edu/gmsl/

Slide 5

Long Period Sea Level Variations at Faraday / Vernadsky Station



Slide 6

Slide 5 summarizes the web site information where (edited) raw data of tidal records are accessible. For example, Faraday/Vernadsky records can be plotted as Slide 6 from the down-linked time-series data.





We are interested in secular change of sea level, as well as tidal constituents of the southern oceans. Thus tide gauge observatories should be connected to the nearby space geodesy observatories to separate sea level fall (rise) from ground rise (fall). Slide 7 summarizes the distribution of such stations in Antarctica.

Slides 8 and 9 (not reproduced here) show 2 pages from the recent paper by Dietrich *et al.* (2001). These ITRF96 coordinates can fill the above SCAR-GGI site log of Casey, Davis, Esperanza, Mawson, O'Higgins, Palmer, Prat, Rothera, San Martin, Syowa, Tera Nova Bay, and Vernadsky. Dots in Slide 9 are registered stations by GLOSS, and increase in number of these stations is essential to monitor sea level variations in a global scale.

Slides 10 and 11 summarize sensor descriptions picked up

Tide Gauge Sector Description in the Reports to SCAN AUSTRALIA 1 = 1 erest 1967 - 1971, continuing 7 Absulute (stanspheric pres oure corrected to give er Cape Porvagi Slide 10 JAPAN Syong owa Absolute pressure sti 1976 - continuing 1976 - continuing Relative pressure 1990 - continuing Electric QWP-801/841). ET ZEALAND Scott Base Feaboro liquid level rec mr. 1957 UNITED EINCOCM/USERAINE Faraday/Vernadaky Ploat-acnaor in well, MIN afield Strait anderra WLR-7 USSR Gegoszarzya Tide pole, 1963 ? Tide gage SUN ?, 21.12.63 Marcograph, 1966 - 1969 . 25. 2. 64. 23. 6 Slide 11 from the SCAR reports (which is also summarized on the

GGI web page). In order to trace the secular change, history of the sensor and its calibration information is very essential. However SCAR reports are not necessarily covering this calibration information enough, and feedback from each country by checking the information on the web pages is welcome. Henk Brolsma from the Austrian Antarctic Division, for example, gave us more complete history of Macquarie Island tide gauges.

From Slide 12 on, we review efforts of JARE for sensor calibration of sea level change. The change rate is considered very small (4-10 mm/yr), and establishment of accurate and stable calibration method by taking locality into consideration is very important. For example, Slide 12 shows an overview of Syowa Station. The tide observations are continuing at the Nishi-no-ura Cove (labeled Pressure W.L.). During JARE-39 wintering period (1998), we made parallel GPS observations as illustrated by Slide 13 at the pressure sensor-type water level recorder site. Simultaneous video monitoring of the sea level variation (Slide 14) was also made, which



Slide 12



Slide 13





Slide 14
Ş2

K2

Slide 16

19.99 (0.04)

6.20 (0.05)



Slide 15

showed an overall 3 cm consistency (Aoki *et al.*, 2000, see also Slide 4) between the GPS and video-monitoring. Close inspection showed that GPS has demonstrated the ability to observe 2-cm accuracy sea level variations on tidal time scale (see also Slide 16). At the symposium, Larry Hothem from the United States Geological Survey presented similar efforts on calibration by the Cape Roberts Tide Gauge Calibration Project.

Historical method by using the level and the staff during the summer season of the open-water period at the benchmark site of Slide 15 (see also BM1040 in Slide 12), is of course necessary, but thickening of sea-ice and change of sea water salinity affect on the recorded pressure value. Thus application of GPS-buoy moored sensor (Slide 17) will be a further effort to have more stable/accurate calibration of the sea level variations. In the SCAR-GGI Permanent Observatories site [URL

	GPS		Pressure Gauge			
	Amp(rmse:cm)	Lag(rmse:°)	Amp(cm)	Lag(°)		
01	24.80 (0.06)	349.0 (0.1)	24.5	350.2		
K1	22.51 (0.06)	356.9 (0.1)	22.2	357.2		
P1	7.40 (0.05)	356.9 (0.4)	7.4	356.2		
M2	25.42 (0.04)	159.8 (0.1)	24.9	160.4		

Table 1. Harmonic constants of the major six components

A possible application of the GPS buoy Winter Submitter

176.6 (0.1)

176.5 (0.4)

20.2

5.7

176.5

175.0

Slide 17



above], there are 18 listed tide gauge observatory sites in Antarctica; 7 along the East Antarctic coast, 9 in the Antarctic Peninsula area, and 2 on the Southern Ocean area. The web pages contain (1) history, (2) location, (3) occupation records, (4) value of coastal bench mark, (5) ITRF coordinates, (6) site photos, and (7) other information as items.

The summary can help substantiate the web information. Continuing efforts by feedback from the participating country/responsible organization will give us more detailed summary at the next WG meeting.

References

Deitrich, R., et al., (2001) "ITRF coord	inates and plate
velocities from repeated GPS campai	gns in Antarctica
- an analysis based on different indiv	idual solutions",
Journal of Geodesy, Number 74, pp 7.	56-766, Springer
Verlag, Germany	

Aoki, S., Ozawa, T., Doi, K. and Shibuya, K. (2000): GPS observation of the sea level variation in Lutzow-Holm Bay, Antarctica. Geophys. Res. Lett., 27, 2285-2288

There were further oral presentations at the Symposium that are not reproduced here:

John Manning.	NMD-GA Online GPS Processing Service (AUSPOS)
U	Upgrades to the Australian Antarctic Geodetic Network
	GPS of Australian Tide Gauge Bench Marks (TGBM)
	Geodetic Survey of the Grove Mountains
	Unification of Goedetic Networks in East Antarctica
Raisa Iakovleva. Larry Hothem.	Development of International Standards on Geographic Information in ISO/TC211 Remote Geodetic Observation
	TAMDEF-1 Project (TransAntarctic Mountains Deformation Monitoring Network)
	Highlights of US Geodetic Activities (past two years) in Antarctica

These are available as PowerPoint presentations and may be downloaded from the website of the Working Group on Geodesy and Geographic Information at the following URL: http://www.scar-ggi.org.au/geodesy/ags01/papers.htm

REPORT OF THE THIRD SCAR ANTARCTIC GEODESY SYMPOSIUM

AGS '01 List of Participants

Appendix 1

Participant Alexander Yuskevitch Alessandro Capra Alexander Klepikov Fedir Zablotsky Henk Brolsma Jan Cisak Jerry Mullins John Manning Kazuo Shibuya Larry Hothem **Reinhard Dietrich** Yevgeny Zanimonskiy Raisa Iakovleva Vladimir Berk Irk Shagimuratov

Contact aerogeodezia@actor.ru alessandro.capra@mail.ing.unibo.it klep@aari.nw.ru fzablots@polynet.lviv.ua Henk.Brolsma@antdiv.gov.au astro@igik.edu.pl jmullins@usgs.gov JohnManning@auslig.gov.au shibuya@nipr.ac.jp Lhothem@erols.com dietrich@ipg.geo.tu-dresden.de yevgen@online.kharkiv.com <u>roskart@dol.ru</u> roskart@dol.ru valdemar@magion.izmiran.koenig.su

Country Russia Italy Russia · Ukraine Australia Poland United States Australia Japan **United States** Germany Poland Russia Russia Russia



L to R: Raisa lakovleva, Alexander Yuskevitch, Vladimir Berk, Jan Cisak (foreground), Yevgeny Zanimonskij (background), Mrs Zanimonskij, Kazou Shibuya, Irk Shagimuratov Jerry Mullins, Russian Interpreter, Beth Manning, Reinhard Dietrich, Alessandro Capra, Larry Hothem, Alexander Klepikov

Appendix 2

Antarctic Geodesy Symposium 2001 Program

Tuesday 17th July 2001

- Welcome party and Icebreaker reception at the Arctic and Antarctic Institute.
- Valery Lukin Director of the Institute welcome ceremony and presentation of the Institute.

Wednesday 18th July 2001

Session 1: Status of WG-GGI Giant Projects

10.00 – 11.00 Chairman: John Manning

- John Manning "Background on the SCAR Working Group and progress on current project activities" & "Background on the GIANT program"
- Alessandro Capra "VLNDEF project for crustal deformation control of Victoria Land"
- Kazuo Shibuya "Updating SCAR-GGI permanent tide gauge observatory sites, Antarctica"

Session 2: Russian Antarctic Activities

11.30 – 12.30 Chairman: Alexander Yuskevich

- Valery Masolov "Activities of the Russian Polar Marine Geological Intelligence Expedition "
- Alexander Yuskevich-"Topographic and geodetic activities of the Federal Service of Geodesy and Cartography of Russia in the Antarctic Continent since 1970"

Session 3: Status of WG-GGI Giant Projects

13.30 – 14.30 Chairman: Larry Hothem

John Manning - "GPS connections to tide gauge benchmarks at Mawson, Davis and Zhong Shan observed in January"

Larry Hothem - "Remote geodetic observatories"

Session 4: International Contacts

15.00 – 16.00 Chairman: Alessandro Capra Alessandro Capra – "International Association of Geodesy" Reinhard Dietrich – "ANTEC"

John Manning - "GIANT Administration"

Session 5: GPS Observations in Antarctica

16.30 – 17.30 Chairman: Reinhard Dietrich

Reinhard Dietrich – "The SCAR GPS Campaigns in the ITRF 2000"

Yevgeny Zanimonskiy – "Contribution of data from the polar regions to the investigation of short term geodynamics. First results and perspectives"

Session 6: Topographic and Geodetic Activities in Antarctica

17.30 - 18.30 Chairman: John Manning

Larry Hothem - "Initial results from the TAMDEF (Transantarctic Mountains Deformation Monitoring Network) project"

- John Manning "Work last southern summer in the Grove mountains"
- 19.00 Symposium Dinner at the Institute
- Guest speaker John Manning

Thursday 19th July 2001

Session 7: Topographic and Geodetic Activites in Antarctica

10.00 – 11.00 Chairman: John Manning

Larry Hothem - "Highlights of US geodetic activities (past two years) in Antarctica"

John Manning - "Upgrade to Australian geodetic network in the SPCM"

Jan Cisak - "Research on atmospheric impact on GPS measurements in the polar regions"

- Jan Cisak "International GPS Service (IGS) Ionosphere Working Group activities"
- Jan Cisak "Influence of ionosphere in the Arctic and Antarctic Regions on GPS positioning precision"

REPORT OF THE THIRD SCAR ANTARCTIC GEODESY SYMPOSIUM

Session 8: Topographic and Geodectic Activities in Antarctica

- 11.30 12.30 Chairman: Jan Cisak
- Fedir Zablotsky "On determination precision of tropospheric delay at the Antarctic coast stations"

John Manning - "Larsemann Hills geodetic survey 2000/2001"

Alexander Klepikov - "Information on GIS of the Antarctic environment"

Session 9: Other Topics

13.30 – 14.30 Chairman: Reinhard Dietrich

Raisa Iakovleva - "Development of international standards on "Geographic Information/Geomatics" in ISO/ TC211"

John Manning - "Internet on-line GPS processing"

- Irk Shagimuratov "The response of the high latitude ionosphere TEC to a magnetic storm obtained from GPS observations"
- Alessandro Capra "Analysis of regional geoid estimation in Victoria Land"

Session 10: Future Cooperative Projects

15.00 – 15.30 Chairman: Reinhard Dietrich

Regional Studies

- Alexander Yuskevich "East Antarctic surveying and map coverage GIS project"
- 15.30-16.30 GIANT business meeting

Report from ANTEC meeting

Program Review

SCAR meeting 2002

- 16.30 17.00 Summary
- 18.00 20.00 Reception in the Open Air

Friday 20th July 2001

Session 11: Tours and Visits around the City

10.00 - 11.00 Visit to the Arctic and Antarctic Institute

12.00 – 13.00 Arctic and Antarctic Museum

Session 12: Visit to the SAE "Aerogeodeziya"

14.00 – 17.00 Chairman: Alexander Yuskevich

SCAR WORKING GROUP ON GEODESY AND GEOGRAPHIC INFORMATION

Antarctic Geodesy Symposium 2001

Appendix 3

St Petersburg, Russia 18-19 July 2001 List of Papers

Wednesday 18th July

Welcome to AARI	Lukin
Introduction	Yuskevitch
SCAR WG-GGI	Manning
GIANT Program	Manning
Victoria Land Deformation Project	Capra
Antarctic Tide Gauges	Shibuya
Grove Mountains	Manning
Tide Gauges at GPS	Manning
Geodynamics	Zanimonskiy
Remote GPS Observatories	Hothem
Ionospherics and GPS	Feltens
GPS Campaigns	Deitrich
Arctic and Antarctic GPS	Barans
Thursday 19th July	
US Geodetic activities	Hothem
Upgrade to Australian GPS Network	Manning
Ionosphere Influence on GPS Positioning	Cisak
Tropospheric delay at coast stations	Zablotsky
Results from TAMDEF	Hothem
Larsemann Hills Geodetic Survey 2000-2001	Manning
GIS and the Environment	Klepikov
TEC from GPS observations	Shagimuratov
ISO TC211	Iakovleva
Geoid in Victoria Land	Capra
On-line GPS Processing	Manning
Report on East Antarctic GIS project	Yuskevitch
Report from ANTEC Workshop, Siena	Manning

SCAR Report

SCAR Report is an irregular series of publications, started in 1986 to complement SCAR Bulletin. Its purpose is to provide SCAR National Committees and other directly involved in the work of SCAR with the full texts of reports of SCAR Working Group and Group of Specialists meetings, that had become too extensive to be published in the Bulletin, and with more comprehensive material from Antarctic Treaty meetings.

SCAR Bulletin

SCAR Bulletin, a quarterly publication of the Scientific Committee on Antarctic Research, is published on behalf of SCAR by Polar Publications, at the Scott Polar Research Institute, Cambridge. It carries reports of SCAR meetings, short summaries of SCAR Working Group and Group of Specialists meetings, notes, reviews, and articles, and material from Antarctic Treaty Consultative Meetings, considered to be of interest to a wide readership. Selections are reprinted as part of *Polar Record*, the journal of SPRI, and a Spanish translation is published by Instituto Antártico Argentino, Buenos Aires, Argentina.

Polar Record

Polar Record appears in January, April, July, and October each year. The Editor welcomes articles, notes and reviews of contemporary or historic interest covering the natural sciences, social sciences and humanities in polar and sub-polar regions. Recent topics have included archaeology, biogeography, botany, ecology, geography, geology, glaciology, international law, medicine, human physiology, politics, pollution chemistry, psychology, and zoology.

Articles usually appear within a year of receipt, short notes within six months. For details contact the Editor of *Polar Record*, Scott Polar Research Institute, Lensfield Road, Cambridge CB2 1ER, United Kingdom. Tel: 01223 336567 (International: +44 1223336567) Fax: 01223 336549 (International: +44 1223336549)

The journal may also be used to advertise new books, forthcoming events of polar interest, etc.

Polar Record is obtainable through the publishers, Cambridge University Press, Edinburgh Building, Shaftesbury Avenue, Cambridge CB2 2RU, and from booksellers. Annual subscription rates for 2002 are: for individuals £57.00 (\$92.00), for institutions £110.00 (\$176.00); single copies cost £30.00 (\$48.00).

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No 23 April 2005

Contents

SCAR Working Group on Geodesy and Geographic Information

Report of the Fifth SCAR Antarctic Geodesy Symposium

Appendices

83

1



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SCIENTIFIC COMMITTEE ON ANTARCTIC RESEARCH

SCAR Report

No 23, April 2005

Contents

SCAR Working Group on Geodesy and Geographic Information

Report of the Fifth SCAR Antarctic Geodesy Symposium, Lviv, Ukraine, 14–17 September, 2003

.

Appendices

.

83

1

Published by the SCIENTIFIC COMMITTEE ON ANTARCTIC RESEARCH at the Scott Polar Research Institute, Cambridge, United Kingdom

SCAR WORKING GROUP ON GEODESY AND GEOGRAPHIC INFORMATION

.

CONTENTS

Page

.

INTRODUCTION

PAPERS PRESENTED AT THE SYMPOSIUM

Valery Lytvynov, Gennadi Milinevsky, Svetlana Kovalenok, Elena Chernysh, Rudolf Greku:	
Ukraine National Antarctic Program: Geodesy Activity	1
John Manning: The Evolution of the GIANT Program	1
Garv Johnston, John Manning, John Dawson, Paul Digney:	-
Geodesy Activities in PCMega	7
Hannu Koivula, Jaakko Mäkinen:	
Geodetic Activities at Finnish Antarctic Research Station Aboa	10
Andrzej Pachuta: An Outline of Polar Expeditions of the Scientists from	
Warsaw University of Technology	13
Olexandr Dorozhynskyy, Volodymyr Glotov: Photogrammetrical Investigations	
of the Antarctic Coast	14
Alexander V Prokopov, Yeugeniy V Remayev: Tropospheric Delay Modeling	
for GPS Measurements in Antarctica	14
Jan Cisak: Overview of the Research on the Atmospheric Inpact on GPS	
Observation in Polar Regions	15
Fedir Zablotskyj, Alexandra Zablotska, Natalya Dovhan:	
An Analysis of Contribution of the Troposphere and Lower Stratosphere layers to forming	
of the Tropospheric Delay Wet Component	23
Alexander Prokopov, Alla Zanimonska: The Second Order Refraction Effects for GPS	
Signals Propagation in Ionosphere	25
I. Shagimuratov, A. Krankowski, L. W. Baran, J. Cisak, G.Yakimova	
Storm-time structure and dynamics of the ionosphere obtained from GPS observations	28
I. Shagimuratov, L. W. Baran, A. Krankowski, J. Cisak, I. Epishov:	
Development of TEC fluctuations in Antarctic ionosphere during storm using	
GPS observations	32
P. Wielgosz, I. Kashani, D. Grejner-Brzezinska, J. Cisak	
Regional Ionosphere Modeling Using Smoothed Pseudoranges	37
Svetlana Kovalenok, Gennadi Milinevsky, Maksim Moskalevsky, Vladimir Glotov,	
Korniliy Tretjak, Rudolf Greku, Yury Ladanovsky, Pavel Bahmach	4.1
Argentine Island Ice Cap Geodesy Survey for Climate Change Investigation	4
Taromyra Kostetska, Lyudov Tankiv-Viikovska	41
E Devester, They Chunging Line Minschare	41
E Dongchen, Zhou Chunxia, Liao Mingsheng Application of SAR Interferemetry in Group Mountaine, Fust Anterotica	40
E Dweeshen, Li Esi, Zhana Shanakui, Jigua Waining, The Establishment of CDS Control	42
E Dongchen, Li Fel, Zhang Shengkai, Jiang Weiping. The Establishment of OFS Control	46
Richard D. Sancher: Positional Accuracy of Airborne Integrated Global Positioning and	40
Inertial Navigation Systems for Manning in Clan Canyon, Arizona	50
A Canra F Mancini M Naousini G Ritalli S Candolf, P Sarti I Vittuari A Zanutta	50
VI NDEE Network for Deformation Control and as a Contribution to the	
Reference Frame Definition	57
P Sarti I Manning A Capra I Vittuari	57
A Project on Local Ties and Co-locations in Antarctica	57
Alexandr Yuskevich	5,
Accomplishment of Topographic–Geodetic Research Works in Antarctica	58
YM Zanimonskiy: On the Randomization of GNSS Solutions	58
K.R.Tretvak: Optimization of Geodynamic Network on the Argentina Islands	20
Neighbouring to Vernadsky Antarctic Station	58

REPORT OF THE FIFTH SCAR ANTARCTIC GEODESY SYMPOSIUM

CONTENTS

Page

G. Bitelli , A. Capra, F. Coren, S. Gandolfi, P.Sterzai	
Geoid Estimation on Northern Victoria Land	59
A, Marchenko, Z. Turtachynska, A. Yakimovich, F. Zablotskyj:	
Gravity Anomalies and Geoid Heights derived from Ers-1, Ers-2, and Topex/Poseidon	
Altimetry in the Antarctic Peninsula Area	60
Gennadi Milinevsky:	
Tidal Observations at Faraday/Vernadsky Antarctic Station	64
J. Krynski, Y.M. Zanimonskiy: Current Results on the Investigation of GPS Positioning	
Accuracy and Consistency	64
Rudolf Greku, Ksenya Bondar, Victor Usenko:	
Application of the Planetary Geodesy Methods (the Geoid Theory) for the	
Reconstruction of the Earth's Interior Structure in the Western Antarctic	71
Rudolf Greku, Gennady Milinevsky, Yuriy Ladanovsky, Pavel Bahmach, Tatyana Greku:	
Results of GPS, Ground Photogrammetry, Echosounding and ERS Interferometric	
Surveys During Ukrainian Antarctic Expeditions	74
M. Jia, J. Dawson, G. Luton, G. Johnston, R. Govind, J. Manning:	
Crustal Motion in East Antarctica Derived from GPS Observations	76
Valentyn Maksymchuk, Yury Gorodysky, Ihor Chobotok,Valentyna Kuznetsova:	
Recent Geodynamics of the Earth's Crust in the Region of Antarctic Station	
"Academic Vernadsky" due to Results of Tectonomagnetic Investigations	81
Yu.V. Kozlenko, I.N. Korchagin, V.D. Solovjov: Gravity Studies of the Western Antarctic	
Region – New Possibilities in Geophysical Modelling	82
APPENDICES	
1. List of Participants	83
2. Symposium Programme	84
3. List of Papers	86

.

Report of the

FIFTH ANTARCTIC GEODESY SYMPOSIUM 2003 Lviv, Ukraine, 14-17 September, 2003

INTRODUCTION

This fifth SCAR Antarctic Geodesy Symposium (AGS03) was held at the University "Lviv Polytechnic", Lviv. It was attended by 38 participants, which included representatives of nine SCAR countries. (See list of attendees in Appendix 1).

The activities included a welcome reception for participants at the Assembly Hall of the University "Lviv Polytechnic", a walking tour of the University and a symposium dinner held at Oles'ko Castle.

The symposium commenced with opening addresses from the University Administration, SCAR Geosciences SSG, Ukrainian Antarctic Centre and the Public Geodetic Service of Ukraine. They were followed by an overview of the Ukraine National Antarctic Program by Dr Milinevsky from the Ukrainian Antarctic Centre detailing geodesy activity in the Argentine Island archipelago.

The program included 36 presentations and a GIANT Business meeting (see Program in Appendix2). It contained a strong focus from Ukraine and Polish scientists on atmospheric studies related to GPS. Dr Milinevsky presented the history and status of the tide gauge at the Faraday/Vernadsky Antarctic station which was installed in 1947 and provides an important record of long term sea level variation due to climate change.

Professor E Dongchen from China confirmed in his paper that Interferometric Synthetic Aperture Radar is potentially a very useful technique to be utilized in Antarctica for measuring ice surface elevation providing it is well controlled with GPS positions.

Australia presented a background paper on the Evolution of the GIANT program, the recent field activity during the very successful Prince Charles Mountains Expedition of Germany and Australia (PCMEGA) and preliminary tectonic motions from their continuous GPS stations in Antarctica Italy presented activities and impressive results from their Victoria land Deformation network (Dr Alessandro Capra) and Dr Sarti proposed to upgrade local geodetic ties at collocated sites to improve the Antarctic and global reference frames.

Dr Alexander Yuskevitch from Russia summarised the methods of the fundamental astronomic geodetic network (FAGN) and the on going development of the high precision geodetic network (H-PGN).

Dr Mullins presented details of the status of development of continuous remote GPS stations by the United States in the Trans Antarctic Mountains, which are designed to run through the Antarctic winter.

Dr Schenke from the Alfred Wegner Institute, Germany, gave details of the coordination of Antarctic bathymetric data and the IHO project for coordination of data in the Southern ocean.

The symposium concluded with a GIANT business meeting. Dr Capra summarised progress against milestones of the program set during the XXVI SCAR in Shanghai in 2002. A joint proposal from Italy and Australia was endorsed to study and to improve the stability of the Terrestrial Reference Frame over Antarctica as the basis for precise measurement of small tectonic motion. The need to identify suitable projects for the International Polar Year 2007/2008 was noted. A proposal by Italy to host a further symposium in the series (2005) was unanimously endorsed.

It was a most a successful event which was extremely well hosted by the University Lviv Polytechnic and the Ukrainian Antarctic Centre.

Most participants provided final versions of their papers or abstract summaries and these are published in this report.

John Manning, Convenor, GIANT

SCAR WORKING GROUP ON GEODESY AND GEOGRAPHIC INFORMATION

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Ukraine National Antarctic Program: Geodesy Activity

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Abstract

The meteorology and climate, hydrology, upper atmosphere physics and geospace researches, ozone layer, seismic and acoustic measurements, glaciology, environment, biology investigations have been provided at the Vernadsky Ukrainian Antarctic station within seven years. The important tasks of Ukrainian National Research Program are the Antarctic Peninsula region GPS geodesy survey, and small ice cap monitoring as indicators of the long-term climate changes. The program of the GIS development for the Argentine Island archipelago and adjacent Antarctic Peninsula region (GIS project «Argentina Islands-Antarctic Peninsula») has been recently started. The main objectives of the GIS project are:

- the high precision geodesic stations network creation in the vicinity of Ukrainian Antarctic Vernadsky station on the base GPS-positioning data;
- (2) the retrieval of the hidden regularities and anomalous events in combined systemland-ice-ocean-atmosphereionosphere. Within 2001/2003 seasons high precision coordinates of geodetic survey marks were measured and local geodetic network was created for Vernadsky station 30x10 square km area. The season permanent GPS-survey at the SCAR-2002 site on Galindez Island within the framework of the GIANT project was started at Vernadsky in 2002. The GPS observation was carried out at the site for 15 days in 2002 and

2003. The registration coordinates accuracy in 2002 was 1-2 millimeters. More than 300 GPS points have been determined for positioning of different geophysical measurements on islands. Galindez ice cap and adjusted to Vernadsky region part of Antarctic Peninsula ice streams mapping have been made using the ERS radar interferometer data. Echo sounding of the Argentine archipelago's seabed in the shallow unsurveyed area (within the framework of the IBCSO project) has been provided in the Vernadsky region since 1997. Determination of detailed local geoids with the altimeter data of the Bellinsgausen Sea has been carried out within the framework of the project ANTEC

In the second part we describe the long term plans of the FGI for the deformation studies in Queen Maud Land. Basis for the time series are the absolute gravity measurements performed in 1994 and 2001 with JILAg-5 absolute gravimeter showing a slight increase in gravity. Absolute gravity measurements will be continued in the next summer season using the new FG5 gravimeter. To control the attraction of the near-field ice masses we will survey the time variation in ice topography with RTK. At the same time the permanent GPS station will provide continuous GPS-time series. We plan to keep on repeating the absolute measurements at Aboa and to extend the measurements to other sites in Queen Maud Land.

The Evolution of the GIANT Program

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Abstract

The SCAR GIANT (Geodetic Infrastructure of Antarctica) program was established in 1992 to provide a common geodetic framework over Antarctica as the basis for recording of positional related science.

For the past ten years this has been an active program and their are nine elements in the current 2002-2004 program :

- · Permanent Geoscientific Observatories;
- Epoch Crustal Movement Campaigns;
- Physical Geodesy;
- Geodetic Control Database;
- Tide Gauge Data;
- Atmospheric Impact on GPS Observations in Antarctica;
- Remote Observatory Technologies

 Ground Truthing for Satellite Missions; Geodetic Advice on positioning limits of special areas in Antarctica

The development and status of each sub element within the overarching GIANT program is discussed and access to data highlighted.

1. Historical Background

GIANT is the acronym for the Geodetic Infrastructure of Antarctica program of the Scientific Committee for Antarctic Research (SCAR). SCAR was formed at The Hague in February 1958. It evolved from a Special Committee on Antarctic Research which was established by the International Council for Science (ICSU) to coordinate the scientific research of the twelve nations who were active in Antarctica during the International Geophysical Year in 1957-58. The ongoing objective of SCAR is to promote scientific collaboration in Antarctic research.

At the first SCAR meeting in 1958 Cartography, as it was known then, was part of Working Group 2 (along with Geology, Glaciology and Morphology). At the III SCAR meeting in September 1959 Cartography met as a Working Group in its own right. The following year at IV SCAR in September 1960, a Permanent Working Group on Cartography was established . The Chief Officer was General Laclavére from France. The name was subsequently changed at V SCAR in October 1961 to the Working Group on Geodesy and Cartography. The Working Groups Chief Officer was B P (Bruce) Lambert from Australia. Since then the Chief Officer position has been held by Australian representatives from the National Mapping Division. In 1988, at XX SCAR in Hobart, the name of the group was changed to the Working Group on Geodesy and Geographic Information (WG -GGI) to better reflect its total scope of activity.

From its inception the working group encouraged compatible mapping of the Antarctic continent and established a set of recommendations and standing resolutions as mapping standards. Initially it recommended the use of the Hayford 1924 International spheroid as the basis for mapping and geodetic computations. The essential role of Geodesy within the working group at that time was the provision of control for exploration and mapping. This has since evolved to include the monitoring of the current tectonic motion of the continent and its linkage to other continents.

Since the formation of the WG-GGI at V SCAR in 1961 group meetings were usually held at the time of the SCAR meetings and all activities were the responsibility of the Chief Officer. At the XX SCAR meeting in Hobart in 1988 the modus operandi was changed from this single responsibility in producing a growing number of products, with a greatly increased work load. A more distributed arrangement was identified, which was reinforced at a special meeting hosted by Germany in Frankfurt in June 1990 as an alternate venue to the SCAR meeting that year. At the subsequent XXII SCAR meeting at Bariloche in 1992, Drew Clarke from Australia was elected Chief Officer and the operational aspects of the WG-GGI was completely reviewed changing from a focus on mapping standards and individual national activities, to a theme based structure with distributed project responsibilities. The Geodetic Infrastructure of Antarctic program was identified as GIANT at the meeting. Since that time the overall WG-GGI program has further evolved into two major umbrella streams each with an overall coordinator:

- Geodesy (GIANT)
- Geographic Information

This structural grouping proved successful and both streams initiated projects and produced products which were increasingly became available through the web site

as Internet technology develo	oped	
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Event	Location	Date
AGS 98	Santiago University,	July 1998
	Santiago	
AGS 99	Polish Academy of	14-16 July 1999
	Science, Warsaw	-
AGS 01	Arctic and Antarctic	
	Institute, St Petersburg	
AGS 02	Land Information	
	New Zealand,	
	Wellington	
AGS03	University Lviv	15-17 th September
	Polytechnic, Ukraine	2003

Tabl	e I	List	of	SCAR	Antarctic	Geode	sy Sym	posia
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The concept of a business meeting at the time of the SCAR week working of working group meetings directly before the main SCAR meeting, and a specialist interperiod meeting was developed. This commenced with the USGS hosting a workshop in Flagstaff immediately before the Boulder IUGG meeting in 1995. This approach was further developed when Chile proposed and hosted a specialist Antarctic Geodesy Symposium (AGS) in Santiago immediately before the Concepion XXV SCAR. There have now been four AGS symposia as in Table 1 above culminating in this fifth AGS03 event in Lviv Ukraine. This series of meetings has provided an important continuity of face to face contact whilst focussing on program milestone for individual projects in the GIANT program.

At the XXVI SCAR meeting in Shanghai in 2002 the long standing and successful WG-GGI (including GIANT) was merged with other SCAR working groups to form the Geoscience Scientific Standing Science Group (GSSG) and as such lost its direct reporting stream to the SCAR Executive Committee. The WG-GGI was renamed the Geospatial Information Group of Experts (GIG) with the intention to broaden its scope to also include Geophysical network information. In the new structure GIANT continues as the coordinating program for SCAR Antarctic Geodesy but as a sub program within GIG, which in turn is a sub group of GSSG. GIANT continues also to contribute expertise and resources to the SCAR Antarctic Neotectonics (ANTEC) program. It is cross linked with the International Association of Geodesy regional sub commission on Antarctica as the GIANT convener is also the co chair of the IAG sub commission on Antarctic Geodetic networks.

Until the 1960s the positioning of geographic features on the Antarctic continent and measurement of baselines to other continental land masses was still only achievable by local triangulation surveys within Antarctica and astronomical astronomic observations. Triangulation chains were difficult to establish due to the need for multi station visibility for angle observations. The networks which were established were limited to the immediate vicinity of the base stations, or as small local area triangulations in isolated mountain areas. It was impossible to connect these local triangulations.



Figure 1: Structure of the Geoscience Standing Group (GSSG)





Optical and microwave electronic distance measuring (EDM) techniques were introduced to the Antarctic continent in the mid sixties, which enabled trilaterations, and large traversing loops, rather than pure triangulation to be undertaken, producing expanded but still isolated geodetic networks. This remained unchanged until the advent of man made satellites, although several over snow survey traverse connections between mountain features were carried out using EDM techniques.

With the advent of man made satellites, space geodesy was applied to address the problem of intra continental connection and to accurately determine the coordinates of some Antarctic stations in a global reference frame. In 1969 the global astro-triangulation PAGEOS program occupied Antarctic sites at McMurdo, Mawson, Palmer



Figure 3 Absolute gravity sites

and Casey, photographing passive satellites against a star background. In the 1970s active microwave positioning from satellites proved more useable than the PAGEOS optical photographic approach and firstly Transit Doppler and later GPS became available on global scale. The improvement in positional accuracies achievable from the different geodetic techniques is summarised in Table 1.

The early Antarctic space geodesy programs were the initiatives of individual countries as part of more extensive global programs, and no coordinated international geodetic program existed on the Antarctic continent. In 1976 the SCAR WG-GGI began to look at the possibility of linking the individual national geodetic networks by Doppler techniques and work commenced on gathering the extent of each nation's geodetic networks with view to a joint

Period	Technique	Baseline accuracy
1950s	Positional Astronomy	+- 200metres
1969-70s	Satellite/Stellar photography (PA GEOS)	10 metres
mid 1970s	TRANSIT Doppler	3-5 metres
late 1980s	GPS	1-2 metre
1990	VLBI	1 decimetre
1995	GPS	1 decimetre
2000	GPS	Several centimetres
2003	GPS_enhanced_VUBL	Sub centimetre

Table 1: Positional accuracy progression in Antarctica sites

approach, but due to logistic limitations no overall plan was implemented to link the individual networks.

In the late 1980's the application of the GPS military navigation system emerged as a civilian geodetic tool with a potential for Antarctica. The XXth meeting in 1988 endorsed a proposal by Australia to test the developing GPS technique for mapping control and potential applications in monitoring crustal motion. This pilot study was undertaken in two phases:

- Feasibility observations January 1990
- Test observations in January 1991

Station	Observing Authority	Receiver Type	Location
McMurdo	USGS	WM102	S7751 E16641
Davis	AUSLIG	Trimble 4000SLD	S6834 E7758
Law	AUSLIG	Trimble 4000SLD	S69 23 E76 23
Mawson	AUSLIG	WM102	S6736 E6253
Dovers	AUSLIG	WM102	S70 14 E65 51
Hobart	U. TAS	MiniMac	S47 48 E147 26
Orroral	AUSLIG	TI4100 Gesar	S3538 E14856
Yaragadee	AUSLIG	T14100 Gesar	S29 02 E115 21
O'Higgins	IFAG	TI4100 Navigator	S63 19 E57 54
Punta Arenas	IFAG	TI4100 Navigator	S53 09 E71 00
Wellington	DOLIS	Trimble 4000SLD	S41 16 E174 47

Table 2: GPS observational sites 1990

Despite problems encountered the trial clearly showed that baseline accuracies in the order of one metre over intercontinental distances were possible even with the low number of GPS satellite available at the time (Govind at al 1990).

With the success of these feasibility studies the WG-GGI initiated an ongoing series of summer GPS epoch surveys. These were coordinated by Reinhard Dietrich from Germany (Dietrich 1996), (Dietrich, 2001) and the sites occupied are shown in Figure 4. All epoch data is archived at University of Dresden as an ongoing collection for science research (Dietrich@ipg.geo.tu-dresden.de).

Despite their success, the GPS campaigns were logistically costly and it was difficult to arrange the simultaneous occupation of all sites, being subject to different logistic arrangements. Consequently in 1993 permanent GPS sites were installed to provide fundamental fiducial stations to link epoch surveys together. The permanent stations were:

- McMurdo
- Mawson

- Amundsen-Scott (ice station)
- Casey
- Davis
- Macquarie Island (1995)

This was a significant technological advance as it provided a potential continuous time series of observations and a network of key sites which could be used as a control framework for subsequent occupations at different times. In 1994 permanent GPS trackers were also installed at :

- O'Higgins
- Syowa
- Kerguelen

Since that time permanent GPS trackers contributing continuous data to world data bases on a daily basis have been established at SANAE (1999) and Palmer. Other annual download GPS base stations are operating at Terra Nova bay, Maitri, Dumont Durville, Cape Roberts, Belgrano and Zhong Shan.(see figure 5)

The technology to power GPS equipment at unattended remote Antarctic observatory sites during the sunless winter is under current development with varying degrees of success. Ideally this requires remote power and satellite data retrieval strategies. The Australian National University has deployed 4 stations in the vicinity of the Prince Charles Mountains in East Antarctica and continues development for regular satellite downloads from some of those sites. Japan is trialling a remote site on an island some 30 km from Syowa and USGS is trialling annual download from remote sites at Finger Point, Mt Fleming and Cape Roberts (collocated with a remote operating tide gauge). This remote operation technology is not quite proven and needs further development to be ready for the international polar year in 2007.

3. The Geodetic Infrastructure of Antarctica

At the XXII SCAR in 1992 the results of the SCAR GPS Antarctic Project 1990-92 were assessed and it was decided to extend the GPS projects to develop collocation network of other techniques such as VLBI, Absolute Gravity, DORIS and tide gauges. This was collectively identified as the Geodetic Infrastructure for Antarctica (GIANT) the coordinating program for Geodesy.

The ongoing GIANT program objectives are to:

- Provide a common geographic reference system for all Antarctic scientists and operators.
- Contribute to global geodesy for the study of the physical processes of the earth and the maintenance of the precise terrestrial reference frame
- Provide information for monitoring the horizontal and vertical motion of the Antarctic.

Since 1992 the GIANT program has been revised and endorsed at each major SCAR conference on a two yearly basis. The components of the current program are:

3.1 Geodesy program (GIANT)

There are nine projects in the program as shown at www. scar-ggi.org.au/geodesy/giant.htm and are summarised as:

1. Permanent Geoscientific Observatories

Project Leader: Australia - Mr John Manning

Goal: To develop an infrastructure of permanent geoscientific (ie. seismologic, geomagnetic, geodetic and gravimetric) stations to bring all individual networks to a common datum, and to provide geoscientific information for the global monitoring and analysis of natural earth processes

2. Epoch Crustal Movement Campaigns

Project Leader: Germany - Prof Reinhard Dietrich Members: Italy, Chile, Japan, China, Australia, USA Goals:

- 1. To densify the geodetic infrastructure established from the permanent observatories; and
- 2. To develop a deformation model for surface movement vectors within a common Antarctic reference frame.

3. Physical Geodesy

Project Leader: Italy - Prof Alessandro Capra

Members: Germany, Australia, Russia, USA, Japan, Canada

Goal: Compilation and analysis of physical geodesy data, for the development of a new high resolution Geoid for the Antarctic.

4. Geodetic Control Data Base

Project Leader: Australia - Mr Glenn Johnstone

Members: Germany, UK, USA

Goal: Maintain the master index for Antarctic positional control, including all levels of accuracy

5. Tide Gauge Data

Project Leader: Japan - Dr Kazuo Shibuya

Members: Australia, China, Germany, New Zealand, Italy, Russia, USA (Amos), UK (Woodworth), other specialists as required

Goal: To consolidate the collection of and access to Antarctic tide gauge information

6. Atmospheric Impact on GPS Observations in Antarctica

Project Leader: Poland - Dr Jan Cisak

Members: Germany, Italy, USA, Australia (IPS), Norway, China, IGS

Goal: To understand the iononspheric and tropospheric impact of the atmosphere on the quality of GPS observations in Antarctica

7. Remote Observatory Technologies

Project Leader: USA - Mr Larry Hothem

Members: Japan (GSI), Australia, Italy, Netherlands (Swartz).

