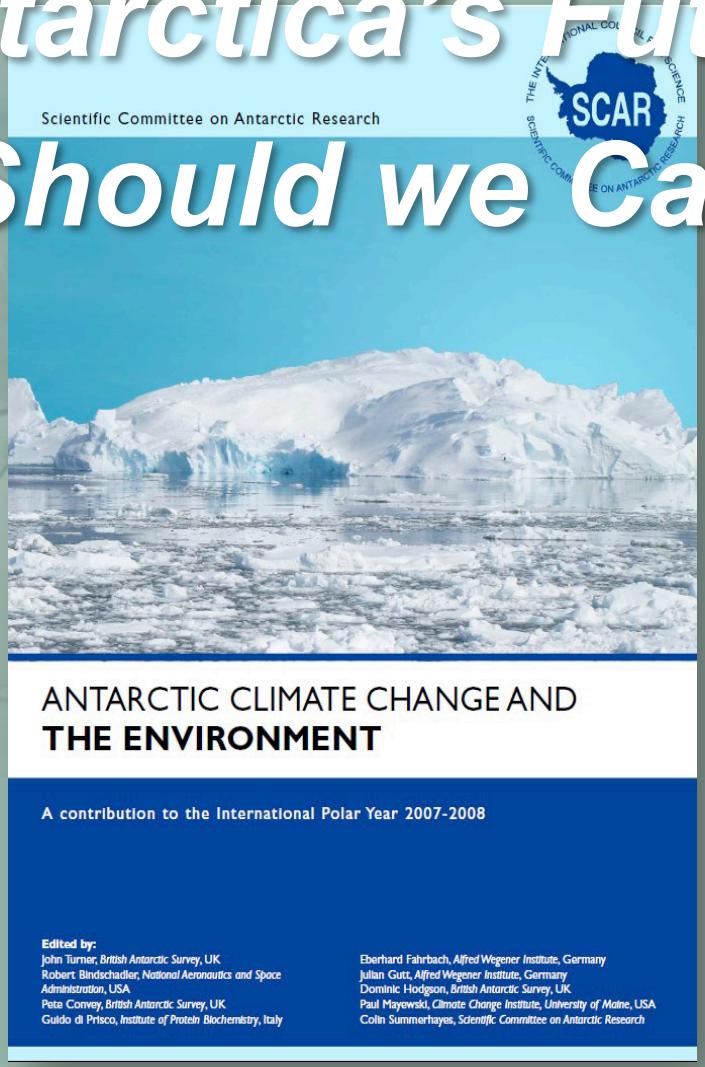
Antarctic Climate Change and the Environment
Antarctica's Future – Should we Care?

An IPY product



100 authors from
13 countries

Talk Outline

- Some context (Antarctica, climate change)
- What are the Key Questions?
- The past (geology and data from ice cores)
- The present (the instrumental period since IGY 1957-58)
- The future (the next 90 years)
- Implications (effect of Antarctica on the rest of the world)

Subtext

We are examining the effects of the interaction of two large-scale geophysical experiments on the atmosphere, one from CFCs, the other from CO_2, and their unintended consequences.

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Some context: Antarctica

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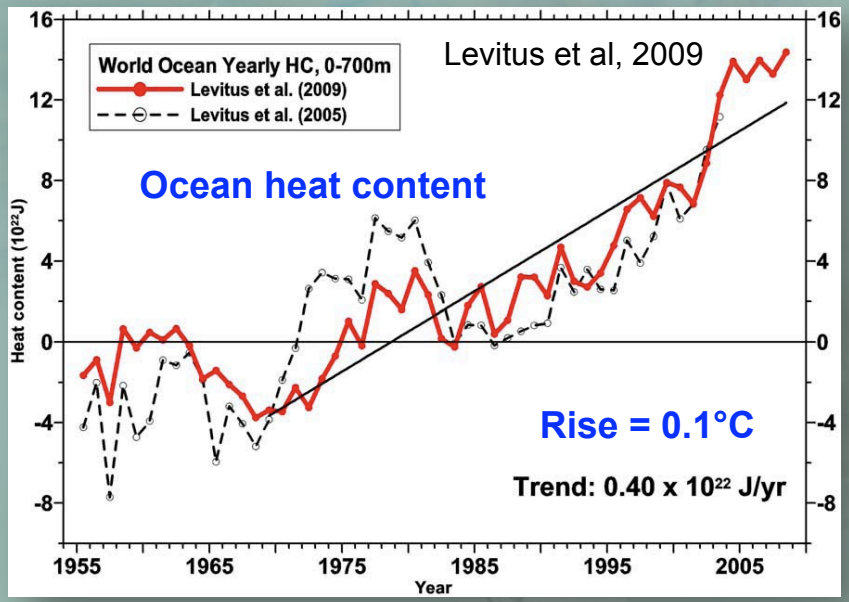
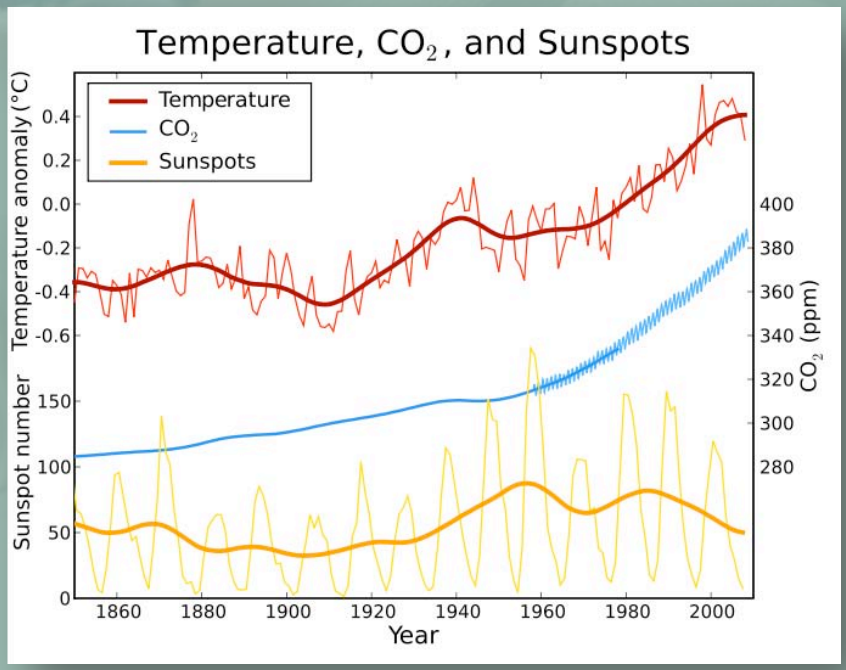
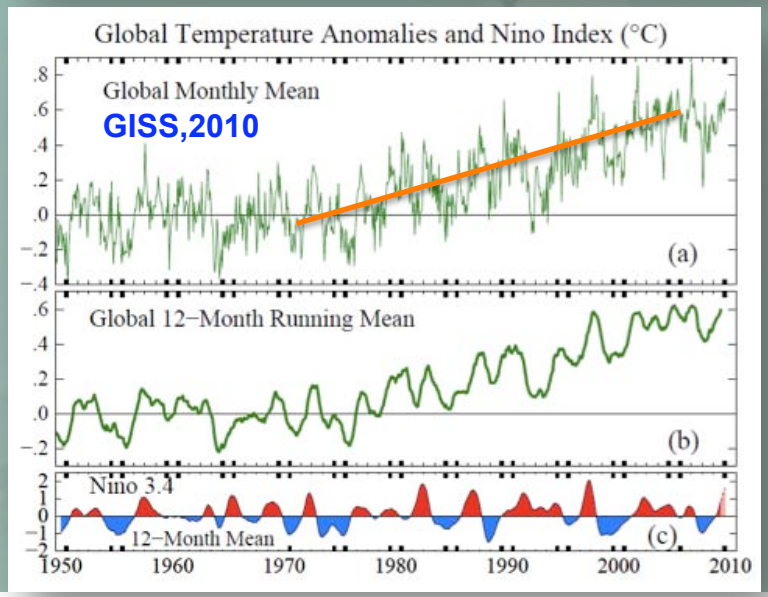
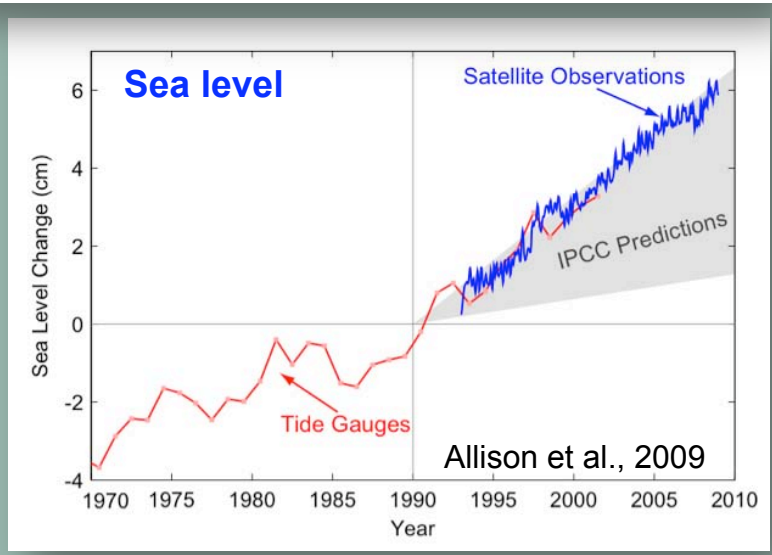
Some context: Global Warming









Some Key Antarctic Climate Questions

- How does the the Antarctic climate system work?
- How does climate change affect the Antarctic ecosystem?
- What are the roles of greenhouse gases, and the ozone hole?
- Sea ice is melting in the Arctic – what about Antarctica?
- Is Antarctica growing or shrinking?
- What will happen over the next 100 years as the world warms?
- Why should we care?

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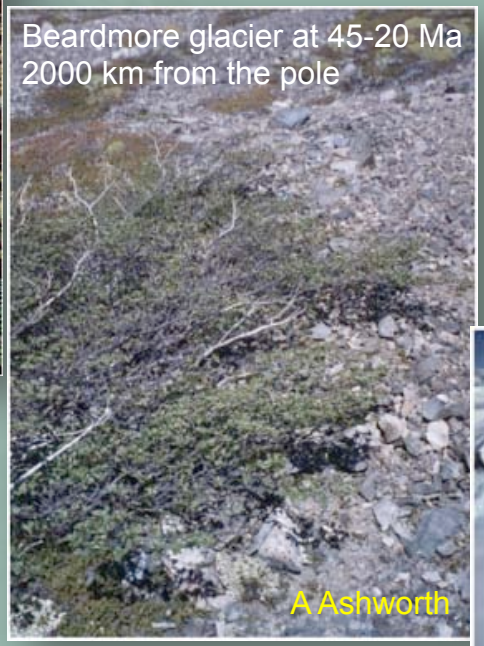
Past: Evolution of the Continent's Climate

Nothofagus (southern beech) 2-3 month growth season at 4-5°C in S Chile.



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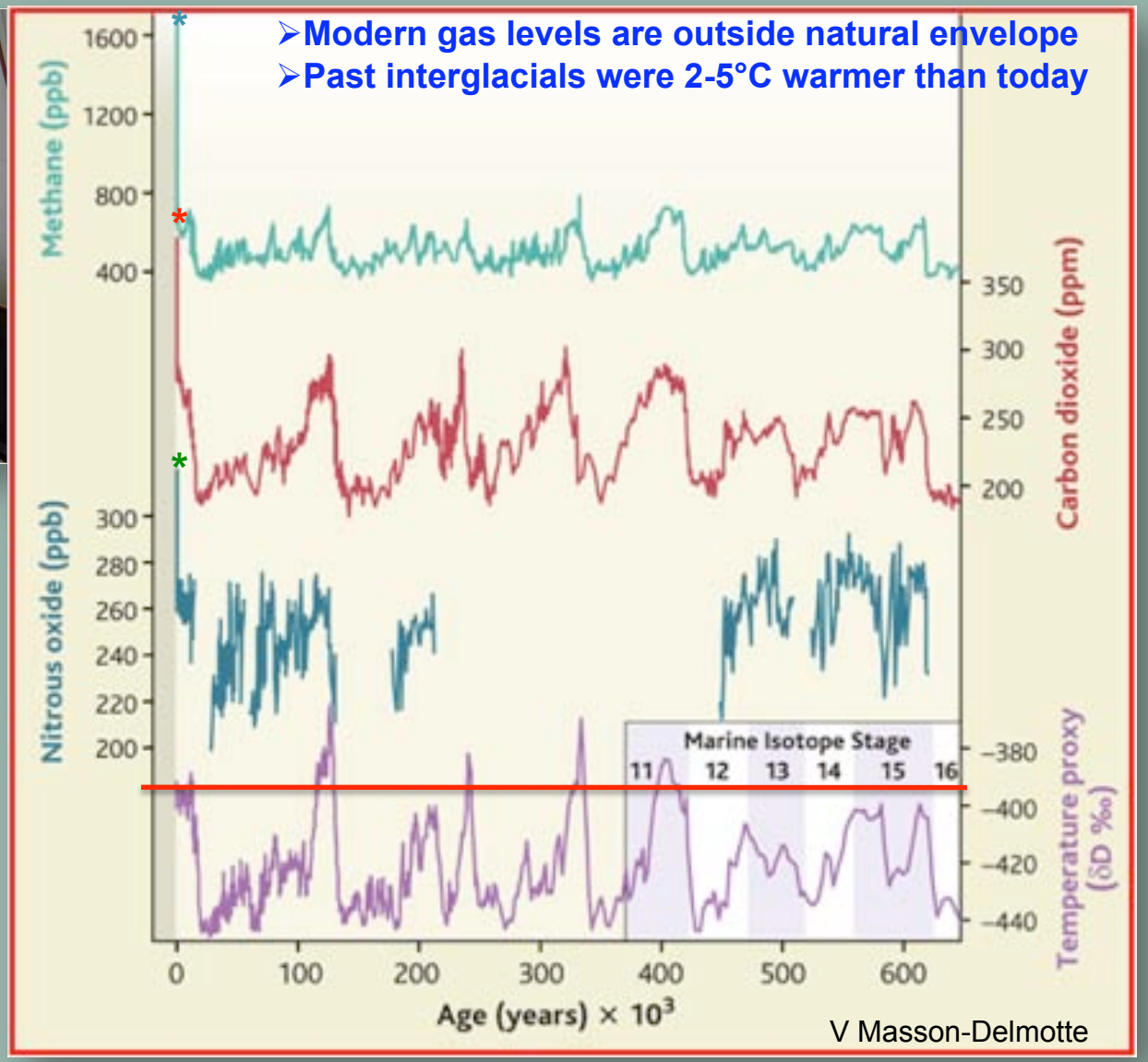
Past: Climate from Ice Cores

