Pathways and impacts of Southern Ocean currents on Antarctic ice-sheet melting in response to global warming

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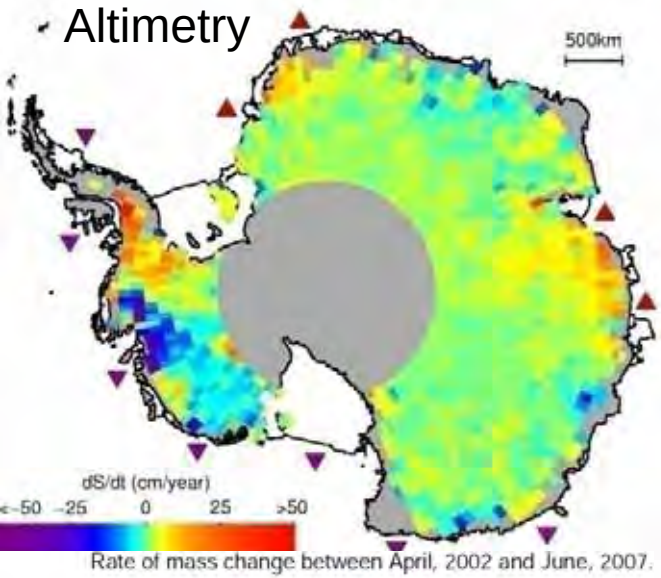
Impacts of ocean currents on ice-sheet melting

Introduction

- Why is the Antarctic Ice Sheet observed to have enhanced mass loss?
- What is the role of ocean circulation on this mass loss?
- What is the relative role of the winds and buoyancy play?
- Are the observed changes due to climate change signals?

Loss of Ice in Antarctica?

Altimetry



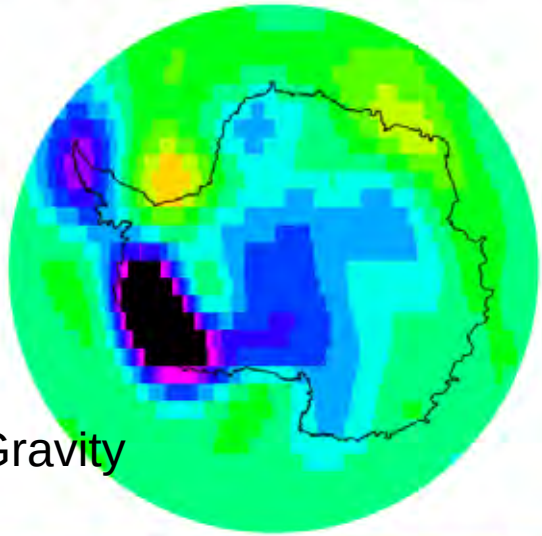
Antarctica is loosing mass

- 0.14 ± 0.41 mm yr-1 SLE, 1961-2003
- 0.21 ± 0.35 mm yr-1 SLE, 1991-2003
- ~0.4 ± 0.35 mm yr-1 SLE,2002-2007

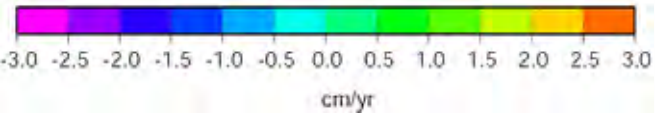
Wahr and Velicogna 2007.

