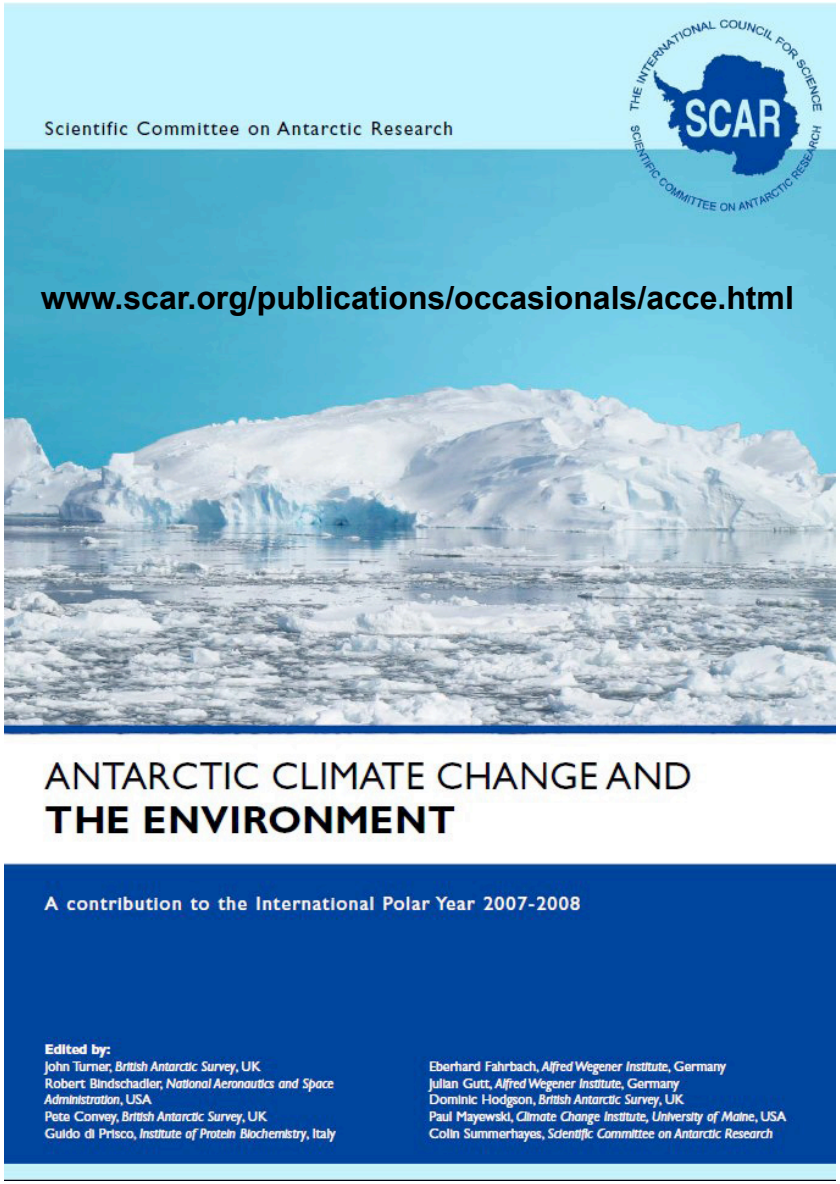
Antarctica's Future – Should We Care?

Melting Ice – Rising Seas – A Creeping Catastrophe?

An IPY product



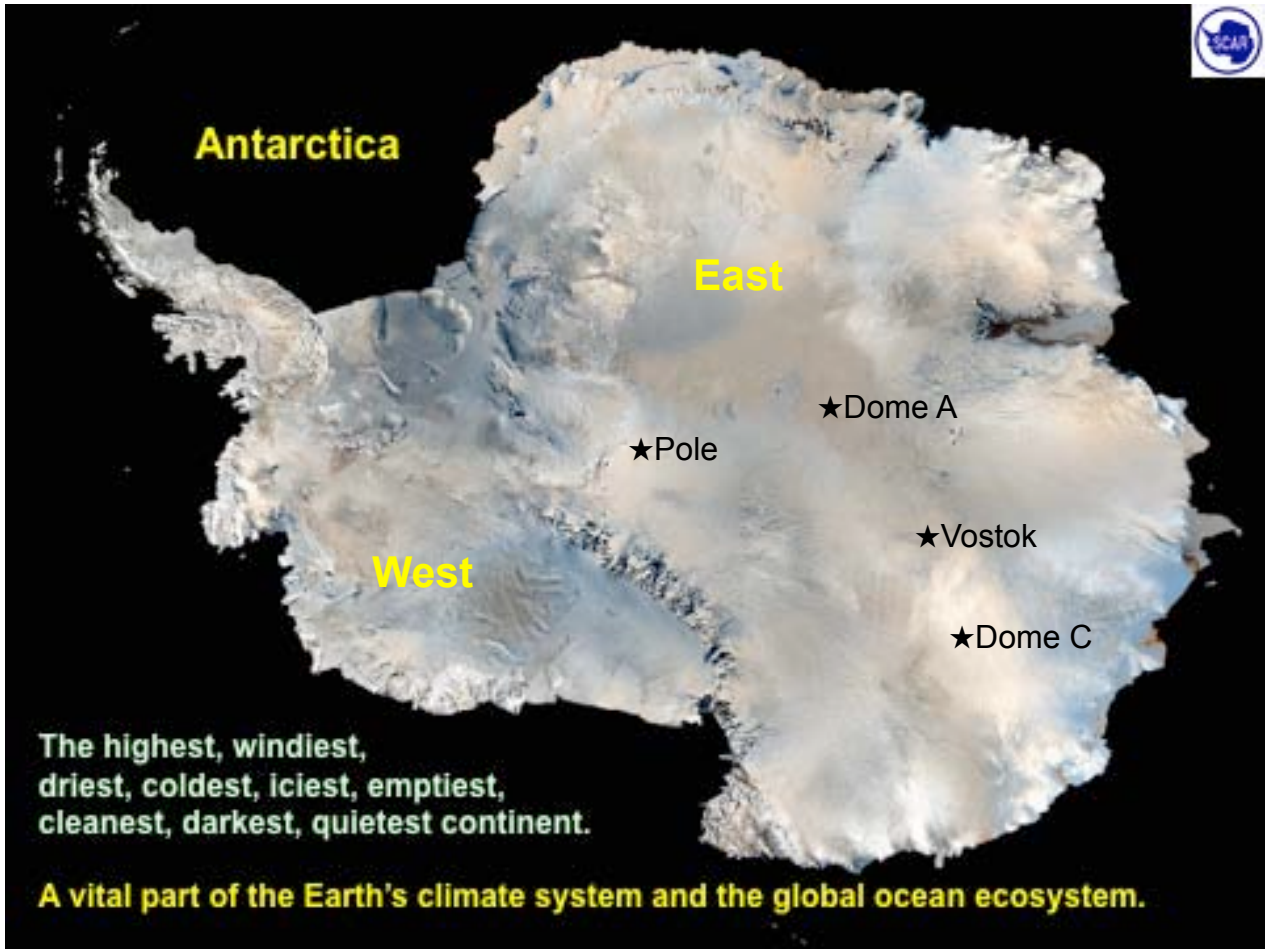
100 authors from 13 countries

SCAR = academies from 35 countries;

Part of ICSU

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?



Agenda

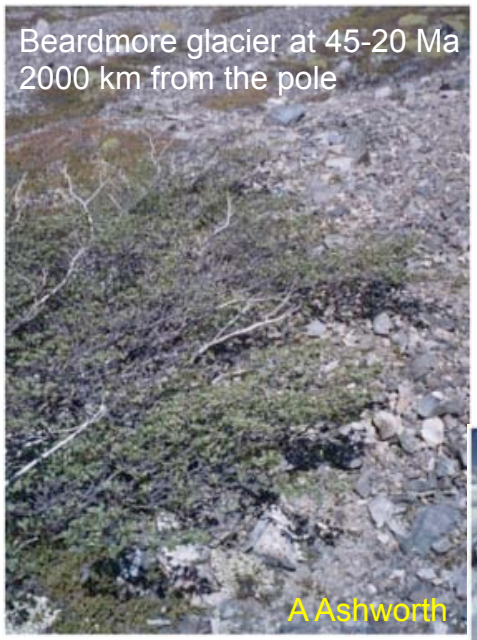
- The past (geology and data from ice cores)
- The present (the instrumental period since IGY 1957-58)
- The future (the next 90 years)
- Implications (effect of Antarctica on the rest of the world)

Subtext

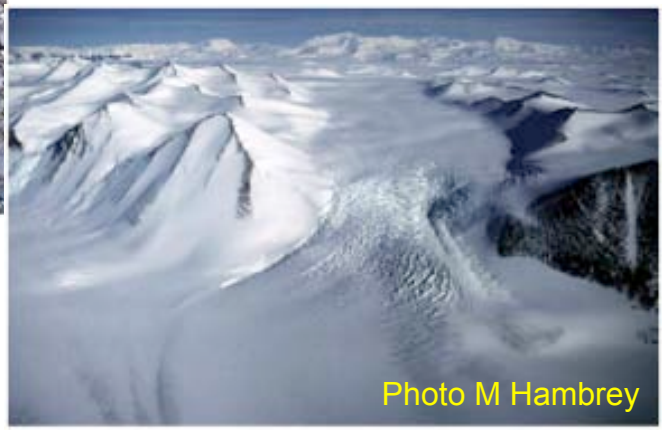
we are examining the effects of the interaction of two large -scale geophysical experiments on the atmosphere, one from CFCs, the other from CO_2, and their unintended consequences.

The Past

Evolution of the continent's climate

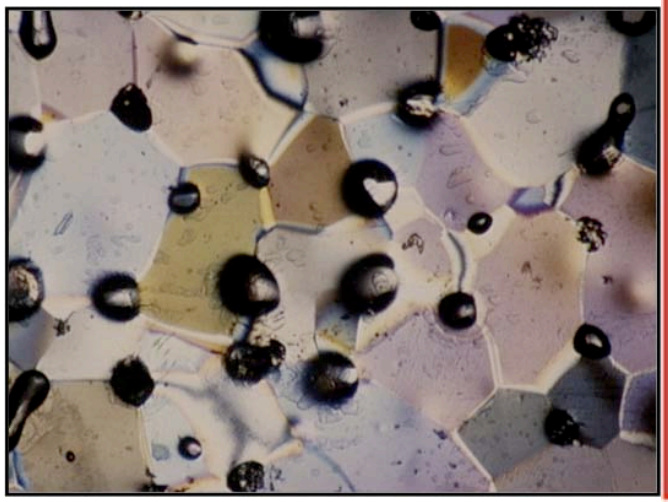


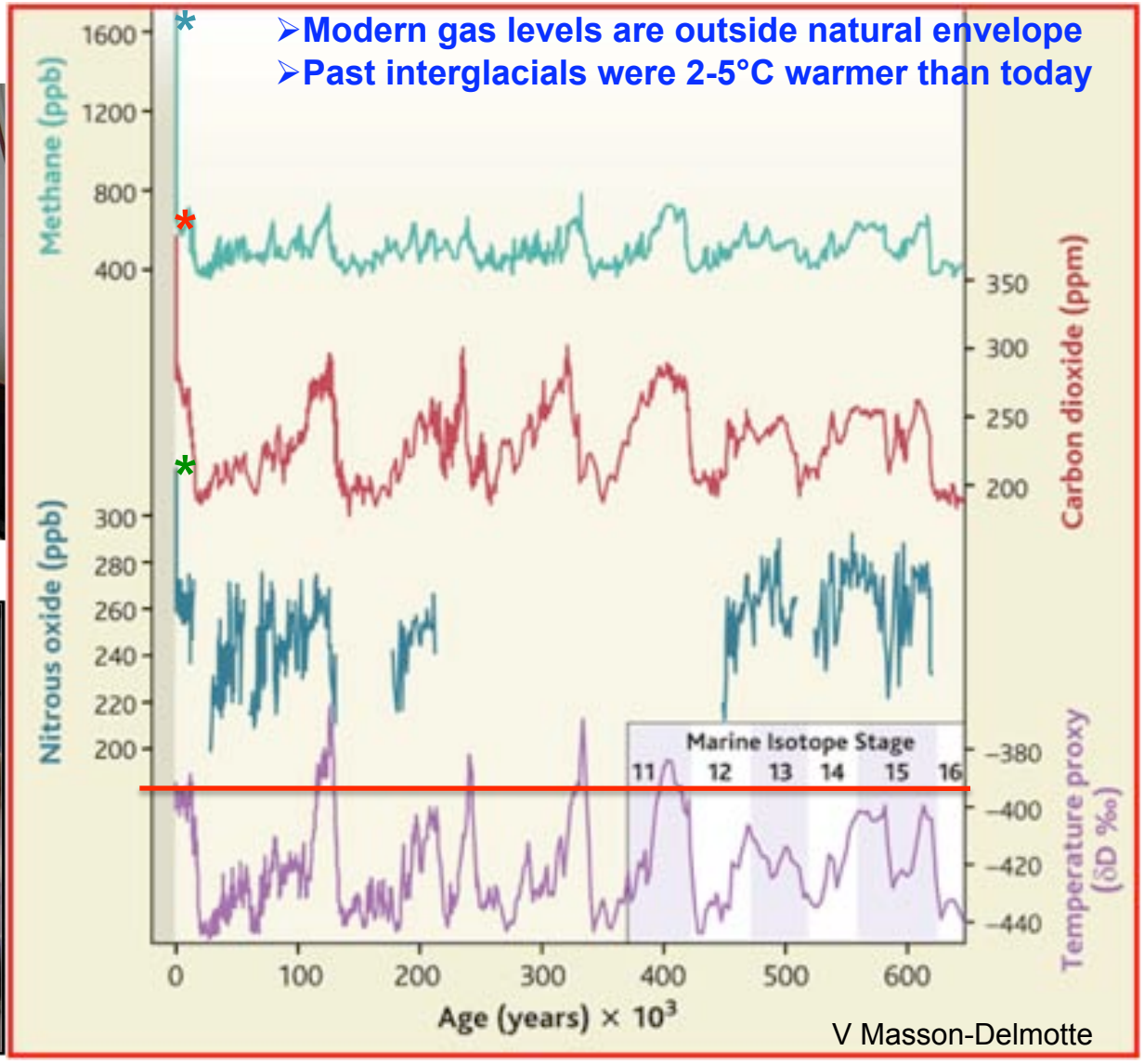
Nothofagus (southern beech) 2-3 month growth season at 4-5°C in S Chile.



Climate from Ice Cores

Dome C EPICA ice core



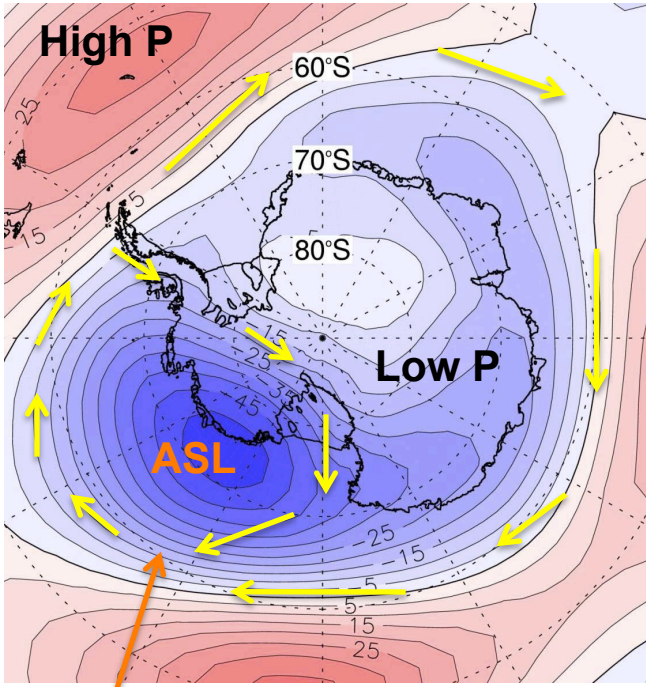


Sea levels during warm interglacials were likely 6.6-9.4m higher than today thus ice sheets may be more sensitive than we thought (*Nature 17 December 2009*)

The Present

The Role of Winds

- There is a pressure and temperature gradient from tropics to poles;
- It creates high pressure at mid latitudes and low pressure at the poles;
- 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.



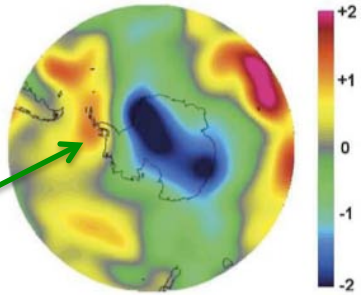
Amundsen Sea Low (ASL) develops because the continent is off-centre.

