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SCAR report

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Contents

ITASE Synthesis Workshop Report

2-5 September 2008
Castine, Maine

SCIENTIFIC COMMITTEE ON ANTARCTIC RESEARCH

at the

Scott Polar Research Institute, Cambridge, United Kingdom

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, carries reports of SCAR meetings, short summaries of SCAR Standing Scientific Groups, Action Groups and Groups of Experts meetings, notes, reviews, and articles, and material from Antarctic Treaty Consultative Meetings, considered to be of interest to a wide readership.

ITASE Synthesis Workshop Final Report

2-5 September 2008

Castine, Maine

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Purpose of the Workshop

The Castine workshop brought together scientists involved in the International Trans-Antarctic Scientific Expedition (ITASE). ITASE is organized under the auspices of the Scientific Committee for Antarctic Research (SCAR) and now comprises twenty-one countries. The international representatives from ITASE have met several times in the past to discuss national traverse plans; coordinate efforts; synthesize results; and develop statistical and other techniques for the interpretation of data. ITASE started with a workshop that led to the development of an international Science and Implementation Plan for ITASE (Mayewski and Goodwin, 1997) followed by meetings in Durham, New Hampshire (March 1999), Potsdam, Germany (September 2002), Milan, Italy (August 2003), and most recently Hobart, Australia (2006). These meetings provide the primary opportunity for ITASE researchers to meet and exchange information.

The Castine workshop provided significant additional momentum for ITASE data synthesis. It focused on identifying the characteristics of climate change that have impacted the Antarctic and surrounding ocean over the past 200-1000+ years in order to provide a basis for assessing the dramatic changes expected as a consequence of the ~4-6^{o}C warming projected for this region by IPCC. Results from this workshop will form the basis for future collaborative efforts between ITASE ice core researchers, meteorologists, oceanographers, and climate modelers stemming from international initiatives such as IPICS and IPY. Workshop findings are being incorporated in the forthcoming document: "Antarctic Climate Change and the Environment" near final production by SCAR.

ITASE Introduction

ITASE is a multi-national effort dedicated to understanding the past 200-1000 years of climate change over Antarctica and the Southern Ocean (Fig. 1). Several of the countries that have recently joined SCAR ITASE such as India, Korea and Poland are still in the process of planning their ITASE activities. Several such as Italy, France, Germany, Sweden, Japan, China, Chile, Brazil, and the US are currently involved in IPY traverses for which results may not be available for another 1-3 years. An emerging compilation of all ITASE and other ice core sites is available through Ice READER (http://www2.umaine.edu/itase/content/icereader/index.html) and summaries of ITASE national products is available through (http://www2.umaine.edu/itase/content/nationals/index.html). The ITASE nations have recovered an extensive array of ice cores and surface based ground penetrating radar data (Fig. 2).

Fig. 1 – ITASE national traverse routes as of 2007.

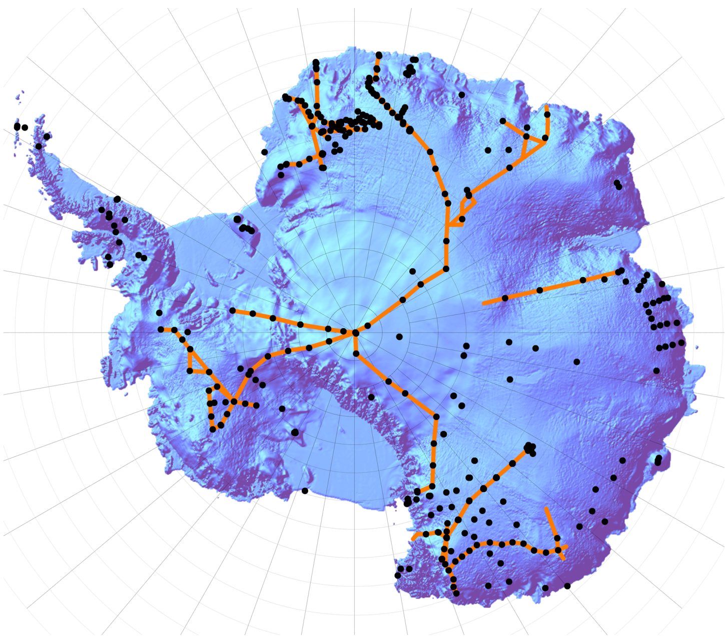

Fig. 2 - Location of Antarctic ice cores (black dots) and GPR routes (red lines) from Ice READER.

Short Overview of Past ITASE Results

ITASE findings have been published in many peer-reviewed publications (eg., see summaries in Mayewski (2003, 2006) and Mayewski et al. (2006)). A few examples are listed below. All publications noted here that are solely by US ITASE researchers are in *italics,* those that are solely non US ITASE, ITASE are <u>underlined</u>, and all others are joint US ITASE and ITASE. There is a clear bias towards US ITASE publications in the following, because they are better known to this PI, but this does not mean that there are not many other non US ITASE contributions. ITASE meetings offer the opportunity to update and further synthesize all ITASE research products.

Examples of US ITASE and ITASE scientific contributions follow:

- Identification of seasonal timing, source contributions, controls on spatial distribution, and covariance association with moisture flux for all major ions (e.g. *Kaspari et al., 2005, Kaspari et al., 2004, Dixon et al., 2004, Pruett et al., 2004*, Han et al., 2001, Isaksson et al., 2001, Curran et al., 2002).
- Precise annual layer counting of ice cores resulting in estimates of past mass balance, identification of moisture source regions, and environmental interpretations (e.g. Palmer et al., 2002, *Kaspari et al., 2004, Kaspari et al., 2005, Dixon et al., 2004, Spikes et al., 2004*).
- Glaciochemical differentiation of annual layers demonstrating that shallow and deep radar reflectors are isochrones (e.g. *Spikes et al., 2004, Arcone et al., 2005)*.
- Highly resolved temporal and spatial volcanic event records (e.g. Palmer et al., 2002; *Dixon et al., 2004, Kurbatov et al., 2006*).
- Identification of stratospheric versus tropospheric source volcanic emission input pathways to Antarctica and utilization of stratospheric source events as evidence of emission plume history over the ice sheet (e.g. Palmer et al., 2002; *Dixon et al., 2004*).
- Differentiation of the relative influence of sea salt spray and salt flowers on Na^{+} loading over Antarctica (e.g. *Kaspari et al., 2005;* plus several non ITASE publications).
- Instrumental record calibrated proxies using ice chemistry tracers from multiple ice cores for: strength of the zonal westerlies, Amundsen Sea Low, East Antarctic High, ENSO, ice surface wind drainage, and the Antarctic Oscillation (eg., *Meyerson et al., 2002*; Bertler et al., 2004b; *Kreutz et al., 2000; Souney et al., 2002*; Goodwin et al. 2003, 2004; Proposito et al., 2004; Shulmeister et al., 2004; Becagli et al., 2004; Ekaykin et al., 2002; Xiao et al., in press; *Kaspari et al., 2005*; *Yan et al., 2005; Mayewski et al., 2004, 2005*).
- Integration of ITASE spatial records and existing shallow with deep ice core records to significantly refine paleoclimate reconstructions and other global scale abrupt climate change correlations *(*eg., *Mayewski et al., 2004, 2005; Shulmeister et al., 2004; Mayewski and Maasch, 2006).*
- Proxies for sea ice, a critical component in the climate system, through studies of sulfur compounds such as sulfate and MSA (eg., Curran et al., 2003; *Dixon et al., 2005*).
- The "Solar Polar" hypothesis for the initiation of annual to decadal scale climate variability over Antarctica and the Southern Ocean and potentially for global scale abrupt climate change events (eg., *Mayewski et al., 2005, Maasch et al., 2005*).
- Demonstration of the current state of the Antarctic climate system relative to the last few hundred years (*Mayewski and Maasch, 2006*).
- Testing meteorological reanalysis products (e.g. Genthon et al., 2005).
- Large-scale calibrations between satellite-deduced surface temperature and ITASE ice core proxies for temperature (eg., Schneider and Steig, 2002; *Schneider et al., 2005*).
- ENSO – sea ice connections utilizing ice core MSA and sulfate series over the Ross Sea embayment region (eg., *Meyerson et al., 2002;* Becagli et al., SCAR abstract 2004).
- Partitioning of the sources of sulfate using sulfur isotopes as an aid to further refining air mass trajectory fingerprinting and the sulfur cycle over Antarctica (*Pruett et al., 2004*).

