



ANTARCTIC TREATY CONSULTATIVE MEETING 2006

IP 76

Agenda Item: ATCM 14

Presented by: SCAR

Original: English

Climate Change: an Antarctic Perspective

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**The SCAR Lecture
for
ATCM XXIX
Edinburgh, 2006**

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Climate Change: an Antarctic Perspective

The presentation slides will be available separately on the SCAR web site, at www.scar.org/communications/.

1. Based on meteorological observations, the average temperature of the Earth has increased by 0.8°C from 1880 to 2005, including an increase of 0.6°C since the 1960s (slide 2).
2. During the past 50 years, the temperature increase has been most marked at high latitudes in the Northern Hemisphere and in the Antarctic Peninsula. No significant annual temperature trend can be detected in the interior of the Antarctic continent (slide 3).
3. The ocean plays a key role in the global climate system because it stores heat and freshwater and moves them around the world. Oceanographic campaigns and models are used to show how the global ocean circulation system connects all the ocean basins and is involved in the formation of deep ocean waters. This global ocean circulation occurs over hundreds of years (slide 4).
4. At a higher level of detail, we see that the Southern Ocean is the place where waters from all the ocean basins are mixed. Deep ocean waters are formed around Antarctica. These processes import climate signals to Antarctica from the rest of the world, and export Antarctic climate signals to the rest of the world. This makes Antarctica an integral part of the global climate system (slide 5).
5. Antarctica and the Arctic are the cold points of the climate system. The Antarctic ice sheet is the largest freshwater reservoir on Earth, containing 90% of the ice and 70% of the total freshwater. If this ice were to melt completely, it would raise sea level by around 70 meters. Because the ice sheet is slow to respond to climate change it retains a long record of the changes that have affected it. In effect it is the long term memory of the climate system (slide 6).
6. The Antarctic ice cap is formed by the successive deposition of snowfall year after year. Successive accumulations have built up to depths of several kilometers in the interior of Antarctica (slide 7).
7. Since the 1960s, logistics and technologies have been developed and continuously improved which make it possible to extract solid cores of ice from drill holes in the ice sheet across Antarctica (slide 8).
8. During the process of transition from porous snow to ice, bubbles of air become entrapped in the ice. The ice also contains many other physical and chemical records of past environmental conditions. Thus, ice cores provide unique climate archives providing information on past climate and environmental changes at local, regional and global scales. They are also unique because they archive past climate change through physical mechanisms – most other paleoclimate archives are obtained through biological indicators (fossil organisms in marine or continental sediments) (slide 9).
9. The chemical composition of the water trapped in the ice allows us to estimate past temperature changes in Antarctica. The chemical composition of the ice also includes information on the impurities transported in the atmosphere. So ice cores enable us to reconstruct past changes in the content of dust and aerosols in the atmosphere at both regional and hemispheric levels. They make possible reconstructions of the ways in which both volcanoes and the sun have forced the atmospheric system to change. The impact of human activities on the composition of the atmosphere can also be determined. When it comes to human emissions of greenhouse gases, ice cores

provide the single direct record of past atmospheric global composition through the greenhouse gas composition of the air bubbles trapped inside the ice (slide 10).

