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

Scientific Committee on Antarctic Research
Antarctic Science Lecture

XXXVII ANTARCTIC TREATY CONSULTATIVE MEETING
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and

the SCAR-PAIS Steering Committee

- 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)

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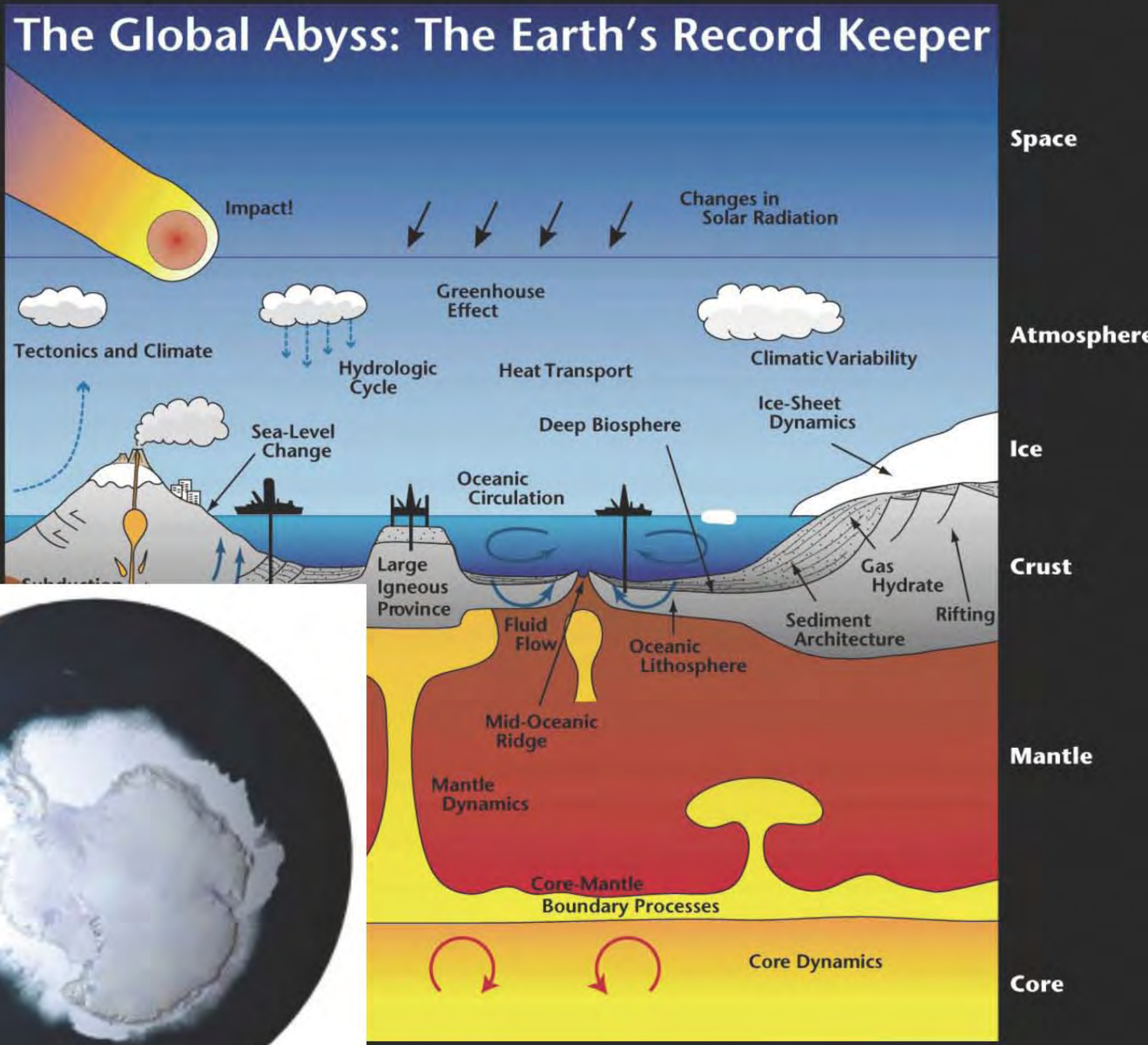
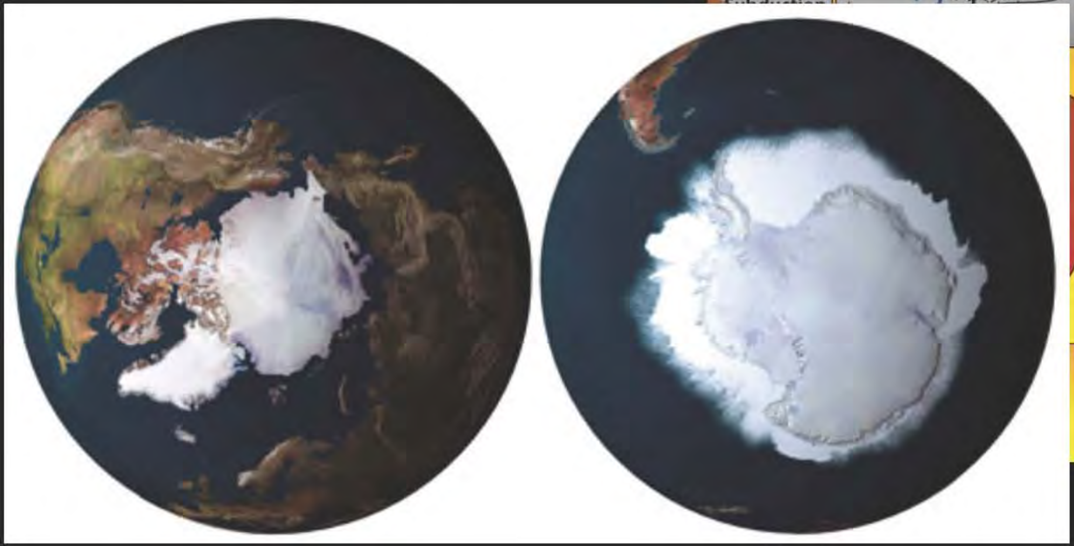
Polar ice plays an important role in the Climate System:

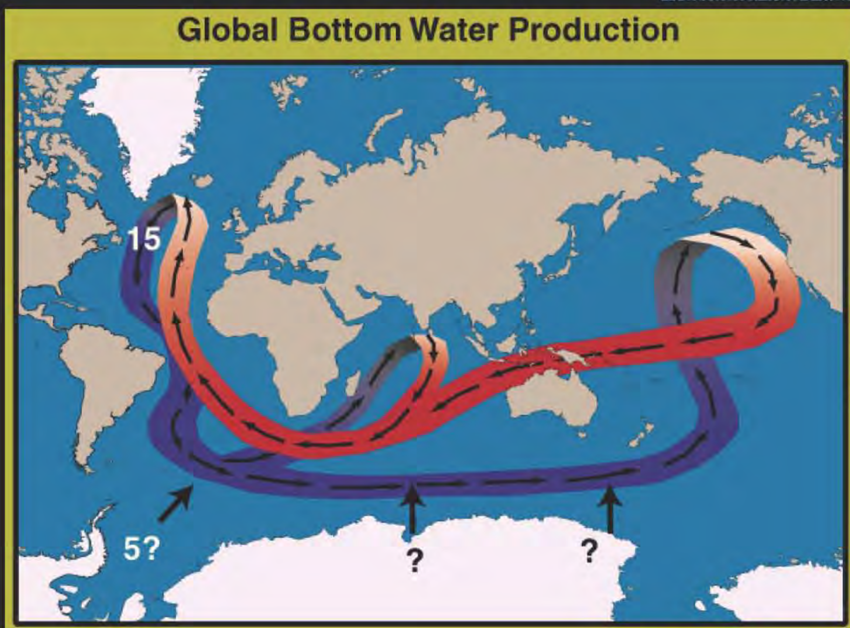
- Earth's albedo
- Ocean circulation
- Sea level
- Air-Sea interactions
- Marine productivity