- Documentation of the impact of solar forcing (via UV induced changes in stratospheric ozone concentration) on zonal westerlies at the edge of the polar vortex (*Mayewski et al., 2005*; van Ommen and Morgan, SCAR abstract 2004; Bertler et al., 2006a).
- Distribution of snow precipitation over the Antarctic continent on varying spatial and temporal scales and dependence on wind and surface slope (eg., Frezzotti et al., 2002, 2004; Ekaykin et al., 2002; Richardson and Holmlund, 1999; Rotschky et al. 2004; *Spikes et al., 2005*.
- Contributions to the development of a global array of high resolution, multi-proxy records of Holocene climate (e.g. *Mayewski et al., 2004, Maasch et al., 2005*).
- Compilation of an Antarctic wide array of glaciochemical data (eg., Bertler et al., 2006b).
- Comparison between ITASE climate proxies and model results (eg., *Steig et al., 2006*; Genthon et al., 2005; *Schneider et al., 2006; Monaghan et al., 2006*).

Full references appear at the end of this report.

ITASE Contributions to the Understanding of Antarctic Climate Change in the Broader Context of SCAR

The Antarctic and Southern Ocean instrumented climate record is particularly sparse. What we do know about pre-instrumental and even recent climate change has been significantly enhanced by ice core records and most assuredly very significantly bolstered by contributions from ITASE. Our current understanding of Antarctic and Southern Ocean climate change is summarized in a report initiated by Mayewski and developed with other members of the AGCS (Antarctica and the Global Climate System) SCAR group entitled: "State of the Antarctic and Southern Ocean Climate System (SASOCS)" and it includes significant contributions by ITASE. A summary of SASOCS was presented to the Antarctic Treaty Consultative Meeting (May 2007) by C. Summerhayes (Exec. Dir. SCAR) on behalf of SCAR and AGCS as follows (the full SASOCS document (SCAR AGCS) is in press in Reviews of Geophysics). Sections in italics benefited directly from ITASE research contributions.

- *Antarctica and the Southern Ocean play a major role in the Earth's climate system. They are being and will continue to be affected by global climate change. Their responses to such change will have significant impact on global conditions, especially sea level.*
- *Modern climate in the region results from the interplay of the ice sheet – ocean – sea ice – atmosphere system and its response to past and present climate forcing.*
- *Superimposed on the long-term trend of post-glacial warming are millennial and finer scale oscillations whose causes are not well understood aside from some associations with the 11-year sunspot cycle.*
- *In the past 50 years unprecedented climatic changes cut across these trends.* They include the near-surface atmospheric warming observed on the west of the Antarctic Peninsula, with associated rapid warming of the surface ocean, retreat of glaciers and the collapse of ice shelves around the Antarctic Peninsula.

- *While ice is being lost from glaciers in the Peninsula and in West Antarctica, East Antarctica shows little change.*
- Consistent with global warming, the Antarctic troposphere has warmed while the stratosphere has cooled. Part of the reason for stratospheric cooling is ozone depletion.
- *Cooling of the stratosphere appears to have encouraged the development of polar stratospheric clouds*, which may have exacerbated ozone depletion.
- *The atmospheric pressure gradient between mid latitudes and Antarctica has steepened over the past 50 years, intensifying the westerlies over the Southern Ocean,* and warming the Antarctic Peninsula*; this change in pressure and wind has had no significant effect as yet on temperature in East Antarctica, which remains cool.*
- The upper kilometer of the circumpolar Southern Ocean has warmed, as have the densest components of Antarctic Bottom Water in the Weddell Sea.
- The coastal ocean has freshened between the Ross Sea and the Southern Indian Ocean, making the Antarctic Bottom Water formed there less saline.
- *Since the early 1970s sea ice has reduced west of the Antarctic Peninsula, and in the Weddell Sea. These decreases are balanced by an increase in the Ross Sea.*
- Projections of Antarctic climate change over the 21st century with a doubling of CO_2 in the atmosphere indicate warming of the sea ice zone; a reduction in sea ice extent; and warming of the Antarctic interior, accompanied by increased snowfall.
- Climate models need further development to forecast change at the regional level.
- *The retreat of the Antarctic ice sheet since the Last Glacial Maximum could be significantly accelerated by global warming.* Ice sheet models are not yet adequate to answer pressing questions about the effect of warming on ice melt and sea level. This topic requires significant research.
- *Threshold effects may have a significant impact on the ice sheet and sea ice extent. During the last glacial and current interglacial, such effects resulted in massive reorganizations of the ocean-atmosphere-cryosphere system, leading to rapid climate change events. Comprehensive sampling and modeling of the ocean-ice-atmosphere system is needed to forecast such events with confidence.*
- A significantly expanded version of SASOCS that will combine physical, chemical, and biological understanding of the Antarctic environment is currently under development to be completed in 2009 as a SCAR contribution entitled: "Antarctic Climate Change and the Environment (ACCE) editors J.T. Turner, P. Convey, G. di Prisco, P.A. Mayewski, D. Hodgson, E. Fahrbach, R. Bindschadler, C. Summerhayes.

ITASE Synthesis Workshop Rationale

There is considerable interest in the past, current, and future state of the climate system over Antarctica and the Southern Ocean as demonstrated by national Antarctic research activities, SCAR, IGBP, IPICS, IPY and IPCC. ITASE has played a pivotal role in the two most recent syntheses addressing climate change over Antarctica and the Southern Ocean notably the recently completed SASOCS (in press) and the forthcoming ACCE reports. ITASE data is emerging rapidly from national laboratories, new national ITASE initiatives are underway, and the necessity for ITASE researchers to organize, exchange ideas, and interact with ice core data users such as oceanographers, meteorologists, climate modelers, and other paleoclimate researchers heightens. To address this need the

Climate Change Institute (CCI) at the University of Maine hosted a joint NSF-SCAR sponsored workshop.

Workshop Goals

(1) To take Antarctica from the most sparsely sampled continent with respect to instrumental era climate to the best sampled for the last 200-1000 years because of the extremely critical role that Antarctic climate change plays in global climate change (oceans, atmosphere, biological systems) for the purpose of refining predictions of future climate change.

(2) To determine where and how Antarctic physical and chemical climate has or has not changed over the last several hundred years.

(3) To develop a coupled ice core – instrumental platform for assessing future climate change over Antarctica.

Intended workshop products

(1) Develop a synthesis of existing ITASE and related data to provide a detailed understanding of Antarctic climate (physical and chemical) change over the past 200-1000 years. Use this synthesis as input to the SCAR ACCE document.

(2) Further the integration of ITASE climate reconstruction products and climate models addressing past and future change.

(3) Synthesize ITASE data relating to the glaciological and geophysicalcharacteristics of the Antarctic ice sheets, including integration of geophysical (GPR) and ice core data.

(4) Update ICE READER (a meta data base maintained by SCAR that contains information concerning ITASE and all other Antarctic ice cores http://www2.umaine.edu/itase/content/icereader/index.html).

(5) Update the ITASE web site and listing of publications for each country. Attendees were requested to bring updates regarding field programs, scientific achievements and publications.

(6) Maintain and further collaboration developed as part of IPY.

Workshop Outcomes:

(1) Workshop description
A short description of the workshop (Appendix A) was prepared by Massimo Frezzotti (Italy), Elisabeth Isaksson (Norway), Meloth Thamban (India), and Dan Dixon (USA) for submission to the IGBP PAGES, SCAR AGCS Notus, and IPY newsletters.

(2) Abstracts presented at the workshop appear in Appendix B and powerpoints presented at the workshop are posted on the ITASE website.

http://www2.umaine.edu/itase/content/Workshop-Report.html

(3) Participants agreed that an ITASE Workshop and a dedicated ITASE volume (JGR?) should be planned for the 2010 SCAR Buenos Aires meeting. A planning team was designated (Nancy Bertler (New Zealand), Mark Curran (Australia), Massimo Frezzotti (Italy), Paul Mayewski (USA), Liz Thomas (United Kingdom).

(4) An ITASE Data Sharing Policy was established and agreed upon at the workshop. All data will be available through the Ice READER website.

http://www.icereader.org

This portal was made available as of 31 October 2008 and instructions for use were sent by email to all ITASE Workshop attendees plus many others on email lists related to ITASE.