Goal: Identify technology and monitor developments for the deployment of geophysical and geodetic measurement sensors, and ancillary support equipment, at unattended remote (no existing infrastructure for power, shelter and communications) Antarctic localities.

8. Ground Truthing for Satellite Missions

Project Leader: Germany - Prof Reinhard Dietrich Members: Italy, Australia, USA (U of Texas) Goal: To ensure new satellite missions are integrated with the Antarctic geodetic system

9. Geodetic Advice on positioning limits of special areas in Antarctica

Project Leader: Chile - Tnt Col Rodrigo Barriga Members: Germany, Australia, USA

Goal: To provide advice to SCAR, through the Geoscience Standing Scientific Group on the geodetic aspects of protected area definitions.

One of the complex elements in The GIANT program is the development of the ellipsoid to geoid separation values to obtain heights above sea level from GPS or altimeter observations. An accurate determination of the Antarctic geoid continues to be severely hampered by the scarcity of gravity information, especially the interior of the continent. Australia produced early versions of the Antarctic Geoid based on GEM and OSU gravity data sets, which are available on the web site. In 1996 NIMA produced EGM96, a new global Gravity data model which however still suffers from lack of Antarctic gravity data. A grid of geoidal separation values based on EGM96 is available NIMA web site and which can be used to on line interpolate a separation value for any location (http://www. nima.mil/GandG/egm96/intpt.htm)

Whilst these earth gravity models still are inadequate for extensive Antarctic research, long wave gravity models from the CHAMP and GRACE satellite are beginning to become available and will improve the situation. Medium wave length gravity however is also required and this can be produced from airborne gravity. The experience from the successful aero gravity activities of Denmark and the Unites States of America in Greenland and the Arctic Ocean offer a technique to dramatically improve this aspect of the Antarctic gravity data set and provide the base for the subsequent computation of the geoid within the GIANT Geoid project. Ultimately terrestrial gravity will be integrated by introduction of precise Absolute gravity at origin sites top produce a continental wide gravimetric framework.

GIANT also provides important geodesy input to two other major activities:

- ANTEC, and
- ITRF

3.2 The Antarctic Neotectonics Group of Specialists ANTEC.

This group of specialists was established following the SCAR XXV meeting in Concepcion with three GIANT representatives. The ANTEC objectives are intertwined with the need for a precise geodetic framework over Antarctica in the establishment of remotely operated sites away from the manned coastal stations and the integration with other geodetic techniques.

3.3 The International Terrestrial Reference Frame (ITRF)

Antarctica is important in the context of global geodesy. In the past global models have heavily relied on observations from Northern Hemisphere sites and the results do not always fit in the Southern Hemisphere or represent the best global picture. Antarctic space geodetic observatories have provided data to rectify this imbalance. Some continuous GPS sites make their data available to the International GPS Service (IGS) using satellite data retrieval systems. Data from continuous GPS sites in Antarctica were used in ITRF 2000 primary determinations (Altimimi 2001) and the epoch surveys have also been processed by Dietrich (2001) as densification of the global reference frame. This results in a network of official published IERS coordinates (with velocities) for Antarctic rock sites which can be used by any scientists in the Global reference frame. Through the GIANT program SCAR has accepted the recommendation that all geodetic networks in Antarctic should be computed in the ITFR 2000 reference fame using The GRS80 ellipsoid.

4. Conclusions

There has been considerable international cooperation in Antarctic Geodesy since SCAR was formed in 1958. The GIANT program was identified in the SCAR 1992 meeting and has evolved as the coordinating program for all SCAR Antarctic geodesy. With advent of man made satellites Geodesy has advance significantly linking isolated geodetic networks and monitoring tectonic motion.



Figure 4. GAP1995 Observational Sites

A number of permanent GPS receivers have been installed in Antarctica and data is increasingly being retrieved by satellite transmission from these sites. This fiducial network of GPS points, augmented by VLBI and other techniques, forms the basis for an integrated geodetic infrastructure as the basis for all scientific spatial data. Data from these sites in Antarctica are of ongoing importance to global geodesy, especially in the determinations of precise orbits and the integration of different observational techniques. These sites provide a stable platform for combining summer epoch campaigns, densifying the ITRF network across Antarctica.

The application of space geodesy technology now enables a more comprehensive study of crustal movements within Antarctica and its relationship to other fragments of the ancient Gondwanaland. GIANT is making a significant contribution to the work of other Antarctic earth scientists such as the newly formed ANTEC group of specialists which is concerned with developing a better understanding of the crustal dynamics of Antarctica.

To meet the continual advancing requirement for accuracy for studying Antarctic geodynamics stresses, GIANT will expand the geodetic network to provide a very stable Antarctic reference frame for geodynamics and become involved in aerogravity campaigns to supplement satellite gravity data in order to improve the geoid.

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Figure 5. Continuous GPS sites

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Geodesy Activities In PCMega 2003

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Figure 1. GPS point on Seavers Nunatak looking south East to Mt Menzies

Abstract

During the Antarctic summer 2003/2004 a major Geodetic Geological Geophysical expedition to the southern Prince Charles Mountains was undertaken jointly between Germany and Australia. This project was termed PCMEGA.

The joint expedition studied geochronology and

metamorphism of the area. Extensive airborne gravity and ice radar survey flights were undertaken over the ice cap to the immediate south of the mountains. Aeromagnetic transects over the Southern PCMs were also flown.

As part of the structural investigation of the area several first epoch GPS sites were established, together with occupations on previously established geodetic survey points, and a number of new mapping control were surveyed. An ice field calibration site for ICESAT, at a satellite crossover point near Mt Cresswell, was surveyed using kinematic GPS and a DORIS beacon was deployed on the glacial stream of the Lambert Glacier.

The GPS points were subsequently processed and the precision achieved on the first epoch occupations assessed. Additionally a GPS point on the nearby Grove Mountains was reoccupied for the third summer in a row to provide information to the ANTEC program from this part of East Antarctica. The preliminary results of these occupations will be presented in this paper.

1. Introduction

In the Austral summer of 2002-3 a geodesy team participated in the Prince Charles Mountains Expedition of Germany and Australian (PCMEGA). The expedition's objective was to undertake a geological and geophysical survey of the Southern Prince Charles Mountains in East Antarctica, including terrestrial and airborne gravity surveys, aeromagnetics, an ice radar survey and the enhancement of the geodetic network. The geodesy component was undertaken by a team consisting of surveyors from Australia (Geoscience Australia) and Germany (Dresden University of Technology).

2. Historical Background

The Prince Charles Mountains (PCM's) were first sighted as distant horizon features on the trimetrogon aerial photographs of the 1947-48 United States Operation Highjump. It was first reached by ground parties from Mawson in 1954 and then explored with aircraft support in the second half of the 1950s, when aerial photography was flown and controlled by sparse astronomical position fixes for reconnaissance mapping.

From the late 1960s the application of distance measuring equipment and the transition to use of helicopter support in the summer enabled a terrestrial geodetic network to be gradually developed through the northern and southern Prince Charles Mountains. This network, know as the Australian Antarctic Geodetic Network (AAGN), was been observed using angles and distances. It was later extended to the east and the west. By January 1976 the geodetic network stretched continuously from Davis to Molodezhnaya. This was a major feat but the positional accuracy suffered from a lack of traditional azimuthal control in poorly conditioned geometric figures, as it was difficult to observe Laplace azimuths in the summer daylight.

With the development of early satellite positioning techniques several Doppler Satellite fixes were observed in the Northern Prince Charles in 1988 and the next year surveyors' trialled the use of GPS for Antarctic geodesy. This quickly became the standard technique used for positioning during summer expedition projects. To provide a framework for these summer campaigns permanent GPS base stations were established at Casey, Davis, Mawson and Macquarie Island from 1993 onwards.

In 1995 and 1997 positional upgrades were observed with GPS at some geodetic network sites in the Southern PCM's. These were relatively short occupations on tripods but produced key tie points and significant improvements were achieved in the absolute accuracy of the geodetic network. Observations continued in 2000/01 along the northeastern edge of the Amery Ice shelf thus strengthening the single line traverse connection to Davis.

From 2000 Geoscience Australia entered into a multi year project under the Australian Antarctic Science Advisory Committee (ASAC) process. The Objectives of this project (ASAC 1159) are:

- To establish a reference framework for understanding the horizontal and vertical motion of Antarctica;
- Provide ANTEC with GPS data relating to vertical and lateral motions of east Antarctica (2001-2005); and
- Accurately co-ordinate points to update and strengthen the existing terrestrial based Australian Antarctic Geodetic Network, thus providing the geodetic infrastructure for all science programs as the positional basis for all geospatial data.

3. PCMEGA 2003

The primary geodetic objective was to obtain accurate ITRF2000 coordinates and gravity values on a network of points across the southern PCM's (SPCM's). This was done by:

- Running GPS base stations at Wilson Bluff, Mt Creswell and the Grove Mountains for high precision positions and to support the aircraft GPS positioning;
- Extending the geodetic framework in the SPCM's with GPS observations at Burke Ridge, Mt Borland, Mount Twigg, and other outcrops;
- Observe GPS at new monuments adjacent to existing geodetic network stations elsewhere; and
- Observing terrestrial gravity at all sites visited.

In addition other tasks completed were

- The establishment a small ICESAT calibration range at a crossover ponit near Mt Creswell using kinematic GPS techniques;
- The deployment DORIS near the Lambert Glacier grounding zone to measure ice flow velocities;
- The measurement of ice flow velocities adjacent to the Wilson Bluff Camp (NE end of the Bluff); and
- Photo-control surveys for satellite imagery at ten sites for the Australian Antarctic Division Mapping program

All GPS observations were taken on rock mounted antenna mounts (see Figure 1 for example) which eliminated the uncertainty of using tripod setups. Where existing AAGN points existed on the feature the new mark was place adjacent to it and connected using terrestrial survey techniques allowing the adjustment of the AAGM network onto the new GPS control. Where no existing AAGN points were present the site was chosen for optimum stability and ease of access. Subsequent re-adjustment of the AAGN using these new points and the connections to the existing control has resulted in significant improvements in the accuracies of the network throughout the area.

More importantly the new GPS network bridges the Lambert Glacier with a number of sites either side of the main stream and a good latitudinal distribution as well (Figure 2).

The observational strategy of running three continuous trackers in the vicinity of the survey while the shorter seven day occupations occurred has resulted in very high coordinate precisions, even on the shorter occupations. Figure 3 and 4 illustrate the daily coordinate repeatability's achieved. Figure 3 shows one of the longer occupations at Mt Creswell and Figure 4 shows Harbour Headland which is one of the shorter occupations.

This first epoch observation at the network of new geodynamic style points has established the framework



Figure 2. Distribution of GPS sites in the Southern Prince Charles Mountains

for future tectonic studies in the region. Subsequent observations on these points will allow a structural investigation of the region, and may give some insight into the processes which formed the Lambert Graben.



Figure 3. Aus367 (Mt Creswell) time series

Additionally, a GPS point on rock in the nearby Grove Mountains was reoccupied for a third summer in a row to provide horizontal movement information to the ANTEC program from this part of East Antarctica. The results of these occupations indicates that the horizontal motion is consistent with the east Antarctic plate, but a small differential vertical motion on this inland site compared to the coastal margin as represented by the IGS sites of Mawson and Davis is present. Figure 5 illustrates the time series for the Grove Mountains site. The continuation of this time series with longer observational spans will improve the understanding of this feature.

Relative gravity observational loops were taken between Davis and Mt Creswell, as well a Mt Creswell and Mawson. These loops were later extended to all



Figure 4. Scatter plot of AUS380 (Harbour Headland) results

sites visited in the area so that gravity values can be computed relative to the fundamental gravity stations and Davis and Mawson. Most points were visited twice for redundancy.

The secondary tasks completed will not be discussed here, but will be recorded at more length in a full technical report being prepared at Geoscience Australia.



Figure 5. AUS351 (Grove Mountains) time series

4. Conclusions

The 2002-03 PCMEGA campaign was an unprecedented success for all disciplines of Geoscience studied. While extremely fortuitous weather conditions certainly contributed to the success of the campaign, the logistical and organisational support provided by the Australian Antarctic Division contributed more.

The geodesy program established 23 new geodynamic

style GPS points with a resultant coordinate precision in the order of 1-2mm horizontal and 2-3mm vertical. Many of these were also connected to the existing AAGN network allowing significant improvements to it. Gravity observations were also taken adjacent to these points enhancing the usability of the gravity values. They can now be used for ground control of airborne or satellite gravity missions.

Geodetic Activities At Finnish Antarctic Research Station Aboa

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Abstract.

We summarise geodetic activities at the Finnish Antarctic research station Aboa since 1989. In 1989–1992 a regional gravity network was established. Absolute gravity measurements were performed in 1994 and 2001. In 2003 a permanent GPS station was installed. In the future we plan to maintain the GPS time series, and to perform absolute-gravity measurements at other sites in Queen Maud Land, too.

Geodetic Activities at Aboa 1989-2001

The Finnish Antarctic Research Station Aboa (73°02' S, 13°25'W) in Western Queen Maud Land (Fig. 1) on the nunatak Basen was built in 1988–1989. It is a summer station and has not been occupied every year. The Finnish Geodetic Institute (FGI) has taken part in five of the ten Finnish scientific Antarctic expeditions (FINNARP) organized so far. Here we summarise shortly the activities of the first four of them. For more information see Ollikainen and Rouhiainen (1990), Jokela *et al.* (1993), Virtanen *et al.* (1994), Mäkinen (1994, 2001).



Figure 1. Finnish Antarctic Research station Aboa is located at 73°02' S, 13°25'W in Western Queen Maud Land.

Finnarp89 (1989/1990) and Finnarp91 (1991/1992).

A regional gravity survey covering 10000 km² was measured using Worden Master and LaCoste&Romberg

gravimeters, with 493 points at the spacing of 5 km. Snowmobile and helicopter transport, and GPS positioning were used. The Aboa reference station was tied to the International Gravity Standardization Network 1971 through station no. 43846J in Montevideo. A set of benchmarks was built around Aboa and measured with static GPS to create a local coordinate system. Snow accumulation and ice motion were studied on stake lines. A concrete pier was constructed on solid basaltic rock for future absolute gravity measurements.

Finnarp93 (1993/1994) and Finnarp2000 (2000/ 2001)

Absolute gravity was measured by the second author with the JILAg-5 of the FGI in January 1994 and in January 2001. The results (Fig. 2) show an apparent gravity change of $+9\pm7 \mu$ gal (one-sigma) over 7 years. The change is thus not statistically significant. In 2001, the 5.5 km stake line of Sinisalo et al. (2003) was re-surveyed by GPS for snow surface elevations, and density of the top 0.5 m layer sampled. A similar local survey within 100 m of the absolute site was performed with tachymeter. The GPS station at the neighbouring Swedish base Wasa was occupied during the SCAR epoch 2001 and 2002 GPS campaigns.



Figure 2. The results of two absolute gravity measurements in 1994 and 2001 show a slight increase in gravity.

Geodetic Activities at Aboa in 2002/2003

The first part of the season was mainly dedicated to the refurbishment of the Aboa station. Finnish Geodetic Institute sent the first author to Aboa for the latter part of the season. His main task was to install a permanent GPS station close to the absolute gravity hut.

Permanent GPS station.

The Aboa permanent GPS station became operational on January 31, 2003 at 10:10 UT. The station (Fig 3) is unoccupied most of the year so the power consumption of the GPS receiver is an essential issue. We chose a Javad EURO80 GDA receiver, which has a power consumption of 1.8-2.4 W only. We collect both code and phase data with 30 s observing interval and store it on a 512MB Compact Flash memory card. Both the receiver and memory card are specified for temperatures down to -40°C. The electronics of the receiver are sealed into a box and it was estimated that the heat produced by the receiver keeps the temperature in the box 20 degrees higher than the outside temperature. This should be sufficient, as temperature measurements at Aboa do not have records below -50°C. The memory card will be changed annually during austral summer expeditions by geodesists or any other research or logistics personnel available.

As an antenna platform we use a 1.5 m high steel grid mast that was anchored to basaltic rock with 1 m long screw bars (Fig.4). The antenna is Ashtech choke ring (ASH701945C_M) with conical Ashtech snow radome. The receiver itself is located in the absolute gravity hut 15 m from the antenna mast.

The power is taken from a Ni-Cd battery pack (24V/1100Ah) located 100 m from the receiver at the main building of the base. During the field season the batteries are charged by diesel generators. When the station is not occupied the batteries are charged by four 50W solar panels, which are on test use. The batteries alone are able to keep the receiver running through the dark period of the austral winter. Finnarp logistics will install in the next season 26 solar panels of 100 W each, and 3 wind generators for shared use of all the research facilities at Aboa.

The permanent GPS station is mainly used for long coordinate time series to support deformation studies, but data are also available for any other geodetic purposes in the area.

RTK Service.

When the Aboa station is occupied the GPS station offers also the RTK correction signal. It is sent using a Satelline-3As/d Epic radio modem (10W) with 430.15 MHz frequency. The RTK correction is available for



Figure 3. The components of the permanent GPS-station at Aboa. Grey boxes indicate components that are used the year around and keep the station operational in winter. White boxes indicate components used only when the station is occupied. Dotted lines indicate future components that are a part of a larger plan to support logistics and research facilities.

any researcher working in the area, to obtain accurate coordinates within 20-30 km from the station.

SCAR 2003 Epoch GPS Campaign.

We did GPS measurements on the Swedish point WASA that has participated in several SCAR epoch GPS campaigns (http://www.tu-dresden.de/ipg/FGHGIPG/Aktuell-Dienste/scargps/database.html). The 2003 campaign was performed between January 20 and February 10, in 2003. We did measurements from January 26 until the end of the campaign using Ashtech _Z receiver and choke ring antenna (ASH700936A_M). We have also data from the permanent GPS station starting from January 31. In the future the data from the permanent GPS station will be contributed to the SCAR epoch campaign database.

Table 1. The coordinates of the benchmarks on Basen. WASA was fixed to it's ITRF96 epoch 1997.1 coordinates by Dietrich et al. (2001)

Point		Sigmas (mm)				
Name	Latitude	Longitude	Height (m)	s(N)	s(E)	s(U)
900001	73°02'28.81537"S	13°24'05.69716''W	495.157	0.2	0.2	0.6
910023	73°02'29.94509"S	13°24'26.36215"W	482.557	0.2	0.1	0.6
910024	73°02'22.87693"S	13°24'32.74326"W	490.790	0.2	0.2	0.6
900032	73°02'37.59744"S	13°24'23.98902"W	467.352	0.8	0.4	1.9
ABOA	73°02'37.57989"S	13°24'25.68634"W	468.640	0.2	0.2	0.7
WASA	73°02'34.22900"S	13°24'50.52273"W	466.396	0.0	0.0	0.0

Local Geodetic Network.

During the Finnarp91 expedition a local geodetic coordinate system was created around Aboa. We remeasured all points located on Basen including the new GPS station. Static GPS measurements were performed with two Ashtech Z-XII receivers and choke ring antennas (ASH700936A_M) using 30 s observing interval. The baselines varied between 15 and 460 m and sessions from a few hours to 24 hours. In the adjustment we fixed the WASA coordinates to those in ITRF96, epoch 1997.1 published by Dietrich *et al.* (2001). The results were processed with Pinnacle software and are shown in Table 1.

Local snow and ice.

RTK will be used by the FGI to support absolute gravity measurements. The snow and ice topography around the gravity point is surveyed using RTK. The density of snow and ice is determined by drilling. From repeated measurements we can estimate the variation in the attraction of the near field ice and snow masses. During this season the 5.5 km stake line was re-built, samples drilled and coordinates measured with RTK. The local tachymetric survey of 2001 was repeated with RTK. While there was no absolute gravity observation in 2003 this will help to estimate annual variability.

Research rationale, future plans

With the repeated absolute gravity observations and with the permanent GPS station we strive to detect gravity change and contemporary crustal motion. They could be caused by past and present-day changes in the ice mass balance. Reconstructions of the last glacial cycle in the Antarctic are not well constrained by observational evidence, and differ appreciably both in ice volumes and in the timing of the deglaciation. Neither is the presentday mass balance well known. Thus there is considerable interest in collecting new observations related to past or present changes of the Antarctic ice mass. For predictions of gravity and vertical rates based on a number of scenarios of the ice mass balance see James and Ivins (1998).

The elevation change of the Antarctic from 1992 to 1996 was mapped by Wingham *et al.* (1998) using satellite radar altimetry. In the drainage basin around Aboa an average annual change of $\pm 4.4 \pm 1.1$ cm is indicated. However, many 1°by 1° squares lack data due to the terrain inclination limitations of the ERS altimetry. Currently, the change in the ice surface elevation is being mapped by ICESAT/GLAS, and in the future by the CRYOSAT mission. Contemporary change in total mass (ice \pm mantle flow due to postglacial rebound) is surveyed by GRACE.

Additional information is obtained by observing the deformation of the solid Earth. GPS provides information on vertical and horizontal motion, while gravity is sensitive to both vertical motion and changes in density distribution. GPS is indifferent to the underlying causes, but for a given amount of vertical motion, the gravity change depends



Figure 4. The antenna mast of the Aboa GPS station

on the mechanism: The response of the Earth to present deglaciation is elastic and for a typical regional load the ratio of gravity change to vertical motion is -0.27 μ gal/mm (James and Ivins, 1998). The response to the past deglaciation ("postglacial rebound") is viscous mantle flow to restore the isostatic balance and the corresponding ratio is about -0.16 μ gal/mm (Wahr *et al.*, 1995). Combining GPS and repeated absolute gravity one thus could, in principle, not only determine total vertical motion, but also separate it into the postglacial rebound signal, and a signal showing present-day variation in ice mass.

In addition to the gravity change due to deformation of the solid Earth, the change in ice mass causes a change in gravity through the direct attraction. The Aboa absolute site is on bedrock, but model calculations show that a surface layer at a distance 15...1000 m from it has a (vertical) attraction of about 25% of the corresponding Bouguer sheet. This is of the same size than the deformation effect of the corresponding regional surface layer, and the nearfield mass variation need not reflect the regional average. Thus the variation in the attraction by the local ice mass could overshadow the deformation effects we are looking for, and must be monitored separately.

We propose to continue both GPS and absolute gravity observations, and extend the latter to other sites in Queen Maud Land. The plan (Fig. 5) for the summer 2003/2004 includes absolute-gravity measurements at the bases Aboa (Finland), Sanae IV (Republic of South Africa) and Novolazarevskaya (Russia), using the recently acquired absolute gravimeter FG5 no. 221 of the FGI. At Aboa we will survey the snow topography with RTK, to control the attraction of the near-field ice/snow masses. At the same time the permanent GPS station at Aboa will provide a continuous time series of coordinates.



Figure 5. Measurement plan for the absolute gravity for the next field season. 1 is Aboa (FIN), 2 is Sanae IV (RSA) and 3. is Novolazarevskaya (RU).

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An Outline of Polar Expeditions of the Scientists from Warsaw University of Technology Andrzej Pachuta

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Abstract

Active exploration of polar area by scientists from Warsaw University of Technology began in the late fifties of the XX century. On the occasion of the III International Geophysical Year Jerzy Fellmann took part in the Spitsbergen Expedition. He has measured the movement of Werenskiold glacier in the area of Hornsund Fiord by photogrammetric methods. The most valuable and spectacular achievement of the first Polish geodetic Antarctic expedition to the Dobrowolski Station on Bunger Oasis was done by Janusz Sledzinski and Zbigniew Zabek during the Antarctic summer 1958/1959. They established the gravimetric point and the direct connection of this point to the Polish gravimetric network. Further geodetic studies at the A.B. Dobrowolski Station were carried out during the Antarctic expedition organized by Polish Academy of Sciences in 1978/1979. The geodetic network and gravimetric measurements have been made by Andrzej Pachuta. The first geodynamic expedition with students' participation was organized to the Spitsbergen by Faculty of Geodesy and Cartography in the summer 1988. Andrzej Pachuta and Ryszard Preuss led this expedition. Dariusz Osuch, Piotr Wypych, Jaros_aw Kutyna, Artur Gustowski were the student participants. During this expedition Zdzislaw Kurczynski and Stanislaw Dabrowski made the photogrammetric measurements in fiord Hornsund. The second geodynamic expedition to the area around fiord Hornsund in Spitsbergena was organized in summer this year. Zdzislaw Kurczynski manages the expedition. Artur Adamek, Michal Sagan and Malgorzata Piskorz are the students from the Warsaw University of Technology participating in this expedition.

Photogrammetrical Investigations of the Antarctic Coast Olexandr Dorozhynskyy, Volodymyr Glotov National University "Lvivska Politechnica", Lviv, Ukraine

Abstract

Changes of the Antarctica coast and the contiguous islands covered with the ice occur in the time with different rate and depend from whole range of factors, foremost from climatic environment. Determination of such quantitative changes, in other words the changes of surface topography, can be effectively solved by photogrammetric methods.

Authors have proposed the conception of the navigationdigital photogrammetry (O. Dorozhynskyy, 1997) and its application for concrete physiographic conditions. Itis developed the technology of the terrestrial navigationdigital photogrammetry which based on the use of digital camera (for obtaining of the digital images of the shore line and glaciers), GPS-device (fixation of the spatial location of the surveying points and investigated objects points) and digital photogrammetric stations (creation of ortophotomaps of the shore line and frontal plans of the rocky shores).

Photogrammetric method has been completely tested in the

field conditions (V.Glotov, 2002,2003) during two seasonal Antarctic expeditions on Ukrainian station "Academic Vernadskyy". There have been produced about 1200 digital images which give rich materials for further researches. The following previous results has been obtained:

• photogrammetric method of investigation of the kinematic processes (changes of ice cover and deformation of the shore line of Antarctic coast) is effective, objective and precise tool for quantitative evaluation of changes on such territories;

• creation of digital cartographic materials is a good basement for application of GIS-technologies for the analysis of spatial changes and systematic storage of data about kinematics of phenomenon will allow for direction of other branches to obtain the information for solution of their specific tasks, namely forecasting of glaciers changes.

Tropospheric Delay Modeling for GPS Measurements in Antarctica Alexander V. Prokopov, Yeugeniy V. Remayev

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Abstract

The accuracy of tropospheric delay modeling for polar regions was investigated. Ray tracing technique and data of radiosounding for Antarctic meteorological stations accessible in the Internet (http://weather.uwyo. edu/upperair/sounding.html) were used in researches. The results show that the errors of known methods of determination of tropospheric corrections for GPS are much higher for Antarctica than for middle latitudes. For example, errors of methods [1,2] for Mirnyj station are 3...4 times above than for USA and Europe.

The effect of the significant contribution of a wet component in delay of a signal at heights above tropopause predicted for Antarctica by F.D.Zablotskyj [3] is confirmed.

On the basis of the IROA method [1] the preliminary version of regional (Antarctic) model for determination of delay from ground meteorological data is developed. The testing which has been carried out by the ray tracing technique with the use of yearly sets of radiosounding profiles obtained for Mirnyj station showed: the accuracy of the developed model in a range of zenith angles $0^{\circ}...80^{\circ}$ is 1,5 ... 2,5 time higher than accuracy of known models.

The obtained results shows the need for further researches with the aim of increasing the accuracy of tropospheric delay models by taking into account the peculiarities of spatial distributions of atmospheric parameters in polar regions.

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Overview of the Research on the Atmospheric Impact on GPS Observation in Polar Regions Jan Cisak

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Abstract

Polar region is one of the best test areas on the Earth for research. The increased, in last years, number of permanent GPS stations there, provides a large amount of data and possibility to create a representative database.

Recent research developments within the framework of the project "Atmospheric impact on GPS observations in Antarctica" are presented in the paper. The effects of both ionospheric and tropospheric disturbances on GPS solutions are discussed. The GPS data, usually those provided by permanent GPS station arrays are commonly used to investigate the structure and dynamics of ionosphere. First results of the project concerned the influence of ionosphere over the Arctic and Antarctic regions on repeatability of co-ordinates of vectors of different length during the quiet and disturbed ionosphere (ionospheric storms).

The new approach of data analysis was conducted. It is based on the analysis of GPS solutions obtained from the overlapped segments of data. Time series of GPS solutions based on the processing overlapped data segments allow for investigation of atmospheric impact on GPS measurements in a new dimension. Such a series can be considered as a record of the process of variations of vector components during varying atmospheric disturbances. The experiments performed concerned the investigation of the response of the measuring system to ionospheric storms as well as the response of the measuring system to tropospheric disturbances.

The two-stage influence of ionosphere, as the fluctuation on local inhomogeneous ionosphere and the refraction on regional inhomogeneous ionosphere, makes ambiguity resolution difficult and causes the errors in vector final solutions. The deep study of the problem should lead to the rejection of bad solutions. It has also been found that the analysis of correlations gives the possibility to correct the horizontal components of the vector obtained using commercial as well as the Bernese software. Similar analysis was performed when looking for the correlation of vector solution and tropospheric data. The results obtained using the Bernese software are not correlated with the tropospheric delay. The repeatability of the vertical component of the vector obtained using commercial programmes is substantially improved after introducing the correction.

1. Introduction

A considerable progress observed in the geodynamic research is the result of a development in measuring techniques (Manning, 2001). The qualitative results on crustal movements presented in some publications (Dietrich *et al.*, 2001, Dietrich *et al.*, 2002) seem, however, to be at the level of their accuracy determination. A realistic estimation of the potential of the experiment is thus necessary to avoid false conclusions describing non-existent occurrences (artefacts), especially when the experiment is difficult or very expensive.

That is exactly the case of the experiments conducted in Antarctica. Seasonal changes of atmospheric conditions frequently make impossible to perform widespread continuous (yearly) GPS observations. On the other hand, those seasonal changes can cause periodic biases in data acquired, as well as periodic deformations of the Earth's crust. Besides data acquired at the growing number of Antarctic IGS permanent stations (recently about 15 stations) there is a large set of data provided by GPS Epoch Crustal Movement Campaigns (http://www.geoscience. scar.org/geodesy/giant.htm) organized for a number of years under the umbrella of SCAR GIANT (Geodetic Infrastructure of ANTarctica) program. About 50 Antarctic stations participated in those campaigns that took place during Antarctic summer only. The question arises whether the seasonality of those campaigns influences the results obtained, and if so, how that influence could be quantitatively evaluated.

The main goal of the GIANT program project on the atmospheric impact on GPS observations in Antarctica is to investigate the atmospheric impact on the quality of GPS observations in Antarctica, and possibly to develop recommendations for future Antarctic GPS campaigns, data post-processing strategies and modelling GPS solutions.

The GPS data, usually those provided by permanent GPS station arrays, are commonly used to investigate the structure and dynamics of the ionosphere (Baran *et al.*, 2001a; Feltens and Jakowsky, 2001) as well as to investigate the troposphere (Kruczyk, 2002). During the realisation of the project it was impossible to concentrate on the atmospheric impact only and separate it from the study of the atmosphere. The results of the investigations of the ionosphere as well as of the troposphere are the output of the project too. The bibliography at the end of the paper includes the majority of publications that summarize the results obtained in the framework of the GIANT project.

2. Project background

The GIANT program project on the atmospheric impact on GPS observations in Antarctica, coordinated by Poland, has been created at the XXVI SCAR meeting in Tokyo in 2000. The Polish project, financed by Polish Scientific Committee, named "The investigation of atmospheric impact on the results of the precise geodetic measurements

with GPS technique in polar conditions" was established in the Institute of Geodesy and Cartography (grant No 8T12E04520) in March 2001. J Cisak - the project leader, reported the first results of the international project to the projects coordinators meeting in Siena in July 2001. One week later the Third Antarctic Geodesy Symposium AGS'01 took place in St. Petersburg. One session of the Symposium was devoted to the problem of the atmospheric impact on GPS technique of measurements. The proceedings of the Symposium were published in SCAR Report, No 21, January 2002, publication of the Scientific Committee on Antarctic Research, Scott Polar Research Institute, Cambridge, UK. As the result of the Symposium, an efficient cooperation between SCAR WG on Geodesy and Geographic Information and IGS IONO WG (Feltens and Jakowsky, 2001) has been established. J. Cisak was invited to take part in the workshop of the IONO WG of IGS that was held in Darmstadt, in February 2002. Some results of the project as well as the SCAR WG GGI activity were presented and published in the special issue of the workshop. The new achievements in the project were presented at the International Workshop on "Atmospheric impact on GPS observations focused on Polar Regions", 15 May 2002, Warsaw, Poland. The papers and presentations of the workshop are placed on the web page of the SCAR Geoscience Standing Group: http://www.geoscience.scar.org/geodesy/warsaw/index. htm. The next interim report of the state of the project was presented to the international geodetic community at the WG GGI meeting during the XXVII SCAR, Shanghai, China, July 2002. The papers with the attempt to correct the final GPS solutions for the Antarctic vectors were presented at the AGS'02, Wellington, New Zeeland, December 2002 (Cisak et al., 2002)

http://www.geoscience.scar.org/geodesy/ags02/index.htm and at the Poland – Italy geodetic meeting, Bressanone, Italy, April 2003 (Cisak *et al.*, 2003c). The project is still running. Everybody is very welcome to contribute to it. The final report is to be prepared and presented at the next SCAR Symposium in Bremen, 2004.

3. Ionosphere

3.1. Influence of non-homogeneity of ionosphere in polar region on the results of GPS measurements

The non-homogeneity of the atmosphere in the Polar Regions is an important factor when considering the influence of ionosphere for the determination of coordinates by use of GPS technique. It has various forms of different range.

The most spectacular form of the non-homogeneity of the atmosphere is the main ionospheric trough, which is the large-scale structure of lowering electron concentration. The concentration of the electrons in the area of ionospheric trough can be even ten times smaller than outside that area. The width of such zone, along the meridian, can reach 2-3 degrees of arc. The latitudinal gradients of the electron concentration in such area can significantly differ

from those in quiet ionosphere and can lead to erroneous determination of phase ambiguities (Baran *et al.*, 2001b; Baran *et al.*, 2001c).

The other forms of the non-homogeneity of the ionosphere in Polar Regions are the bubbles with dimension of a few hundreds or even a thousand kilometres. The electron concentration inside the bubbles can exceed the concentration outside it by a factor 10 to 100. The edges of that type of non-homogeneity are characterized by large gradients.

The non-homogeneities of the atmosphere in the range of tens of kilometres can substantially affect GPS measurements and the accuracy of GPS solutions. The intensity of those non-homogeneities during the magnetic storms can grow up to several times, and cause substantial fluctuation of GPS signal phases (Epishov *et al.*, 2002). Such fluctuations can be observed even in the latitudes below 60°.

During the occurrence of large electron concentration gradients the ionospheric refraction can strongly affect the determination of ambiguity and result in growing errors of GPS solutions. The correlation between the growth of unsolved ambiguities and variations in TEC values due to ionospheric storms is clearly visible when calculating vectors from GPS data in Polar Regions; it leads to erroneous determination of vector components (Cisak *et al.*, 2002c; Cisak *et al.*, 2003a). The GPS signal passing through the area of electron concentration changes demonstrates phase fluctuations that can result in loss of lock to satellites what further affects continuity in phase recording.



Fig. 3.1.1. The number of satellites with a loss of lock on L2 against the number of satellites observed

Fig. 3.1.1 (Stewart and Langley, 1999) presents the comparison of the number of satellites for which a loss of lock on L2 occurred with the number of satellites visible in Fairbanks (Alaska) during high activity of ionosphere in 27 August 1998 (upper graph) and for quiet ionosphere in 13 December 1998 (lower graph).

The influence of the electron concentration changes, resulting as the refraction of signal path and its differential lengthening with respect to different frequencies (Fig. 3.1.2) causes the second order refraction errors. Thus, the use of L3 combination does not completely remove the ionospheric effect from GPS solutions. For modelling and estimation of those effects the model errors of one

layer model can be used (Zanimonskaya and Prokopov, 2001).



Fig. 3.1.2. Refraction of the signal path during the ionospheric trough. The dot-lines correspond to lower frequency signal (L2) and continuous lines - higher frequency (L1). The contour lines correspond to the electron density in units 104 el/m3

Incorrectness of the ionosphere modelling using single layer approximation results in non-linearity in both TEC and pseudo-range determination (Brunner and Gu, 1991; Zanimonskaya and Prokopov, 2001). That non-linearity affects also other parameters, e.g. TZD (Krynski *et al.*, 2002b) and vector components.

Similarly to optical systems the effect of non-homogeneity of the ionosphere is proportional to the measure of nonhomogeneity itself.



Fig. 3.1.3. 3D distribution of electron density during the ionospheric storm in 13 September 1999

Fig. 3.1.4 shows the errors of the pseudo-range estimation from L3 combination, during the transition of the signal through the inhomogeneous structures of ionosphere of different size. In the compartments of inhomogeneous ionosphere of the shape of lens the largest divergence of electron contents from not violated ionosphere was considered equal to $5 \cdot 105 \cdot m$ -3. The dimension of inhomogeneous structures of the ionosphere in the cases shown in Fig. 3.1.2 and Fig. 3.1.3 is about 1000 km and electron density change is $2 \cdot 105 \text{ el/m3}$. Taking into account data form Fig. 3.1.4, those ionospheric disturbances affect pseudo-range by about 3 cm. It results in systematic errors in GPS solutions, mainly through the erroneous ambiguity determination.



Fig. 3.1.4. Dependence of the second order errors in pseudo-ranges on the dimension of inhomogeneous elements of ionosphere with fixed maximum of electron density changes

3.2 Dependence of variations in vector components from the electron concentration in ionosphere for the Antarctic GPS stations.

Seasonal changes of atmospheric conditions frequently disturb the continuity in tracking GPS satellites (during all seasons). Those changes can cause periodic errors in GPS solutions and suggest the periodic movements of the Earth's crust, what naturally is an artefact. Besides an increasing number of permanent Antarctic stations, for several years the periodic GPS Epoch Crustal Movement Campaigns (Detrich, and Rülke, 2002) have been conducted. More than 50 stations take part in those campaigns. They are organized during the Antarctic summer only. It is questionable whether the results of oneseason campaigns reflect the real changes in the stations co-ordinates and indicate the actual crustal movements. The first results of investigation of the influence of ionosphere on GPS solutions, obtained in the framework of this project were presented at the Antarctic Geodesy Symposium AGS'01 in St. Petersburg in July 2001 (Krankowski et al., 2001a). Data form the second part of February 1999 acquired at several stations of Northern Hemisphere and several Antarctic stations were used in the analysis (Table 3.2.1.).

Table 3.2.1. Vectors and their lengths examined in the analysis

Baseline	Distance [km]	Baseline	Distance [km]
Onsala-Metsahovi	784	Onsala - Ny-Alesund	2387
Onsala-Kiruna	1250	Onsala – Thule	3622
Onsala-Tromso	1406	O'Higgins - Arctowski	132
Onsala-Hoefn	1640	Davis - Mawson	636
Onsala-Reykjavik	1956	Davis - Casey	1397

Table 3.2.1. Vectors and their lengths examined in the analysis

All vectors were determined using the Bernese v.4.2. software with use of QIF strategy (Quasi Ionosphere Free) from 24h, 12h and 6h sessions. Dispersion in vector components (from 5 solutions) reaches the level of 20 cm when sub-daily sessions were processed, while for 24h sessions the dispersion do not exceed 7 cm. The maximum differences were obtained for observations collected from 12:00 – 18:00 UT, when TEC shows the large dynamics of changes. Similar large differences occurred for long vectors (over 650 km) as well as for short ones, e.g. Arctowski – O'Higgins (132 km). For the stations in

Northern Hemisphere (vector Onsala – Metsahovi) the differences were significantly smaller. This experiments and results obtained were encouraging to look for the confirmations of the results with use of the larger statistic material and with using new research methods.