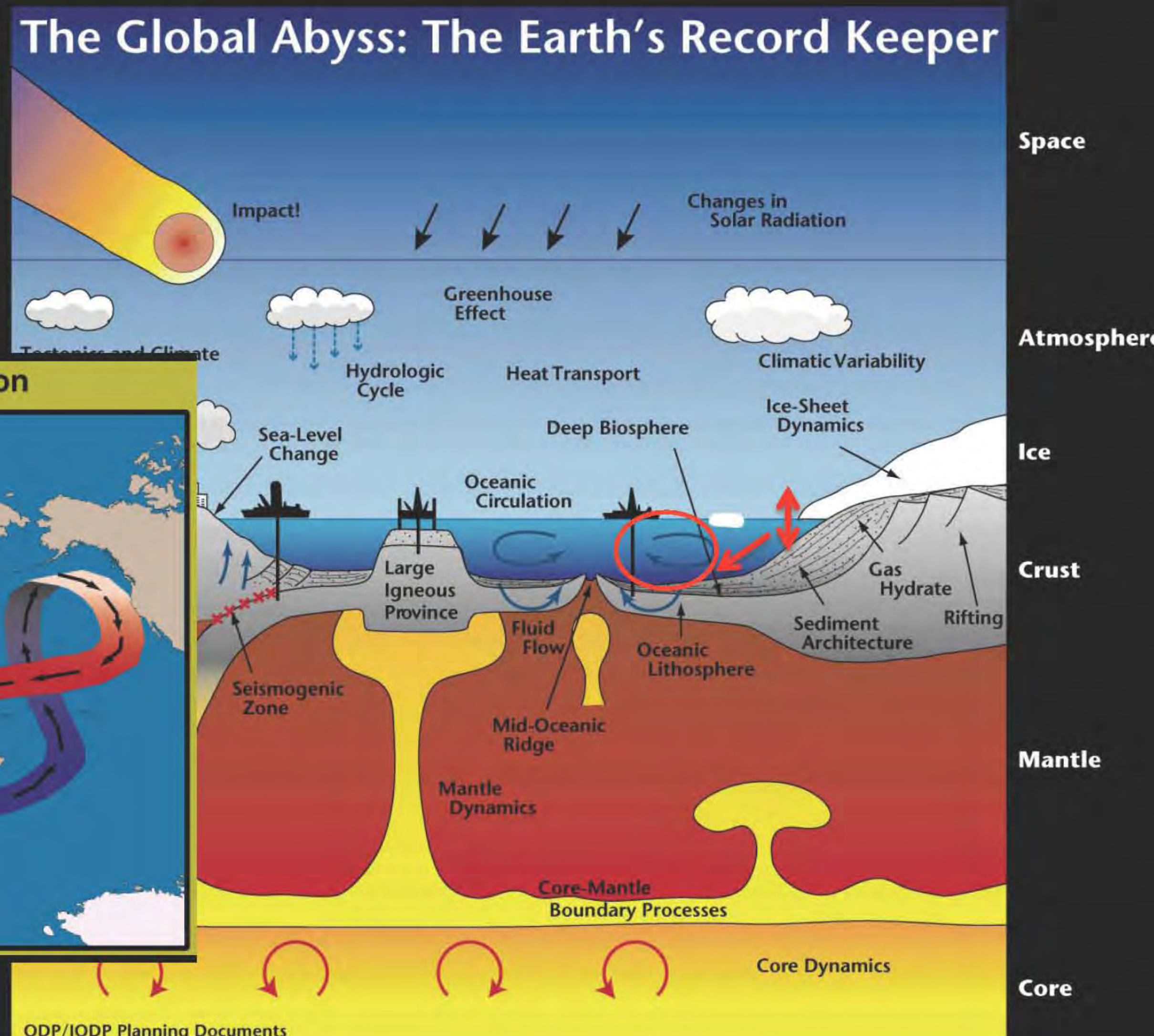




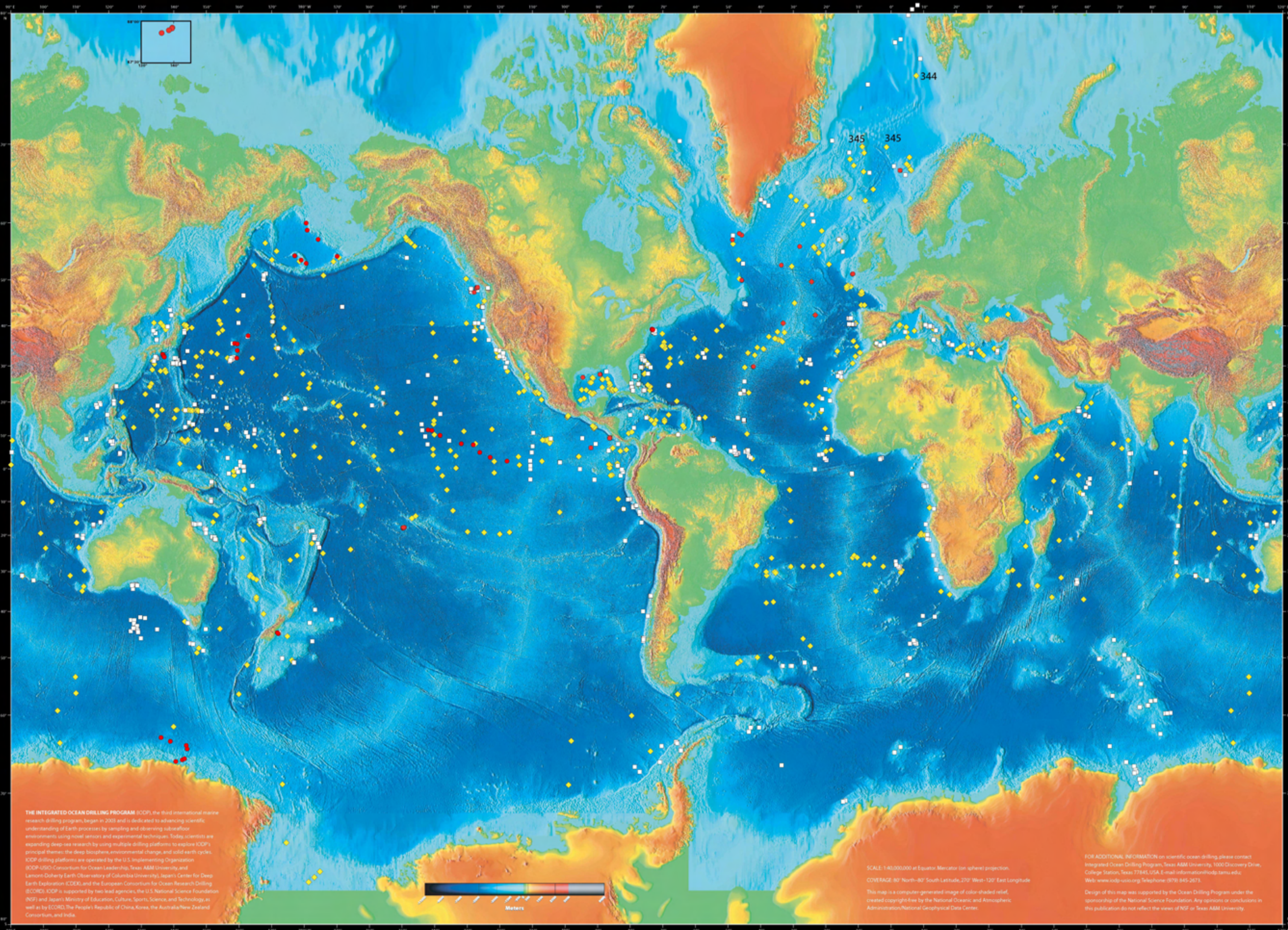
Earth System: Ice Sheet-Ocean Interactions

Sea Level & Bottom Water Production





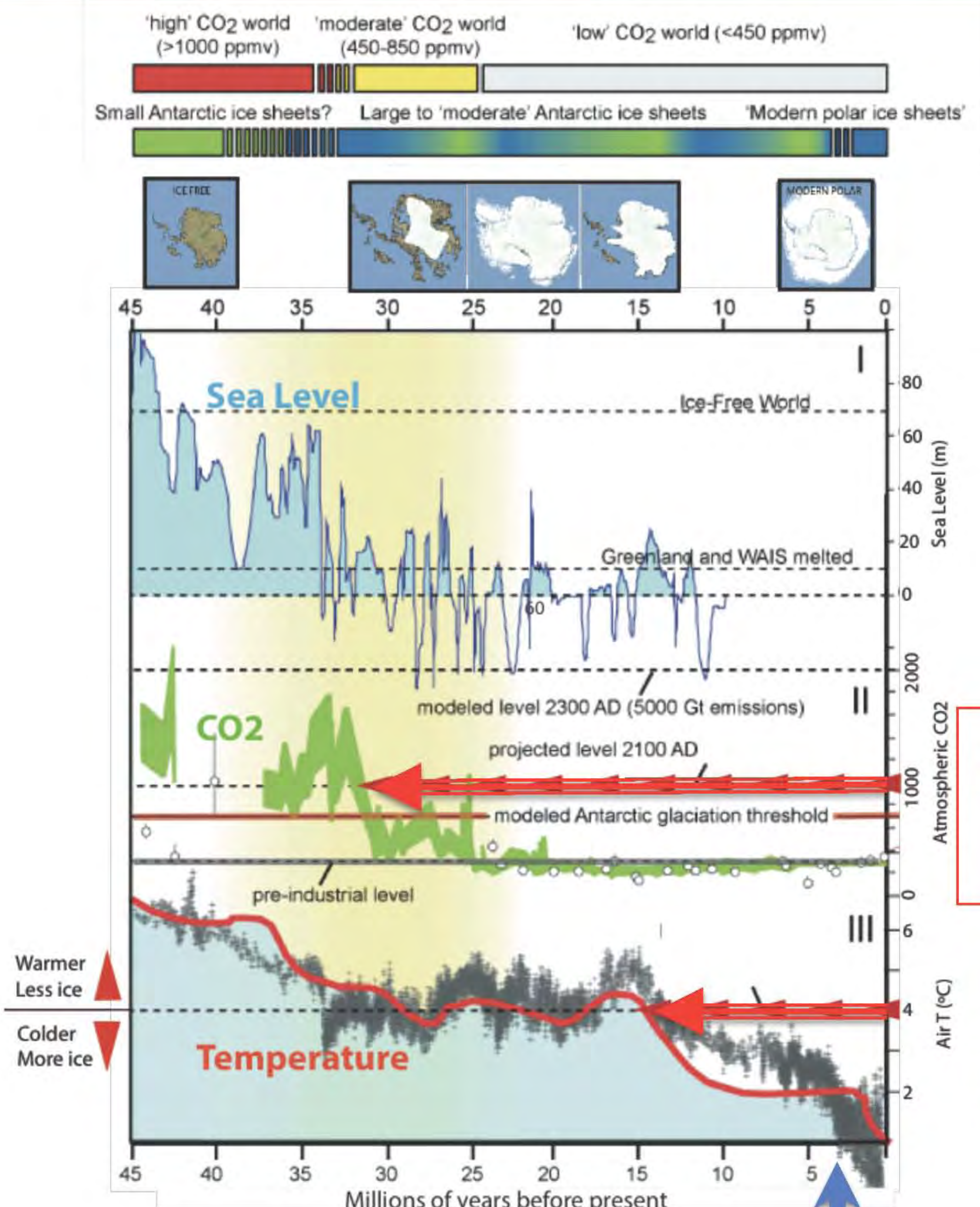
Despite their important role in the global system, polar areas are largely unsampled



◆ 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

EARTH'S PAST CLIMATE RECORD & WHY WE NEED ANTARCTIC RECORDS



Projected 2100 CO_2 concentrations, IPCC RCP8.5 TAKE US BACK TO WHEN ANTARCTICA DID NOT SUPPORT ICE SHEETS

Projected 2100 T (ºC), IPCC AR5 RCP8.5 NOT EXPERIENCED IN OUR PLANET SINCE AROUND 15 Ma

Northern Hemisphere Glaciations start around 3 million years ago

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 paleoceanograhic consequences
- How does ice sheet/sea ice variability affect bottom water formation and how it relates to global circulation?

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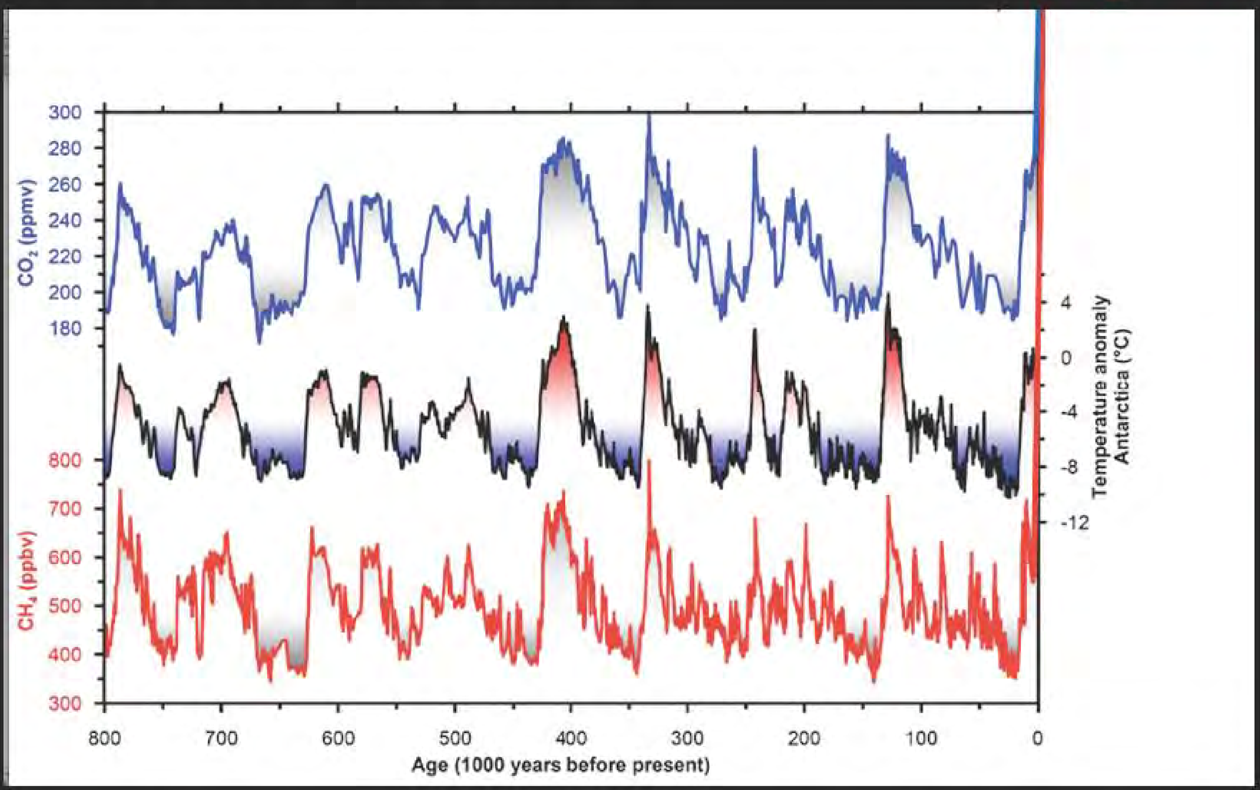
ICE CORES
Continuous reconstructions of past climate back to 800,000 years

Ice Core record from Dome C

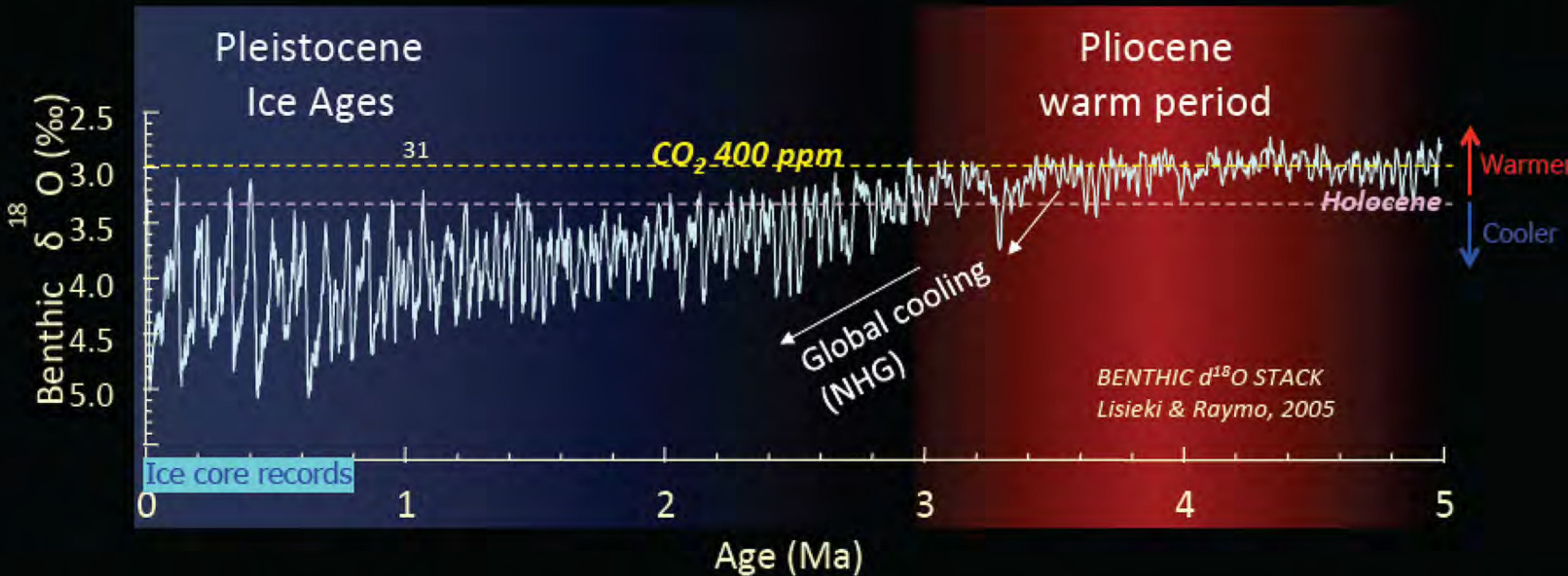
CO_2= 400 ppm in 2013



Levels of CO_2 much lower than present in the past 800,000 years!!!