Purpose: to collect ITASE core data from people/institutions willing to supply data.

Ice READER will contain two types of data:

(i) Metadata (available publicly) as currently defined on the website (ice core, GPR, other) including: location, date collected, types of measurements, sampling and analytical methods to be submitted by individual ITASE researchers, teams, institutions directly to Ice READER.

(ii) Data (password protected), either stored on Ice READER or available through Ice READER on other websites, will be available only to data contributors.

Examples of types of data to include:
Metadata

Raw data measurements
Raw depth
Depth/age and uncertainty
Measurement (planned, finished, analytical method, sample processing method)
Model output
Data storage location (ie. existing data center)
Data ownership

Policy for use of password protected data:

Available to any Ice READER data contributors, but ONLY for viewing (plotting, comparison).

Email alerts will be sent automatically to all password holders signaling input of new data.

Password protected data will be available for use in scientific products (papers, reports, websites, etc.) ONLY with permission of the data "owner".

Andrei Kurbatov akurbatov@maine.edu will coordinate access to Ice Reader for metadata uploading and password protected data so that input can be made directly by data holders.

(5) Workshop participants developed a preliminary compilation of ITASE and related research based on published data and near or in review research (Figure 3).

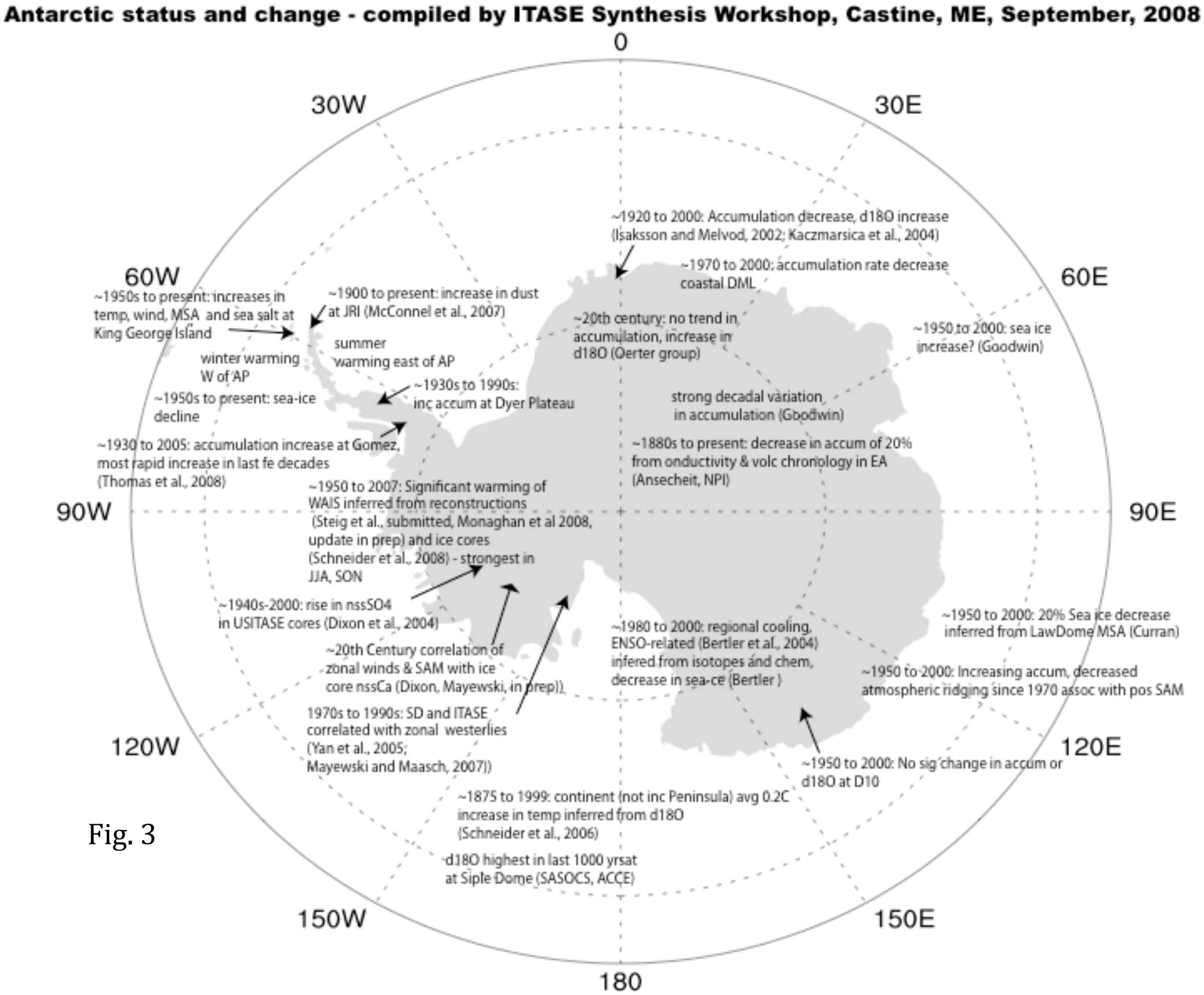

Fig. 3

The compilation revealed an important new potential view of recent (past 200 years) changes in temperature over West Antarctica and portions of coastal East Antarctica, sea ice extent, and atmospheric circulation (zonal westerlies and SAM) that demonstrated the necessity for several ITASE study projects.

(6) ITASE study projects. Four major research activities were developed from the workshop. Plans for undertaking these activities follow. Several people have offered to be involved in these activities and contribute institutional resources.

(i) Proxy Atmospheric Reanalysis of AnTarctica (PARAT)

Synoptic climate anomalies for ENSO, SAM, circumpolar westerlies, lows, etc. eg., 1960-90.

Stage 1 - Self Organized Mapping (SOMS) and time series of climate reanalysis data at seasonal resolutin available on Ice READER.

Stage 2 – Mapping proxy climate data by ice core measurement.

Stage 3 – Mapping of proxy climate data to synoptic climate types.

Stage 4 – Calibration and verification of proxy climate data to reanalysis data.

Stage 5 – Development of proxy atmospheric reanalysis climatology for 1960-2008.

Stage 6 – Extend proxy atmospheric reanalysis climatology to 1815 (Tambora).

Stage 7 –Evaluate partial SAM inices against instrumental SAM reconstructed indices.

(ii) ITASE Antarctic sea ice reconstruction (1850 to present)

Stage 1 – Data request, review goals.

Stage 2 – Contour map synthesis project.

Stage 3 – Sea salt budget – frost flower contribution – test proxy.

Stage 4 – Sea ice reconstruction from sea salts.

Stage 5 – Sea ice reconstruction from MSA.

(iii) Synthesis of accumulation and physical properties using GPR, ice core etc. over at least the bomb layer era to Tambora across Antarctica in order to address: quality control, change/variability in spatial distribution, temporal variability/change of snow accumulation at pluriannual/decadal/atomic bomb (1966-1955)/Tambora (1816)/Kuwae (1453), snow accumulation vs isotope temperature variability at decadal scales, improvement of surface mass balance knowledge, verification/validation of snow accumulation prediction models, and to develop a distribution map with change respect average, and a data base available on the website.

(iv) Temperature reconstruction for Antarctica (last 200 years).

Appendix A – ITASE Synthesis Workshop Report submitted for publication in SCAR AGCS and PAGES Newsletters.

Submitted to IGBP PAGES Newsletter, SCAR AGCS Nexus Newsletter, and IPY

International Trans Antarctic Scientific Expedition (ITASE) Synthesis Workshop:

Recent Change in the Climate and Atmospheric Chemistry over Antarctica

Castine, Maine, USA, September 2-5, 2008

Daniel Dixon[1], Massimo Frezzotti[2], Elisabeth Isaksson[3], Thamban Meloth[4]

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Changing global climate is forcing scientists to vigorously test the existing paradigms and to find improved evidence of how the climate system really works at various time scales. With polar regions being the pacemakers of climate change, it is imperative to gain critical knowledge on the role and response of the cryosphere system in a warming scenario. However, due to the lack of long-term instrumental climate records in remote places like Antarctica, scientists are focusing on ice core proxy climate records buried in the vast ice sheets of Antarctica that provide valuable information on climate change from interannual to millennial scales. One such multi-national effort to obtain climate archives from Antarctica is the International Trans-Antarctic Scientific Expedition (ITASE). Operating since 1990, twenty-one countries are now involved in ITASE programs to understand the impact of global change on the Antarctic continent and the influence of Antarctica on global change during the last ~200-1000+ years.