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

J Turner and others

Continent cools while peninsula warms

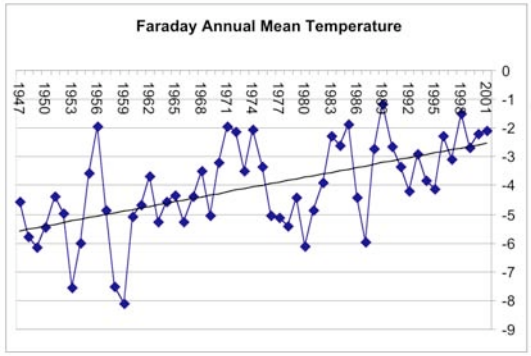
Change in mean
Ann. Temp. °C
(1969-2000)

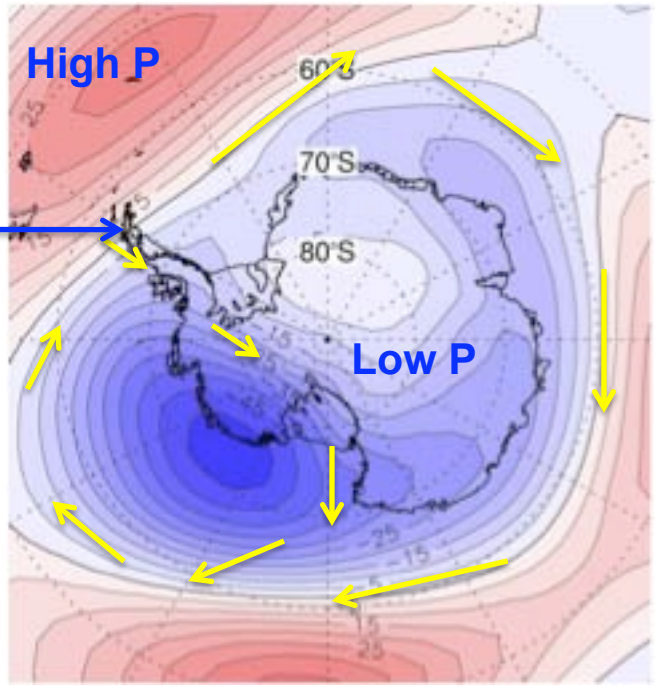


West peninsula

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

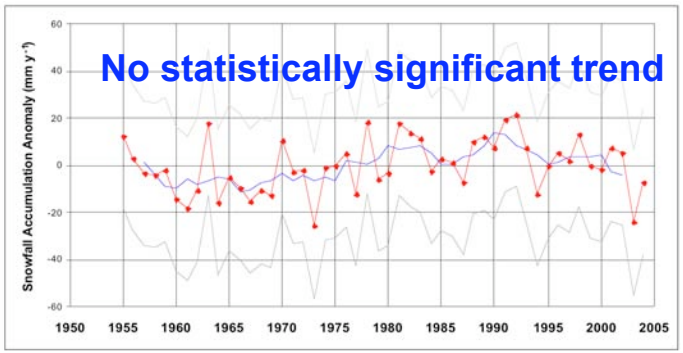
Air warms at 0.53°C/decade at Faraday/Vernadsky since 1950. (1.03°C/decade in winter)





Correlates with decrease in sea ice.

Interior is a desert



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

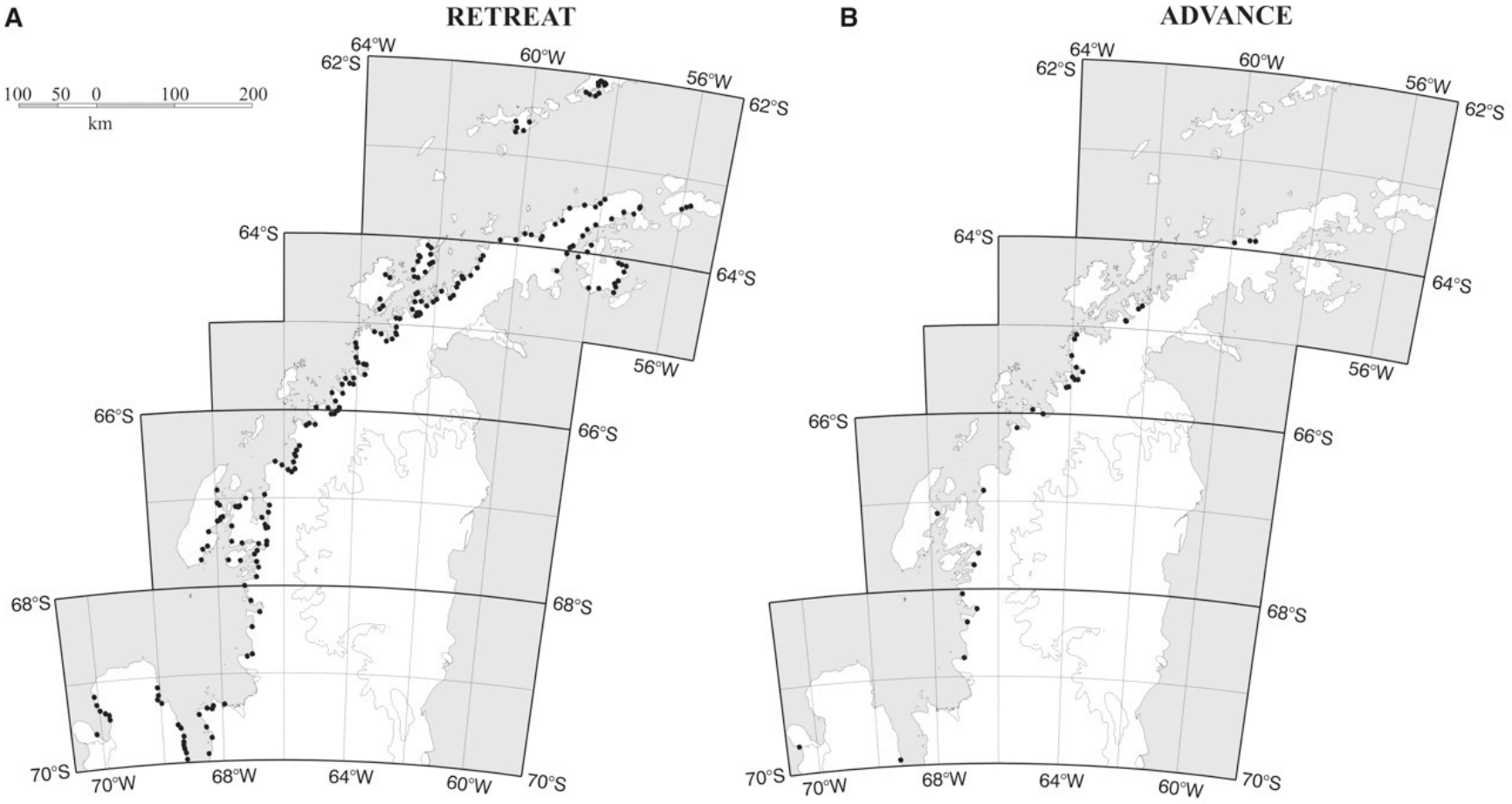
Most along coast.

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

244 glaciers : 87% have retreated over last 50y



Cooke et al., 2005

Warming AND Cooling?

Causes?

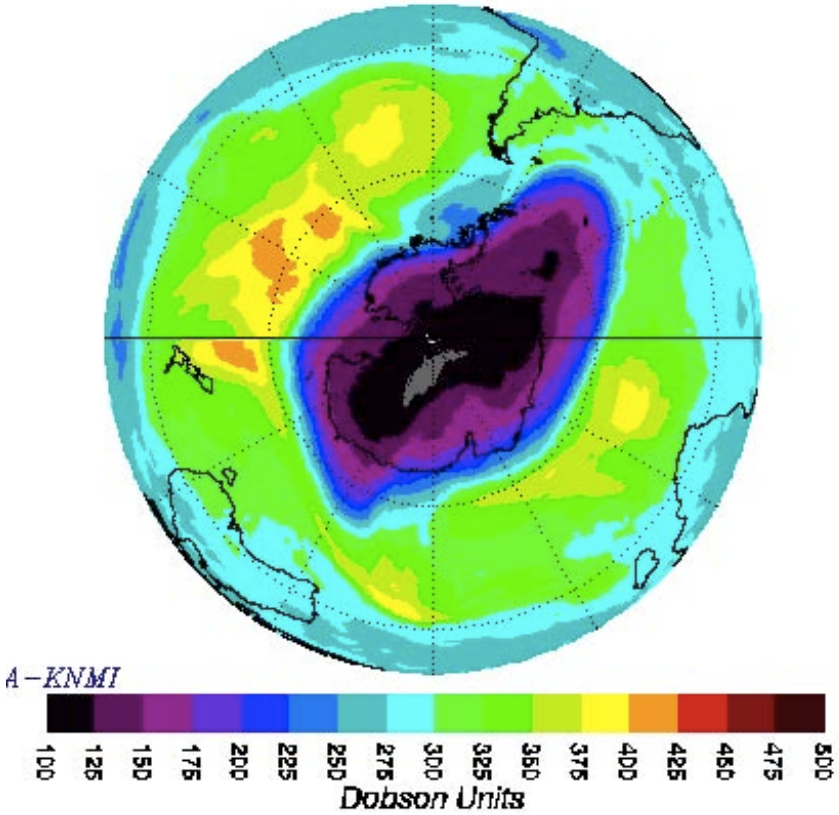
Greenhouse Gases?

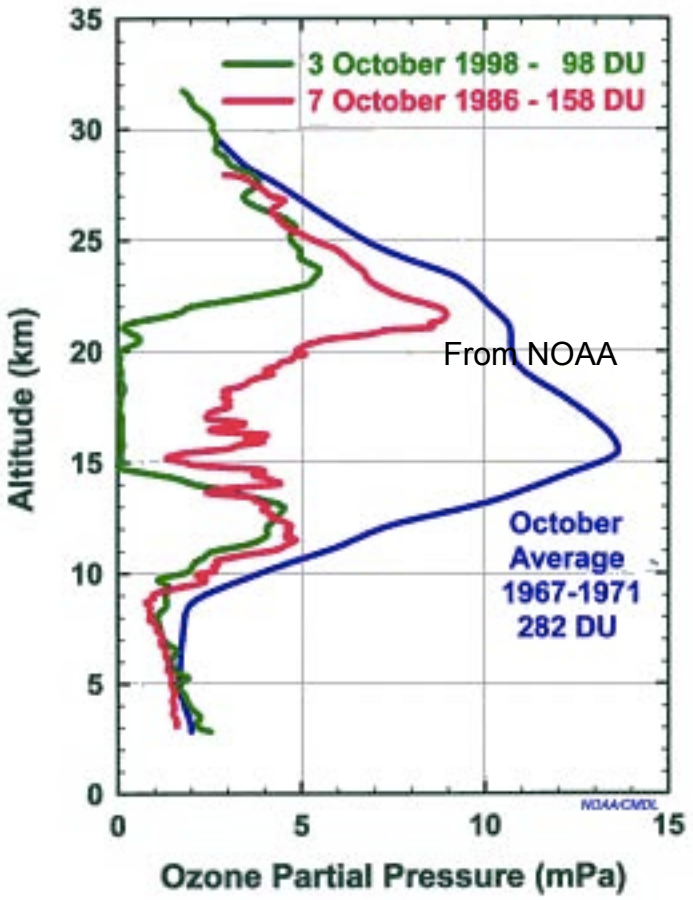
The Ozone Hole?

Ozone Hole

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

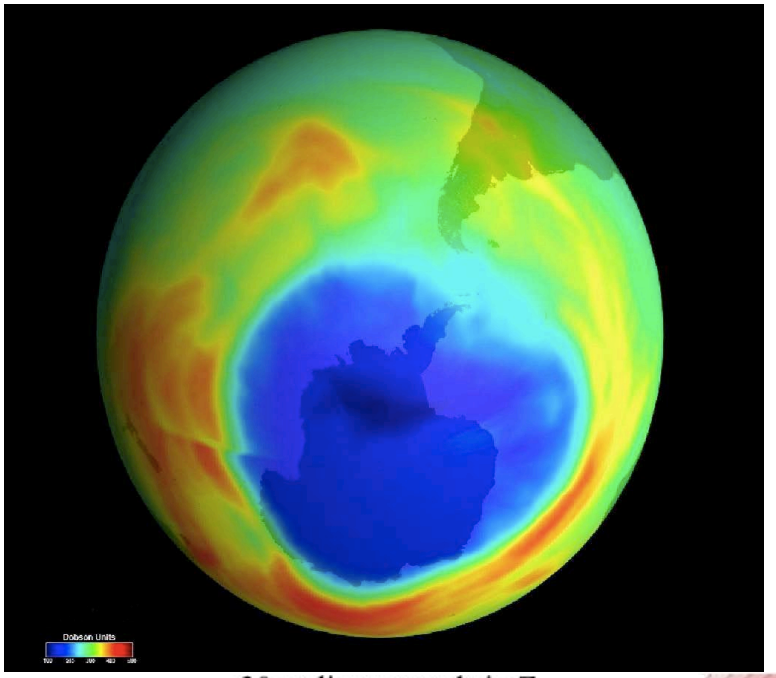
10 October 2006 (NASA)



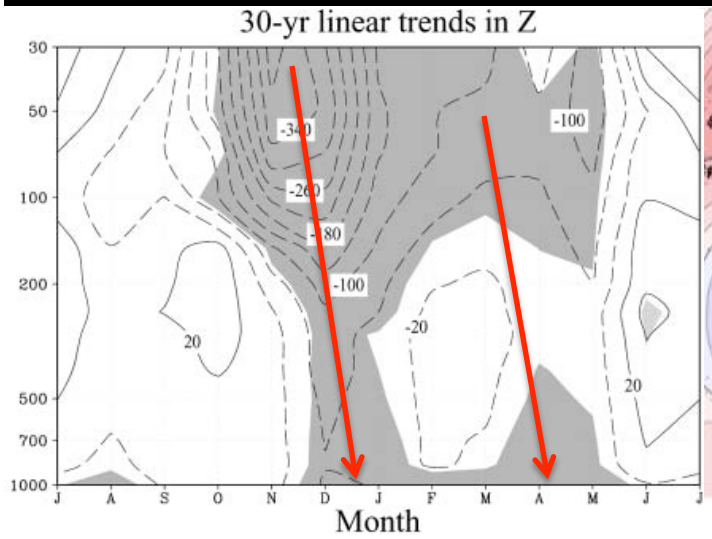


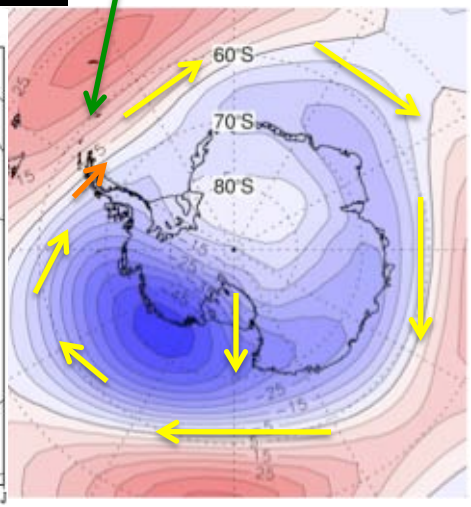
- **The polar vortex (westerly circumpolar winds) bound the ozone hole;**
- **They are strongest in winter, when temperatures are coldest (< -80°C);**
- **Polar stratospheric ice clouds form inside the vortex; they catalyze CFC breakdown to give Cl^{-};**
- **In spring, when sun arrives, $Cl^{-} + O_3$ ➔ $ClO + O_2$;**
- **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 %.**

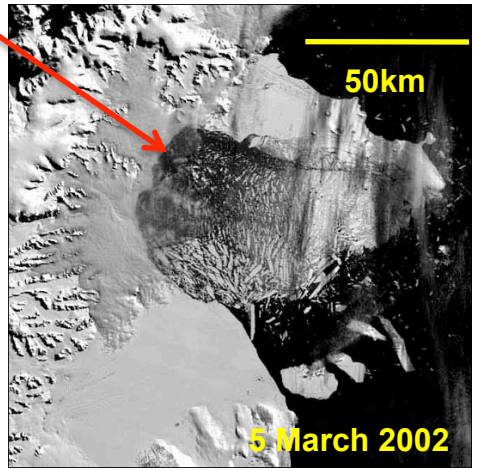
Winds driven by Ozone Hole shield Antarctica from global warming



- 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;
- They melted the Larsen B ice shelf

