Back to the Future: Past Antarctic Climates, Ice Sheet History & Their Relevance for Understanding Future Trends

Scientific Committee on Antarctic Research
Antarctic Science Lecture

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and
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• Why do we need paleoclimate records from Antarctica?

• Long-term paleoclimate records – Technical Challenges: The need for collaborative international efforts - The role of SCAR

• How past Antarctic environmental conditions can inform future changes

• The road ahead: SCAR-Past Antarctic Ice Sheet Dynamics (PAIS)
Polar ice plays an important role in the Climate System:

- Earth’s albedo
- Ocean circulation
- Sea level
- Air-Sea interactions
- Marine productivity
Despite their important role in the global system, polar areas are largely unsampled.
Deep Sea Drilling Project  
Ocean Drilling Program  
Integrated Ocean Drilling Program

more than 200 expeditions in the history of Ocean Drilling – 16 in high-latitudes
Northern Hemisphere Glaciations start around 3 million years ago

Projected 2100 CO₂ concentrations, IPCC RCP8.5 take us back to when Antarctica did not support ice sheets

Projected 2100 T (°C), IPCC AR5 RCP8.5 not experienced in our planet since around 15 Ma
Critical questions that need to be addressed with long-term sedimentary records from the Antarctic margins

- How do ice sheets and sea level respond to a warming climate?

- How was the Antarctic and the Southern Ocean different under high CO$_2$ conditions (i.e., 400 ppm, 600 ppm, >1000 ppm)?

- What forcing mechanisms, thresholds, rates?

- Opening and closing of gateways and their paleoceanographic consequences

- How does ice sheet/sea ice variability affect bottom water formation and how it relates to global circulation?
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ICE CORES
Continuous reconstructions of past climate back to 800,000 years

Ice Core record from Dome C

$\text{CO}_2 = 400$ ppm in 2013

Levels of $\text{CO}_2$ much lower than present in the past 800,000 years!!!

In order to have an analogue to present $\text{CO}_2$ conditions and what this might mean for ice sheet stability we need to have longer records so we can see further back in time
Last time the Earth experienced CO$_2$ concentrations similar to present is during the warm Pliocene: 5-3 million years ago.

The level of warming during the warm Pliocene is within range of the estimates of the Earth's global temperature & CO$_2$ increases for the 21st century (IPCC, 2013).

Long-term (>1 Ma) records are needed if we are to understand ice sheet dynamics under these conditions.
Long-term records from Antarctic Outcrops

99.7% of the continent is covered by ice
Subglacial Access

Wright and Siegert (2012)
Long-term records from marine sediments
Detailed understanding of past environments and climate are essential for a more complete understanding of climate variability and the forces that control future change and responses to change.
SCAR’s role in advancing our understanding of past Antarctic paleoclimates & ice sheet behavior

- **SCAR-ANTOSTRAT (ANTarctic Offshore STRATigraphy) 1996-2002**
  Reconstruct the glacial history of Antarctica through stratigraphic studies of the continental margin using geophysical data. Towards the end of the Program the aim was also to reconstruct the Cenozoic paleoclimatic and glacial history of the Antarctic region from the study of the sedimentary record surrounding the continent.

- **SCAR-ACE (Antarctic Climate Evolution) 2003-2012**
  “to link climate and ice sheet modeling studies with geophysical surveys and geological studies on and around the continent.”

- **SCAR-PAIS (Past Antarctic Ice Sheet Dynamics) 2013-2020**
  “Reconstruct past Antarctic ice sheet dynamics and its contribution to sea level change in response to past warm climates with elevated temperatures and CO₂ (i.e., from greenhouse to warmer than present icehouse climates).”
Summary

- Antarctica is key to understanding how ice sheets will respond to forecasted elevated temperatures and CO$_2$ concentrations.

- Long-term (>1 million years) paleoclimate & ice sheet dynamics records are key in informing future trends of ice sheet behaviour.

- There are major technological and logistical challenges that can be overcome through national and international coordination and collaboration through COMNAP.

- SCAR has been central to community coordination and collaborations to obtain and integrate long-term paleoclimate and glacial history records.
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How past Antarctic environmental conditions can inform future changes

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Environmental reconstructions in Antarctica

Greenhouse world (55-34 million years)
>1000 ppm CO₂

Analog for conditions in 2100:
IPCC AR5-RCP 8.5
936 ppm CO₂
1313 ppm when considering combined greenhouse gases CO₂-equivalent
latest Early Eocene
~50 millions of years

3D preservation of conifer branches in concretions - can withstand cool climates with snow

NLE *Araucaria araucana*, Monkey Puzzle, Chilean Andes

*Slide courtesy of J. Francis*  
R. Stephens PhD
Pollen from – 50 million years, Wilkes Land IODP Site 1356

Pollen of extent palms

Mean Annual T: >13.3 °C
Cold Month mean T: >5 °C + 3 °C
Warm Month mean T: >22.8 °C

Bush and Weng, 2006

Pollen from Wilkes Land

Pollen of extent Bombacaceae plants

Mean Annual T: >16.8
Cold Month mean T: >10.6 °C + 3 °C
Warm Month mean T: >21.5 °C

Bush and Weng, 2006


Other Organic components in these sediments provide T 20-25°C
We have learned that Greenhouse Antarctica (CO₂ > 1000 ppm):

- Did not sustain ice sheets until 34 million years ago when a continental ice sheet grew in Antarctica.
- Global sea levels were 60-80 m higher than today.
- Temperatures were high, much higher than previously thought.