At the idyllic coastal Maine village of Castine, Prof. Paul Mayewski and his group from the Climate Change Institute at University of Maine collected 32 glaciologists, geophysicists and climate modelers to discuss and synthesize the results obtained thus far from the ITASE programs. This synthesis workshop generated many fruitful discussions on the data, and also future directions.

By combining available meteorological data from the Antarctic and Southern Ocean with firn/ice core proxies for a variety of climate parameters (e.g., moisture balance, atmospheric circulation and temperature) ITASE is actively working to extend the Antarctic climate and atmospheric chemistry records back at least ~200 years. This offers the temporal perspective needed to assess the multi-decadal variability of natural Antarctic climate.

The main focus for this workshop was to get an updated overview of newly collected firn/ice cores and available data sets. A large effort is planned to make the data available online in order to facilitate a number of synthesis products. In addition, we had a number of presentations from the participants with information both on syntheses of previously collected data and also new developments from the many participating countries. One of the important new results discovered by members of the ITASE group is that the climate of West Antarctica appears to have warmed during the last several decades.

Other interesting aspects discussed were the importance of the Southern Annular Mode (SAM) in Antarctic climate change as well as climate teleconnections related to extra-tropical systems like the El Nino Southern Oscillation (ENSO). It was also concluded that firn/ice core records should be interpreted in combination with snow Ground Penetrating Radar (GPR) surveys to ensure continuous chronology and climate data from the cores.

Based on the available data and our current state of knowledge we agreed that the following synthesis products from the ITASE community will be created in the near future:

1. Temporal variability of snow accumulation using well-dated firn/ice cores with reference horizons such as sulphur peak from the eruptions of Tambora 1815 as well as the atomic bomb tests of 1964/65.
2. Sea ice proxy reconstruction using a combination of sea salt and methanesulphonic acid (MSA) records from coastal ice cores around Antarctica.
3. Proxy Atmospheric Reanalysis of AnTarctica (PARAT).
4. Temperature reconstruction during the past 200 years using ice core proxy data.

In addition to the interesting talks and discussions, we also enjoyed an afternoon of sailing in Penobscot Bay on the polar-class schooner Bowdoin which has sailed many times to Greenland.

ITASE is jointly sponsored by the Scientific Committee on Antarctic Research (SCAR) and the Past Global Changes (PAGES) project of the International Geosphere Biosphere Program (IGBP). The next workshop is planned to take part in connection with the SCAR meeting in Buenos Aires (Argentina) in July 2010.

Attendees included:

ITASE International colleagues:

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Appendix B – ITASE Synthesis Workshop Abstracts

The Norwegian-US IPY traverse 2007/2008: First results from dielectric profiling of four shallow firn cores

Helgard Anschütz, Elisabeth Isaksson, Sanja Forsström

Antarctica's mass balance is still quite uncertain today and vast parts of the East Antarctic ice sheet are not covered by ground-based measurements. Yet knowledge of the variability of accumulation rates in Antarctica is crucial for estimation of future sea-level change. The Norwegian-US IPY traverse through East Antarctica aims to close some of those data gaps and to help constraining the mass balance of the East Antarctic ice sheet and its impact on sea-level rise.

Here, we present first results of ice-core records obtained from the first leg of the traverse in 2007/2008. We show data from dielectric profiling on four shallow (20-25 m deep) firn cores along the traverse route, going through Dronning Maud Land from Norwegian Troll Station to South Pole. Dielectric profiling (DEP) yields high-resolution information about dielectric permittivity and electrical conductivity along the firn core.

As electrical conductivity is sensitive to total salt content and acidity, the records of electrical conductivity can be used to date the firn cores by detection of large past volcanic eruptions. We discuss the presence and depth of prominent events like the Tambora eruption within the different firn cores. Furthermore dielectric permittivity is used to calculate density according to mixing models like the one established by Looyenga and compared to bulk density.

Using the density data and the volcanic chronology, accumulation rates are calculated for the last 200-250 years. Their spatial variability between the different drilling sites is discussed as well as the temporal accumulation pattern. Our firn cores show accumulation rates in the range of 25-42 mm a-1 w.e., based on the preliminary core chronology. Three firn cores show a decrease in accumulation for the time period 1884-2008 in relation to 1762-1884.

We compare the accumulation data with other data sets from Dronning Maud Land and discuss upcoming use of the dielectric permittivity for calibration of radar data and the subsequent calculation of the accumulation pattern along the entire traverse route. Chemical analysis of more traverse cores will be carried out soon and the data will then be used in conjunction with the DEP-based dating presented here to constrain the depth-age relations and verify volcanic origin of conductivity peaks.

Together, the data from the Norwegian-US IPY traverse should provide valuable insight in the variation of accumulation rates and related physical parameters on the remote East Antarctic plateau and will serve as ground-truthing for satellite data.

GENESIS AND DEFORMATION OF FIRN STRATIGRAPHY IN WEST AND EAST ANTARCTICA: EVIDENCE FROM THE US ITASE SUBSURFACE RADAR PROFILES.

Steven A. Arcone

U. S. Army ERDC-Cold Regions Research and Engineering Laboratory, Hanover, NH

The US contribution to the ITASE program obtained shallow and deep radar profiles along its thousands of km of traverse during 1999–2003 over West Antarctica, and along its 1200 km traverse behind the Transantarctic Mountains in East Antarctica during 2006–2007. I discuss the shallow profiles, which used short-pulse radar operating at 400 MHz to profile depths of 56–135 m in West Antarctica, and at 200 MHz to depths of about 90 m in East Antarctica. Throughout West Antarctica we consistently encountered continuous and extensive layering, which I argue, is caused by thin layers of density contrasts associated with widespread hoar formation. Differential deposition rates caused by wind interacting with topography and ice movement distort these layers, with horizons changing depths by tens of meters over tens of km. In contrast, layered stratigraphy extending hundreds of km is non existent from Byrd Glacier to Titan Dome in East Antarctica. Instead, the firn consists of buried megadunes, as is the deep ice below as seen in the deep radar profiles. Their outstanding features are the prograding deposits, some of which extend over 20 km, yet originate from the relatively smaller accumulation sections, and the thick and unstratified metamorphosed zones beneath their relatively larger areas of zero accumulation glazed surfaces. These zones extended up to 35 km. The West Antarctica profiles revealed ideal sites where ITASE located its ice cores, extensive stratigraphy from which to determine spatially averaged historical accumulation rates, and an increased understanding of the more conventional accumulation processes. In contrast, most of our East Antarctica profiles will help us to understand the dynamics of a more complicated accumulation process that can provide over 20 km of horizontally oriented deposits despite apparent low accumulation rates.

A 150-year reconstruction of the Southern Annular Mode

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Southern Hemisphere climate variability is dominated by two oscillating drivers: the Southern Annular Mode (SAM) and the El Nino Southern Oscillation (ENSO).

Combined, the two forcings can enhance or partially off-set their influence on Southern Hemisphere climate.

An ice core from coastal Victoria Land in the Ross Sea Region, spanning the past 150 years, provides insights into the relationship between regional temperature, sea-ice extent, SAM, and ENSO. Our results record (d18O, dD, deuterium excess, major ion and trace elements) show that more than 50% of the regional temperature variability can be explained by combined SAM and ENSO forcing. Sea-ice extent is negatively correlated to temperature variability with more (less) extensive sea-ice during warmer (colder) years. This inverse relationship is explained by a positive ENSO forcing of sea-surface temperatures and a negative ENSO forcing of regional air temperature. Transfer functions are used to convert water isotope and deuterium excess records into a proxy index for SAM. Our data suggest that over the last 150 years mean annual SAM increased overall by almost 1 sigma standard deviation. The increase occurs predominantly during 1868-1944 and 1971-present. We conclude that ozone depletion can only partially explain the observed intensification of the polar vortex.

However, to test the reliability of our record and its regional significance, it is necessary to correlate our data with high resolution ice core records from other Antarctic sites. The ITASE data set is a unique and excellent dataset to permit such an evaluation and improvement of our data interpretation.