10. Thanks to logistical support from national operational agencies, several long deep ice cores have recently been obtained by drilling at various locations in Antarctica. In the search for the longest and most detailed climate records, the European Project for Ice Coring in Antarctica (EPICA) reached a depth of 3270 m at Dome C in 2005, and 2774 m at Kohnen Station in January 2006, while the Japanese reached a depth of 3029m at Dome F in January 2006. At Dome C, the EPICA ice core provide the oldest climate record from Antarctica, extending back to 800 000 years, almost twice as long as the record from Vostok. The Dome F ice cores may extent even further back in time (slide 11).
11. The operational support provided by the national Antarctic programs is coordinated through COMNAP (Council of Managers of National Antarctic Programs) (slide 12).
12. Deep drilling projects such as EPICA Dome C require intense operational support due to climatic and geographic constraints. At Dome C, the operators had to transport a total of 1000 tons of equipment over 1200 km, during the 8 to 10 weeks per year available for field work. About 28 drillers and scientists were necessary for the drilling and in situ processing of the ice cores. EPICA Dome C was supported by 10 national programs and the European Commission (5th and 6th PCRDT) (slide 13). The EPICA Dome C deep drilling lasted from 1996 to 2005 (slide 14). The ice cores are sampled on site and split into working and archive sections (slide 15).
13. Knowing the present-day relationship between the surface temperature and the isotopic composition of the snow, we can use isotopic measurements made in ice cores to calculate past temperatures (slide 16).
14. Long Antarctic climate records from Vostok, Dome F and Dome C show the same history of Antarctic temperatures. These records confirm that ice ages separated by interglacial periods, one of which we are now living in, occurred about once every 100 000 years (slide 17).
15. High resolution measurements in ice cores from Greenland show that during glacial periods the climate has changed abruptly in what are called “Dansgaard-Oeschger events”. Antarctic ice cores now reveal that each abrupt climate change of the north Atlantic, seen in Greenland ice, has an Antarctic counterpart. These abrupt changes involve abrupt reorganisations of the global deep ocean circulation that connects the Arctic and the Antarctic (slide 18).
16. The temperature change since the last glacial maximum and the current interglacial period is estimated to be $9 \pm 2^{\circ}\text{C}$.at Dome C, corresponding to a maximum warming rate of 1.5°C over 1000 years. During the past 400,000 years, changes between ice ages and warm periods (interglacials) had a similar amplitude. In the older period (from 800,000 to 400,000 years ago), the differences in temperature between ice ages and interglacials were smaller. Within the temperature record it is important to note the long, warm interglacial that occurred 400,000 years ago, to which we shall return later (slide 19).
17. The occurrence of ice ages is first triggered by changes in the orbit of the Earth around the Sun, which modulates the seasonal and latitudinal distribution of incoming solar radiation (slide 20). Secondly there are amplifying feedbacks within the climate system caused by changes in the albedo (surface reflection) and in the amounts of greenhouse gases in the atmosphere. These feedbacks mean that what we see as the climate record in ice cores does not simply mimic the Earth’s orbital signal.
18. Past and future changes in solar irradiance (energy) received by the Earth can be precisely calculated for various seasons and various locations. The modern orbital

configuration is very similar to the orbital configuration that occurred 400,000 years ago, when the Dome C record showed that there was an unusually long interglacial period. Because the astronomical conditions now and 400,000 years ago are similar, we would expect that the current warm period should last as long as that one – around 28,000 years (slide 21).

19. By directly overlaying the Dome C climate data for the past 30,000 years on top of the first 30,000 years of the 400,000 year old interglacial, we can show that the records are very similar, as might be expected from the similarity in the annual insolation at 75° during these two periods of time (slide 22). This period is characterised by greenhouse gas contents rather similar to the current interglacial period prior to the industrial era. This long-lasting warm period is attributed to a specific characteristic of the Earth orbit, with a small eccentricity. Because the same astronomical situation is taking place now and in the future tens of thousand of years, it is not expected that the current warm period should end due to natural causes. It is expected that the current warm period should be a “super interglacial”.
20. Dome C temperature records exhibit a large change in the intensity of warm periods between the periods from 800 000 to 400 000 years and from 400 000 years to nowadays. Early warm periods appear as “lukewarm” interglacials. There is no current theory for this dramatic change in the intensity of warm periods. They are not restricted to Antarctica, as revealed by similar changes in methane and CO₂, which form parts of the natural global carbon cycle (slide 23). The present (industrial) levels of both methane and CO₂ are considerably higher than anything experienced in the atmosphere of the last 650,000 years (slide 23)
21. In summary, natural fluctuations of greenhouse gases have been reconstructed from Antarctic ice cores back to 650 000 years (current analyses are being conducted to go back to 800 000 years at Dome C). The correlation between Antarctic temperature, methane and carbon dioxide fluctuations is very strong and constant throughout this period. This is good evidence for there being strong feedbacks between climate and the carbon cycle. However, we do not yet fully understand the mechanism behind this relationship, and that means it is a challenge for climate modellers. The current level of methane in the atmosphere is two times larger than its natural level; the current level of carbon dioxide is 30% above the natural levels during warm periods. These increases are due to human activities (intensive agriculture and massive use of fossil fuels)(slide 24).
22. Most climate scientists consider that the continued addition of greenhouse gases to the atmosphere will cause the climate to warm. We can use state-of-the-art climate models to forecast future change based on increases in greenhouses gases. These calculations suggest that future climate change in response to increased anthropogenic greenhouse gases is likely to be stronger in Antarctica than across the globe (slide 25).
23. It is instructive to use climate models to see how warming might be spread across Antarctica with different amounts of CO₂ in the atmosphere. Typically, a doubling of carbon dioxide concentrations in the atmosphere is expected to induce a warming of 2.5°C on the central Plateau; a quadrupling of carbon dioxide levels is expected to produce a warming of 6°C on the central Plateau (slide 26). One way to assess the realism of climate models is to test them against known past changes. Climate models are able to simulate the order of magnitude of temperature increase from the last glacial maximum to present-day (8.5°C). The future temperature change expected from a quadrupling of carbon dioxide levels (6°C) is comparable in magnitude to the change since the last ice age; however, it would take place 25 times faster than any past natural changes (slide 26).