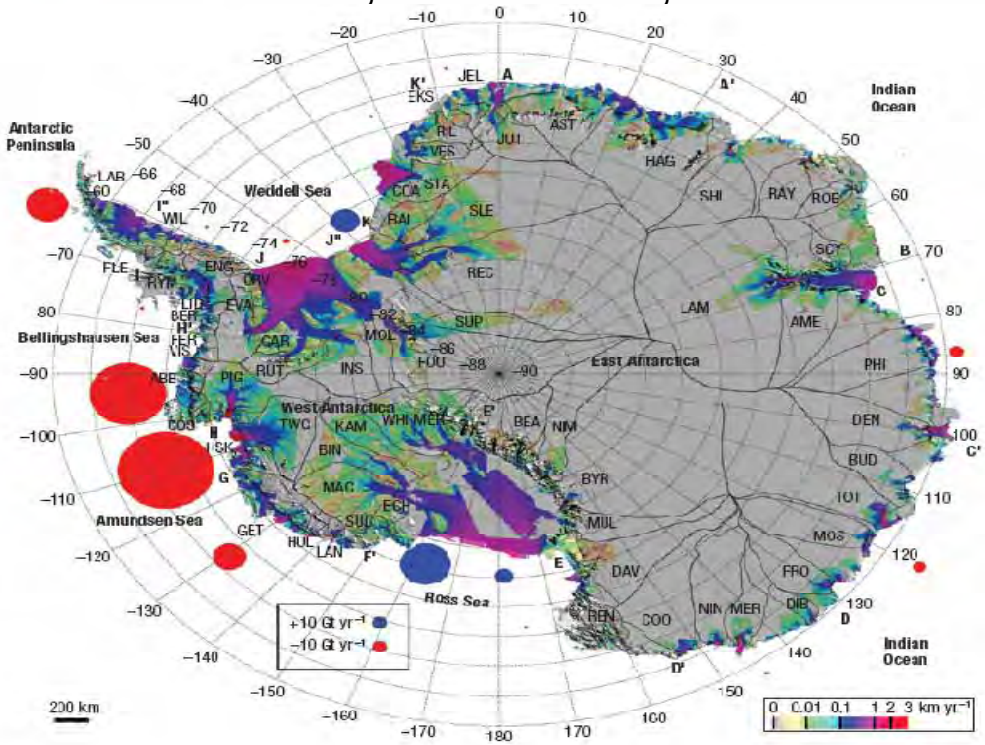
Increasing evidence of melt

- Jacobs 2001, Rintoul 2006, Helm et al 2010



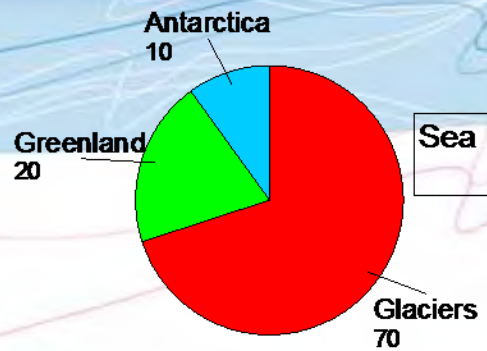
Gravity



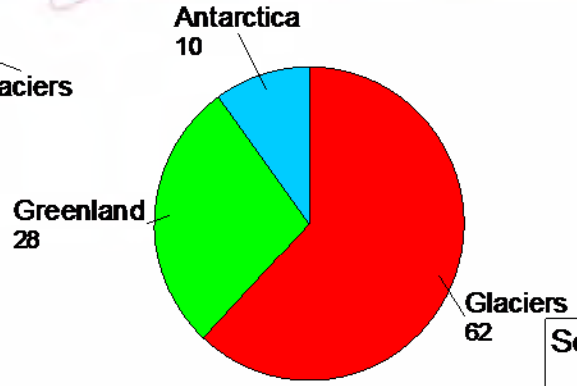


Antarctic contributing a rising faction of sea-level

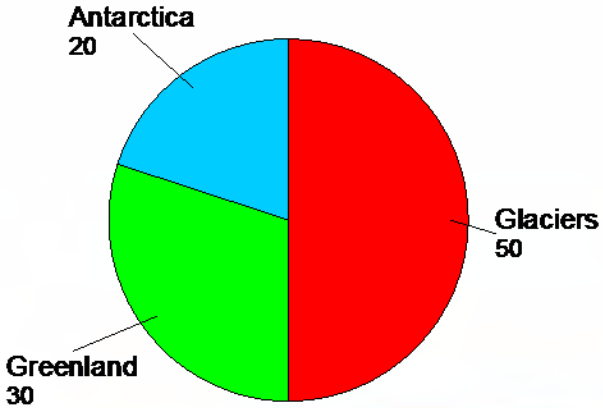
Sea Level Rise (%) [*IPCC*, 2006]]
100% = 1.28 mm a^{-1}