Dome C EPICA ice core

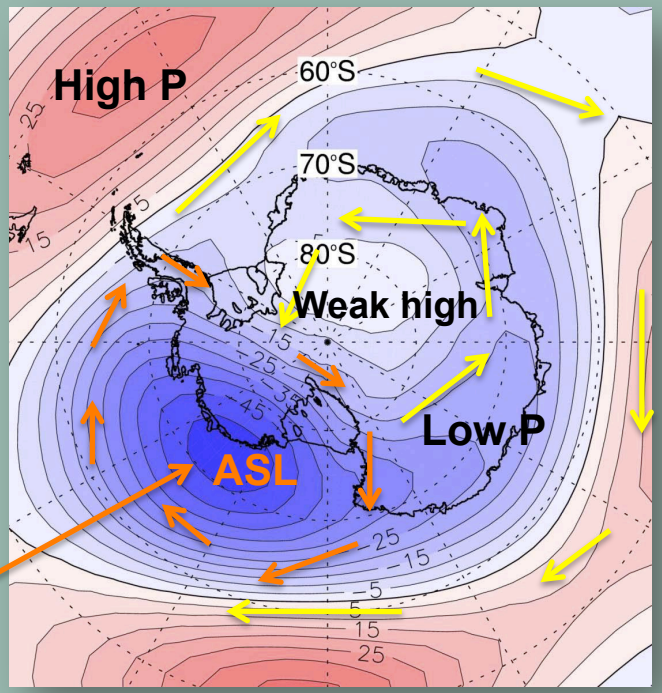
Sea levels during warm interglacials could have been 6.6-9.4m higher than today thus ice sheets may be more sensitive than we thought (*Nature 17 December 2009*)



V Masson-Delmotte

Present: The Role of Winds

- Here we see the Pressure anomaly pattern (isobars);
- Winds run along the contours;
- They create a Polar Vortex extending from surface to stratosphere;
- This strong barrier of winds keeps warm moist air away.
- There is local high pressure at the pole



Amundsen Sea Low (ASL) develops because the continent is off-centre.

This local circulation makes West Antarctica respond differently from East Antarctica to climate change.

J Turner and others

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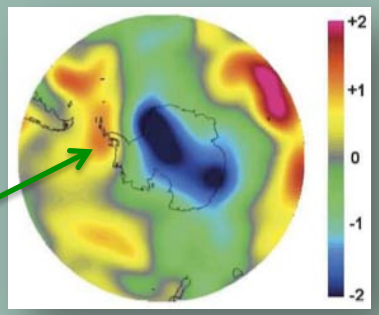
Continent cools while peninsula warms

Change in mean Ann. Temp. °C (1969-2000)

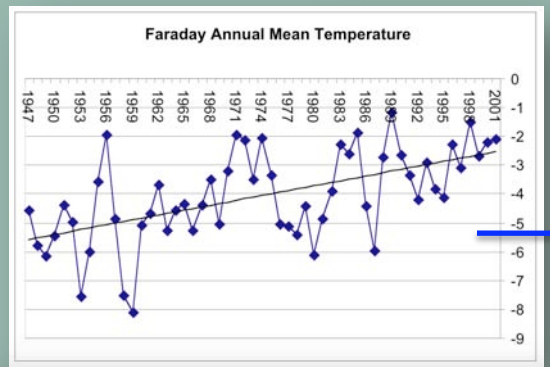


Thompson and Solomon 2002

West peninsula

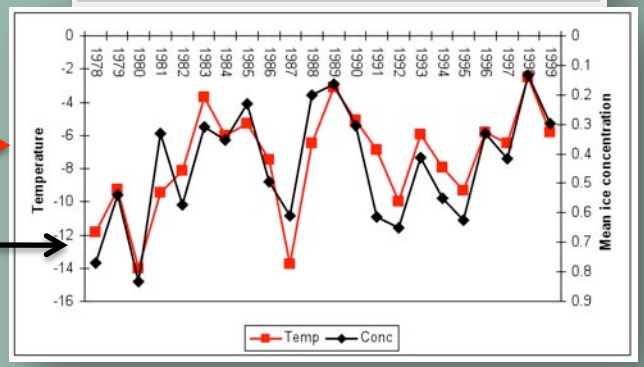
Warm air is brought in from the north by Amundsen Sea Low.

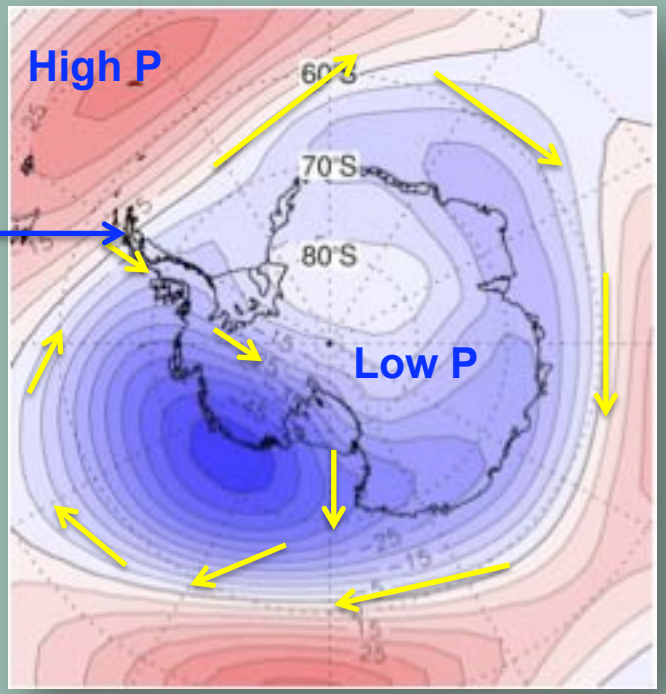
Air warms at 0.53°C/decade at Faraday/Vernadsky since 1950.



(1.03°C/decade in winter)

Correlates with decrease in sea ice.





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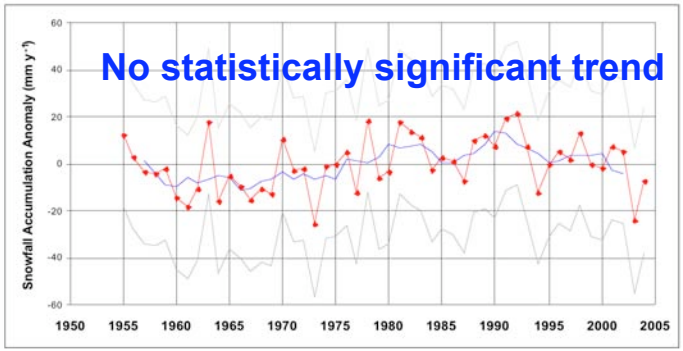
Interior is a desert



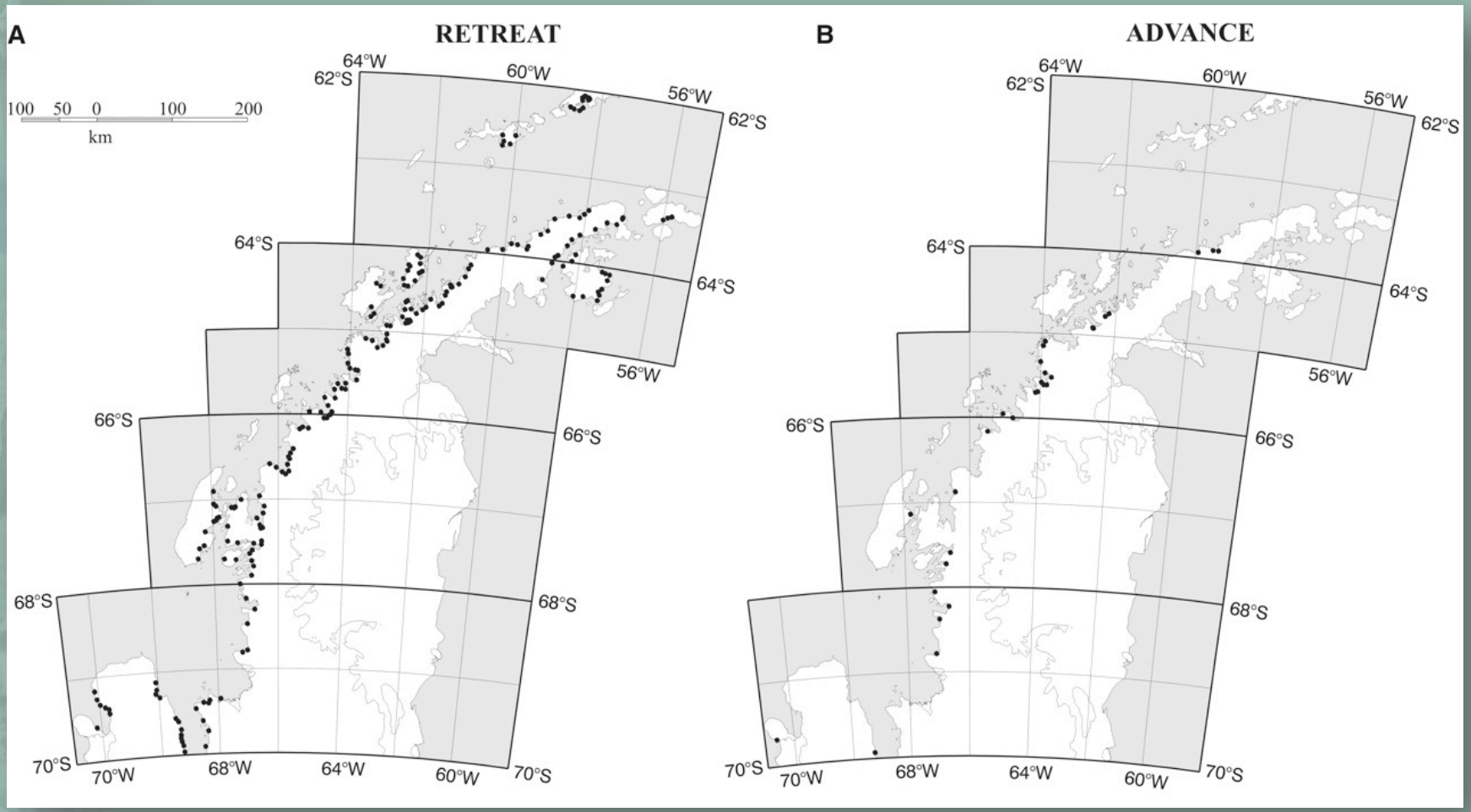
Snowfall accum. (= surface mass balance) mm/yr

Most along coast.

Interior is a desert because cold air does not hold much moisture, and warm wet winds do not penetrate to the interior.

From papers by Monaghan, and by Van de Berg et al., 2006

Response of Antarctic Peninsula glaciers to warming and snowfall



Cooke et al., 2005

244 glaciers : 87% have retreated over last 50y

Warming AND Cooling?

Causes?

Greenhouse Gases?

The Ozone Hole?

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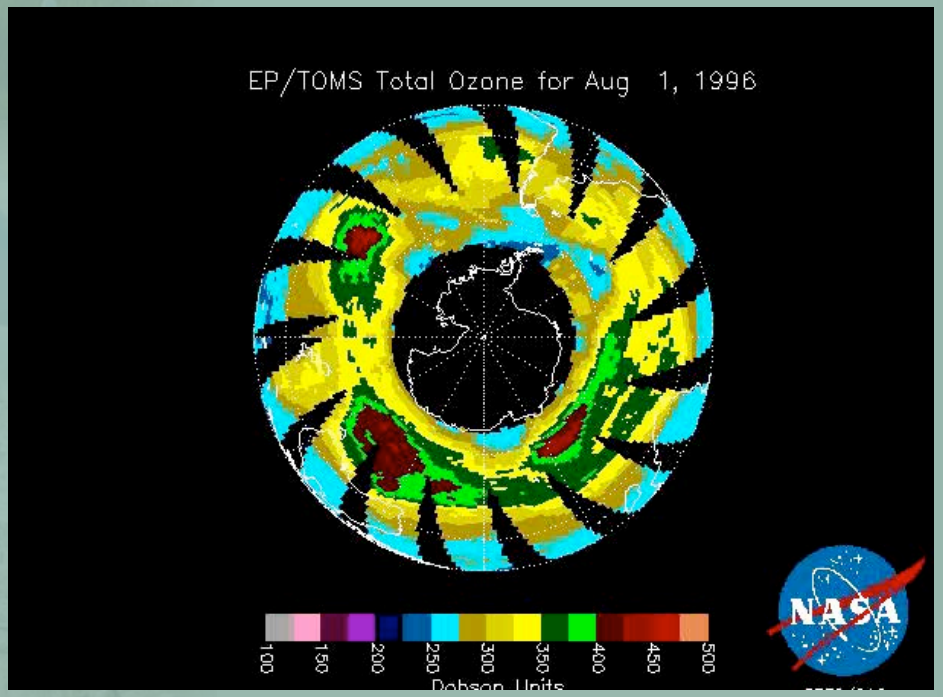
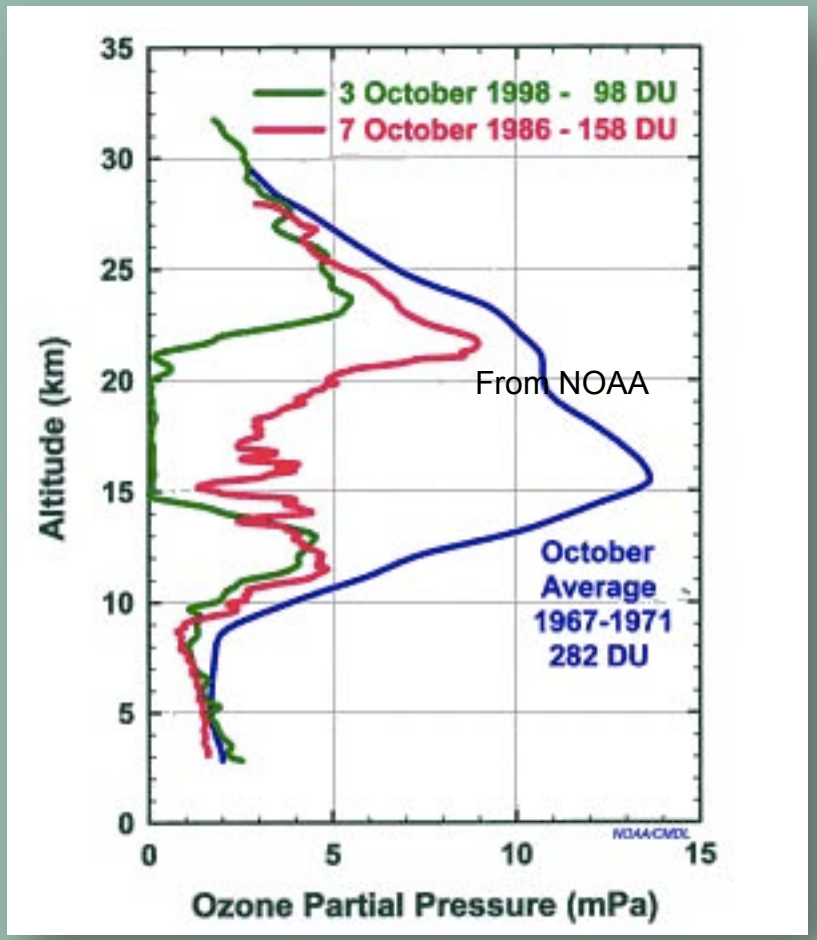
Ozone Hole