GPS data from several permanent IGS Antarctic stations (Fig.3.2.1) were analysed, separately those from summer and from winter seasons. The Bernese v.4.2 software with QIF ambiguity resolution strategy was used to process the data in daily sessions with 23h overlap. (Cisak *et al.*, 2003).



Fig. 3.2.1. The map of Antarctic permanent GPS stations and analysed vectors

The Ionosphere Working Group of the International GPS Service publishes the global maps and arrays of TEC values, given in function of latitude and longitude with 2h temporal resolution. Annual variations of TEC values for 2001 obtained from IONEX data by calculating daily averages over Antarctic Davis (DAV1) and European Borowa Gora (BOGO) stations as well as the Ap index representing in linear scale a measure of geomagnetic activity are presented in Fig. 3.2.2.



Fig. 3.2.2. Annual variations of diurnal mean TEC over DAV1 and BOGO stations obtained from IONEX data and the Ap index

Seasonal variations of the ionosphere are clearly visible in the graph; it is especially distinct over the Antarctic station Davis. Data of particular interest correspond to time intervals that have been marked on the graph (Fig. 3.2.2). The first data set corresponds to the vicinity of 64DOY2001 when the occurrence of ionospheric storm was detected in the analysis of time series of GPS solutions of vectors between EPN stations (Zanimonskiy et al., 2002). The third data set covers the period of extremely active ionosphere that took place in October and November 2001. The impact of the atmosphere on GPS solutions of vectors was carefully analysed for that period (Cisak, et al., 2002). The lowest electron concentration and the lowest geomagnetic activity in 2001 occurred in July. Thus the July 2001 data (second data set marked in Fig.3.2.2) was included to the analysis. Averaged solutions for lengths and vertical components of vectors between selected Antarctic permanent GPS stations for the chosen data sets are given in Table 3.2.2. Table 3.2.2.

Vector	Vector length [m]				
	March (9 days)	July (30 days)	Oct. (30 days)	Nov. (30 days)	
MAWI-DAVI	636437,6895 ±0,0005	636437,6893 ±0,0002	636437,6885 ±0,0003	636437,6873 ±0,0003	
DAVI-CASI	1397636.0179 ±0,0007	1.397636,0193 ±0.0003	1397636,0141 ±0,0005	1397636,0134 ±0,0005	
MAWI-CASI	2028197,5492 ±0,0017	2028197,5484 ±0,0004	2028197,\$446 ±0,0007	2028197,5424 ±0,0008	
	Vertical component (m)				
MAW1-DAV1	44,4544 ±0,0011	44,4482 ±0,0006	44,4522 ±0,0006	44,4521 ±0,0006	
DAVI-CASI	22,5020 ±0,0018	22,4934 ±0.0010	22,5054 ±0,0009	22,5065 ±0,0009	
MAW1-CAS1	22,5109 ±0,0026	22,4911 ±0,0013	22,5139 ±0,0012	22,50% ±0,0010	

Differences between the average lengths and vertical components of the vectors calculated during the period of the unstable and quiet ionosphere (July 2001) are given in Table 3.2.3. Variations of the solutions shown in Table 3.2.2. for different seasons are quite substantial. In most cases they exceed their accuracy estimated by using a common error propagation procedure. The differences obtained (Table 3.2.3.) were interpreted by means of statistical analysis of correlations of GPS solutions for vector components, and by means of parameters from the processing with the Bernese software, i.e. _2, number of ambiguities resolved, number of single differences used in the solution, internal accuracy parameters, etc. with ionospheric data from IGS IONO-WG (IONEX) and also with the data received directly from IONO-WG, kindly provided by Dr. Manuel Hernandez-Pajares. Table 3.2.3.

		Table 3.2.3.				
Vector	Difference in vector length [mm]					
	March (9 days)	July (30 days)	Oct. (30 days)	Nov. (30 days)		
MAW1-DAV1	0.2+0.5 1,1±0,5	0,0 ±0,2 0,0 ±0,2	-0,8±0,3 0,4±0,3	-1,9±0,3 -0,7±0,3		
DAVI-CASI	1.5±0,7 2,5±0,7	0,0 ±0.3 0,0 ±0.3	-5,2±0,5 -0,3±0,5	-5.9±0.5		
MAW1-CAS1	0,8±1,5 3,7±1,6	0,0 ±0,4 0,0 ±0,4	-3,8±0,7 -0,1±0,7	-6,0±0,8 -2,3±0,8		
	Difference in vertical component [mm]					
MAWI-DAVI	6,1±1,1	0,0±0,5	4,1±0,6	3,8±0,6		
DAVI-CASI	8.6±1.8	0,0±0.9	11.8±0,9	13,2±0,8		
MAWI-CASI	19.8±2.3	0,0±1,2	22,8±1,2	18,5±0,9		

The problem concerns the errors, resulting from nonlinearity of calculating algorithms and from second order effects of signal propagation in the ionosphere. The nonlinearity of the algorithms used for the data processing of satellite observations was widely discussed in the literature (e.g. Tiberius, 1998). The weak non-linearity causes the known effect of detection, i.e. the conversion of variations of process parameters or random input signals into biases in output results. For determination of metrological properties of measurement system the qualitative and quantitative assessment of conversion of random error into systematic error is needed. The growth of random errors of GPS observations during the ionosphere's storm (Baran *et al.*, 2002) can be used as a signal for testing the hypothesis of the detection.

The second order effects of the ionosphere can also be considered as the source of non-linearity in the process of solving ambiguities. The existence of other sources of nonlinearity cannot be excluded but the complex technology, instrumentation, software, mathematical and physical models of different sources of disturbances of GPS signal make the description of the phenomena quite difficult.

Polar regions, in particular the Antarctic - a continent being the extensive international research laboratory, are suitable test areas for investigating ionosphere's effects on GPS solutions. During the Antarctic winter the diurnal changes of electron concentration are insignificant. It is due to a low and almost not varying altitude of the Sun over the region. The changes in electron concentration over Antarctic are caused mainly by geomagnetic activity. The Antarctic winter in 2001 was exceptionally quiet in the sense of geomagnetic activity as compared with other years. The results of GPS positioning from that winter can thus be considered as reference in studying the ionosphere's impact on GPS solutions obtained in other years as well as in different seasons. Overlapping sessions of 24-hour were processed to smooth random errors in GPS solutions and to eliminate short-term biases. The TEC data from IONEX files was respectively averaged over 24h with 1h temporal resolution (Fig. 3.2.2).



Fig. 3.2.3. Variations of vector length and uncertainty of ambiguity estimation versus TEC (a), and time series of uncertainties of ambiguity estimation for the periods investigated (b)

Fig. 3.2.3a shows the relationship between DAV1-CAS1 vector length (dD) and diurnal average of TEC (upper graph) as well as the relationship between the uncertainty of ambiguity estimation in the vector calculation and diurnal average of TEC (lower graph). Diurnal average of

TEC presents stronger correlation with the uncertainty of ambiguity resolution (correlation coefficient of 0.64) than with vector length (correlation coefficient of 0.51).

Due to a regional scale of dynamics of the ionosphere in Antarctica, the ionospheric disturbances affect similarly GPS data acquired at the investigated stations. Thus the GPS vector solutions obtained with the Bernese software are practically free of TEC differences between the stations. It should also be noted that the time series of uncertainties of ambiguity resolution do not substantially differ for different vectors and do not depend on their length (Fig.3.2.3b). The same conclusions are drawn from the analysis of GPS solutions for EPN vectors.

The obtained results indicate the dependence of ambiguity resolution on the state of ionosphere. Crucial role in both performed quantitative and qualitative analysis played the use of time series of GPS solutions based on overlapped sessions (Krynski and Zanimonskiy, 2002). Correlations shown in Fig. 3.2.3 indicate a possibility of modelling the ionospheric effects on GPS solutions. For example, the solutions for vector length could get corrected by using the regression model of dD = k(TECdmv) based on TEC data. For DAV1-CAS1 vector of 1398 km, the correction equals to +3 mm/10TECU. Generally, the unstable ionosphere causes shortening of vector length obtained from GPS solution. The vector lengths corrected with the model are shown italic in Table 3.2.3. Introducing the corrections resulted in the decrease of seasonal dispersion in both October and November data and made them more similar to the July data when the ionosphere was quiet. Although in most cases the applied corrections improve the obtained results, there are exemptions when the procedure does not seem suitable (Table 3.2.3). They might happen due to relatively small amount of data processed as well as larger and more irregular disturbances of the ionosphere.

4. Troposphere

4.1 Dependence of variations in vector components from the Total Zenith Delay for the Antarctic GPS stations.

Time series of vector components obtained with the

Monthly averaged temperature, pressure and dH (MAW1-DAV1)



Fig.4.1.1. Annual variations of monthly averages of temperature, atmospheric pressure as well as vertical component of the MAWI-DAV1 vector

SCAR WORKING GROUP ON GEODESY AND GEOGRAPHIC INFORMATION

Bernese v.4.2 software for daily sessions of GPS observations from a number of permanent stations acquired in July, October and November 2001, were used to investigate the impact of varying meteorological conditions on GPS solutions. Analysed data correspond to the periods substantially distinguished in terms of dynamics of the atmosphere. Variations in monthly average of temperature, atmospheric pressure as well as vertical component of the MAWI-DAVI vector are given in Fig. 4.1.1.

Variations in vertical components of the vectors defined by pairs of investigated GPS permanent stations in Antarctica are correlated with seasonal variations of atmospheric pressure. Similar conclusion was already drawn from the analysis of GPS solutions and meteorological data in mid-latitudes (Haefele and Kaniuth., 2001).

Tropospheric impact on GPS measurements is described in terms of tropospheric delay. To increase reliability of results obtained, tropospheric delay data from two independent sources was considered in the analysis. First, the Tropospheric Zenith Delay (TZD), available on IGS web pages, in the form of time series with 1h temporal resolution was considered. Second, the TZD data derived from radio sounding over the majority of permanent GPS stations in Antarctica, also in the form of time series but with 12h temporal resolution. The results obtained with use of both data sources were close to each other at the acceptable level.

Time series of atmospheric pressure and TZD at the Antarctic GPS stations (Fig. 4.1.2) as well as correlation of TZD and atmospheric pressure variations with vertical components of respective vectors (Fig. 4.1.3) were analysed.

TZD from IGS solutions

296

300

284

288 29 DOY2001

229

228

775

224

223

222

221

304



Fig. 4.1.2. Variations of atmospheric pressure and TZD for Mawson (a) and Davis (b stations



Fig. 4.1.3. Variations of differential TZD versus variations of atmospheric pressure and GPS-derived vertical component of DAV1 - CAS1 vector

No significant effect of variations of troposphere on GPS solutions observed (Fig. 4.1.3) proves sufficient modelling of troposphere in the Bernese v.4.2 software when computing vectors of a few hundred kilometres length and longer; GPS solutions obtained are practically free

of the tropospheric effect.

In case of commercial programmes used to process GPS data, the experiments conducted with EPN data indicate correlation of GPS-derived vector components with TZD. Correlation coefficients derived could efficiently be used to correct GPS solutions obtained with commercial software. It applies not only to GPS solutions for mid-latitude stations but also for those in Polar Regions.

5. Conclusions

The non-modelled delays of GPS signal when passing the atmosphere affect GPS solutions for station positions and vector components and result in variations in time series of such solutions. To improve GPS solutions with no better models of atmosphere, corrections to the computed vector components, calculated using correlation analysis, could be applied. Data from Antarctic GPS stations are especially suitable for modelling such correlation functions and determining their parameters due to a distinct seasonal variability of ionosphere in Polar Regions.

The results discussed in the paper focus on the analysis of the impact of ionospheric disturbances on variations of vector lengths obtained at high latitudes from GPS data. Variations of GPS solutions for lengths of vectors are commonly explained in terms of non-modelled variations of the ionosphere. Besides their direct effect on GPS solutions, they affect them indirectly by violating the mechanism of integer ambiguity resolution. Correlation analysis conducted using data sets from chosen Antarctic stations shows a possibility of using simple empirical models for partial eliminating the non-modelled in GPS processing software effects of ionosphere. Modelling ionospheric effects on the results of GPS data processing requires further research with use of larger data samples. GPS solutions corrected with such empirical models seem more suitable for geodynamics research.

The results of the research on the tropospheric impact on GPS solutions show seasonal dependence of height differences between Antarctic stations from changes of atmospheric pressure. Modelling the satellite signal passing through the troposphere in the Bernese v. 4.2 software seams satisfactory. No correlation between vector components obtained using the Bernese software and Total Zenith Delay was found. The analysis of time series of GPS solutions based on EPN data, obtained using commercial software shows the possibility of using empirical models to partially eliminate from GPS solutions the non-modelled in processing GPS data effects of troposphere – similarly to the ionospheric one.

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An Analysis of Contribution of the Troposphere and Lower Stratosphere Layers to Forming of the Tropospheric Delay Wet Component

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Abstract

An estimation was made of the most influential layers of the lower atmosphere into quantity formation of the wet component of zenith tropospheric delay in summer in the Antarctic regions as well as in the West and South-West regions of Ukraine.

The Central Antarctica Region is distinguished especially inasmuch as an extratropospheric part of the wet component and is there dominating in the total value of wet component.

An analysis of the most widely used Saastamoinen and

Hopfield analytical models assigned for the determination of the wet component was realized.

The lower (neutral) atmosphere is one of the main error sources which reduces essentially an accuracy of GPS measurements. The error caused by the neutral atmosphere effect (tropospheric delay) has two components – dry and wet ones.

The total tropospheric delay is expressed as:

$$d_{trop} = d_d^2 \cdot m_d + d_w^2 \cdot m_w,$$

where d_d^{c} and d_w^{c} are zenith dry and wet components

respectively; m_d, m_w are mapping functions of the components of zenith tropospheric delay at zenith angles $Z > 0^\circ$.

On the whole it may be defined either by vertical profiles of the meteorological parameters measured at the moment of GPS measurements or by the way of modeling of such profiles. The first way is pretty unwieldy, expensive and inefficient.

The second one presents as a rule the generally averaged vertical profiles in the form of analytical models and resolves to determine the first component of tropospheric delay with relatively high accuracy. A determination of the second component is a problem task as the wet component forecasting is very complicated because of the difficulty of the establishment of water vapour quantity in the lower atmosphere. Therefore the error of the determination of the wet component amounts to several tens of millimetres even in the zenith zone.

The cause of unsatisfactory precision of the determination of the wet component of zenith tropospheric delay in polar regions by means of existing analytical models consists in the following. In general it is accepted that the value of water vapour pressure drops to zero at the boundary of troposphere and tropopause and therefore an air humidity profile for the determination of water vapour pressure is recommended to take into consideration to the upper boundary of troposphere. Practically all analytical models for the determination of the wet component are constructed on that ground. This approach satisfies to some extent the reality for low and middle latitudes. At high latitudes and first of all in Antarctic Region both the stratification itself and the structure of the lower atmosphere differ essentially.

Though the value of the wet component of zenith tropospheric delay is here significantly less than in the middle latitudes, the essential part of it, namely about 20%, concentrates in the lower stratosphere of the Antarctic coast zone. It should be noted that the differences of air temperatures at the altitude of 17 km above sea level average -16° in summer period between Odesa and Mirnyj stations and -15° between Odesa and Heise Island (the Central Arctic) stations. Thus as a result of the establishment of the "warm" lower stratosphere in polar regions during the summer period, a considerable proportion of water vapour mass part accumulates here and that is what forms a certain increase of water vapour partial pressure and the value of zenith tropospheric delay wet component accordingly.

Table I

Average quantitative characteristics (%) of the wet component of zenith tropospheric delay and of the water vapour pressure in the different atmospheric layers at the stations

Wet	Wet component d_w^Z			Vapour pressure e			
0.04- 2 km	2 km- Н _{ткор}	Н _{тка} - Но	H _{TROP}	Hu	0.04- 2 km	2 km- Н _{ткор}	Н _{лю} -Н
			Mi	nyj			
48.4	30.2	21.4	8.12	25.21	52.8	29.1	18.1
			Ode	ssa			
60.4	38.9	0.8	10.92	24.00	63.7	35.8	0.5

The averaged percentage of the wet component d_w and the water vapour partial pressure e in three high atmospheric layers of Mirnyj and Odesa stations for summer period are shown in table 1.

The values H_{TROP} characterize the upper boundary of troposphere and the values H $_{U^-}$ the upper boundary of relative humidity sounding.

As it is obvious, the value of the wet component of zenith tropospheric delay which is formed by extratropospheric layers of atmosphere exceeds 20% at Mirnyj station and amounts to 0.8% only at Odessa station. According to table 1 a close correlation between the distribution of the wet component of zenith tropospheric delay and water vapour partial pressure is observed.

As long as the aim of our paper was to make an estimation of the most influential layers of the lower atmosphere into quantity formation of the wet component of zenith tropospheric delay in summer period we chose additionally 14 vertical profiles obtained from aerological sounding for each station:

Mirnyj – Antarctic Coast Zone;

Vostok - the Central Antarctica;

Lviv - the West region of Ukraine;

Odessa - the South-West region of Ukraine.

At the same time the atmospheric models were made up for the vertical profiles with the measurements of the relative humidity not less than up to the altitude of 24 km above sea level (the mean isobaric surface corresponds to 30 hPa).

A special attention was devoted to the Central Antarctica where the extremely low temperatures cause a very small content of water vapour in the air. Thus, the average monthly surface quantity of water vapour pressure at Vostok station amounts to only 0.25 hPa for January and declines to 0.03 hPa at the upper boundary of the troposphere.

Table 2 Averaged meteorological parameters and parts of the wet component of zenith tropospheric delay d_x (mm)

H _o	Ð		11	d.,	d_	d_	d_	d_	d_	ŏd.	ðd_
km	'°	' °	0.0	850	700	500	H _{TROP}	30	total.	(SA)	(HO)
					(Ddess	a				
0.04	1010. 4	18.8	77	84.6	51.6	30.8	8.4	1.4	176.7	10.1	8.8
						Lviv	, .				
0.33	976	17.8	77	68.8	54.6	36.5	12.3	2.4	174.7	22.1	18.7
					1	Mirny	(i				
0.04	983.8	-4.2	73	16.1	11.7	6.3	2.4	7.9	46.4	10.2	-0.7
	Vostok										
3.49	633.0	- 34.5	70	-	-	3.1	2.2	14.1	19.4	16.1	13.6

Notice: P_0 , t_0 , U_0 - atmospheric pressure (hPa), air temperature (°_) and relative humidity (%) at the station level H_0 ;

 d_w - part of the wet component of zenith tropospheric delay in the atmospheric layers "station level = 850 hPa", "850 - 700 hPa", "700 - 500 hPa", "500 hPa upper boundary of the troposphere – 30 h

upper boundary of the troposphere ", " upper boundary of the troposphere – 30 hPa "; $d_{w(seed)}$ - total value of the wet component of zenith tropospheric delay;

 δd_{φ} (SA) and δd_{φ} (HO) – differences between the total value of the wet component of zenith tropospheric delay obtained by means of the aerological profile and the total value of the wet component calculated after *Saastamoinen* _ *Hopfield* models.

In addition, we give the results (table 2) which characterize the percentage part of the wet component of zenith tropospheric delay in the above mentioned atmospheric layers. Table 3.

Table 3 Averaged parts of the wet component of zenith tropospheric delay in the atmospheric layers

Station	Н ₀ - 850 hPa	850- 700 hPa	700- 500 hPa	500 hPa - H _{srop}	
Odessa	47.9	29.3	17.4	4.6	0.9
Lviv	39.4	31.2	21.0	7.0	1.4
Mirnyj	34.8	25,2	17.9	5.2	16.9
Vostok	-	-	16.0	11.3	72.7

As it is obvious from the data of tables 1-3, the two lower layers of troposphere "station level -850 hPa" and "850 -700 hPa" import about 70% into the total quantity of the wet component in the middle latitudes. The next layer "700 -500 hPa" adds another almost 20%. Hence, the three lower layers of the troposphere import about 95% of the wet component into the total quantity of it at Odessa station and over of 90% - at Lviv one.

The contribution of these layers at the Antarctic coast zone decreases to 80%, and in the Central Antarctica it amounts to only 16%.

On the basis of our investigations the following should be noted for the summer period:

 in the middle latitudes a predominant mass of the atmospheric water vapour is located in the lower half of the troposphere. The part of the wet component of zenith tropospheric delay amounts to 5.5% and 8.4% in the layers of the atmosphere between 500 and 30 hPa at the Odessa and Lviv stations accordingly;

- at the high latitudes and especially in Antarctica the water vapour is pushed up into higher layers of the atmosphere. At the same time this process increases with displacement from the coast zone to the central part of the continent. So the part of the wet component of zenith tropospheric delay makes up in the atmospheric layers from 500 to 30 hPa 22.1% at Mirnyj station and 84% (!) at Vostok one;
- the existing analytical models, as it is shown in table 2, do not provide a high accuracy of determination of the wet component of zenith tropospheric delay.

Conclusions

The extratropospheric contribution to the formation of the total value of the wet component of zenith tropospheric delay is very essential in polar regions and first of all in Antarctica in contrast to the middle latitudes. For more precise account of the wet component of tropospheric delay influence on the results of GPS measurements in summer period in polar regions it is necessary to include to the total humidity the extratropospheric part of it up to the about 25 km height. This value may be modelled on the basis of detailed analysis of the lower atmosphere stratification by means of aerological data of the polar stations at which the permanent GPS observations or the long GPS campaigns are already being carried out.

The Second Order Refraction Effects for GPS Signals Propagation in Ionosphere

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When measuring on the Earth – Space satellite direction the radio signal experience the additional delay caused by the difference between the speed of light in vacuum and speed of signal propagation in medium and by refractive lengthening of the signal path while crossing the ionosphere and troposphere. To reduce the tropospheric effect the correction models are usually used. To reduce ionospheric effect dual-frequency methods are used besides the modeling. These methods are instrumental methods and they are based on the fact that ionosphere is a dispersive medium.

One of the weakness of existing dual-frequency methods is the fact that these methods use measuring equation obtained on the assumption that signals with different frequencies propagate along the same rectified trajectory. This means that the refractive effects of spatial separating of the ray paths with different carrier frequencies and their refractive lengthening due to bending are not take into account. More over while deriving the equations the square root in the formula for refractive index of ionosphere was replaced by linear function of electron concentration (i.e. the higher order terms in the inverse power of frequency series expansion of the refractive index aren't take into account) and the influence of the Earth's magnetic field can be neglected.

Errors caused by effects mentioned above (which are usually called the second order effects) have been studied in [1, 2, 3] where it was shown that the total residual error at high values of electron concentration on big zenith angles run up to several cm

In general case the following mathematical model can be used for error calculation [3]:

$$\sigma_{sep} = \frac{f_2^2}{f_1^2 - f_2^2} \left[\Delta D_2 - \Delta D_1 + \Delta S_2 - \frac{f_1^2}{f_2^2} \Delta S_1 \right]$$

$$\sigma_{length} = \Delta D_1$$

where, σ_{sep} , σ_{length} - refractive errors caused by the separating effect of the ray paths and the lengthening accordingly (these formulas allow for all the second order effects mentioned above). $\Delta D = Cds - L$

$$\Delta S_i = \begin{cases} \int_{S_i}^{S_i} (n-1)ds & \text{-for phase measurements} \\ \int_{S_i}^{S_i} (\frac{1}{n}-1)ds & \text{-for code measurements} \end{cases}$$

- *n* is the refractive index of ionosphere;
- ΔD_i is refraction lengthening of a signal path with the frequency;
- ΔS_i is a delay of a signal with the frequency ;
- S_i is a signal path with the frequency;
- s is a ray coordinate;
- *L* is a distance from a receiver to a satellite along the straight line.

Errors σ_{sep} and σ_{tength} were calculated for various frequencies f and zenith angles z_0 (code measurements). Though these errors appear in the measurement equation with the opposite signs, the total error (the residual refraction error of the two-frequency method) at high values of electron concentration on big zenith angles can reach several sm. One can see it on the Fig. 1 where the data obtained with the use of the biexponential model of electron concentration profile are shown.



Fig. 1. The refraction errors of the two-frequency method for Nm=5.106 cm-3, =1227.46 MHz, =1575.60 MHz (a solid line is for total effect, a dashed line is for lengthening effect, a dash-and-dot line is for space separation effect).

The left plot on Fig. 1 corresponds to the case when geomagnetic field is not taken into account. The right plot corresponds to the case with the following parameters of geomagnetic field: gyrofrequency is equal to 1.4 MHz and $\cos\theta$ =0.5, , where θ is the average angle between the satellite-receiver line and lines of the geomagnetic field.

When analyzed errors are essential special steps to calculate and exclude these errors from measurement results are necessary. Let's consider the theoretical base of the possible methods of such calculations.

Geometrical distance between a satellite and a receiver can be written as [1]:

$$L = S_1 + \Omega_1 \int_D N_e ds - k_1 \tag{1}$$

$$L = S_i + \Omega_i \int_{P_i} N_e ds - I_i - k_1$$
(1a)

where (1) is written for the frequency f_1 , and (1a) is for the f_i ;

$$\Omega_{i} = \frac{C_{x}}{2f_{i}^{2}} (1 \operatorname{m} \frac{C_{y}}{f_{i}} \overline{H_{0} \cos \theta} + \frac{C_{x}}{4f_{i}^{2}} N_{m} \eta),$$

$$C_{x} = \frac{e^{2}}{4\pi^{2} \varepsilon_{0} m}, C_{y} = \frac{\mu_{0} e}{2\pi m},$$

٠

and the common symbols are used (N_e is the electron concentration; e, m are electron charge and electron mass; ε_0, μ_0 are permittivity and permeability in vacuum; H_0 is the amplitude of the geomagnetic field, $\overline{H_0} \cos\theta$ is the average value of the geomagnetic field effect; η is the shape parameter: ,

$$\eta = \frac{\int_{P_1}^{Ne^2 ds}}{N_m \int_{P_1}^{Ne ds}} , N_m \text{ is the maximum value of } Ne, \\ k_1 \text{ is identical with } \Delta D_1 \text{).}$$

According to the estimations [1] the stated above formulas allow to take into account the second order effects in wide range of ionospheric conditions with an error not exceeding 1 mm.

As one can see there is an additional item I in the equation (1a) which is take into consideration the spatial separating effect of the ray paths P_1 and P_r . Basically, the equations (1), (1a) can be considered for any given frequencies f_1, f_2 , K, f_n . Then, according to (1a), the unknowns are,

$$L + k_1, \overline{H_0 \cos \theta}, N_m \eta, \int_{P_1}^{Neds} \text{ and } I_1 K I_m$$

Hence, in general case, the system of n + 4 equations is necessary to determine the geometric length of the trajectory $L+k_1$ between the satellite and the receiver (without the determination of the refractive lengthening k_1 , which needs a special examination). At the same time, according to the definition of *I*, the number of equations in the system is equal to n + 1. To bring the number of the equations in correspondence with the number of the unknowns the 2-nd order expansion of *I* in terms of

$$\frac{1}{f^2} \quad \text{at } f_2 \text{ could be used:} \\ I_i = I(f_i) = I(f_2) + \left(\frac{1}{f_i^2} - \frac{1}{f_2^2}\right) \frac{\partial I}{\partial(\frac{1}{f^2})} \Big|_{f=f_2}$$
(2)

Under such approach the minimum number of the unknowns is equal to six and using (2) we've accordingly obtained the system of six equations:

$$L = S_1 + \Omega(f_1, H_0 \cos\theta, N_m \eta) \int_{P_1} Neds - k_1$$
(3)

$$L = S_2 + \Omega(f_2, \overline{H_0 \cos\theta}, N_m \eta) \int_{P_1}^{Neds} - I(f_2) - k_1$$

$$L = S_i + \Omega(f_i, \overline{H_0 \cos\theta}, N_m \eta) \int_{P_1}^{Neds} - [I(f_2)] + (\frac{1}{f_i^2} - \frac{1}{f_2^2}) \frac{\partial I}{\partial (\frac{1}{f^2})} \Big|_{f=f_2} - k_1, i = 3 \text{K} 6$$

Taking into account that Ω is a linear function of $H_0 \cos\theta$ and $N_m \eta$ with the coefficients, depending on the frequency, the system can be written as:

$$L = S_{1} + a(f_{1}) \int_{P_{1}}^{Neds} + b(f_{1}) \overline{H_{0} \cos\theta} \int_{P_{1}}^{Neds} + c(f_{1}) N_{m} \eta \int_{P_{1}}^{Neds} - k_{1}$$

$$L = S_{2} + a(f_{2}) \int_{P_{1}}^{Neds} + b(f_{2}) \overline{H_{0} \cos\theta} \int_{P_{1}}^{Neds} + c(f_{2}) N_{m} \eta \int_{P_{1}}^{Neds} - I(f_{2}) - k_{1}$$

$$L = S_{i} + a(f_{i}) \int_{P_{1}}^{Neds} + b(f_{i}) \overline{H_{0} \cos\theta} \int_{P_{1}}^{Neds} + c(f_{i}) N_{m} \eta \int_{P_{1}}^{Neds} - [I(f_{2}) + (\frac{1}{f_{i}^{2}} - \frac{1}{f_{2}^{2}}) \frac{\partial I}{\partial(\frac{1}{f^{2}})}]$$

$$f = f_{2}] - k_{1} \quad i = 3 K 6$$
where
$$a(f) = \frac{C_{x}}{2f^{2}}, b(f) = m \frac{C_{x}C_{y}}{2f^{3}}, c(f) = \frac{C_{x}^{2}}{8f^{4}}$$
(4)

Then, the system is linear in relation to the unknowns,

$$L + k_1, \int_{P_1}^{Neds} H_0 \cos\theta \cdot \int_{P_1}^{Neds} H_0 \cdot \int_{P_1}^{Neds} H$$

and can be easily solved analytically. The obtained solution allows for the all second order effects by instrumental means, but it needs the measurements of pseudorange L_i on six different carrier frequencies.

The method considered above is instrumental. All the input information is gained from the measurements.

6-frequency systems aren't in plan for the near future, but developed in USA and Europa systems (GPS III and Galileo) are providing access for 3 carrier frequencies. Thus we consider a combined method of allowing for ionosphere impact. For that we leave 3 equations and 3 most important for our problem unknowns in system (3). The rest of the unknowns we determine on the base of GPS measurements instead of modelling (combined method).

While choosing the unknowns we take into account that there is a formula for I in [4]. Besides, the IAGA model is recommended for the calculation of H_0 . Thus, we have three unknowns

$$L, \int_{P_{i}} Neds \text{ and } N_{m} \eta$$

and the similar to (3) system:
$$L = S_{1} + \Omega_{1} \int_{P_{i}} Neds - k_{1}$$

$$L = S_{2} + \Omega_{2} \int_{P_{i}} Neds - I(f_{2}) - k_{1}$$

$$L = S_{3} + \Omega_{3} \int_{P_{i}} Neds - I(f_{3}) - k_{1}$$

where

$$\Omega_i = \Omega(f_i, \overline{H_0 \cos \theta}, N_m \eta)$$

Having excluded $\int_{P_1}^{Neds}$, we reduce the system (5) to the system of two equations:

$$S = \frac{1}{\Omega_2 - \Omega_1} (\Omega_2 S_1 - \Omega_1 S_2) - [k_1 - k_2]$$

$$S = \frac{1}{\Omega_3 - \Omega_1} (\Omega_3 S_1 - \Omega_1 S_3) - [k_1 - k_3]$$
where
$$k_i = I(f_i) \frac{\Omega_1}{\Omega_i - \Omega_1}, i = 2,3$$
(6)

and $[k_1 - k_i]$ is calculated by the corresponding formula from [4].

Using (4),
$$\Omega_{i} - \Omega_{1}$$
 and $\Omega_{i}S_{1} - \Omega_{1}S_{i}$ will take the form:
 $\Omega_{i} - \Omega_{1} = a(f_{i}) + b(f_{i})H_{0}\cos\theta + c(f_{i})N_{m}\eta - a(f_{1}) - b(f_{1})H_{0}\cos\theta - c(f_{1})N_{m}\eta = a(f_{i}) - a(f_{1})) + (b(f_{i}) - b(f_{1}))H_{0}\cos\theta + (7)$
 $(c(f_{i}) - c(f_{1}))N_{m}\eta = a_{i1} + b_{i1}H_{0}\cos\theta + c_{i1}N_{m}\eta$
 $\Omega_{i}L_{1} - \Omega_{1}L_{i} = (a(f_{i})S_{1} - a(f_{1})S_{i}) + (b(f_{i})S_{1} - b(f_{1})S_{i})H_{0}\cos\theta + (c(f_{i})S_{1} - c(f_{1})S_{i})N_{m}\eta = a_{i1} + B_{i1}H_{0}\cos\theta + C_{i1}N_{m}\eta$

According to (7) we get the solution from system (6)

$$L + [k_1 - k_2] = \frac{A_{21} + B_{21}H_0\cos\theta + C_{21}N_m\eta}{a_{21} + b_{21}\overline{H_0\cos\theta} + c_{21}N_m\eta} = \frac{A_{31} + B_{31}\overline{H_0\cos\theta} + C_{31}N_m\eta}{a_{31} + b_{31}\overline{H_0\cos\theta} + c_{31}N_m\eta}$$
(8)

there $N_m \eta$ is determined from the quadratic equation $(N_m \eta)^2 (G_m - G_m) = N_m \eta \eta$

$$(N_{m}\eta)^{2}(C_{21}c_{31} - C_{31}c_{21}) + N_{m}\eta(ab_{31}C_{21} + AB_{21}c_{31} - ab_{21}C_{31} - AB_{31}c_{21}) + ab_{31}AB_{21} - ab_{21}AB_{31} = 0$$

where (9)

 $AB_{i1} = A_{i1} + B_{i1}\overline{H_0}\cos\theta$, $ab_{i1} = a_{i1} + b_{i1}\overline{H_0}\cos\theta$ Formula (8) and equation (9) give a solution which allow for second order refractive ionospheric effects on the base of the 3 frequency pseudorange measurements and models of geomagnetic influence and spatial separation of the ray paths.

In some cases it may be useful to choose different set of unknowns. For example, L, $\int_{P_1} Neds$ and $\overline{H_0 \cos \theta}$

when the last unknown is difficult to model (during the huge magnetic storms or near the magnetic poles). Following the discourse described above one can obtain the similar to (8) and (9) equations.

When $f_3 \rightarrow f_2$ and the second order items are neglected we have the passage to the limit of the standard dualfrequency method. Equation (9) is turning into the identity

 $ab_{21}AB_{21} - ab_{21}AB_{21} \equiv 0$ and formula (8) is being reduce

and formula (8) is being reduced to the measurement equation of the currently used model [1].

For dual-frequency GNSS the allowing for the second order ionospheric effects by the instrumental or combined methods is impossible, since there is no resource to receive the additional information (there aren't additional carrier frequencies). In this case it is possible to take advantage of the model approach. The entry values for the method of ionospheric error modeling, developed by us, are TEC (on which the parameters of analytical model of the electron concentration profile are determined) and a zenith angle (on which the value of the correction is determined using the obtained model). It is necessary to mark, that this method will not eliminate the refractive effect completely, since the value of TEC is determined with some error. Besides, the allocation of electrons in ionosphere could a little differ from a model, but this factor is not so essential as TEC.

Conclusions

Three approaches to solving the problem of modeling and elimination of the second order ionospheric errors are considered. That are instrumental approach (when all the information is gained from the measurement), model approach (when the independently defined refractive error correction is put in the results of the measurements) and combined one. These methods assumed to be useful for increase of accuracy of GNSS, both the systems which is now in use and the perspective multi-frequency ones (Galileo, GPS-III).

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Storm-time Structure and Dynamics of the Ionosphere Obtained from GPS Observations

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Abstract.

The analyses of the structure of the ionosphere during the greatest storm in recent years, which took place on 31 March 2001 obtained by multi-stations technique using GPS observations of IGS and EPN network are presented. Storm-time changes of the ionosphere were analyzed via the TEC maps for American and European regions. The response of the ionosphere in the Antarctic area eliminates temporal TEC variations obtained over an individual station. High spatial resolution of TEC maps was realized using GPS observation from 80-100 European and American stations. The TEC maps were produced in latitudinal range of 40-75 with 15 min interval. Timedepended features of the ionospheric storm were identified using the differential TEC maps based on the deviation of TEC during the storm in comparison to a quiet period. The response of TEC to geomagnetic storm consists of effects of both enhancement and depletion (positive and negative disturbances). A short-duration positive effect on the first stage of the storm was observed over Europe on subauroral ionosphere probably due to the auroral particle precipitation. The enhancement of TEC exceeds 150% compared to the quiet time. The negative effect took place during daytime on the first day of storm and lasted till next night.

In the American sector the effect was more pronounced than over Europe. The essential changes of the ionosphere are observed on subauroral latitude, which we attribute to the occurrence of ionospheric trough and it developed during the storm. Maximal latitudinal gradients which occurred at the equatorial or polar walls of the trough depend on geophysical conditions. Over America the spatial distribution of TEC demonstrate the large scale structures, which probably can be associated with perturbations of the neutral winds. The strong storm effect took place over the Antarctic and Arctic regions also. During 31 March day time depression of TEC exceeded 200% daytime level of TEC in comparison to night TEC. The diurnal variations TEC over a high latitude station are essentially modified. In the auroral region in magnetic storm period the ionospheric different scale irregularities developed, which caused increasing intensity phase fluctuations of GPS signals. On the whole the results demonstrate complex storm patterns as a function of geophysical conditions, longitude, latitude and time.

Key words: Ionosphere, TEC, modeling of ionosphere

1 Introduction

Two severe geomagnetic storms took place on March 19

and March 31, 2001. The main phase of the first storm started about 11 UT on March 19. The Dst index reached its minimum value -160 nT at 13 UT on March 20 (Figure 1). Simultaneously K_p index amounted to 7 and $_Kp \approx 44$ (Figure 2). The second investigated storm started about 04 UT on March 31. The Dst index decreased sharply to -358 nT at 08:00 UT. The K_p index reached the value of 9 between 06:00 and 12:00 UT on March 31 (_Kp amounted of 61). The recovery phase took place after 09:00 UT on April 4, when Dst gradually returned to its regular level.



Days of March and April 2001 Fig. 1. Dst index



Fig.2. Variations of sum Kp during March 2001

2 Data source and estimation technique

The GPS data from IGS (International GPS Service) permanent network were used to obtain TEC changes on the global scale during both storms. A dense GPS network provided TEC measurements with high temporal and spatial resolution. The analyses of the storms were carried out over North America, Antarctica and Europe. To present the temporal and spatial variation of TEC during the storms, we created the instantaneous TEC maps. The data from over 80 European and 100 American GPS stations were used to create TEC maps. Precise dual frequency GPS phase measurements were used (Baran *et al.*, 1997).

While estimating TEC; the ionosphere was approximated as a single layer at a fixed height of 400 km above the Earth's surface. The simple geometric factor was used to convert slant TEC into vertical one. A sun-fixed reference frame was used (local time/ geomagnetic latitude). In order to produce TEC maps, the TEC measurements from all stations were fitted to a spherical harmonic expansion as functions of geographic latitude and longitude. The maximum degree/order of the spherical expansion was 16. The maps were derived with a 15-minute resolution.

3 Results

3.1 the storm on March 19, 2001

Over Europe, the storm started just after local noon on

March 19 (Figure 3). Storm-time effects occurred in TEC in the evening and during night, as the TEC increase at auroral and subauroral latitudes.



Fig. 3. Storm development over Europe

The analyses of TEC variations for the individual satellite passes show that during the driven phase of the storm, different scale irregularities developed at high latitudes. Patch-like structures with a strong TEC increase were observed. It is interesting, that similar structures but with decreased TEC were also observed (Baran *et al.*, 2002, Shagimuratov *et al.*, 2002).