Sea Level Rise (%) [*Meier et al.*, 2007]
100% = 1.8 mm a^{-1}



Sea Level Rise (%) [latest GRACE data)]
100% = 2.2 mm a^{-1}



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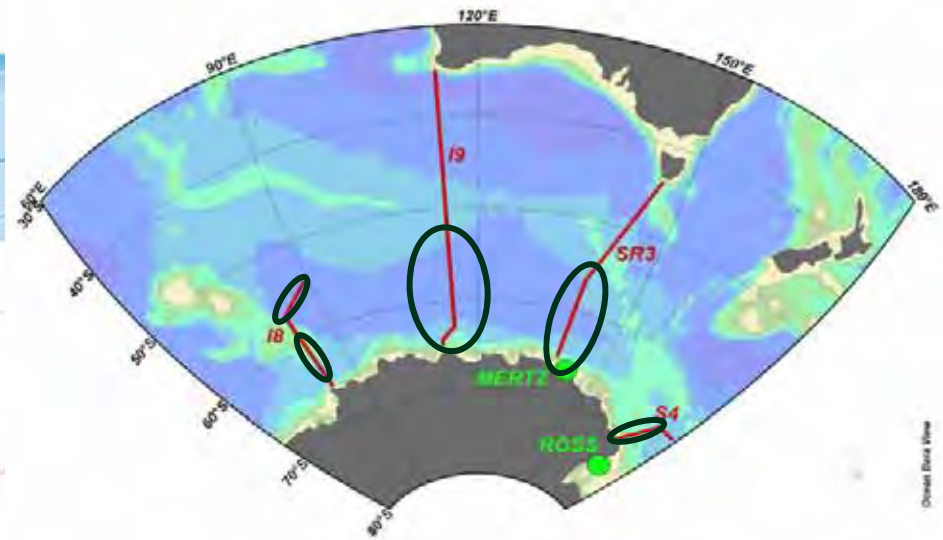
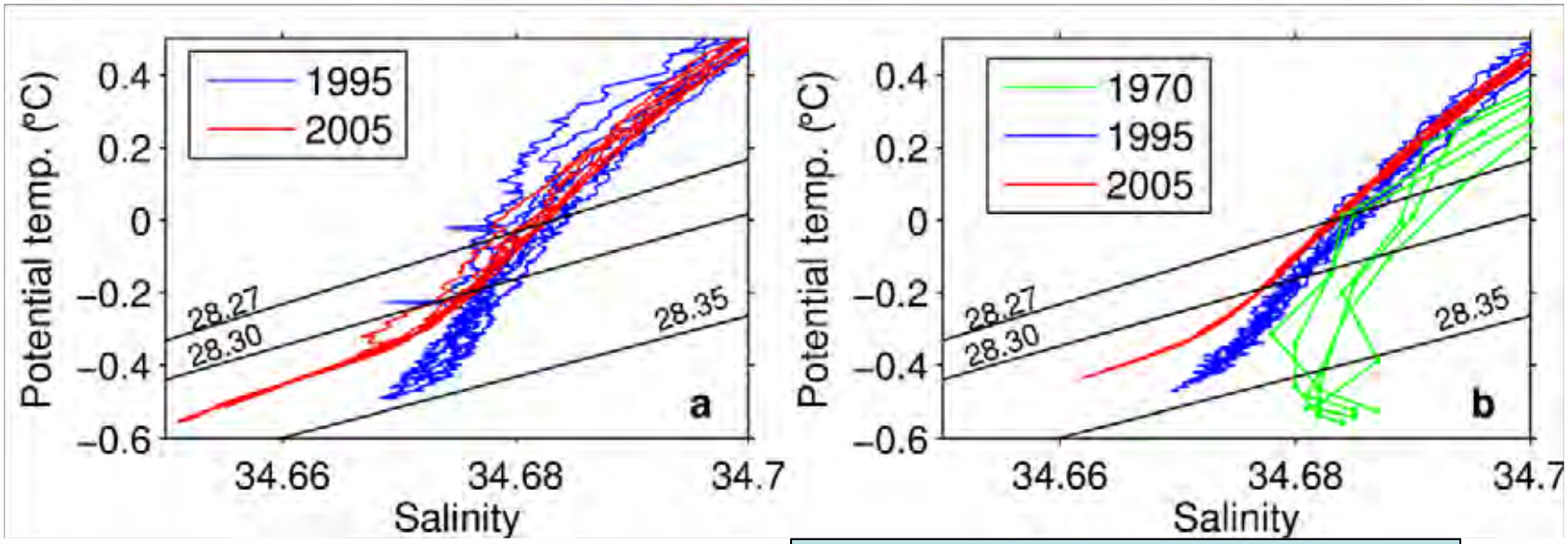
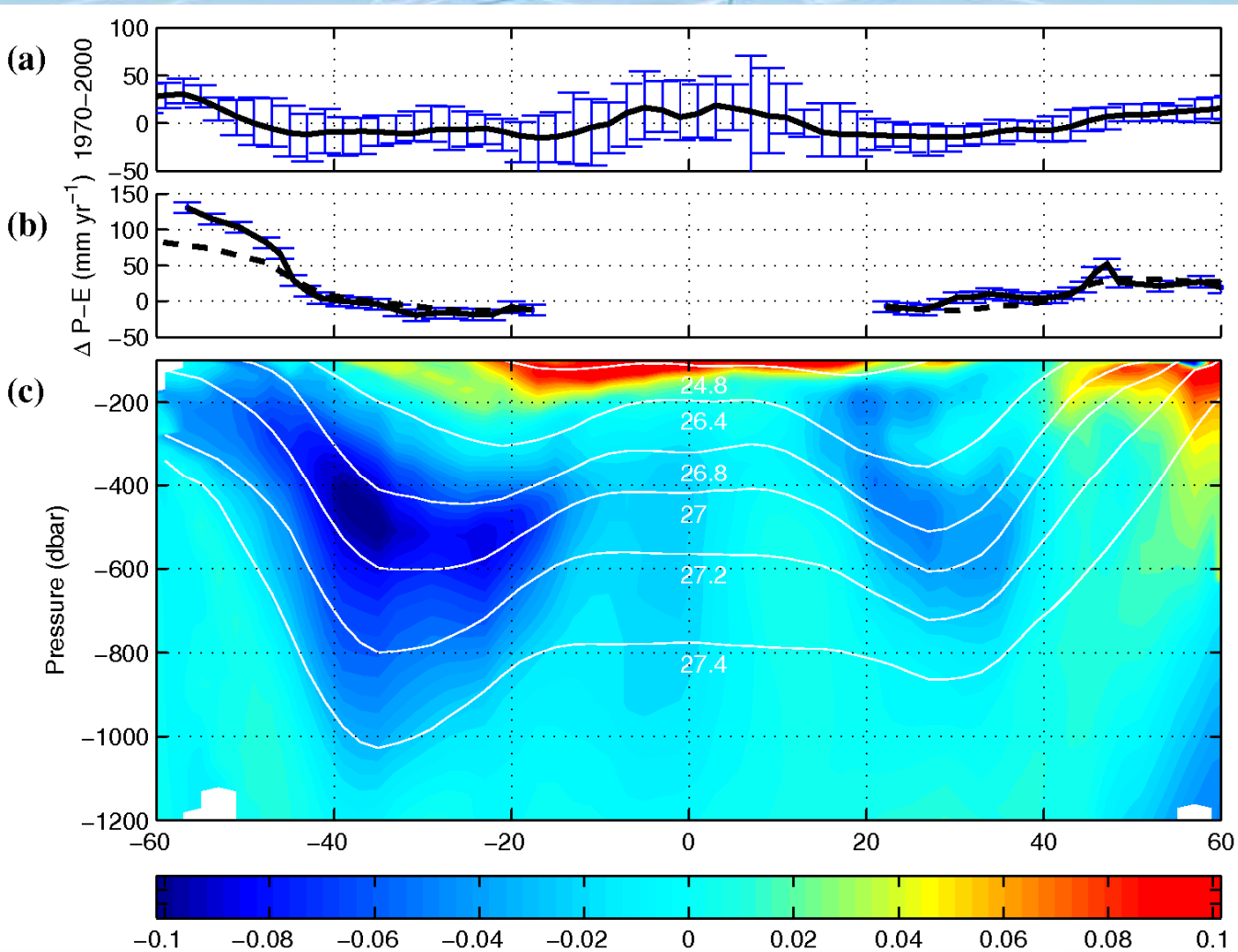
Southern Ocean Change