The Maine Automated Density Gauge Experiment: Data from East Antarctica collected on ITASE 2006-2007.

Dan Breton – CCI – UMaine

MADGE is a gamma-ray density gauge designed to provide high precision (+/- 0.004 g/cm3) and high vertical resolution (3.3mm) density profiles of firn and ice cores using a fast gamma-ray counting system, electronic calipers and a stepper motor controlled actuator. Density profiles were measured along the recent ITASE traverse route and provide new information regarding the differences in firn structure between medium and low accumulation zones on the East Antarctic plateau. Recent efforts to improve instrument performance will also be discussed.

Reconstructed Air Temperature and Snowfall Fields over Continental Antarctica

Applied to Testing IPCC Climate Model Performance

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Two-meter air temperatures at monthly time scales and annual snowfall amounts have been reconstructed over the Antarctic continent at high spatial resolution by combining sparse observations since the International Geophysical Year with the spatial information contained in atmospheric model fields since the mid 1980s. The spatial and temporal characteristics of these fields and their inter-relationships are discussed. Next the fields are applied to assessing the performance of a subset of global climate models participating in the IPCC fourth assessment report (AR4, 2007). It is found that collectively the models have about the right snowfall sensitivity to temperature change, but that they are warming continental Antarctica at the global rate whereas the warming is much more muted in reality. The cause is traced to a spuriously amplified water vapor feedback. Recent efforts to identify the origin of this feedback will be summarized, and the implications for future Antarctic climate projections will be discussed. The desirability of extending such comparisons to a wider range of variables and for more extended time periods within the context of the ITASE project is outlined.

TRAVERSES FROM PATRIOT HILLS TO SOUTH POLE: CHILEAN CONTRIBUTION TO ITASE

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Two oversnow tractor traverses have been performed by Chile from Patriot Hills to the South Pole and the East Antarctic ice sheet in 2004 and in 2008. These initiatives are a contribution, in collaboration with Brazil (2004), to the ITASE programme. In 2004 seven firn cores of a depth ranging from 4 m to 46 m were drilled from South Pole to Patriot Hills with a 50 m electro-mechanical drill every 2 degrees of latitude, with a total of 225 m of firn samples which are being analysed for their chemical composition at the Climate Change Institute, University of Maine, and in Brazil. In 2008 two firn cores with a total firn sample depth of 34 m were drilled from 88ºS/48ºE to 88º30'S/82º30'W with a 20 m electromechanical drill. In addition 105 surface snow samples were collected every 10 km along the route in 2004, and 20 surface snow samples in 2008 every 20 km. Additional measurements included ice depth soundings with a 150 MHz ice depth radar on loan from the University of Kansas, USA in 2004 and a radar from CECS in 2008; snow accumulation radar soundings of the top ~60 m firn layers of the glacier by means of a GSSI SIR 3000 400 MHz GPR in 2004; precise GPS positioning; stake deployment, gravity measurements and surface snow density (down to 1.2 m) every 20 km along the route; surface snow density (top ~1.2 m layer); and surface snow samples every 40 km for microbiological studies.

Results of chemical species for two 2004 cores are presented (IC5, 42.5 m depth, 82°30.5'S, 79°28'W, 950 m a.s.l. and IC6, 36 m depth 81°03'S, 79°51'W, 750 m a.s.l.), as well as general results from these two expeditions. The mean chemical concentrations for IC5 and IC6 agree with the spatial distribution as summarized by Bertler et al. (2006).

Ice core proxy measures of sea ice extent from MSA data

Mark Curran

The instrumental record of Antarctic sea ice extent from satellite measurements is only 30 years long. During this short period, only the sector west of the Antarctic Peninsula, shows evidence of a decrease in sea ice extent. While we cannot ever obtain large scale remote sensed sea ice information prior to the 1970s, we can explore the use of various proxy records (e.g. Whaling ship positions, marine sediment records, ice core records, krill catch data, penguin population changes etc). While there may be many flaws and various assumptions associated with these proxy records, they are all that exists to perhaps provide some insight to sea ice conditions around Antarctica prior to the satellite era.

Curran et al. (2003) reported a correlation between methanesulphonic acid (MSA) concentrations from a Law Dome ice core and 22 years of satellite-derived sea ice extent. They used this correlation to apply an instrumental calibration to the longer MSA record (1841 to 1995 A.D.) producing a proxy record or sea ice extent in the East Antarctic sector 80o-140oE. The results suggested that there has been a 20% decline in sea ice extent since about 1950. The decline was not uniform, showing large cyclical variations, with periods of about 11 years, that confuse trend detection over the relatively short satellite era. The decline was in good agreement with that suggested from whaling ship positions (de la Mare, 1997).

More recently de la Mare found that Antarctic sea ice changes varied significantly between regions, with most showing a decline, however some showing increased sea ice extent or no significant change (de La Mare, 2008). This regional approach is more consistent with the regional differences we see today from the satellite data. A regional approach is currently being investigated for MSA proxy records. Consistent with the earlier work of Curran et al., (2003), positive correlations between MSA and sea ice extent have been reported in different regions around Antarctica (Foster et al., 2006 and Abram et al., 2006), although negative correlation have been found in other sites (Abram et al., 2006). Work is in progress to improve the spatial extent MSA proxy through the ITASE records and to produce sea ice proxy data covering the last 200 years.

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20th Century Forcing of the Antarctic Atmosphere

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Ice cores provide us with a window through which past atmospheric conditions can be viewed. The addition of seven new ice cores to the US ITASE collection, which now totals 23 fully analyzed cores, allows past atmospheric conditions for the last 200+ years to be contrasted and compared at near continental-scale.

Examination of the data reveals that non-sea-salt-calcium (nssCa) concentrations have been rising since ~1850 AD over much of West Antarctica. Correlations between ice core nssCa concentrations and Southern Hemisphere 850 mb zonal winds (from 1948-2000) suggest a strong link between the strength of the polar westerlies and dust transport into West Antarctica (Yan et al., 2005). The strength of these correlations gives us confidence in using nssCa as a proxy for zonal wind strength around Antarctica. Increased nssCa concentrations in central and coastal West Antarctica imply intensification of Antarctic polar westerlies starting around 1850 and increasing up to the present day. These observations also suggest that the recent increasing trend of the Southern Annular Mode (SAM) toward a more positive state (Thompson and Solomon, 2002) is actually part of a process that began as early as 1850.

A Holocene climate record from Siple Dome reveals that the polar westerlies have not been this intense for several millennia. The last time Antarctic polar westerlies were as strong as today West Antarctica had just experienced a rapid cooling event and was starting to warm slowly. The present day situation is occurring in a starkly contrasting setting where West Antarctic atmospheric temperatures are higher than they have been at any other time during the Holocene (AGCS., in press). The present day intensification of the SAM is likely a direct result of natural and anthropogenic forcings (Thompson and Solomon, 2002; Marshall et al., 2004), the latter composed primarily of greenhouse gas increases and ozone depletion. As greenhouse gas emissions are set to push global temperatures even higher in the near future we should expect to observe further increases in the state of the SAM. The question of whether or not the westerlies will collapse abruptly as following the last such intensification is critical to the future of Antarctic and Southern Ocean climate change.

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20th Century Variability and Trends in the SAM from Reconstructions, Observations, and the IPCC AR4 Models

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The Southern Hemisphere Annular Mode (SAM) is examined from reconstructions, observed indices, and simulations from 17 Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report (AR4) models from 1865- 2005. Comparisons reveal the models often have a weaker meridional pressure gradient, and they do not fully simulate periods of strong low-frequency natural variability within the reconstructions during the 1930s and 1960s.

The various seasonal indices are examined to understand the relative roles of forced and natural fluctuations. The models capture the recent (1957-2005) positive SAM trends in austral summer and autumn, with ozone driving summer trends; the relative forcing of the autumn trends is uncertain. The models also produce significant spring trends during this period not seen in observations, suggesting the models are too sensitive to the forcing in spring and/or are not resolving internal climate processes that dampen SAM trends. The majority of models produce significant positive 100-yr trends in the SAM (1905-2005) in all seasons, yet long-term trends are not present outside of austral summer in the reconstructions. In a historical perspective, the recent 30-year trend in summer is the strongest in the last 140 years, while in autumn negative trends after 1930 are actually stronger than the recent positive trend. These large natural fluctuations and inter-model differences make attributing the recent autumn trends especially difficult. Similarly, the disparate model and observationally-based spring trends warrant further study, and cast doubt onto the reliability of future SAM projections in this season.