In order to have an analogue to present 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

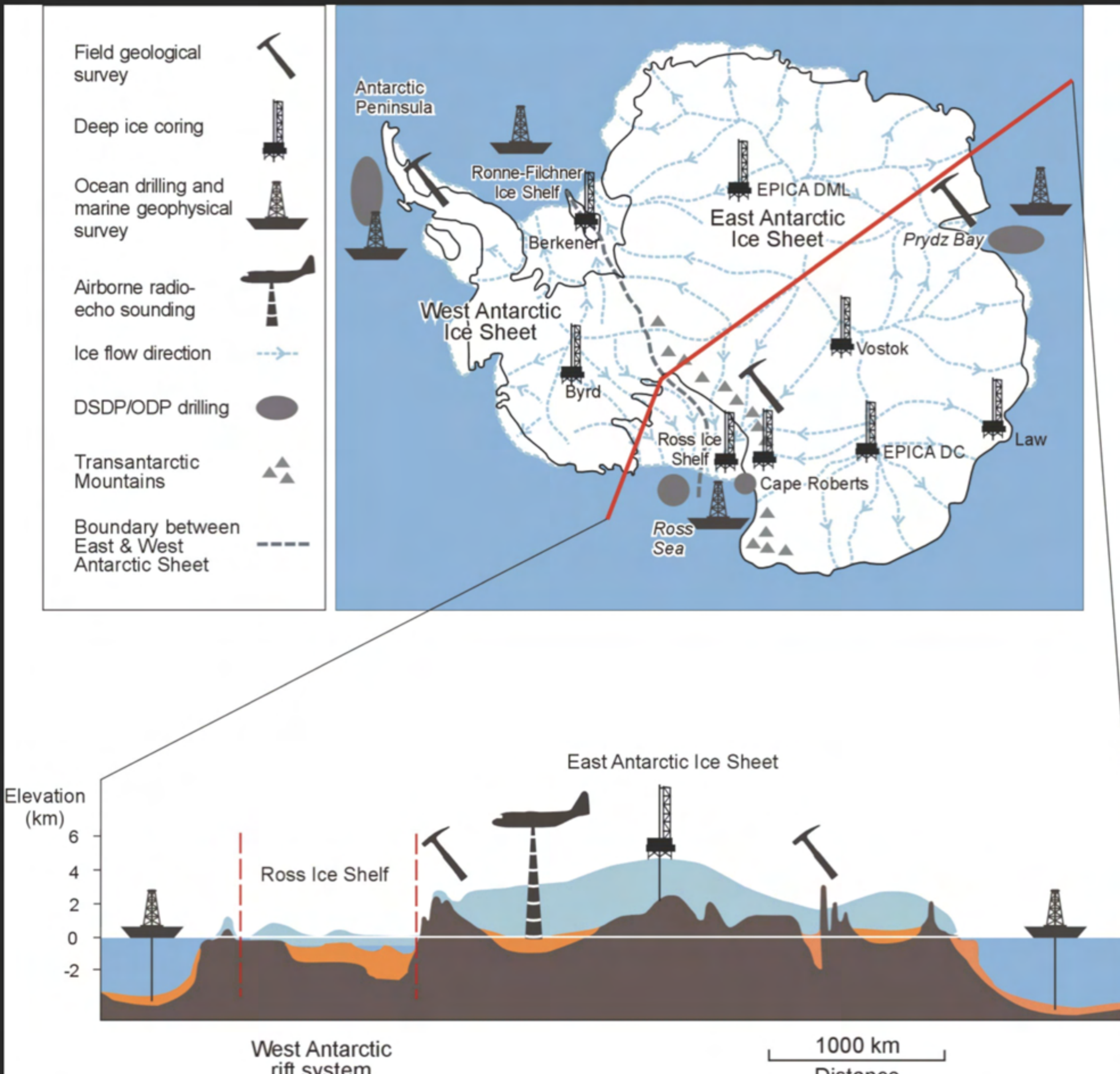
Last time the Earth experienced CO_2 concentrations similar to present is during the warm Pliocene: 5-3 million years ago