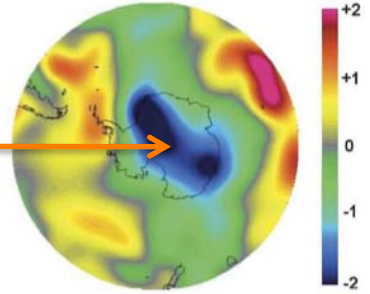






Z = geopotential height anomaly

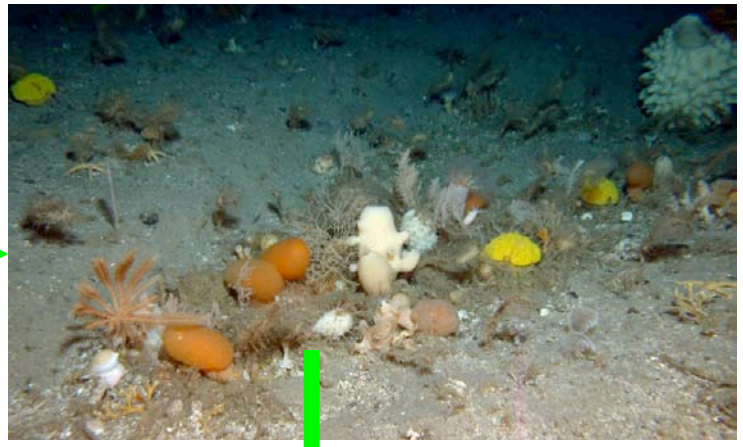
This strengthening of the 'normal' surface winds helps to keep East Antarctica cold

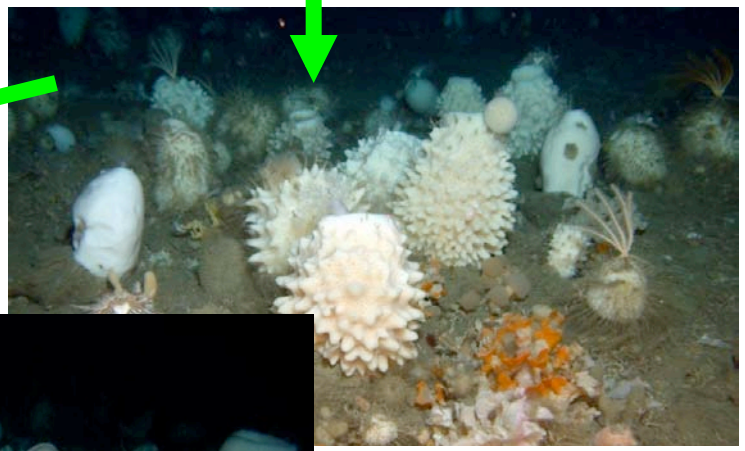


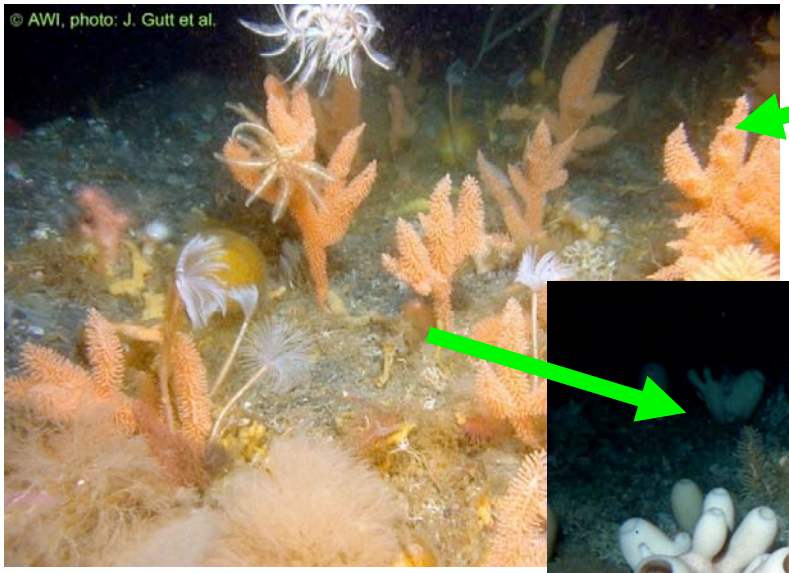
Change in mean
Ann. Temp. °C 1969-2000

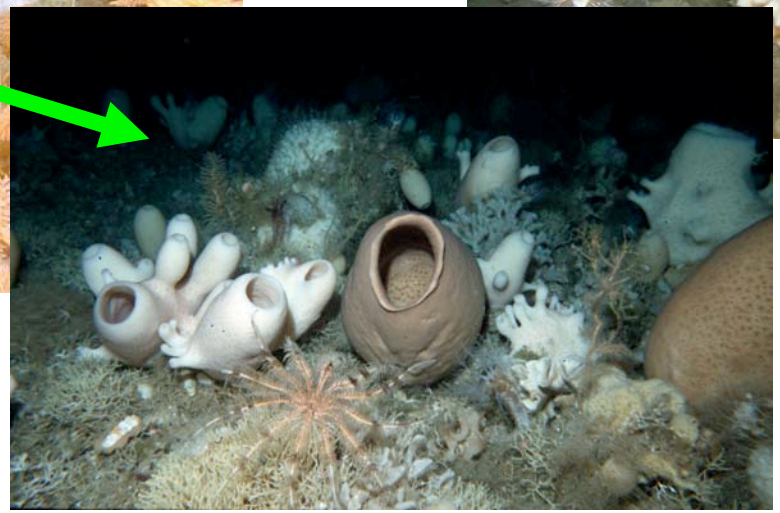
Rich Benthic Ecosystem

Present = Colonisation of Larsen B space









Future for benthic organisms

Adaptation

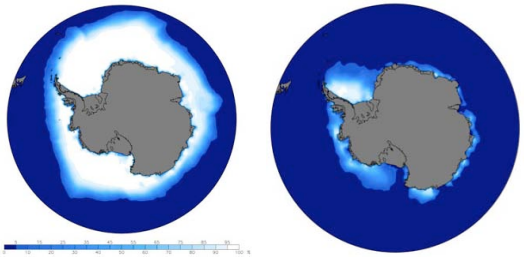
Evolution

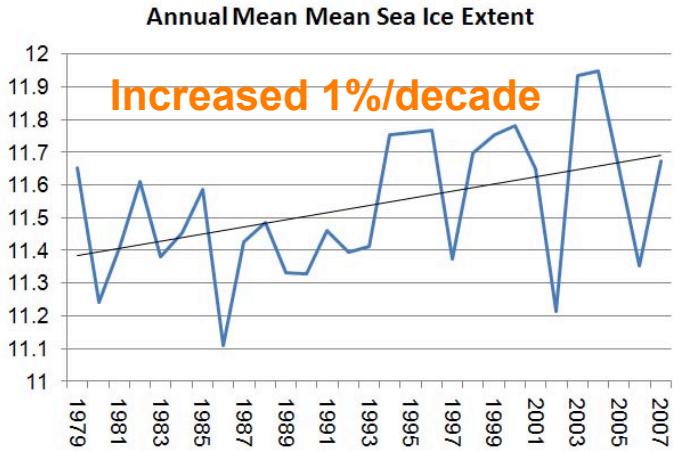
Migration

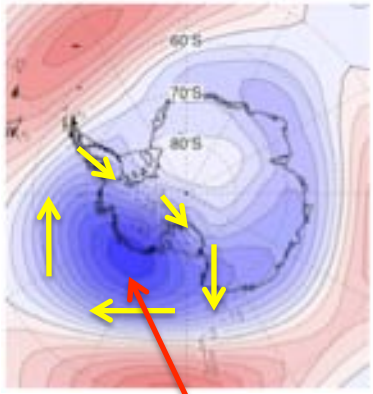
Extinction

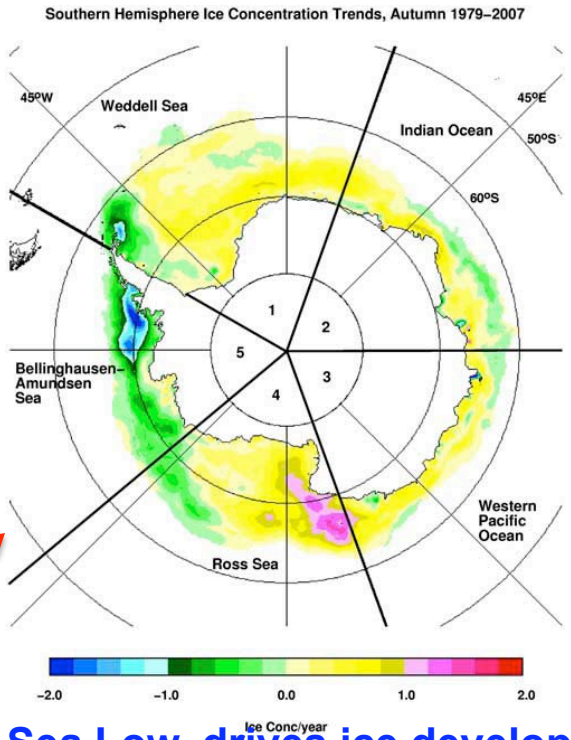
J. Gutt, AWI

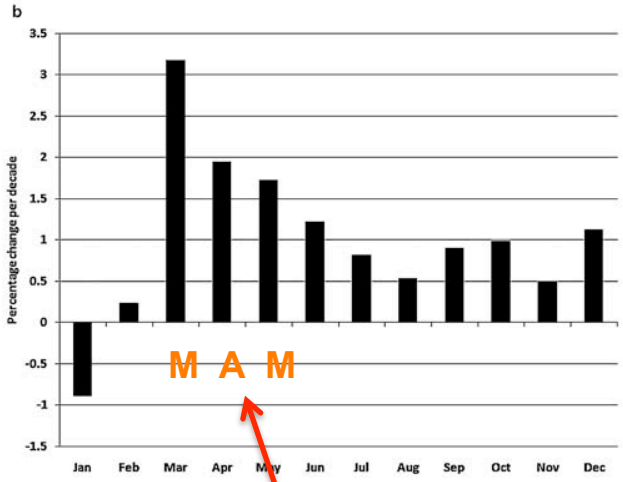
Ozone Hole affects sea ice











Sea ice extent % change/decade

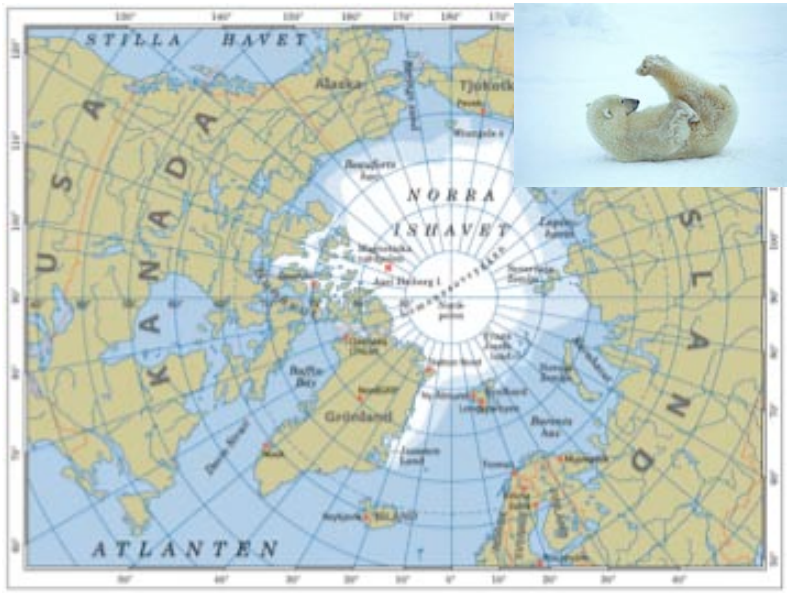
Amundsen Sea Low, drives ice development especially in autumn

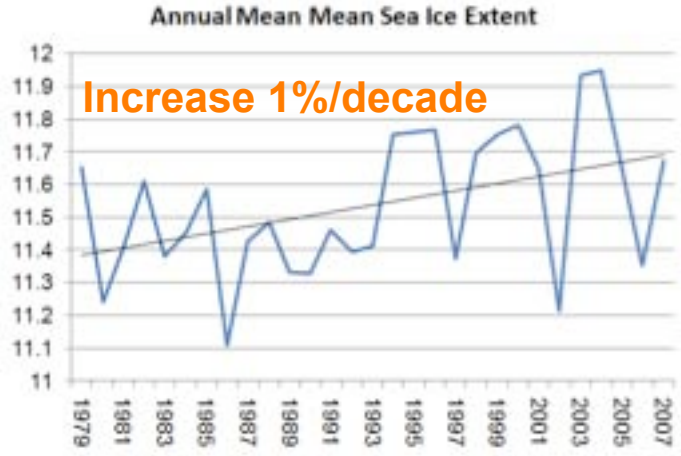
Exacerbated by the ozone hole

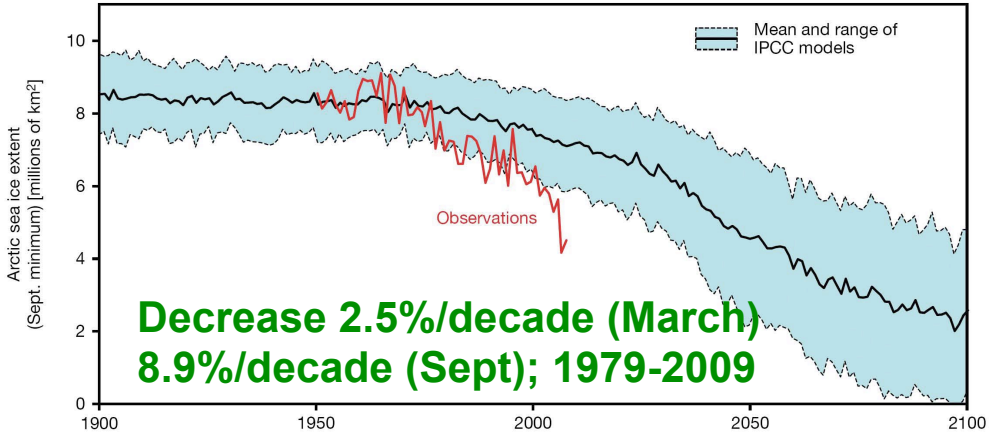
(keeps Antarctic cool and strengthens winds in late summer, autumn)

Turner et al., 2009

Antarctic sea ice differs from the Arctic





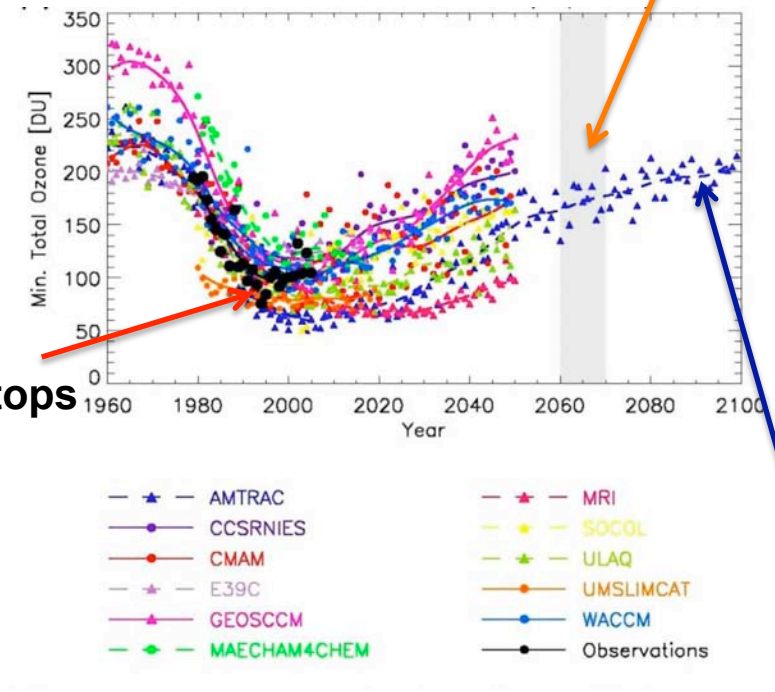


Arctic has no shielding wall of wind, and easy access by warm water and warm wind from the south