During daytime on March 20, the negative effect occurred with a maximum at latitudes over 55°N. The weak negative effect took place also at latitudes under 40°N. The negative phase of the storm lasted through the next day (March 21) and the following night. The negative phase was mostly pronounced at latitudes over 50°-55°N.



-150100-75-50-25-10 0 10 25 50 75 100 150 Fig.4a. The differential maps of TEC over Europe for

March 19, 2001 (geographic coordinates).



Fig.4b. The differential maps of TEC over Europe for March 20, 2001 (geographic coordinates).

On Figures 4a and 4b you can see the differential maps of TEC over Europe for March 19 and 20. Nighttime TEC increase took place on March 19/20 at auroral and subauroral latitudes. The increase reached 100-150%. The positive effect occurred also at latitudes below 50°N. The TEC depression, observed at latitudes about 55°N can be attributed to the effect of the midlatitude trough. On March 20, after 06:00 UT the negative effect prevailed over Europe and lasted until 06:00 UT on March 21.

3.2 the storm on march 31, 2001

Figure 5 presents storm development over North America region on March 31.



Fig. 5. Storm development over North America

Before the start of the storm the positive effect took place during the local daytime on March 31. The negative effect occurred during the following night and TEC depression reached 75 %. The negative effect lasted through the following local day.

During the driven phase of the storm, large-scale structures of the increased TEC were observed in the ionosphere. The structures are related to the occurrence of the midlatitude trough and strong perturbations induced in the ionization processes, such as particle precipitation at high latitudes (Figure 6a and 6b).



Fig.6a. Differential maps of TEC over North America for March 31, 2001 (geographic coordinates).

In the periods of geomagnetic storms (on March 19 and 31) the satellite/receiver biases of O'Higgins and McMurdo receivers increased sharply. On March 31 satellite/receiver biases reached the value of 4 meters at OHIG and MCM4, respectively (Figure 7).

Figure 8 presents diurnal variations of the TEC over single Antarctic stations for the period of storm of March 31, 2001. For a period of quiet day - 26 March 2001 the TEC values at Antarctic stations (Casey, Davis, Syowa, Sanae) reached the values of 30, 60, 50, 40 TECU, respectively. On March 31 2001 absolute TEC values decreased sharply to 15, 25, 18, 20 TECU, respectively.

4. Conclusion

The GPS observations of the IGS network were used to study the response of the ionosphere to two severe geomagnetic storms of March 2001 over European, North America, and Antarctic sectors. The following conclusions can be made:

REPORT OF THE FIFTH SCAR ANTARCTIC GEODESY SYMPOSIUM



Fig.6b. Differential maps of TEC over North America for April 1, 2001 (geographic coordinates).

- The storm on March 19 was less intensive than the storm on March 31 (Dst = -160nT and Dst = -358, respectively).
- The storm on March 19 developed gradually. The driven phase of the first storm was prolonged but the storm of March 31 was of a short duration (only 4 hours).
- The main feature of both storms under investigation was a strong negative TEC effect. The TEC depression amounted up to 75-100%.
- The duration of the negative phase was longer for the weaker storm of March 19.
- The response of the ionosphere to both storms was more pronounced and longer over North America and Antarctica sectors than Europe.
- Both storms began with a positive phase. The maximum positive effect took place at auroral and subauroral ionosphere. The strong increase of TEC (~150%) at high latitudes can be attributed to the particle precipitation.
- The high deviation of TEC relative to quiet conditions gave rise to the displacement of the minimum of the midlatitude through.
- During the storms the intensive large-scale irregularities were observed at the auroral and subauroral ionosphere.
- The regional behaviour of the response of the ionosphere to the geomagnetic storms is clearly visible.



Fig.7 The satellite/receiver biases of OHIG and MCM4 receivers for March 2001



Fig.8 Diurnal variation of TEC over Antarctic stations for period 29 March -1 April 2001 (dashed line) and quiet day 26 March, 2001 (solid line)

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Development of Tec Fluctuations in Antarctic Ionosphere During Storm Using GPS Observations

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Abstract.

1 Introduction

GPS observations of the Antarctic stations belonging to IGS network were used to study TEC fluctuations on high-latitude ionosphere during storms. Dual-frequency GPS phase measurements along individual satellite passes with 30 sec sampling interval were served as raw data. The ionospheric irregularities of different scale develop in the auroral, polar ionosphere. It is a common phenomenon which causes the phase fluctuations of GPS signals. We distinguished the variations of TEC related with the ionospheric structures of the spatial scale bigger than 200-300 km. At diagram of temporal variations of TEC along satellite pass the structure of TEC corresponds to the time scale bigger than 15-30min on the 4-6-th hour duration of tracking satellite by individual stations. We attribute the variations of the time scale smaller than 15-30 min to TEC fluctuations related to small scale ionospheric irregularities. We used the rate of TEC index (ROTI) expressed in TECU/min as the measure of TEC fluctuations. The large scale ionospheric structures cause the increase of the horizontal gradients and difficulties of the carrier phase ambiguity resolution in relative GPS positioning. In turn the phase fluctuations can cause the cycle slips. At polar stations: MCM4, CAS1, DAV1 we detected the ionospheric structures of enhanced TEC bigger than 3-5 time relative background, while the TEC increased to 10-30 TECU in about 10-15min. The structures were observed during a storm as well as during moderate geomagnetic activity. The structures probably can be attributed to polar cap patches. At lower latitude station: OHIG during the storm can essentially increase the horizontal gradient which we attribute to the occurrence of the ionospheric trough and it storm-time dynamics.

The ROTI data was used to study the developments of phase fluctuations over the Antarctic ionosphere during geomagnetic disturbances. During storms the intensity of phase fluctuations increased. The occurrence of phase fluctuations was even detected during the active storm period of 31 March 2001 at middle latitude station OHIG located at 49 corrected geomagnetic latitude. The stormtime features in longitude and latitude development of phase fluctuations were obtained for the Antarctic region. The correlation between activity of phase fluctuations and magnetic field variation of Mowsen station was established.

Key words: Ionosphere, TEC, modeling of ionosphere

The structure of the high-latitude ionosphere is very complicated and varied. Strong changes of the ionosphere occur during geomagnetic disturbances. The dramatic changes took place very frequently in the auroral and polar ionosphere. In this region the irregularities of differential scales are developed commonly which cause the fluctuations of total electron content. In the paper we distinguished two types of TEC fluctuations. In the first, the large scale fluctuations (LSF) of TEC which are caused by the ionospheric irregularities with scale bigger than 100-300 km. These ionospheric structures occurred as the deep spatial variations of TEC. The second type of fluctuations is the irregularities with size about ten kilometers which cause the phase fluctuations GPS signals. The small irregularities can co-exist with large scale structures. In the report we present the analysis of the development of TEC fluctuations in March 2001. Two great geomagnetic storms took place on 20 and 31 March. The storm on March 31st was the severest one in the last decade. The Kp index reached maximal value of 9 and Kp made up 60. The Dst index reached maximum magnitudes with extremely high value about -360 nT. The geomagnetic conditions during March 2001 are presented in Figure 1 as variation of sum Kp index.



Fig.1. Variations of sum Kp during March 2001

2 The TEC data base

The GPS observations of the Antarctic IGS stations were used to study the development of TEC fluctuations in highlatitude ionosphere. The standard GPS measurements with 30 sec sampling provide the detection of the irregularities with size bigger than 6-10 km. In the Table 1 there are geographic and corrected geomagnetic coordinates of the stations. The broad longitudinal area of Antarctic stations enables to study the time development of TEC fluctuations.

The dynamics of the high-latitude ionosphere are controlled by the geomagnetic field. In the Table 1 you can see that geomagnetic latitudes are essentially different from geographic one. So in Antarctic region we can choose from middle-latitude station – OHIG, auroral - SYOG, MAW1 to polar stations - MCM4, CAS1, DAV1.

Station	Geographic		Con Geom		
	latitude	longitude	latitude	longitude	night
OHIG	-63.32	- 57.90	-48.93	12.23	03:47
CAS1	-66.28	1 10.52	-80.66	1 <i>5</i> 9.10	18:19
MCM4	-77.84	166.67	-79.95	325.00	07:07
PALM	-64.63	-64.05	-49.93	8.94	04:02
VESL	-71.67	-2.84	-61.67	43.56	01:46
SYOG	-69.01	39.58	-66.65	72.51	23:55
MAW1	-67.60	62.87	-70.68	91.49	22:39
DAV1	-68.58	77.97	-74.91	101.92	21:56

Table 1. Antarctic IGS stations

Table 1. Antarctic IGS stations

3 Large scale fluctuation of TEC

For the analysis of spatial and temporal changes of TEC during storm we used the high precision dual-frequency GPS phase measurements that provide more precise measurements of TEC than group delay ones. Phase ambiguities were removed by fitting phase measurements to the code data. After the above procedure the phase measurements contained satellite-receiver biases only. The



Fig.2a. TEC variations for satellites observed at different stations for during the storm (dashed line) and quiet period (solid line).

absolute TEC and the instrumental biases were estimated using the single site algorithm (Baran *et al.*, 1997). The biases were determined for every individual station using the GPS measurements for all satellite passes over station during 24 hour period. Using this procedure an absolute . TEC for all satellite passes observed over single station during 24 hour period is calculated.

The spatial and temporal variations of TEC are clearly seen on the time variations of TEC along individual satellite passes. Figures 2a and 2b give an example of the TEC variations for individual satellite passes as observed from different stations during storm (dashed line) and quiet period (solid line). The vertical TEC in units of 1016 el/m2 is plotted as a function of universal time (UT). This represents a part of diurnal TEC pattern sampled by satellites at these times. The spatial positions of satellites on figures also are presented (cross). Because the GPS satellites are on 12 sidereal hour orbits, the tracks repeat day by day (only the satellites arrive 4 min earlier each day). The plot approximately indicates that the satellites ionospheric trace for two days under consideration.

The series of large scale fluctuations (LSF) as enhancement of TEC are clearly shown on temporal patterns (Figures 2a and 2b). At the polar stations (CAS1, MCM4, DAW1) the TEC patterns demonstrate the great variability during disturbed as well as quiet days. During



Fig.2b. TEC variations for satellites observed at different stations for during the storm (dashed line) and quiet period (solid line).



Fig.3. The Magnetic activity at Mawson and the phase fluctuations occurrence at different stations on March 28-31. The plots show the phase fluctuations for individual satellites, the mark points out location of geomagnetic midnight

storm the intensity of the fluctuations dramatically increased. The TEC increase of a factor of 2-8, the enhancement of TEC can exceed 10-20 TECU to relative phone. At lower latitudes the intensity LSF decreased. We attribute the TEC enhancement as occurrence of the polar cap ionospheric patches. These responses to F region plasma patch as the GPS ray encounter the patches structures (Weber et al., 1984). Polar cap patches are large regions of enhanced F region plasma density observed traveling trough the ionospheric polar cap under the influence of the high-latitude convection (Pederson et al., 2000). Discrete F region electron density is enhancement of a factor 2 or more. Patches are typically considered to be of the order of 100-1000 km in horizontal extent. The travelling speed of the patch is between 300-900 m-3 (Rodger et al., 1999). Thus in the temporary pattern shown the variations of TEC along satellite passes the duration of occurrence of the patches can be 10 min or more.

The patterns of TEC fluctuation demonstrate the similar structures at spaced stations. It is well seen in Figure 2a for DAV1 and MAW1. Very similar portrait of the patch structures shows the TEC variation for PRN 15 and PRN 17 at CAS1 stations (top panel on Figure 2a) for March 2001. The time delays between the similar discrete structures correspond to a propagation velocity of the patch, and it is about 700 ms-1.

The deep variations of TEC are observed very frequently at polar stations. Analyses of data of MCM4 stations show that patch-like structures (about 90%)

cases) were registered during March-April 2001 period. Over auroral station - VESL during quiet day the TEC demonstrates smooth run, during storm the LSF are often observed. The amplitudes of the TEC fluctuations in this region are smaller than on polar stations. At middle latitude station (OHIG) the large structures can be detected during the storm which we attribute to the occurrence of main ionospheric trough. In the time the horizontal gradients in the ionosphere over OHIG station increased. The sign storm time gradients can even be opposite to quiet geomagnetic conditions (Figure 2b).

4. Phase fluctuations of GPS signals

The TEC fluctuations, also called phase fluctuations, are caused by the presence of medium and small scale irregularities in the ionosphere. To estimate the phase fluctuations the dual-frequency phase measurements with 30 sec sample interval usually are used. The rate of TEC changes 1 min apart (ROT) is the source of the intensity of phase fluctuations study. The use of these relatively infrequent samples enables to study irregularity structures in the order of kilometers. When using ROT we avoid the problem of phase ambiguities.

As a measure of ionospheric activity we used also the Rate of TEC Index (ROTI) based on standard deviation of ROT (Pi et al., 1997)

$$ROTI = \sqrt{\left\langle ROT^2 \right\rangle - \left\langle ROT \right\rangle^2}$$

ROTI has been estimated in 10-min interval.



Fig.4a. Location of TEC fluctuations derived from GPS measurements in Geomagnetic local time and Corrected geomagnetic latitude for 26.03.2001, 30.03.2001 and 31.03.2001 on the different stations in south hemisphere. Intensity of fluctuations is indicated with following symbols: crosses represent fluctuations between 0.3 and 0.5 TEC/min, rhombs – bigger than 1.5 TEC/min. Fig.4b. Location of TEC fluctuations derived from GPS measurements in Geomagnetic local time and Corrected geomagnetic latitude for 26.03.2001, 30.03.2001 and 31.03.2001 on the different stations in south hemisphere. Intensity of fluctuations is indicated with following symbols: crosses represent fluctuations between 0.3 and 0.5 TEC/min, rhombs – bigger than 1.5 TEC/min. Fig.4c. Location of TEC fluctuations derived from GPS measurements in Geomagnetic local time and Corrected geomagnetic latitude for 26.03.2001, 30.03.2001 and 31.03.2001 on the different stations in south hemisphere. Intensity of fluctuations is indicated with following symbols: crosses represent fluctuations between 0.3 and 0.5 TEC/min, rhombs – bigger than 1.5 TEC/min.

35

The Figure 3 demonstrates the occurrence of the phase fluctuations (ROT) during 28-31 March 2001 with the most disturbed storm day - 31 March. The plot shows the variations of raw phase fluctuations for all satellites observed from Antarctic stations during 24 hour period. The top panel demonstrates the behaviour of variations of geomagnetic field at Mawson station. In the pictures the mark points out the location of the geomagnetic midnight. The maximum occurrence of phase fluctuations took place usually around local midnight (MN) (Aarons et al., 2000), it is clearly seen at auroral stations (SYOG, VESL). In the same time the picture demonstrates that the developments of phase fluctuations are controlled by the geomagnetic activity. During the storm over Mawson station the development of phase fluctuation correlate with variations of geomagnetic field.

On polar stations the phase fluctuations all day are observed. On middle-latitude station - OHIG the fluctuations occurred only during storm day of 31 March. It is evident that during 31 March auroral oval for irregularities until middle latitudes was expanded.

The latitudinal occurrence of intensity of phase fluctuations depended on time is presented in Figure 4 (The polar coordinates - Corrected Geomagnetic Latitude (CGL) and Magnetic Local Time (MLT)). The intensity of the fluctuations with correspondence to the symbols is indicated. Figure 4a illustrates the exhibition of phase fluctuation over polar station - CAS1 and auroral one - MAV1. As Aarons showed, a dominant factor in the development of phase fluctuations during quiet period is the location of station relative to auroral oval. During quiet day of 26 March the maximal intensity is observed around magnetic local midnight. The geomagnetic storms modify the diurnal patterns of phase fluctuations extending the time of development and increasing their intensity. At polar site of CAS1 the weak intensity during storm increased more than at auroral station of MAV1. The developments of fluctuations over DAV1 station are more clearly controlled by geomagnetic activity. Figure 4b illustrates the exhibition of phase fluctuation over middle latitude station - OHIG and polar station - MCM4. In quiet and moderate magnetic activity at OHIG phase fluctuations are very weak and only in the most disturbed day 31 March the fluctuations occurred. It appeared during the greatest storms when the oval irregularities until middle latitudes are developed.

Figure 4c demonstrates the occurrence of phase fluctuations at lower (SYOG) and higher latitude edge of auroral oval. The intensity of fluctuations is essentially lower over SYOG than over DAV1 station. During storm day the fluctuations are registered the whole time, their intensity also markedly increased in the storm time.

5 Conclusion

The occurrence of TEC fluctuations depends on the geomagnetic latitude of a site. In the Antarctic region the difference between geomagnetic and geographic coordinates of site can be bigger than 10 degrees. So in the Antarctic region we can distinguish midlatitude, subauroral, auroral and polar stations.

Maximal TEC fluctuations took place at polar stations. The variations of TEC during storm reached 10-40 TEC. The enhancement of TEC exceeded 2-8 times a relative phone. Deep variations of TEC observed along individual satellite passes related to polar patches. They are transferred across line-of-sight of the receiver-satellite. The speed of the patches obtained from GPS observations was bigger than 700 m s-1.

At lower latitudes the fluctuations of GPS signals are attributed to small and middle-scale irregularities. The intensity of phase fluctuations depends on geomagnetic activity. During maximal phase of storm on 31 March 2001 the fluctuations of moderate intensity were observed at middle latitude station of OHIG. The development of TEC strongly correlates with the geomagnetic field variations of Mawson'station. The ionospheric gradients increased essentially during the storm. The irregular gradients sometimes exceed the regular ones. During the storm time it can cause the increasing of errors in determining phase ambiguities of GPS observations in the Antarctic region.

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Regional Ionosphere Modeling Using Smoothed Pseudoranges

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Abstract

This paper demonstrates the concept and some practical examples of the ionospheric total electron content (TEC) modeling using undifferenced phase-smoothed pseudorange GPS observations. After the smoothing process, the pseudorange observations are, in fact, equivalent to the carrier phase observations, where the integer ambiguities might be biased. The resulting TEC estimates were tested against the International GPS Service (IGS) TEC data for some American, European and Antarctic stations. The point-measurements of TEC were interpolated using the Kriging technique, in order to create TEC maps. The quality of the ionosphere representation was tested by comparison to the reference IGS Global Ionosphere Maps (GIMs).

Key words: GPS, Ionosphere, Kriging

1. Introduction

Spatial and temporal characteristics of the ionosphere are of primary interest in their own scientific context, but they are also of special interest to communication, surveillance and safety-critical systems, as they affect the skywave signal channel characteristics. The TEC is one of the important parameters in ionospheric research and one of the most important parameters in the trans-ionospheric radio propagation studies (Ma and Maruyama, 2001).

Today, GPS delivers large volumes of data suitable for continuous, near or real-time ionosphere monitoring during the disturbed and quiet geomagnetic conditions, and offers an attractive alternative to the traditional methods. Currently, the well established and commonly used GPSderived GIMs provided by IGS have spatial resolution of 2.5° and 5.0° in latitude and longitude, respectively, and 2-hour temporal resolution (Feltens and Jakowski, 2002). Thus, although IGS supports the scientific community with quality GPS products, IGS GIMs cannot reproduce local, short-lasting processes in the ionosphere. In addition, the resolution of these products might not be sufficient to support high quality GPS positioning, especially in the presence of local ionospheric (Cisak *et al.*, 2003a).

The need to produce high-resolution regional ionosphere models, supporting navigation, static and kinematic positioning and space weather research, is commonly recognized (Komjathy, 1997). Gao and Liu (2002) pointed out that the interpolation methods might give better results, as compared to the mathematical function representation of TEC (e.g., spherical harmonics expansion). Thus, in this paper we investigate the applicability of the Kriging interpolation/prediction method for TEC representation (Journel and Huijbregts, 1992). This paper presents some preliminary test results and the comparison with the IGS GIMs.

2. Methodology

The double frequency GPS phase and code observations, collected at the reference station network, were used in the approach presented here. The carrier phase observations are used to smooth the pseudoranges, as described by Springer (1999). The Differential Code Biases (DCBs) for satellites, denoted as Δb^k , are provided by IGS (ftp://gage.upc.es/pub/gps_data/GPS_IONO) and the DCBs for the receivers, Δb_i , are derived from the GPS receiver calibration performed using the BERNESE software (Hugentobler *et al*, 2001). Next, the geometry-free linear combination of the un-differenced GPS observations is applied to derive the ionospheric delay related to the first GPS frequency (Schaer, 1999):

$$I_i^k = (\tilde{P}_{i,4}^k - c(\Delta b^k + \Delta b_i)) / \xi_4$$
(1)

where:

 I_i^k - ionospheric delay $P_{i,d}^k$ - un-differenced pseudorange geometry-free linear combination (phase-smoothed)

c - speed of light

 Δb^k - DCB of satellite k

 Δb - DCB of receiver i

 ξ_4 - coefficient converting ionospheric

delay on P_4 to P_1

The relationship between the absolute TEC and the ionospheric delay is shown in the following formula (Schaer, 1999):

$$I_{t}^{k} = \pm \frac{C_{x}}{2} TEC f_{1}^{-2} = \xi_{TEC} TEC$$
(2)
where $\frac{C_{x}}{2} = 40.3 \times 10^{16} \text{ ms}^{-2}/\text{TECU}$

is the proportionality factor; $\xi_{TEC} = 0.162$ m/TECU is the ionospheric delay caused by 1 TECU on the first GPS frequency $-f_1$.

For the TEC representation, a single layer model (SLM) was used. SLM assumes that all the free electrons are contained in a shell of infinitesimal thickness at altitude H. A mapping function converting slant TEC to the vertical one is needed as shown in (Mannucci *et al.*, 1993).

In order to create regional TEC maps, the Kriging method was used (Davies, 1986; Stanislawska *et al.*, 2000 and 2002). Kriging is an estimation and interpolation method applied in geostatistics, which uses the known sample values and a variogram to determine the unknown values at different locations/times. It utilizes the spatial and temporal correlation properties of the underlying phenomenon, and incorporates the measures of the error and uncertainty of the estimates. At each location, Kriging produces an estimate and a confidence bound on the estimate, the Kriging variance.

3. Numerical Tests

At the first stage of the numerical analysis, GPS observations from five CORS stations (COLB, SIDN, MCON, LEBA and PKTN) with the average separation of ~100km, located in the southern part of the State of Ohio, were selected. The 60-second sampling rate and the elevation mask of 20° were used in the processing. The vertical TEC values were obtained according to the methodology presented above using the MPGPSTM software (Wielgosz *et al.*, 2003). The data from the magnetically active day of April 29, 2003 were processed and analyzed. Figure 1 indicates that the active geomagnetic period started around 12:00 UT, and the Kp index reached the value of 6 between 18:00–21:00, which reflects a minor geomagnetic storm.



Figure 1. Kp index during the experiment.

The TEC values and the respective ionosphere pierce point (IPP) coordinates were calculated in geographic reference system (geographic latitude and longitude). Geographic reference frame was used to produce the epoch-specific instantaneous regional maps of the ionosphere. After analyzing the geographic location of IPPs for all the observational epochs, a region located between $35^\circ - 45^\circ$ north geographic latitude and 272° - 282° longitude was selected to produce the regional ionosphere maps. This area was covered by IPPs for most of the processed epochs; thus, the instantaneous ionosphere mapping was possible.

The TEC values obtained at the IPPs were interpolated using Kriging to create high-resolution instantaneous regional maps of the ionosphere. The results were analyzed and compared to the reference IGS maps, as described in the following section. In order to compare the IGS TEC over different geographic regions, TEC was calculated using observations from the European IGS station, LAMA, and the Antarctic IGS station, CAS1. The results were compared to those obtained from the IGS GIMs. In the following, the TEC calculated using the MPGPSTM software is denoted as "OSU-TEC".

4. Results And Analysis

The first analysis is concerned with the internal consistency of the model and the satellite/receiver DCB validation. The TEC values calculated from several CORS stations and GPS satellites were compared (Figure 2). It was shown that the TEC derived from the observations to each satellite is consistent between the neighboring stations, what confirms that the calibrated receiver DCBs are correct.



Figure 2. Comparison of the OSU-TEC observed to satellite PRN 04 from three CORS stations (COLB, PKTN and MCON) on April 29, 2003.

Figure 3 illustrates the examples of regional instantaneous ionosphere maps produced with the Kriging technique. For every map a semi-variogram was calculated and introduced to the interpolation process. The approach applied here allows a fast generation of the regional ionosphere maps, practically, for every observational epoch. Figure 3 illustrates the maps at the selected epochs. Notice that the local time for this region is -5UT hours, and the maximum electron density, due to the geomagnetic disturbances, occurred for this area in the local evening. The resulting maps may allow detecting the local ionospheric phenomena, e.g. local TEC peaks of 1-3 TECU (Figure 3). The obtained ionosphere grid has the resolution of 0.08° in latitude and 0.12° in longitude. Such a dense TEC grid can be easily interpolated using simple linear interpolation and can be effectively used to support global navigation satellite systems (GNSS).

4.1 Comparison to IGS GIMs

In order to validate the instantaneous regional ionosphere maps, a comparison to IGS GIMs was performed. It should be noted that the IGS GIMs are a combination of GIMs provided by several analysis centers (ACs). All the ACs involved may use different approaches to the TEC derivation from GPS observations, as well as different TEC representation/modeling techniques. As it was mentioned



Figure 3. Comparison between the ionosphere maps derived using Kriging (OSU-TEC) and the IGS GIMs

in the introduction, the spatial resolution of the final IGS GIMs is 2.5° in latitude and 5.0° in longitude. For the comparison purposes, an area covering regional model was extracted from the IGS GIMs. Figure 3, right column, presents the example ionosphere maps for the selected epochs extracted from the IGS GIMs.

In general, the OSU-TEC is comparable to the IGS GIMs. It is noticeable, however, that GIMs' general TEC level is higher about 3–5 TECU, as compared to the maps generated using the Kriging method. This could be explained by the global nature of GIMs. IGS ACs often use TEC representation algorithms, which result in the model resolution comparable with the whole area of the region under investigation (Schaer, 1999). In addition, the sampling rate of the data sets and the network density used in the global and some regional models is much lower than the one investigated here. It should be noted that the investigated region is covered by only 8 GIM grid points.

This also explains why the TEC derived from GIMs is very smooth over the entire analyzed region. In contrast to GIMs, local features in the ionosphere represented by the regional models can be observed. However, some of these features might be caused by a clustered distribution of IPPs. Local distribution within the clusters, however, is more than sufficient. We believe that a regional model should correspond to a more accurate local ionosphere representation.

4.2 TEC comparison over different regions

The reasons for the above-mentioned systematic bias between the OSU-TEC and the IGS GIMs were further investigated using two additional data sets (OSU and IGS GIMs' TEC values at IPPs) for comparison of some permanent IGS stations in North America, Europe and Antarctica. First, the consistency of the results in time domain from both data sets was tested for the COLB station, as shown in Figure 4 (DOY 163/2003). This Figure displays a very similar diurnal TEC behavior for both curves and a difference in the scale factor. This difference in scale is shown in Figure 5 and 6 by the means of direct comparison of both data sets.

Similar investigations were performed for the TEC data obtained from the international project "Atmospheric



Figure 4. Diurnal TEC variations interpolated over COLB station derived from OSU-TEC and IGS GIMs, June 12, 2003.



Figure 5. Comparison of the OSU-TEC variations for all satellites observed at SIDN station on June 12, 2003, to the TEC interpolated from the IGS GIMs (plot) and linear trends for the rest CORS stations (equations)



Figure 6. Comparison of the OSU-TEC variations for different satellites observed in COLB, LAMA and CAS1 data with the TEC interpolated from the IGS GIMs (June 12, 2003).



Figure 7. Comparison of TEC over the Antarctic CAS1 station derived from the UPC data with the TEC interpolated from the IGS GIMs' (November 2001).

impact on GPS measurements in Antarctica" (Cisak *et al.*, 2003a and 2003b). Some of the results are shown in Figure 7. The TEC data with the 1-minute temporal resolution for some Antarctic stations were provided by Dr. M. Hernandez-Pajares from UPC (Hernandez-Pajares *et al.*, 1999). In that case, the earlier conclusion that the scale difference is caused by the very smooth character of the IGS GIMs seems to be confirmed.

5. Conclusions And Future Developments

The analyses presented here show that the TEC-recovery methodology, which takes the advantage of the phasesmoothed pseudoranges, is efficient, and enables generation of the real-time regional TEC maps, when applying the Kriging method. The primary advantages of the instantaneous regional ionosphere mapping presented here are the high temporal (one observational epoch) and spatial (0.08° in latitude and 0.12° in longitude) resolutions. Owing to the fact that DCBs do not change significantly during the course of a day, their values can be used even a few days after the calibration. This may allow producing instantaneous TEC maps in near-real time. However, the systematic bias between both TEC estimation sets (OSU-TEC and IGS GIMs) needs to be further investigated.

Future studies will include the investigations of the behavior of the selected ionospheric storms over the Antarctic region using the proposed approach. The impact of the ionospheric disturbances on the variations of the GPS vector components, at high latitudes, will be also investigated.

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Argentine Island Ice Cap Geodesy Survey for Climate Change Investigation

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Abstract

The geodesy survey of small island ice caps in Antarctic Peninsula region within the framework of the GIS project for the Argentine Islands archipelago has been started in 2002. The purpose of monitoring is the possible regional climate changes observation on shape, position, dynamics and future of archipelago small ice caps. The task was determined by the latest data of regional warming up to 5°C in the Faraday/Vernadsky area during the last century. The main objectives of the survey are creation of the largescale digital maps (1:25,000 – 1:1,000) for the Argentina Islands region, producing the precision geodesic data for ice cap monitoring and the evolution model creation. The geomorphology monitoring of the ice caps is based on the GPS and photogrammetric survey. The changes of size, shape, deformation, moving velocity and the edge position of ice caps on Argentine Islands archipelago shows the possibility to use the geodetic survey data of the ice cap for the regional climate variability study. The research is based on historical data ice cap observation of Galindez Island and other islands in the area. On the base the photogrammetric survey the large-scale digital map (1:1,000) of the Marina Point of Galindez Island was created. The data of fifty years meteorological observations and tide data at Faraday/Vernadsky station, long-term variability in sea-ice extent/thickness, monitoring of ozone layer and UV energy flow, hydrological measurements provided at Vernadsky, the upper atmosphere changes measurements over Antarctica, the botanical evidence of climate changes are the additional sources for the climate pattern of the Antarctic Peninsula.

About the Influence of the Solar Activity on GPS-Supervision

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Abstract

The state-of-the art review of influence of Solar activity on condition ionosphere is made which, in turn, influences of GPS-supervision. Is shown, that for specification of model ionosphere it is necessary to find exacter connections between the phenomena occurring on the Sun, and condition ionosphere.

Application of SAR Interferometry in Grove Mountains, East Antarctica

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Abstract

Synthetic aperture radar interferometry has been proposed as a potential technique for digital elevation model (DEM) generation, topographic mapping, and surface motion detection especially in the inaccessible areas. Grove Mountains Area locates to the southwest of Princess Elizabeth Land, inland areas of east Antarctica. The topographical map of the core area (11×10 KM2) was printed after the field surveying with GPS and total station was finished under the atrocious weather conditions during the 16th CHINARE (Chinese National Antarctic Research Expedition) 1999/2000. This paper will present an experimental investigation of the ERS-1/2 SAR tandem data in 1996 on DEM generation of the Grove Mountains Core Area, analyze the data processing, and compare the DEM with the actual topographic form. It is confirmed that InSAR is a very useful technique to be utilized in Antarctica, and can be used to produce more products instead of dangerous field surveying.

Key words: Synthetic aperture radar interferometry, ERS-1/2 Tandem, GPS, DEM, Antarctica.

1. Introduction

Maps of Antarctica's interior remained mostly white blanks into the mid-1980s. Satellites using visible light had produced detailed surface images, but their angles of view excluded more than 1.2 million square miles poleward of about 82° south latitude. Then in 1997, the Canadian RADARSAT-1 satellite was rotated in orbit. With its synthetic aperture radar (SAR) antenna looking south



Figure 1: Grove Mountains, East Antarctica.

towards Antarctica, it permitted the first high-resolution mapping of the entire continent of Antarctica. In other areas of Antarctica, DEM and topographic mapping have been obtained by means of different methods or their integration such as synthetic aperture radar, radar altimeter, laser altimeter, radar echo sounding, GPS surveys, aerial photographs, and geodetic maps.

In 1998, China planned to take the first time expedition to Grove Mountains Area (see also Figure 1), which locates to the southwest of Princess Elizabeth Land, inland areas of east Antarctica. Adopting Landsat4 TM images, Chinese Antarctic Center of Surveying and Mapping (CACSM) had completed the colorful satellite image map of the Grove Mountains in the scale of the 1:100 000 in August 1998 to ensure the expedition route and navigation to Grove Mountains Area during the 15th CHINARE 1998/1999. Then the topographical map of the core area (see also Figure 2) was printed after the field surveying with GPS and total station was finished under the atrocious weather conditions during the 16th CHINARE 1999/2000.

However, in Antarctica, traditional mapping method is no longer a most efficient means to obtain the topographical maps or DEM in large areas especially in abominable



Figure 2: Grove Mountains Core Area.

environment. Synthetic aperture radar interferometry has been proposed as a potential technique for digital elevation model (DEM) generation, topographic mapping, and surface motion detection especially in the inaccessible areas. So we bought radar image data from ESA and a case study for DEM generation was done in Grove Mountains. In this paper, the primary experiment result based on ERS-1/2 tandem data is presented. Moreover, with the hardwon field surveying data, comparing and analyzing DEM generated by using tandem radar image data with DEM generated with the topographic points is carried out.

2. Methodology

The tandem operation of ERS-1 and ERS-2 satellites, with a short temporal baseline, put forward a better time correlation for DEM generation. It utilizes the two single look complex image of the same area to form interfere and further obtain the three dimension information. The principle to get height h is illuminated in the following geometry figure.

With reference to Figure 3, the height (h) is given by $h \cdot H - r_1(\cos \xi \sqrt{1 - \sin^2(\theta - \xi)}) - \sin \xi \sin(\theta - \xi))$ (1) where H is the flying beight, ξ is the baseline tilt angle, θ is the side looking angle and related to the interferometric phase difference ϕ as follows: $4\pi = -2 + 4\pi = -2 + 4\pi$

 $\phi = \frac{4\pi}{\lambda}(r_2 - r_1) = \frac{4\pi}{\lambda}(B_x \sin \theta - B_y \cos \theta) \quad (2)$

where λ is the wavelength , r_1 and r_2 are the distances between the radar antennas and the scatter.





In this study, the interferometric SAR data processing mainly includes: (1) coregistration of the complex image data; (2) formation of the interferogram; (3) Phase unwrapping; (4) DEM generation. Indeed, baseline refinement, removal of flat earth, noise filtering, etc. are always indispensable to obtain a high-precision DEM.

DEM of Grove Mountains was generated by the ERS tandem data. Since we have DEM generated with the topographic points obtained during the field surveying, then we can perform a comparison.

3. Field Surveying

Grove Mountains Area, with bare peaks at inland areas of east Antarctica, is located to the south of the Zhongshan Station about 400 km. Its geographical extension is $72^{\circ}40'-73^{\circ}10'S$, $74^{\circ}00'-75^{\circ}45'E$, and the area is about 3200 km²; meanwhile, the core area extension is $72^{\circ}50'54''-72^{\circ}56'20''S$, $74^{\circ}54'07''-75^{\circ}14'09''E$, and its area is about 110 km². Grove Mountains is of typical inland character and also an ideal midway station place for



Figure 4: TM color satellite image map.



Figure 5: ERS-1 radar image.

expedition teams extending to the South Pole.

In the core area, there are two exposed mountains, many rock peaks, and detritus strips on the surface of the ice sheet with the altitude of 2000 meters, which has great topographical undulation and is densely covered by ice crack. The weather there is atrocious for it has blustery or milky weather half of a year and the average temperature is about thirty degrees below zero centigrade, which brings great difficulties for field surveying and operations.

TM color satellite image map and ERS-1 radar image (1996/02/10) of the core area are illustrated in Figure 4 and Figure 5 respectively. In TM image map, ice face is in light green, blue-ice face is in blue green, horn and bare rocks are in brown. The Mount Harding, Zhakroff Ridge, Jingyu Peak, Tianhe Range, Zhonghua Peak, and Lianhua Peak can be easily interpreted from both of them, and the general position is coherent. Meanwhile some difference occurs inevitably because radar image and TM image are in different characters and the error exists.

In order to provide geologists with the topography of Grove Mountains, our geodetic surveyors has conducted the field surveying with GPS and total station and completed the mapping experiment in the Grove Mountains Core Area during the 16th CHINARE 1999/2000 summer expedition. The topographical map of the core area at the scale of 1:25 000 (see also Figure 6) was printed after the field surveying was finished in 31 days by two surveyors of CACSM under the atrocious weather conditions, and 14,300 topographical points were obtained through post-processing differential GPS (DGPS) technique and forward intersection method with total station. WGS-84 coordinate system and Transverse Mercator map projection are adopted. The center meridian is 75°E, and the vertical contour interval is 10 meters.



Figure 6: Topographical map of Grove Mountains Core Area.



Figure 7. Interferogram of the core area

4. Dem Generation With Insar And Data Interpretation

The information of the tandem single-look complex image pair is listed in Table 1. The perpendicular baseline is about 164m, and parallel baseline is about 94m. Baseline parameter plays a very important role in flat earth effect removal and geometric transformation from phase to elevation, so it is very important to adopting precise baseline parameter. In practice, baseline accuracy at centimeter level is the basic requirement for producing high-precision DEM. ESA attached five sets of orbit vector data at intervals of 4.2 seconds within the head file while distributing SAR image data. In this study, we adopted ERS-1/2 high precision orbits calculated and provided by Delft Institute for Earth-Oriented Space Research (DEOS).

Table 1. ERS-1/2 tandem data information

Satellite	Orbit	Track	Frame	Date
ERS-1	23910	375	5139	1996-02-10
ERS-2	04237	375	5139	1996-02-11

Table 1. ERS-1/2 tandem data information

Interferogram, which is defined as the product of the complex SAR values of the second image with the complex conjugate of the reference image, includes both the amplitude and phase information of SAR image pair. And it is the basis for DEM generation. Figure 7 shows the interferogram of Grove Mountains Core Area. After the fieldwork, we get to know that disordered blocks of rocks and snow cover on the tops of the mountains and peaks, which causes the discontinuous interferometric phase fringe of these areas.

Once the phase is unwrapped, an absolute phase is required to obtain the absolute pixel height. A point with known elevation in the scene can be used to provide an absolute elevation reference. In Grove Mountains, two geodetic control points and one are set on the top of Mount Harding and Zhakroff Ridge respectively, while it is impossible to find their location in radar image because the field GPS surveying was done in 2000 and the SAR images were acquired in 1996. And even if they are in the radar image, it is also difficult to find them. For the particular environment in this location, it's trouble to find feature points too. On the other hand, ice-sheet flowed and changed a lot in such a long period. So we could only find a relatively flat and stable area to appoint a point as the reference point. Area west to Mount Harding is relatively stable because of the blocking effect of Mount Harding. Meanwhile, with reference to the coherence of the core area (see also Fig.8), which depends on the terrain conditions, the brighter means the better coherence. Generally speaking, the areas covered mostly by ice and snow to the west of the Mount Harding and Zhakroff Ridge have relatively better coherence. Other areas covered by ice and snows such as northwest terrace take



Figure 8: Coherence of the core area



Figure 9: DEM generated by using tandem radar image data

second place. And coherence of the top of the mountains and peaks are the worst. A point to the west of Mount Harding with rough elevation of 1867 meters is selected as the reference point.

After phase unwrapping, the DEM was generated. In order to show intuitionistic vision, color perspective model of the grid DEM is formed as Figure 9. In those areas of high topographic deviationism, the deviation is fairly large for the layover and shadow effect caused by side-glanced radar observing mode. Compared with the perspective model from the DEM generated with the topographical points obtained during the field surveying (see also Figure 10), the terrain tendency and the main terrain character are coincident. Red stands for the higher, and blue the lower. Mount Harding and Zhakroff Ridge are obvious in Figure 9 and Figure 10, while Jingyu Peak, Zhonghua Peak and Lianhua Peak are not exactly presented in Fig.9. Meanwhile, Fig.9 doesn't show the valley and lower terrain that can be clearly given in Fig.10. The details of the topography information in the two following figures exist differences and need more study and analysis.