Rintoul, Science 2006

Comparison with models

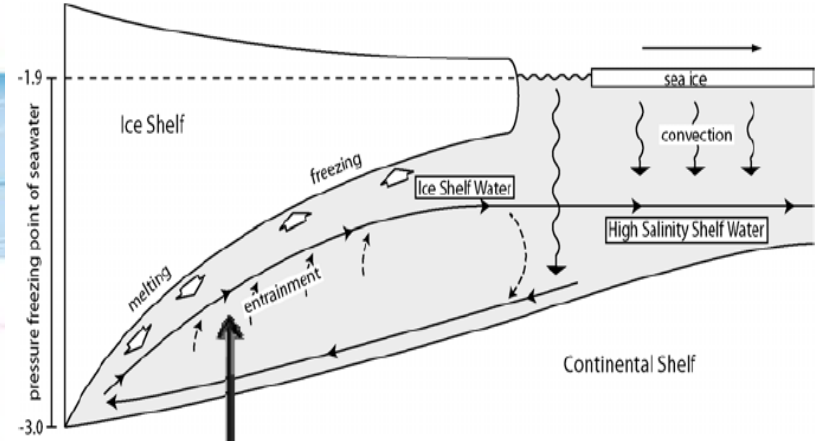


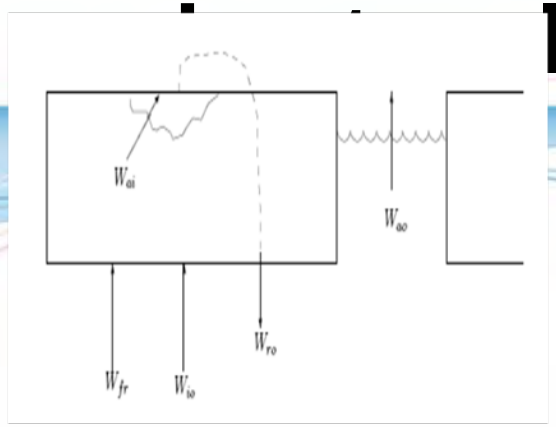
10 IPCC models
1970-2000

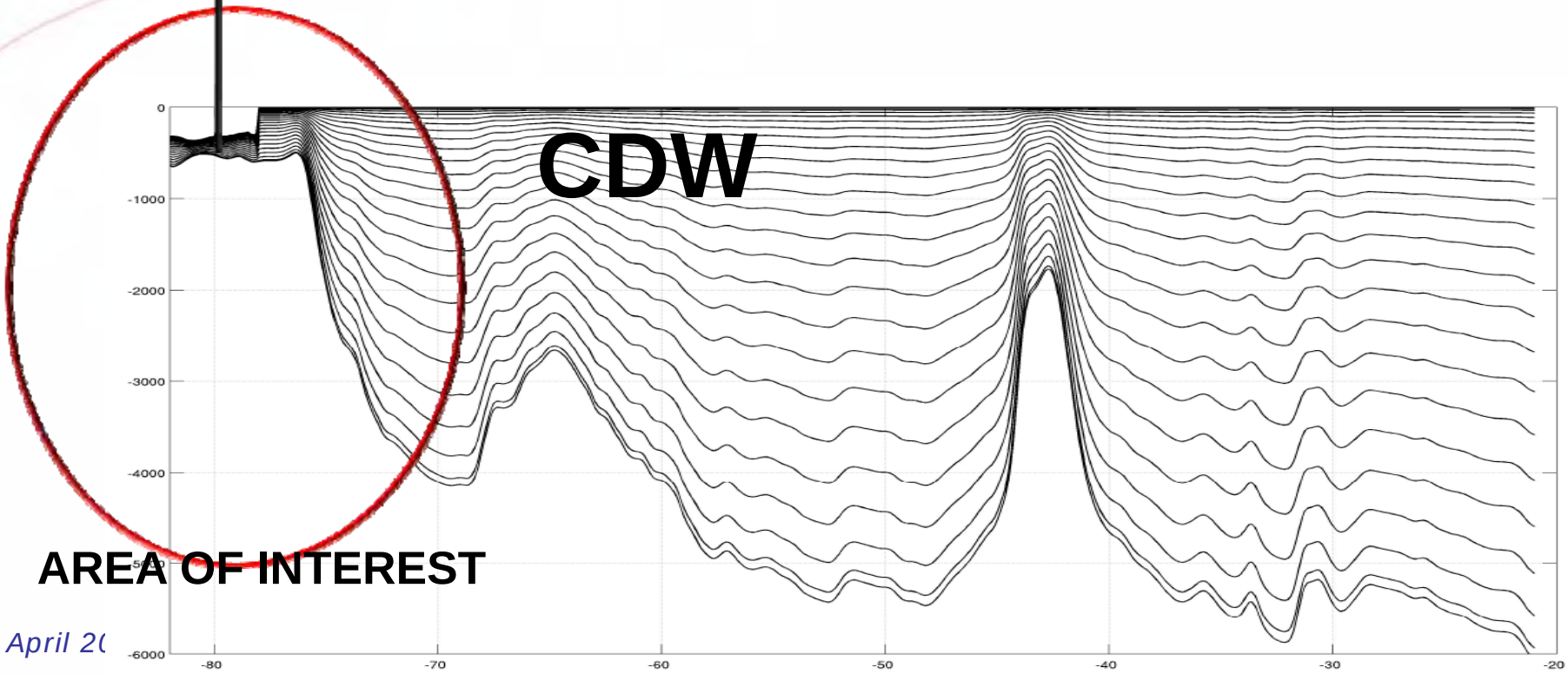
Estimated P-E

+16±6% in S. Ocean
+ 7±4% in N.H
- 3±2% in S.T. gyres

Impacts of ocean currents on ice-
lting







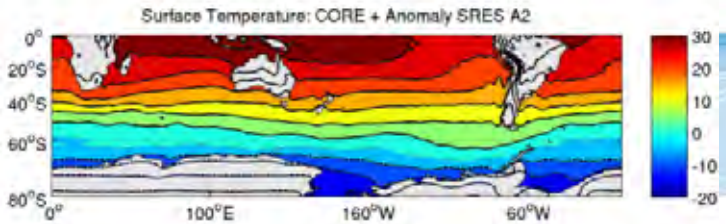
Model Setup

- ROMS (Regional Ocean Modelling System, Shchepetkin et al, 2005)
- Ice shelf dynamics after Hunter (2006)
- Sea ice model after Budgell (2004)
- 1/8 degree horizontally, circumpolar, 20S-85S
- 25 vertical levels ~40,000,000 grid points
- No flux correction at surface
- Initialization: WOA (Conkright, 2002)
- Surface forcing: CORE (Large and Seager, 2008)

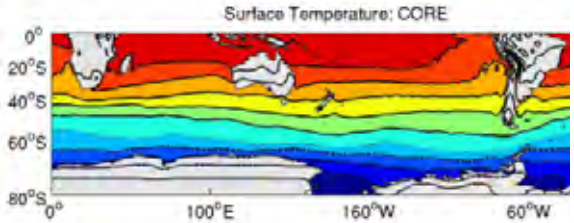
Scenarios - 12 years of integration

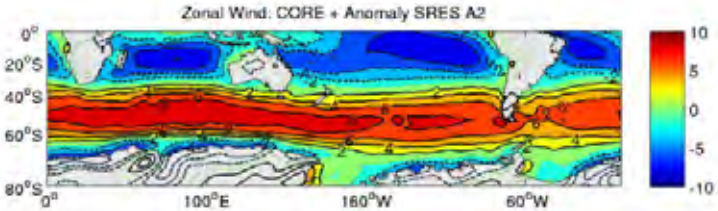
1. Base run (CORE atmospheric forcing)
2. All IPCC forcing terms (CORE + IPCC anomalies)
3. Dynamic forcing only (CORE + IPCC wind anomaly)
4. Buoyancy forcing only (CORE + IPCC rain, temperature, radiation anomalies)