Lasts from 1 Sept to 31 Dec, with peak low from 1 Oct to 1 Nov





- The polar vortex (westerly circumpolar winds) bound the ozone hole;
- They are strongest in winter, when temperatures are coldest (< -80°C);
- Polar stratospheric ice clouds form inside the vortex; they catalyze CFC breakdown to give Cl^-, which destroys Ozone
- The absence of O_3 (a greenhouse gas) cools the temperature by 15°C;
- Loss of ozone from 1980 onwards strengthened the polar vortex winds by 15 %.

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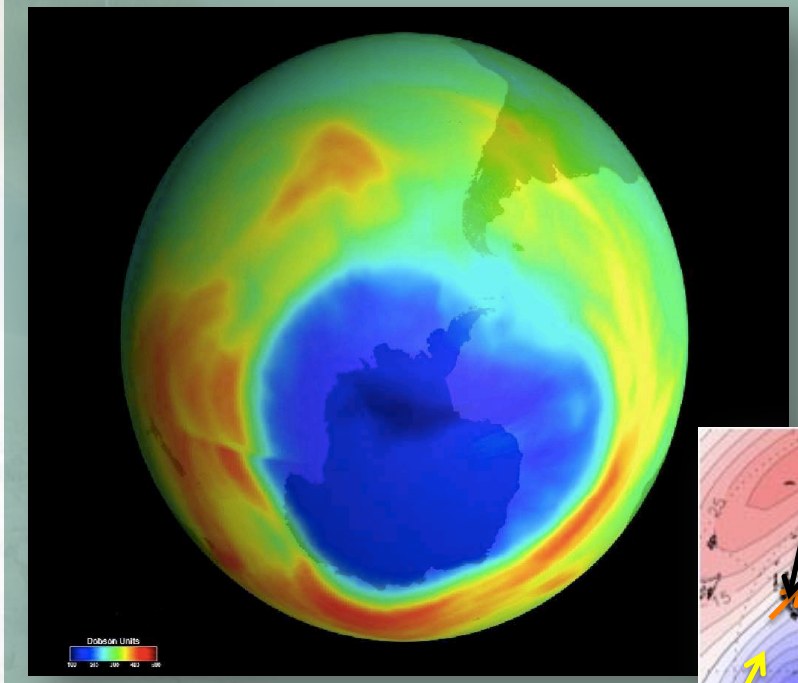
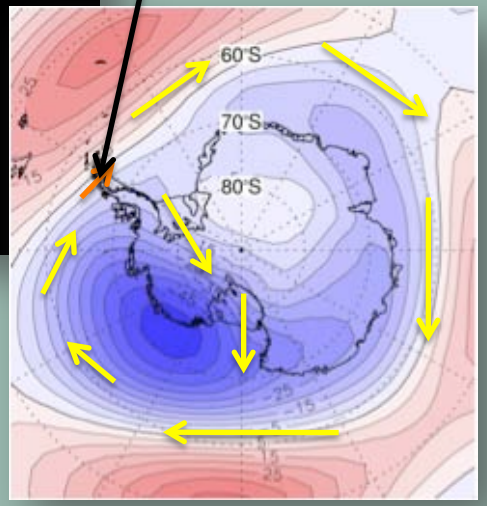
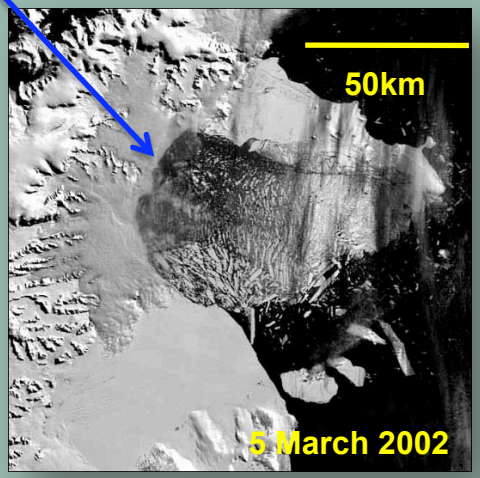
Winds driven by Ozone Hole help shield Antarctica from global warming

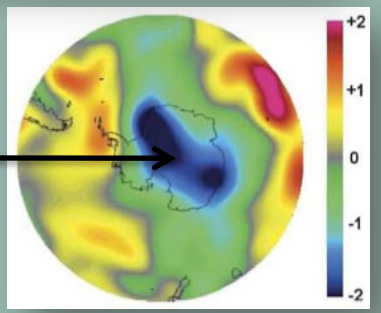


- Ozone hole strengthens stratospheric winds;
- These propagate down to the surface;
- Warm surface winds are now strong enough in summer and autumn to cross the mountains of the peninsula;
- Collapse of the Larsen B ice shelf





This strengthening of the 'normal' surface winds helps to keep East Antarctica cold



Change in mean
Ann. Temp. °C 1969-2000

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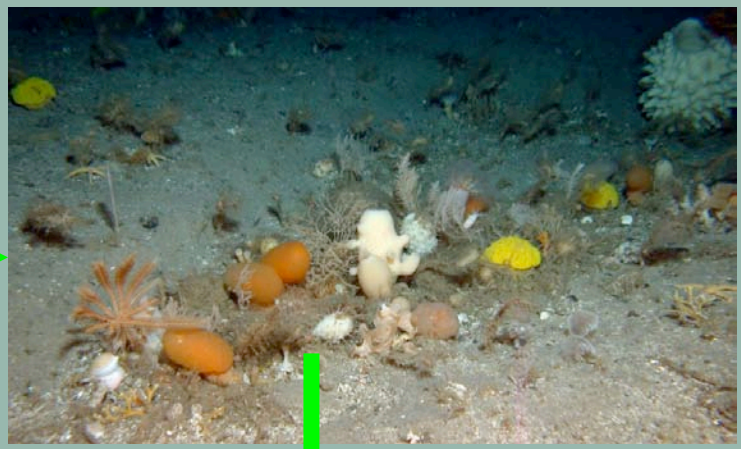
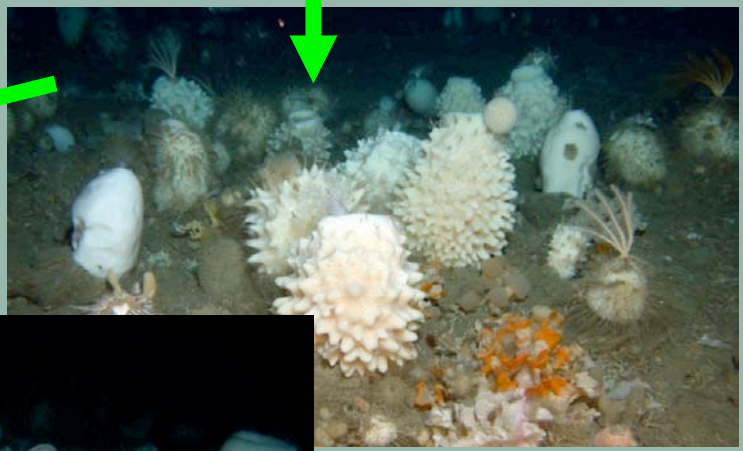
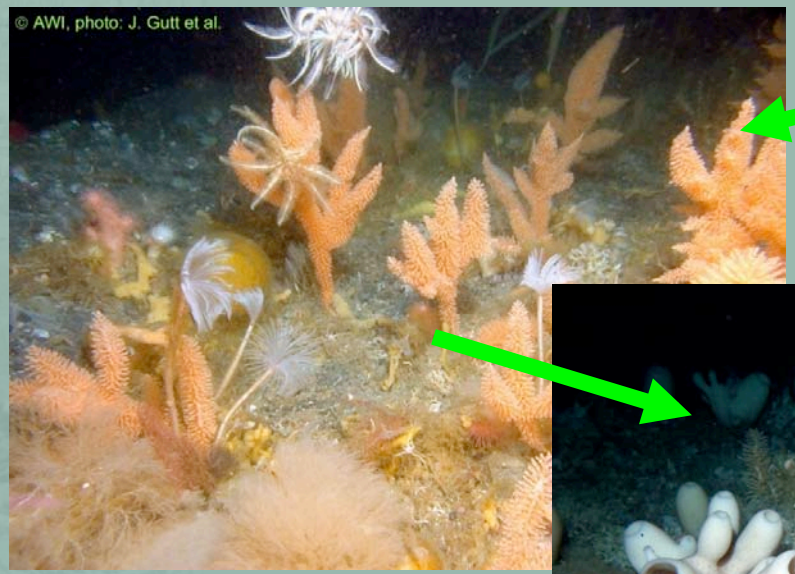
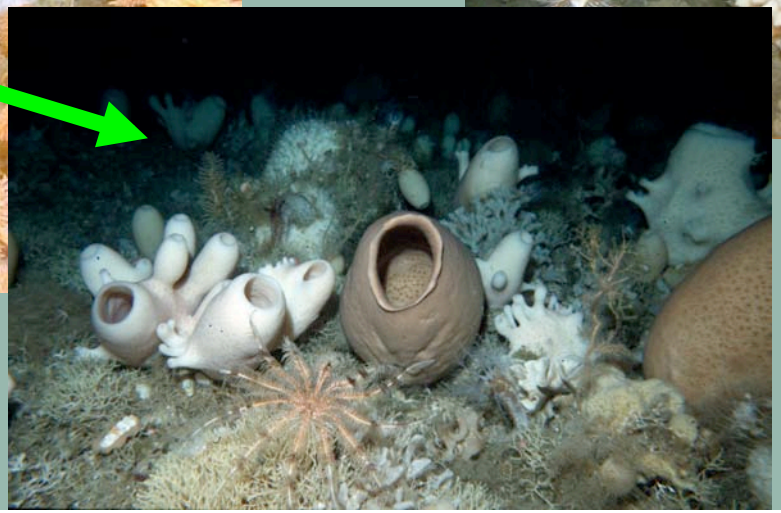
Rich Benthic Ecosystem

Present = Colonisation of Larsen B space









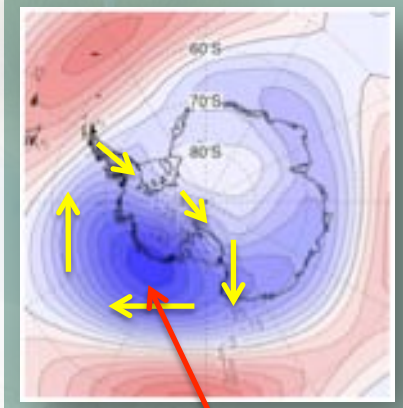
J. Gutt, AWI

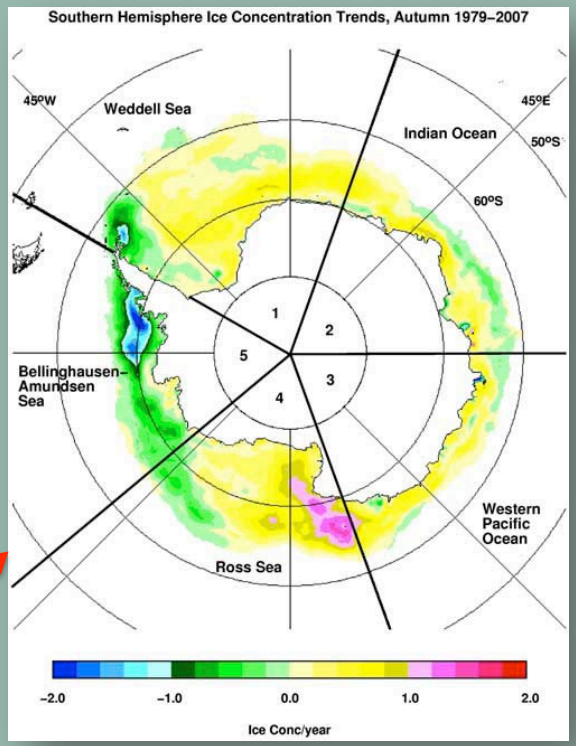
Future for benthic organisms

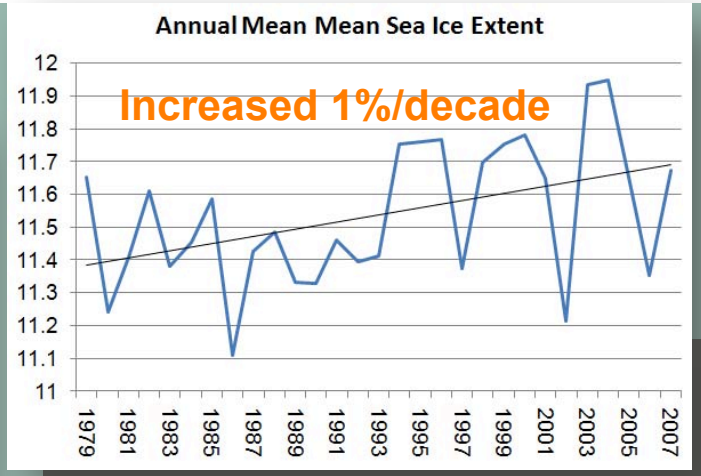
- Adaptation
- Evolution
- Migration
- Extinction