Fig.10. DEM generated with the topographic points obtained during the field surveying

Table 2. Results of the comparison of the two DEM

Terrain	Flat terri	Billy terrain	
1 cartan	Relatively stable	Flowing	
Mean	2.3m	13.7m	-61.9m
RMS	5.4m	20.3	89,3m

Table 2. Results of the comparison of the two DEM

From 1996 to 2000, changes in Grove Mountains may be caused by snow accumulation, ice-snow melting and ice sheet flowing, and ice sheet flowing is the main factor. However, according to the topographic feature, ice sheet flow and the coherence of the core area, relatively flat and stable areas can be found. It is more reasonable to assess the DEM difference in three different terrains listed in Table 2 than only to compare the whole area.

With the measured results listed in Table 2, the quality of DEM difference of the relatively stable areas is preferable, which confirms that InSAR is valid to be utilized in this area. For the flowing ice surface, the corresponding DEM difference gets larger, which is mainly caused by the changes in ice surface. The result is unsatisfied in the hilly terrains because of the surface of the mountains covered by snow and blocks of rocks, which brings noises and difficulties to obtain accurate height.

5. Conclusions And Future Activities

From the primary study and other researchers' study on DEM generation and topographic mapping, it could be shown that InSAR will be very useful to be utilized in Antarctica as a new mean for producing topographic products more effective instead of field surveying.

In order to obtain high-precision DEM, formation of the interferogram, phase unwrapping, and other crucial steps must be further studied to reduce the error. Band C can penetrate to the ice surface, but here this penetration effect to DEM generation is neglected. Moreover, we can analyze the properties of snow cover on InSAR phase and coherence, and the effect on DEM generation and mapping.

Scientists have been very interested in Antarctic ice sheet flow, ice sheet kinematic characteristics, and mass balance. InSAR can also be an effective tool in these research fields by adopting more pairs of radar image data. During the 19th CHINARE 2002/2003, our researchers has set eight ground control points covering all Grove Mountains area, which will help us to utilize interferometric SAR image data or others to precisely produce the topographical map of the whole Grove Mountains area and extract the topographic information of Antarctic inland ice sheet.

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The Establishment of GPS Control Network and Data Analysis in the Grove Mountains, East Antarctica

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Abstract

In order to provide the satellite image map for the field expedition, during the 19th CHINARE (Chinese National Antarctic Research Expedition) 2002/2003 summer season, GPS control network was established in Grove Mountains, East Antarctica. Its geographical extension is 72° to 73°S, 73° to 76°E, and its area is about 8000km². In the inland ice sheet where the elevation is approximately 2000m, seven permanent GPS control marks were set with the support of helicopter and vehicles. Simultaneously observing with Zhongshan permanent GPS station, we constructed the geodetic network with these seven points by Trimble 4000ssi GPS receiver. Processed by the high-accuracy GPS software°™GAMIT, the positioning precision is good enough to satisfy with the acquirement of cartography in this area.

Key Words geodetic network, satellite image, Grove Mountains, Antarctica

1. Background

Grove Mountains is located in Princess Elizabeth land in East Antarctica, about 400km inland from Zhongshan Station and 160km east of the Mawson Escarpment, it consists of a scattered group of mountains and nunataks. The range includes 73°-76°E, 72°-73°S, extending an area of 8000km2. Grove Mountains has great topographical undulation and is densely covered by ice crevice, the weather there is atrocious [1]. The average temperature in January is -18.5°E which is 18°E lower than Zhongshan Station, and the average wind velocity is more than 10m/s [2]. So it has been one of our ideal midway station points



Fig.1: GPS control network in the Grove Mountains

(Note: the coordinates in Fig.1 are the approximate coordinates with single point positioning)

in the route from Zhongshan Station to eastern Antarctic ice-cover and in the expedition of Antarctic Pole Point.

During the 1998/1999 Antarctic summer season, the 15th CHINARE (Chinese National Antarctic Research Expedition) first went to the Grove Mountains for research and expedition. During the 1999/2000 summer season, the 16th CHINARE carried out the second expedition in the Grove Mountains, the surveyors utilized the Differential GPS technology and mapped the core area which covers 110 km2 at the scale of 1:25000 [3]. In the summer 2002/2003, it is the third time that the 19th CHINARE went to the Grove Mountains, the surveyors established 7 permanent geodetic points in this area, collected data on those points with GPS receivers, and prepared for the topographic mapping with the satellite image.

Besides CHINARE, ANARE (Australia National Antarctic Research Expedition) and RAE(Russian Antarctic Expedition) also have been to the Grove Mountains several times since 1950s[4].

2. Geodetic surveys 2002/2003 in the Grove Mountains

During the 2002/2003 summer season, the 19th CHINARE carried out the third expedition in the Grove Mountains, the main tasks include: geodetic survey, meteorite collection, ice kinematics and geology expedition etc.

In order to provide the satellite image map for the field expedition, the surveyors established 7 permanent geodetic points in Cooke PK-the north section of the Gale Escarpment-Mount Harding-Melvold NTKS-Black NTKS-the south section of the Gale Escarpment and the *Fig.2: GPS benchmark in the Grove Mountains*



middle section of the Gale Escarpment, and the GPS control network is shown in Fig.1.

In January 19, 2003, the Z-9 helicopter flew from Zhongshan Station to the camp No.5 at the foot of the Mount Harding, then the helicopter flew to the Cooke PK for GPS observation and ice sampling etc. This is the first time that Chinese helicopter flew to the Grove Mountains under the furious weather conditions without foreign aids. On account of the long distance between Zhongshan Station and the Grove Mountains, the fuel carried by the helicopter can only maintain the single fly to the Grove Mountains, the helicopter had to be replenished the fuel so that it can fly back to Zhongshan Station. But the temperature in the Grove Mountains is so low that the helicopter couldn't close the engine, so the helicopter can only stay in the Grove Mountains for a short time.

Shortly after its arrival at camp No.5, the helicopter carried the surveyors to Cooke PK. Because the wind near the foot of the Cooke PK is too violent, the helicopter had to land on ice far away. The permanent geodetic mark which carved Z001 was established on a nunatak to the

south of Cooke PK, the mark is illustrated in Fig.2 below. Only small amount of data were collected on this point because the helicopter had to fly back in an hour.

Except for Cooke PK, snow vehicles were utilized when collecting GPS data on other 6 points. On the apparent and flat solid bedrock, the surveyors used the impact drill to drill an aperture in the bedrock, then put the screw of the benchmark into the aperture and clung it with glue. After the benchmark was stable enough, the GPS antenna was mounted over the benchmark and began to collect data. About one hour's GPS data were collected on each point. The satellite cutoff angle was set to 15 degree and the sample interval was 15 second. After observation, photos were taken from different directions for the benchmark. GPS observation in the Grove Mountains is shown in Fig.3.



Fig.3: GPS observation in the Grove Mountains The observation records are shown in table 1.

Table 1	GPS observation	record in	Grove	Mountains	

			(GPS obsc	rvation time is GMT)	
Point	Date	Start	โร้เม่รโ	Receiver Type	Antenna Type	Vert Antenna Height
2001	2003.1.19	10:13:45	10:35:30	Trimble-4000SSI	4000SSE	0.200m
7.002	2003.1.20	08:54:15	09:55:45	Trimble-4000 SS1	4000SSE	0.243m
Z003	2003.1.22	11:20:45	12:38:15	Trimble4000 SSI	4000SSE	0.200m
2004	2003.1.25	16:23:15	17.24:00	Trimble-4000 SSI	4000SSE	0.243m
2005	2003.1.25	18:46:15	19:46:30	Trimble-1000 SSI	4000SSE	0.200m
2006	2003.1.27	11:35:45	12:38:00	Trimble4000 SSI	4000SSE	0.200m
2007	2003.1.27	15:56:15	16:57:15	Trimble-4000 SSI	40008SE	0.200m

3. Data Processing

A high-accuracy GPS processing software package-GAMIT was utilized, and the data were processed on ULTRA2 workstation. GAMIT is a comprehensive GPS analysis package developed by MIT and Scripps for the estimation of three-dimensional relative positions of ground stations and satellites orbits. The software is composed of ARC-Model-SINCLN-DBCLN-CVIEW and SOLVE modules etc [4].

The data were processed using IGS precise ephemeris in the ITRF 2000 Reference Frame, at epoch 2000 and the baseline was constituted with the Zhongshan permanent GPS station. The ephemeris precision is one of the most important factors in GPS data processing, and its influence on baseline processing can be given in the formula below:

$$\frac{|\Delta \mathbf{r}|}{10|\mathbf{r}|} - \frac{|\Delta b|}{|b|} - \frac{|\Delta \mathbf{r}|}{4|\mathbf{r}|} \tag{1}$$

Where $|\Delta r|$ is the error of satellite orbit, r is the satellite

earth centre position vector, $|\Delta b|$ is error of the base line vector and b is the base line vector between the two stations [5].

The main limiting factors in GPS baseline processing are listed below:

- The satellite clock offset
- The receiver clock offset
- The influence of ionosphere refraction
- The influence of troposphere refraction
- The phase center correction of the satellite and receiver
- The tidal correction of the station

The quality of the data is also important for the precision and reliability of baseline. The data edit which included fixing the cycle slips and eliminating the remained residuals is the main job in processing data. When editing the data, run AUTCLN module firstly, which allows better handling of poor data and provides quality statistics for each station. Then CVIEW should be run to examine the phase residuals from the initial solution and to add instructions for deleting data to the AUTCLN command file and fix remaining small cycle slips interactively. After that, clean X-file can be drawn for baseline resolution [6].

Basing on the data edit, ARC-MODEL and SOLVE can be run sequentially. The coordinates of the control points are shown in table 2.

Point	t montion.		Coordinates	
ID	Location	X (m)	Y (m)	Z(m)
Z001	Cooke PK	513123.2465	1857351.9446	-6061561.744
Z002	North of Gale Escarpment	476009,4087	1828996.9854	-6073542.7912
Z003	Mount Harding	485917.0248	1818191.2331	-6076090.8947
Z004	Melvold NTKS	510881.2294	1811322.8830	-6075661.3398
Z005	Black NTKS	499957.5196	1804891.3702	-6078525.0285
Z0 06	South of Gale Escarpment	473679.3826	1798618.4237	-6082789.418
Z007	Middle of Gale	475350.6838	1810866.8957	-6078894.7289

Table 2. The coordinates of the Grove Mountains control points

Table 2. The coordinates of the Grove Mountains control points

 The precision of the control points are listed in table.3:

 Table 3. The precision of the control points

 Point ID
 $X_m_ Y_m_ Z_m_-$

	r_m_	<u> </u>
8.8486	10.1408	14.1732
0.0486	0.0414	0.0341
0.4087	0.1673	0.1505
0.0971	0.1793	0.1236
0.2774	0.1639	0.2417
0.0697	0.0441	0.0262
0.0373	0.0991	0.0877
	A_m_ 8.8486 0.0486 0.4087 0.0971 0.2774 0.0697 0.0373	X_m_ Y_m_ 8.8486 10.1408 0.0486 0.0414 0.4087 0.1673 0.0971 0.1793 0.2774 0.1639 0.0697 0.0441 0.0373 0.0991

Table 3. The precision of the control points

From table 3, the conclusion can be drawn that the precision of Z001 is poor because of the short observation time. Besides Z001 point, the other 6 points can satisfy the need of the satellite image mapping at the scale of 1:50000.

4. Conclusion and suggestions

The precision of the 6 points in the Grove Mountains

except for Z001 are high enough to satisfy the need of the satellite image mapping at the scale of 1:50000.

Because of the limitation of the logistic support, short term GPS data were observed at Z001 point. As a result, the precision of this point is too low to use. If it is possible, Z001 should be re-observed in next expedition and 2-3 points should be established in the north part of the Grove Mountains, so the geodetic network would be more equivalent.

2-3 points should be re-observed in next expedition so as to get multi-session repetitive data for analysis of the crustal movement and geodynamics. The control points in the Grove Mountains can be analyzed together with the points in Larsemann Hills and Amery Ice Shelf, this would be of great importance to the research of geodynamics and ice kinematics of east Antarctica.

Additionally, this geodetic network should be combined with the geodetic network made by Australia and Russia if possible, which would unify the geodetic network in the Grove Mountains and Lambert Glacier-Amery Ice Shelf System in east Antarctica.

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Positional Accuracy of Airborne Integrated Global Positioning and Inertial Navigation Systems for Mapping in Glen Canyon, Arizona

Richard D. Sanchez and Larry D. Hothem

Any use of trade, product, or firm names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

Abstract

High-resolution airborne and satellite image sensor systems integrated with onboard data collection based on the Global Positioning System (GPS) and inertial navigation systems (INS) may offer a quick and costeffective way to gather accurate topographic map information without ground control or aerial triangulation. The Applanix Corporation's Position and Orientation Solutions for Direct Georeferencing of aerial photography was used in this project to examine the positional accuracy of integrated GPS/INS for rough terrain mapping in Glen Canyon, Arizona. The research application in this study yielded important information on the potential of airborne integrated GPS/INS data-capture systems for deployment to Antarctica.

Introduction

Over the past decade, several publications have confirmed the potential of utilizing the Global Positioning System (GPS) and inertial navigation system (INS) technology for the direct observation of exterior orientation data (Schwarz, 1993; Ackerman, 1995; Skaloud, 1996). Increasingly, onboard GPS/INS data collection is part of the service offered by aerial companies. Many software systems can now access such data to reduce or eliminate the need for ground control points. In many cases, it is the enabling technology for the collection of light detection and ranging (lidar), synthetic aperature radar, and multibeam sonar data. It was not until recently that the remote sensing and photogrammetric mapping community gave serious attention to using integrated GPS/INS technology to measure camera attitude to an accuracy that permits photogrammetric mapping without conventionally determining the camera exterior orientation parameters from aerial triangulation. The process of direct observation of exterior orientation data with airborne integrated GPS/ INS is often referred to as "direct measurement," "direct sensor orientation," "direct exterior orientation," and "direct geocoding." However, throughout this paper, the authors will refer to this process by the more widely used term "direct georeferencing."

Many earth science mapping applications, especially in rural or remote areas, can be realized more efficiently and economically with the reduction of ground control and tie point data. This can be achieved by direct georeferencing of the exterior orientation of an imaging sensor using an integrated system comprising a GPS receiver and an INS component. The GPS produces precise positions that are subject to errors arising from loss of satellite lock and resolution of phase ambiguities. Information from the INS can be used to correct these errors while the GPS data are used to continuously calibrate the INS. Hence, when used together, the two components may provide an appealing solution to positioning and orientation problems in mapping applications. Nevertheless, the use of this technology is not without its own technical problems, and an understanding of its limits and usefulness is critical for addressing mapping applications. A crucial issue to mapping applications and direct georeferencing is the accuracy, scale, and consistency achievable by an integrated system.

Numerous documented GPS/INS-related field tests have been conducted over the years (Cramer, 1999; Cramer, Stallmann, and Haala, 2000). These tests were flown over well-surveyed sites and were carefully evaluated by private and public institutions in collaboration with Applanix Corp. The results from these tests, which measured the difference between the Applanix Position and Orientation Solutions for Direct Georeferencing (POS/DG)-computed camera orientation and the camera orientation obtained from aerial triangulation, demonstrated reliable performance. Although the difference of GPS/INS-derived omega, phi, kappa, (ω, Φ, κ) from aerial triangulation angles gives a good measure of GPS/INS performance, it does not allow the separation of GPS/INS errors from aerial triangulation errors (Hutton, Savina, and Lithopoulos, 1997). A better gage of performance is to apply GPS/INS-derived values to the exterior camera orientation plus the camera interior report parameters using digital photogrammetric software and then to compare the accuracy of terrain mapping with the well-surveyed reference points visible in the image (Abdullah, 1997). The purpose of this project was to test the terrain-mapping accuracy of Applanix POS/DG in an area of rapidly changing relief using this approach.

Project Test Area

The regional location of the project area was in the southernmost part of Glen Canyon, a section of the Colorado Plateau and canyon lands of Arizona and Utah formed by the Colorado River (fig.1). The marked change in relief in this area provided an excellent test for measuring the potential of GPS/INS for terrain mapping and ultimately providing agencies like the USGS's Grand Canyon Monitoring and Research Center (GCMRC) a continuous source of reliable data to study landscape and habitat changes along the Colorado River corridor. The canyon lands, which date back nearly 2 billion years on



Figure 1. Project area is located between Page and Lees Ferry, Arizona.

the bottom and 250 million years at the top, are a rough succession of resistant beds forming deep, narrow gaps with vertical and overhanging cliffs separated by slopes and valleys carved out by the Colorado River beginning 5 to 6 million years ago (Zimmer, 2001). During 1869 to1872, U.S. Army Major John Wesley Powell explored the Glen Canyon as part of the expedition of the Colorado River (Powell, 1875). As many a fisherman and passerby will affirm, the cliffs, riverbanks, and sandbars of the canyon offer nesting places to rock wrens, canyon wrens, peregrine falcons, ravens, and high-flying condors. Since the completion of the Glen Canyon Dam in 1963, the water temperature downriver averages 46° F (8° C) year round. This constant flow of clear, cold tail water, along with the introduction of trout and shrimp-like scuds, eliminated most of the native fish, such as the Colorado squawfish and the humpback chub (Ray Hall, U.S. Park Ranger, oral commun., September 26, 2001). The damregulated flows decreased the sediment supply and have affected the habitats of the endangered willow fly-catcher and Kanab ambersnail. The canyon's ecosystem and desert environment are also home to deer mice, pocket mice, packrats, spotted skunks, ringtail cats, gray foxes, beavers, bobcats, coyotes, jackrabbits, antelopes, squirrels, badgers, and mule deer. Seasonal wildlife includes a large population of ducks and some Canadian Geese. Plants such as joint-fir or Mormon Tea (Ephedra), Horsetail (Equisetum L.), salt cedar or Tamarix (Tamarix gallica), and varieties of cacti dominate the canyon ecosystem (Gaines, 1957).

Direct Georeferencing Concept

The determination of the exterior orientation parameters is a fundamental requirement for the geometric evaluation of terrestrial and remotely sensed images. Conventionally, this is accomplished by an indirect approach of applying a number of known ground control points and their corresponding image coordinates. Using a mathematical model for the transformation between object and image space, we can calculate the exterior orientation to relate the local image coordinates to the global reference coordinate system. This process is accomplished with the spatial resection of single images, a method that is generalized to an aerial triangulation of multiple frames or images (Skaloud and others, 1996). The photogrammetric collinearity equations are applied to connect overlapping images by means of tie points and to relate the local model coordinates to the global reference coordinate system through control points. Consequently, exterior orientation parameters for the perspective center of each image can be estimated as one group of the unknown parameters within a least squares adjustment.

In the direct approach, the GPS and the inertial measurement unit (IMU) provides measurement of the true physical position and orientation of the camera or sensor (Schwarz and others, 1993). Unlike the indirect approach of aerial triangulation, the exterior orientation parameters are determined independently of the camera or sensor. Before using the position and orientation components (GPS antenna and IMU) for sensor orientation, we must determine the correct time, spatial eccentricity, and boresight alignment between the camera coordinate frame and IMU. The calibration of the GPS/IMU and camera is vital since minor errors will cause major inaccuracies in object point determination.

System Configuration and Calibration

Sensor Configuration

The commercial airborne integrated GPS/INS used in this project is the POS AV 310 from Applanix Corp., Richmond Hill, Ontario, Canada. The POS AV-DG package comprises four main components: (1) a dual-frequency L1/L2 carrier phase embedded GPS receiver (NovAtel MiLLennium), (2) a POS IMU, (3) the POS computer system, and (4) the POS/ DG postprocessing software. Several occupied geodetic monuments (Airport, T96, Davian, Signal Hill, Navajo Point, Flagstaff NCMN, and L404) along the canyon rim served as base stations. In addition, 11 aerial panel points with documented horizontal and vertical coordinates were placed along the flight corridor to test the accuracy of the POS/DG position and height information later. For the test, the POS IMU was rigidly mounted on a Wild RC30 aerial camera. The GPS antenna was centered above the camera on top of the fuselage of the National Oceanic and Atmospheric Administration's (NOAA) Cessna Citation jet. The integration of the collected POS/DG raw data was computed at the camera perspective center using the Applanix POS/DG Post Processing software.

Boresight Calibration

The spatial offsets between the different sensor components have to be identified to relate the position and orientation information provided by the GPS/IMU to the perspective center of the camera. The angular and linear misalignments between the POS IMU body frame and the imaging sensor are referred to as "boresight" components. Immediately after the actual fly-over of the Glen Canyon project area, the test flight for the boresight calibration was carried out over a well-surveyed range in the nearby Hopi Reservation. Aerial photographs were collected at a flying height of 1,524 m (5,000 ft) and a photographic scale of 1:10,000. Three rows of 7 targets consisting of 21 photographs with 60 percent forward and 30 percent side overlap were collected. The test range covered a 4.5- x 14.8-km (2.8- x 9.2-mi) area. Static GPS data were collected using several base stations (Airport, T96, Davian, Signal Hill, Navajo Point, Flagstaff NCMN, and L404) located near the test range to check for any systematic errors caused by different baseline length. To resolve the boresight transformation, the National Geodetic Survey (NGS) compared the GPS/IMU positioning/orientation results with the aerial triangulation solution. The NGS then used data from the POS/DG and aerial triangulation from the flight to resolve the fixed misalignment angles between the IMU and the camera.

Terrain Mapping

The NOAA carried out the overflight of the project area on September 6, 1999, at altitudes between 3,200 to 3,500 meters (10,500 to 11,500ft). The acquired misalignment angles from the Hopi Range test flight were applied to the POS/DG data, and the camera perspective center coordinates (in easting, northing, and elevation) and the camera orientation parameters (in angles ω , Φ , κ) were computed by Applanix. The POS/DG-computed data at camera perspective center, as well as the camera's internal geometry and lens characteristics, were then applied by the USGS to geometrically correct the scanned aerial frames (4027 through 4032, see fig. 2) using the Softcopy Exploitation Tool Set (Socet Set) software (Socet Set is a trademark of BAE Systems Solutions, Inc.).

Surveyed Reference Points

To synchronize with the POS/DG data collection and to know the precise grid coordinate of any point in the project area, a field team directed by the GCMRC placed 15 aerial panels along the corridor of the Glen Canyon before the overflight. Many of these panels were placed over old survey markers. To validate the positional accuracy of the panels, the U.S. Geological Survey (USGS) conducted static surveys of these old monuments in September 2001. The selected points were occupied for over 30 minutes at 5-second intervals using two Ashtech Z-12 receivers. Simultaneous collection from the Flagstaff (FST1) Continuous Operating Reference Station (CORS) at 5-second intervals provided the RINEX files (range and



Figure 2. Coverage of aerial frames applied in the evaluation.

carrier phase or binary measurements, predicted orbital coordinates or ephemeris data, and site information files) used in the postprocessing with Ashtech Solutions version 2.5. Traditional setup of the antenna over the survey marker was used in these static surveys. For geodetic coordinates and details about each survey marker revisited, see appendix A of this report.

In addition to their use as panel points, the survey markers in the Lees Ferry area proved invaluable for checking the accuracy of auxiliary GPS instruments. The Ashtech Z12 GPS rover and the simultaneous collection of FST1 CORS produced postprocessed differentially corrected positions that were used in determining the horizontal and vertical accuracy levels of the auxiliary GPS instruments. Experimentation with an OmniSTAR Model 3000LR12 (an integrated RT-DGPS system for GPS observations and reception of broadcast range correction) produced differentially corrected positions with horizontal and vertical accuracies at the submeter level. The Rockwell PLGR II with PPS for point positions determined by autonomous methods produced horizontal and vertical accuracies in the decimeter-to-meter range. (See appendix B).

Comparison with Survey Reference Points

Three stereoscopic models were generated with Socet Set photogrammetric software using the POS/DG computed data and the camera's report parameters (fig. 3).

In each stereomodel, a thorough examination for undesirable y-parallax or disparity was conducted by moving between the river corridor and the canyon rim of the interior and corners of the stereomodel, respectively. The results varied from negligible to excessive. In one model the effect of y-parallax made it difficult to perform reliable measurements. Absolute orientation was then examined using the horizontal and vertical coordinates of the visible panel point in the three models and the values

REPORT OF THE FIFTH SCAR ANTARCTIC GEODESY SYMPOSIUM



Figure 3. The flow process applied in this study for generating the stereomodels for testing the accuracy of Position and Orientation Solutions for Direct Georeferencing of aerial photographs.

of their corresponding surveyed reference positions. The difference between the logged surveyed reference positions and corresponding panel points displayed in the stereoimage were measured on the digital photogrammetric workstation. The difference was determined by subtracting the values of the panel point from the surveyed reference position. The measured panel point values in the stereoimage were roughly parallel to the ground level at an average vertical positional bias of +2.59 m. Figure 4 and table 1 show the results of the comparison of the panel point coordinates in the stereoimages against the values of the logged survey referenced positions.



Figure 4. Difference, in meters, between coordinate values of ground-surveyed reference points and corresponding panel points measured on the digital photogrammetric workstation.

A comparison using the same ground-surveyed reference points shown above with Aeroscan ALMS lidar data collected by the GCMRC in late March 2000 at a flight altitude of 3,048 m (10,000 ft), with a pulse rate of 15 kHz and a scan rate of 13 Hz, showed a lower vertical positional

REF.	PANEL #	Delta X	Delta Y	Delta Z
1	6BC	+0.07	+0.19	+2.48
2	114	- 0.02	- 0.05	+3.28
3	115	+0.19	+0.24	+3.02
4	211	+0.56	+0.16	+3.11
5	212	+0.16	+0.08	+1.88
6	214	+0.19	+0.35	+1.78
7	G307B	- 0.02	- 0.03	+2.58
Av	erage	+0.16 m	+0.14 m	+2.59 m

Table 1. Statistical rundown of the difference between the ground-surveyed reference points and corresponding panel points measured on the digital photogrammetric workstation.

bias (0.21 m to 0.55 m) than those found in the processed POS/DG of aerial photographs. Although there was some improvement in the vertical accuracy of the DG lidar system measurements, the lower vertical positional bias of the lidar data still does not meet accuracy standards for large-scale mapping and could result in significant errors in studies related to volume determination.

Discussion Of Results

Although the horizontal positioning results proved accurate, the higher than normal vertical positional bias results of this study do not meet National Mapping Accuracy Standards (NMAS) or American Society of Photogrammetry and Remote Sensing (ASPRS) accuracy standards for large-scale mapping. Other authors made comparable findings (for example, Cramer, 1999; Colomina, 1999; and Greening and others, 2000). Greening suggested 1:8,000 scale as the "lower limit below which airborne GPS errors can become relatively dominant to the point where a significant reduction in the number of ground control is not possible."

Several factors may have contributed to the higher than normal vertical positional bias between the coordinate values of surveyed reference points and corresponding aerial panel positions in the image. The most demanding applications of large-scale airborne mapping, with required mapping accuracy at the 10- to 20-cm range, call for higher precision of the exterior orientation, which is largely dependent on the imaging sensor and flight altitude. In this study, a 153-mm calibrated focal length of the Wild RC30 and high-flying height of 3,200 to 3,500 m (10,500 to 11,500 ft) was used. In accordance with a typical soft C-factor (Light, 1999), a suggested minimum of 1,000 m (3,300 ft) flight altitude with the 153-mm focal length camera may have resulted in lower RMS values and achieved a higher precision desirable in large-scale mapping. Further, the aerial photographs flown separately for the boresight calibration were collected with the same camera, but at a flying height of 1,524 m (5,000 ft), which may have caused a shift in the Z value. The influence of ground position errors resulting from imaging sensors and flight altitudes have been dealt with in detail (Greiner-Brzezinska, 1999).

Another problematic concern of GPS/INS-derived position orientation data is the stereo-model residual parallax issue. During the setup of the stereomodels, it was found that the y-parallax varied significantly. In one of the models, the effect of y-parallax made it awkward to take reliable measurements. The y-parallax disparity took the form of an unusually high average difference between the coordinate values of surveyed reference points and corresponding panel points, as well as imperfect, out-offocus three-dimensional images in the display of the digital photogrammetric workstation.

Several geodetic factors also may have contributed to the high RMS values in the exterior orientation solution. Because of the marked difference in canyon relief and changes in bedrock

Densities, there exists a "deflection of the vertical" (that is, an angle of departure of the gravity vector from the corresponding ellipsoidal normal). In the canyon area where there are marked geoidal undulations, the separation between the geoid and ellipsoid can vary rapidly and in a nonlinear manner.

Although the lidar data results were lower in vertical positional bias than those found in the processed POS/DG of aerial photographs, several factors may have played a part in their high elevation measurement. These factors range from the lidar processing algorithms to the source of beam. Factors originating from the source of the beam include problems with the

- 1) lever arm and GPS position,
- 2) INS gyros (drift and alignment),
- 3) laser frame (misalignment in INS),
- 4) scanning (mirror), and
- range (timing, bias, noise). Any of these factors not being adjusted properly may have resulted in mismatched profiles and introduced elevation errors.

Recommendations

The higher than normal vertical positional bias results of this study did not meet large-scale mapping accuracy standards. It is important to keep in mind the limitations of airborne integrated GPS/INS mapping technology and to balance the criteria for its use against practical considerations of large-scale mapping in canyon-like or mountainous terrain. For the time being, precision large-scale mapping of 1:8,000 scale or better will require a combination of airborne GPS/INS and aerial triangulation to exploit the benefits offered by direct external orientation data and minimize potential mapping accuracy limitations.

Additional research is needed to examine the

- influence on mapping accuracy of geodetic complexities in areas of marked changes in relief and therelationship of IMU performance to significant gravity anomalies and deflection of the vertical;
- (2) output of POS/DG computed data at camera .perspective center in a Cartesian coordinate system

to replicate the true spatial geometry of the object space;

- (3) large scale mapping application of the "Total Orientation Procedure" concept (Colomina, 2000) for optimal sensor orientation using a combination GPS/INS and aerial triangulation;
- (4) adequate rigidity in the relationship between IMU and camera reference frame; and
- (5) accuracy limits of GPS-aided INS of LiDAR data for meeting NMAS and ASPRS standards

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Appendix A

Field Record Summary -	Glen Canyon 9/24-27/01
------------------------	------------------------

SITE	COORDINATES1	SURVEY MARKER	STAMP MARKING
NAME			
GCP 6BC	LAT: 36° 52' 28.66827" N.	92.5 mm in	BUREAU OF
. ·	LON: 111° 33' 27.78332'' W.	diameter brass	RECLAMATION
	ELLIP. HT: 939.401 meters	. survey marker	
000.011	MSL: 962.824 meters	00 F	
GCP 211	LAI: 36° 51' 48.14314" N.	92.5 mm in diameter hmos	
	LON: 111° 34° 37.31705" W.	Giameter Drass	GEODETIC SURVET
	MSI - 960 055 motors	Survey marker	
GCP 212	LAT: 36° 51' 57.56024" N	60 mm in diameter	BANNER INC.
	LON: 111° 35' 12.31421'' W.	aluminum survey	
	ELLIP. HT: 930.269 meters	marker	
	MSL: 953.664 meters		
GCP 214	LAT: 36° 51' 48.23613" N.	12.7 mm in	NO STAMP
	LON: 111° 35' 55.43807'' W.	diameter	MARKING
	ELLIP. HT: 939.976 meters	unthreaded rebar	
	MSL: 963.352 meters		
GCP 114	LAT: 36° 53' 11.18031" N.	92.5 mm in	BUREAU OF
	LON: 111° 31' 51.77007'' W.	diameter brass	RECLAMATION
	ELLIP. HT: 951.340 meters	survey marker	
CCD 115	MSL: 977.784 meters	No our our modern	
GCP 115	LAT: 30' 53 10.41023 N.	Y 10×10 Bidr DI 9.	MARKING
	EUN: 111 31 10.30107 VV.	mile	MARRING
	MSL: 971.383 meters		
GCP G307B	LAT: 36° 52' 28.89023" N.	No survey marker:	
	LON: 111° 34' 00.98043" W.	photo location RL	MARKING
	ELLIP. HT: 935.380 meters	-	
	MSL: 958.799 meters		

APPENDIX B POSITIONAL COMPARISON OF GROUND CONTROL POINT #214 (NAD83/GRS-80)

Ashtech Z-12* (STATIC SURVEY)	OmniSTAR LR12 (RT-DGPS)	Difference, in meters
Lat: 36° 51_48.23613_N	36° 51 48.195 N	0.662
Long: 111°35_55.43807_W.	111° 35 55.463 W.	-0.583
Ellip. Height: 939.976 m	939.692 m	-0.284
	PLGR II	

(PPS)

36° 51 48.15 N.

111° 35 55.60 W.

GCP #214

GCP #214 Old Coordinates

945 m

1.386

-3.779

-5.024

(Unknown method)

36° 51_	48.23_N	0.099
111° 35	55.44 W.	-0.045
9	39.280 m	-0.684

Processed Image Display Coordinates

(Socet Set Workstation)

36° 51_ 48.258_ N	-0.354
111° 35_ 55.446_ W.	-0.187
941.760 m	-1.784

* GPS static data collected at 5-second data rate on September 25, 2001; post-processed with corresponding RINEX file downloaded from NGS National FTS1 CORS Web Site

VLNDEF Network for Deformation Control and as a Contribution to the Reference Frame Definition

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Abstract

VLNDEF (Victoria Land Network for DEFormationn control) Geodetic Program is within the activity of GIANT (Geodetic Infrastructure of Antarctica) SCAR (Scientific Committee on Antarctic Research) Program. Moreover the geodetic activities are established within the actions of ANTEC (ANTarctic NeoTECtonics) SCAR (Scientific Committee on Antarctic Research) Group of Specialists. During 1999-2000 and 2000-2001 Italian expeditions was established and completely surveyed a network of 27 stations, over an area of 700 km northward and 300 km westward. The average distance between vertexes is in a range of 70-80 km and covering the area from TNB (Terra Nova Bay Italian base) to the Oates Coast [1,2].

In 2002-03 campaign the repetition of the whole network has been made.

Due to the long connections involved, session duration of about 48 hours was initially planned; this duration was recently increased and session duration in 2002-03 campaign was around 7 days; in agreement with Scientific International Community guidelines and thanks to the increased storage capabilities, time series of about 20-50 days were also collected on selected vertexes.

In the area the TNB1 GPS permanent station is operating since the 1998 when it was installed in proximity of the Italian summer station at Terra Nova Bay [3]. Data collected during the survey operations over the VLNDEF points have been fully processed in the attempt to constrain solutions within a specific reference frame. A subset of TNB1 data have also been requested by the scientific community in the frame of the SCAR GPS epoch campaign and in the realisation of the new International Terrestrial Reference Frame year 2000. Basically the TNB1 data processing is performed by means of the scientific Bernese GPS software Version 4.2. TNB1 Data are routinely processed in addition to 7 Antarctic IGS (International GPS Service for Geodynamics) permanent stations in order to strength the results within a specific ITRF. Results, integration with data from provided by other peri-antarctic GPS permanent stations and an attempt in the evaluation of the regional displacement are here presented.

Preliminary results of VLNDEF surveying repetition and deformation analysis are presented.

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A Project on Local Ties and Co-locations in Antarctica

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Abstracts

Co-locations between Space Geodesy techniques are nowadays fundamental for global geodetic multitechnique products (e.g.: ITRF, EOP). When colocations involve tide gauges and other geophysical instruments, the importance of geodetic observatories increases, widening the research field and the scientific perspectives. In order to be effective, co-locations must be accurately measured with efficient and comprehensive local ties performed with terrestrial measurements. Work is being done on this subject and a few methodologies have already been tested and presented. Geoscience Australia and the Italian Institute of Radioastronomy-
CNR have separately developed methodologies capable to produce SINEX files for co-located Space Geodesy techniques. The information contained in SINEX files is fundamental for a complete and rigorous approach to techniques combination.

These SINEX have been used or tested for ITRF2000 computation and results have been very encouraging. Starting from this positive experience and making use of the knowledge acquired on this topic, we have decided to start a new project in one of the most inacessible and unknown parts of planet earth: Antarctica. The quality of scientific information coming from this region has to be of the highest level and its quantity possibly increased: it is fundamental for a good understanding of global geophysical processes. With this presentation, we are reviewing the most recent situation that concerns the Antarctic co-locations and the amount and quality of information currently available. We are also presenting the joint Italian-Australian project on local ties that we hope will be soon part of the GIANT programme.

Accomplishment of Topographic-Geodetic Research Works in Antarctica

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Abstract

During the period of 1995-1999 through the efforts of specialists from the 17 countries in accordance with the GIANT program, there had been created a global geodetic GPS network of Antarctica (ITRF) which included 45 points (ellipsoid WGS-84). At present, specialists of the Russian Federation have started the development works on the territory of Antarctica with the aid of satellite means and methods of fundamental astronomic-geodetic network (FAGN) and high-precision geodetic network (H-PGN). In the accomplishment of satellite observations, the two-frequency aligned (combined) receivers GLONASS/GPS "Javad" (USA) are used. Observations of fragments FAGN and HPGN are carried out using the network method of carrying out performances of simultaneous measurements on a great number of points. In addition to the points

situated on the territory of Antarctica, the observations are also carried out on the points situated in Moscow, St. Petersburg, Irkutsk, Khabarovsk. Simultaneously with the satellite observations on points FAGN and H-PGN, gravimetric observations are carried out. While creating FAGN and H-PGN their connection with the existing global GPS network was ensured. A preliminary processing of the results of satellite measurements is accomplished using software: Pinnacle, GPSurvey, Trimble GPLoad. The catalogue of the coordinates of points FAGN and H-PGN is presented in the system ellipsoid WGS-84. The main aim of these research works is revealing tidal signals of GPS observations and determining exact coordinates, heights, speed of movement and deformation of glacier (ice) surface in the region under research.

On the Randomization of GNSS Solutions

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Abstract

Time series of GNSS solutions are quite specific. The variations in it have a complex structure. Besides a random part they contain also components of a chaotic character as well as biases. Models errors, non-modelled effects and varying satellites configuration cause systematic variations in GPS solutions. The analysis of such time series indicates the existence of a number of periodic components and trends that are not modelled in data processing stage. In particular, periodic variations with dominating 12h and 24h periods are distinguished. Numerous changes (jerks) in satellite configuration occur

with a period of one sidereal day. They cause specific variations in time series of the components of computed vectors from GPS data. Variations in such a time series correspond rather to a chaotic process then a random one. Jerks can be suppressed by optimising the length of overlapping sessions and eliminating the disturbing results.

In this study a new method of suppressing the variations in GNSS solution due to changes in satellite configuration is presented. This realization of bootstrap method have been adapted to GNSS software.

Optimization of Geodynamic Network on the Argentina Islands Neighbouring Vernadsky Antarctic Station

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Abstract

According to the results of paleomagnetic, magnetometric and geological-tectonic researches there are obtained considerable differences in the tectonic structure of the archipelago Argentina islands. Geodetic methods, namely

local GPS-networks can add and provide with new information about modern geodynamics of the Antarctic Peninsula. Mainly it concerns to the territory of Argentina Islands contiguous to Ukrainian Antarctic station "Academic Vernadskyy". With this purpose in the frame of seasonal 8-th Ukrainian Antarctic expedition (February-March 2003) in the district of Antarctic station "Academic Vernadskyy" it was created the precise geodetic network of ambient islands by the join efforts of scientists of National University "Lvivska Politechnika" (K. Tretyak, V. Glotov) and Close Corporation "ECOMM" (J. Ladanovskyy, P. Bahmach). The network was developed not only with purpose to study the deformations and movements of the earth's crust on the territory of Antarctic peninsula but also for creation of control geodetic network for implementation of topographical-geodetic works on the station "Academic Vernadskyy" which is located in the north part of Antarctic peninsula (south latitude B=65015', western longitude L=64015').