French ITASE and ITASE related activities, recent and future

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While the french polar institute (IPEV) hauls hundreds of tons of cargo over thousands of km each year, to supply the French-Italian Concordia station at Dome C, logistical support for surface scientific expeditions like ITASE is still limited. In the recent years, much of the direct french contributions to ITASE have been in partnership with our Italian colleagues who provided the logistics. The last such collaboration was in 2000-2001. During that campaign, sites of older accumulation determinations were revisited. The more recent determinations based on atmospheric-bomb horizon dating proved significantly different from (lower accumulation than) the older ones. A complete re-evaluation of accumulation reports in the 90-180°E sector of Antarctica (East Wilkes – Victoria Lands) in the last 50 years was thus carried out, all reports being qualtity controled based on the method of determination used (Magand et al. 2007). Quality-control filtering results in a significant reduction of the best estimate of plateau accumulation, with potential impact on climate model performance evaluation (Genthon et al., 2008a).

More recently, the GLACIOCLIM-SAMBA observatory (http://www-lgge.obs.ujf-grenoble.fr/~christo/glacioclim/samba/) was deployed and surveyed since 2003-04, to monitor the surface mass balance at the coast of Adélie Land, at the Dome C, and along a 150-km transect directed inland from the coast. The observatory is process- and model-validation oriented, with at least one full annual survey, and deployement of various meteorlogical and nivological automatic instruments on the field. Out of 3 different, up-to-date, high-resolution meteorological and climate models, only one properly reproduces the observed meso-scale variability of accumulation along the transect. While much of the ITASE activities concentrate on the low-accumulation Antarctic plateau, the coast to plateau transition region is where accumulation is largest and predicted to change most in this century (Genthon et al. 2008b). Accumulation monitoring along transects in the coast-plateau transition zone, like that deployed as part of GLACIOCLIM-SAMBA, are thus crucial to better evaluate and improve climate models used to predict Antarctic surface accumulation changes, and impact on sea-level.

The French and italian contribution to TASTE-IDEA, the IPY multi-national ITASE traverse, was delayed twice due to logistical constrains. Instead, in 2006-07 a few shallow cores and pits were sampled during the GLACIOCLIM-SAMBA transect activities and analyzed for water isotops, chemical species, and artifical radionuclides (absolute dating), in an attempt to reconstuct annual variations of accumulation and chemical tracers. Annual records are crucial to properly validate variability and trends in climate models (Genthon et al. 2005). As this proved failry successful in Adelie Land, more such reconstruction are planned with the GLACIOCLIM-SAMBA logistics, while the first leg of TASTE-IDEA, from Talos Dome to Dome C, is now scheduled for 2009-2010.

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CLIMATE MODES AND THE INTERPRETATION OF MULTI-DECADAL CLIMATE VARIABILITY IN THE WESTERN PACIFIC SECTOR FROM ANTARCTIC ICE CORES

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New high resolution (monthly to annual) paleoclimate time series deduced from Antarctic ice core and south-west Pacific coral chemistry, together with multi-decadal coastline evolution in NSW and south-east Queensland, Australia (Goodwin et al., 2006), indicate that the climate variability of the past 1500 years in the western Pacific sector is defined by multi-decadal to centennial behaviour of the major climate modes: the extratropical Southern Annular Mode (SAM); the Pacific-South American mode (PSA); the Interdecadal Pacific Oscillation (IPO); and the El-Nino-Southern Oscillation (ENSO). The paleoclimate time series describe the climate system response to solar and volcanic forcing, and internal dynamics. A 700 year (1300-1995 AD), winter mid-latitude MSLP and SAM time series for the Australian and New Zealand sector has been reconstructed from the sea-salt sodium (Na) ion concentration in ice cores from Law Dome (DSS), 66° 46' S, 112° 48' E, circum-Antarctic station MSLP observations, NCEP/NCAR Reanalysis (NNR) MSLP, and wind field data (Goodwin et al., 2004). More recent work has shown that the Law Dome proxy MSLP time series records the variance in the pressure and windfield anomalies in the Australian and New Zealand sector that are associated with the propagating PSA modes (South Pacific wave train from the Australian to Antarctic Peninsula regions) in addition to the SAM variability in the Australian and New Zealand sector. The Siple Dome (West Antarctic) sea-salt sodium (Na) time series (Mayewski et al., 2004) records the variance in the pressure and wind fields in the Amundsen Sea region (Kreutz et al., 2000) which is principally associated with the propagating PSA modes. Hence, the Siple Dome Na time series spanning 0 AD to 1994 AD is also used to reconstruct the propagating PSA modes, and the SAM in the south-west Pacific sector, and has been applied to reconstruct the multidecadal resolution Tasman Sea mean wind field and wave direction over the past 1500 years, following the methods in Goodwin (2005).

At a multidecadal to centennial time scale the extratropical circulation has experienced shifts in mean state. From 600 to 1000 AD the circulation was shifted towards the PSA2 +ve mode. High amplitude climate variability occurred from 1000 and 1500 AD accompanied by a shift in mean state towards the meridional PSA 1 +ve (PSA 2 –ve) and –ve SAM modes. From 1500 to 1700 AD the circulation transitioned to reduced amplitude climate variability and a shift in mean state to the opposite more zonal phases +ve SAM and PSA 1 -ve and PSA 2 +ve modes. Since 1800 the circulation returned to high amplitude climate variability towards the meridional –ve SAM and PSA 1 +ve and PSA 2 +ve circulations. This interpretation highlights the non-stationarity of the spatial teleconnection patterns and the resulting variance in the phase, coupling and synchronization of the propagating tropical climate modes together with the polar annular mode. The oscillating statistical relationship between correlated and anti-correlated Na concentration anomalies at DSS and SD can be interpreted as evidence for climate fluctuations between synchronized to coupled circulation with phase lag on 30-40 year cycles (as hypothesized by Tsonis et al., 2007).

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German contribution to ITASE in recent years

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Abstract:
Spatio- temporal variations of the recently determined accumulation rate are investigated using ground- penetrating radar (GPR) measurements and firn- core studies. The study area is located on Ritscherflya in western Dronning Maud Land, Antarctica, at an elevation range 1400-1560 m. Accumulation rates are derived from internal reflection horizons (IRHs), tracked with GPR, which are connected to a dated firn core. GPR- derived internal layer depths show small relief along a 22 km profile on an ice flowline. Average accumulation rates are about 190 kg m□□ a□□ (1980-2005) with spatial variability (1) of 5% along the GPR profile. The interannual variability obtained from four dated firn cores is one order of magnitude higher, showing 1 standard deviations around 30%. Mean temporal variations of GPR- derived accumulation rates are of the same magnitude or even higher than spatial variations. Temporal differences between 1980-90 and 1990-2005, obtained from two dated IRHs along the GPR profile, indicate temporally non- stationary processes, linked to spatial variations. Comparison with similarly obtained accumulation data from another coastal area in central Dronning Maud Land confirms this observation. Our results contribute to understanding spatio- temporal variations of the accumulation processes, necessary for the validation of satellite data (e.g. altimetry studies and gravity missions such as Gravity Recovery and Climate Experiment (GRACE)).

The second part of the talk will show examples of ASIRAS data (Airborne SAR Interferometric Radar Altimeter System) measured in DML in 2007. This new high resolution Radar system has potential to map spatio-tempor al variations of accumulation rates at larger scales.

Tropical Pacific - high latitude South Atlantic teleconnections as seen in the network of ice cores from coastal Dronning Maud Land (DML), Antarctica

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In recent years there has been increased focus on the interaction between Antarctic climate and the tropical ENSO. A detailed study of the complicated nature of the interaction with the climatic system around Antarctica is hampered by the network of instrumental records being sparse and of short duration. The proxies from ice cores provide therefore a useful extension to available data. We use a network of ice cores from coastal Dronning Maud Land (DML) to examine the role of ENSO in the temporal variability of $\delta^{18}O$. It is demonstrated that the isotope records from the analyzed coastal cores capture a signature of large-scale circulation processes affecting the seasonal variations of snow deposition, thereby suggesting the presence of a strong bias in snow accumulation. Our analysis suggests that a multi-decadal positive trend in mean annual $\delta^{18}O$ values from these cores is not directly related to local temperature, but appears to be caused by warming of the western Pacific. A westward displacement of the enhanced tropical convection centre causes an increase in winter sea level pressure north of DML, leading to less winter precipitation, i.e. more positive annual $\delta^{18}O$ values at the ice cores sites. These results are in line with the negative trend in accumulation in DML, evident since approximately 1925

The SPRESSO South Pole Ice Core.