Anomalous forcing: Examples

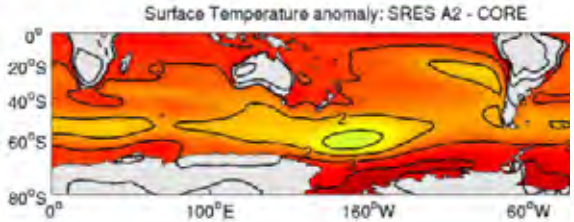


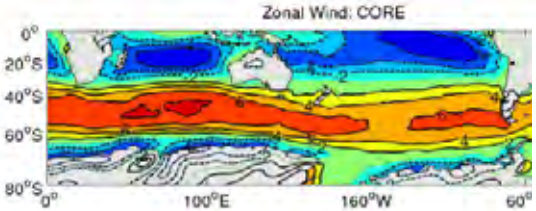
Average anomalies from 10 CMIP3 models

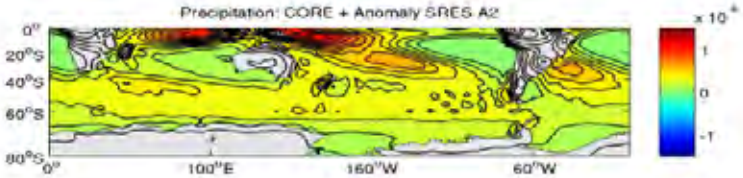




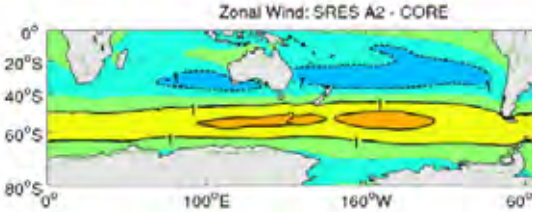
P-E change