24. The wealth of information from deep ice cores reveals that Antarctica is a crucial area for extracting key information about past climate and environmental change. Extracting this information required very significant coordinated support from national agencies working independently or through COMNAP. Antarctica is experiencing large regional changes today that are expected to increase with the increasing human emissions of greenhouse gases (+20% since 1990). The Antarctic environment and biodiversity are particularly vulnerable to climate change and human pressure (slide 27).
25. Key uncertainties still remain on climate change in Antarctica. Large areas of the Antarctic continent are still scientifically unknown. We need a better understanding of the current, past and future evolution of the Antarctic ice cap, in order to evaluate the risk of climate induced sea level rise. The evolution of Antarctic climate at decadal time scales, and at the regional scale, remains uncertain, as does the history of the climate system prior to 800,000 years (slide 28).
26. During the next International Polar Year, between 2007 and 2009, intensive international efforts will be made to document unexplored areas of Antarctica and the Southern Ocean, and to improve understanding of the processes at work within the whole system (slide 29). In taking matters forward, we expect to benefit from a new coordinated effort to integrate all the national activities in ice core science: International Partnership for Ice Core Science (IPICS) (slide 29).
27. The development of IPICS is motivated by the increasing complexity of challenges in ice core science, such as the need for improved spatial coverage, and deeper and older cores in more difficult places. This informal international planning group includes representatives from 18 nations and is coordinated by Ed Brook (USA) and Eric Wolff (UK). Two meetings have been organised in the past 2 years. The project is supported by NSF's Office of Polar Programmes and by the European Polar Board of ESF. It is officially endorsed by the IPY committee and is affiliated to PAGES and SCAR (slide 30).
28. IPICS has agreed on four targets: (i) the oldest ice core, back to 1.5 million years in Antarctica; -ii) a new Greenland ice core extending back to the last interglacial period and beyond; (iii) a network of ice cores from north and south covering the past 40 000 years; (iv) an array of ice cores from ice caps and glaciers covering the past 2000 years. The idea for the last three of these is to increase the resolution of the ice core record in both time and space, so that we can identify the speed, nature, extent and timing of climate change with unprecedented accuracy. (Slide 31).
29. A number of locations have been identified for future work, but substantial areas of Antarctica remain un-sampled (slide 32).
30. It is crucial for the understanding of past climate change to obtain records of atmospheric greenhouse composition prior to 1 million years ago. This remote time period marked a change from small ice ages occurring around 40 000 years apart to large ice ages occurring 100 000 years apart. This transition remains unexplained (slide 33).
31. The take-home message is that given the continuing rise in greenhouse gases we expect Antarctica to warm, with profound implications for changes in global sea-level. West Antarctica is already vulnerable, especially in the Antarctic Peninsula. East Antarctica, however, remains cool for the time being. Our ability to forecast the rates and magnitudes of possible change is limited by our numerical models of climate change, which in turn are limited by the lack of data on how Antarctic climate has evolved and the mechanisms involved. More ice coring will fill that gap, enabling forecasts to be refined for the benefit of decision makers. The only place in the world

where we can obtain these data in sufficient amounts with adequate resolution over the longest possible time scale is Antarctica. For accurate predictions of Antarctica's role in global climate change we need more investment both in ice core drilling on Antarctica and in coupled ocean-atmosphere-ice modelling of Antarctic climate (slide 34).