Created geodynamic network covers north-eastern contiguous in the radius of 15 kilometers islands and the part of continent. The network is based on 8 geodetic station. The centers of stations are seated in the basement of rocks. The eccentricities of antennas of the phase centers were determined simultaneously on the special hard base for receivers Leica SR-399, SR-9500 and Trimble 4600LS before the beginning of observations.

The measurements were implemented from 12 to 28 of February with use of three double frequency GPS-receivers (firm Trimble 4800 and firm Leica SR-399 and SR9500) and single frequency receiver Trimble 4600LS.

Receiver Trimble 4800 was working during all time on the station VER1 in the mode of temporary permanent station. Duration of vectors measurements varies from 2 to 12 hours depending on weather conditions and transport limitation. For increasing of trustworthiness and accuracy of determination of station coordinates in the measured vectors it were applied the correction of eccentricities of the phase centers of GPS-antennas and it was fulfilled a posteriori network optimization.

In the result of considering of eccentricities of the phase centers of GPS-antennas and a posteriori network optimization the maximum errors of determination of plane coordinates of stations decreases from 5,7mm to 4,3 mm, and mean error from 2,9mm to 2,4mm. Maximum error of altitude determination decreases from 7,3 to 5,5 mm, and mean error from 3,9 to 3,2 mm. In percentage ratio maximum errors decrease on 25% and mean errors on 15%. Optimized network is more homogenous according to the accuracy.

It should be mentioned that relative error of determination of vector of station displacement after implementation of equal according to accuracy next circle will be approximately 3*10-7. Taking into account that values of velocity of the earth surface deformations in the plane and seismic not active regions is 10-7 1/year and in mountain region is 10-6-10-5 1/year, then already in the next year on the assumption of repeated measurements it can be obtained the reliable quantitative parameters of passing of modern deformation processes in this region. It will allow to improve the modern regional geodynamic model of the Antarctic peninsula.

Geoid Estimation on Northern Victoria Land

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Abstract

A program for local geoid determination through gravimetric measurements was started in Victoria Land [1], in an area located around the Italian base Terra Nova Bay. The program started an activity planned on a more extended area, with the aim to evaluate an high accuracy geoid for all northern Victoria Land.

Points distributed on a regular grid of 3.75' latitude and 15' longitude, corresponding to an average distance of 10 km, were measured in Mount Melbourne and Mount Murchison area. Moreover sparse points were measured around the planned grid.

The positioning of gravimetric stations has been made by precise GPS method in order to obtain a decimeter accuracy in coordinate determination. This accuracy, overall for the height, is fundamental for high accuracy geoid estimation. The gravimetric closure has been made on IRGS (Italian Relative Gravity Station) located at Terra Nova Bay. Gravimetric data will be reduced using the DTM from BEDMAP project for the interior and using the DEM generated by INSAR surveying along the coast. Preliminary results of local geoid estimation are presented.

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Gravity Anomalies and Geoid Heights Derived from ERS-1, ERS-2, and TOPEX/ POSEIDON Altimetry in the Antarctic Peninsula Area

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Abstract.

Gravity anomalies in the area between the Antarctic Peninsula and South America were determined using satellite altimetry observations of the Sea Surface Heights over this region. The satellite data applied in the analysis include ERS-1, ERS-2, and TOPEX/POSEIDON altimetry from 1992 to 2001. The solutions for gravity anomalies and geoid heights at (2'x4') and (3'x3') grid points, respectively, are evaluated by the Tikhonov regularization method. The estimation is based on the kernel functions described by singular point harmonic functions. Comparison with the independent KMS99 and KMS01 solutions of the Geodetic Division of the Danish National Survey and Cadastre was performed.

1. Introduction

This paper represents further continuation of the recent study by (Marchenko and Tartachynska, 2003) on the inversion of the Sea Surface Heights (SSH) into the gravity anomalies Δg in the closed region of Black sea and will focus here on the recovery of the gravity anomalies Δg and geoid heights N from the ERS-1, ERS-2, and TOPEX/POSEIDON altimetry (SSH) in thôse marine part of the region between the Antarctic Peninsula and South America. Computations of the gravity anomalies and geoid heights from the combination of ERS1, ERS2, and TOPEX/POSEIDON Sea Surface Heights (SSH) in the area at longitude from 60°W to 70°W and latitude from 60°S to 70°S are discussed, where the Ukrainian Antarctic station Vernadsky is located in the central part of the chosen region.

The following data sets corrected by CSL AVISO for different geophysical and instrumental effects are used:

- subset 1 represents 63660 ERS1 Sea Surface Heights corrected by AVISO and taken for the period from October 1992 to June 1996 of the ERS-1 mission;
- subset 2 represents 13'x3'119 values of the corrected ERS2 SSH taken for the period from April 1995 to September 2001 of the ERS-2 mission;
- subset 3 represents 361175 TOPEX-POSEIDON corrected SSH also extracted from the AVISO database and taken for the period from October 1992 to October 2001 of the TOPEX/POSEIDON mission.

The first 3'x3'E1E2TP solution for gravity anomalies and geoid heights is evaluated at the coordinates of the KMS2001 (3'x3') grid points over the marine part of studying area by means of the Tikhonov regularization method using kernel functions (analytical covariance functions) described by singular point harmonic functions. The dependence of the regularization parameter on the variance of the studying field and the variance of the noise is considered. An optimal kernel function was adopted as the modified Poisson kernel or the so-called dipole kernel. The second 2'x4'E1E2TP solution at the coordinates of KMS1999 (2'x4') grid points was constructed especially for further comparison with the KMS1999 gravity anomalies inverted by FFT method in the Geodetic Division of the Danish National Survey and Cadastre from multimission satellite altimetry data (see, Andersen and Knudsen 1998; Knudsen and Andersen, 1998). The comparison of 3'x3'E1E2TP geoid heights with KMS2001 3'x3' solution is analyzed.

2. Method

As before (Marchenko, and Tartachynska, 2003) the traditional "remove-restore" procedure was used to get the initial information δN for further determination of the gravity anomalies Δg :

$$aN = SSH - N_{EGM96},\tag{1}$$

where SSH are the corrected Sea Surface Heights, assumed to be coincided with the geoid height N: N_{EGM96} is the long wavelength part of N adopted according to the EGM96 gravity field model (360, 360).

Then the prediction of the residual gravity anomalies $\delta \Delta g_{\rm p}$ and the residual geoid heights $\delta N_{\rm p}$ was estimated at some point *P* (preferably inside the studying area) applying the regularization method

$$\ddot{\mathbf{a}}Ag_{\mathrm{P}} = \mathbf{C}_{\mathbf{a}A\mathbf{g}\mathbf{a}N} (\mathbf{C} + \alpha \mathbf{C}_{\mathrm{nn}})^{-1} \mathbf{I}, \qquad (2)$$
$$\delta N_{\mathrm{P}} = \mathbf{C}_{\mathbf{a}N,\mathbf{a}N} (\mathbf{C} + \alpha \mathbf{C}_{\mathrm{nn}})^{-1} \mathbf{I}, \qquad (3)$$

where 1 is the q-vector consisting in this case of the components δN_i (i = 1, 2, ...q); q is the number of the observations δN_i ; C is the $(q \times q)$ - covariance matrix of the residual geoid height δN ; $C_{\Delta\delta g,\delta N}$ is the $(1 \times q)$ - cross-covariance matrix between $\delta \Delta g$ and δN ; $C_{\delta N,\delta N}$ is the $(1 \times q)$ - cross-covariance matrix of δAg and δN ; $C_{\delta N,\delta N}$ is the $(1 \times q)$ - covariance matrix of the measurements noise **n**; α is the Tikhonov regularization parameter (Neyman, 1979; Moritz, 1980; Marchenko and Tartachynska, 2003).

Having the values (1) at some set of scattered points and the above covariance matrixes, the residual gravity anomalies $\delta\Delta g$ and the residual geoid heights δN can be estimated straightforward at chosen grid points by the regularization method. After solving this basic problem the predicted gravity anomalies Δg and geoid undulations N can be restored at the same grid by means of the EGM96 gravity field model

$$\Delta g = \Delta g_{\rm EGM96} + \delta \Delta g_{\rm eGM96} \tag{4}$$

(5)

$$N = N_{\rm EGM96} + \delta N_{\rm .}$$

For further use of the relationships (2), (3) the following problems have to be solved:

- 1. The construction of the analytical covariance function K(P,Q) of the anomalous potential T.
- 2. The choice of a suitable method for the computation of the regularization parameter α .
- 3. Preprocessing or prediction of 19959 regular distributed SSH values by the collocation method at 3'x3' grid points, because of a large total number (=557954) of observations.

The analytical covariance function or reproducing kernel K(P,Q), described only by singular point harmonic functions (Marchenko and Lelgemann, 1998; Marchenko, 1998), is chosen in the following way

$$K_{\rm n}(P,Q) = \left[\frac{GM}{R}\right]^2 \beta_{\rm n} \sigma^{\rm n+l} \vartheta_{\rm n} , \quad \sigma = \frac{R_{\rm B}^2}{r_{\rm P} r_{\rm Q}} , \qquad (6)$$

where R is the Earth's mean radius; R_B is the Bjerhammar's sphere radius; r_p and r_q are the geocentric distances to the external points P and Q; GM is the product of the gravitational constant G and the planet's mass M; \bigcup_n is the dimensionless potential of eccentric radial multipole of the degree n; β_n represents some dimensionless coefficient. Expressions for the analytical auto-covariance function of geoid heights and cross-covariance function between gravity anomalies and geoid undulations (based on the covariance propagation) can be found in (Marchenko, 1998).

Note now that the traditional determination of the regularization parameter α in (2) or (3) according to (Tikhonov and Arsenin, 1974; Neyman, 1979) requires in the frame of a special iterative process the inversion of matrixes with a dimension equal to the number q of observations. So, when a number of observations are large we come to a time consuming procedure. As before (Marchenko, and Tartachynska, 2003) to avoid this difficulty another possible value of α is used

$$\alpha = 1 + \sqrt{1 + \text{Trace}(\text{CC}_{nn}) / \text{Trace}(\text{CC}_{nn})} , \quad (7)$$

leading to the estimation of prior to the matrix inversion in (2) and (3).

Simplest illustration of possible values of the regularization parameter given by (7) can be made under several assumptions. First one, geodetic measurements of one kind only are considered. Second one, the matrix C_{nn} can be represented as C_{nn} , dI where d is the variance of a noise and I is the unite matrix. Third one, the matrix C can be described by the Dirac delta function and can be written as $C=C_0I$, where C_0 is the variance of a studying field. With these assumptions the expressions for the regularization parameter corresponded to (7) are found as

$$\alpha = 1, \tag{8}$$

$$\alpha = 1 + \sqrt{1 + \frac{C_0}{d}}. \tag{9}$$

In fact, the first root (8) corresponds in (2) and (3) to the least-squares collocation solution. The second root (9) corresponds to the relationship (7) under the adopted assumptions and can serve for the illustration of a possible dependence of α on the given C_0 and d. Note again that the formulae (7) and (9) represent only possible upper limit of (Marchenko, and Tartachynska, 2003), which requires a further improvement of the considered estimation of α .

4. Results and conclusions

Removing the contribution of the geopotential model EGM96 (360,360) from altimetry data (SSH) the residual geoid heights δN were adopted as initial information. Then the empirical covariance function (ECF) of the residual geoid heights $\delta N = \delta SSH$ was constructed and approximated by the analytical covariance function (ACF) based on the radial multipoles potentials or ACF of the so-called point singularities (Marchenko and Lelgemann, 1998). As a result, the optimal degree n = 1 in the formula (6) was chosen from ECF approximation that corresponds to the dipole kernel function (Poisson kernel without zero degree harmonics). The optimal ACF has the following essential parameters: (a) the variance of the field $var(\delta N)=0.1214$ m_; (b) the correlation length $\xi=0.384$; (c) the curvature parameter $\chi=4.074$.

Then to avoid a large total number of observations (=557954) the computation of the regular distributed SSH values at 19959 (3'x3') grid points by the collocation method was made before the application of the relationships (2) and (3), using the nearest scattered SSH values around every grid point within the radius search = 5' (mean value of applied SSH for the prediction is equal 47) and Gaussian covariance function on this step. Fig. 1 illustrates such regular SSH data distribution at 3x3 grid points where predicted SSH values are known. In the following this regular (3'x3') grid was adopted as initial information for the recovery of the gravity anomalies and geoid heights by the Tikhonov regularization method to obtain the solution 2x4E1E2TP at 27342 (2'x4') grid points and the solution 3x3E1E2TP at 2'x4'356 (3'x3') grid points filled all studying area.

According to the expressions (2), (3) and (7), the prediction of the residual gravity anomalies $\delta \Delta g$ and the residual geoid heights δN was done by the regularization method at the adopted grids points with the resolution (2'x4') and (3'x3'), completely filled all marine part of the studying area. Note that the regularization parameter consists the value $\alpha = 3.55$ computed according to (7). Statistics of the estimated δN and $\delta \Delta g$ and their accuracy are shown in Table 1.

Accuracy distributions are shown in Fig. 2 and Fig. 3. Fig. 4 and Fig. 5 illustrate the gravity anomalies and geoid heights computed by the regularization method and based on the adopted 19959 (3'x3') grid values SSH, obtained preliminary from ERS-1, ERS-2, and TOPEX/POSEIDON altimetry (see, Fig. 1).



Fig.1. Distribution of the predicted at 19959 points SSH values of the (3'x3') regular grid

tatistics	δ <i>N</i> , m, (3'×3') grid	δΔg, mGal, (2'×4') grid
finimum	-2.81	-90.48
laximum	0.30	44.22
iean	-1.13	-15.81
tandard deviation	0.38	14.39

Table 1. Statistics of the predicted residual geoid heights δN and gravity anomalies $\delta \Delta g$ at (2'x4') and (3'x3') grid



Fig. 2. Accuracy of the geoid prediction from ERS-1, ERS-2, and Topex/Poseidon altimetry. Contour interval: 0.01 m



Fig.3. Accuracy of the gravity anomalies inversion from ERS-1, ERS-2, and Topex/Poseidon altimetry. Contour interval: 1 mGal

Intistias	3x3E1E2	I'P solution	2x4E1E2TP solution		
lausues	<i>N</i> , m	N, m ON, m		σΔg, mGal	
4inimum	3.22	0.04	-112.06	3.91	
4aximum	20.39	0.34	100.64	16.44	
4can	12.45	0.05	5.18	4.63	

Table 2. Statistics of the 2x4E1E2TP gravity anomalies and 3x3E1E2TP geoid heights restored at (2'x4') and (3'x3') grids, respectively, and their accuracy estimations

Table 3 illustrates the comparison of the constructed above 3x3E1E2TP geoid solution and 2x4E1E2TP gravity anomalies, obtained from ERS-1, ERS-2, and TOPEX/POSEIDON altimetry, with the (3) KMS2001 SSH and (2'x4') KMS1999 gravity anomalies derived also from multimission satellite altimetry data. Note here a good accordance of the 3x3E1E2TP and KMS2001 solutions in terms of the mean and standard deviations of the predicted geoid heights. Nevertheless, we get large differences between 2x4E1E2TP and KMS1999 gravity anomalies demonstrated by the Table 3 and Fig. 6. These discrepancies have rather a systematic character, which possibly connects with the initial data distribution (see Fig. 1). On the one hand, larger differences have located typically around islands and near the seashore where initial data may be absent and inverted gravity anomalies reflect mostly the results of the extrapolation. This conclusion has confirmed by the accuracy distribution of the geoid heights and gravity anomalies shown in the Fig. 2 and Fig. 3, respectively. On the other hand, such deviations may be caused by difference in the adopted methods of data processing. The Tikhonov regularization method was applied in this paper for the whole studying



Fig. 4. Gravity anomalies inverted from ERS-1, ERS-2, and Topex/Poseidon altimetry. Contour interval: 10 mGal



Fig. 5. Geoid heights from ERS-1, ERS-2, and Topex/ Poseidon altimetry. Contour interval: 0.5 m.

geographical region without any separation to cells and based on the ERS-1, ERS-2, and Topex/Poseidon data. In the case of (2'x4') KMS1999 solution the inversion of gravity anomalies was done by "piecewise processing" of multimission satellite altimetry within every (1° x 5°) chosen rectangular cell using FFT method (Andersen and

Statistic	N – N _{KM52001} , m	Δg-Δg _{KMS1999} , mGal
Minimum	-0.98	-89.46
Maximum	1.26	40.77
Mcan	0.03	-14.95
Standard deviation	0.16	8.72

Table 3. Comparison of the predicted (3) geoid heights and (2'x4') gravity anomalies with the KMS2001 and KMS1999 solutions, respectively



Fig. 6. Differences between (2'x4') inverted gravity anomalies and KMS2001 solution. Contour interval: 10 mGal

Knudsen 1998; Knudsen and Andersen, 1998). As a result, further improvement of the considered above solutions in the frame of the regularization method is expected after including gravimetry, GEOSAT altimetry, etc. data.

Acknowledgments.

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Tidal Observations at Faraday/Vernadsky Antarctic Station

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Abstract

The history and ongoing information on tide measurements at the Base F/Faraday/ Vernadsky Station, and future development of tide gauge are discussed. Faraday/ Vernadsky station has the longest time series of sea level changes in Antarctica. The British Antarctic Survey occupied a research station in the Argentine Islands from 1947 to 1996. The original hut was replaced in 1954 by a purpose - built geophysical observatory. The ownership of the Faraday Station was transferred to Ukraine in 6 February 1996, and renamed as "Akademik Vernadsky". Sea level observation is ongoing by the Ukrainian Antarctic Center. The station is equipped with an old float gauge and a more recent but simple technology pressure gauge provided by Proudman Oceanographic Laboratory (POL, UK). Since 2000, ongoing hydrological measurements were started at the Vernadsky (profiles of sea temperature, salinity and oxygen). The tide measurements development lays in provision of an ongoing tide gauge data program at Vernadsky including maintenance of the POL equipment. Aid in the upgrade of tide gauge equipment and data communication mechanisms. Tide gauge at Galindez Island (65° 15' S, 64° 16' W) included in Global Sea Level Observing System Development in the Atlantic and Indian Oceans to monitor long-term sea level variations due to climate change. The Proudman Oceanographic Laboratory is currently collecting the Faraday/ Vernadsky tide gauge records.

Current Results on the Investigation of GPS Positioning Accuracy and Consistency

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Abstract

Considerable progress observed in geodynamics research is mainly the result of development of measuring techniques. The qualitative results on crustal movements presented in some publications seem, however, to be at the level of their accuracy determination. A realistic estimation of the potential of the experiment is necessary to avoid false conclusions that may describe the non-existent occurrences (artefacts), especially when experiment is difficult or very expensive. Uncertainty of vector components estimation, obtained from processing GPS data using either commercial or scientific software, represents rather an internal consistency than the accuracy of positioning. The problem of reliable accuracy estimation of GPS positioning concerns all fields of surveying practice including GPS positioning for geodynamics. The strategy of GPS solutions quality analysis based on the concept of overlapped sessions with optimum length and temporal resolution is presented. The strategy was verified with use of data from the Antarctic and European permanent GPS stations processed with both Bernese and Pinnacle software packages. Numerical examples are given.

Keywords: Global Positioning System (GPS) – Positioning accuracy – Statistical analysis

Introduction

It is well known that the solutions for vector components or coordinates obtained from processing precise GPS data from different observing sessions vary usually much stronger than their precision estimate indicates. Standard deviations of GPS solutions provided by processing software reflect the internal consistency of data processed and the internal precision. In general they do not, however, indicate the actual accuracy of GPS positioning in the real scale (e.g. Dubbini *et al.*, 2003).

An extensive research is conducted to improve the precision of GPS solutions by using better models for GPS observations, and to improve the precision estimate (e.g. Teunissen, 2002). One approach is to study the variations of GPS solutions using data from permanent GPS stations. Time series of GPS solutions are particularly suitable for such investigations (Krynski and Zanimonskiy, 2002). The tools of statistical analysis and spectral analysis are useful to separate factors causing variations in GPS solutions and to estimate their magnitudes.

Time series of GPS solutions do not exactly represent a random process. The variations in GPS solutions have a complex structure. Besides a random part that is mainly due to observation noise they contain also components of a chaotic character as well as biases (Krynski *et al.*, 2002a). Model errors, non-modelled effects and varying satellite configuration, including multipath cause systematic variations in GPS solutions. In addition, due to non-linearity of the system, data noise generates biases in computed results. Missed cycles in integer ambiguity resolution and sudden changes in satellite configuration due to a rise of a new satellite or satellite's repair are the main sources of chaotic errors.

The choice of the method used to suppress disturbances in time series corresponds to their character, i.e. random or chaotic. Noise, external with respect to measuring system, is simply filtered out using the smoothing procedure that employs a rectangular window. The size of the window becomes a parameter to be determined. According to the classical procedure of time series processing, the optimum size of the window can be estimated at each filtering stage. The analysis of such time series indicates the existence of a number of periodic components and trends that are not modelled in data processing stage (Bruyninx, 2001; Poutanen et al., 2001; Krynski et al., 2002). Major part of the power spectrum of the variations is concentrated in diurnal and larger periods. In particular, periodic variations with dominating 12h and 24h periods (Krynski et al., 2000) are distinguished. Few hours' long periods in the spectrum are most probably the artefacts (King et al., 2002) caused by the effects that are dominated by random noise processes due to non-linearity of the system (Krynski and Zanimonskiy, 2002).

GPS solutions based on processing of as long as 24h sessions, that are common for establishing and maintaining geodetic reference frame and for geodynamic applications, are considered as ones smoothed off for daily and subdaily periodic biases. The use of shorter observing sessions with preserving high quality of GPS positioning as well as the improvement of real-time GPS positioning performance requires the investigation of periodic biases. their detection, their source specification and an attempt towards their modelling.

Due to a large amount of information contained in time series of GPS solutions based on overlapped sessions it becomes possible to apply statistical tests to detect outliers. Numerous sudden changes (jerks) in satellite configuration occur with a period of one sidereal day. They cause specific variations in time series of the components of computed vectors from GPS data with periods significantly smaller than one sidereal day, i.e. even of the order of 1h. Variations in such a time series correspond rather to a chaotic process then a random one. Jerks can be suppressed by optimising the length of overlapping sessions and eliminating the disturbing results (Krynski and Zanimonskiy, 2002; Cisak *et al.*, 2002).

In spite of jerks in GPS solutions the continuous change of satellite constellation causes smooth changes of parameters of measuring process, i.e. signal to noise ratio, atmospheric delays, multipath, orbit corrections, etc. High regularity of changes in satellite constellation makes all those variations periodic with a half of sidereal day period. Spectral and correlation analysis of time series of GPS solutions shows the existence of such period (Krynski *et al.*, 2002). Periodic terms with periods of half of sidereal day and one sidereal day occur in informative parameters such as vector components as well as in non-informative parameters, like standard deviations of GPS solutions provided by processing software, cross-correlation coefficients of vector components, number of single measurements taken to the solution, etc.

A careful estimation of an optimum length of a session used to calculate positions from GPS data is needed due to jerk type variations in GPS solutions corresponding to a satellite rising or even more distinguishably to its descending as well as to ionospheric storms. The optimum length of a session does not necessarily correspond to longer ones. With the increase of the session length an internal accuracy of the output data increases but at the same time the increase of spectral leakage is observed. Thus the extension of a session length used for computing GPS data reduces the estimated uncertainty of the solution but it simultaneously decreases Nyquist frequency. The sum of those two counteracting effects depends also on spectrum of noise and the signal itself. The increase of Nyquist frequency can be accomplished by using overlapping sessions. Correlation accompanying time series of solutions obtained from overlapping GPS sessions is significantly smaller than the one in the classical time of a random process. For example, the correlation coefficient in time series based on solutions from the sessions with 87% overlap is at the level of 0.5 (Krynski et al., 2002) while such a coefficient for a wideband random process reaches 0.5 in case of 50% overlap (Harris, 1978).

Predictability of the reaction of the GPS measuring system (both receiver and processing software) on disturbances and inadequacy of models used is difficult due to user's limited access to the algorithms applied to data processing. That reaction could, however, be viewed experimentally by statistical and correlation analysis of time series of GPS solutions.

Numerical experiments

The problem of reliable accuracy estimation of GPS positioning can be investigated using time series of GPS solutions obtained from sessions of different lengths for vectors of different length, located in different geographic regions. Practical needs, potentiality of accessible data processing infrastructure, and the experience gained in GPS research contributed towards making the choice of GPS data for processing and determining its strategy for numerical experiments.

As an example, GPS data provided by two EUREF Permanent Network Stations BOGO and JOZE from 2001 was used to generate time series of BOGO-JOZE vector (42 km length) components with the Bernese v.4.2 and Pinnacle software. With the Bernese software the GPS solutions were obtained from processing 1h, 2h, 3h, 4h, and 6h sessions over 19 days in August, with overlap (1h shift), 3h sessions with 2.5h overlap (30m shift), and 24h sessions with 23h overlap over 4 months (February-May). GPS solutions were obtained with Pinnacle from processing 2h - 28h sessions with 1h time resolution (1h shift), over 15 days in August. Chosen data represent two different periods of seasonal atmospheric dynamics in Europe, i.e. winter-spring corresponds to quiet atmosphere while summer to a disturbed one. Data set from the Antarctic stations used covered the period of extremely active ionosphere (October and November 2001) as well as the period of quiet ionosphere in July 2001. Time series of GPS solutions generated were then the subjects of statistical analysis. The dispersion of GPS solutions as well as their averaged combinations together with their precision estimates was analysed. The conceptual scheme of forming groups of GPS solutions for further statistical analysis is shown in Fig. 1.

Dispersion of GPS solutions grows with the size of sample, i.e. with a number of solutions that form the group investigated; that also corresponds to the length of data window used. On the other hand the dispersion of the average solution from the group of sessions decreases with growing number of sessions in the group investigated. The plots illustrating those dispersions for vertical component of the vector calculated with the Bernese software using 3h sessions with 0.5h shift over 3 months are given in Fig. 2a and Fig. 2b, respectively.

In both cases shown in Fig. 2, the change of the variation rate of dispersion is observed around data window of 12h. For longer windows the change of the variation rate of dispersion becomes substantially less significant. The mechanisms that affect GPS solutions obtained from sessions shorter than 12h differ from those observed in the solutions from longer sessions. Solutions from sessions shorter than 12h are mainly affected with noise and periodic biases due to varying GPS satellite constellation. Fig. 2b also shows that vertical component of 42 km vector can be determined from 12h GPS data with accuracy of 6-7 mm at one sigma level.



Fig. 1. The scheme of forming groups of GPS solutions and estimating their statistics



Fig. 2. The rms of vertical component from single sessions in the group of n sessions (a) and rms of average solutions in the groups of n sessions (b) versus the length of data window. Grey line at (a) corresponds to the rms in 3 months long group of sessions. Dashed line at (b) corresponds to the accuracy (3_level) of average solution from 3 months data

The increase of the length of session (data window) used to generate GPS solutions, results in reduction of dispersion of those solutions, mainly due to averaging noise and periodic biases. Time series of GPS solutions based on longer sessions is much smoother as compared with the one derived from short sessions. The effect of such a smoothing procedure could be simulated by combining and averaging GPS solutions obtained using short data window. The effect of smoothing GPS-derived vertical component of the vector obtained from 3h data window, by applying running average with 12,5h window may be seen by comparison of Fig. 3a and Fig. 3b, respectively.



Fig. 3. Time series of vertical component of the vector obtained from processing 3h sessions with 30m shift (a), and running average of vertical component of the vector obtained from processing 3h sessions with 30m shift with a window of 12.5h (averaging current groups of 20 solutions from single sessions) (b)

The results shown so far indicate the external accuracy estimate of GPS solutions that is based on analysis of repeatability with use of regular time series of high temporal resolution. Such an accuracy estimate does not coincide with standard deviations provided by GPS processing software that reflect an internal accuracy of the system. Short period biases, including non-modelled effects, some with unstable amplitudes, that affect GPS solutions are as systematic-type terms not reflected in uncertainty estimation. Therefore, calculated uncertainty is usually much too optimistic as the accuracy estimate. Comparison of external with internal accuracy of determination of the length and vertical component of the vector obtained using the Bernese and Pinnacle software from sessions of different length with 1h shift, are given in Fig. 4 and Fig. 5, respectively.

The dispersion of GPS solutions obtained using the Bernese software is larger than that from the Pinnacle software, when short sessions were processed. That phenomenon is more distinct in case of vector length than of the vertical component. In spite of large dispersion of GPS solutions that might be explained by the use of QIF strategy for processing data for 42 km vector with the Bernese software, the software-provided standard deviations of the solutions obtained are at the very low level. That discrepancy is particularly distinguished for solutions based on short sessions. Both height difference and the length of a vector examined was determined with the accuracy of about 5 cm (one sigma level) from 2h



Fig. 4. Standard deviations of the GPS-derived vector lengths provided by processing software and estimated by statistical analysis of time series of GPS solutions.



Fig. 5. Standard deviations of the GPS-derived vertical component provided by processing software and estimated by statistical analysis of time series of GPS solution

sessions while precision of the solution provided by the Bernese software was at the level of single millimetres. The discrepancy between the external and internal estimate of accuracy of GPS solutions decreases with increase of session length while their ratio remains the same. In case of solutions based on 24h sessions it drops down to the level of a few millimetres although their internal accuracy estimated remain a few times better than the external accuracy.

The effect of noise and periodic biases on GPS solutions can also be reduced by averaging the solutions over the groups of sessions, e.g. the mean of n, e.g. 2h sessions, that form the group. Such simple averaging does not remove all effects that are eliminated when processing with the Bernese software one session of length corresponding to the length of the respective group of short sessions. The external accuracy based on analysis of groups of sessions is thus overestimated although its trend remains similar to the one related to single sessions.

For GPS solutions obtained using the Pinnacle software that is less sophisticated in terms of GPS observations modelling then the Bernese one, the main trends for the external accuracy getting improved with growing session length are preserved. Different image has, however, the mutual relationship of the external and internal accuracy. The internal accuracy estimate given by Pinnacle is more realistic then in case of the Bernese software. A vertical component of a vector examined was determined with the accuracy of about 3.5 cm (one sigma level) from 2h sessions while precision of the solution provided by the Pinnacle software was about 2 cm. For the vector length the external and internal accuracy was 2 cm and 1.5 cm, respectively. Moreover, for a certain length of session, internal accuracy coincides with the external one. With further growing session length the internal

accuracy of the solutions becomes overestimated. Such a singularity corresponds to 12h and 4h sessions in case of vertical component and vector length determination, respectively.

GPS solutions obtained using the Pinnacle software, averaged over the groups of sessions, practically coincide with the ones corresponding to respective single sessions. It particularly concerns vertical component.

The discrepancy between the external accuracy and internal consistency of GPS solutions obtained using the Bernese software was investigated for numerous vectors of European Permanent Network of length from a few tens to a few hundred kilometres and for some vectors of length up to a few thousand kilometres in Antarctic (Cisak et al., 2003a, 2003b). 3h and 24h GPS sessions covering 4 months of 2001 were processed. The correlation between two accuracy estimates, the external and the internal one is given in Fig. 7. Internal accuracy differs from the external one by a scale factor of about 7 and 10 for a vertical component and vector length, respectively.



Fig. 6 Correlation between the external accuracy and the internal accuracy of GPS solution provided by the Bernese software



Fig.7 Deviations from average values of vectors components vs. internal accuracy of GPS solution

The observed simple functional relationship between the external and internal estimate of accuracy was fulfilled for the vectors of different length (from a few tens to a few thousand of kilometres) from different geographical regions (mid- and high latitudes).

Analysis in detail of the relations of the external and internal estimate of accuracy of GPS solutions is not satisfactorily effective due to the poor discretisation of the software-provided standard deviation that are usually expressed by numbers consisting of one or two digits. Large random errors of GPS solutions present in cases of short observation sessions processed, long vectors calculated, poor satellites configuration visible or ionospheric storms occurred, make the discretisation effect negligible.

The OHIG-MCM4 vector as a long one (3.9 thousand kilometres) and as located at high latitudes (Antarctic) is a good example of coincidence of a number of sources of random errors. Similar effects are observed in the solutions for BOGO-JOZE vector (42 km) based on 3 h sessions. Deviations from the mean for vectors components versus internal accuracy of GPS solutions provided by the Bernese software are shown in Fig. 7.

The larger software-provided standard deviation of GPS solutions the larger is the dispersion of the vector components estimated. GPS solutions for a long vector length may be separated onto two subsets (grey and black marks in Fig. 7). One of them evidently contains a bias. It is possible to separate subsets heuristically by means of analysis of the results in the stacked time domain. Dispersion of vertical component and vector length as well as software-provided standard deviation of the estimated length of the vector versus time of day corresponding to the beginning of 24h session are shown in Fig. 8.



Fig. 8 Dispersion of vertical component and vector length as well as software-provided standard deviation of the estimated length of the vector versus time of day corresponding to the beginning of 24h session (OHIG-MCM4 vector)

The results in Fig. 8 show the non-uniformly weighted data (e.g. due to the choice of reference satellite) in diurnal sessions. A third part of GPS solutions obtained for OHIG-MCM4 vector components (black marks in Fig. 7 and Fig. 8) are non-acceptable due to biases in vector length estimated. Uniform weighting in processing GPS observations from 24h sessions could substantially reduce or even eliminate from GPS solutions the influence of changes of satellites configuration of diurnal and half-diurnal periods.

Significant differences in systematic and random errors in vector length, in the numbers of observations and ambiguities resolved, as well as in random errors in vertical component between two subsets examined are observed (Fig. 9). Bias in the vector components and their uncertainty estimated using GPS data from one subset exceeds maximum dispersion obtained. It results in discrepancy of constant sign between the corresponding parameters determined from two data sets considered. The reasons and mechanisms of generation of asymmetry in distribution of results require further investigation. Such differences may occur due to the errors generated in the process of ambiguity resolution. Those errors can be amplified by poor configuration of visible satellites. The "configurationally induced" problem of ambiguity resolution is in particular frequently faced when processing GPS data from the stations in high latitudes, in particular in



Fig. 9 Time series for OHIG-MCM4 vector vertical component, its length, number of single differences used and number of ambiguites resolved

Antarctic. Therefore, polar regions are considered suitable test areas for advanced analysis of GPS positioning.

Similar, "ionospherically induced" problem of ambiguity resolution was already reported (Cisak *et al.*, 2003a; 2003b). The problems addressed above can also affect GPS positioning at mid-latitude permanent GPS stations, but their effect is smaller and its separation becomes more difficult. Mutual analysis of time series of both fix and float GPS solutions is a powerful tool for studying such problems, using for example a wide range of data provided by EPN stations.



Fig. 10. Dispersion of lengths and vertical components of the vectors vs. internal accuracy of GPS solutions (fix - grey marks, and float - black marks)

Dispersion of the lengths and vertical components of BOGO-JOZE and BOGO-BOR1 vectors versus internal accuracy of GPS solutions (fix - grey marks, and float black marks) are shown in Fig. 10. No essential difference in solutions and their error estimates for vectors of 42 and 250 km length is observed. On the other hand no significant biases were detected and the larger standard deviations estimated the lager are random errors.

Strategy of GPS solution quality analysis

The strategy developed for detecting and modelling biases in time series of GPS solutions is given in Fig. 11.

Temporal resolution of a series of GPS output solutions is determined by a sampling rate that corresponds to the length of session when data is processed in consecutive blocks. The longer the processed GPS sessions the smoother become solutions and consequently time series obtained. Smoothing obviously reduces random effects but also some periodic biases. Solutions based on shorter sessions are thus affected by larger biases than those based on longer ones. To study biases in GPS solutions the examination of time series with sufficient temporal resolution is required. Thus time series of GPS solutions obtained from short sessions is preferable despite of increased noise level with shortening the length of session processed. Shortening the sessions is, however, limited by the length of the vector determined. Therefore, in order to increase temporal resolution of time series the overlapped sessions need to be processed. Overlapping the sessions

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Fig. 11 Flowchart of the strategy of GPS solutions quality analysis

causes an increase of correlation between consecutive GPS solutions that has to be carefully considered when estimating statistical parameters of such time series. It allows, however, efficiently detect and separate chaotic effects from biases. Power spectrum density at Nyquist frequency can be used as an indicator of need of a further increase of temporal resolution of a series by processing either shortened sessions or more overlapped sessions. Time series, optimal with respect to the structure of investigated biases, consist of GPS solutions obtained from optimum session length and optimum sampling time. Such series reflect very clearly periodic biases as well as chaotic terms. Therefore they are suitable to detect and estimate periodic biases. Similar strategy with four hours window stepped by 30 minutes, followed by a running average procedure, was used for investigation of the vertical shift caused by Earth tides (Neumeyer et al., 2002).

Long time series can be directly processed for filtering noise and modelling periodic biases. In case of short time series stacked solutions need to be calculated over e.g. one-day period and then filtered and processed to model biases. Finally the models could be correlated with the external data, e.g. troposphere or ionosphere parameters in order to separate biases and find their sources.

Conclusions

A dispersion of GPS-derived vector components that is considered as an external accuracy estimate does not coincide with processing software-provided estimated accuracy of vector components determination that is the internal accuracy estimate. The discrepancy between externally and internally estimated accuracy was investigated using statistical analysis of time series of vector components obtained with the Bernese and Pinnacle software. Internal accuracy provided by the Bernese software differs from the external one, in the case investigated, by a scale factor of about 7 and 10 for a vertical component and vector length, respectively. Internal accuracy estimation provided by the Pinnacle software can be considered as the acceptable rough estimate of accuracy.

Accuracy and precision of GPS solutions based on data from permanent stations or from long-term geodynamics campaigns, especially in polar regions, need to be estimated by investigating time series of overlapping solutions using the tools of statistical analysis. The described strategy of quality analysis of GPS solutions besides their filtering allows for estimation of biases and chaotic effects. That procedure is not suitable for estimation of accuracy of GPS solutions obtained from single, short time occupation of sites. The majority of noise can be filtered using simplified statistical analysis of overlapped solutions based on sub-intervals of the observed session. Biases and jerks, however, can only be roughly estimated externally using the results of extended statistical analyses.

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Application of the Planetary Geodesy Methods (The Geoid Theory) for the Reconstruction of the Earth's Interior Structure in the Western Antarctic

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Abstract

The algorithm for calculation of differential geoid heights and anomalous harmonic densities inside the Earth is represented in the paper. Expansion of external gravitational potential in series of spherical functions is used. The application of geopotential topography and anomalous harmonic densities for studing of structural features of regional deep sections is illustrated. The structure of the Scotia Arc Region with a technique named by us as the gravimetric tomography method is considered along typical latitudinal and longitudinal cross-sections, and also on maps of the differential geoid for different ranges of spherical harmonics.

1. Theoretical background

Density of the Earth's interior can be presented as a sum of normal and anomalous components:

$$\rho = \rho_1 + \rho_3$$

where normal density _ determines normal gravity potential of the Earth; disturbing potential is caused by anomalous density _ .

The global gravity models describe the disturbing potential of the Earth which depends on spherical coordinates of the point on its surface. It can be represented as Newton's integral

$$V(r,\theta,\lambda) = G \iiint_{\nu} \frac{\rho}{l} d\nu$$

where G - gravitational constant, 1 - distance from the investigated point to the surface of the Earth, v - elementary volume. So, there is a linear dependence between $__V$, i.e. V=N_ where N is a linear operator.

Hence, the inverse gravitational problem can be formulated

in the following way:

$$=N^{-1}V_{2}$$

the operator N^{-1} is unique if V is determined in the whole 3-dimensional space [Moritz, 1990]. The kernel of the operator N^{-1} consists of set of possible distributions of density _0 inside closed contour S (within the Earth), which generate ground external potential.