Elena Korotkikh, Paul Mayewski, Karl Kreutz (CCI, University of Maine), Vladimir Aizen (University of Idaho)

The South Pole SPRESSO (South Pole Remote Earth Science and Seismological Observatory) ice core was drilled during 2002, at 89.93°S, 144.39°W, to a depth of 292 meters as part of the International Trans Antarctic Science Expedition (ITASE). The ice age-depth relationship was determined from visual layer counting by Tony Glow and Debra Meese. In previous work by Meyerson et al (2002) the ice core recovered from South Pole was analyzed for the marine biogenic sulfur species methanesulfonate (MS) and showed a ~500 year long proxy record of the polar expression of the El Niño-Southern Oscillation (ENSO) and southeastern Pacific sea-ice extent variations.

The SPRESSO core presents an opportunity to extend this record to about 2000 years ago. We will conduct high resolution sampling of a ~200 meter section of the SPRESSO core using our Climate Change Institute continuous melter system. All samples will be analyzed for MS, soluble major ions (Na^{2+}, K^{+}, Mg^{2+}, Ca^{2+}, Cl^{-}, NO^{3-} ,SO_4 $^{2-}$), trace elements (Zn, Pb, Hg, Cd, Cu, V, Mn, Ni, As, Al, Fe, Se, and REEs), and stable oxygen isotopes ratios. We will use the ABAKUS particle counter for the first 50 meters (covering the last 350 years) to determine the insoluble dust content.

Insights into 20th-Century Antarctic and global climate change from ITASE (and other) high-resolution stable isotope records

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In this presentation I will highlight three recent papers that make use of the detailed, well-dated ice core stable isotope records from ITASE and related projects. I will then discuss how these new records may be incorporated into modeling studies. The new records fill in a large data gap in meteorological observations that has complicated the understanding of climate variability and the detection of climate change over the Antarctic as a whole, and particularly the West Antarctic ice sheet. In the first paper (Schneider et al., 2006), we presented an annual-resolution reconstruction of Antarctic mean surface temperatures over the past two centuries. The reconstruction shows large year-to-year and decadal scale variability connected to the Southern Annular Mode, but also a detectable 20-th Century warming trend. In the second paper (Schneider and Noone, 2007), we evaluated the covariance of water isotope records in a global network of ice cores spanning twentieth-century climate change. It was found that while Greenland and Antarctic isotope records have distinctive signals, when analyzing globally distributed records collectively, clear signals of the major patterns of global climate variability emerge. These include the signatures of ENSO, the Northern and Southern Annular modes, and the 20th-century warming trend. In the most recent paper (Schneider and Steig, 2008), we combine several West Antarctic records into a stack spanning the 20th-Century. We find very large anomalies during the 1936-45 decade. This period was previously known to have been warm at high Northern latitudes, but was unknown in the high Southern latitudes. Our record shows warmth in the West Antarctic that we hypothesize was driven by the large 1939-42 El Nino event that was unprecedented in its long duration (3 years). These results suggest that tropical warming, whether associated with an El Nino event or with long-term climate change, exerts a strong influence on West Antarctic climate.

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Scanning Electron Microscopic Characterization of U.S. ITASE Firn/Ice Cores

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Our understanding of the physical properties of firn, particularly grain size and its correlation with other parameters, such as chemistry, has been revolutionized by recent methodologies. A scanning electron microscope (SEM), in combination with energy dispersive spectroscopy (EDS) was used to describe the physical and chemical characteristics of samples collected during the 2002, 2006 and 2007 ITASE traverses. SEM analysis allows for the determination of firn grain area sans the pore filler required for thin-section analysis with an optical microscope and universal stage. Because no filler is required, porosity and internal surface volume can also be calculated. Additionally, EDS analysis of impurities provides an assessment of the relationship between chemical content, chemical location (i.e. in grain boundaries or within the crystal lattice) and grain growth.

Comparison of grain sizes from 3 cores collected on the 2002 traverse using traditional methods versus SEM has shown grain sizes from SEM images to be substantially smaller (37-59%). Grain size measurements from 3 cores collected during the 2006 traverse revealed an increase in grain size between 60 and 70 meters larger than that seen for the 10 meter increments observed at shallower depths. This trend was accompanied by a marked increase in sample variance. Samples above 60 meters had on average 12 times less variance than samples below 60 meters. Porosity calculations indicated a site specific difference (06-1 was 6-7% less porous than both 06-2 and 06-3). Chemical impurities analyzed at 30, 60, and 90 meters in all three 2006 cores were found to contain Na, Si, Ca, Cl, S, and K (although not in all impurities, nor at all depths). Most of the impurities examined were soluble species and observed on crystal facets, rather than at grain boundaries.

Traditional methods of grain size measurement rely on birefringence patterns; however, if the c-axes of adjacent grains are identical individual grains may be indistinguishable, resulting in artificially high measurements. This likely explains the differences in average grain area observed between techniques. The marked increase in both grain size and variance could be related to a higher frequency of low angle grain boundaries below 60 meters. Low angle grain boundaries have less energy and therefore sublimate less rapidly, making the boundaries difficult to see or absent, again potentially resulting in an artificially inflated average grain size and a lower sample population. Alternatively, the increased sample variance could be a result of the predicted pattern of grain growth, in which a few large grains grow at the expense of smaller grains. The observation of site specific trends in porosity underscores the advantages of using the SEM for both grain size and porosity measurements; as if only grain size had been calculated the data would have shown the sites to be very similar. Finally, the finding of chemical impurities located primarily in the crystal lattice in firn is contrary to observations in ice, where the impurities are primarily located at the grain boundaries, suggesting migration during densification. This could potentially alter the chemical signal and therefore, interpretation of paleoclimate records.

The synthesis of grain size, porosity, chemical data, stratigraphy and others to be completed in the future (including crystallographic orientation patterns) provide a detailed understanding of the interplay between chemistry and physical structure in ice sheets. It is the combination of these details and their relationships that will greatly enhance our understanding of firn metamorphism and the interpretation of paleoclimate records.

Temperature in West Antarctica over the last 50 and 200 years

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ITASE has collected more than 200 shallow ice cores, providing an unprecedented picture of Antarctic glaciochemistry over the last few hundred years. Yet the challenge to use these data to quantitatively reconstruct past climate in Antarctica over the last 200 years – the stated goal of the original ITASE science planning documents – still lies largely ahead of us. Ironically, the greatest challenge may no longer lie in the paucity of ice core data, but rather in the paucity of instrumental data against which to calibrate the ice cores. With this in mind, several attempts have recently been made to improve our understanding of recent climate -- and in particular temperature variability -- in Antarctica, based largely on instrumental data. Our approach (Steig et al., 2008) has been to use statistical climate field reconstruction to combine the spatial information from satellites with temporal data from weather stations. Among the findings is that, in the last 50 years, significant warming has occurred over most of West Antarctica, extending well beyond the Antarctic Peninsula, an area much larger than previously reported. This warming exceeds 0.1 °C/decade in the last 50 years, and is strongest in winter and spring. Although this is partly offset by fall cooling in East Antarctica, this effect is restricted to the 1980s and 1990s. The continent-wide average surface temperature trend is positive and significant at >0.05°C/decade since 1957. Comparison with simulations from coupled and atmosphere-only general circulation models suggests that these changes are closely associated with variations in sea ice.

Having established what we believe to be the most reliable reconstruction of Antarctic temperature change to date, we use the growing database of annually resolved and well0dated (Steig et al., 2005) ice core isotopes records from ITASE (and earlier programs) to extend this reconstruction over the last 200 years. While we cannot confidently reconstruct East Antarctic temperature during this time period, verification statistics show that the reconstruction is reliable for West Antarctica. Our results are consistent with our earlier results based on a simple composite of ice core records (Schneider et al., 2006). We find that there has been warming on average in West Antarctica throughout the 20th century; the trend is dominated by the influence of several relatively strong El Niño events in the late 20th century. Preliminary data from the WAIS Divide core suggests that this warming may be unprecedented in the last 200 years or more.