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Climate change : an Antarctic perspective

Valérie Masson-Delmotte

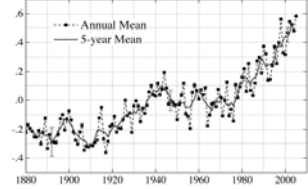
The XXIX Antarctic Treaty Consultative Meeting
Edinburgh, June 2006

Scientific Committee on Antarctic Research

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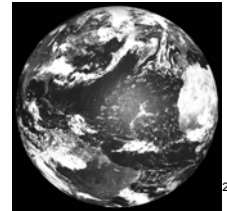
The monitoring of global warming

Change in global mean surface temperature (°C)



+0.6°C since the 1960s

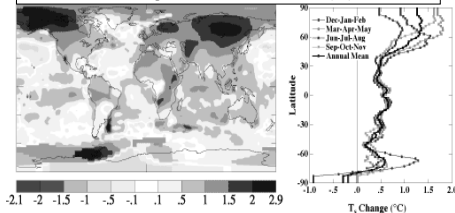
+0.8°C since the 1880s



2

Global versus regional warming

Trends in surface temperature from 1955 to 2005 (°C)

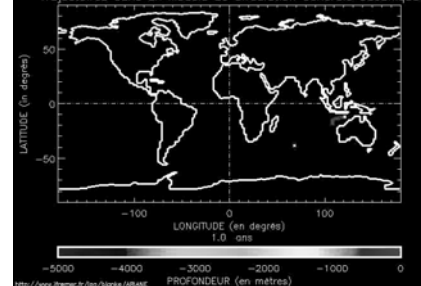


Complex recent temperature evolution in Antarctica
Why?

3

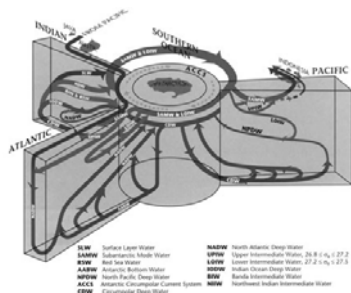
Links between Antarctica and the global climate system

Trajectoires dans un Modèle de Circulation Générale Océanique



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Links between Antarctica and the global climate system



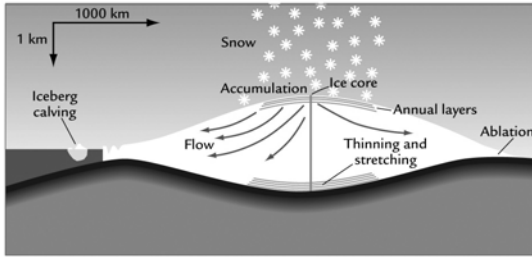
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Antarctica : a key climate area

- The « cold point » of the climate system
- Around Antarctica : intense exchanges between ocean, sea-ice and atmosphere
- Antarctic ice cap :
- ◆ The largest freshwater reservoir (70 % of the Earth's freshwater, ~60 m of global sea-level)
- ◆ The long term memory of the climate system

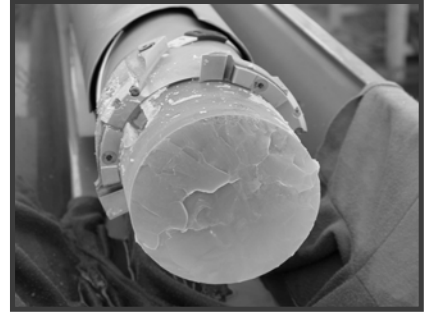
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Archiving in ice caps



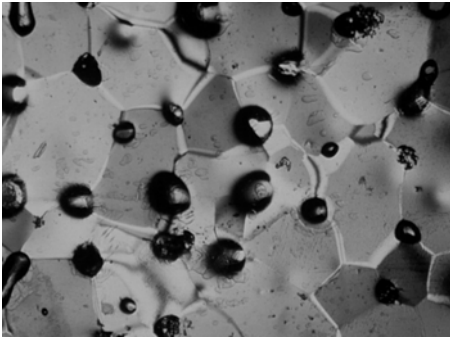
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Sampling the cold point of the global climate system^{IP 76}



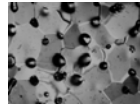
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Hidden inside the ice



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Climatic information preserved in the ice



Water isotopic composition

- ➔ Past local temperature changes
- Antarctic climate change*

Ice chemistry

- ➔ Impurities transported by the atmosphere
- Dust, aerosols, pollution...
- Volcanism, solar activity (climate forcings)*

Air trapped in the ice

- ➔ Atmospheric composition
- Greenhouse gases*

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Recent completion of drilling projects

EPICA Kohnen Station

Jan. 2006
2774 m
500 000 years?