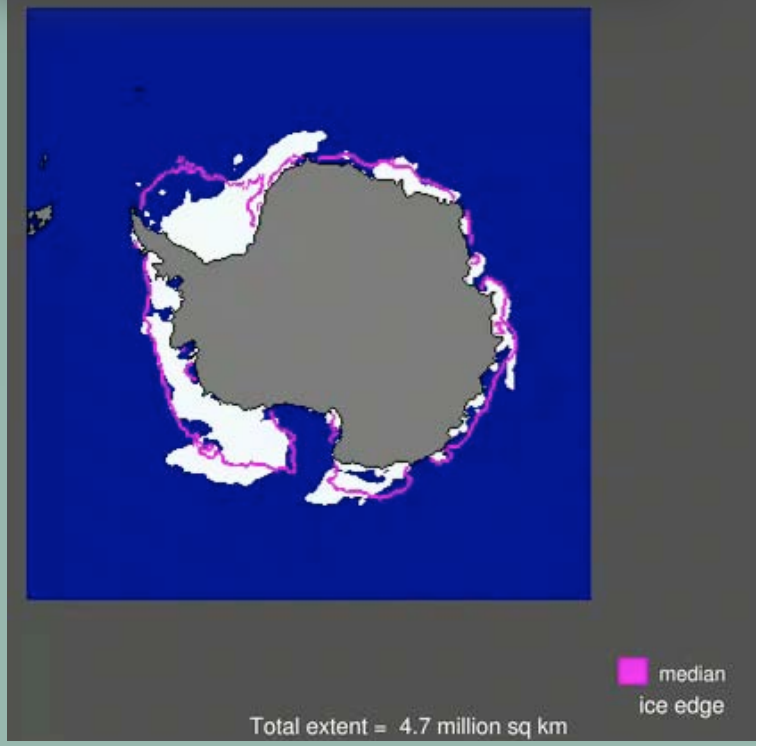
Ozone Hole affects sea ice

Turner et al., 2009









Amundsen Sea Low, drives ice development especially in autumn

Exacerbated by the Ozone hole
(keeps Antarctic cool and strengthens winds in late summer, autumn)

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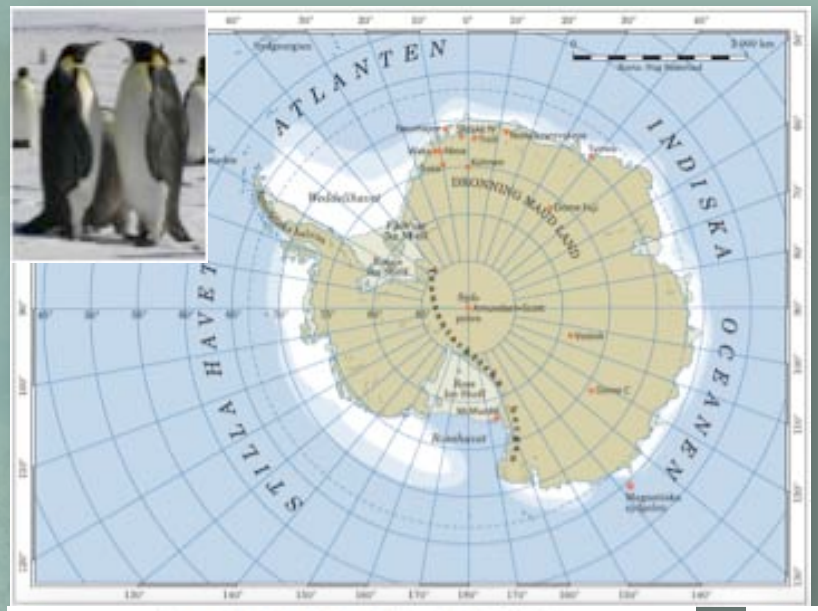
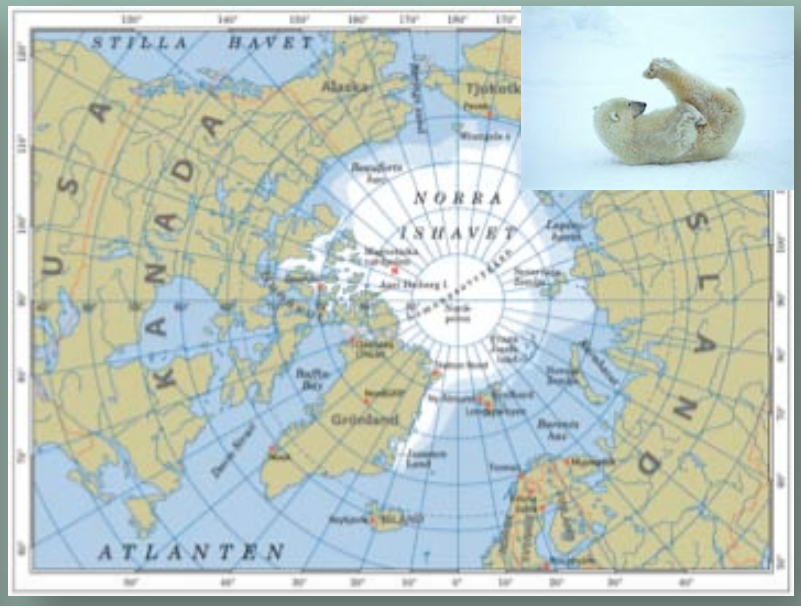
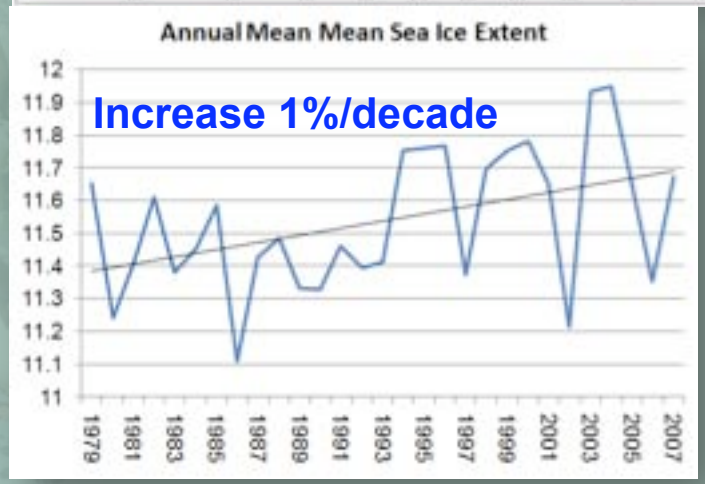
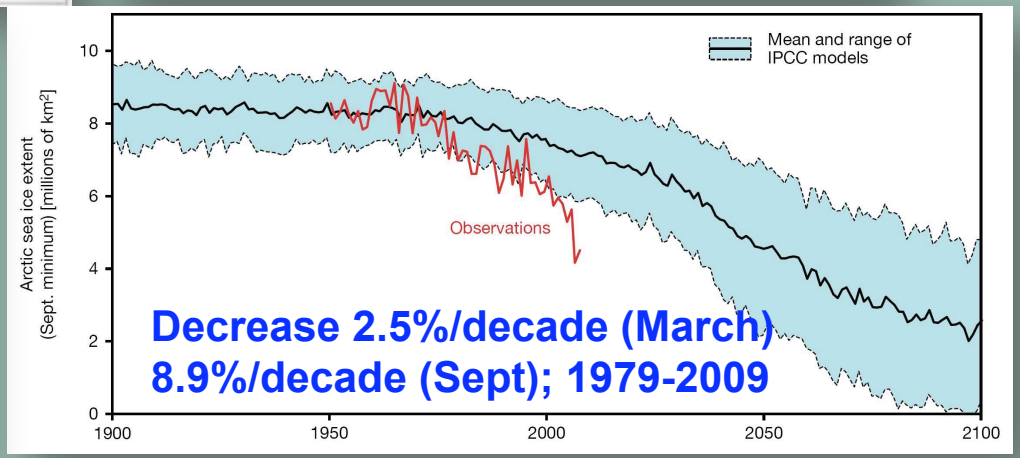
Antarctic sea ice differs from the Arctic







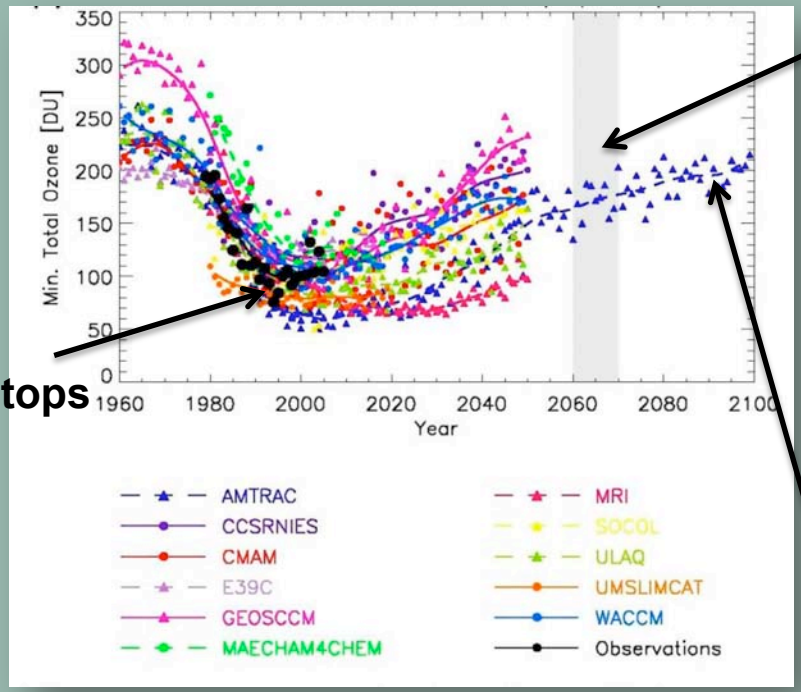


Arctic has no shielding wall of wind, and easy access by warm water and warm wind from the south

The Future of the Ozone Hole

Expected return to 1980 values by 2070

Minimum total column ozone (Sept-Oct)