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

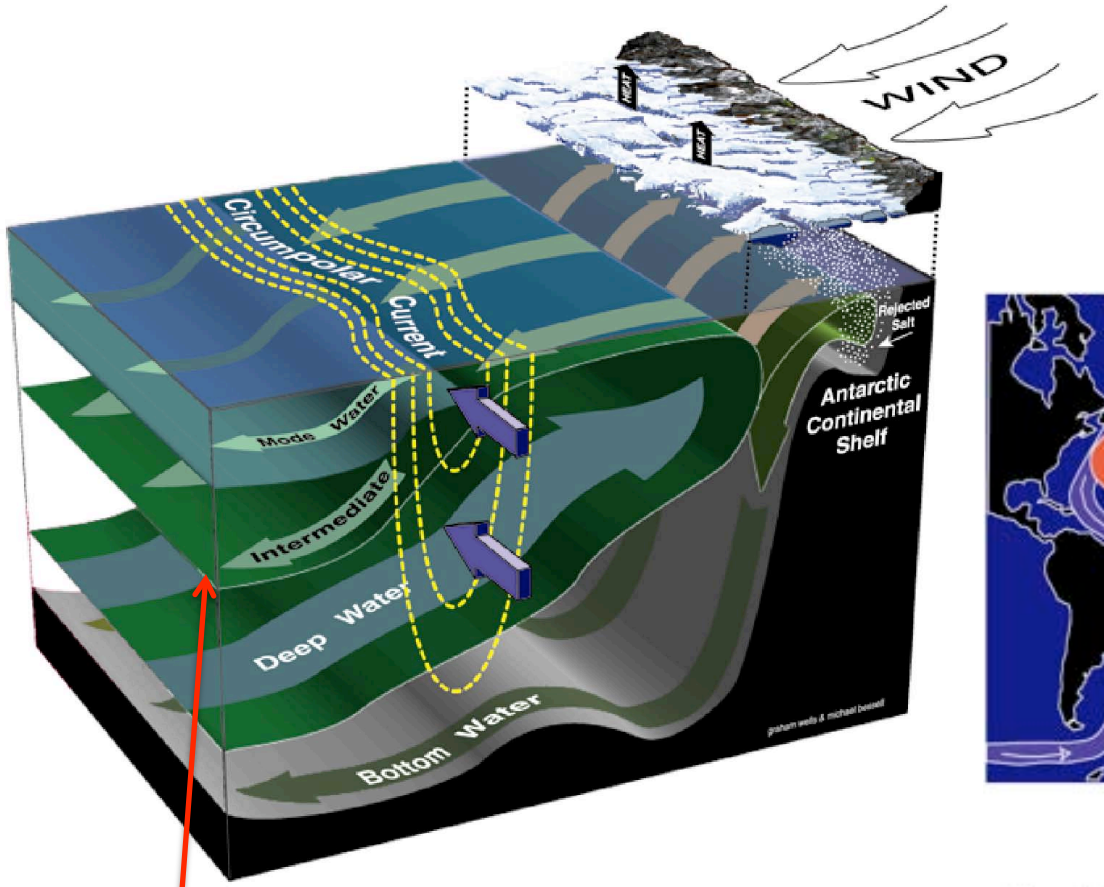
By 2070 no more shielding

Bodecker et al., 2004, & WMO 2006

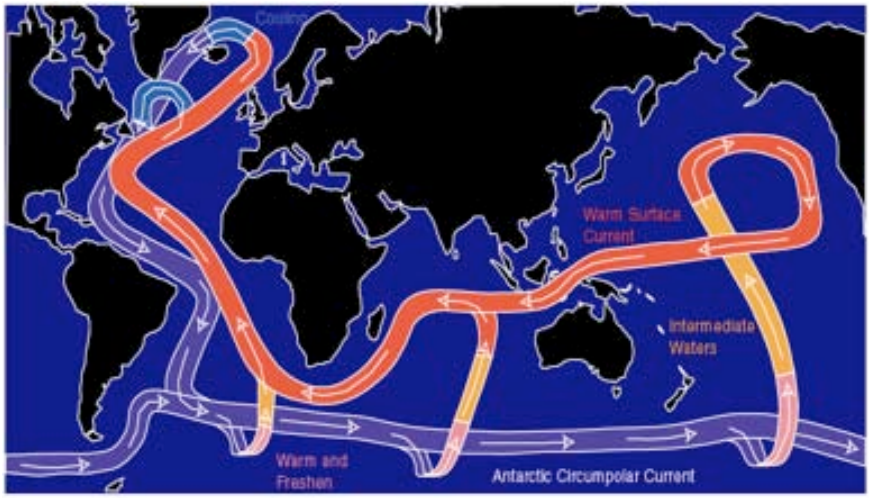
The Oceans Connect Everything

Climate signals are shared

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



Rintoul, 2001

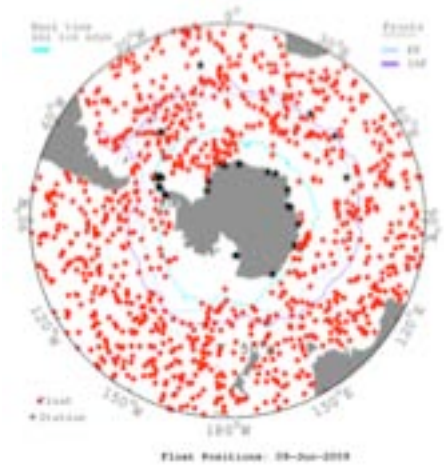


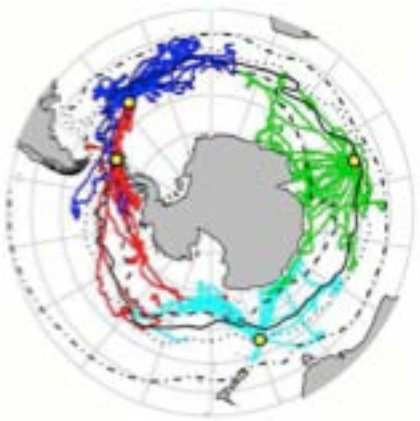
Thermohaline Conveyor Belt (after Doos and Webb)

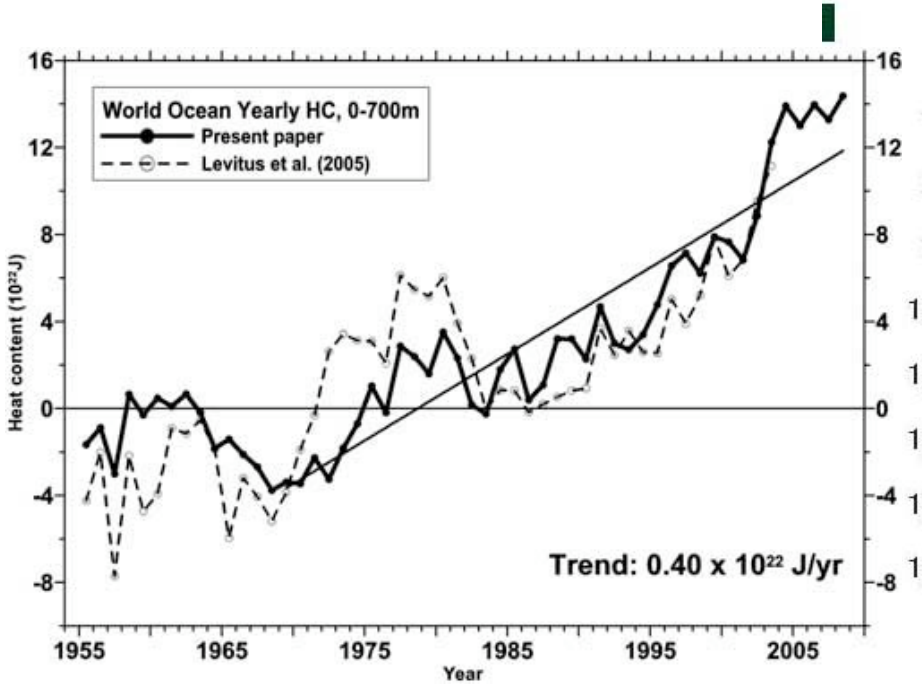
t96g_occam/thermohaline2

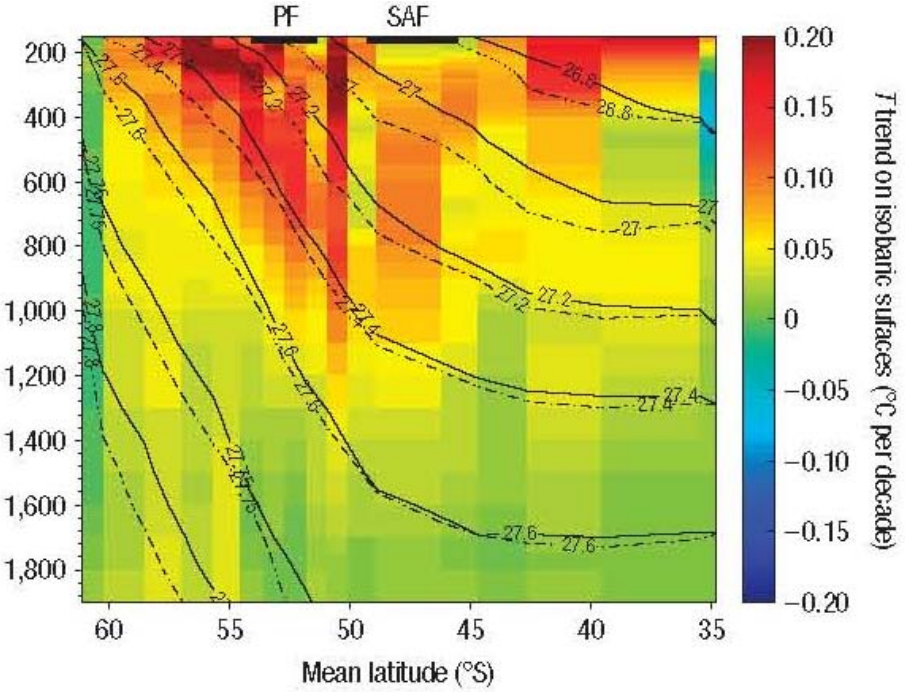
nutrients exported north provide 75% of global ocean productivity north of 30S.

Southern Ocean Warming





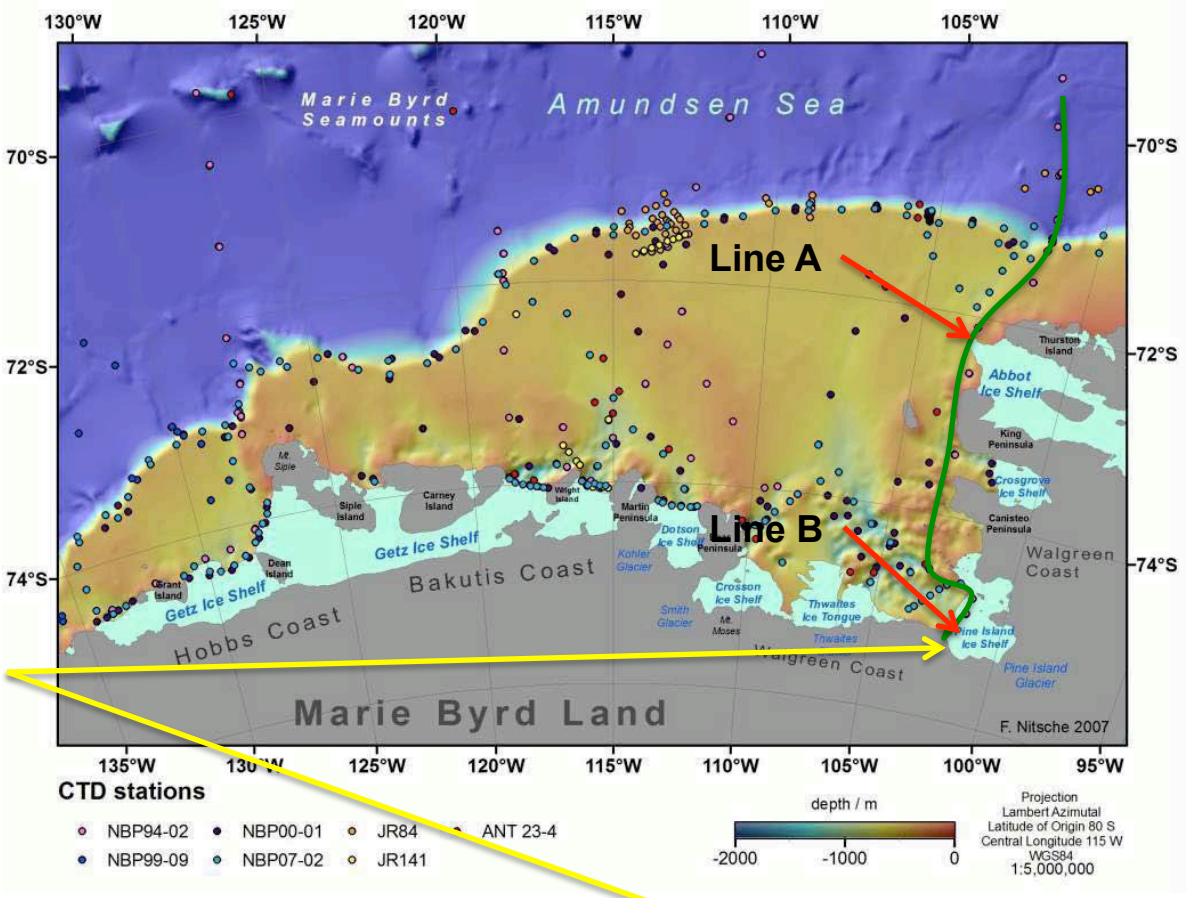




Levitus et al, 2009

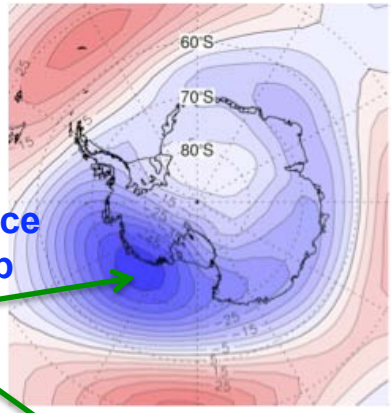
Boning et al 2008

Warm ocean melts Pine Island Glacier from beneath

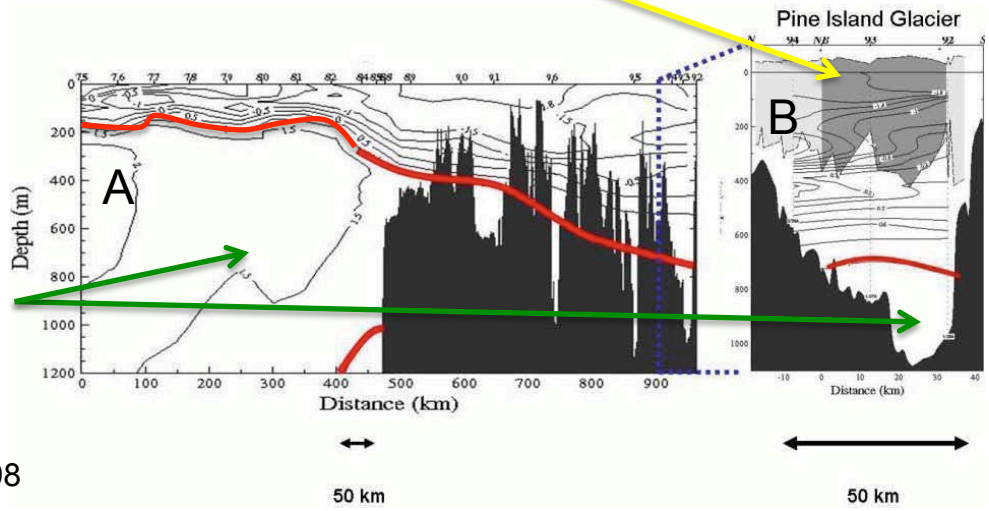


Pine Island Ice Shelf

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



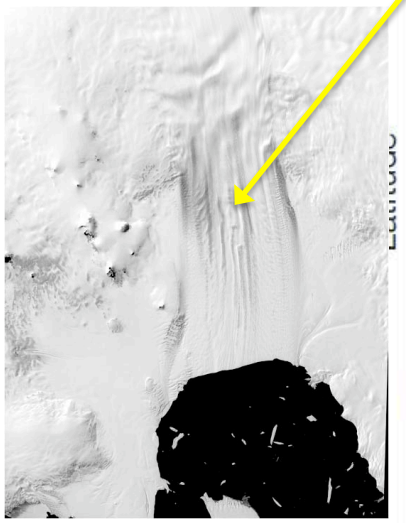
Upwelling Circumpolar Deep Water is warmer than 1°C