Dome F

Jan. 2006
3029 m
1 000 000 years?

Vostok

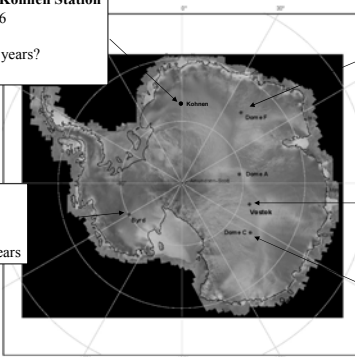
1996
3623 m
400 000 years

EPICA Dome C

Dec. 2004
3270 m
800 000 years

Byrd

1968
2164 m
80 000 years



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Operational Support - The National Antarctic Programs and COMNAP

Council of Managers of National Antarctic Programs

- **The National Antarctic Programs (NAPs):** implementing and managing national activities in Antarctica
- **Major activity:** direct operational support to scientific projects
- **NAPs together in COMNAP to:**
 - improve their ability to conduct their respective operations effectively and efficiently
 - promote and facilitate collaboration on operational projects of mutual interest
- **Indirect, but immediate and tangible effect for science:** improved support of scientific projects by National Programs

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Deep drilling projects : need for intense operational support

The example of EPICA Dome C

- Climatic and geographic constraints : 3233 m elevation, -54.5°C, 75°S, 123°E
- Transport by traverses : 1200 km from DDU
- Window for summer field work : 8 to 10 weeks
- Drilling capability : 0 to 250 meters per week
- Equipment required : 1000 tons, 7 convoys
- Personnel required : 8 drillers, 20 scientists

European Project for Ice Coring in Antarctica
Support by 10 national programs (Belgium, Denmark, France, Germany, Italy, The Netherlands, UK, Norway, Sweden, Switzerland), the European Commission (5th and 6th PCRD) and European Science Foundation



EPICA deep drilling

EDC96

1996/1997 : casing 130m

1997/1998 : 364m

1998/1999 : 781m

EDC99

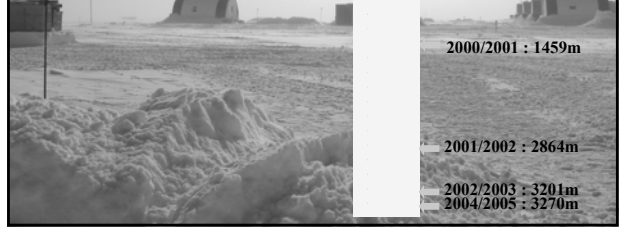
1999/2000 : casing

2000/2001 : 1459m

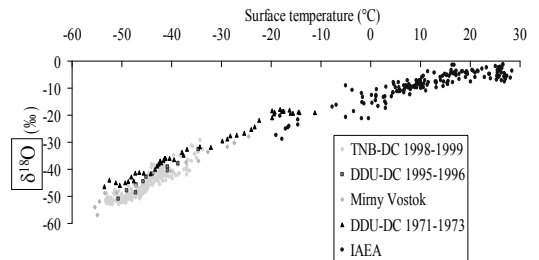
2001/2002 : 2864m

2002/2003 : 3201m

2004/2005 : 3270m

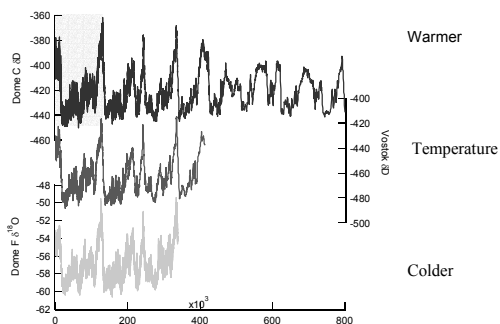


Paleothermometry



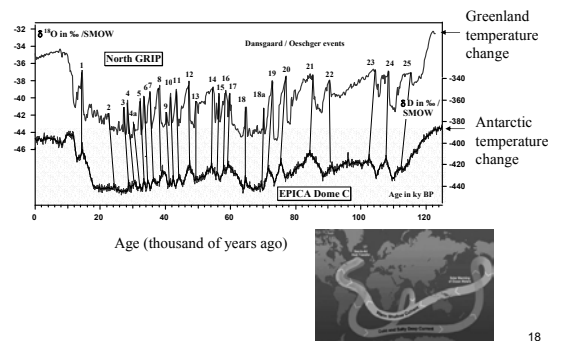
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Climate records in Dome C deep ice