The uniquely defined inverse Newton's operator provides harmonic density _ .

 $_{-} = N^{-1}V^{-1}$

Thus, the solution could be found in the way of summation of definite harmonic density and the density of ground potential $_{0}$.

$$\bar{\rho}_a = \rho_0 + \rho_h$$

The densities of ground potential characterize features of spherical stratification inside the Earth. Local heterogeneity is described by anomalous harmonic density h^{-1} .

2. The algorithm for calculation of the disturbing potential (or geoid height)

The geoid height above reference ellipsoid is found from the well-known formula

$$\zeta = R \sum_{n=2}^{2} \sum_{m=0}^{n} (c_{nm} \cos m\lambda + s_{nm} \sin m\lambda) P_{nm} (\cos \hat{A}),$$

where R = 6371 km - radius of the Earth, _nm and s_{nm} - normalized coefficients of external spherical harmonics of gravity potential, _ - longitude of the investigated point, _ - polar distance of the investigated point, P_{om}(cos_) - Legendre polynomial, z - number of harmonics to the 360th inclusive.

The formula taken from [Shabanova, 1962] was used for calculation of normalized spherical functions:

$$P_{nm}(\cos \hat{A}) = \cos \hat{A} \sqrt{\frac{4n^2 - 1}{n^2 - k^2}} P_{n-1,m}(\cos \hat{A}) - \sqrt{\frac{2n - 1}{2n - 3}} \frac{(n - 1)^2 - m^2}{n^2 - m^2} P_{n-2,m}(\cos \hat{A})$$

The necessary set of formules for calculation of any spherical function can be received on the base of following ones

$$P_{00}(\cos \hat{A}) = 1,$$

$$P_{11}(\cos \hat{A}) = \sqrt{3}\sin \hat{A},$$

$$P_{10}(\cos \hat{A}) = \sqrt{3}\cos \hat{A},$$

$$P_{mm}(\cos \hat{A}) = \sin \hat{A}\sqrt{\frac{2m+1}{2m}}P_{m-1,m-1}(\cos \hat{A}), m > 1$$

3. The algorithm for calculation of anomalous harmomic densities

The solution of the inverse gravity problem is given by Moritz [1990] under condition that distribution of density is a continuous function which can be approximated uniformly with a system of polynomials.

The density as a function of spherical coordinates can be expansed in series of spherical harmonics

$$\rho(r,\theta,\lambda) = \sum_{n=0}^{\infty} \sum_{m=0}^{n} (a_{nm} \cos m\lambda + b_{nm} \sin m\lambda) P_{nm}(\cos B) = \sum_{n=0}^{\infty} \sum_{m=0}^{n} f_{nm}(r) Y_{nm};$$

The coefficients f_{nm} (= a_{nm} or b_{nm}) are arbitrary and can be represented as polynomials

$$f_{nm}(r) = \sum_{k=0}^{N} x_{nmk} r_k$$

Having excluded a general solution, which corresponds to the densities of ground potential, the expression for anomalous harmonic densities as a series of internal spherical harmonics is received

$$\rho_h(r,\theta,\lambda) = \sum_{m} \sum_{nm} r^n Y_{nm}(\theta,\lambda)$$

$$= (2n+1)(2n+3)_{V}$$

where $x_{nm} = \frac{1}{4\pi G R^{2n+3}} V_{nm}$, V_{nm} - coefficients of external gravity potential,

 $V_{nm} (= c_{nm} \cdot GMR^n \text{ or } s_{nm} \cdot GMR^n)$, M - mass of the Earth.

Thus, external spherical harmonics are used for determination of internal spherical harmonics. The internal spherical harmonics are used to receive distribution of positive and negative density inhomogeneities, which does not change external gravity potential as their total mass is equal to zero.

The final formula is

$$\rho_{h} = \sum_{n=2}^{7} \sum_{m=0}^{n} \frac{M(2n+1)(2n+3)}{4\pi R^{n+3}} \cdot r^{n} (c_{nm} \cos m\lambda + s_{nm} \sin m\lambda) P_{nm} (\cos B)$$

Corresponding number of harmonics z is taken to calculate the density $_{h}$ on the depth (R-r).

4. Estimation of the depth of disturbing layer according to the number of harmonic

The obtained above density anomalies obviously are situated in different depths. However the mathematical methods used in physical geodesy though suppose but have no evident connection with the real geological structure of the Earth. Therefore a following question is remained: what layers of the Earth are responsible for disturbing gravitational potential.

In our method an assessment of the disturbing layer's depth is computed by a known harmonic function in physical geodesy in the case of the potential of the internal masses confined by a sphere

$$\frac{1}{r} \sum_{n=0}^{\infty} \frac{\rho^n}{R^{n+1}} p_n(\cos\psi)$$

where r is the distance from the sphere surface down to the disturbing mass, ρ is the distance from the center of the sphere up to the disturbing mass, R is the radius of the sphere, $P_{\mu}(\cos\Psi)$ is the Legendre polynomial of nth degree, Ψ is the central angle between R and ρ .

Calculations was carries out from $n_{min}=2$. At the right part of the expression the normalizing coefficient $(2n+1)^{1/2}$ was considered. If $\Psi = 0$, $P_n(\cos \Psi) = 1$ for any n, _nd r = R- ρ . Under this condition for specified values of r, ρ and R corresponding n was found.

Obviously, for large n the series

$$\frac{\rho''}{R^{n+1}}$$

converge weakly. That is why restrictions are included into the procedure of calculation. Maximal degree n_{max} is defined under condition

$$r - \frac{R}{\sum_{n=0}^{n_{\max}} \left(\frac{\rho}{R}\right)^n} \le 0.1r$$

where coefficient 0.1 means 10% error from r.

Relationship between harmonic degrees n and depths r of disturbing layers is shown on the bilogarithmic diagram (Fig.-1). Main boundaries of the lithosphere are shown in accordance with the Bullard's density model of the Earth. The program allows to compute values of the disturbing gravity potential in terms of heights of the geoid, values of harmonic anomalies in units of g/cm3 and values of upper cover depths of disturbing layers of the Earth. Spherical coefficients of two geoid models OSU91A and EGM96 are used.



Figure 1. Relationship between harmonic degrees n and depths r of the disturbing layers of the Earth. Value n is the sum of harmonicas in a range from degree 2 up to n. Depth r corresponds to upper cover of the disturbing layer, which thickness is considered from the center of the Earth 5. Examples of density structure in the Scotia Arc

5. Examples of density structure in the Scotia Arc region

Deep structure and geodynamics of the Scotia Arc and adjacent provinces within limits of 48°S-66°S and 80°W-10°W are submitted with the EGM96 gravity geoid model. The distribution of density inhomogeneities of the Earth is displayed along the Scotia Sea's central 58°S latitudinal vertical cross-section (Fig. 2) and on 100 km and 1 km lateral levels with the spatial resolution of 30 km also (Fig. 3).

The images of differential anomalies (relatively of homogeneous deep layers) as three-dimensional surfaces show a detailed distribution of masses in the upper layers of the lithosphere, geometry and sizes of density inhomogeneities, their displacement in depth under influence of dynamic processes, and correlation of subsurface bodies with the bottom topography also.



Figure 2. Maps of differential geoids topography corresponding disturbing layers with indicated depths of the upper cover. Lighter tint is more dense structure. The area of increased density is noted in depth of 100 km with epicenter 50°S, 47°W. It is a root part of the really Scotia body. On smaller depths (1 km) a structural differentiation of the Scotia Sea and correlation with the bottom relief are increased.



Figure 3. Vertical cross-section of the geopotential along 58°S latitude.

The roots of the South Sandwich Island ridge (1) are sloped to the Scotia Sea side and are immersed into depths 25-30 km. The SS Trench (2) is traced up to depth of 20 km. A fragment (3) of a joint area of the Shackleton F.Z. and the Western Scotia Ridge is observed at 57° W.

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Results of GPS, Ground Photogrammetry, Echosounding and ERS Interferometric Surveys during Ukrainian Antarctic Expeditions

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Abstract

The region of Ukrainian Antarctic geodetic and topographic surveyes includes the Argentine Archipelago where the Vernadsky/Faraday Ukrainian Antarctic Station is located and an adjoining part of the Antarctic Peninsula. Following works in this area are carried out under the auspices of the Ukrainian Antarctic Center within the State Program of the Ukrainian Antarctic Research for the SCAR's GIANT, ANTEC and IBCSO Projects:

- Seasonal many days GPS observations at the "SCAR GPS 2002" site on Galindez Island;
- Restoration of coordinates of the British triangulation stations and creation of new network on islands;
- Large-scale topographic mapping of islands and ground photogrammetry survey;
- Echosounding of the Argentine archipelago's seabed in the shallow water unsurveyed areas;
- Mapping of the Galindez ice cap and ice streams of the Antarctic Peninsula with the ERS radar interferometry;
- Determination of the Bellinsgausen sea geoid with the altimeter data for geological purposes.

The main goal of these works consists in following: creation with the GPS survey of a precision geodetic network and determination of geodynamic characteristics of the region, determination massbalans and dynamics of the ice cover



Figure 1. Topographic map of the Galindez (Ukrainian Antarctic Station) and Winter Islands by the GPS survey at geophysical polygons. Contour isoline: 5m

by the satellite radar interferometry, modeling of a deep structure of the lithosphere with the altimeter data, creation of the "Vernadsky-Argentine Islands" GIS.

Seasonal continuous GPS observations

Observations with dual frequency Tr_mble 4700 receiver were carried out during two weeks in 2002 and 2003 to monitor the physical stability of the main station and for the estimation of the regional tectonic stability of the area. Four IGS GPS stations were used for processing of our measurements by the Space Geodesy Analysis Centre (AUSPOS), Australia. Differences between coordinates are: 3.1 mm in latitude, 6.4 mm in longitude, 5.0 mm in height. RMS were from 3 mm to 7 mm. Horizontal vector of the ground mark displacement during one year is 7.2 mm at azimuth 64.5°.

Coastal GPS survey

Local network of GPS sites was created in an approximate 10-15 km radius around the main observing station and relatively the "SCAR GPS 2002" site. More than 300 GPS points had determined for positioning of different geophysical measurements on islands. They are different objects on the Vernadsky station (meteorological and geophysical pavilions, masts and antennas), british triangulation stations, tidal gauge, fixed points for the stereophotogrammetric survey, and points of geomagnetic, geological and biological samples. 30 points are fixed in rock and can be used for repeated observations and expansion of a local geodetic network. One of results is shown in Fig. 1 as a topographic map of the Galindez Island by the GPS measurements.

Ground Photogrammetry for mapping of the Galindez Island ice cliff

Stereophotogrammetric survey of the coastal line and ice cliff were carried out by a Sony DSC-F717 digital carnera on a boat. 70 overlapping images were made for the Galindez and Winter Islands along lenght of 1000 m (Fig. 2). Coordinates of the reference marks (x) were determined by GPS. Comparison of the topographic data allows to estimate a seasonal changeability of the ice cap by layers with high accuracy.

Now the processing of stereopairs is implemented with the



Figure 2. Fragment of a photomontage shows the southeast coast of the Galindez Island with the cliff of the island ice cap (height approximately 50 m).



Figure 3. Boat echosounding survey during season expeditions 1998-2003.

DEM with 20 m resolution and an electronic map of the bottom topography were constructed (Fig. 3). On this base different morphometric and geomorphological maps (slope, aspect, curvature, ridge and channel directions) were created with the LandSerf software (Lester Univ., UK). Depths within the archipelago are not more than 70 m. The general natural of the bottom is rock with thin mud and sand sediments distributed in morphological traps. ERDAS software. These field works have been carried out in collaboration with the Lvov Polytechnic University

Research of the Archipelago's bottom topography

The archipelago of the Argentine Islands is located on the western shelf of the Antarctic Peninsula. It is separated from the Peninsula by deep (more than 300_{-}) and wide (7 km) Penola strait. The archipelago is tectonic mesoblock, which is broken at smaller fragments by system of fractures.

Echo-sounding and geological sampling on the equipped boat were carried out in the internal water between islands of the archipelago during March - April 1998 and then added in 2002 and 2003 (Fig. 2). Total tracks extention is 400 km approximately. Depths and co-ordinates were recorded with two second period (or 5 m distance approximately). Depth accuracy is not worse than 0.1 %. Depths are corrected for the tidal level.



-64.34 -64.32 -64.3 -64.28 -64.26 -64.24 -64.22 Figure 4. Bathymetric map of the Argentine Archipelago's sea-bed with the season Ukrainian expeditions (1998-2003). Contour interval is 10 m

Topography of the Flask Glacier (Antarctic Peninsula with the interferometry technique by the ERS SAR images

12 radar ERS1/2 images (including the Tandem mission) for the same area of the Graham Land on area $100\Box100$ km are received. These images are used for investigation of variability of the ground and ice cover topography for period 1996-2003, and for geological, oceanological and ecological researches also.



Figure 5. ERS-2 image of 27.02.96 for the Flask Glacier flowing from the Bruce Plateau (1700 m) to the Weddell Sea;

A – area of the fragment is 36km x 32km

B - amplitude image of the fragment distinguished from A for interferometry processing, area is 7×15 km

C - phase interferogram by two Tandem images

D - 3D image by DEM from the interferogram

Topographic-geodetic works in a complex with other

researches at the Vernadsky station (seismology, geomagnetism...) will be an important contribution to a fundamental area of studying of geodynamic processes.

Crustal Motion in East Antarctica Derived from GPS Observations

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Abstract

Eight years of continuous permanent GPS data and three years of GPS campaign data are used to provide current estimates of crustal motion in Antarctica within the International Terrestrial Reference Frame 2000 (ITRF2000) (Altamimi *et al.* 2002). Crustal motions derived for this paper are compared with published results from several groups. The crustal motion estimates are consistent with that provided by other groups in the horizontal components but not in the vertical component.

1 Introduction

Current-day velocities of crustal deformation in Antarctica are important indicators for many geodetic and geophysical studies, including plate motion, intra-plate tectonics, Antarctic postglacial rebound and absolute sea level change. GPS geodesy has the potential to measure velocities of the crust directly over periods of maybe a few years, especially in horizontal components, as demonstrated by Dietrich *et al.* (2001) and Sella *et al.* (2001).

In this paper, almost eight years of continuous permanent GPS data and three years of GPS campaign data, for a total of 50 sites in the Antarctic and Australian regions are analysed with three strategies (A, B and C). Solution A is a combination of the Geoscience Australia's IGS RNAAC (Regional Network Associate Analysis Centre) solutions as submitted to the IGS from 1996 to present. Solution B is a combination of the re-processed daily regional solutions only using data observed during the Geoscience Australia Antarctic campaigns of 2001, 2002 and 2003. While solution C is a combination of re-processed daily regional solutions from continuous permanent GPS data from 1995 to 2001 in Antarctica and Australia region.

The crustal velocities in Antarctica relative to ITRF2000 are derived. These results are compared with that provided by several other groups and some conclusions are drawn from this analysis and comparison.

2. Data

This research uses GPS data collected from both continuous GPS networks operated by Geoscience Australia (formerly, AUSLIG) and also other organizations, and additionally includes Antarctic summer campaign data as well.

Continuous GPS sites around this region have gradually increased since 1989. Up to now more than 40 such GPS sites are available around this region. However due to inconsistent hardware and software description and availability of reliable precise IGS orbital products, only the data after 1995 are used in this paper. Data from another 33 Antarctica sites, which were collected during three summer campaigns are also used. Seven Antarctica sites, which have at least a three-year time span of GPS data, are shown in Figure 1. The occupation and duration history of all sites are listed in Table 1.

3. Data Processing

Three data processing strategies (A, B and C) are reviewed in this paper. The Bernese GPS Software Version 4.2 (Hugentobler, *et al.*, 2001) is used in the daily data processing for all three strategies.

3.1 Weekly Combined Regional IGS RNAAC Solutions (Strategy A)

In the case of processing Strategy A the GPS data from the 16 Australia regional sites (including the Australian Antarctic sites) are processed and combined into weekly SINEX files and stored as products of the IGS RNAAC. The data spans the period 1 January 1996 to 31 July 2003. IGS final orbital and the Earth rotation parameters are used. This data has not been re-processed and the computed solution strategy is not consistent over the period of the solution but generally reflects the IGS standard at the time of computation (around 30 days after observation). For historical reasons ionosphere free floating solutions are used as final solutions.

3.2 Reprocessed Daily Solutions (Strategy B and C)

For processing strategy B and C the GPS data are processed on a daily basis using the Bernese Processing Engine (BPE) of the Bernese GPS Software Version 4.2. Dual-frequency carrier-phase and code data are used. RINEX file sizes less than 70% of normal size are excluded. Code measurements are only used for receiver clock synchronisation. The elevation cut-off angle is 10° with elevation-dependant data weighting. The data sampling rate is 30 seconds for strategy B and 180 seconds for strategy C. Standards and procedures for the data processing are briefly summarised as follows:

- Precise satellite orbits and the Earth rotation parameters provided by the IGS are used for the daily data processing.
- All stations are corrected for site displacement due to solid Earth and pole tides (McCarthy, 1996) and ocean tidal loading using GOT00.2 model provided by Scherneck (www.oso.chalmers.se/~loading).

REPORT OF THE FIFTH SCAR ANTARCTIC GEODESY SYMPOSIUM

Table 1 Site occupations used in this analysis

(* denotes continuous occupation, numerical values for sites A351 denote occupation days for that year's campaign)

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Site	1995	1996	1997	1998	1999	2000	2001	2002	2003	Span(years)
					ŀ	Antarctic	plate	-		- F ())
A351							17	45	46	3
CAS1	*	*	*	*	*	*	*	45	50	9
DAV1	*	*	*	*	*	*	*	45	50	9
DUM1				*	*	*	*			4
KERG	*	*	*	*	*	*	*	45	50	9
MAW1	*	*	*	*	*	*	*	45	50	9
MCM1	*									
MCM4	*	*	*	*	*	*	*	45	50	9
					A	Australia	plate			-
ALIC	*	*	*	*	*	*	*			7
AUCK	*	*	*	*	*	*	*			7
BUR1				*	*	*				3
CEDU	*		*	*	*	*	*			7
COCO	*	*	*	*	*	*	*			, 7
DARW	*	*	*	*	*	*	*			, 7
DST1		*	*	*	*	*	*			, 6
GRIM	*	*	*	*	*					5
HIL1			*	*	*	*	*			5
HOB2	*	*	*	*	*	*	*			3 7
JAB1			*	*	*	*	*			5
KARR	*	*	*	*	*	*	*			5 7
KOUC					*	*	*			3
NOUM				*	*	*	*			4
PERT	*	*	*	*	*	*	*			7
STR1				*	*	*	*			4
SUVA					*	*	*			3
TIDI		*	*	*	*	*	*			6
TOW2	*	*	*	*	*	*	*			7
WEL1	*	*	*							3
YAR1	*	*	*	*	*	*	*			7
						Eurasia p	late			,
вако				*	*	r *	*			4
BINT					*	*	*			3
GETI				*	*	*	*			4
NTUS			*	*	*	*	*			5
						Pacific pl	late			2
CHAT	*	*	*	*	*	*	*			7
FALE				*	*	*	*			4
KWJ1		*	*	*	*	*	*			6
MAC1	*	*	*	*	*	*	*			° 7



Fig. 1 Antarctica GPS sites, which have at least three-year time span of GPS data

- The IGS_01 antenna phase centre variation models (igscb.jpl.nasa.gov/igscb/station/general/ igs_01.pcv).
- Carrier phase pre-processing is conducted on a baseline by baseline mode using triple differences. Checking simultaneously different linear combinations of L1 and L2, cycle slips are fixed in most cases. If cycle slips cannot be fixed reliably, bad data points are removed or new ambiguity parameters are set up. In addition, a data screening step in a baseline by baseline mode on the basis of weighted post-fit residuals is performed and outliers are marked and are not used for the final processing.
- Ionosphere delay estimation using geometry-free combination L4 to support ambiguity resolution.
- Estimation of tropospheric delay and floating coordinates using ionosphere-free combination L3 to support ambiguity resolution.
- Ambiguity resolution in a baseline by baseline mode using L1 and L2 phase data with stochastic ionospheric constraints and with floating coordinates, ionospheric and tropospheric delay supporting.
- Estimation of coordinates and tropospheric delay (at a 1-hour interval for each station) and generating of the daily Normal Equations (NEQ) with and without tropospheric parameters and results in the international standard Software Independent Exchange (SINEX) format.
- Weekly sets of troposphere estimates are recomputed on the NEQ level using weekly combined coordinates for the study of long-term change of integrated water vapour.



Fig.2 Coordinate time series for site MAW1 (strategy A)



Fig.3 Coordinate time series for site A351 (strategy B)



Fig.4 Coordinate time series for site MAWI (strategy C)

4. Data Analysis

Crustal velocity estimates are based on a weighted least squares line fit of the weekly position estimates for strategy A, and to the daily position estimates for the strategies B and C. Twelve IGS core stations around this region comprise the reference network. The reference stations, which are constrained to their ITRF2000 values with weighted constraints on Net-Translation/Net-Rotation/ Net-Scale change and their rates, are listed in bold letters in Table 1. Incorrect antenna heights are corrected using Bernese GPS Software Version 4.2. Outliers, defined as both points that lie off the best fit line by more than 3 times

REPORT OF THE FIFTH SCAR ANTARCTIC GEODESY SYMPOSIUM

Site	Solution		Velocit	v	Veloci	tv standar	d deviation
		(mm/yr)))	2		.)
		East	North	Vertical	East	North	Vertical
CAS1	А	2.6	-9.7	2.2	0.6	0.4	1.5
	В	2.1	-9.5	4.0	0.2	0.2	0.2
	С	3.1	-9.4	5.0	0.2	0.2	0.3
DAV1	А	-0.8	-5.4	3.5	0.4	0.4	1.1
	В	-1.3	-5.6	3.0	0.3	0.2	0.7
	С	-0.4	-5.2	1.6	0.2	0.2	0.3
KERG	А						
	В	6.0	-2.7	5.0	0.2	0.2	0.1
	С	8.0	-4.1	4.2	0.2	0.2	0.3
MAW1	Α	-2.2	-3.1	4.3	0.5	0.4	1.1
	В	-1.9	-2.5	3.5	0.3	0.2	0.5
	С	-1.1	-2.9	2.1 .	0.2	0.2	0.3
MCM4	А						
	В	6.3	-10.0	-1.1	0.5	0.4	2.0
	С	8.3	-11.5	10.0	0.2	0.2	0.4
A351	А						
	В	-2.9	-4.7	-0.5	0.3	0.3	1.0
	С	-2.3	-5.1	-0.9	0.8	0.6	3.2

Table 2 Estimated velocities and their standard deviations for the three solution strategies

the standard deviation and points whose residuals are larger than 3cm for vertical component, and 2cm for horizontal components, are not used in the final combined solutions. In this paper, velocity error estimates account for only white noise and parameters of annual and semi-annual signals are not estimated due to the use of limited campaign data. Therefore, the estimated standard deviations for velocities may be not very reliable at this stage.

Typical time series plots are shown in Figure 2 for strategy A, in Figure 3 for strategy

B and in Figure 4 for strategy

C. The estimated velocities and their standard deviations for the three solution strategies are listed in Table 2.

5. Comparison Of Results

The crustal motion velocities derived from GPS are compared with that from other groups. The results of comparisons are listed in Table 3. The NUVEL1A-NNR values are from DeMets et al, 1990 and DeMets et al., 1994. The ITRF2000 values are from Altamimi, 2002. The JPL values are from JPL, 2003. The IGS (weekly) MIT values are from Herring, 2003. The SOPAC values are from Bock, 2003. Table 3 shows that the velocities in horizontal directions from all groups are compatible. The RMS velocity differences are generally less than 1mm/yr and have a maximum RMS of 1.2 mm/yr. On the other hand, the velocities in vertical direction show greater variability than that in the horizontal directions. When the likely outliers (indicated in bold) are included the maximum RMS is 8.1 mm/yr and the all RMS values are larger than 3 mm/yr. When the likely outliers are excluded then all the RMS values are less than 2 mm/yr. Further analysis of the relative motions between plates and intraplate deformation analysis are beyond of the scope of this paper and will be discussed in the future.

Summary

Three solution strategies have been used to derive current crustal motion velocities in Antarctica. All results in horizontal directions from the three solution strategies are compatible with that from others. Significant inconsistency in vertical component between different groups exists. Likely outliers in the vertical component are visible for all sites between the IGS (WEEKLY) MIT estimates and all other solutions. Another likely outlier appears between the MCM4 solution C and other solutions, the explanation of which is not clear at this stage. Further analysis of MCM4 in time will provide more conclusive estimates of velocity and perhaps time series discontinuity. Much longer time data spans, more accurate loading corrections and velocity estimation models, which take into account annual and semi-annual signals, may be needed to derive reliable results in the vertical component.

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Table 3 Velocity comparisons (- denotes velocity unavailability. Bold values show likely outliers and values for mean and RMS differences in the vertical are calculated excluding these outliers).

Site	Solution	Velocity (m	m/yr)		
		East	North		Vertical
CAS1	NUVEL1A-NNR	2.0	-8.7		-
	ITRF2000	2.6	-9.6		3.7
	JPL	2.7	-11.2		4.6
	SOPAC	1.9	-9.9		3.5
	IGS (WEEKLY) MIT	2.0	-9.6		-6.8
	IGS (WEEKLY) Official	2.6	-10.2		2.8
	Α	2.6	-9.7		2.0
	В	2.1	-9.5		4.0
	С	3.1	-9.4		5.0
	MEAN	2.5	-9.9	2.4	3.7
	RMS	0.4	0.6	3.5	1.0
DAV1	NUVELIA-NNR	-2.2	-2.9		-
	ITRF2000	-1.5	-4.8		4.3
	JPL	-1.7	-5.6		1.7
	SOPAC	-2.0	-4.9		3.1
	IGS (WEEKLY) MIT	-1.7	-5.0		-8.5
	IGS (WEEKLY) Official	-1.6	-5.9		2.4
	А	-0.9	-5.5		3.6
	В	-1.3	-5.6		3.0
	С	-0.4	-5.2		1.6
	MEAN	-1.4	-5.3	1.4	2.8
	RMS	0.5	0.4	4.1	1.0
KERG	NUVEL1A-NNR	6.4	-1.3		-
	ITRF2000	6.0	-3.1		5.0
	JPL	4.5	-4.3		0.9
	SOPAC	5.8	-3.7		4.9
	IGS (WEEKLY) MIT	5.9	-2.5		-7.6
	IGS (WEEKLY) Official	5.6	-3.6		4.1
	A	-	-		-
	В	6.0	-2.7		5.0
	С	8.0	-4.1		4.2
	MEAN	5.9	-3.4	2.3	4.0
	RMS	1.0	0.7	4.6	1.6
MAW1	NUVEL1A-NNR	-2.1	0.3		-
	ITRF2000	-2.3	-2.6		2.8
	JPL	-2.8	-4.7		0.4
	SOPAC	-2.0	-3.0		1.1
	IGS (WEEKLY) MIT	-2.3	-2.8		-15.0
	IGS (WEEKLY) Official	-2.9	-3.5		0.8
	Dietrich et al. (2001)	-3.0	-5.0		-
	А	-2.3	-3.2		4.5
	В	-1.9	-2.5		3.5
	С	-1.1	-2.9		2.1
	MEAN	-2.2	-3.4	-1.1	2.1
	RMS	0.6	0.9	6.1	1.5

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MCM4	NUVEL1A-NNR	7.5	-11.7		-
	ITRF2000	9.7	-11.7		0.8
	JPL	10.0	-11.9		-1.1
	SOPAC	8.7	-11.6		2.5
	IGS (WEEKLY) MIT	9.2	-10.9		-16.8
	IGS (WEEKLY) Official	9.1	-12.0		1.7
	Α	-	-		-
	В	6.3	-10.0		-1.1
	С	8.3	-11.5		10.0
	MEAN	8.7	-11.3	-0.6	0.6
	RMS	1.2	0.7	8.1	1.6
A351	NUVELIA-NNR	-4.3	-2.3		-
	ITRF2000	-	-		-
	JPL	-	-		-
	SOPAC	-	-		-
	IGS (WEEKLY) MIT	-	-		-
	IGS (WEEKLY) Official	-	-		-
	А	-	-		-
	В	-2.9	-4.7		-0.5
	Ċ	-2.3	-5.1		-0.9
	MEAN	-2.6	-4.9		-0.7
	RMS	-	-		-

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Recent Geodynamics of the Earth's Crust in the Region of Antarctic Station "Academic Vernadsky"

Due To Results Of Tectonomagnetic Investigations

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Abstract

The studying of the tectonic activity in the region of location of "Academic Vernadsky" station (64°15', 65°15') is actual since near the station the large regional deep faults were revealed. The important feature of the Antarctic

station location is that archipelago Argentine islands lies in the subduction zone of Eastern-Pacific and Antarctic plates and thus under influence of intense tectonic stresses. Tectonomagnetic investigations in the region of the

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Antarctic station "Academic Vernadsky" were initiated in 1998. In 2001 and 2002 these works were repeated. They were aimed at the study of the recent geodynamics of the region, detection of active deep faults and glacier motion study. The tectonomagnetic method is based on the study of the anomalous magnetic field temporal variations, caused by various physical-chemical processes in the Earth's lithosphere. The methodology presupposes laying of longterm points and profiles, at which repeatitive observations of geomagnetic field F are performed at the temporal interval. In addition the parameter of DDF- anomalous geomagnetic field F variation is determined for the period of time between the cycles of observations.

The tectonomagnetic works were carried out over the profile Barñhany-Rasmussen of the length 11 km, on which 7 tectonomagnetic points had been set up and three cycles of observations had been performed. The profile crosses crosswise the strike the main rock-forming complexes in the west-east direction. A mean-square error of the survey was about 0.7 nT.

As a result of these observations were determined that anomalous magnetic field temporal variations (DDF- anomalies) have the values from some few to about 15 nT. The morphology of DDF field have certain regularities, which can be seen for period 1998-2001 and for period 1998-2002 (the total changes), as well. The eastern part of the profile is characterized by rather low positive values of DDF with the extremum +2.6 nT. The DDF of the western part is noticebly more anomalous: from -3,5 nT to -15 nt. Another peculiarity of DDF curves consist in similarity between DDF for 1998-2001 and total DDF.

Evident correlation between the static field DFa and DDF allow us to conclude that observed anomalies DDF may be of double nature: a part of it is a result of magnetzation effect under influence of secular variation, another part may be caused by piesomagnetic effect on account of crust stressed state changes.

By the help of mathematical modelling we made the quantitative evaluations of observed tectonomagnetic anomalies. Due to these evaluations the Earth's crust rocks in the region of archipelago stay under expend horizontal stresses of sublatitudinal alongation. The values of these stresses variations may be about several bar per year. *Antarctic Geodesy*

Gravity Studies of the Western Antarctic Region – New Possibilities in Geophysical Modelling.

Yu.V. Kozłenko, I.N. Korchagin, V.D. Solovjov

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Abstract

Knowledge of gravity anomalies space distribution has a great value to understanding their relationships with geology and major crust features of different tectonic elements of the West Antarctic region that is rather poorly studied now. That is why there is a necessity to use different gravity measurements- high resolution satellite models in conjunction with shipboard, airborne and land based gravity- for 3D geophysical modelling. Usually short-wave anomalies show obvious correlation with the geology of outcrops which consist of Mesozoic plutons of diverse composition emplaced in metamorphic rocks and members of the Antarctic Peninsula Volcanic Group.

Simultaneous analysis of remote altimeter, marine on-board and land base gravity measurements allows to elaborate some criteriouses of geological objects density models construction in wide depth's values- from near surface local structures to large-scale upper mantle heterogeneities. First experience of such works becomes available during "Ernst Krenkel" Expeditions where a possibility to compare the observed on-board marine gravity anomalies with satellite altimeter data was realized. It was noted that close relationship between the local bottom relief features and calculated Geosat altimeter data was not existed. Both types of measurements are confirmed to anomalies with total length that is more than 20 km.

It is known that the Antarctic land base gravity data sets are characterized by standard errors estimated about 2,5 mGal for Free-air anomalies in the previous works. New results of such measurements are not published and realization of international program to compile Antarctic gravity data south of 60°S is not finished. Now it is necessary to compile different gravity anomalies data into a digital database and prepare the anomaly map for the Vernadsky station region.

REPORT OF THE FIFTH SCAR ANTARCTIC GEODESY SYMPOSIUM

Appendix 1

AGS '03 List of Participants

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Appendix 2

Antarctic Geodesy: Recent Work and Future Prospects AGS'03 5th International Antarctic Geodesy Symposium Lviv, Ukraine, September 15-17, 2003 PROGRAM

Monday, 15th September 2003

9:00-10:00	Registration of the Symposium participants (Assembly Hall of the University "Lviv Polytechnic", S.Bandera str., 12)
10:00-11:30	Plenary session.
	Chairman Fedir Zablotskyj
10:00-10:30	Presentation of the Symposium participants.
	Welcomes from the University Administration of "Lviv Polytechnic", SCAR Geoscience SSG, Ukrainian Antarctic Center, Public Geodetic Service of Ukraine;
10:30-11:00	Valery Lytyynov, Gennadi Milinevsky, Svetlana Kovalenok, Elena Chernysh, Rudolf Greku
	Ukraine National Antarctic Program: geodesy activity
12:00-13:00	Walking-tour of the University "Lviv Polytechnic"
14:00 Session	1: 2002/2003 Austral Summer Geodesy Activities Chairman Jerry Mullins
14:00-14:20	John Manning, Gary Johnston Geodesy during the PCMEGA2002/2003 summer season
14:20-14:40	Larry Hothem U.S. Geodetic Activities in Antarctica - an Update
14:40-15:00	Hannu Koivula, Jaakko Makinen Geodetic activities at Finish Antarctic research station Aboa
15:00-15:20	Andrzej Pachuta An outline of polar expeditions of the scientists from Warsaw University of Technology
15:20-15:40	Hans Werner Schenke Actual and planned activities in geodesy and bathymetry
15:40-16:00	Olexandr Dorozhynskyy and Volodymyr Glotov Photogrammetrical investigations of the Antarctic coast
16:20 Session	2: Atmospheric impacts on GPS observations in Antarctica Chairman Jan Cisak
16:20-16:40 Antarctica	Alexander Prokopov, Yeugenij Remayev Troposphere delay modeling for GPS measurements in
16:40-17:00	Jan Cisak Overview of the research on the atmospheric impact on GPS observation in polar regions
17:00-17:20	Fedir Zablotskyj, Olexandra Zablotska and Natalya Dovhan An analysis of contribution of the troposphere and lower stratosphere layers to forming of the tropospheric delay wet component
17:20-17:40	Alexander Prokopov, Alla Zanimonska The Second Order Refraction Effects for GPS Signals Propagation in the Ionosphere
17:40-18:00	I. Shagimuratov, A. Krankowski, L. W. Baran, J. Cisak, G.Yakimova Storm-time structure and dynamics of the ionosphere obtained from GPS observations
18:00-18:20	I. Shagimuratov, L. W. Baran, A. Krankowski, J. Cisak, I. Epishov Development of TEC fluctuations in Antarctic ionosphere during storm using GPS observations
18:20-18:40	P. Wielgosz, I. Kashani, D. Grejner-Brzezinska, J. Cisak Regional Ionosphere Modeling Using Smoothed Pseudoranges
18:40-19:00	Svetlana Kovalenok, Gennadi Milinevsky, Vladimir Glotov, Korniliy Tretjak, Rudolf Greku, Yury Ladanovsky, Pavel Bahmach Argentine Island ice cap geodesy survey for climate change investigation
19:00	Ice-breaker party
	Tuesday, 16th September 2003
9:00 Session	1 3: Local and Regional geodetic networks; past and future Chairman Larry Hothem

- **9:00-9:20** *E Dongchen, Zhou Chunxia, Liao Mingsheng* Application of SAR Interferometry in Grove Mountains, East Antarctica
- 9:20-9:40 *E Dongchen, Zhang Shengkai, Jiang Weiping* The Establishment of GPS Control Network and

REPORT OF THE FIFTH SCAR ANTARCTIC GEODESY SYMPOSIUM

9:40-10:00	Data Analysis in the Grove Mountains, East Antarctica Richard D. Sanchez Positional Accuracy of Airborne Integrated Global Positioning and Inertial Navigation Systems for Mapping in Glen Canyon, Arizona
10:00-10:20 10:20-11:00	A.Capra, F. Mancini, M. Negusini, G. Bitelli, S. Gandolfi, P. Sarti, L. Vittuari, A. Zanutta VLNDEF network for deformation control and as a contribution to the Reference Frame definition Larry Hothem Experiences with Remote GPS Observatories in Southern Victoria Land
11:20 Session	1: Local and Regional geodetic networks; past and future Chairman E Dongchen
11:20-11:40	Larry Hothem LIDAR Data and Comparisons with Other Measurements
11:40-12:00	P.Sarti, J.Manning, A.Capra, L.Vittuari A project on local ties and co-locations in Antarctica
12:00-12:20	Alexander Yuskevich Accomplishment of topographic-geodetic research works in Antarctica
12:20-12:40	Yevgen Zanimonskiy On the Randomization of GNSS Solutions
12:40-13:00	Kornylij Tretyak Optimization of geodynamic network on the Argentina Islands neighbouring to Vernadsky antarctic station
14:00 Session	5: Antarctic Gravity and Sea level monitoring Chairman Alessandro Capra
14:00-14:20 14:20-14:40	G. Bitelli, A. Capra, F. Coren, S. Gandolfi, P. Sterzai Geoid estimation on Northern Victoria Land Alexander Marchenko, Zoryana Tartachynska, Alexander Yakimovich, Fedir Zablotskyj Gravity anomalies and geoid heights derived from ERS-1, ERS-2, and TOPEX/POSEIDON altimetry in the Antarctic Peninsula area
14:40-15:00	Gennadi Milinevsky Tidal observations at Faraday/Vernadsky Antarctic Station
15:00-15:20	<i>Krynski J., Cisak J., Zanimonskiy Y.</i> Contribution of data from polar regions to the investigation of GPS positioning accuracy and short-term geodynamics. Current results and perspectives
15:20-15:40	Rudolf Greku, Ksenya Bondar, Victor Usenko Application of the Planetary Geodesy Methods (the Geoid Theory) for the Reconstruction of the Earth's Interior Structure in the Western Antarctic
16:00-18:30	City-tour "By streets of the old Lviv"
19:30-22:00	Opera – house
	Wednesday, 17th September 2003
9-00 Session	6:The SCAR Antarctic Neotectonics program Chairman Phil O'Brien
9:00-9:20	Gary Johnston The determination of tectonic motion from long occupation of GPS in East Antarctica
9:20-9:40	Valentyn Maksymchuk, Yury Gorodysky, Ihor Chobotok, Valentyna Kuznetsova Recent Geodynamics of the Earth's Crust in the Region of Antarctic Station Akademik Vernadsky due to Results of Tectonomagnetic Investigations
9:40-10:00	Yu.V. Kozlenko, I.N. Korchagin, V.D. Solovjov Gravity studies of the western Antarctic region – new possibilities in geophysical modeling
10:20 Session	7: GIANT Program activities Chairman Gary Johnston
10:20-10:40	Phil O'Brien The New SCAR - What should we do next?
10:40-11:00	John Manning, Gary Johnston Overview of the GIANT program
11:00-11:20	Gary Johnston The creation of a project to improve the stability of the Antarctic Reference Frame within ITRF
11:20-11:40	Gary Johnston The sub project of high precision local ties between collocated techniques in Antarctica (ex VLBI-GPS, GPS-DORIS, GPS-GLONASS, GPS –tide gauge benchmarks, tide gauge calibration and ties to coastal benchmarks)
11:40-12:30	Proposals for the International Polar Year 2007
	Proposals for an AGS04 meeting Closing the Symposium

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SCAR WORKING GROUP ON GEODESY AND GEOGRAPHIC INFORMATION

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Appendix 3

Antarctic Geodesy Symposium 2003

Monday, 15 September 2003

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Ukraine National Antarctic Program: geodesy activity	Lytvynov
Evolution of the SCAR GIANT program	Manning
Geodesy activities in the Prince Charles Mountains	Johnston
U.S. Geodetic Activities in Antarctica - an Update	Hothem
Geodetic activities at Finish Antarctic research station Aboa	Koivula
An outline of polar expeditions of the scientists from Warsaw University of Technology	Pachuta
Actual and planned activities in geodesy and bathymetry	Schenke
Photogrammetric investigations of the Antarctic coast	Dorozhynskyy
Troposphere delay modeling for GPS measurements in Antarctica	Prokopov
Overview of the research on the atmospheric impact on GPS observation in polar regions	Cisak
An analysis of contribution of the troposphere and lower stratosphere layers to forming of	
the troposphere delay wet component	Zablotskyj
The Second Order Refraction Effects for GPS Signals Propagation in the lonosphere	Prokopov
Storm-time structure and dynamics of the ionosphere obtained from GPS observations	Shagimuratov
Development of TEC fluctuations in Antarctic ionosphere during storm using GPS observations	Shagimuratov
Regional Ionosphere Modeling Using Smoothed Pseudoranges	Wielgosz
Argentine Island ice cap geodesy survey for climate change investigation	Kovalenok
On the influence of the Solar activity on the results of GPS measurements	Kostetska
Tuesday, 16 September 2003	
Application of SAR Interferometry in Grove Mountains, East Antarctica	Dongchen
The Establishment of GPS Control Network and Data Analysis in the Grove Mountains,	
East Antarctica	Dongchen
Positional Accuracy of Airborne Integrated Global Positioning and Inertial Navigation Systems	
for Mapping in Glen Canyon, Arizona	Sanchez
VLNDEF network for deformation control and as a contribution to the Reference Frame definition	Capra
Experiences with Remote GPS Observatories in Southern Victoria Land	Hothem
LIDAR Data and Comparisons with Other Measurements	Hothem
A project on local ties and co-locations in Antarctica	Sarti
Accomplishment of topographic-geodetic research works in Antarctica	Yuskevich
On the Randomization of GNSS Solutions	Zanimonskiy
Optimization of geodynamic network on the Argentina Islands neighboring to Vernadsky	
Antarctic station	Tretyak
Geoid's estimation on Northern Victoria Land	Bitelli
Gravity anomalies and geoid heights derived from ERS-1, ERS-2, and TOPEX/POSEIDON	
altimetry in the Antarctic Peninsula area	Marchenko
Tidal observations at Faraday/Vernadsky Antarctic Station	Milinevsky
Contribution of data from polar regions to the investigation of GPS positioning accuracy and	
short-term geodynamics. Current results and perspectives	Krynski
Application of the Planetary Geodesy Methods (the Geoid Theory) for the Reconstruction	<i>a</i> .
of the Earth's Interior Structure in the Western Antarctic	Greku
Results of the GPS, Ground Photogrammetry, Echosounding and ERS Interferometric Survey	Greku
Wednesday, 17th September 2003	
The determination of tectonic motion from long occupation of GPS in East Antarctica	Johnston
Recent Geodynamics of the Earth's Crust in the Region of Antarctic Station Akademik	
Vernadsky Due to Results of Tectonomagnetic Investigations	Maksymchuk
Gravity studies of the western Antarctic region – new possibilities in geophysical modeling	Kozlenko
The New SCAR - What should we do next?	O'Brien
The sub project of high precision local ties between collocated techniques in Antarctica	
(ex VLBI-GPS, GPS-DORIS, GPS-GLONASS, GPS –tide gauge benchmarks, tide gauge	
calibration and ties to coastal benchmarks)	Johnston

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SCAR Report

SCAR Report is an irregular series of publications, started in 1986 to complement SCAR Bulletin. Its purpose is to provide SCAR National Committees and other directly involved in the work of SCAR with the full texts of reports of SCAR Standing Scientific Groups and Group of Experts meetings, that had become too extensive to be published in the Bulletin, and with more comprehensive material from Antarctic Treaty meetings.