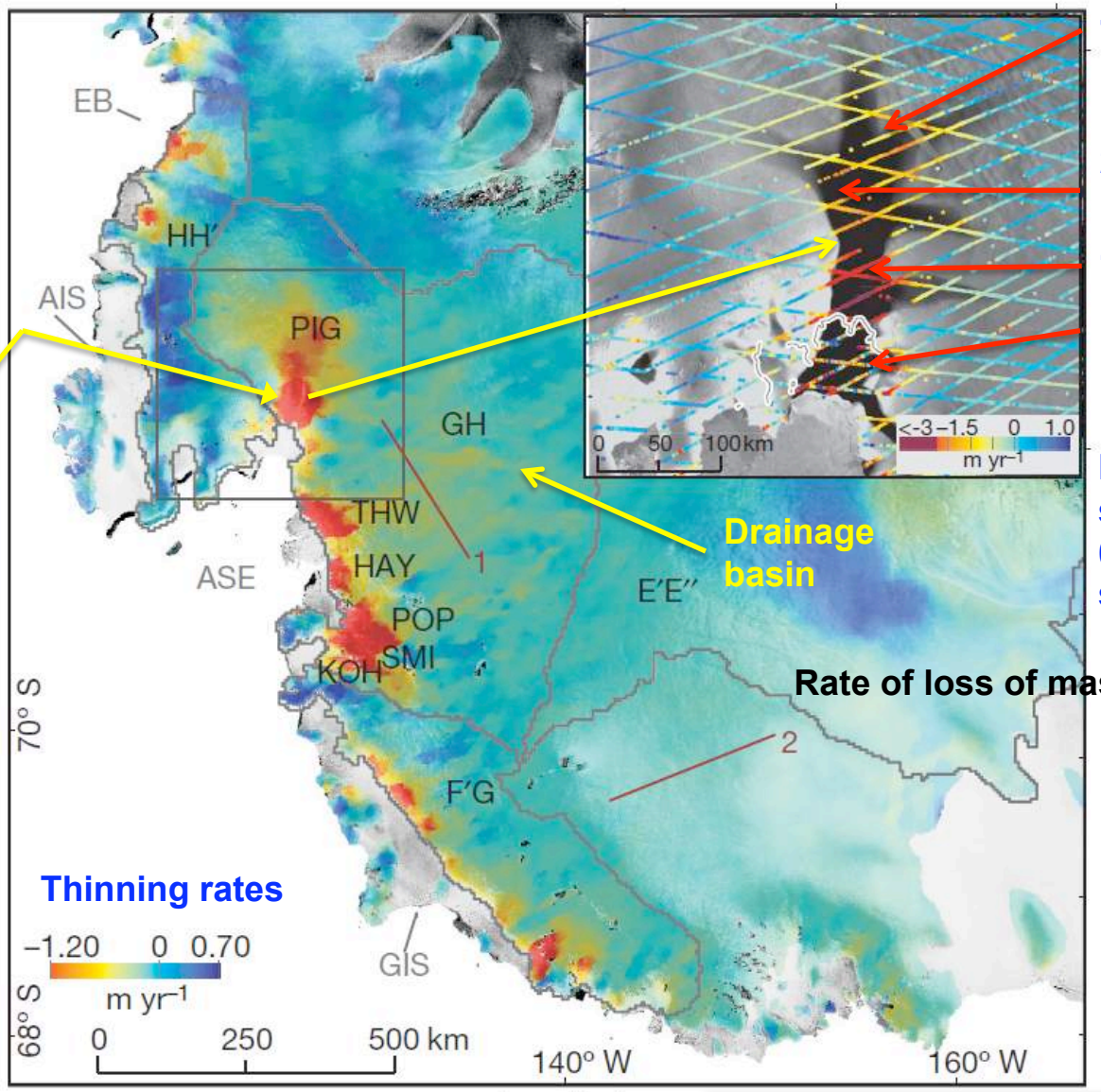
After Helmer et al 1998

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

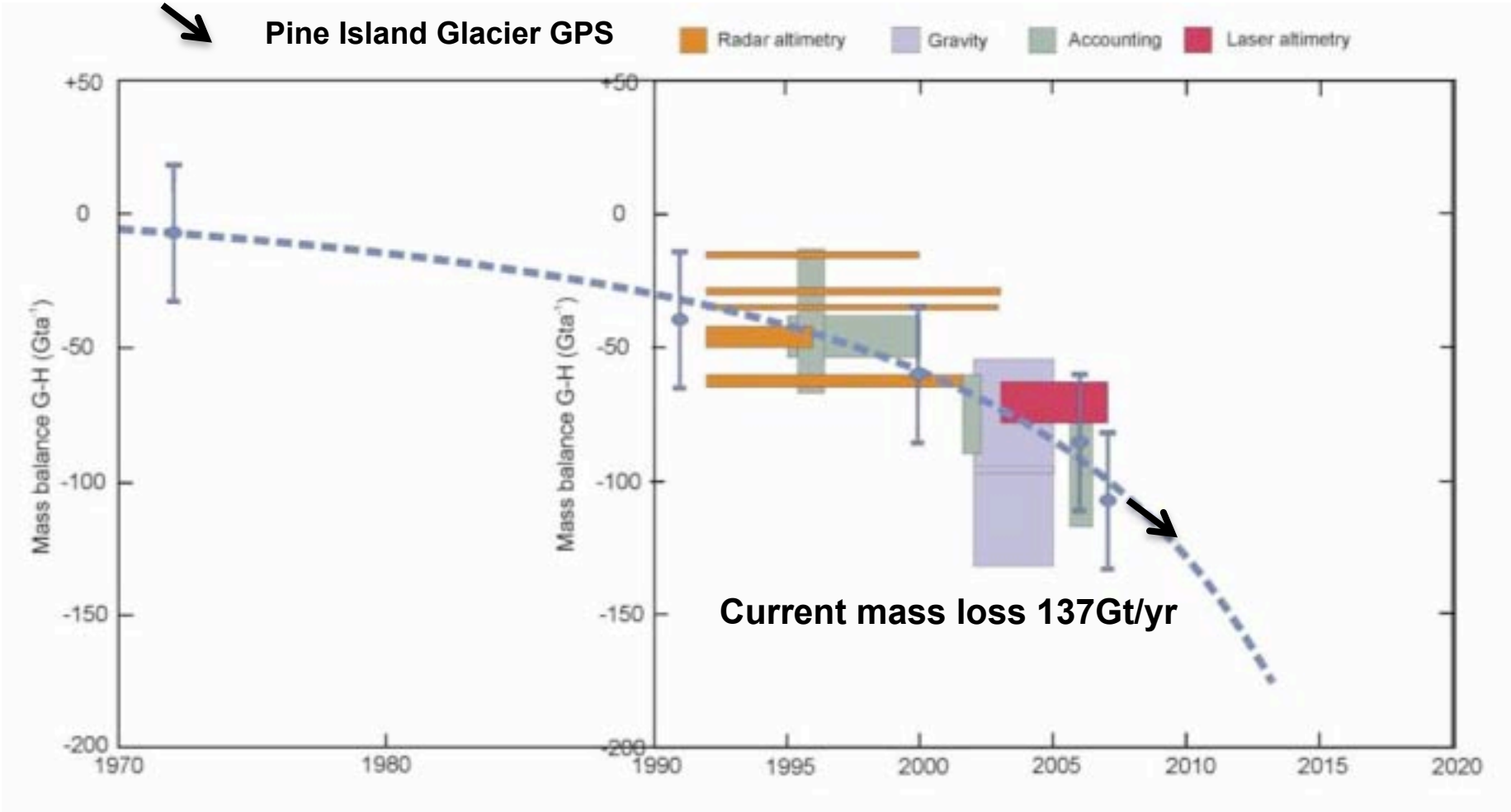
PIG alone could soon contribute 0.5mm/yr to global sea level

Rate of loss of mass is increasing

Thinning rates

Pritchard et al., 2009 – Nature, 23 September 2009

Increasing loss of ice mass from Amundsen Sea embayment



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).

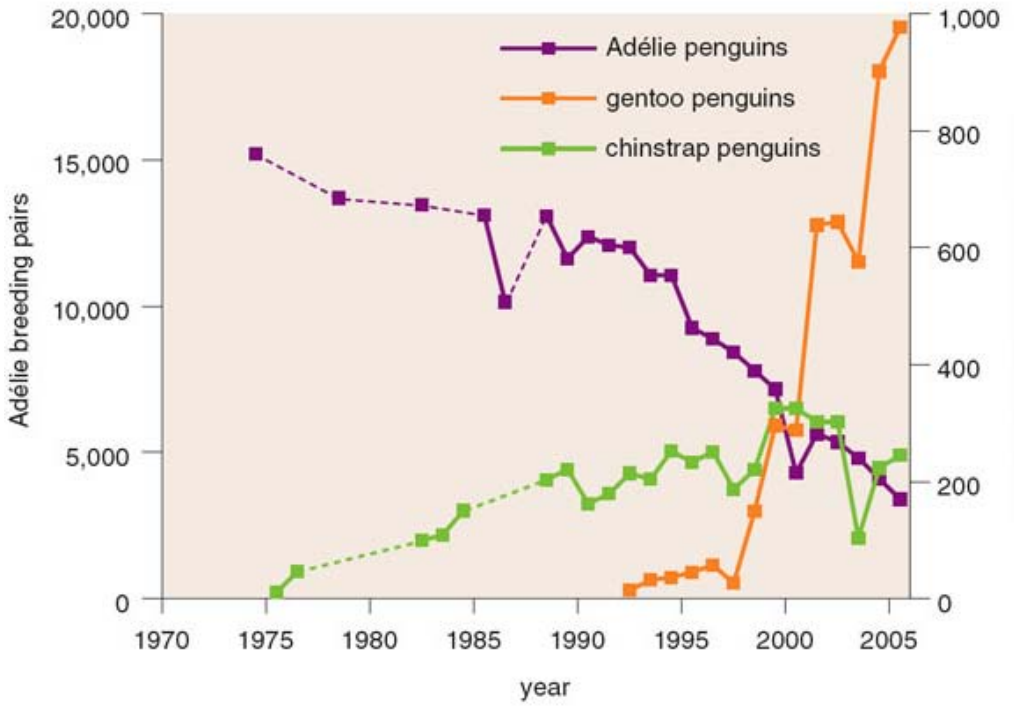
Thus, overall, Antarctic ice sheet is shrinking.

D Vaughan

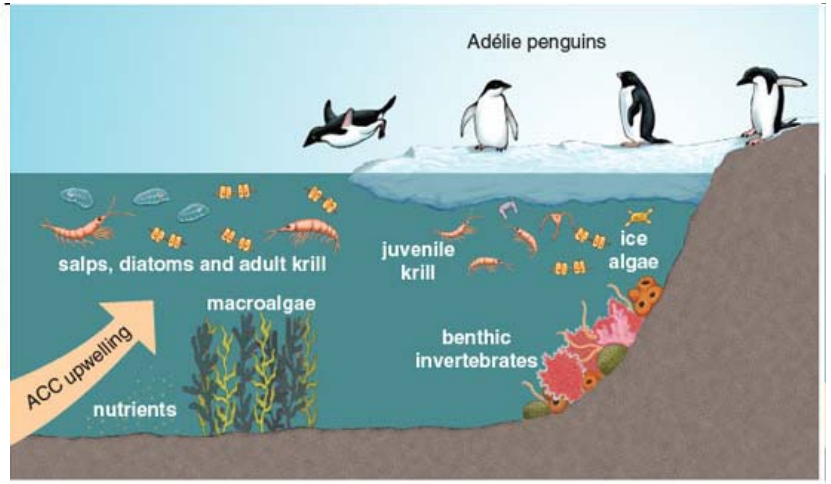
BIOLOGISTS ARE OBSERVING CHANGES IN PENGUIN POPULATIONS

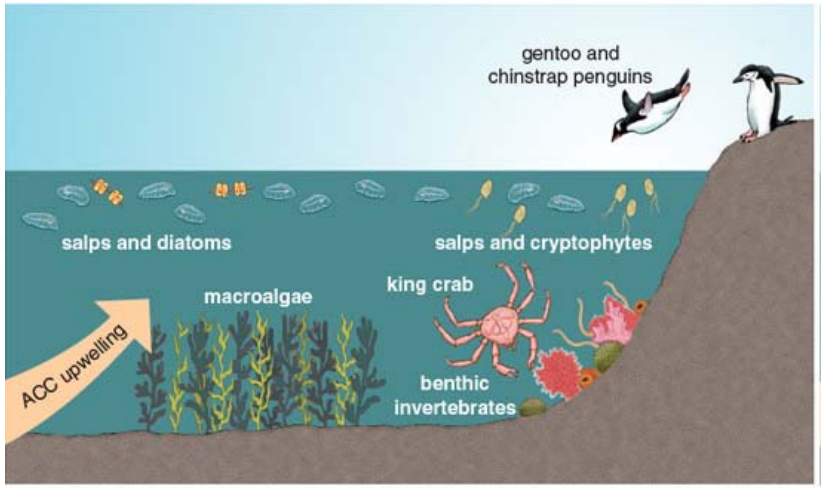
A Ashworth

Breeding success and ecological response



More snowfall and less sea ice →

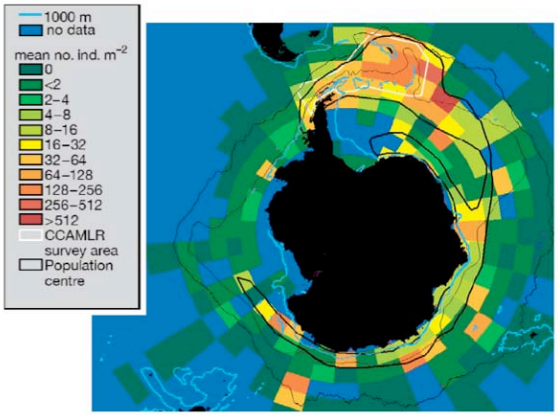




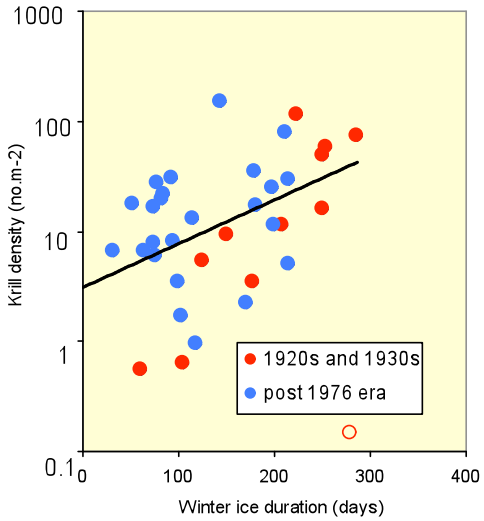
Shifts in the penguin population on the western Antarctic Peninsula are attributed to changes in precipitation patterns and sea ice.

McClintock 2008

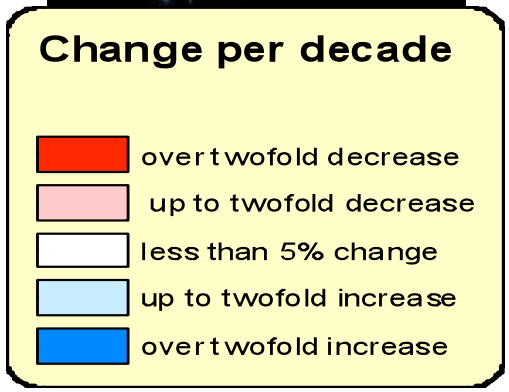
Responses of Southern Ocean Ecosystems to Change