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

Tools of Exploration



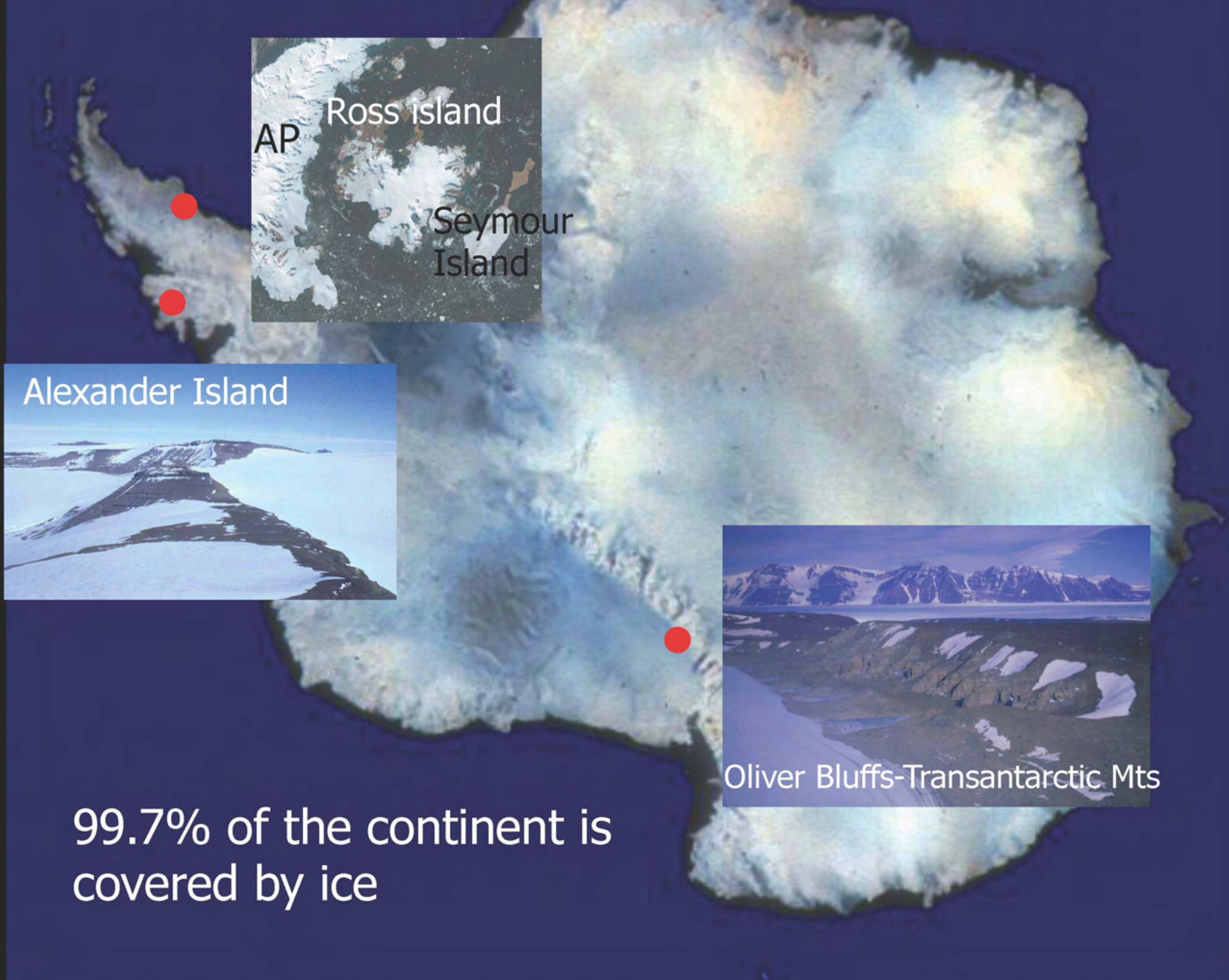
Outcrops

Subglacial records

Marine records

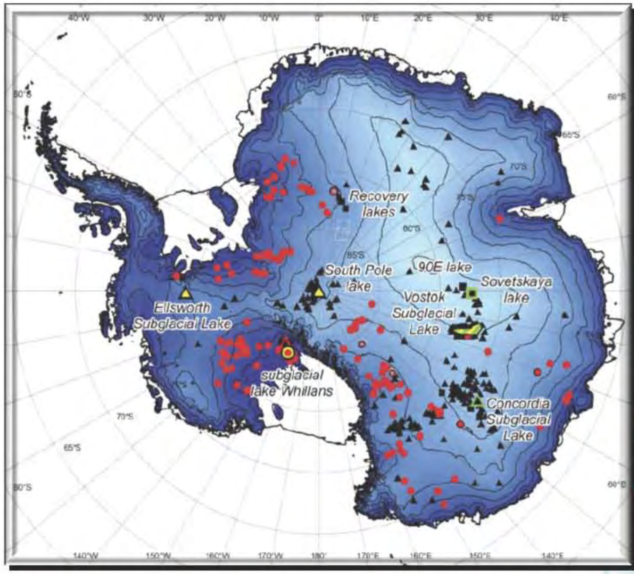
COMNAP

Long-term records from Antarctic Outcrops

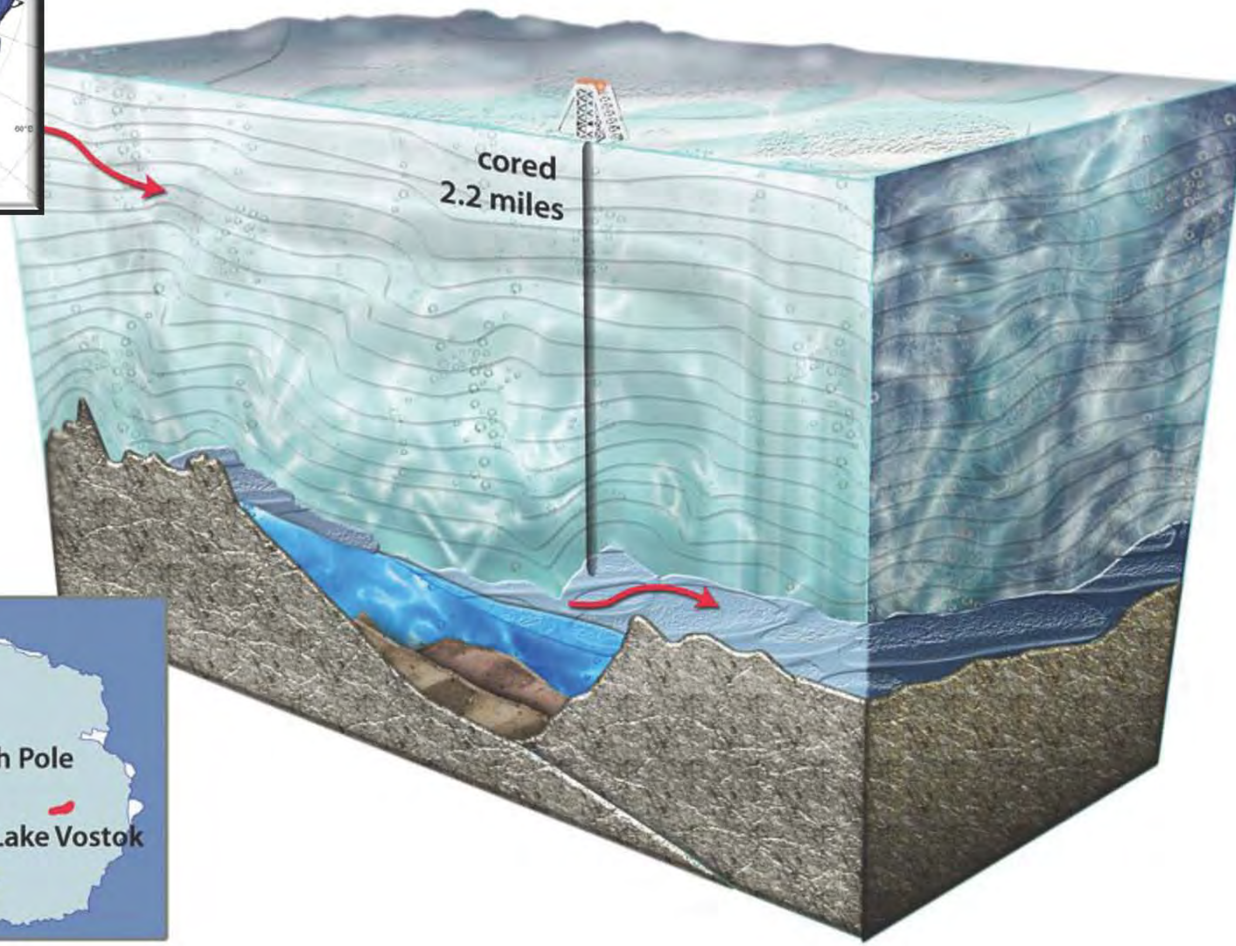


99.7% of the continent is covered by ice

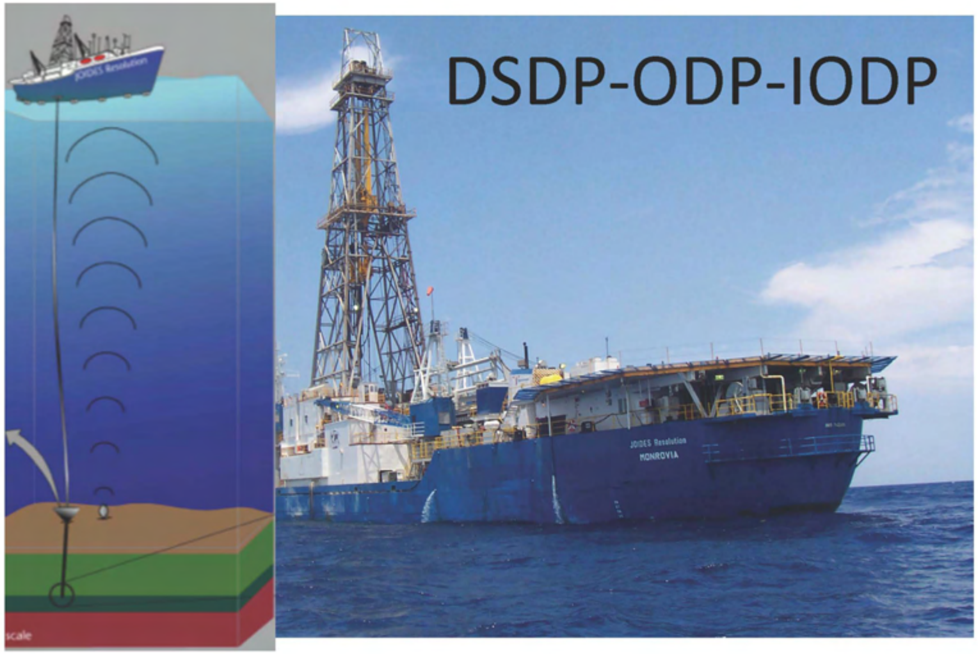
Subglacial Access

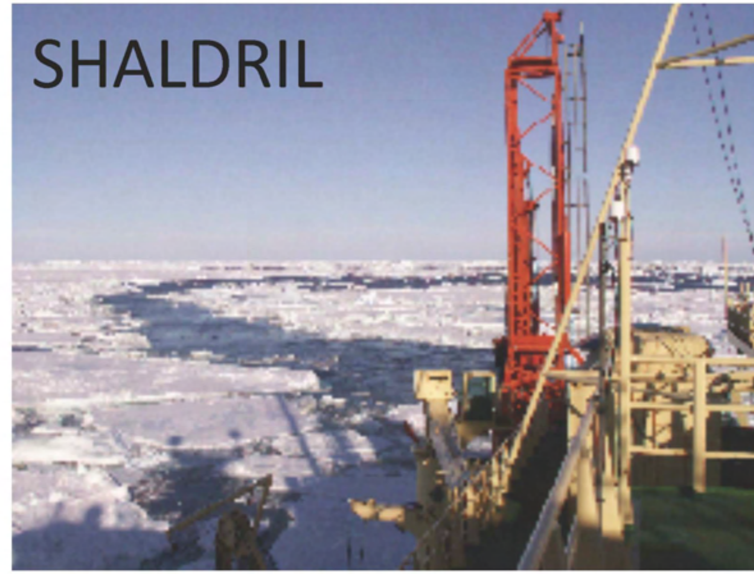


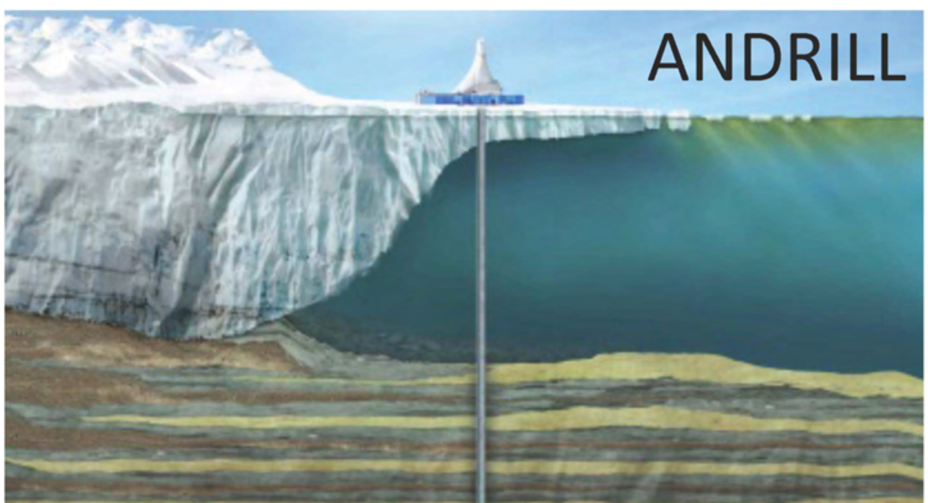
Wright and Siegert (2012)



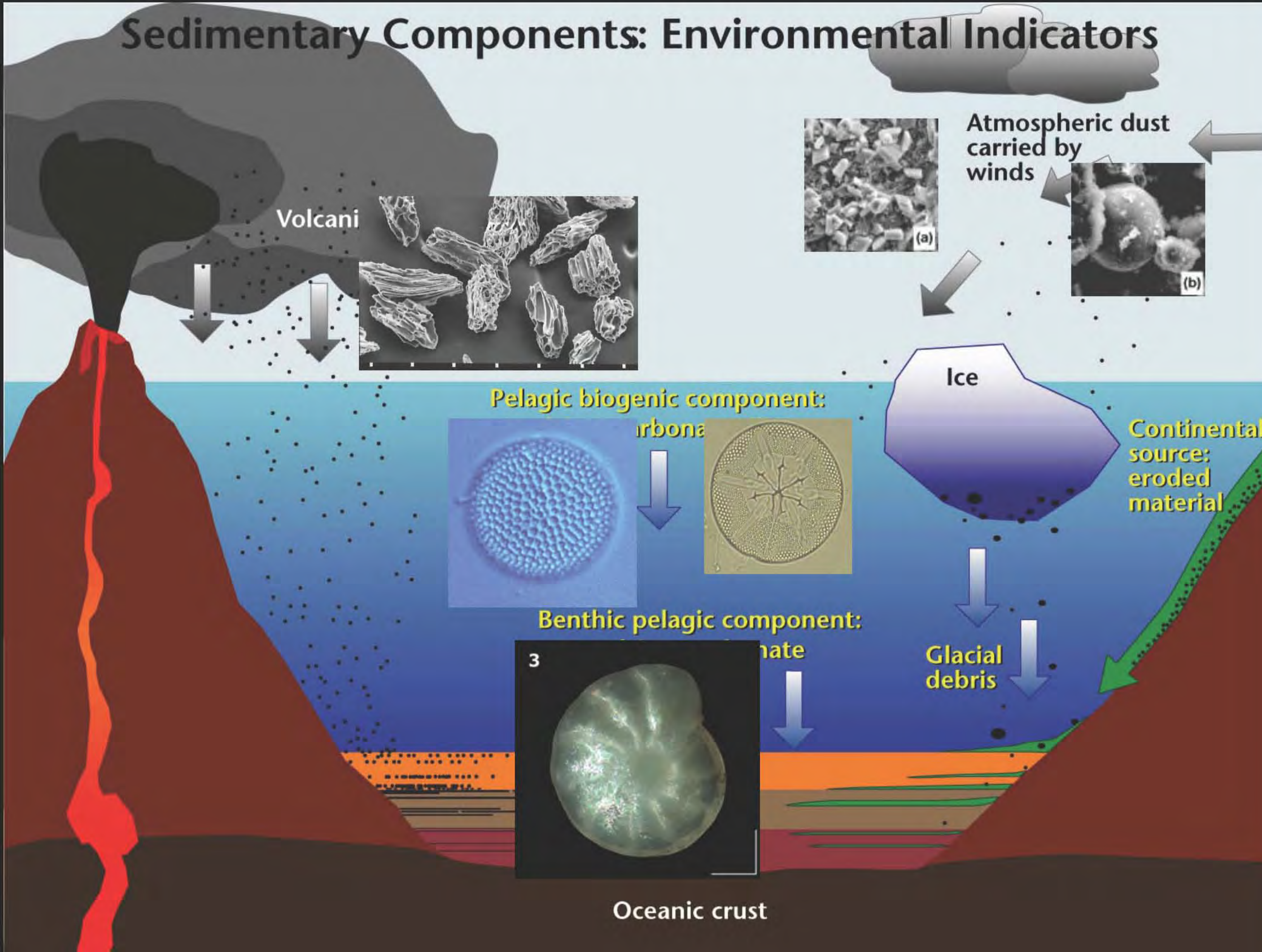
Long-term records from marine sediments



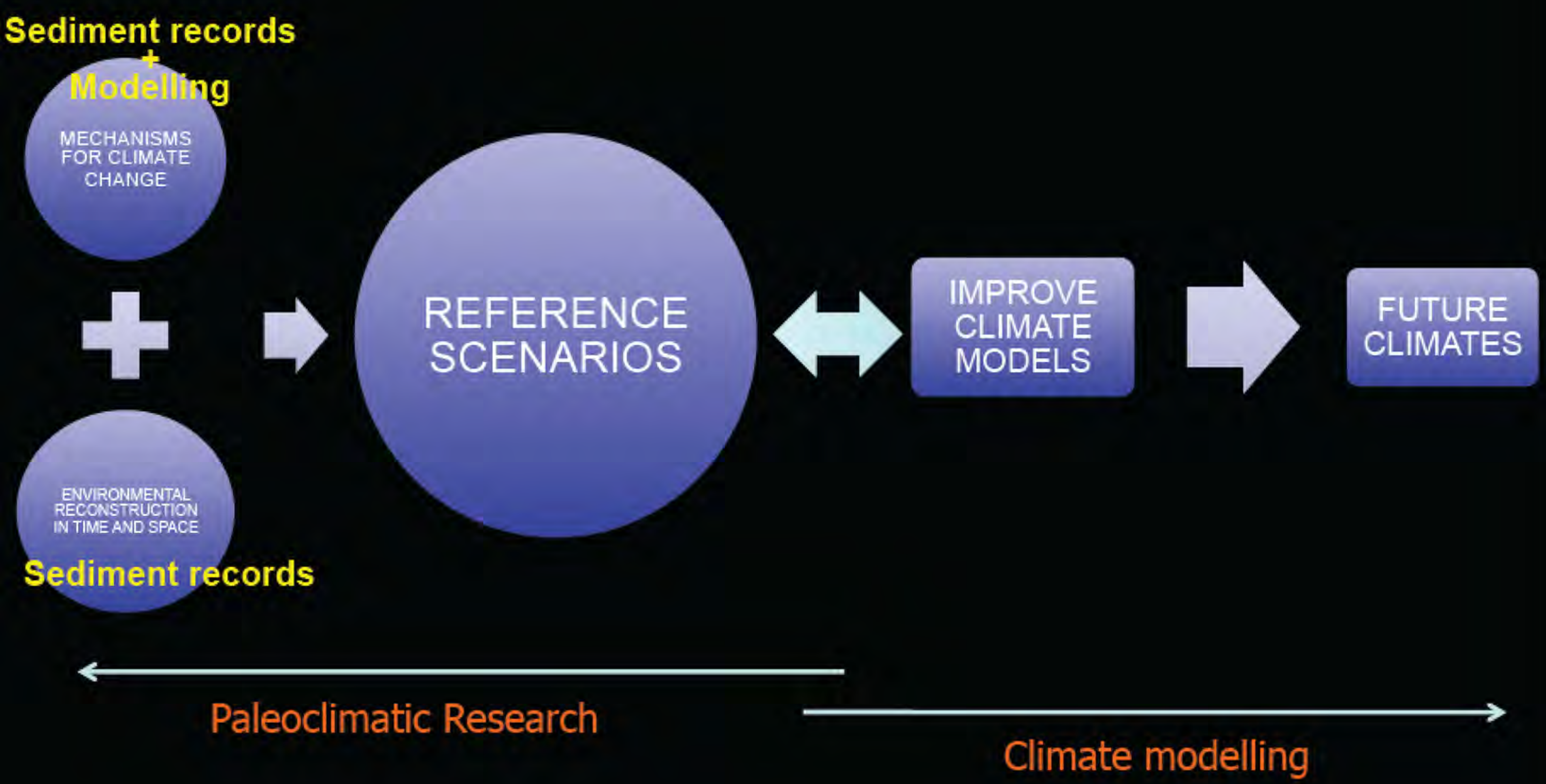





MD03-2597
2680 cm


Sedimentary Components: Environmental Indicators
Atmospheric dust carried by winds
(a)
(b)
Volcani
Ice
Pelagic biogenic component:
rbona
Continental source: eroded material
Benthic pelagic component:
nate
3
Glacial debris
Oceanic crust