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Polish Achievements in the Past Climate Reconstruction

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The Antarctic Cenozoic sediments contain record of global climate deterioration. The opening of the Drake and Tasman Passages and progressive isolation of Antarctica by the Antarctic Circumpolar Current led to the transition from a warm, ice free climate in early Eocene to a colder one and glacial conditions since the end of Eocene. The glacial history of Antarctica in the geological time scale has been revealed mostly from logs obtained during deep see drillings.

Polish geological investigations delivered additionally some important evidences of glaciations from outcrops on the King George Island, supporting climatic scenario deduced from marine sediments. The following glacimarine and glacial sediments intercalated with interglacial clastics bearing terrestrial fauna were found: 1/ Eocene, local alpine glaciers activity, Harve Cove Glacial Event (45-41 Ma), 2/ Oligocene, continental, Polonez Glaciation (36-32 Ma), 3/ Miocene, continental Melville Glaciation (23-20 Ma).

Local environmental changes in the sensitive margin of Antarctic glaciers during Holocene, are delivered from paleolimnological studies carried out by many teams including Polish one. High impact of new formed and evolved watershed on sedimentation in glacial lakes, as well as serious problems with reliable stratigraphy, constrain regional and global meaning of recorded changes.

Both, geological and paleolimnological data support regional and global climatic records from ice cores, covering almost 1 Ma, prolonging it back to 40 Ma (geology) and enriching in local event following the last glaciation (paleolimnology).

Spatio-temporal records of snow and ice composition within the coastal East Antarctica: environmental and climatic implications

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Surface snow and shallow ice cores from the Ingrid Christensen Coast (ICC) and the coastal Dronning Maud Land (DML) region respectively, were studied for their major ionic, trace metal, stable isotope and micro-particle composition to assess the spatial and temporal variations in the environmental variability in the coastal region of East Antarctica.

Glacio-chemical profiles of an ice core from a coastal site of the central DML revealed the variability in sea-spray and volcanic aerosol components to the site during past ~500 years. SEM-EDS studies revealed that the micro-particles accreted in the ice during the Agung (1963) and Karkatau (1883) eruptions harboured microbial cells (both coocoid and rods), suggesting that these ash particles may provide a significant micro-niche for microbes and nanobes in the Antarctic ice. The nitrate profile of this core closely follow the South Pole ^{10}Be record at least during the past 200 years, suggesting that small changes in solar activity may indeed influence the environmental changes over Antarctica. Highly resolved proxy records of $\delta^{18}O$ and δD in another high-accumulation core revealed the intrinsic correlation between the summer $\delta^{18}O$ record, annual mean surface air temperatures in the region and the combined ENSO-AAO index. Snow accumulation at the site illustrates a significant decreasing trend for the past two decades and demonstrated a varied relation with summer temperature prior and subsequent to the year 1997 (major ENSO event).

Spatial variations in the major ionic and trace metal composition of surface snow samples collected during the austral summer of 2006/07 along short transects in the Ingrid Christensen Coast suggests that the sea salt constituents reveal a dramatic reduction from the ice edge to the inland sites. The estimated non-sea-salt sulphate ($nssSO_4^{2-}$) reveal large variations with extremely high $nssSO_4^{2-}$ depletion comparable to that in frost flowers especially within the sea/ice edge samples. It is cautioned that the extreme fractionation in the sulphate aerosols occur even during the summer time, leading to serious underestimation in the assessment of summer atmospheric sulphate budget within the coastal Antarctica. Study of sulphur species and bromide in the samples suggests an important biological pathway for the cycling of sulphur species in the coastal Antarctic region. Elevated biogenic bromide in region could react with ozone leading to BrO enhancement with subsequent dimethylsulfide (DMS) oxidation and production of sulfur aerosols. Since BrO based DMS oxidation is much faster than OH^-/NO_3^- pathway, elevated Br^- in the coastal region could contribute more towards formation of cloud condensation nuclei.

Investigating circulation changes on the southwestern Antarctic Peninsula from the Gomez ice core

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We present results from a new medium depth (136 metres) ice core drilled in a high accumulation site (73.59°S, 70.36°W) known as Gomez, on the south-western Antarctic Peninsula during 2007. The Gomez record reveals a doubling of snowfall since the 1850s, with acceleration in recent decades. Comparison with published accumulation records indicates that this rapid increase is the largest observed across the region. Evaluation of the relationships between Gomez accumulation and the primary modes of atmospheric circulation variability reveals a strong, temporally stable and positive relationship with the Southern Annular Mode (SAM). Furthermore, the SAM is demonstrated to be a primary factor governing decadal variability of accumulation at the core site however, the association with ENSO is complex: while sometimes statistically significant, the relationship is not temporally stable. Thus, at decadal scales we can utilise the Gomez accumulation as a suitable proxy for SAM variability but not for ENSO. These initial studies reveal that the Gomez site is sensitive to hemispheric-scale circulation patterns and thus we will present additional chemistry and isotope data from the new ice core to investigate the sub-seasonal relationships with the SAM.

Air mass variability on the Antarctic plateau

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A knowledge of atmospheric conditions on the Antarctic plateau is essential in order to interpret correctly the climate signals locked into ice cores. The limited number of in-situ meteorological observations show that the variability of surface temperature is larger than at the coastal stations on a range of timescales as a result of the rapid changes of air mass that can occur. The reanalysis fields show that surface temperatures here are strongly dependent on long wave activity around the Antarctic, with periods of amplified long waves feeding warm maritime air masses onto the highest parts of the plateau. Such episodes are also important for giving snowfall rather than the ubiquitous diamond dust. Inter-annual variability of temperature is strongly dependent on the amplitude of the long waves, with small amplitudes resulting in longer periods of isolation from maritime air masses and therefore lower temperatures.

Since the development of the ozone hole in the early 1980s the Southern Annular Mode has become more positive with implications for conditions on the plateau. There has been a drop in surface temperatures as the area has become more isolated from more northerly latitudes. The drop in temperature at Amundsen-Scott station has been attributed to fewer intrusions of maritime air from the Weddell Sea sector.

First results from radar profiles collected along the US-ITASE traverse from Taylor Dome to South Pole (2006-2008)

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Abstract. The 2006-07 and 2007-2008 US-ITASE traverses from Taylor Dome to South Pole in East Antarctica provided opportunities to survey the subglacial and englacial environments using 3 MHz and 200 MHz radar. We present first results of these new ground-based radar data. A prominent basal deformation layer indicates different ice flow regimes for the northern and southern halves of the Byrd Glacier drainage. Buried dune stratigraphy that appear to be related to the Megadunes toward the west, occur at depths of up to 1,500 m. At least two new water-filled subglacial lakes were discovered, while two recently-drained lakes identified from repeat ICESat surface elevation surveys appear to be devoid of water.

Introduction

The International Trans-Antarctic Scientific Expedition (ITASE) is a multi-disciplinary research program whose goal is to reconstruct the recent climate history of Antarctica through ice coring and related geophysical, glaciological, and paleoclimate observations along traverses throughout the continent. The U.S. component of ITASE (US-ITASE) operates numerous scientific projects from a heavy traverse platform consisting of two tractor trains. The US-ITASE traverses provided an opportunity to collect ground-based radar data over long distances, covering a wide range of glaciological and geological environments (Figure 1). A third vehicle, a Pisten Bully used to scout for crevasses ahead of the heavy trains, was available for local radar profiles near the ice core sites. The size of the traverse trains makes it possible to collect shallow (200 MHz) and deep (3 MHz) radar simultaneously.

The first phase of US-ITASE collected over 3,000 km of deep-penetrating radar data along a series of traverses centered at Byrd Station (80S, 120W) and ending in January, 2003 at South Pole (references?). During the second traverse, vehicles drove from Taylor Dome to Byrd Glacier (2006-07 field season) in East Antarctica and then to South Pole via Titan Dome (2007-08 field season). Shallow (~100 m) 200 MHz profiles were recorded simultaneously with deep radar at 3 MHz and both were used in the field to determine the suitability of ice core sites.

The purpose of this paper is to show first results from both radar systems focusing on features of current glaciological interest: the Megadunes area, basal ice flow regimes, and subglacial lakes.

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