SCAR Bulletin

SCAR Bulletin, a quarterly publication of the Scientific Committee on Antarctic Research, is published on behalf of SCAR by Polar Publications, at the Scott Polar Research Institute, Cambridge. It carries reports of SCAR meetings, short summaries of SCAR Working Group and Group of Specialists meetings, notes, reviews, and articles, and material from Antarctic Treaty Consultative Meetings, considered to be of interest to a wide readership. Selections are reprinted as part of Polar Record, the journal of SPRI, and a Spanish translation is published by Instituto Antártico Argentino, Buenos Aires, Argentina.

Polar Record

Polar Record appears in January, April, July, and October each year. The Editor welcomes articles, notes and reviews of contemporary or historic interest covering the natural sciences, social sciences and humanities in polar and sub-polar regions. Recent topics have included archaeology, biogeography, botany, ecology, geography, geology, glaciology, international law, medicine, human physiology, politics, pollution chemistry, psychology, and zoology.

Articles usually appear within a year of receipt, short notes within six months. For details contact the Editor of Polar Record, Scott Polar Research Institute, Lensfield Road, Cambridge CB2 1ER, United Kingdom. Tel: 01223 336567 (International: +44 1223 336567)

Fax: 01223 336549 (International: +44 1223 336549) The journal may also be used to advertise new books,

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Contents

SCAR Group of Specialists on Environmental Affairs and Conservation (GOSEAC)

Report of a GOSEAC XII Meeting, College Station, Texas, United States, 24-27 April 2002

Appendices



Published by the

SCIENTIFIC COMMITTEE ON ANTARCTIC RESEARCH

at the

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SCIENTIFIC COMMITTEE ON ANTARCTIC RESEARCH

SCAR Report

No 22, November 2002

Contents

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1

7

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SCAR Group of Specialists on Environmental Affairs and Conservation GOSEAC

Report of GOSEAC XII Meeting College Station, Texas, United States, 24-27 April 2002

The Dean of the College of Geosciences, Dr David B Prior, welcomed the members of the Group to Texas A & M University and outlined some of the impending developments at the College for environmental research and management. In replying on behalf of the Group David Walton thanked Dr Prior for the warm welcome to College Station and thanked Professor Chuck Kennicutt, Director of the Geochemical and Enviromental Research Group, for invitation to meet in his department with its excellent facilities.

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The following members of the Group were present:

D W H Walton (Convenor), E S E Fanta, M Fukuchi, M C Kennicutt, J Valencia.

J M Acero, P J Barrett, J E Haugland, H Miller and M Oehme were unable to attend. Dr J A Jatko (Environmental Officer, USAP) attended as an observer, and Dr R H Rutford (President of SCAR) attended the last two days of the meeting. P D Clarkson (Executive Secretary) provided secretarial support for the meeting. The address list of participants and members is given in Appendix 1.

1. Adoption of Agenda and Appointment of Rapporteurs

The draft agenda was adopted with the addition of items on "Marine acoustic technology" (2.5), "Comments on Annex 2 of the Protocol" (4.3), and "Report on CCAMLR" under 11. Any Other Business. (See Appendix 2)

The Convenor proposed that participants should assist the secretary with writing the report as follows: Items 2 and 3 - M Fukuchi; Items 4 and 5 - D W H Walton; Item 6 - E S E Fanta; Item 7 - J Valencia; Items 8, 9 and 10 - MC Kennicutt.

2. Matters Arising from GOSEAC XI

The report of GOSEAC XI, July 1999, has been published in the SCAR Report series, No 18, January 2001.

2.1 South Georgia Environmental Management Plan

A copy of the Environmental Management Plan for South Georgia, compiled by Dr E McIntosh and Professor D W H Walton and published by the British Antarctic Survey on behalf of the Government of South Georgia and the South Sandwich Islands was tabled. The Convenor explained that the compilers of the document consulted widely, both in terms of published management plans for other sub-Antarctic islands outside the Antarctic Treaty Area, and in terms of the user constituency such as tour operators and university researchers. The plan will be revised on a 5-year basis. Copies of the report have been distributed to the user community, including all companies fishing in South Georgian waters, and all relevant tourist companies. Additional copies of the report may be purchased at £15.00 (USD 25.00) via the British Antarctic Survey. Further information can be found on the South Georgia website at:

http://www.sgisland.org

It was noted that the management plans for the French sub-Antarctic islands have still not been published but that management plans now exist for all the other subantarctic islands.

2.2 Wildlife diseases

The Convenor drew attention to the report of the CEP IV meeting, specifically paragraph 41, that "noted that the risk that human activities in Antarctica might introduce diseases was currently assessed to be very low. ...[and] agreed that the work of the intersessional contact group was now complete." Australia offered "to compile best practice for prevention of diseases, particularly simple, effective, practical and low-cost measures, and report to a future CEP meeting." Thus SCAR has no further Treaty obligation on this topic.

2.3 Subglacial lakes

The report of the meeting of the Group of Specialists on Subglacial Antarctic Lake Exploration (SALE) held in Bologna, Italy, during December 2001 is now available on the SALE website at:

http://salegos-scar.montana.edu/

Concern was expressed at a Russian proposal to deepen the existing hole by a further 50 m that may have important environmental consequences. Consultations with appropriate experts have been initiated.

2.4 SCAR Review

The Convenor informed the Group that this would be the last meeting of GOSEAC. The re-structuring of SCAR will take effect at XXVII SCAR in Shanghai when GOSEAC and its functions will be replaced, at least in part, by a new Standing Committee, the Antarctic Treaty Standing Committee. The following information on the new committee is taken from the document *Implementation* of the SCAR Review that was circulated by the SCAR Secretariat.

Terms of Reference

- 1. To provide independent scientific advice and information to SCAR on scientific and technical matters relevant to the implementation of the Madrid Protocol.
 - CEP environmental issues (conservation, protected species, protected areas, review of the Protocol annexes);
 - scientific environmental research;
 - Interaction between tourism activities and field research;
 - Living resources;
- 2. Prepare documents or technical reports at the request of the Executive Committee on scientific and technical matters, such as listed on 1;
- 3. Identify upcoming issues on the agendas of the ATCM and CEP
 - other AT bodies;
 - pertinent international organizations.
- 4. Establish and maintain links with all Antarctic Treaty bodies, such as CCAMLR, CCAS, IWC, and CEP. (Positive interactions)
- 5. Report to the SCAR Executive Committee as appropriate.

Membership

- 1. The Antarctic Treaty Standing Committee shall have three members appointed by the Executive Committee.
- 2. Two of the members will be appointed Chief Officer and Deputy Chief Officer by the Executive Committee.
- 3. With the approval of the Executive Committee, the Chief Officer may co-opt additional members to a meeting where the expertise of the additional members will be relevant to the issues for discussion.

The Group was not convinced that replacing GOSEAC with the new Committee would easily allow the quality and diversity of outputs to be maintained. It did, however, recognize the value of co-opting individuals with specific expertise relevant to the agenda of any meeting that would go some way towards meeting the challenge. It was felt that GOSEAC had been particularly effective over the years because it had varied its membership according to the priorities of the time, the members had been able to hold very open discussions not possible by e-mail, and the subjects had all been treated from an interdisciplinary point of view.

The Group agreed that the following key points should be brought to the attention of the Executive Committee:

- 1. SCAR must remain engaged with the ATCM both to protect its scientific functions and to ensure the provision of independent scientific and environmental advice regardless of that given by others.
- 2. The balance of experitise in the new Committee needs to be carefully addressed and it is essential that it maintains close contact with COMNAP,

SCALOP, AEON and CCAMLR. It should also be responsible for links with other outside bodies such as IUCN and UNEP.

- 3. It is not clear how the Committee will interact successfully with the Standing Scientific Groups on specific issues.
- 4. There is a need to ensure that all the functions provided by GOSEAC, particularly its interdisciplinarity and its ability to conduct interdisciplinary and inter-organizational consultation, are reflected adequately within the new system.

GOSEAC considers its key activities to include the following:

- assessment of protected and managed area plans and the development of the management plan handbook;
- b. development of scientific monitoring and the production of the production of the handbook;
- c. development of the ecosystem/habitat matrices;
- d. conservation initiatives;
- e. education and training initiatives;
- f. environmental impact assessment methodology and checklists;
- g. scientific advice to the Antarctic Treaty Legal Expert Group on liability issues;
- h. preparatory work for the State of the Antarctic Environment Report (SAER);
- i. preparation of papers for the ATCM and the CEP.

2.5 *Marine acoustic technology*

After XXVI SCAR, a workshop on this subject was held in Cambridge, United Kingdom, during September 2001, and the draft workshop report entitled *Impacts of marine acoustic technology on the Antarctic environment* was circulated for information. GOSEAC welcomed this report, particularly the comprehensive coverage of both the acoustic techniques employed and the range of marine biota that may be affected. It was noted that the report would also provide valuable insights for those working in non-Antarctic areas and should be made more generally available.

The final report of the workshop will be published in the SCAR Report series and will be tabled at CEPV (XXV ATCM). It was suggested that, due to the technical nature of much of the report, a good executive summary should be provided as well as a covering Working Paper with the report annexed to the paper.

3. External Environmental Activities

3.1 UNEP Report

The Executive Secretary reported on the current status of the SCAR contribution to the UNEP report on "Persistent Toxic Substances in the Global Environment". Dr J H Priddle (former Convenor of GLOCHANT) had undertaken the required literature survey of research on toxic pollutants in the Antarctic environment. A partially edited draft of the contribution was available for inspection. Dr Priddle will present the edited draft at a workshop in Montreal, Canada, during May 2002. The final version will be circulated through SCAR after the Montreal workshop. The final UNEP report is scheduled for completion during 2003.

It was noted that the literature survey could form a substantial scoping resource for the SAER (see Item 9.2).

3.2 GIWA Meeting

The Convenor reported on the background to the Global International Waters Assessment (GIWA) that has been initiated by UNEP with funding from the Global Environmental Facility (GEF). SCAR had been approached to provide a contribution for the Antarctic region. The SCAR Executive Committee had agreed that SCAR should contribute within its competence but that many of the aspects relating to the Southern Ocean, specifically to fisheries, should be referred to CCAMLR. Dr Saburenkov of the CCAMLR Secretariat is liaising with GIWA. COMNAP would also need to be involved in some specific subject areas. There needs also to be interaction with. SCOR to ensure integrated coverage.

The Group discussed how SCAR might progress this matter and suggested that a single international workshop of invited participants with access to the relevant data might be the most effective way to prepare a draft contribution from SCAR. ESE Fanta offered to host the workshop in Curitiba, Brazil. The Group agreed to recommend this proposal to the SCAR Executive Committee.

4. ATCM reports

4.1 Report of XII ATSCM at The Hague in 2000

The report by the SCAR observers of the Eleventh Antarctic Treaty Special Consultative Meeting and the CEP III meeting was tabled. The Convenor drew attention to the action items for SCAR and noted that those still outstanding are on the agenda for the current GOSEAC meeting.

4.2 Report of XXV ATCM at St Petersburg in 2001

The report by the SCAR observers of the Twenty-fourth Antarctic Treaty Consultative Meeting and the CEP IV meeting was tabled. The Convenor drew attention to the action items for SCAR and noted that these are on the agenda for the current GOSEAC meeting. Concern was also expressed at the possibility of siting any new stations on King George Island or in close proximity to any existing stations.

4.3 Comments on Annex II to the Protocol

The Convenor reported that, at CEP IV, the Chairman of the CEP had proposed to undertake a rolling review of the

Annexes to the Protocol, beginning with Annex II – Conservation of Antarctic Fauna and Flora. This had been precipitated by the SCAR proposal that the species listed as Specially Protected Species in Appendix 1 to the Annex should be revised and the meaning of Special Protection should be clarified. In response to a general invitation for input to this process, the President of SCAR had asked that GOSEAC provide some comments on aspects off Annex II that might need revision.

The Group considered a list of comments that needed to be addressed. This produced a lively and useful discussion that elaborated various of the comments listed and identified some additional areas, particularly some that were inconsistent with other parts of the Protocol and other Annexes. The Convenor agreed to compile a paper in the light of the discussion and to circulate the paper to relevant groups in SCAR before submitting a final version to the SCAR Executive Committee for forwarding to the Chairman of the CEP.

5. Specially Protected Species

5.1 Second SCAR response to the Intersessional Contact Group

XXV ATCM Working Paper 5 Progress Report of the Inter-Sessional Contact Group on Specially Protected Species in Antarctica and the latest SCAR response to the Intersessional Contact Group on Specially Protected Species was tabled. The Convenor explained that Tito Acero is now preparing a new draft Working Paper for submission to the CEP V meeting at XXV ATCM in Warsaw, Poland, during September 2002. SCAR would need to consider how to respond to this.

5.2 Proposal for SCAR mechanisms for providing advice

The Convenor presented a draft paper indicating how SCAR and IUCN might coordinate their expertise to assess the conservation status of Antarctic fauna and flora. A paper on the application of IUCN Red List criteria at regional levels was also tabled. The proposed scheme is reproduced in Appendix 3 and requires further discussion with the appropriate SCAR committees.

6. Protected and Managed Areas

6.1 Systematic Environmental–Geographic Framework

XXV ATCM Working Paper 12 Systematic Environmental-Geographic Framework for Protected Areas under Annex V of the Protocol was tabled. Some Parties at the CEP IV meeting did see value in the paper but other were less than enthusiastic, although the CEP did encourage New Zealand to pursue the topic and consult with SCAR over relevant part of the report.

The SCAR Ecosystem Matrix (Lewis Smith, 1994) was developed for biological purposes and does not include

SCAR GROUP OF SPECIALISTS ON ENVIRONMENTAL AFFAIRS AND CONSERVATION

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many of the geographical criteria listed in the paper. Combining the matrix with a GIS database would move some way towards the Framework that is being proposed. However, the Group considered that the Framework could encourage a "Noah's Ark" or formalistic box-filling approach that could be counter-productive to good conservation. Conservation is a dynamic activity; protected areas should be under continuous review and, when the purpose for which they were designated has been served, they should be de-listed. The Group felt that holding a workshop on this in conjunction with SCAR meeting or symposium, as had been suggested, would not be appropriate.

It was suggested that it might be appropriate for SCAR to prepare a paper to ATCM on the science of conservation and how it has changed since the Agreed Measures were introduced. In this way a clearer view of best practice and present challenges could be presented.

Lewis Smith, R I. 1994. Environmental-Geographic basis for the Protected Area System. In R I Lewis Smith, D W H Walton and P R Dingwall, (ed), *Developing the Antarctic Protected Area System*, Cambridge, World Conservation Union and Scientific Committee on Antarctic Research, 27-36.

6.2 Managed Areas

6.2.1 Deception Island Plan

A summary document by R Downie on the Management Plan for Deception Island was tabled. It described the strategy for the management of the island and reported on the international expedition to the island during February 2002. The expedition comprised 15 representatives from six National Antarctic Programmes and two NGOs, all of which have an interest in the island. The aims of the expedition included environmental audits, floristic reviews, clean-up requirements, tourist activities. an island-wide oil spill contingency plan, and the zoning categories for the island. It was noted that Brazil had current scientific activities at the island and, although not part of the expedition, should be included in all future discussions of the plan.

An Information Paper on these activities will be submitted to CEP V and a new draft management plan drawing on the findings of the expedition will be prepared.

6.2.2 Larsemann Hills Plan

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XXV ATCM Information Paper 59 Report on Development of a Larsemann Hills Antarctic Specially Managed Area Management Plan was tabled for information. This is a joint undertaking by the Australian, Chinese and Russian National Programmes that was welcomed by the Group. The paper proposed that the draft plan will be submitted to SCAR for comment before submission to CEP VI in 2003.

6.3 Specially Protected Area Plans

The Group congratulated the originators of the eleven management plans on the standard of preparation, particularly of the maps that are a considerable improvement over many of the maps that have been adopted in the past.

It was felt that plans should contain more, rather than less, detail but that only essential information should be included in the plan; any additional information should be placed in an annex or an appendix.

The Group expressed concerned that statements on poultry products occur in all the plans under consideration whereas there is, at present, no scientific evidence that Newcastle's disease has been or can be transferred to the Antarctic avifauna. Under the precautionary principle the Group felt that the agreed treatment of poultry would be useful in all plans that are designated specifically to protect birds but was not clear why it should be included in other plans.

Detailed comments on each plan will be provided to the leaders of the two contact groups for assessing the plans; only general comments are given here.

6.3.1 Dion Islands, Marguerite Bay (SPA 8)

The Group questioned the reason for changing the title of the Area; noted a number of numerical errors; and some names missing from the maps.

6.3.2 Green Island, Berthelot Islands (SPA 9)

Some minor numerical errors and some minor language clarifications were highlighted; it was noted that a replacement Map 2 is being prepared.

6.3.3 Ablation Point/Ganymede Heights, Alexander Island (SSSI 29)

Some minor changes were proposed. It was also suggested that there should be a geological map because the geology is one of the reasons for designation.

6.3.4 Mt Flora, Hope Bay (SSSI 31)

Some minor revisions to the boundaries were suggested, including designating the glacier margins as the boundaries so that changes to the glaciers will not necessitate revision of the boundary descriptions.

6.3.5 Cape Hallett, Victoria Land (SPA 7)

Some minor changes were suggested. It was also suggested that an additional inset location map showing the Ross Sea region would be helpful.

6.3.6 Cape Royds, Ross Island (SSSI 1)

A revised description of one boundary was suggested. It was also suggested that an additional inset location map showing the Ross Sea region would be helpful.

6.3.7 Barwick & Balham valleys, Victoria Land (SSSI 3)

Some minor changes were proposed. It was also suggested that there should be a geological / geomorphological map because the geology and geomorphology are two of the reasons for designation, and that an additional inset location map showing the Ross Sea region would be helpful.

6.3.8 Cape Crozier, Ross Island (SSSI 4)

The extension of the terrestrial boundaries was discussed. It was suggested that an additional inset location map showing the Ross Sea region would be helpful.

6.3.9 Northwest White Island, McMurdo Sound (SSSI 18)

The difficulty of defining the coastline of the island, leading to a poor quality map, was recognized. It was suggested that an additional inset location map showing the Ross Sea region would be helpful.

6.3.10 Avian Island, Marguerite Bay (SPA 21)

The Group suggested that parts of 6 (i) now given in Annex 1 should be restored to the main body of the management plan. The value of a 100 m wide off-shore buffer zone was questioned.

6.3.11 Byers Peninsula, Livingston Island (SSSI 6)

The Group suggested that parts of 6 (i) now given in Annex 1 should be restored to the main body of the management plan. It was also suggested that there should be a geological / geomorphological map because the geology and geomorphology are two of the reasons for designation.

6.3.12 North Coronation Island (SPA 18)

The United Kingdom's attempt to revise the Management Plan for SPA no 18 has identified the fact that the original values for protecting this site are based largely on assumptions that cannot be substantiated by available data. Significant physical restrictions on access to the site, by both sea and air, make the collection of data extremely difficult.

----Consequently, the United Kingdom had proposed three options on how best to proceed.

- Maintain the status quo. Continue with protection of the site as an SPA without alteration of the values to be protected. Amend the Management Plan to meet the requirements of Annex V, whilst recognizing the severe limitations in knowledge about the site;
- Continue with protection of the site as an SPA, but amend the values to be protected. Possibilities include, the potential usefulness of the area as a reference and/or wilderness site. But it would be important to recognize that insufficient data are currently available to adequately substantiate such an approach;
- 3. Terminate the designation of this SPA on the grounds that insufficient data are available to justify continued protection of the site.

The argument for keeping the site is that, as a pristine area, it should be used as a reference site. However, the counter argument is that if there are no baseline data (as in this case) it cannot be used as a reference site.

The Group proposed that SPA no 18 should be de-listed as there were no compelling scientific reasons to continue site protection.

6.4 Marine Protected Areas

6.4.1 Balleny Islands

XXIV ATCM Information Paper 19 The Balleny Islands -Aide Memoire was tabled for information. The Convenor reported that a revised management plan was still in preparation. The Group felt that a schematic outlining the steps necessary for consultations on the designation of protected and managed areas, especially those with marine components, was required (see Appendix 3). An informal discussion on marine protected areas will be held in Wellington, New Zealand, on 30 May 2002.

6.5 Management activities

XXIV ATCM Information Paper 30 Report on Management Activities at SSSI 25 was tabled. The site is protected for its Pliocene fossil content, particularly well-preserved vertebrate remains of fossil dolphins and probably at least one other vertebrate species. During a visit to the Site (summer 2001–02) the exposed fossils were found to be degrading due to natural weathering processes. The Australian Antarctic Division is taking expert advice on removal and/or *in situ* conservation of the material. This would appear to be a clear case of active conservation management, and as such is welcomed by the Group.

7. Environmental Monitoring

7.1 Station monitoring

The Group received the report of a 3-year monitoring project at McMurdo Station. The preliminary findings are based on extensive sampling of the terrestrial and marine environments. Now there is to be a database available on the evolution of the impact of human activities in the area. Preliminary recommendations contain the mitigation actions required. The main conclusions are that monitoring stations can generate best practice for management of support activities for science. There is an opportunity to identify impacts on different components of the ecosystem and, if necessary, suggest environmental remediation.

Monitoring at McMurdo has provided sufficient information for management decisions. Physical and chemical monitoring at present offer the most costeffective alternative to deal with impacts of logistical and scientific research at stations on the time-scale that managers use.

The meeting discussed the new advances in biological monitoring and considered it was timely for a workshop on this topic. AEON and COMNAP would need to be

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involved.

The meeting thanked Professor Kennicutt for his presentation and for providing copies of reports of this monitoring programme.

7.2 Cumulative impacts

The Group based its discussion on the report of the workshop held in La Jolla during June 2000 entitled: Assessment of possible cumulative environmental impacts of commercial ship-based tourism in the Antarctic Treaty area. This document is also available on the NSF website at:

http://nsf.gov/cgi-bin/getpub?nsf02201

This document collected all available information from the last 10 years of tourism in the Antarctic Peninsula area. The data included: numbers of tourist visits; passengers landing; relevant research; examples of possible cumulative effects, impact evidence and mitigation measures; and management measures.

Conclusions of the workshop indicate that there is a need for detecting, avoiding and mitigating cumulative adverse impacts of Antarctic ship-based tourism. Some of the needs are for site monitoring, coordination with related research and monitoring programmes, and improved management of visit timing and frequency at particular sites.

The available information is insufficient for prediction of how, and to what extent, the physical features and biota may be affected by recurrent seasonal visits. One of the difficulties is how to differentiate natural changes on the sites from the ones induced by human activities. The Group noted the limited scientific investigations in the field and considered more research would be helpful.

The Group thanked J Jatko for distributing and presenting the workshop report.

8. Bioprospecting

The utilization of Antarctic fauna and flora as a source of materials for the biotechnology industry continues to generate interest from commercial concerns. It appears that the Convention on Biodiversity does not apply to areas not under national sovereignty, thus there is no clear overarching authority to respond to possible pressures on Antarctic resources other than through national programmes. Bioprospecting occurs at two levels:

- 1. study of genetic materials and determination of commercially important genetic codes and
- 2. harvesting of *in situ* organisms for extraction of biochemicals.

In the first case, the Convenor brought to the attention of the Group that a patent had been filed for a protein (marinomonin) isolated from a bacterium collected from an Antarctic lake sediment. The patent (WO 01/44275) had been filed by Unilever. Such patent efforts might well restrict the use of this knowledge by Antarctic scientists. While no current instance of harvesting for biotechnology is known, there are obvious environmental ramifications of the taking of animals and plants as a commercial venture. No action is recommended at present, but it was felt by the Group that developments related to bioprospecting should be closely watched as they may develop into important pressures on Antarctic resources.

9. State of the Antarctic environment

The Group noted that the issue of production a State of the Antarctic Environment Report has been discussed for a number of years. It was also felt that little progress had been made toward the implementation and conduct of such an activity. The Group noted the utility of the report both from scientific and political standpoints. Concern was also expressed that the absence of a response by the community will result in a gap in the UNEP effort for a world-wide evaluation of the state of the environment. It is likely that this gap will be filled by UNEP by one mechanism or another.

9.1 Ross Sea report

The Ross Sea report was tabled. The Group congratulated the New Zealand programme for the development of an impressive document. The Group will follow developments related to the next steps to be taken by New Zealand to implement the report's recommendations.

9.2 Scoping paper

The Convenor tabled a draft working paper expanding on the previous suggested outline of one possible approach to a State of the Antarctic Environment Report. The content and framework for the report is consistent with other UNEP reports. The Group reaffirmed the utility of the suggested approach. The Group agreed to review the draft paper and provide the Convenor with comments for a final revision before the paper is presented to the Working Groups and the SCAR Delegates in Shanghai.

10. Liability Issues

10.1 Associated and Dependent Ecosystems

The joint SCAR-COMNAP paper to XXIV ATCM Working Paper 14 Response to XXIII ATCM Resolution 5 (1999) had been circulated for information. SCAR had been asked to provide an explanation of the scientific basis for the term "dependent and associated ecosystem" phraseology. The Group noted that this advice had been provided and no further action was required.

10.2 Worst case scenarios

The Executive Secretary reported on the current status of the discussions by the Legal Expert Group at the ATCM concerning the development of an annex or annexes on environmental liability. The Legal Expert Group had requested COMNAP, in consultation with SCAR, to advise on worst and lesser case scenarios for environmental impacts. In this context, COMNAP had asked SCAR to advise on a case where rats were introduced to an island in the South Shetland Islands and began breeding. The implicit assumption here is the effects of predation on native bird species.

The Group considered that rats would not be able to survive a winter in the South Shetland Islands unless they were able to find shelter and a food supply in a station complex. Rats are known to have escaped ashore in the South Shetland Islands in the past but there are no rats present today, indicating that they were unable to establish viable populations. Rats have survived on South Georgia by nesting in tussac grass and feeding on the plant roots but the winters are much less severe than farther south. Rat populations on South Georgia have been contained in some areas by glaciers and snowfields. A phanerogamic flora would be essential for their survival and this is absent from the South Shetland Islands.

The Group considered that a potentially more serious situation could be the introduction of disease into an Antarctic species that might be caused by diseased rats. In the worst case a species might be exterminated on the island; in a less than worst case the population might be

Convenor

severely reduced until a natural immunity was developed and the species began to recover. The Group considered this to be extremely unlikely and it is offered only as an example.

11. Any Other Business

11.1 CCAMLR

ESEFanta reported on the 20th meeting of the CCAMLR Scientific Committee, October 2001. She noted that the Working Groups on Ecosystem Monitoring and Management, and on Fish Stock Assessment had met previously and suggested that there should be closer collaboration and exchange of information between these two CCAMLR Working Groups, the CCAMLR Scientific Committee and SCAR. In particular, SCAR might become more actively involved with ecosystem monitoring through the CCAMLR Ecosystem Monitoring Programme. The existing linkage between the Bird Biology Subcommittee and the Group of Specialists on Seals and CCAMLR has been very productive. Problems still exist in reviewing protected areas and clearer information on the reviewing procedure is needed (see Appendix 3).

Appendix 1

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Agenda

1. Adoption of Agenda and Appointment of Rapporteurs

2. Matters Arising from GOSEAC XI

- 2.1 South Georgia Environmental Management Plan
- 2.2 Wildlife diseases

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- 2.3 Vostok Lake
- 2.4 SCAR Review
- 2.5 Marine Acoustic technology

3. External Environmental Activities

- 3.1 UNEP Report
- 3.2 GIWA Meeting

4. ATCM reports

- 4.1 Report of XII ATSCM at The Hague in 2000
- 4.2 Report of XXV ATCM at St Petersburg in 2001
- 4.3 Comments on Annex II to the Protocol

5. Specially Protected Species

- 5.1 Second SCAR response to Intersessional Group
- 5.2 Proposal for SCAR mechanisms for providing advice

6. Protected and Managed Areas

- 6.1 Systematic Environmental–Geographic Framework
- 6.2 Managed Areas
 - 6.2.1 Deception Island Plan
 - 6.2.2 Larsemann Hills Plan
- 6.3 Specially Protected Area Plans6.3.1 Dion Islands, Marguerite Bay (SPA 8)

- 6.3.2 Green Island, Berthelot Islands (SPA 9)
- 6.3.3 Ablation Point/Ganymede Heights, Alexander Island (SSSI 29)
- 6.3.4 Mt Flora, Hope Bay (SSSI 31)
- 6.3.5 Cape Hallett, Victoria Land (SPA 7)
- 6.3.6 Cape Royds, Ross Island (SSSI 1)
- 6.3.7 Barwick & Balham valleys, Victoria Land (SSSI 3)
- 6.3.8 Cape Crozier, Ross Island (SSSI 4)
- 6.3.9 Northwest White Island, McMurdo Sound (SSSI 18)
- 6.3.10 Avian Island, Marguerite Bay (SPA 21)
- 6.3.11 Byers Peninsula, Livingston Island (SSSI 6)
- 6.3.12 North Coronation Island (SPA 18)
- 6.4 Marine Protected Areas
 - 6.4.1 Balleny Islands
- 6.5 Management activities

7. Environmental Monitoring

- 7.1 Station monitoring
- 7.2 Cumulative impacts
- 8. Bioprospecting

9. State of the Antarctic environment

- 9.1 Ross Sea report
- 9.2 Scoping paper

10. Liability Issues

10.1 Associated and Dependent Ecosystems10.2 Worst case scenarios

11. Any Other Business

11.1 CCAMLR

Appendix 2

Appendix 3

Proposed process by which

SCAR assesses conservation status of Antarctic flora and fauna

- 1. SCAR establishes a group to review all species currently identified by IUCN as globally threatened in the IUCN Red List (ie. categories of Vulnerable, Endangered and Critically Endangered) which meet the Antarctic Treaty criteria for occurring in the Antarctic Treaty area, either as breeders or as summer migrants. This initial review to assess whether the species are also regionally threatened, with respect to the Antarctic Treaty area and the CCAMLR area. The criteria and approach to guide this evaluation should be those set out in the Gardenfors et al (2001) and/or later versions as approved by IUCN.
- The SCAR group would then discuss its recommendations with appropriate IUCN Red List Authority Groups (through some mechanism yet to be developed with IUCN) to ensure consistency of use and interpretation of criteria with the IUCN global assessment and/or with other regional assessments.
- 3. The SCAR group would then proceed to consider/ review (in terms of their status in the Antarctic Treaty region and according to the above approaches and criteria) species identified in the IUCN Red List as globally Near Threatened or Data Deficient.

It would follow this with a similar review of all species endemic (or near-endemic) to the Antarctic Treaty area.

- 4. The SCAR group would consult with appropriate IUCN groups in respect of any taxa which, in its opinion, might merit recognition under the IUCN categories of global threat and through this process suggest appropriate changes to the next annual revision of the IUCN Red List.
- 5. For species considered to meet the criteria for regionally threatened status, recommendations would be forwarded for consideration by the CEP. These recommendations should be accompanied by a brief indicative statement of the kinds of land-based

management actions which might be appropriate to protect, or improve the status of, the species concerned.

Mechanisms

The main review process would require SCAR to establish some new group with appropriate membership, including scientists involved in the categorization of threatened species and those with scientific knowledge of the species or species groups concerned. This group would need to function so as to produce an annual/regular review and report on an appropriate time frame for transmission to CEP and/or IUCN.

It seems likely that expert groups might be needed for birds, marine mammals, marine vertebrates, marine invertebrates, terrestrial invertebrates, plants (this might even require separate groups for lichens and mosses). It is possible that IUCN will not have established groups covering all of these fields. SCAR needs to recognize the fact that the scientific conservation issue needs to be addressed regardless of the competent legal authority for some of these groups.

For the review of species endemic to the Antarctic Treaty area (and what about the CCAMLR area?), a considerably larger advisory and/or correspondence group would need establishing, in order to ensure that all relevant groups of plants and animals received a consistent review. For this exercise, it may be appropriate to expand the membership of the main group in order to ensure a comprehensive evaluation.

An initial timetable could be for globally threatened species to be identified by 2003/04, near threatened by 2004/05 and endemics by 2005/06.

Reference

Gärdenfors U *et al.* 2001. The application of IUCN Red List Criteria at regional levels. *Conservation Biology*, **15**, 1206-1212.

REPORT OF GOSEAC XII MEETING

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Appendix	4

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SCAR

submit to SCAR

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AEON	Antarctic Environmental Officers Network	GOSEAC	Group of Specialists on Environmental Affairs and Conservation
AT	Antarctic Treaty	ICG	Interrsessional Contact Group
ATCM	Antarctic Treaty Consultative Meeting	IUCN	World Conservation Union
ATSCM	Antarctic Treaty Special Consultative	IWC	International Whaling Commission
	Meeting	NGO	Non-Governmental Organization
CCAMLR	Commission for the Conservation of	NSF	National Science Foundation
	Antarctic Marine Living Resources	SAER	State of the Antarctic Environment Report
CCAS	Convention for the Conservation of Antarctic Seals	SALE	Group of Specialists on Subglacial Antarctic Lake Exploration
CEP COMNAP	Committee for Environmental Protection Council of Managers of National Antarctic	SCALOP	Standing Committee on Antarctic Logistics and Operations
	Programmes	SCAR	Scientific Committee on Antarctic Research
GEF	Global Environmental Facility	SCOR	Scientific Committee on Oceanic Research
GIWA	Global International Waters Assessment	SPA	Specially Protected Area
GLOCHANT	Group of Specialists on Global Change	SSSI	Site of Special Scientific Interest
	and the Antarctic	UNEP	United Nations Environment Programme

Appendix 5

Review of Management Plans

The current procedure for reviewing management plans for protected areas is given in the following table.

ATCM

submit to CEP

CCAMLR

Submit to EMM

Author

Scientific Committee

Author

Commission



ATCM

Postscript

At the XXVII SCAR meeting in Shanghai, China, during July 2002, the Delegates agreed to close the Group of Specialists on Environmental Affairs and Conservation (GOSEAC). Many of the functions of GOSEAC will become the responsibility of a new Standing Committee on the Antarctic Treaty System.

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The membership of this Committee will be Professor DWHWalton (Chief Officer), Professor MCKennicutt II and Professor DM Stoddart. They will draw on the knowledge and expertise of the wider SCAR community as appropriate to develop papers for SCAR to submit to the Antarctic Treaty Consultative Meetings.

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SCAR Report

SCAR Report is an irregular series of publications, started in 1986 to complement SCAR Bulletin. Its purpose is to provide SCAR National Committees and other directly involved in the work of SCAR with the full texts of reports of SCAR Working Group and Group of Specialists meetings, that had become too extensive to be published in the Bulletin, and with more comprehensive material from Antarctic Treaty meetings.

SCAR Bulletin

SCAR Bulletin, a quarterly publication of the Scientific Committee on Antarctic Research, is published on behalf of SCAR by Polar Publications, at the Scott Polar Research Institute, Cambridge. It carries reports of SCAR meetings, short summaries of SCAR Working Group and Group of Specialists meetings, notes, reviews, and articles, and material from Antarctic Treaty Consultative Meetings, considered to be of interest to a wide readership. Selections are reprinted as part of *Polar Record*, the journal of SPRI, and a Spanish translation is published by Instituto Antártico Argentino, Buenos Aires, Argentina.

Polar Record

Polar Record appears in January, April, July, and October each year. The Editor welcomes articles, notes and reviews of contemporary or historic interest covering the natural sciences, social sciences and humanities in polar and sub-polar regions. Recent topics have included archaeology, biogeography, botany, ecology, geography, geology, glaciology, international law, medicine, human physiology, politics, pollution chemistry, psychology, and zoology.

Articles usually appear within a year of receipt, short notes within six months. For details contact the Editor of *Polar Record*, Scott Polar Research Institute, Lensfield Road, Cambridge CB2 1ER, United Kingdom. Tel: 01223 336567 (International: +44 1223 336567) Fax: 01223 336549 (International: +44 1223 336549)

The journal may also be used to advertise new books, forthcoming events of polar interest, etc.

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