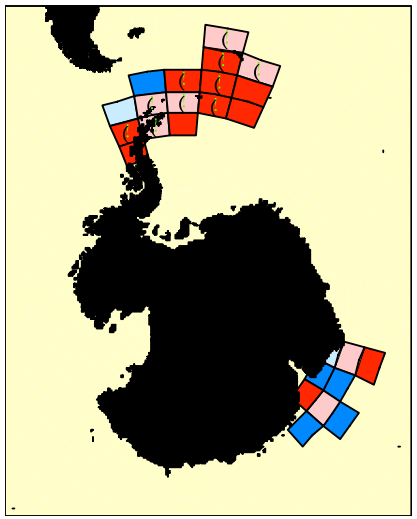


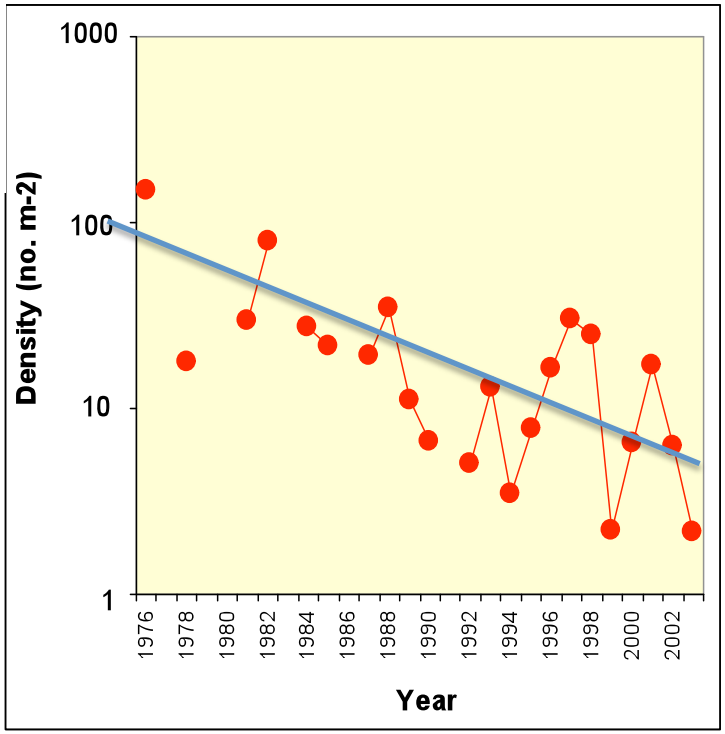
As sea ice decreases, krill decrease



As krill decrease, salps increase

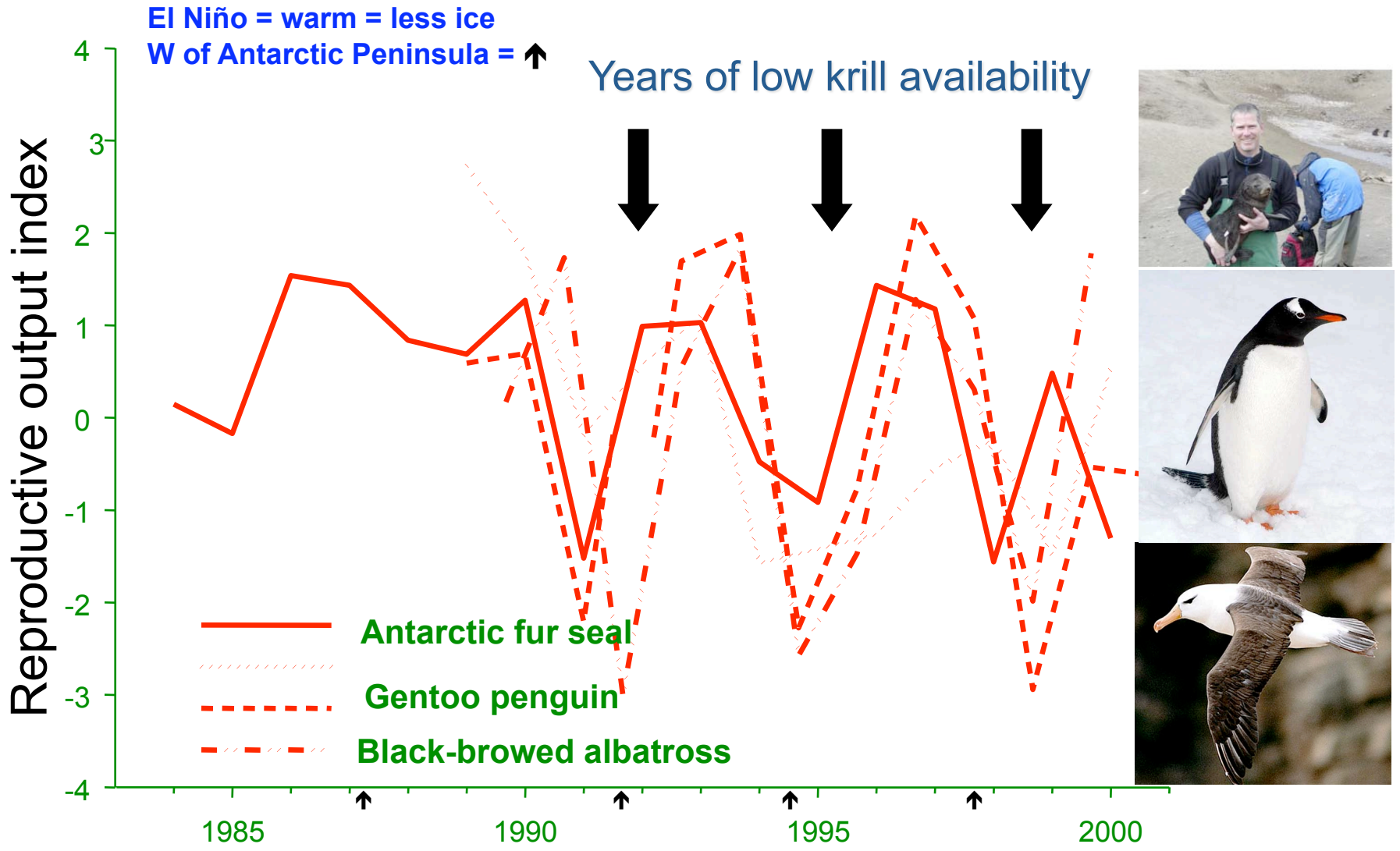






Atkinson et al, 2004, Nature

Interannual variability



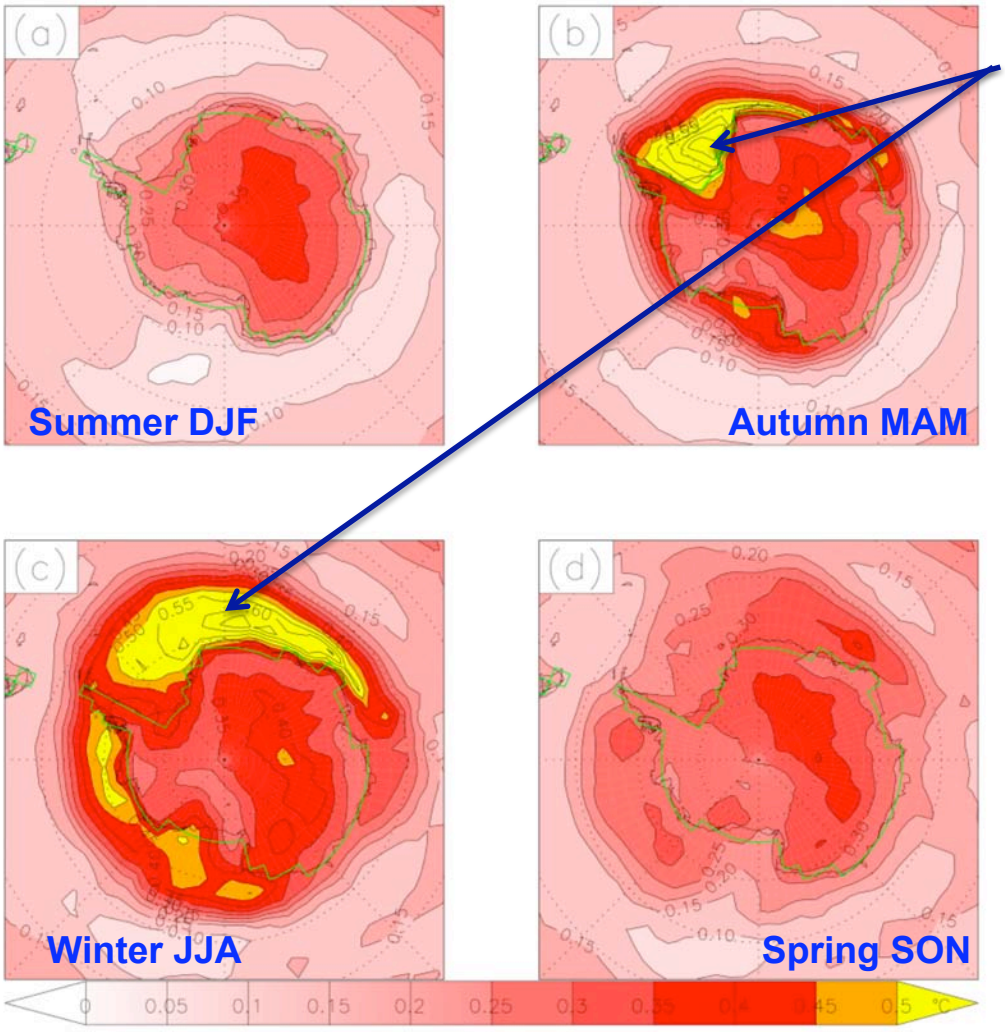
Implication: will have less production if Ocean warms and sea ice shrinks.

Reid & Croxall, 2008

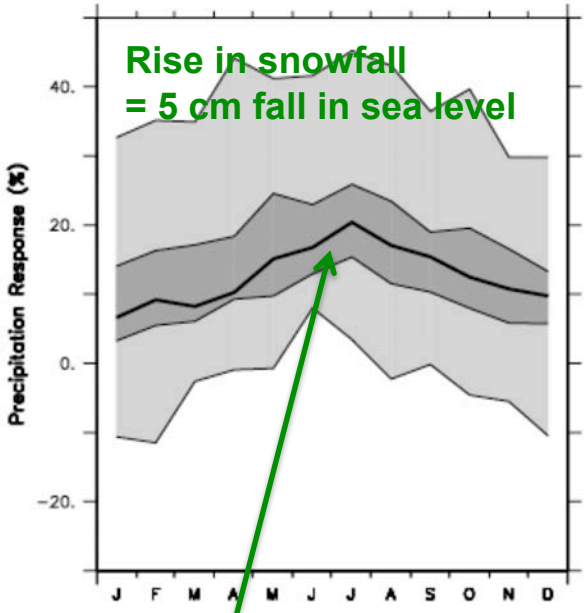
The Future

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) .



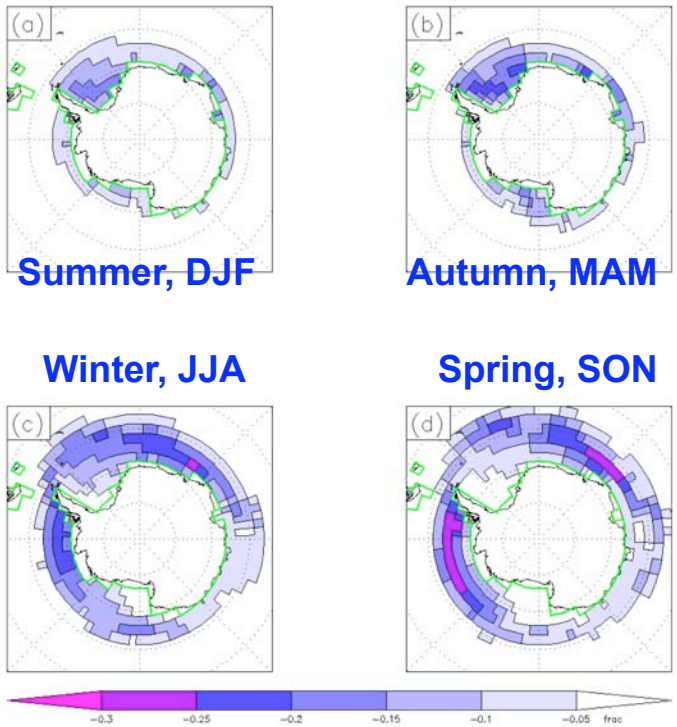
Most warming is over sea ice, due to retreat of sea ice edge in winter; otherwise, little seasonal trend (av. 0.34°C/decade).



Precipitation as % difference 2080-99 minus 1980-99

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

33% decrease in the fraction of surface covered by ice

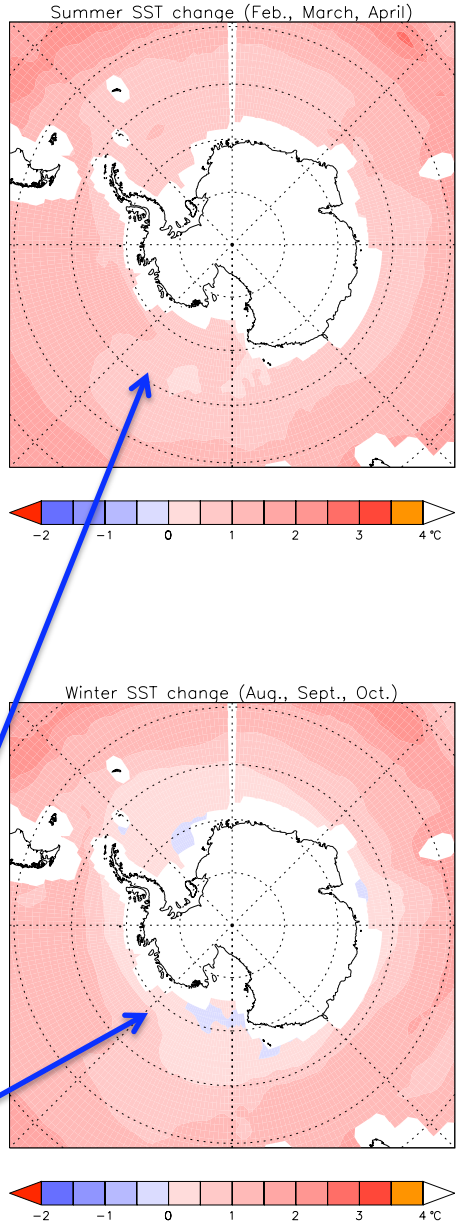


Summer, DJF

Autumn, MAM

Winter, JJA

Spring, SON

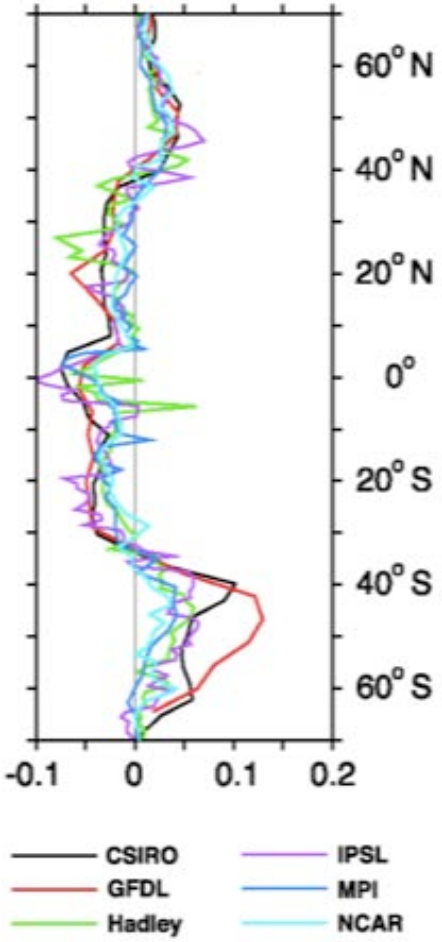


Temperature change: smaller than in air due to higher heat capacity of the ocean.

Summer: 0.5 to 1.0°C warmer south of 60°S. Amundsen Sea up to 1.0 to 1.25°C.

Winter: temperatures similar to today.

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



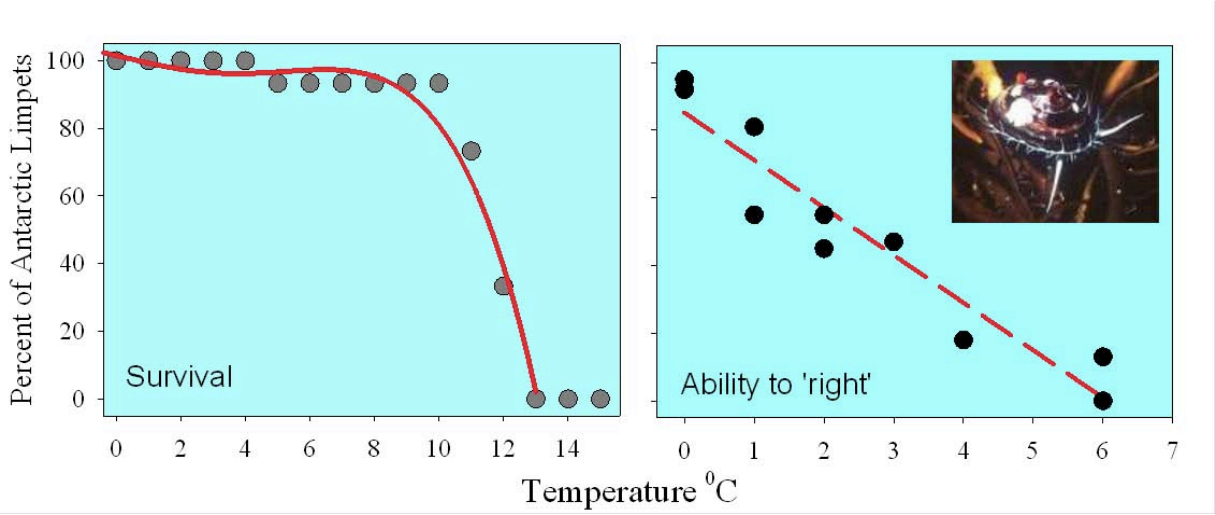
Flowering plants native to Antarctica, will thrive with warming

Grass *Deschampsia antarctica*

Pearlwort *Colobanthus quitensis,*
- found as cushions

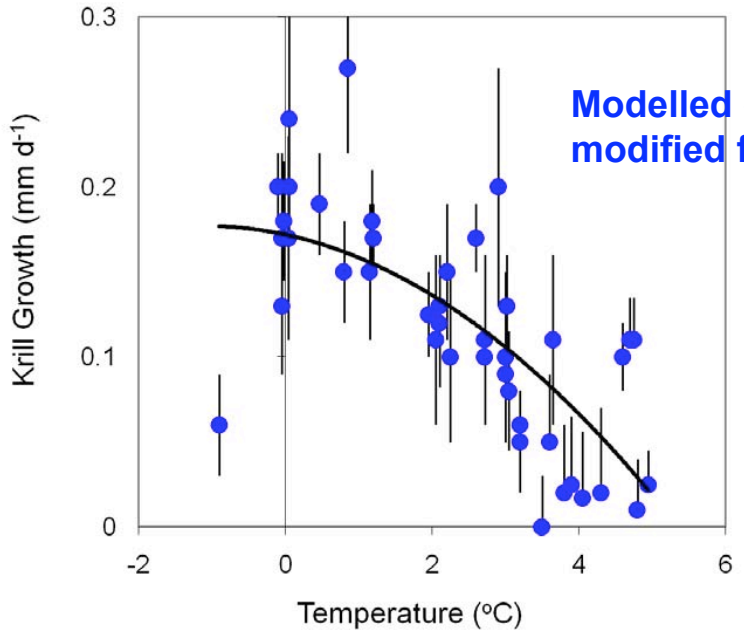
Photos P. Convey

Acute temperature influence on Antarctic marine organisms



Experimental data on the limpet *Nacella concinna*

From L.Peck



Modelled daily growth rates for krill, modified from Atkinson et al, 2004

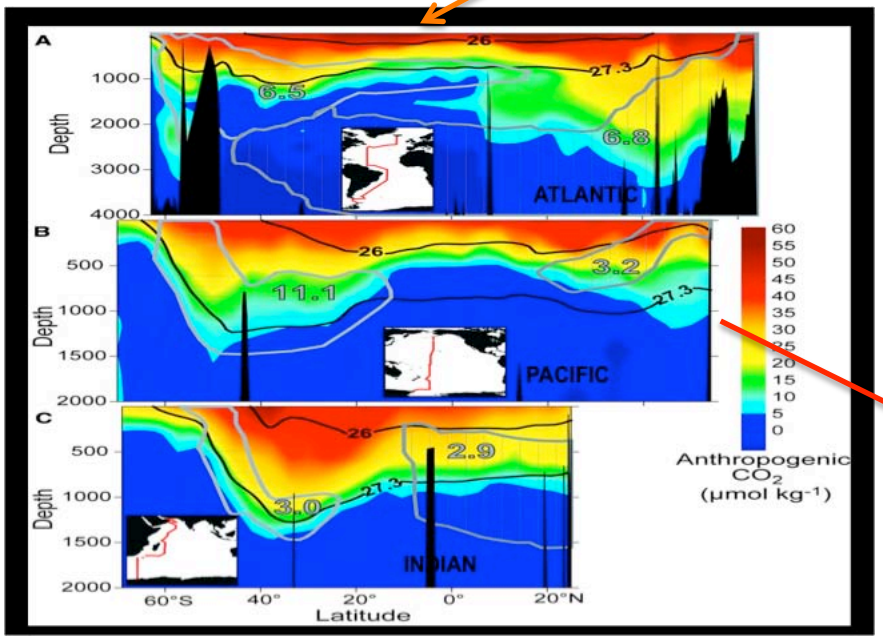
Note - some Antarctic species are also found around South Georgia in water 3°C warmer, suggesting an ability to adapt to change.