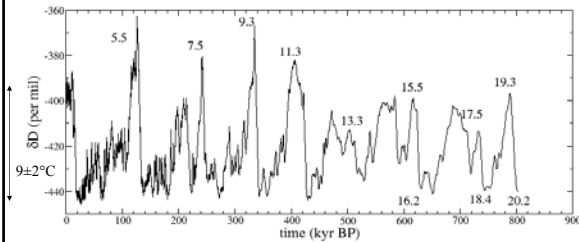
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Rapid climate changes in Antarctica



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Temperature history at Dome C (as a function of time)



Ice ages each 100 000 years

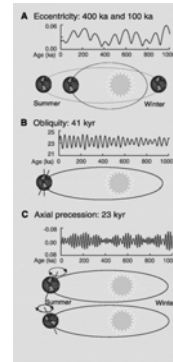
Changes in the intensity
of warm periods : why?

Very long warm period ~400 000 years ago

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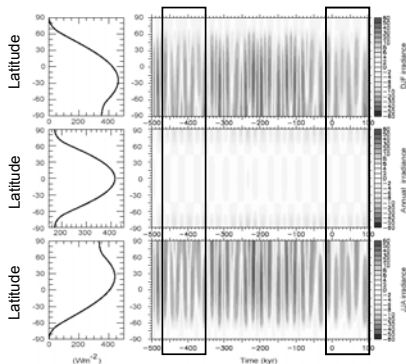
Ice ages : orbital theory

11/76



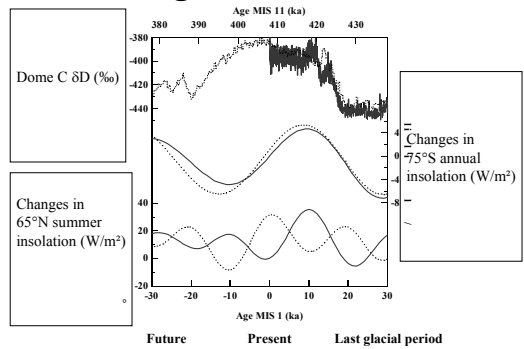
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Orbital theory : our past and our future



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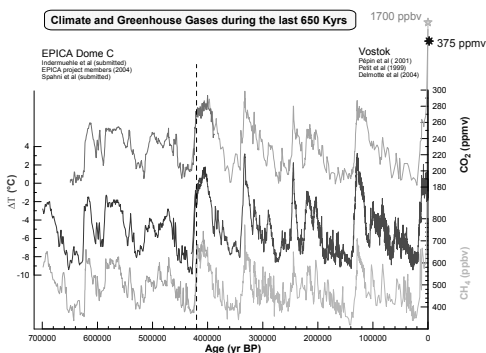
Insights for the future



Our future : a « super-interglacial » period

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Evolution of greenhouse gases



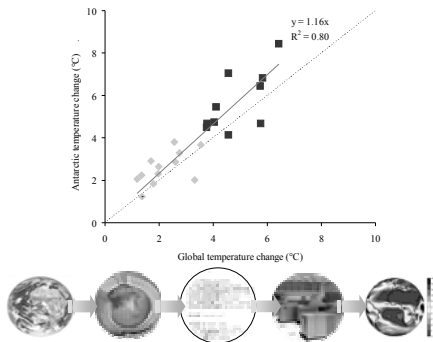
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Evolution of greenhouse gases

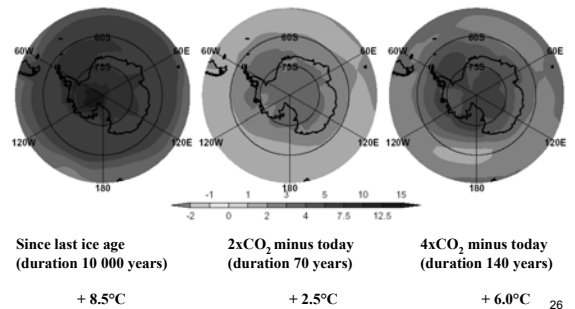
- Stable relationships between past Antarctic temperature changes and global greenhouse concentrations : carbon cycle « feedbacks »
- It remains a challenge to explain the natural carbon cycle (the EPICA challenge)
- Unprecedented change in the atmospheric composition due to human activities in the industrial era