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 CO_2 (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 thechnological 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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Environmental reconstructions in Antarctica

Greenhouse world (55-34 million years)

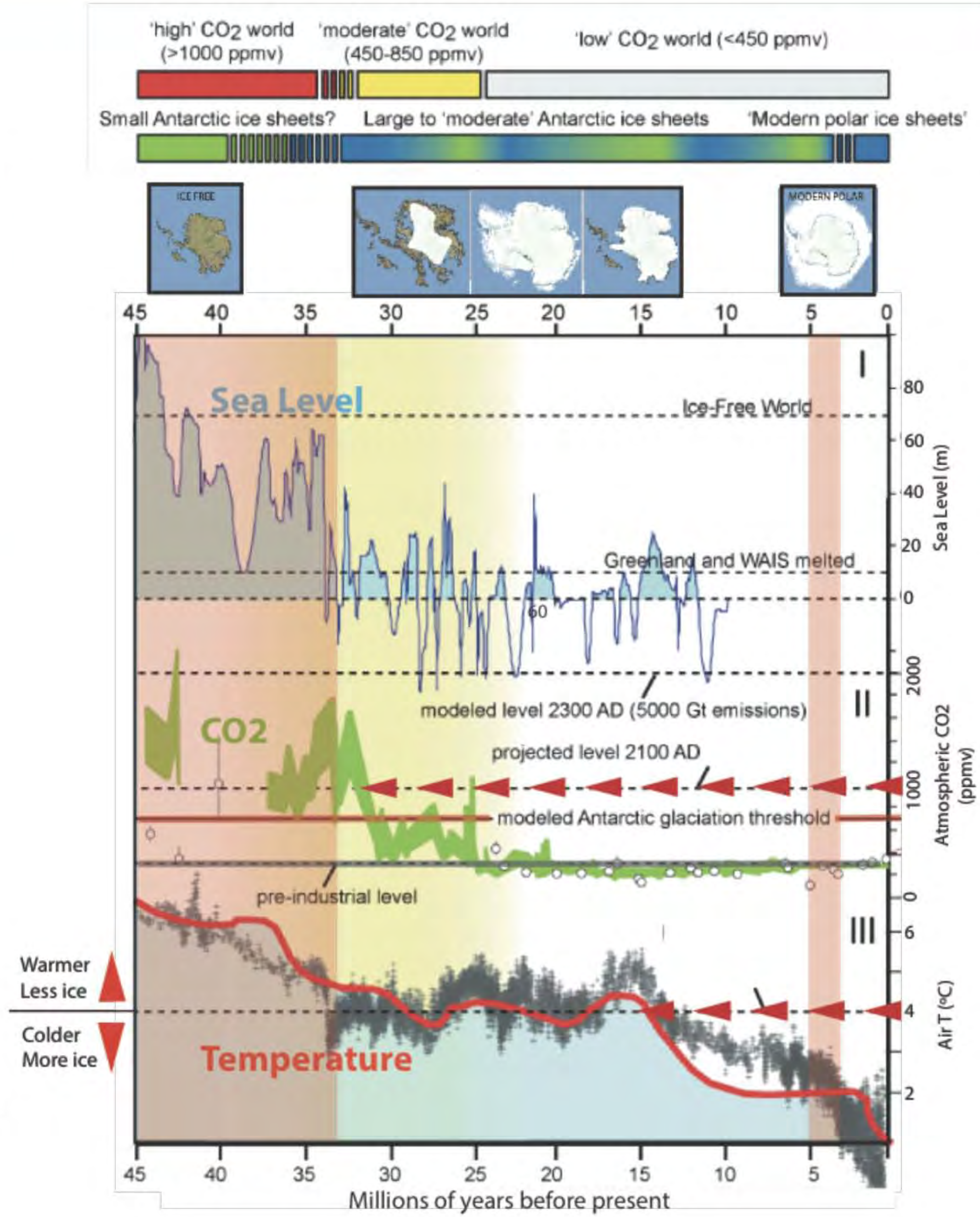
>1000 ppm CO_2

Analog for conditions in 2100:

IPCC AR5-RCP 8.5

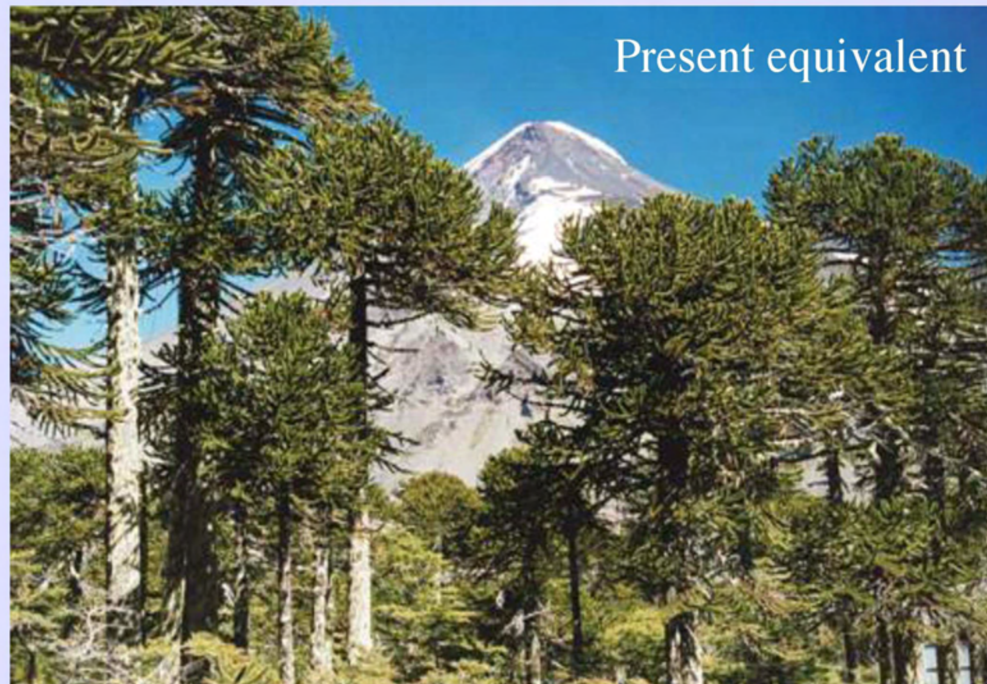
936 ppm CO_2

1313 ppm when considering combined greenhouse gases CO_2-equivalent



latest Early Eocene ~50 millions of years

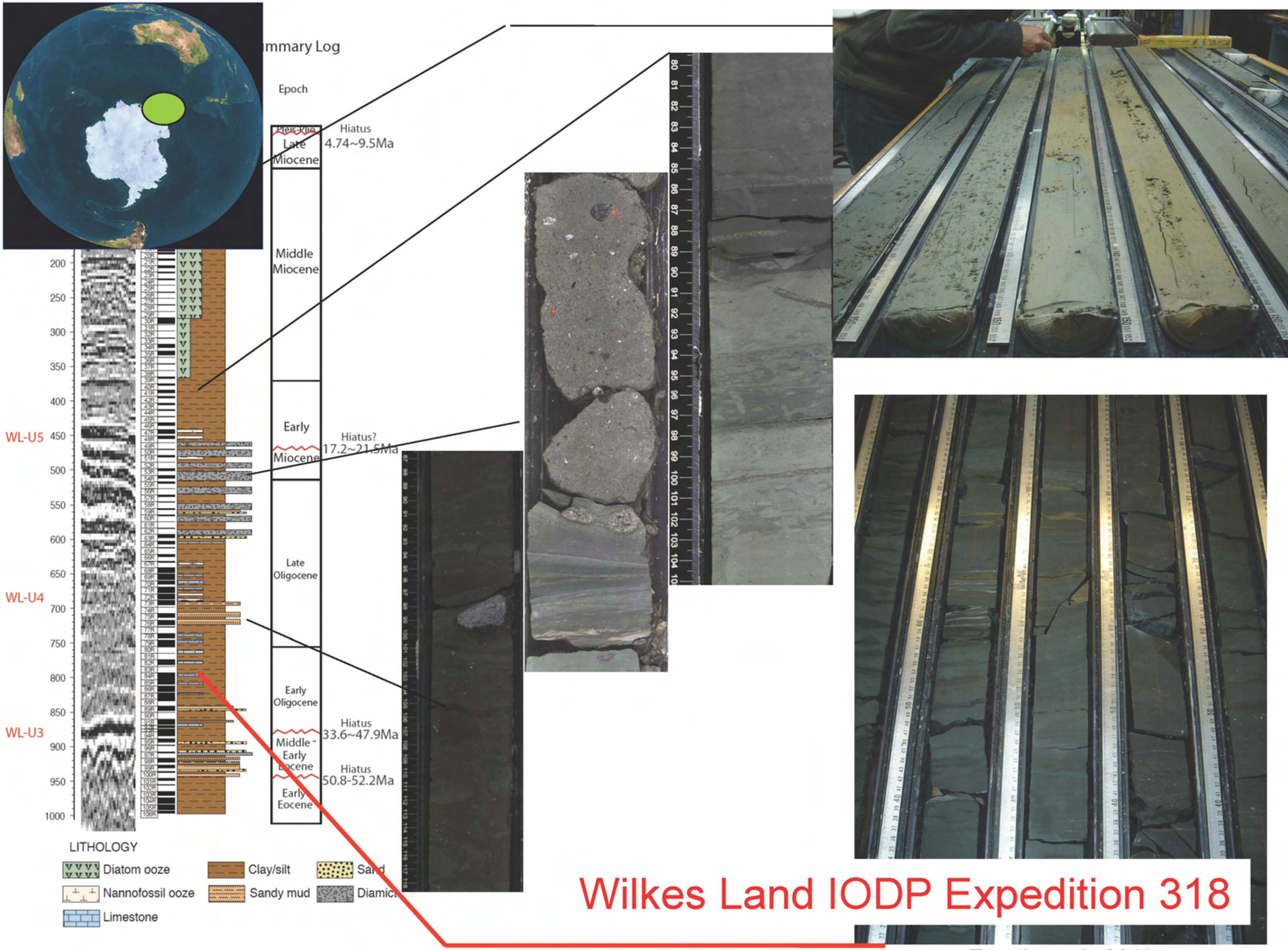
3D preservation of conifer branches in concretions - can withstand cool climates with snow



NLE *Araucaria araucana*, Monkey Puzzle, Chilean Andes

Araucaria araucana

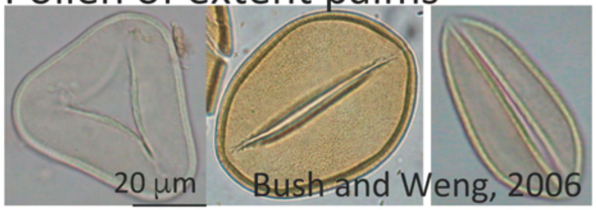
Slide courtesy of J. Francis R. Stephens PhD



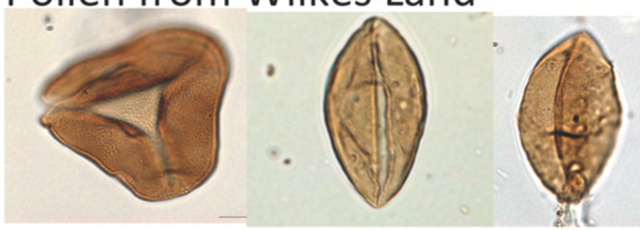
Escutia et al., 2011

Pollen from – 50 million years, Wilkes Land IODP Site 1356

Pollen of extent palms



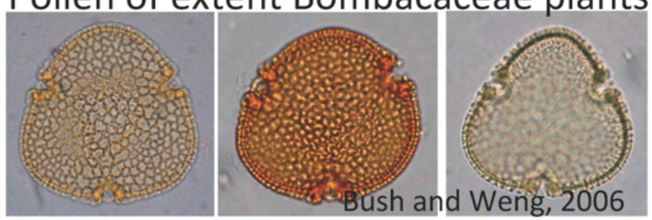
Pollen from Wilkes Land



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

Pross et al., Nature, 2012

Pollen of extent Bombacaceae plants



Pollen from Wilkes Land

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

Other Organic components in these sediments provide T 20-25°C

We have learned that Greenhouse Antarctica (CO_2 > 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.