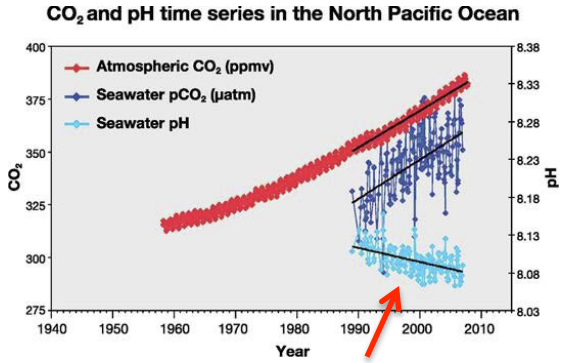
Take ecology as well as experimental results into consideration in assessing future impacts.

Acidification of the Southern Ocean

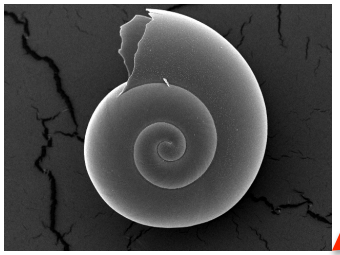
% saturation in aragonite; blue = undersaturated; dissolution may begin

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

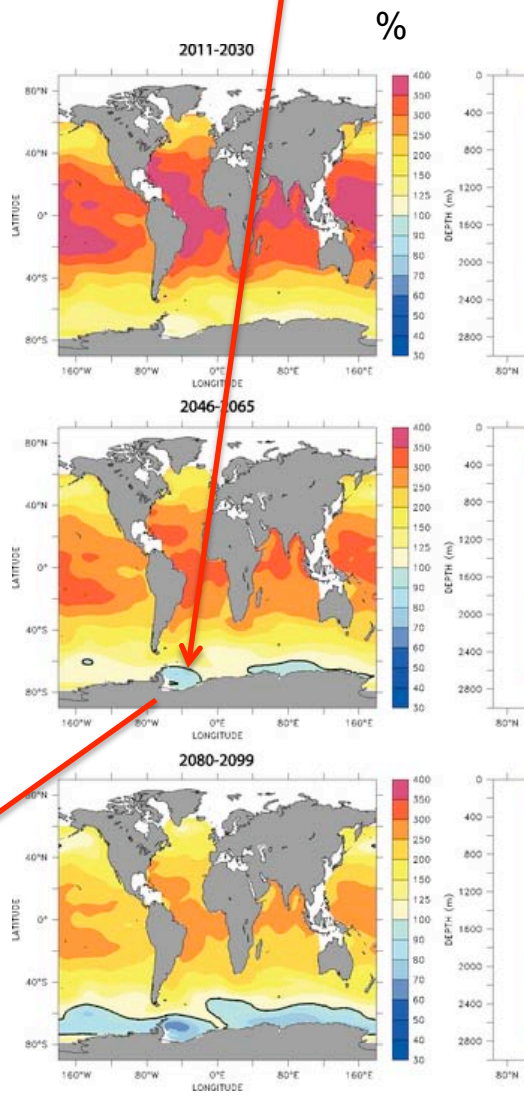




Increasing acidity; Feely 2008



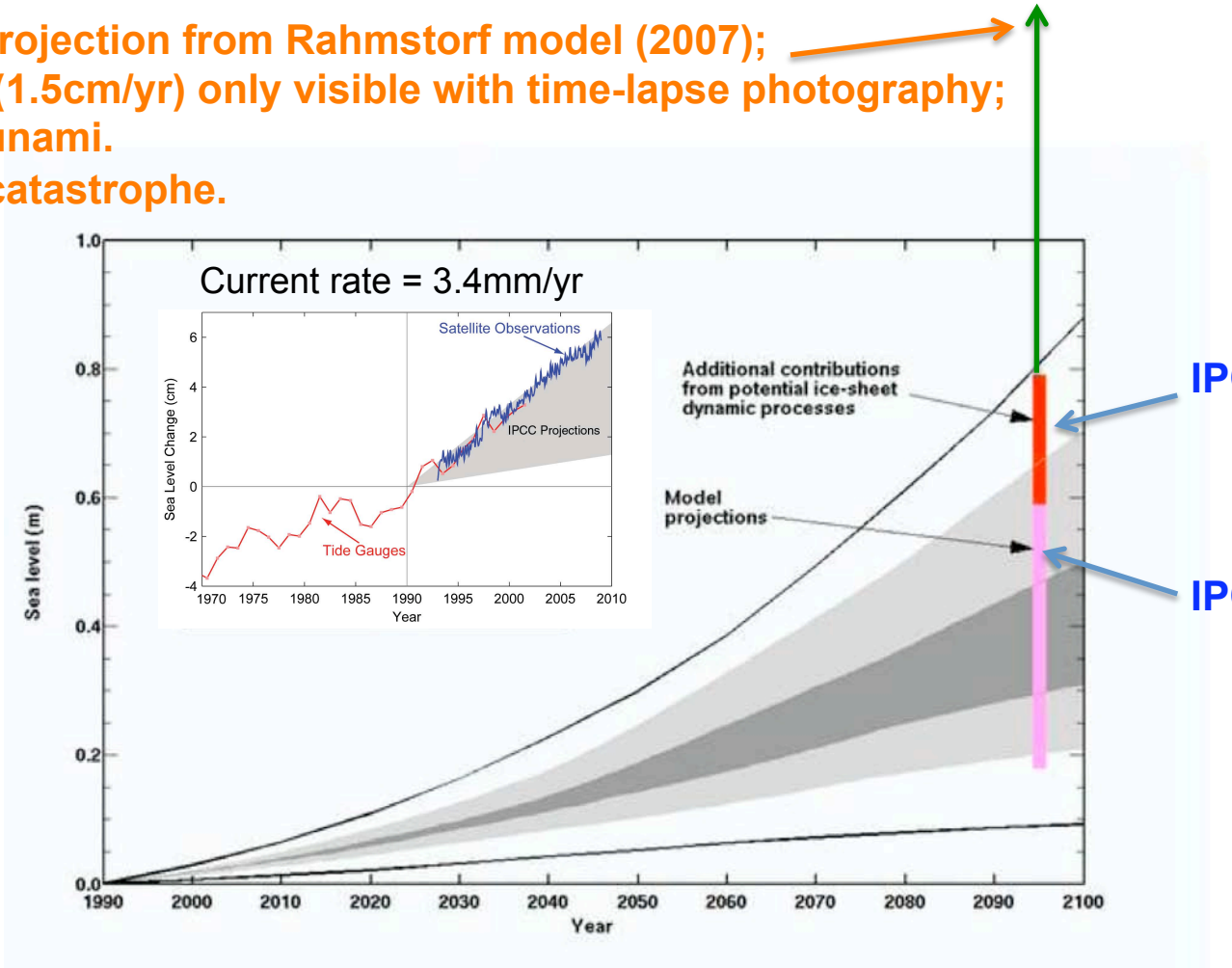
Aragonite pteropod - planktonic marine snail – a major food in the Southern Ocean (N. Bednarsek, BAS)



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

Projected change in sea level to 2100

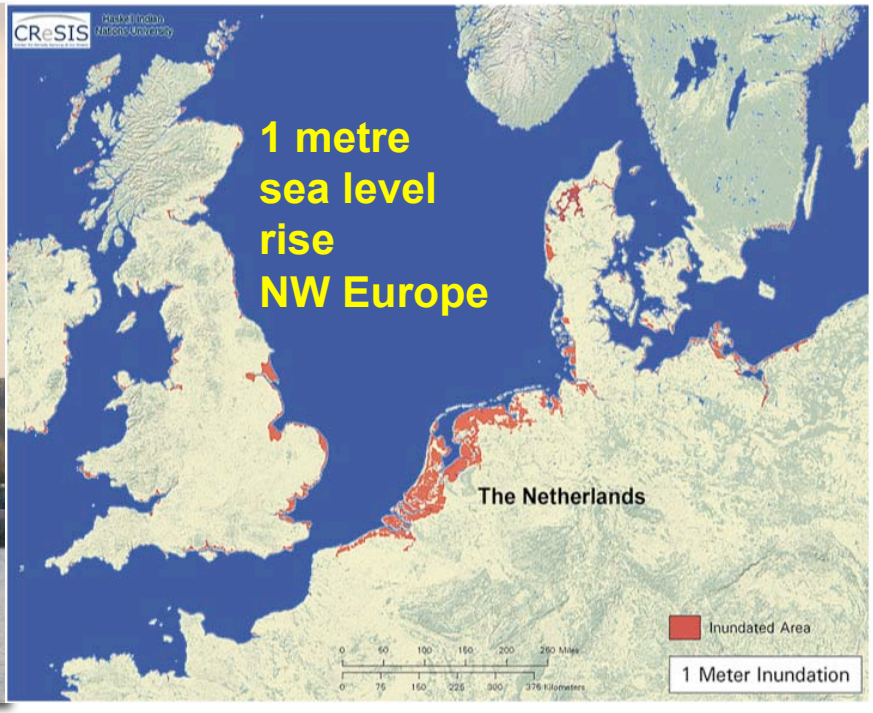
- 1.4 m max projection from Rahmstorf model (2007);
- = Daily rise (1.5cm/yr) only visible with time-lapse photography;
- i.e. Not a tsunami.
- A creeping catastrophe.



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

Church et al., 2008

Melting Antarctic ice – rising global seas: - how will coastal megacities cope?



London – estimated bill for one flood: £30bn = 2% of GDP

Take Home Messages

➢**How does the the Antarctic climate system work?** ***It is the world's refrigerator, locking ice away and saving us from experiencing higher sea levels. It gets climate signals from the north, and sends climate signals back, mainly via the ocean. The Southern Ocean is a climate integrator.***

➢**How does climate change affect the Antarctic ecosystem?** ***Adélie penguins decline on a warmer Antarctic Peninsula; krill decline and salps grow in a warmer ocean; warmer conditions with less sea ice lower the breeding success of seals, albatross, and penguins.***

➢**What are the roles of greenhouse gases, and the ozone hole?** ***The ozone hole strengths the circumpolar winds and Amundsen Sea Low, shielding the continent from warming.***

➢**Sea ice is melting in the Arctic – what about Antarctica?** ***The wall of wind keeps warmer air and surface water away, so sea ice is growing very slightly.***

➢**Is Antarctica growing or shrinking?** ***ASE is shrinking as much as Greenland, and 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 precipitation increases 20%; the ocean warms slightly (0.5-1.0°C), with less effect on organisms than has been expected.***

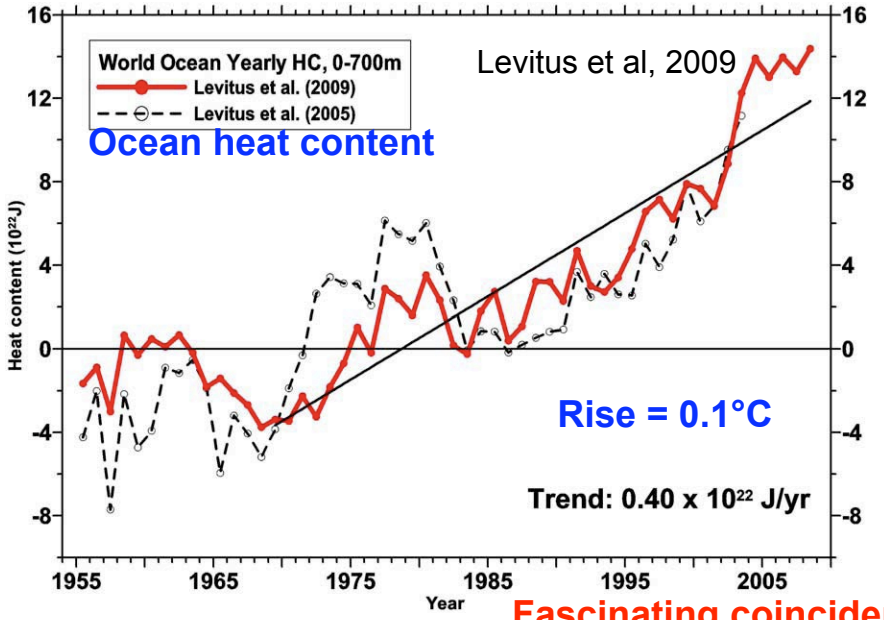
➢**Why should we care?** ***By 2100 West Antarctic ice sheet may discharge enough ice to raise sea level up to 1.4m(+) – a significant challenge for coastal populations everywhere.***

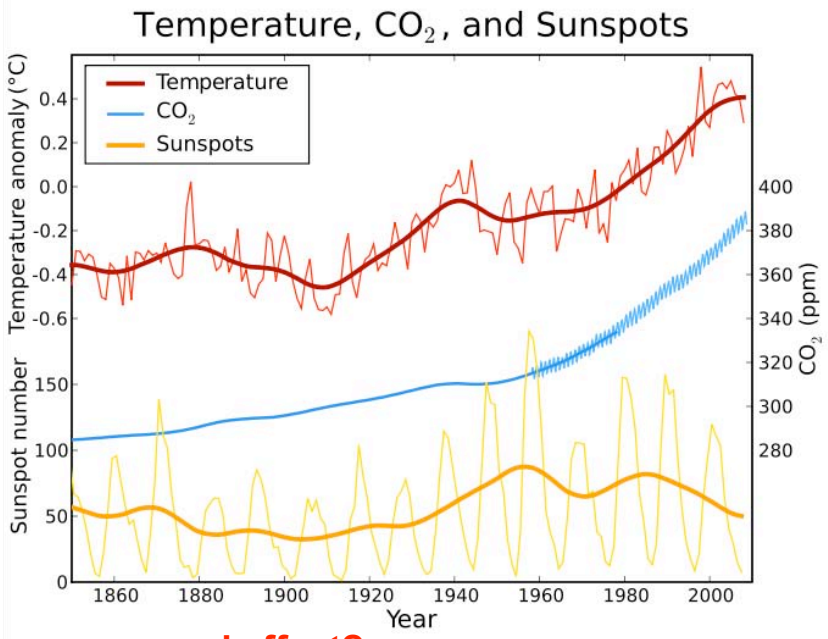
SCAR


Thank you for your attention!