We do not know how representative are our records of Antarctic-wide conditions. Considering IPCC (2013) forecasts CO₂ concentrations around 1000 ppm for 2100 ...

We need more comprehensive records to constrain regional differences & continental-ocean gradients and models – Are we going back to greenhouse conditions?

Greenland Ice sheet:
7 m SLE

West Antarctic Ice Sheet:
7 m SLE

East Antarctic Ice Sheet:
60 m SLE

No ice sheets
In Antarctica

Courtesy of K. Miller
Environmental reconstructions in Antarctica during the warm Pliocene: 5-3 million years ago

Pliocene Warm Period
3-5 million years ago
- 400 ppm CO₂
- 2-3°C warmer
- ice sheets, continents and oceans similar to today: Similar Climate System

Good analog for the near future (next decades?)
IPCC AR5 RCP2.6 in 2100 421 ppm CO₂
475 when considering combined greenhouse gases CO₂-equivalent
ANDRILL MIS cores: Ross Sea

marine-based WAIS dynamic during the Pliocene

Naish et al., Nature 2009
Polar ice sheet & sea-level response during warm periods 5-3 million years ago

7 meters sea level rise
*Pollard and DeConto*, 2009

Far field records indicate global mean sea level during the warm Pliocene
22m ± 10m above present

- GIS = +7m (*Dolan et al.*, 2011)
- WAIS = +7m (*Pollard & DeConto*, 2009) BUT BASED IN RECORDS FROM ONE LOCATION!!!

The “missing” 8 meters of sea level have to come from East Antarctica, but from where?
We have learned that last time Earth had similar CO₂ concentrations to today (CO₂ > 400 ppm):

- The West Antarctic Ice Sheet was highly dynamic and at times collapsed but need to calibrate models with data from other sites.

- Records from the Wilkes Land margin also show the ice sheet to be dynamic.

- Sea surface temperatures from few localities around Antarctica indicate higher T than today (5- 2.5°C)

- Under these higher CO₂ and temperature scenarios mean global sea levels were around 20 m above present sea level.

More records are needed from around Antarctica to provide additional boundary conditions to models that can inform about what can be expected in the future.
Greenhouse.......... to ............ Icehouse

34 million years ago

WHAT ARE THE FORCING MECHANISMS FOR CHANGE?

Icehouse.......... to ............ Greenhouse???

Future?
Tectonic Forcing

0 Ma

 Orbital Forcing

 CO₂ Forcing

Oceanic Forcing

ADDITIONAL BOUNDARY CONDITIONS FROM SEDIMENT RECORDS ARE NEEDED TO CALIBRATE MODELS AND BETTER CONSTRAIN THE FORCINGS
SUMMARY

- Past environmental conditions can be interpreted from sediment records.
- Sediment records can also provide information about forcing mechanisms for changing conditions.
- Existing data is too sparse to provide for needed boundary conditions to the models.

Sediment records + Modelling

REFERENCE SCENARIOS

IMPROVE CLIMATE MODELS

FUTURE CLIMATES

Climate modelling

Paleoclimatic Research
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FOUR DECADES OF ANTARCTIC DRILLING

- Antarctic Peninsula, Shaldril (2005,2006)
- Antarctic Peninsula, Leg 178 (1998)
- SE Pacific Ocean, DSDP 35 (1974)
- Weddell Sea, ODP Leg 113 (1987)
- Ross Sea
- Wilkes Land, IODP Exp 318 (2010)

SHALDRIL
DVDP/CIROS/CRP/ANDRILL (SCAR-ACE)
ODP/IODP (SCAR-ANTOSTRAT & SCAR-ACE)
DSDP
SCAR
Past Antarctic Ice Sheet Dynamics (PAIS)
2013-2020
PAIS marine-continental transects & links to Ice cores

- Subglacial Lake drilling
- ANDRILL CH program
- Previous drill sites

PAIS selected continent-to-abyss transects along single ice drainage systems (2012-2020)

Modified from Rignot et al., 2011

NASA
Final Summary

- IPCC 2013 projections have not been experienced on our Planet for more than 3 million years. Then, the Earth only sustained ice sheets in Antarctica. Long-term geological records of Antarctic paleoclimate & ice sheet dynamics are therefore key to informing future trends of ice sheet behaviour & sea level.

- We can reconstruct past environmental conditions and forcing mechanisms, but existing records are at this time too few and dispersed to provide for solid reference scenarios for future climate and ice sheet modelling.

- The SCAR-PAIS Research Programme is undertaking a major effort to reconstruct past Antarctic ice sheet dynamics and its contribution to sea level change in response to past warm climates with elevated temperatures and CO₂ that can be used as reference scenarios for future change.

- For this endeavour, there are major technological and logistical challenges that will be overcome through national and international coordination and collaborations.
Thank you for your attention