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Simulated future climate change in central Antarctica



Simulated past and future climate change in central Antarctica



Conclusions

- Antarctica is a crucial area for extracting key information about past climate and environmental change
- Extracting this information generally requires very significant coordinated national operational supports (COMNAP)
- Antarctica is experiencing large changes today that are expected to increase with the increasing human emissions of greenhouse gases (+20 % since 1990)
- The Antarctic environment and biodiversity are particularly vulnerable to climate change and human pressure

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Climate change in Antarctica : key uncertainties

- Large areas of Antarctica still unknown
- Current and past evolution of Antarctic ice cap mass balance
- Evolution of Antarctic climate at time scales of decades
- Regional changes in Pacific, Indian, Atlantic sectors
- Antarctic climate change prior to 800 000 years

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Perspectives

- 2007-2009 : International Polar Year
Coordinated traverses : surface and bedrock characteristics, recent climate change
- IPICS : International Partnership for Ice Core Science
- <http://www.nicl-smo.unh.edu/IPICS/>
sponsored by NSF/OPP and European Polar Board.

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IPICS

- Ice coring scientific objectives are increasingly complex
 - More cores to see spatial patterns
 - Deeper and older cores, in more difficult places
 - ➔ International cooperation can help meet these goals
- Informal international planning group
 - Discussing long term new ice coring projects
 - Representatives from 18 countries : Australia, Belgium, Canada, China, Denmark, France, Germany, Italy, Japan, Korea, Netherlands, New Zealand, Norway, Russia, Sweden, Switzerland, United Kingdom, United States
 - Involves representatives of operational support, science, drilling
 - Co-chairs: Eric Wolff (BAS), Ed Brook (OSU)
- Meetings: Washington D.C. 2004, Brussels 2005
 - Support from NSF/OPP, European Polar Board
 - IPY Endorsement
 - Affiliation to PAGES and SCAR

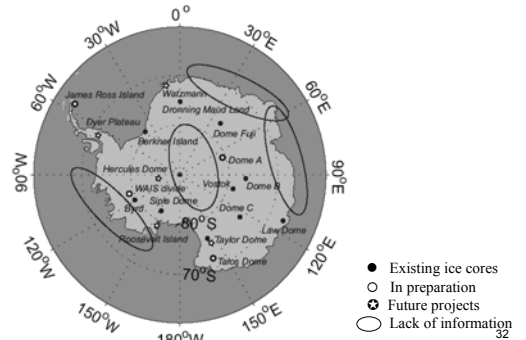
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IPICS

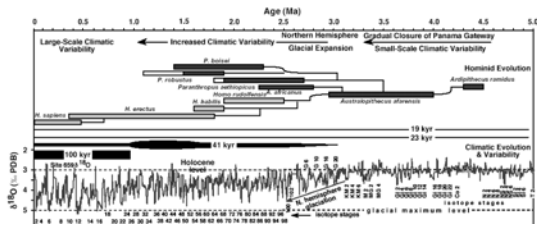
- The oldest ice core: A 1.5 million year record of climate and greenhouse gases from Antarctica.
- The last interglacial and beyond: A northwest Greenland deep ice core drilling project.
- The IPICS 40,000 year network: a bipolar record of climate forcing and response.
- The IPICS 2kyr array: a network of ice core climate and climate forcing records for the last two millennia

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Ongoing and future projects



Why look for climate change prior to 1 million years?



Past climates are essential to test and improve the understanding of climate change mechanisms including feedbacks between the global carbon cycle and climate

Need understanding of the shift from small ice ages with periodicities of 40 000 years to large ice ages with periodicities of 100 000 years : natural carbon cycle?

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Take home messages

- Antarctica will continue to warm with profound implications for global sea level.
- Our models of future climate change need improving using targetted ice coring programmes to give more reliable predictions on which to base decision making
- Only in Antarctica can we gain the long term data we need for this, so more investment is required in ice coring and climate modeling to ensure accurate predictions of future change.

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