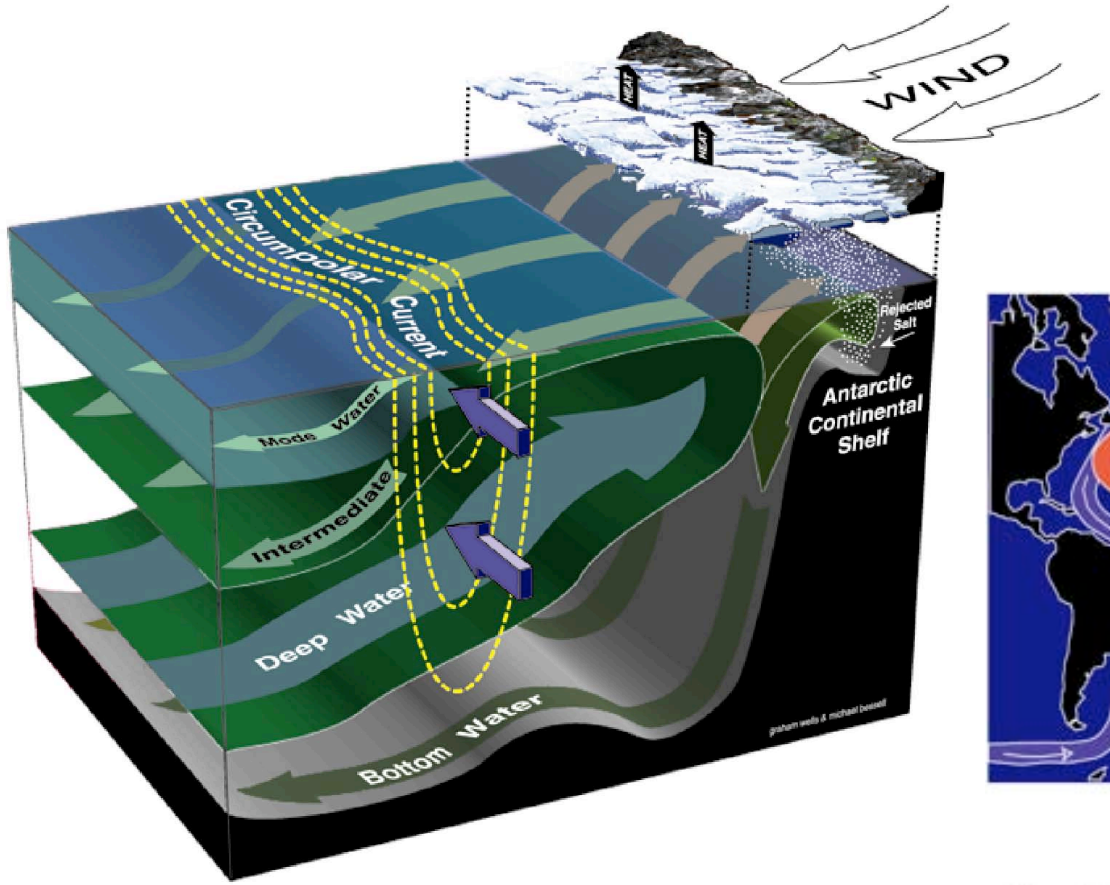
Montreal Protocol stops CFC emissions

AMTRAC model best matches observations

By 2070 no more shielding

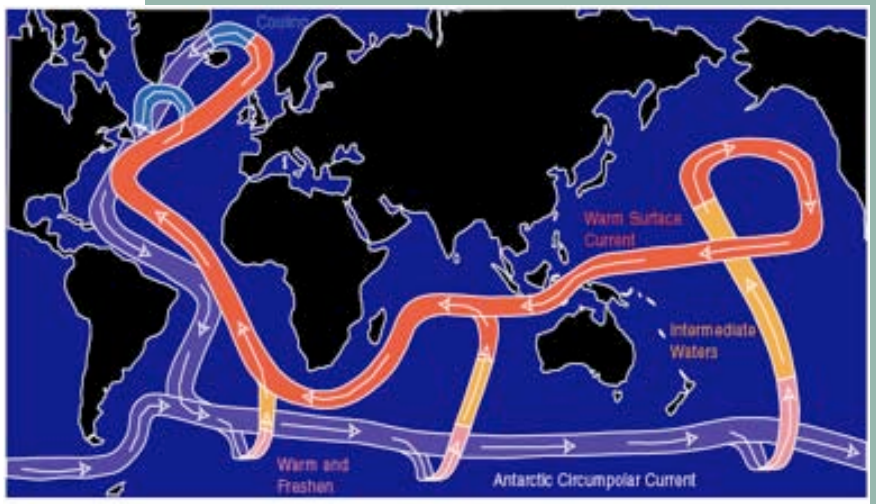
Bodecker et al., 2004, & WMO 2006

The Oceans Connect Everything



Climate signals are shared

- **Pole-to-Pole**
- **Ocean-to-Ocean**



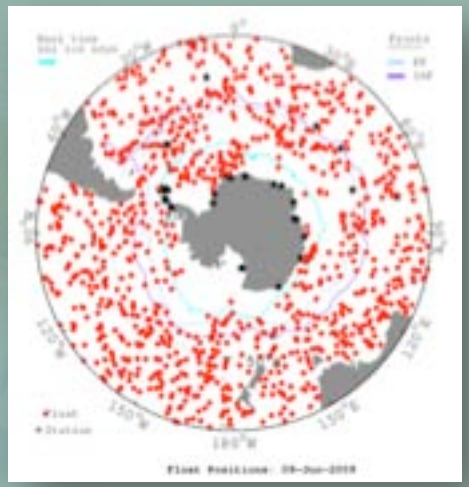
Thermohaline Conveyor Belt (after Doos and Webb)

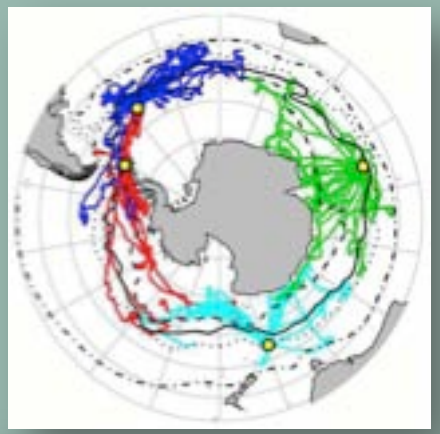
t96g_occam/thermohaline2

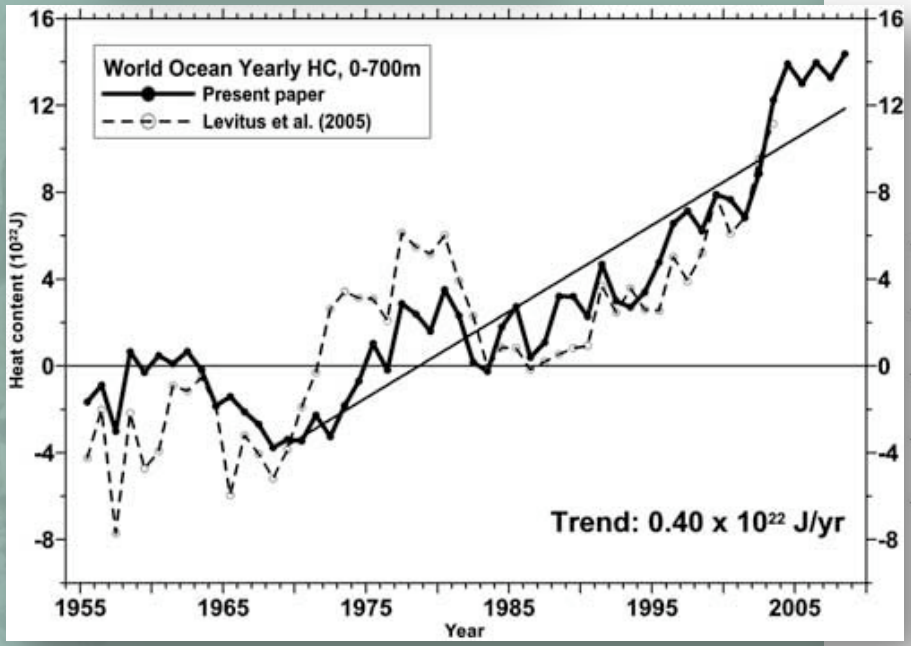
Rintoul, 2001

nutrients exported north provide 75% of global ocean productivity north of 30S.