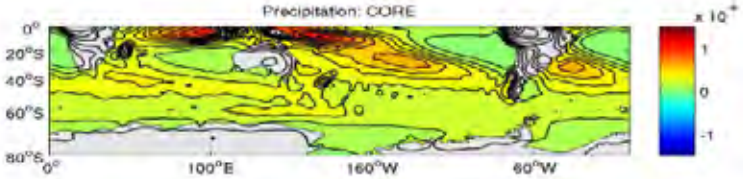




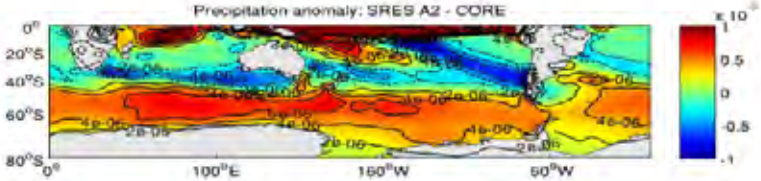


Sea Surface Temp.





Zonal Wind



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Iceshelf mask

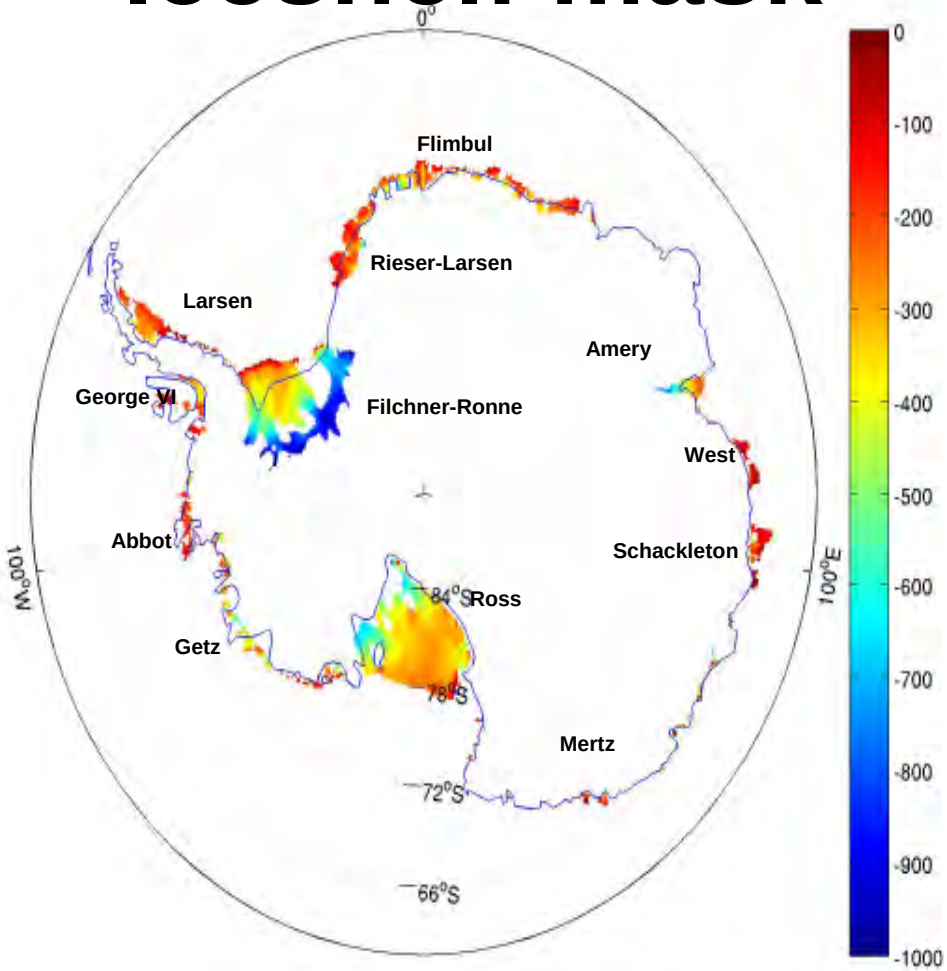
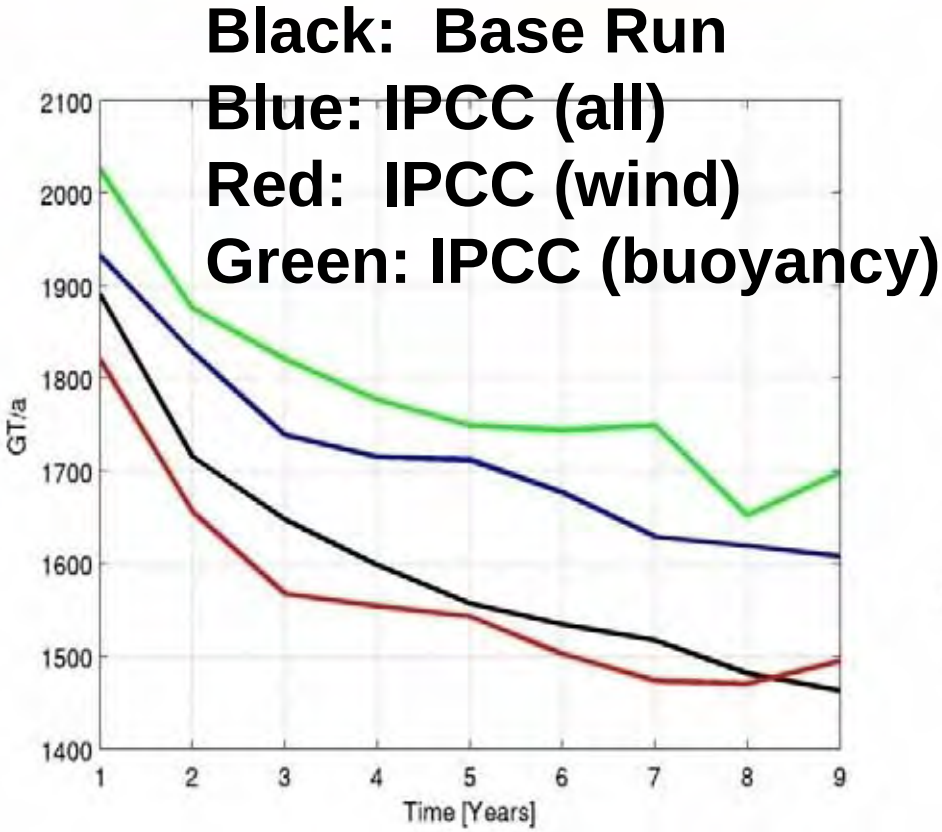