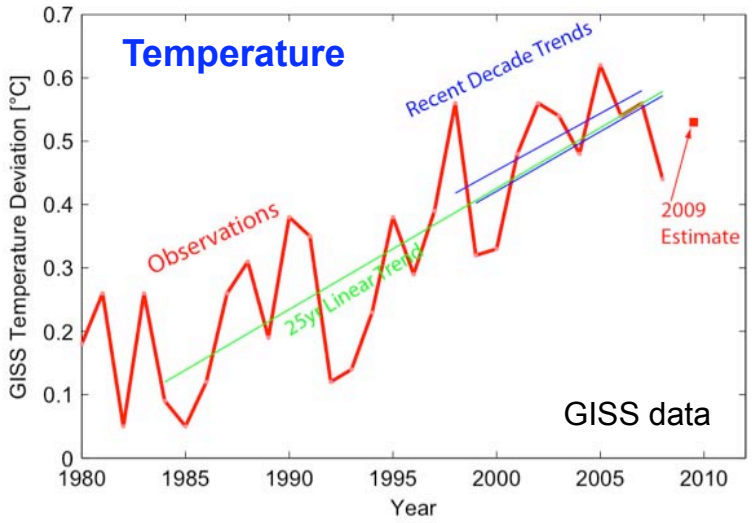

The End

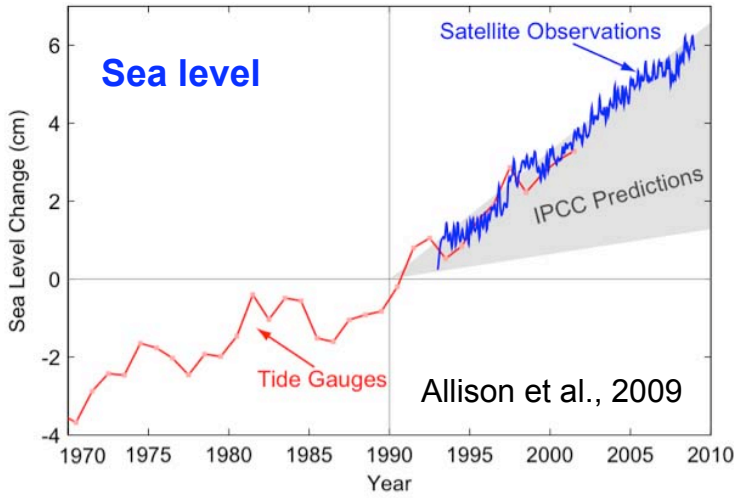
The context - global changes



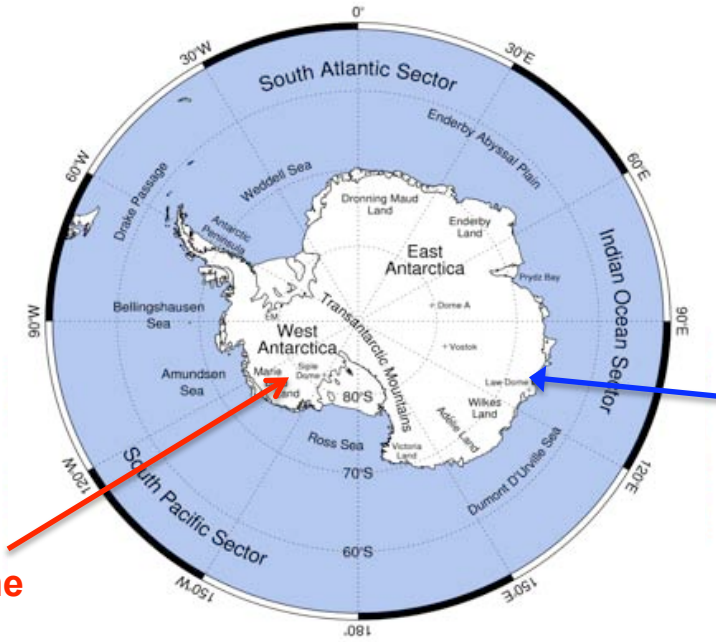


Fascinating coincidence or cause and effect?





Ice core data show Recent CO_2-related warming



High resolution records from areas of rapid accumulation

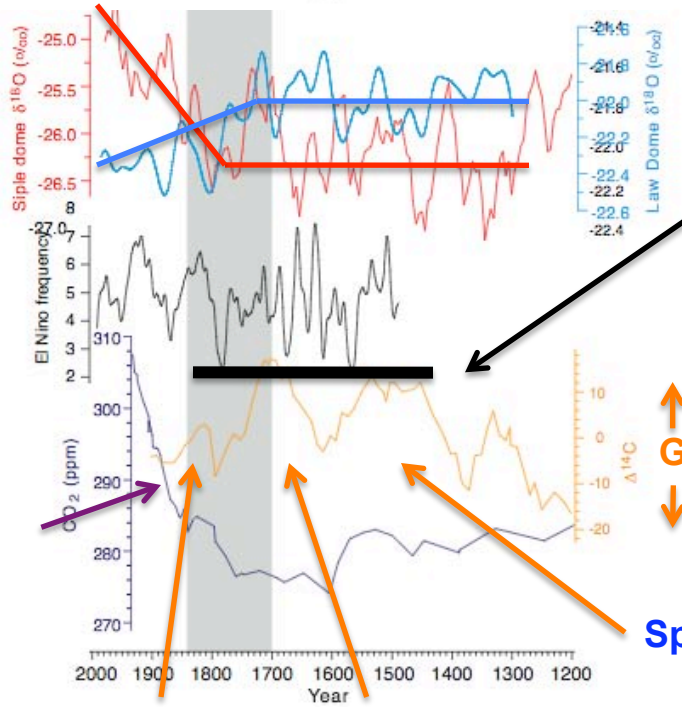
Law Dome

Siple Dome

Post 1750-1800, Siple Dome warms in parallel with rise in CO_2

Law Dome cools, suggesting major change in atmospheric circulation

Possible cause = weakening of Amundsen Sea Low Pressure Cell



Little Ice Age ?1400 - ?1850

Down
Global solar output
Up

CO_2 from ice cores associated with Industrial Revolution

Sporer Minimum 1400-1520

Dalton Sunspot Minimum 1790-1830

Maunder Minimum 1645-1715

Mayweski et al, 2009

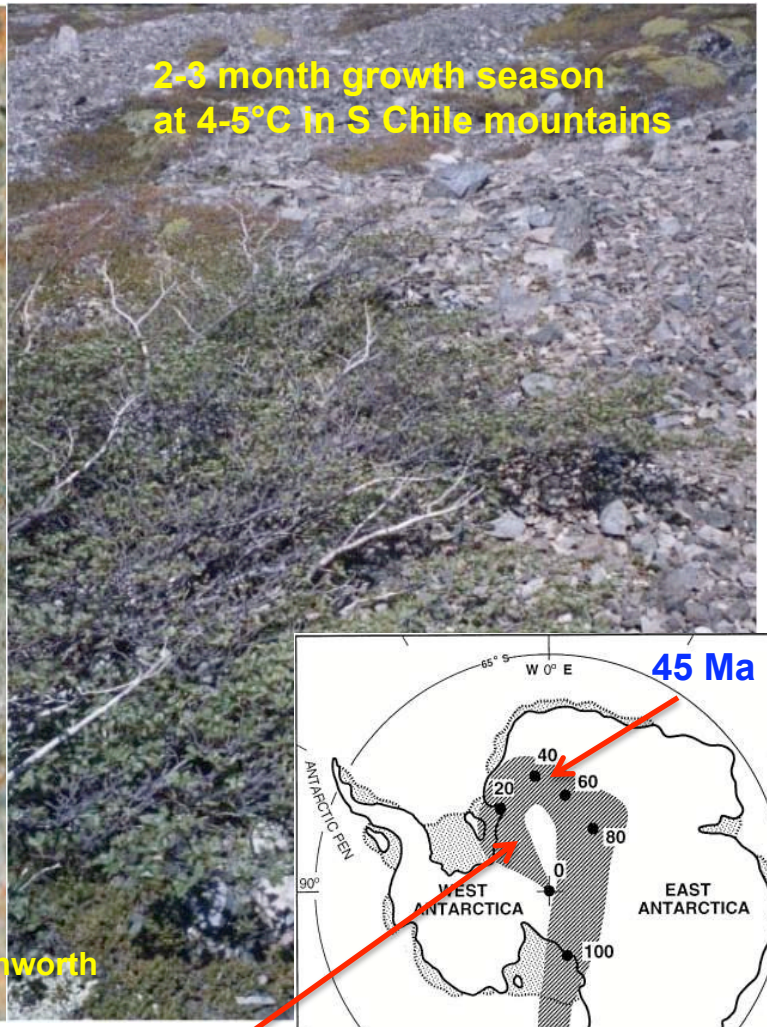
Nothofagus (southern beech) in Beardmore Glacier area (500 km from pole)

Cooling in mid-Eocene at 45 Ma replaced humid forest with Nothofagus trees

Nothofagus pumilio leaf

Fossil Leaf 20 Ma+

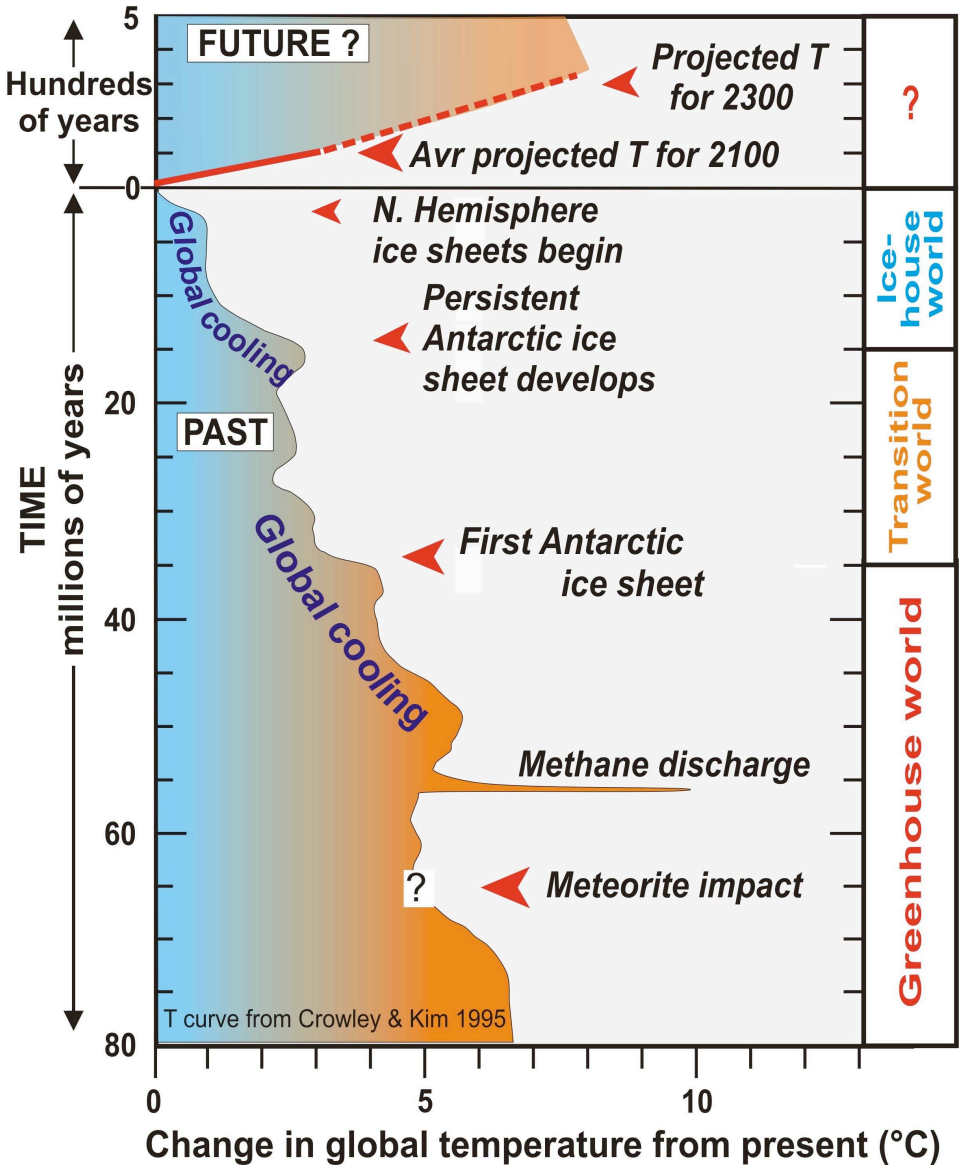
From A Ashworth



2-3 month growth season
at 4-5°C in S Chile mountains

No vegetation after 14Ma in E Antarctica

Global cooling (change in av. temp.) as CO_2 drops from 1000+ to 200 ppm



Human activities; the Anthropocene

Low ice age CO_2
180 ppm in glacials
280 ppm in interglacials

CO_2 below 400 ppm

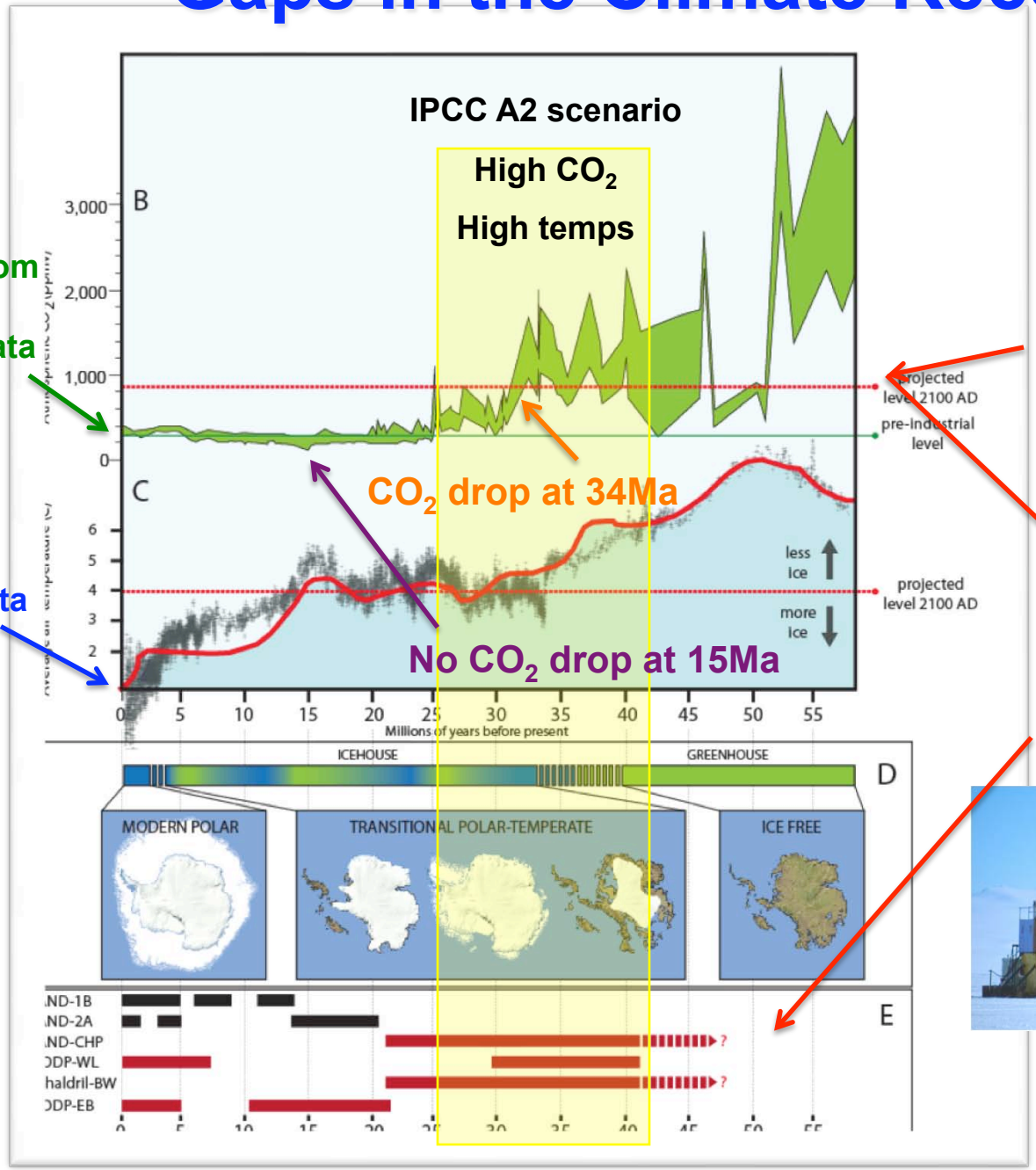
CO_2 750-450

Catastrophic event – release of methane hydrates

High CO_2 from volcanic out-gassing in mid-ocean ridge growth

Modified from Crowley & Kim, 1995

Gaps in the Climate Record



ppm CO_2 from deep sea alkenone data

Temp °C from deep sea $d^{18}O$ data

Need data from high-CO_2 period

ANDRILL

Plan for Antarctic Drilling 2010-2015

Pagani et al., 2005

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