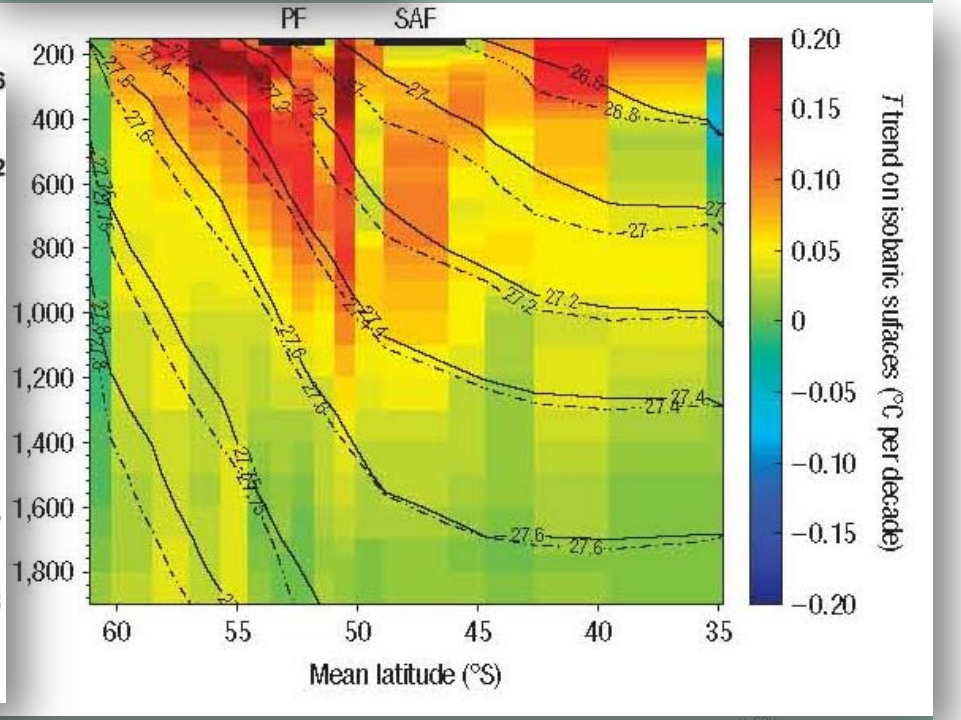
Southern Ocean Warming





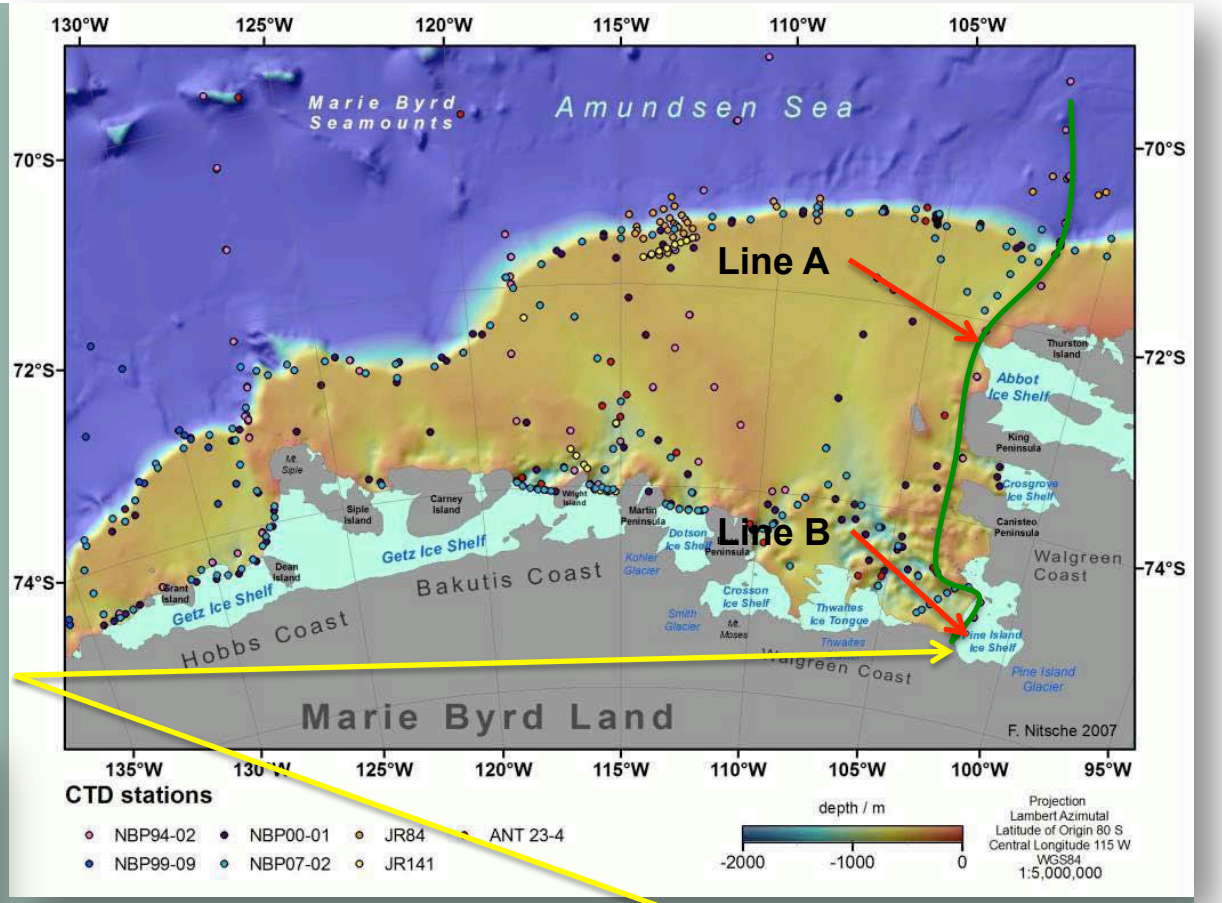


Levitus et al, 2009



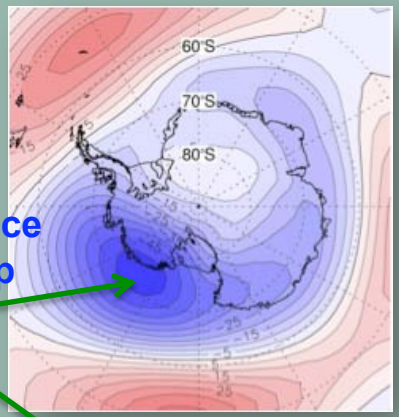
Boning et al 2008

Warm ocean melts Pine Island Glacier from beneath

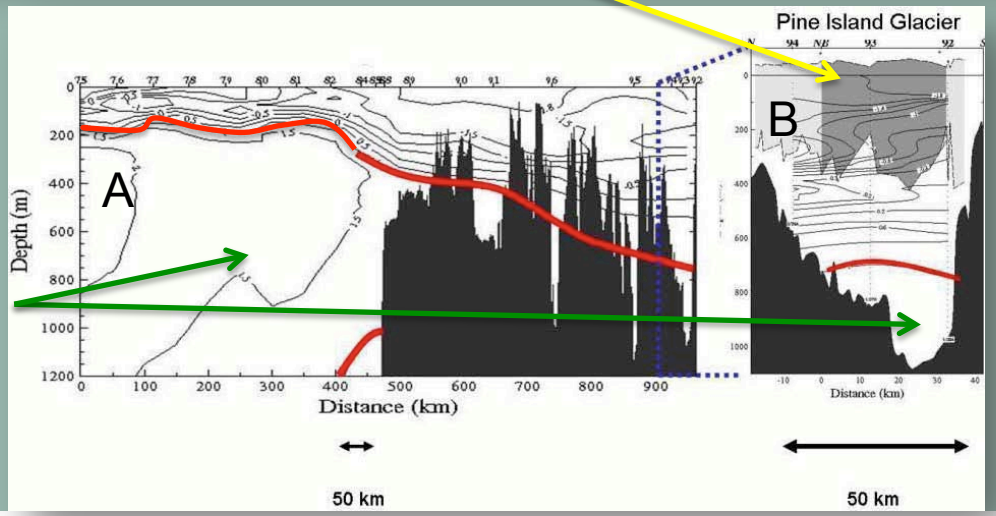


Pine Island Ice Shelf

Large low pressure cells (ASL) force warm subsurface water to well up



Upwelling Circumpolar Deep Water is warmer than 1°C

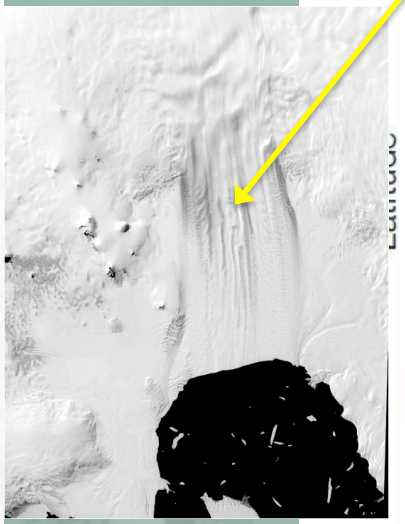


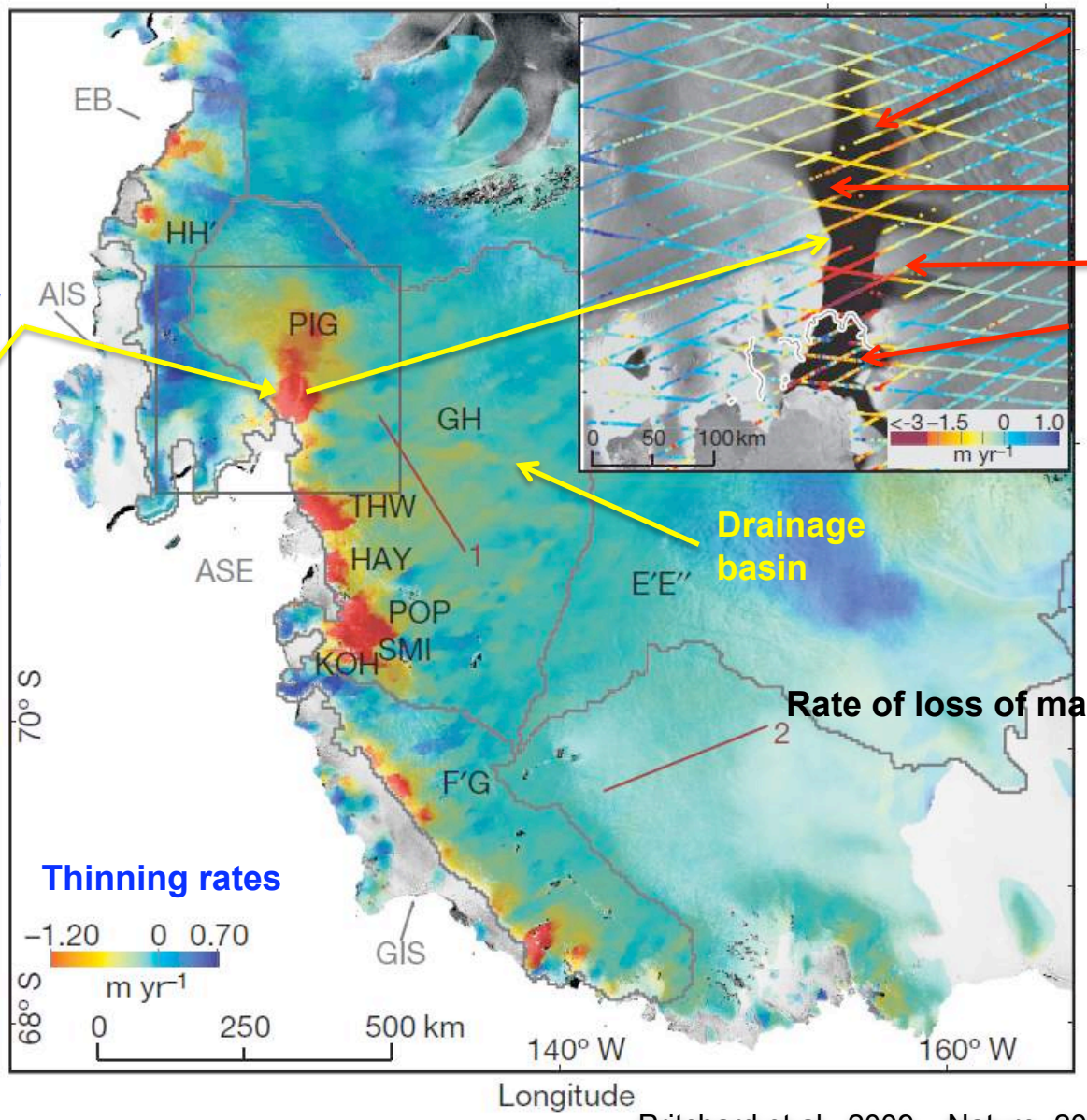
After Helmer et al 1998

Current state of Amundsen Sea Embayment

PIG moving at 10m/day at the grounding line = 75% rate increase since 1970

Pine Island Glacier





1 m/day

2.5m/day

7 m/day

10 m/day

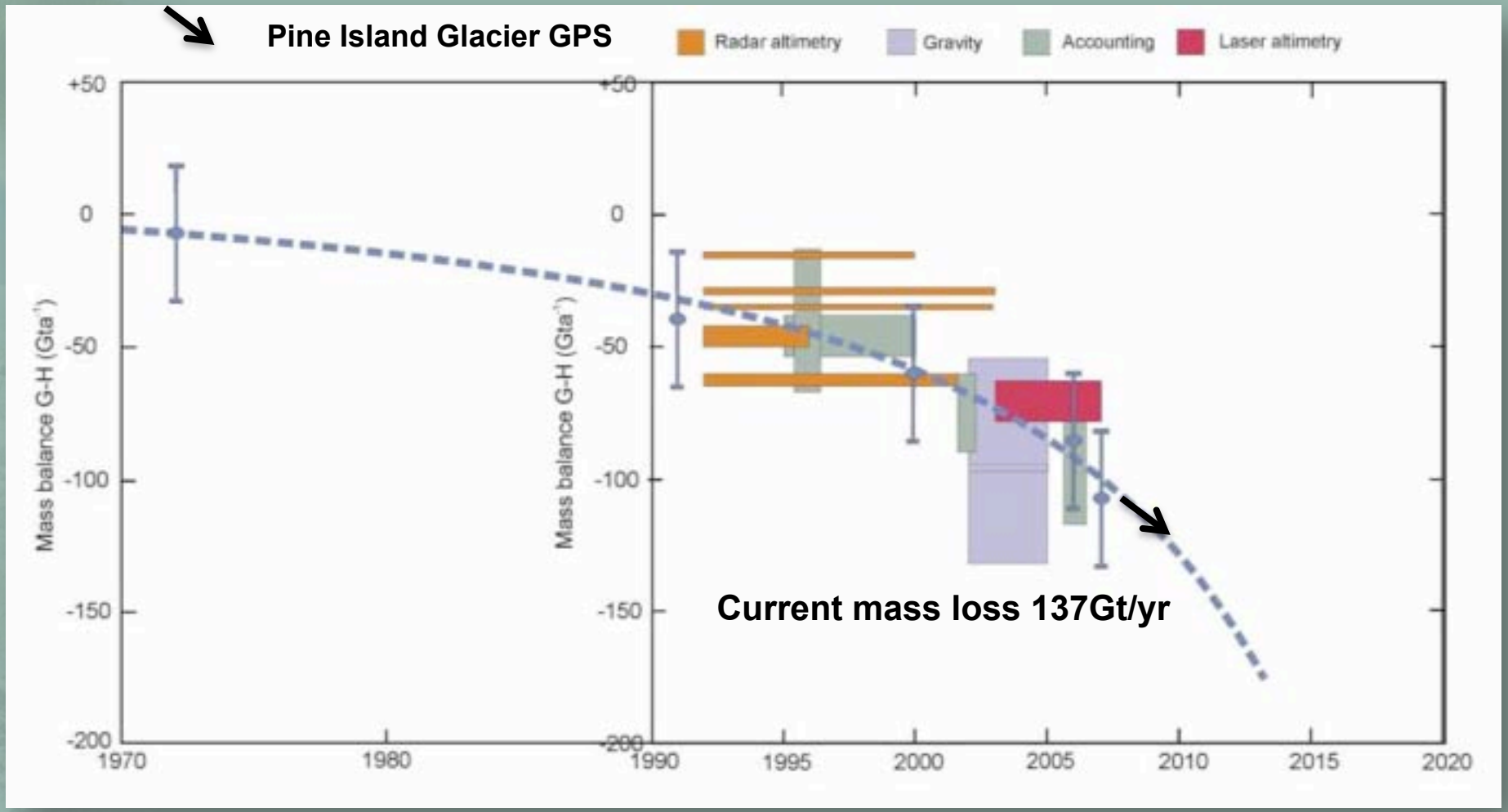
Drainage basin

PIG alone could soon contribute 0.5mm/yr to global sea level

Rate of loss of mass is increasing

Pritchard et al., 2009 – Nature, 2009

Increasing loss of ice mass from Amundsen Sea embayment



D Vaughan

Note – subtract from that the mass balance of East Antarctica (between near zero and slightly positive, e.g. +15.1 +/- 10.7 Gt/yr; Zwally et al, 2005).

Thus, overall, Antarctic ice sheet is shrinking.

BIOLOGISTS ARE OBSERVING CHANGES IN PENGUIN POPULATIONS

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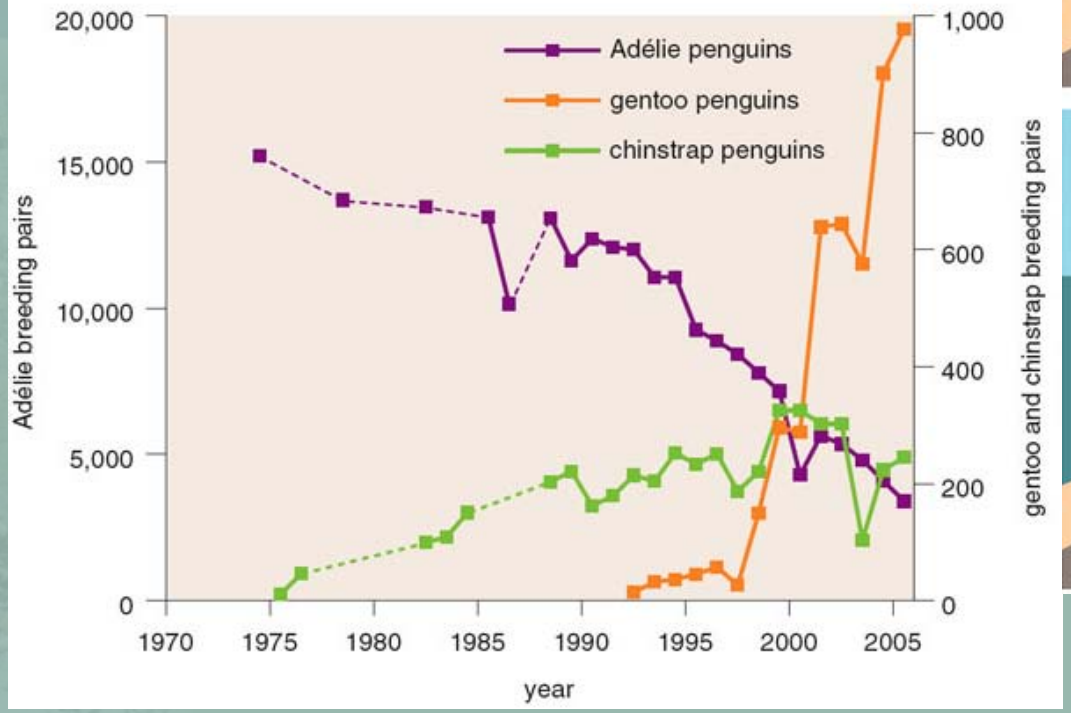
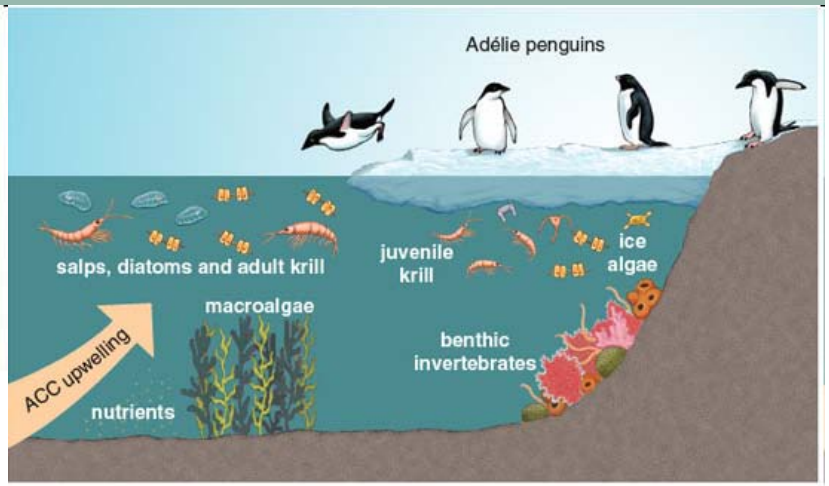
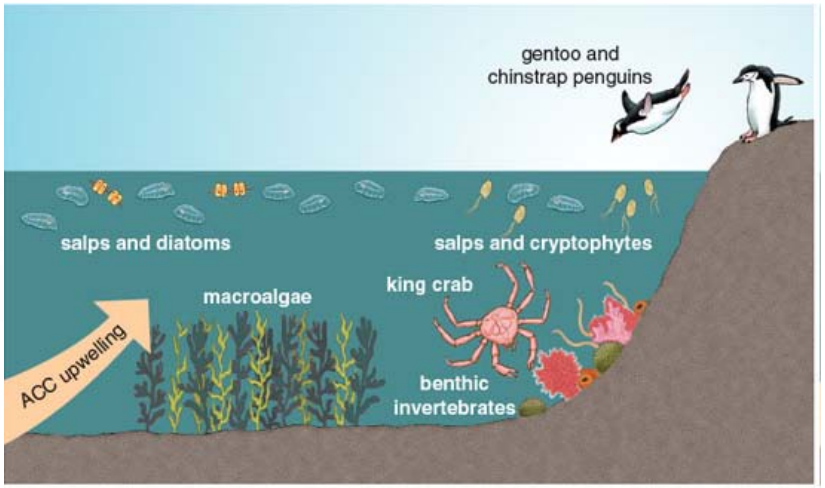
Breeding success and ecological response





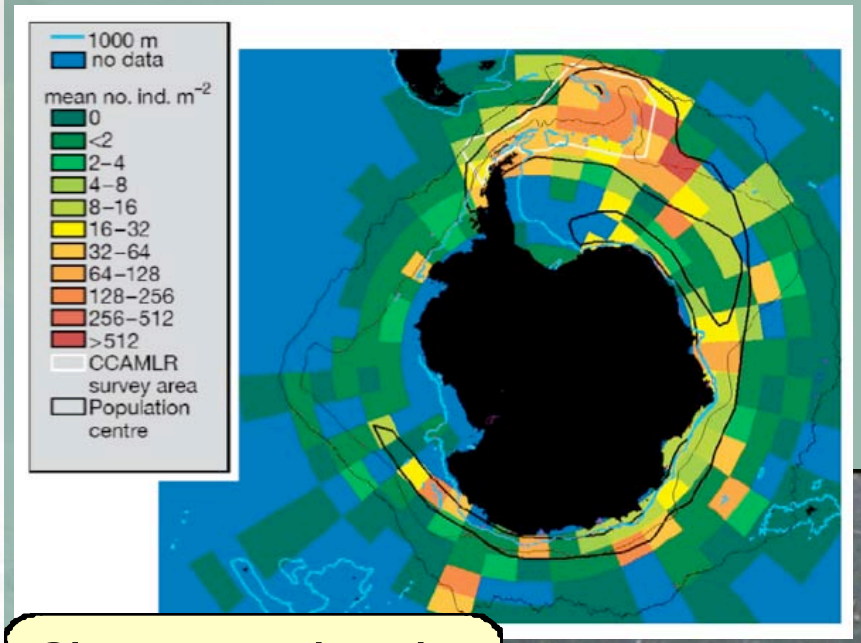


More snowfall and less sea ice →

Shifts in the penguin population on the western Antarctic Peninsula are attributed to changes in precipitation patterns and sea ice.