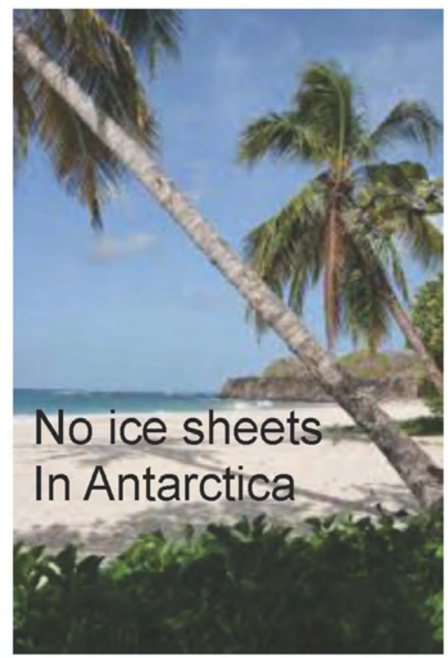
Considering IPCC (2013) forecasts CO_2 concentrations around 1000 ppm for 2100 …

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

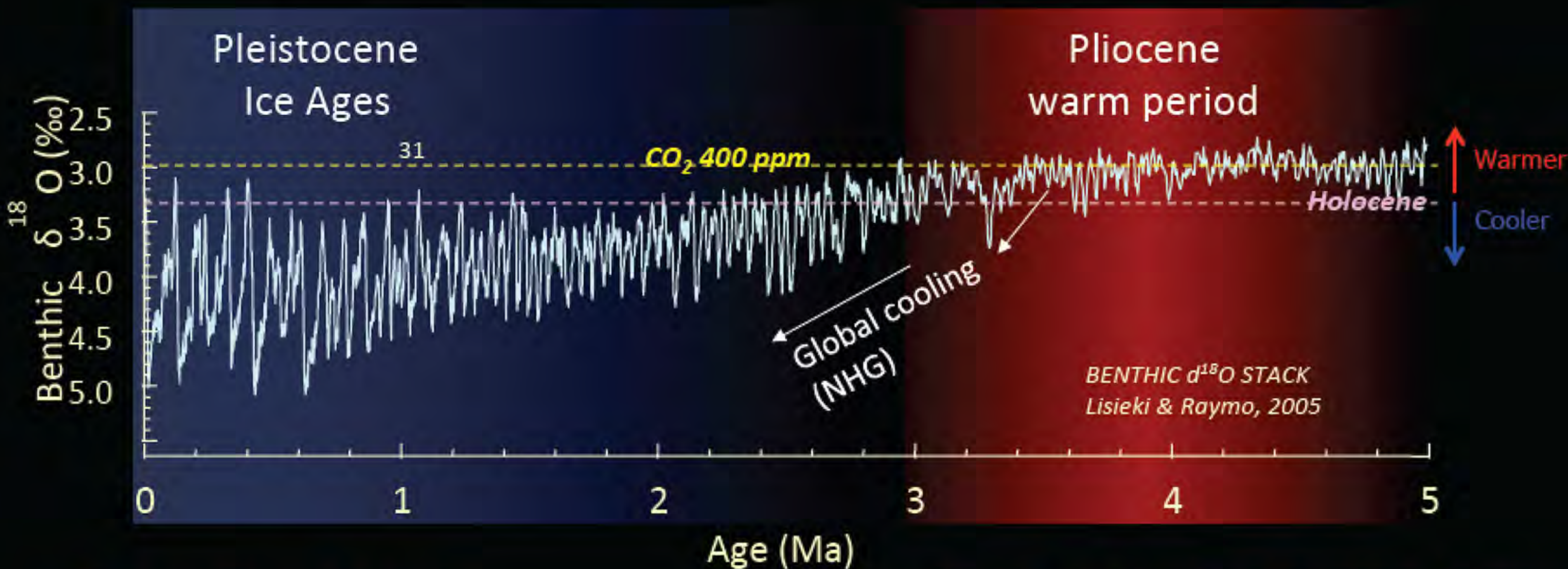
Greenland Ice sheet:
7 m SLE

West Antarctic Ice Sheet:
7 m SLE

East Antarctic Ice Sheet:
60 m SLE



Environmental reconstructions in Antarctica during the warm Pliocene: 5-3 million years ago



Pliocene Warm Period
3-5 million years ago

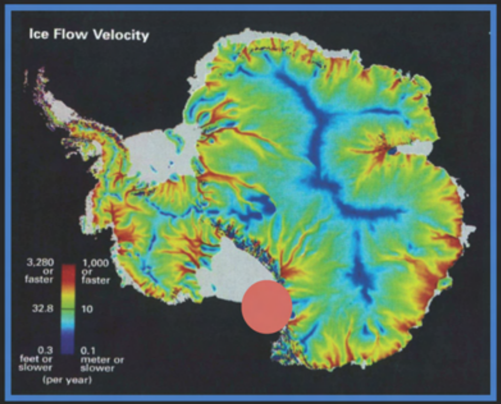
- 400 ppm CO_2
- 2-3°C warmer
- ice sheets, continents and oceans similar to today: Similar Climate System

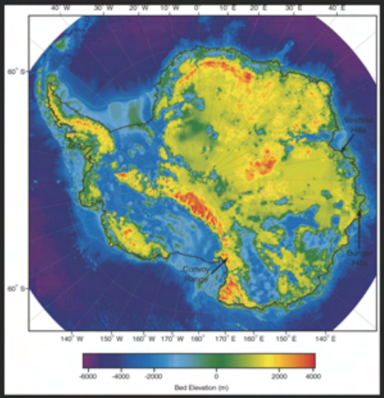
Good analog for the near future (next decades?)