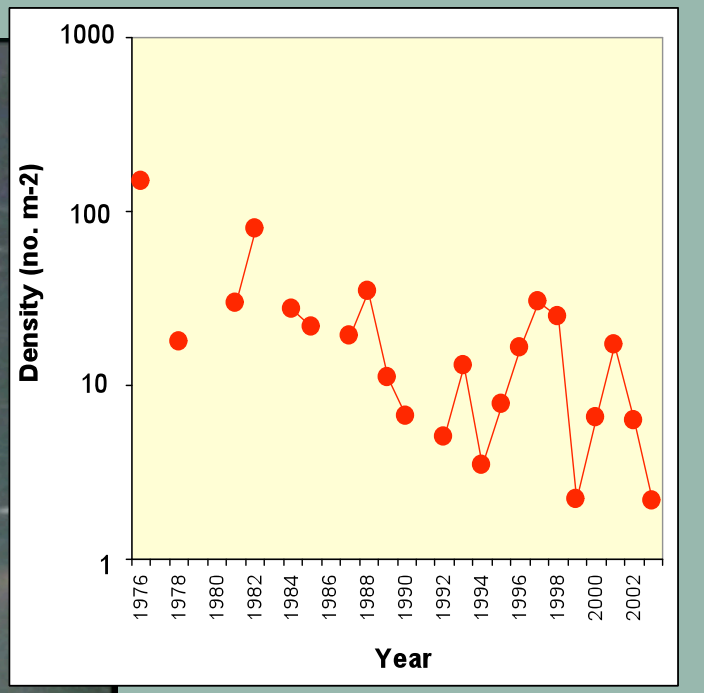
McClintock 2008

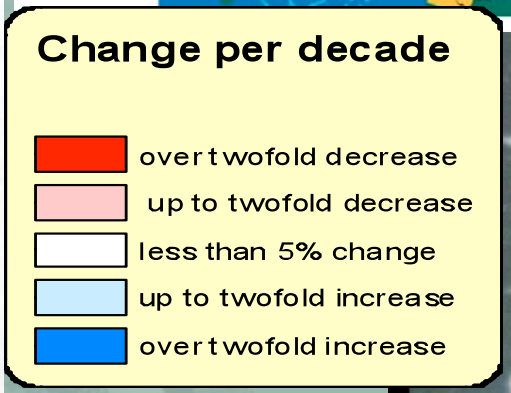
Responses of Southern Ocean Ecosystems to Change



As sea ice decreases, krill decrease

As krill decrease, salps increase



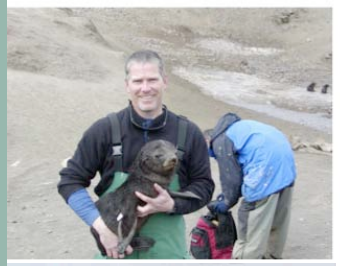


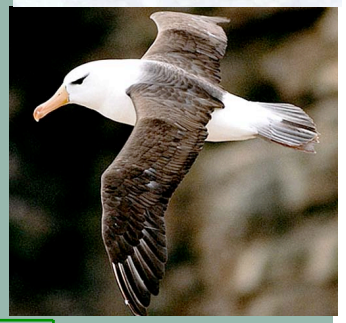
Atkinson et al, 2004, Nature

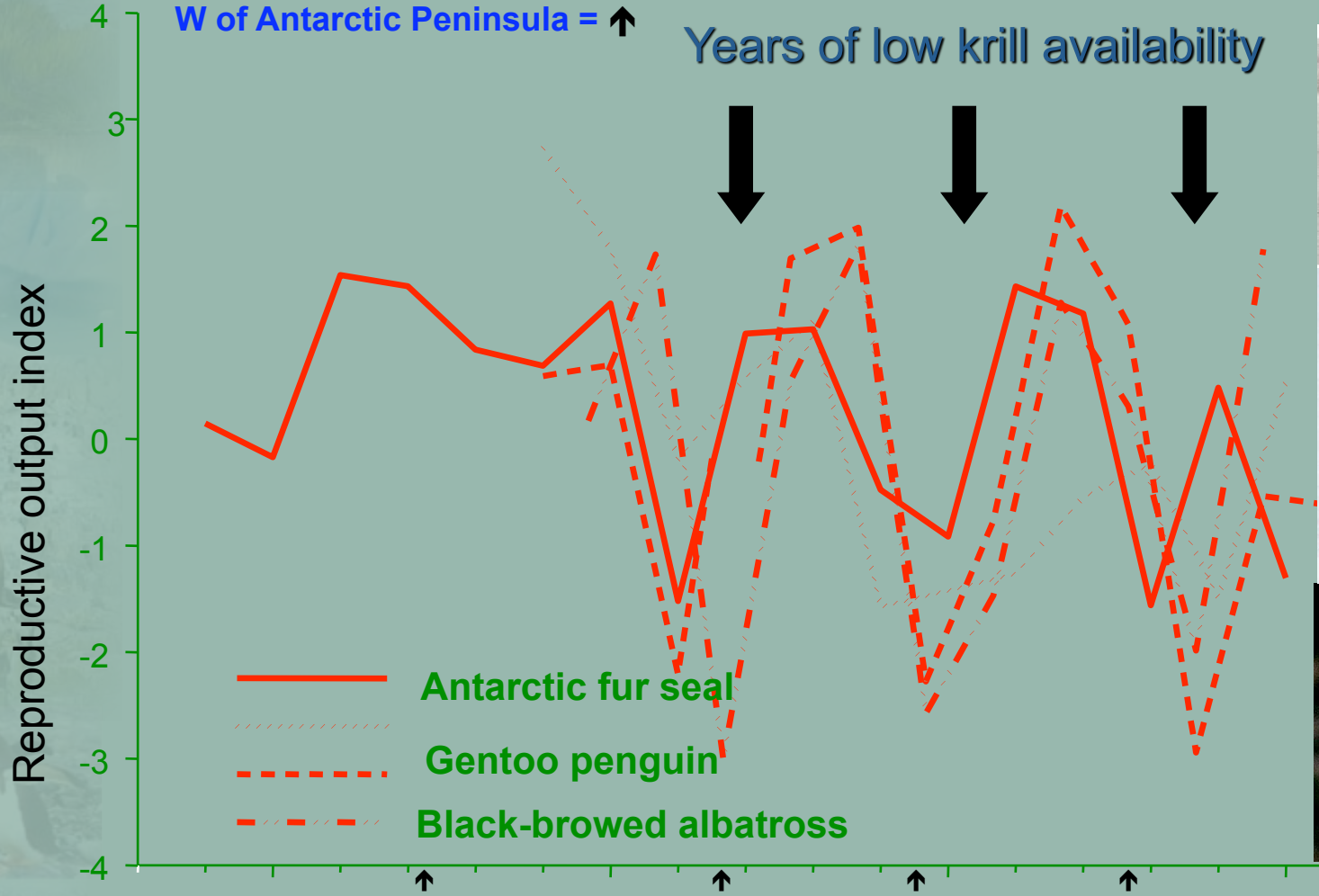
Interannual variability

El Niño = warm = less ice
W of Antarctic Peninsula = ↑

Years of low krill availability





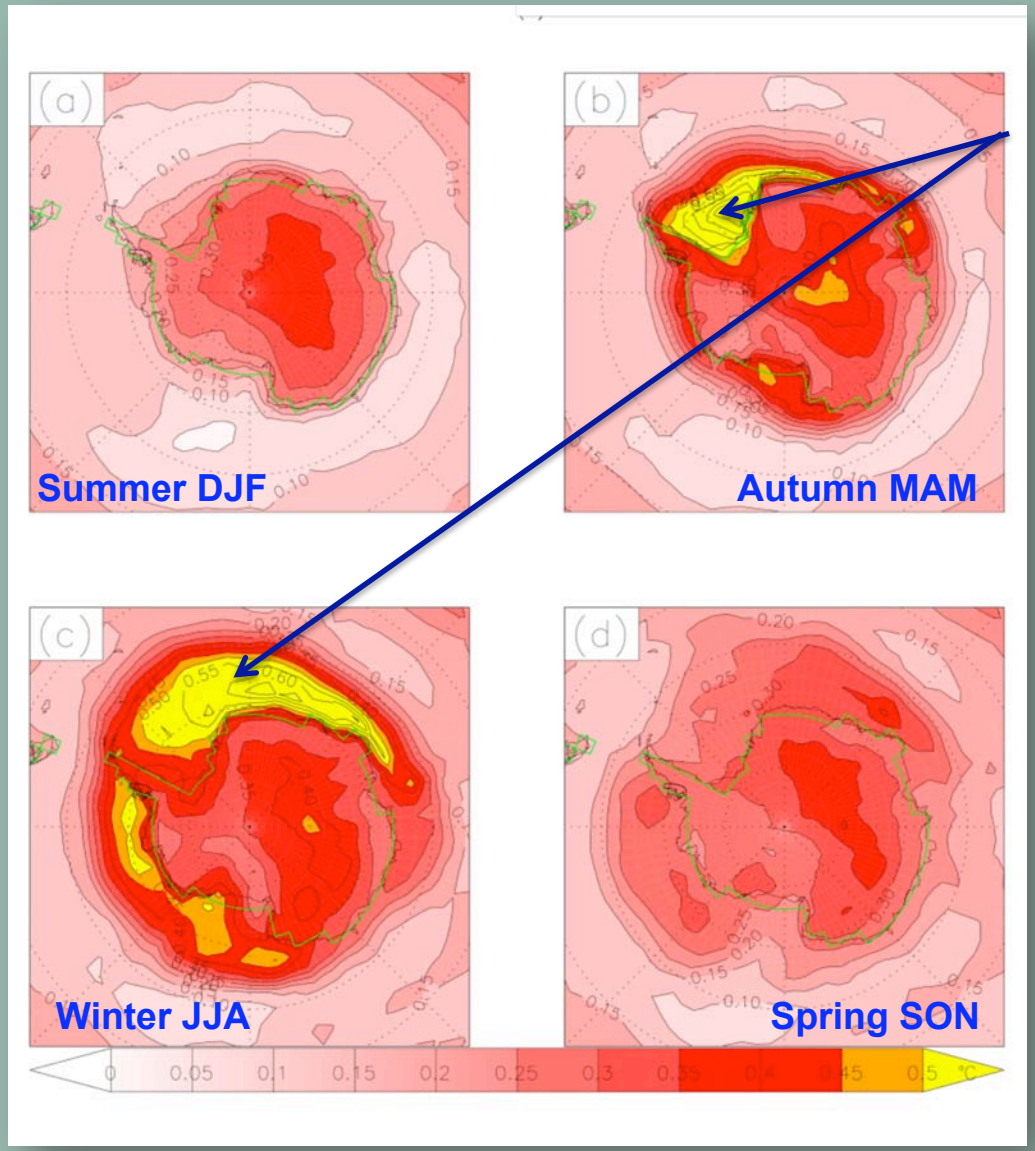


Reid & Croxall, 2008

Implication: will have less production if ocean warms and sea ice shrinks.

Projected Antarctic warming by 2100

3.4°C by 2100
from weighted average of 19 IPCC models based on 2 x CO_2
(the IPCC A1B scenario) .



Most warming is over sea ice, due to retreat of sea ice edge in winter; otherwise, little seasonal trend (av. 0.34°C/decade).

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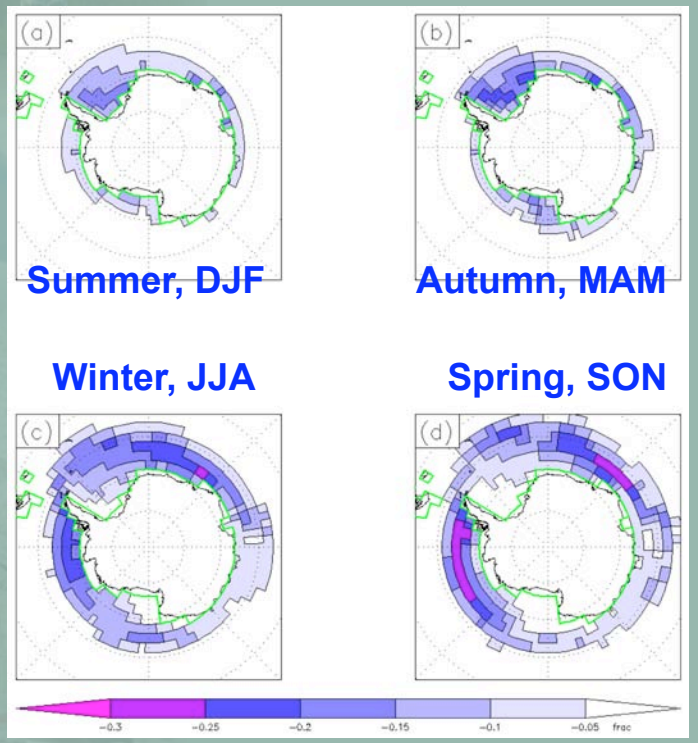
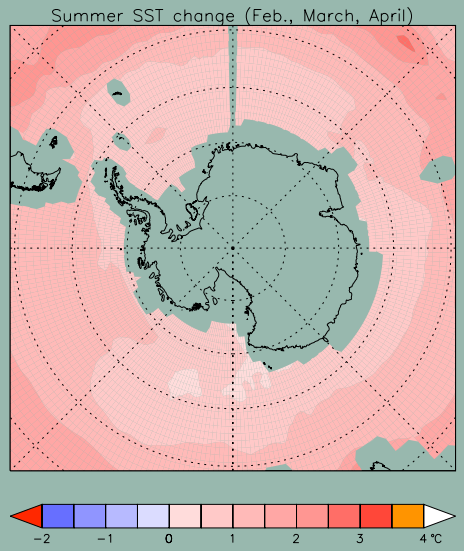
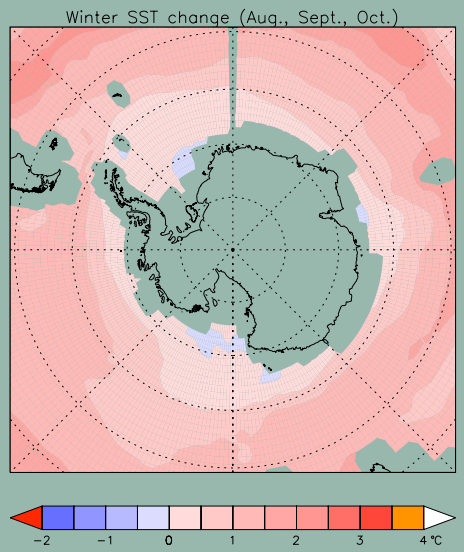
Ocean will warm and become more productive; sea ice will shrink

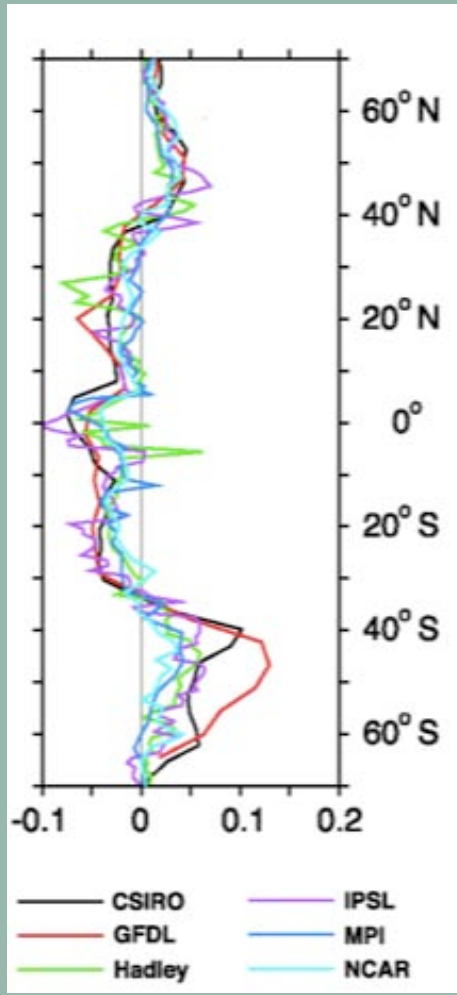
33% decrease in the fraction of surface covered by ice







Primary productivity change PgC/degree; Pg = Petagram = 10^{15}grams



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Flowering plants native to Antarctica, will thrive with warming

Grass *Deschampsia antarctica*

Pearlwort *Colobanthus quitensis,*
- found as cushions

Photos P. Convey

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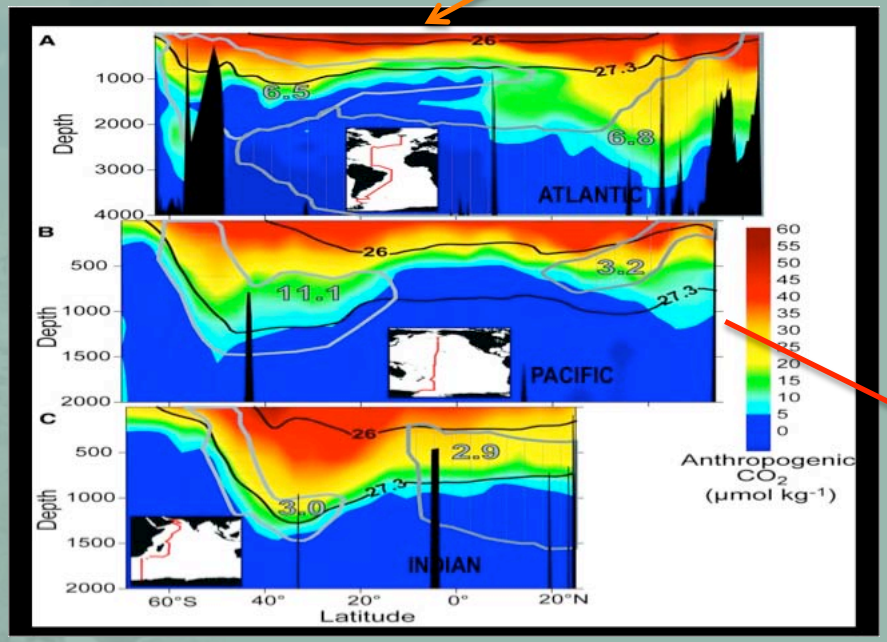
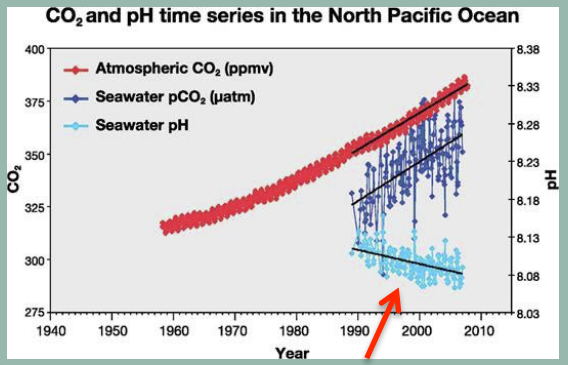
Acidification of the Southern Ocean

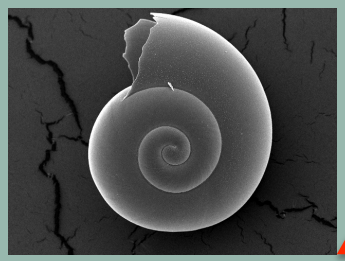
% saturation in aragonite; blue = undersaturated; dissolution may begin

Ocean takes up 35% of human emissions; Southern Ocean takes up 40% of that

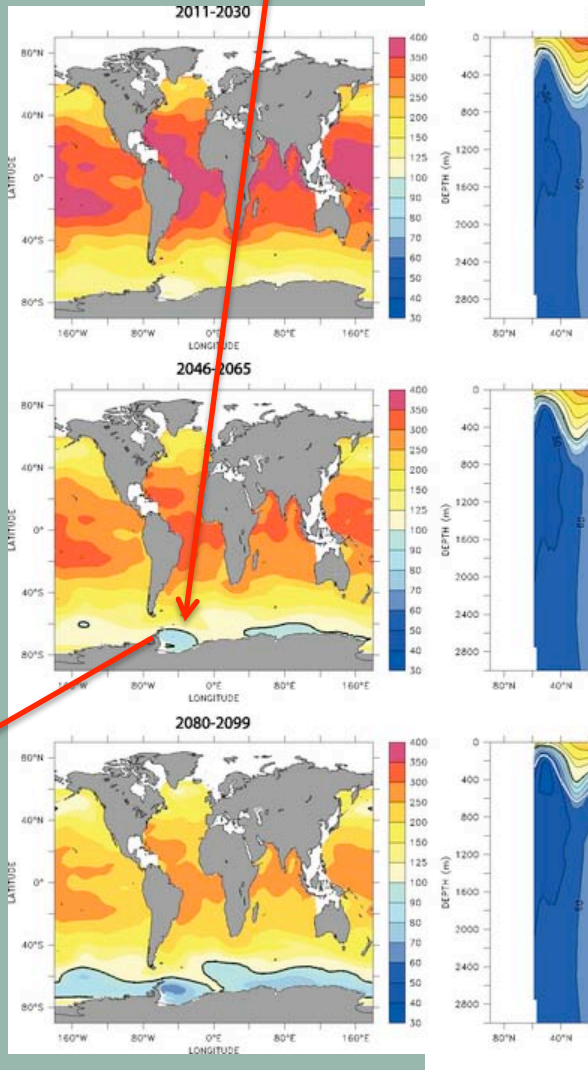




Increasing acidity; Feely 2008



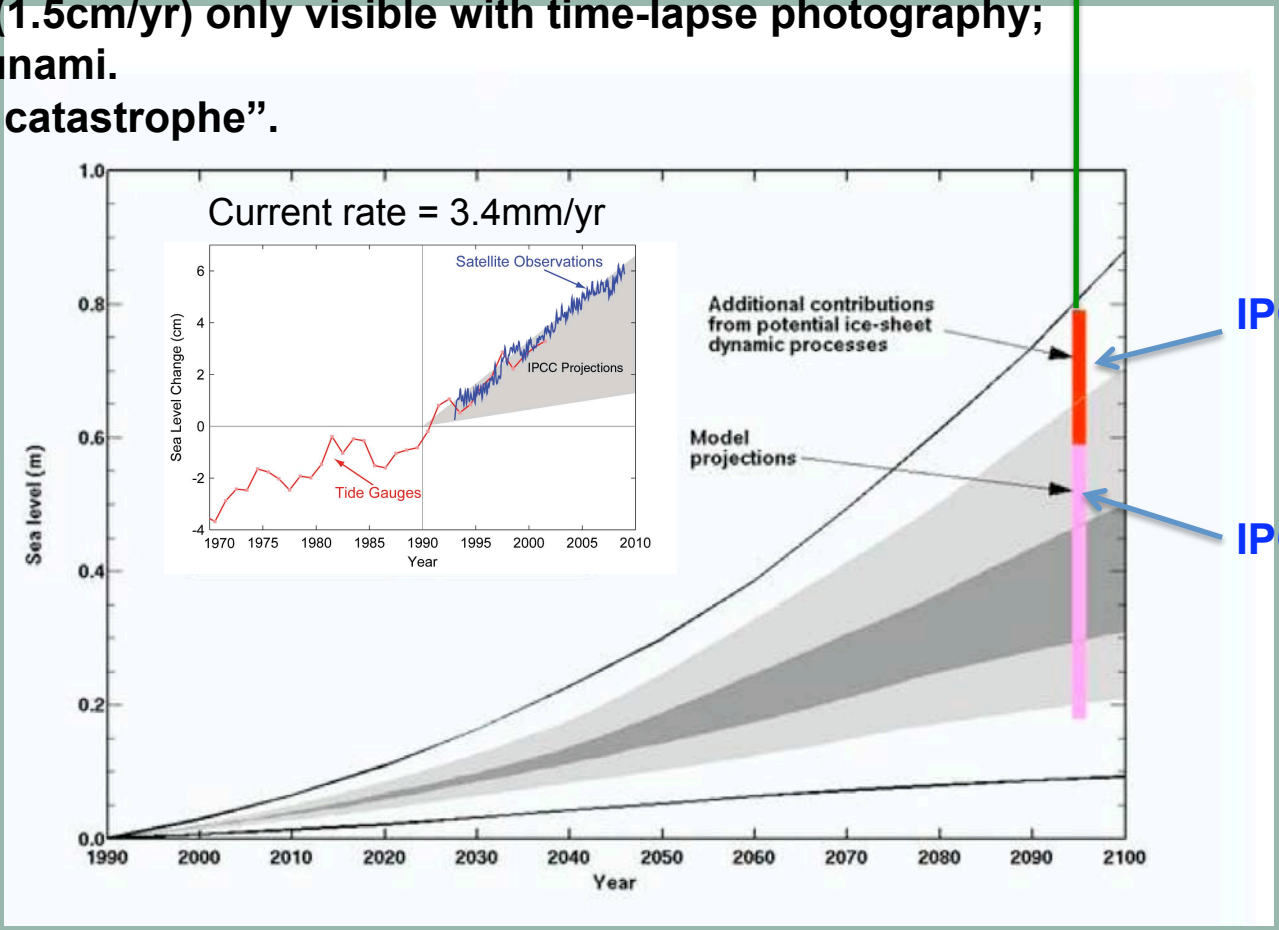
Aragonite pteropod - planktonic marine snail – a major food in the Southern Ocean (N. Bednarsek, BAS)



Ocean Carbon-Cycle Model Intercomparison Project (OCMIP-2) models (adapted from Orr et al., 2005)

Projected change in sea level to 2100

- 1.4 m max projection from Rahmstorf model (2007);
- = Daily rise (1.5cm/yr) only visible with time-lapse photography;
- i.e. Not a tsunami.
- A “creeping catastrophe”.



- 146 million people live within 1m of sea level;
- 1.4m rise will have significant effect on coastal megacities and offshore platforms;

Church et al., 2008

Take Home Messages

- **How does the the Antarctic climate system work?** ***Antarctica locks ice away keeping sea level low. It exchanges climate signals with the Arctic. The Southern Ocean integrates climate signals across the Atlantic-Pacific-Indian oceans.***

- **How does climate change affect the Antarctic ecosystem?** ***Adélie penguins decline on a warmer Peninsula; krill decline and salps grow in a warmer ocean; seals, albatross, and penguins produce fewer young under warmer conditions with less sea ice.***

- **What are the roles of greenhouse gases, and the ozone hole?** ***The ozone hole shields the continent from warming by strengthening the circumpolar winds.***

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Take Home Messages

- **Sea ice is melting in the Arctic – what about Antarctica?** ***Sea ice is growing because the wall of wind keeps warmer air and surface water away.***

- **Is Antarctica growing or shrinking?** ***ASE is shrinking as much as Greenland; the rate is going up.***

- **What will happen over the next 100 years as the world warms?** ***The ozone hole disappears; sea ice declines 33%; the continent warm 3°C; winter snow increases 20%; the ocean warms 0.5-1.0°; organisms are less affected than has been expected.***

- **Why should we care?** ***By 2100 West Antarctic ice sheet may discharge enough ice to raise sea level up to 1.9m – a significant challenge for coastal populations everywhere.***

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