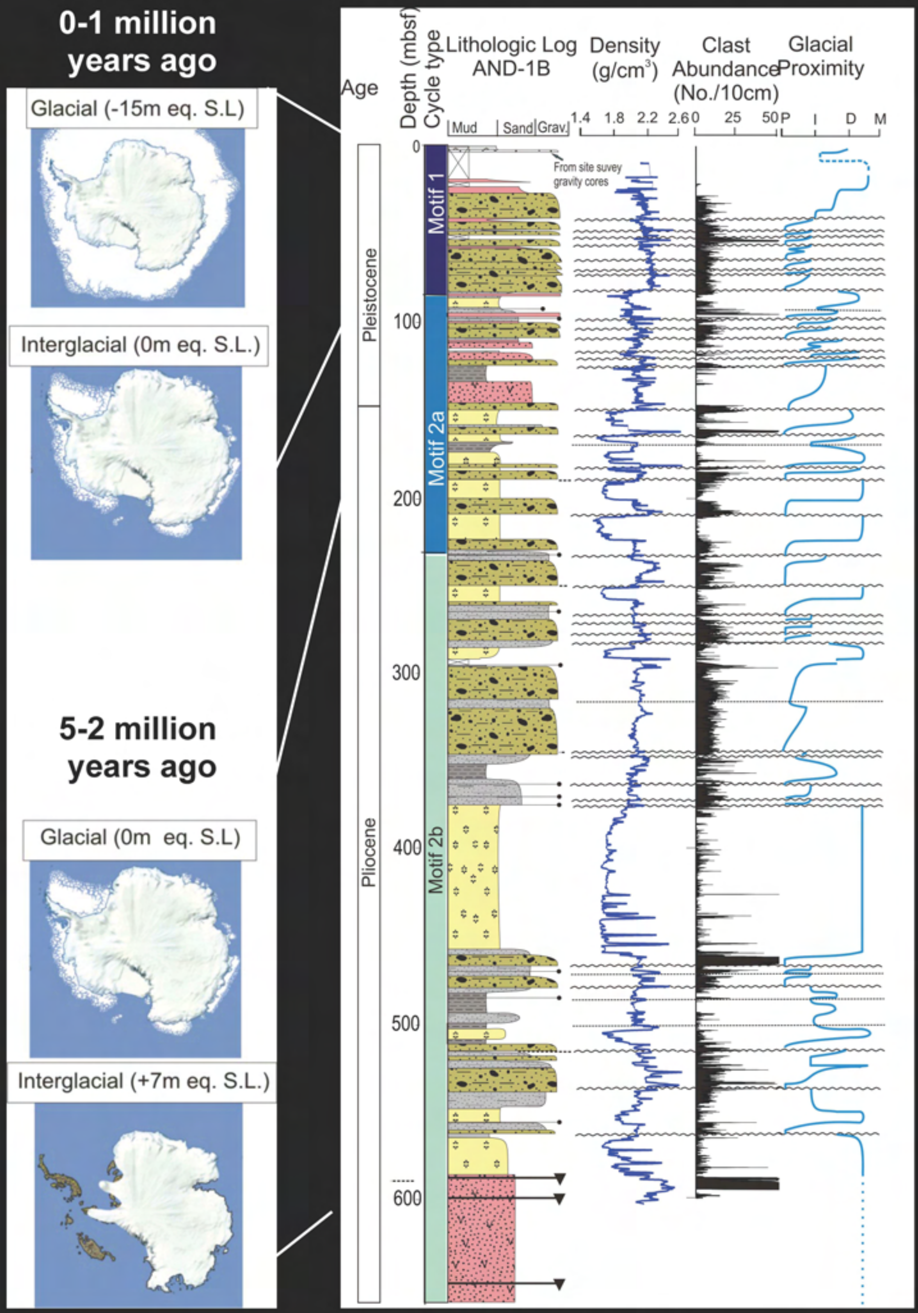
IPCC AR5 RCP2.6 in 2100 421 ppm CO_2

475 when considering combined greenhouse gases CO_2-equivalent

ANDRILL MIS cores: Ross Sea

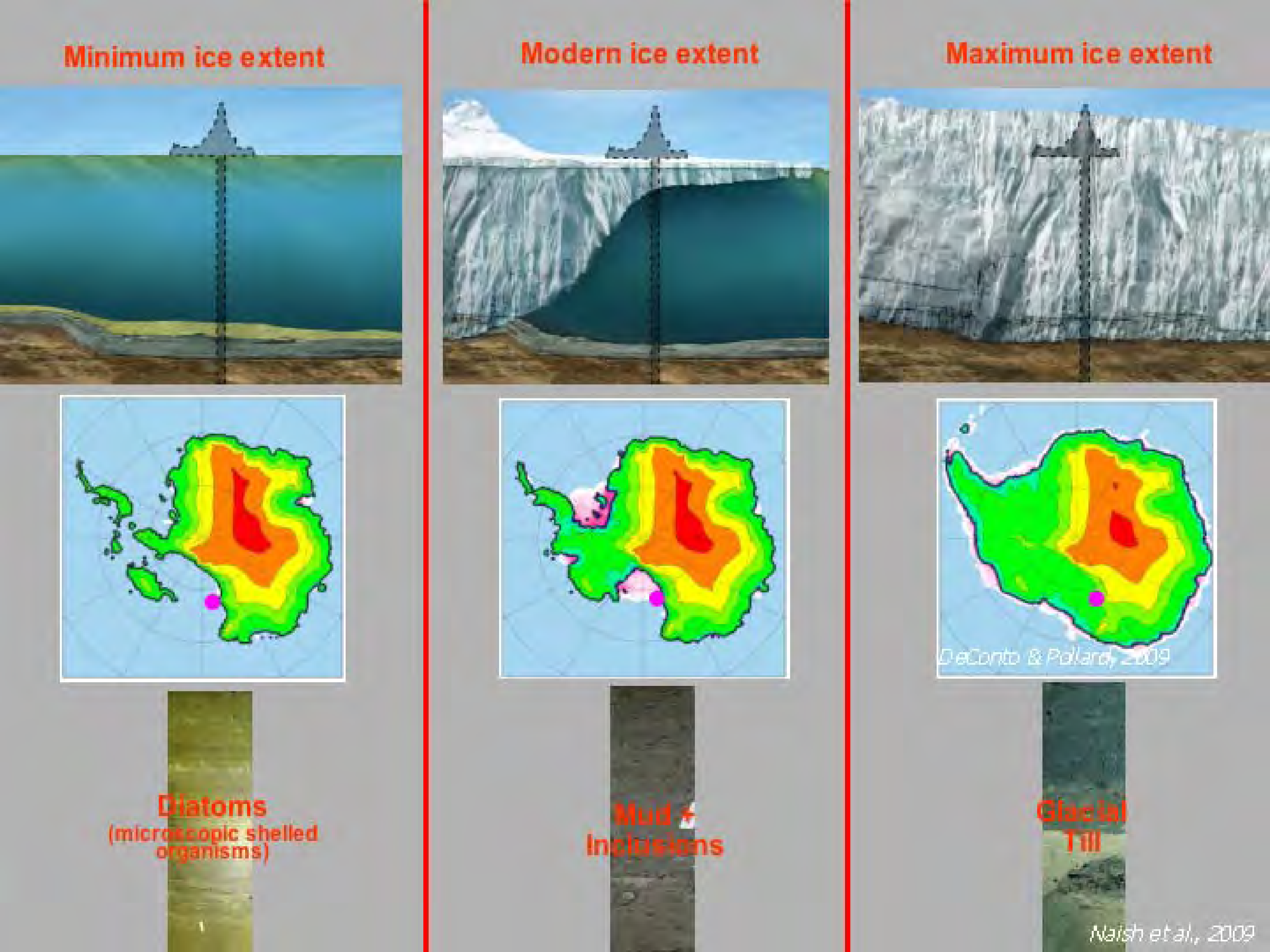




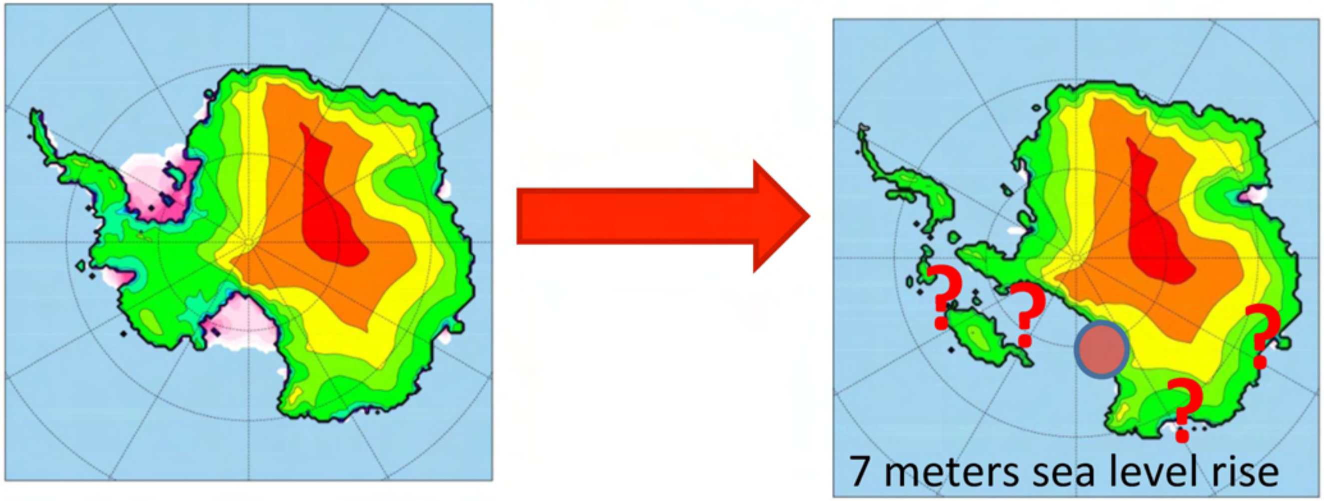


marine-based WAIS dynamic during the Pliocene

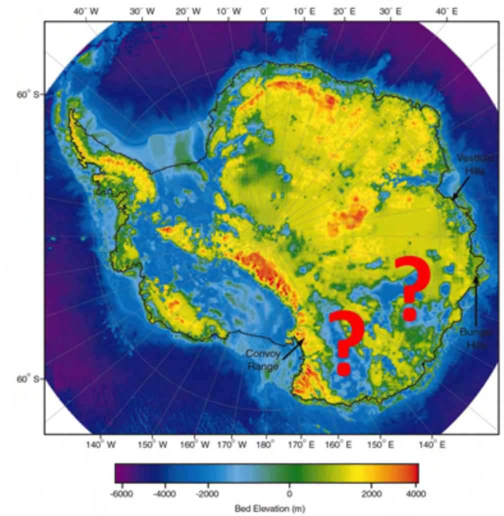
Naish et al., Nature 2009


Minimum ice extent
Modern ice extent
Maximum ice extent
DeConto & Pollard, 2009
Diatoms
(microscopic shelled organisms)
Mud +
Inclusions
Glacial
Till
Naish et al., 2009

Polar ice sheet & sea-level response during warm periods 5-3 million years ago



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 CO_2 concentrations to today (CO_2 > 400 ppm):

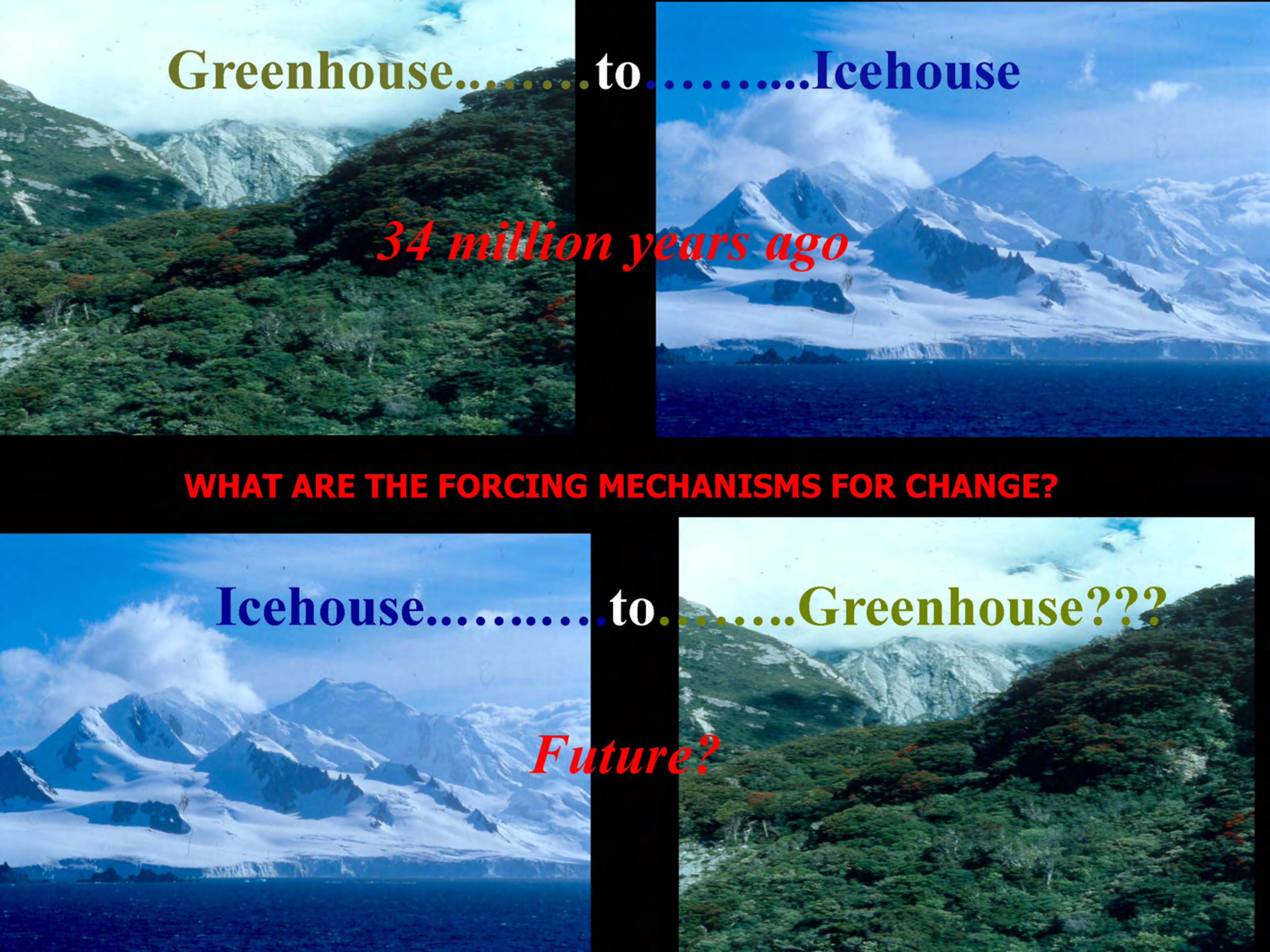
- The West Antarctic Ice Sheet was highly dynamic and at times collapsed but need to calibrate models with data from other sites.

- 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)

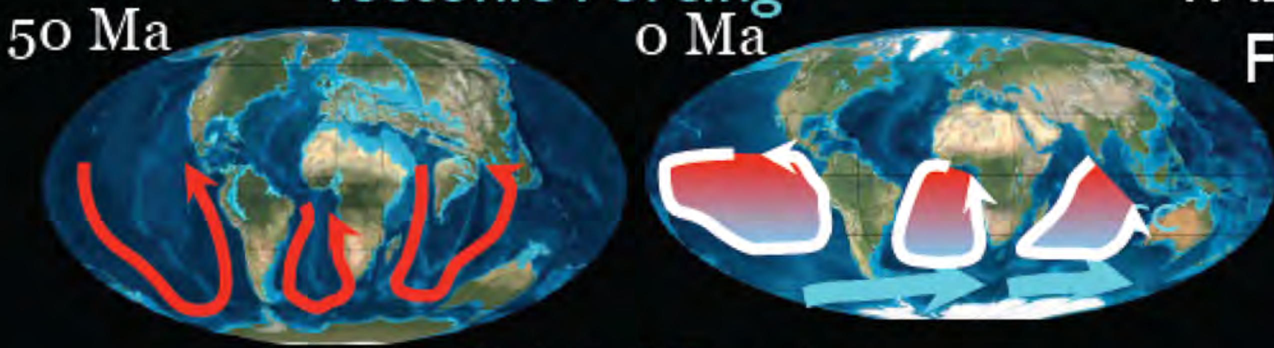
- Under these higher CO_2 and temperature scenarios mean global sea levels were around 20 m above present sea level.

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

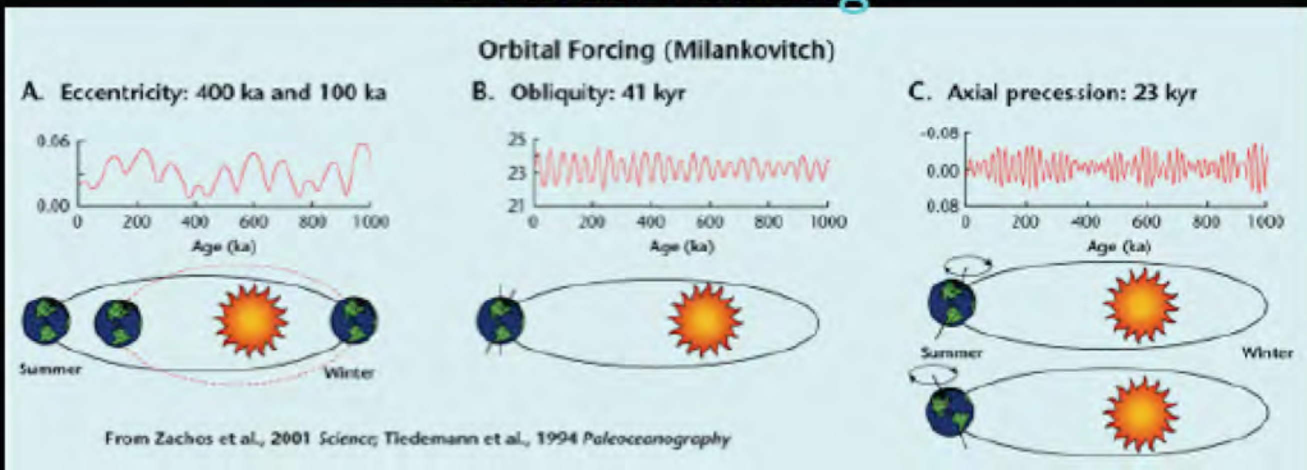

Greenhouse.........to..........Icehouse
34 million years ago
WHAT ARE THE FORCING MECHANISMS FOR CHANGE?
Icehouse...........to........Greenhouse???
Future?

PALEOCLIMATE & ICE SHEET FORCING MECHANISMS

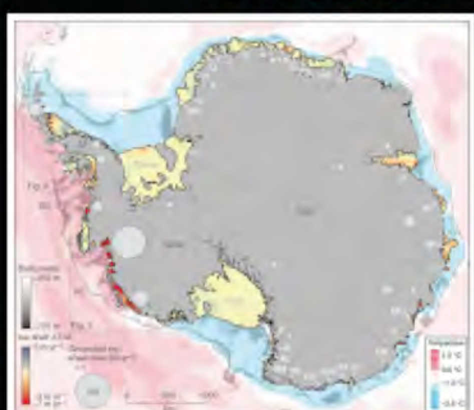
Tectonic Forcing

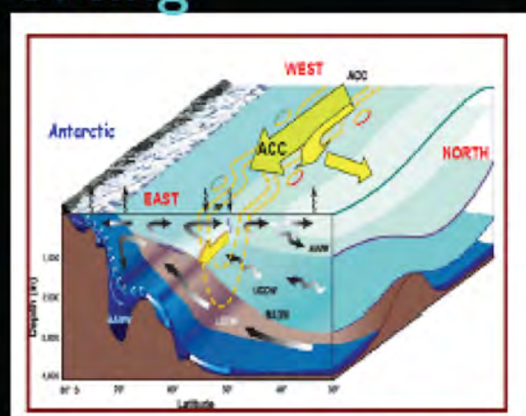


Orbital Forcing

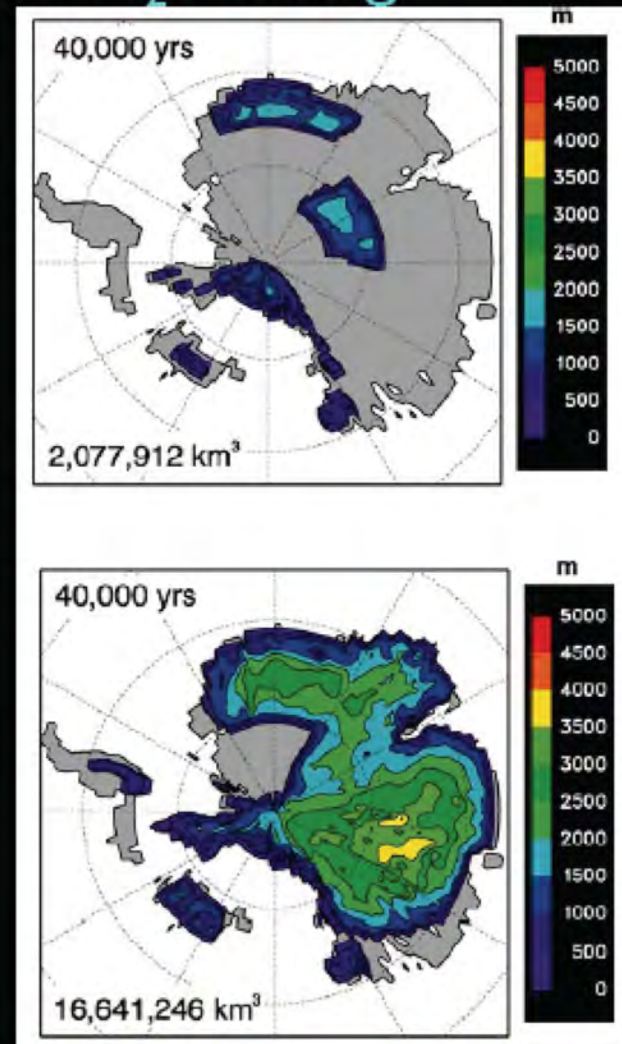


Oceanic Forcing





CO_2 Forcing



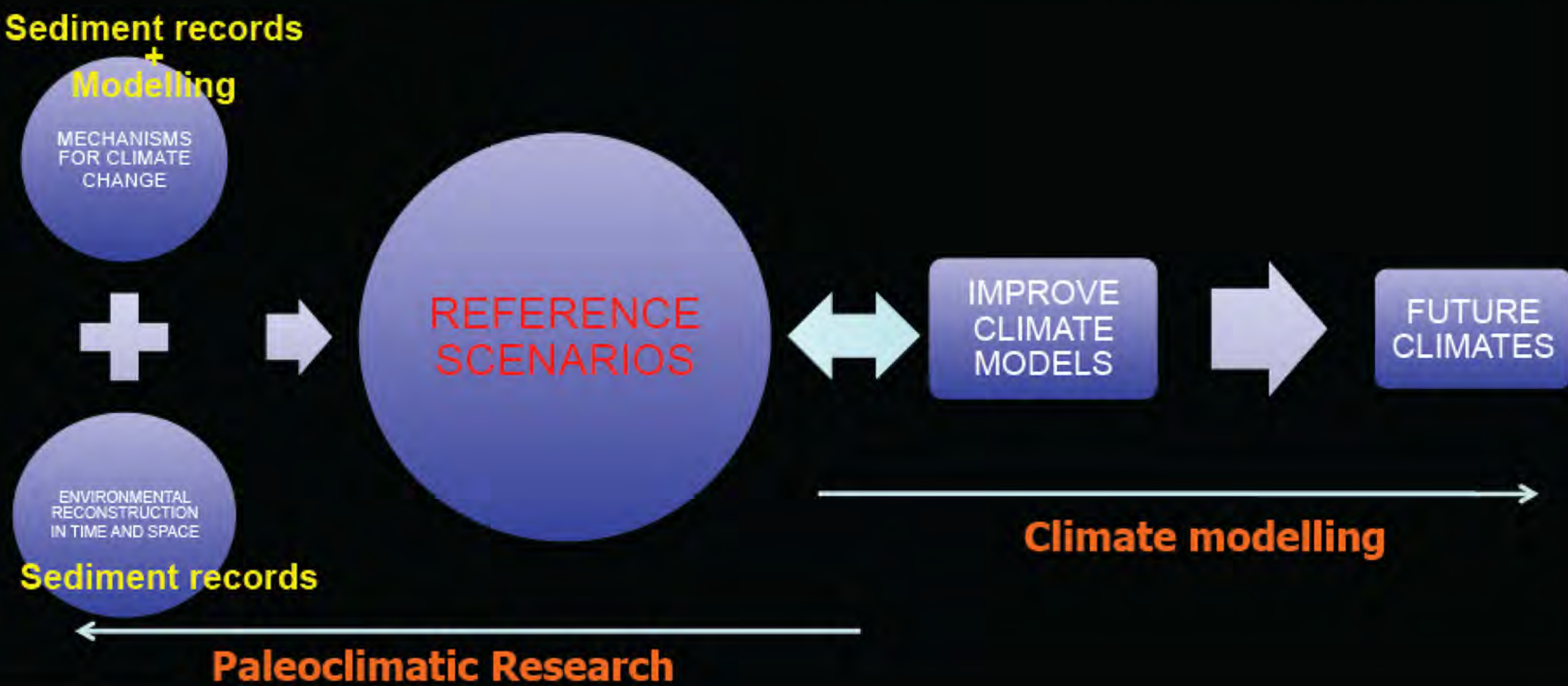
ADDITIONAL BOUNDARY CONDITIONS FROM SEDIMENT RECORDS ARE NEEDED TO CALIBARTE MODELS AND BETTER CONSTRAIN THE FORCINGS

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 TO SPARSE TO PROVIDE FOR NEEDED BOUNDARY CONDITIONS TO THE MODELS



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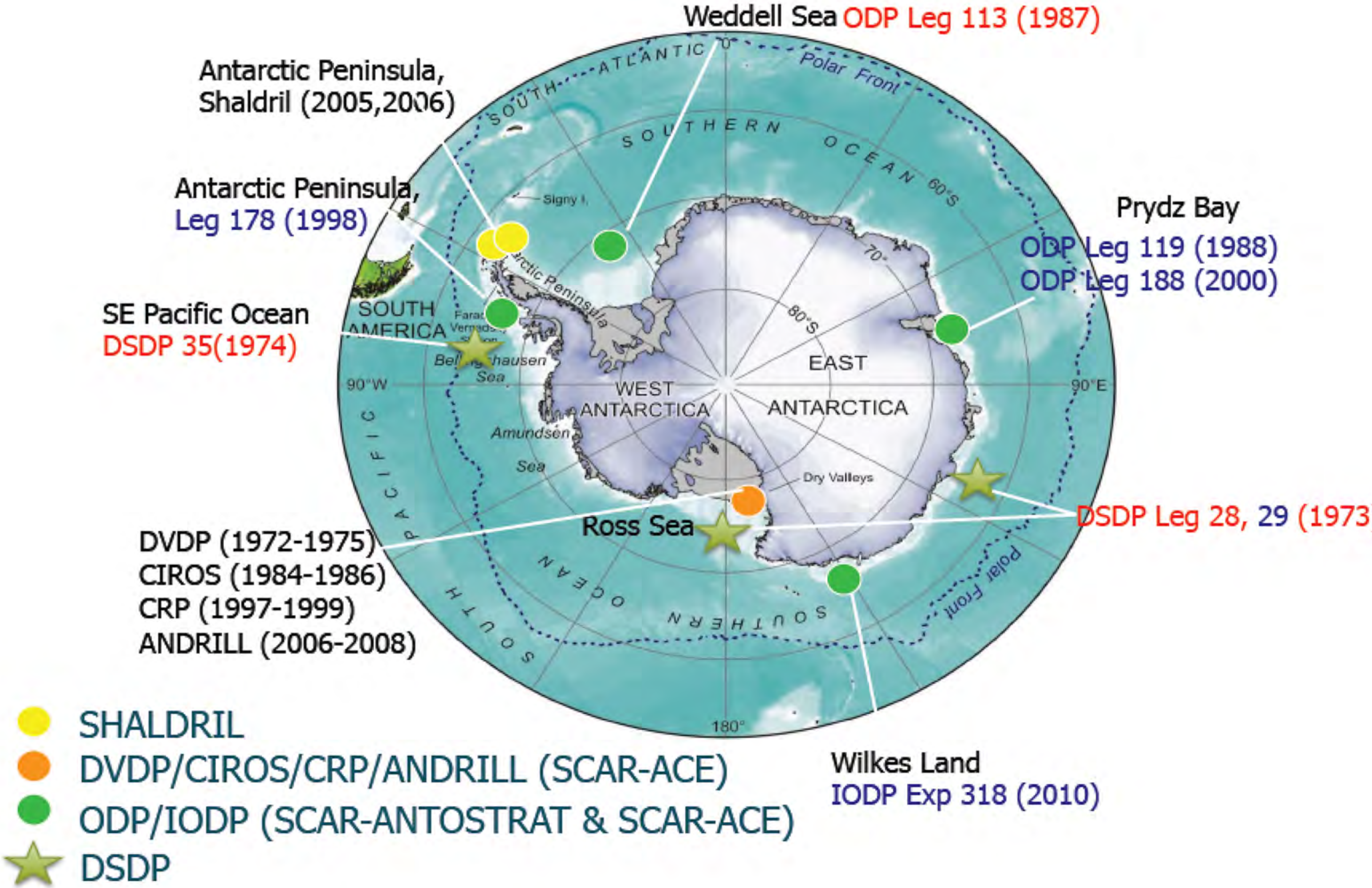
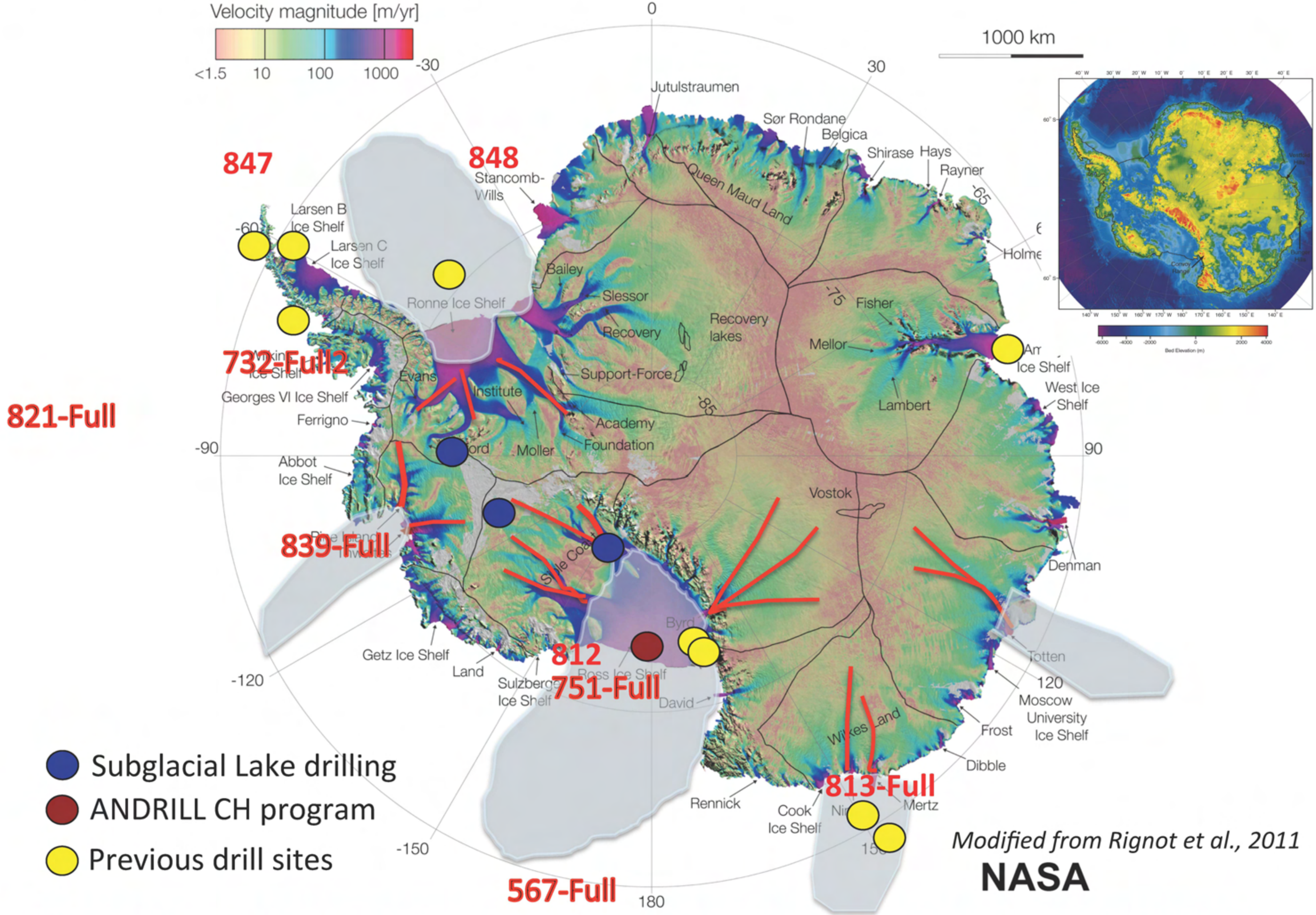
FOUR DECADES OF ANTARCTIC DRILLING



SCAR
Past Antarctic Ice Sheet Dynamics
(PAIS)
2013-2020

PAIS marine-continental transects & links to Ice cores



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

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 mechanims, 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 CO_2 that can be used as reference scenarios for future change.

- For this endevour, there are major thechnological and logistical challenges that will be overcomed trough national and international coordination and collaborations.


Thank you for your attention