Figure 1: The iceshelf mask used for the model simulations. Based on the Bedmap data set (Lythe et al, 2004).

Freshwater fluxes



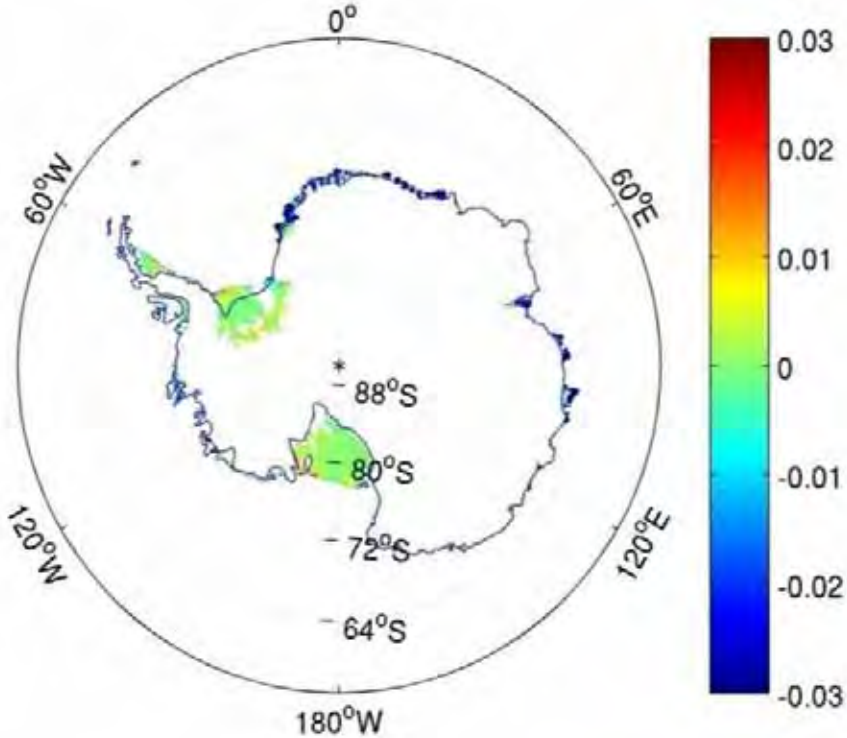


Figure 3: Left: Simulated freshwater fluxes emanating from the ice-shelves (Gigatonnes per annum) . Right: Spatial pattern of anomalous freshwater flux for scenario IV. Blue/ red anomalies indicate enhanced/reduced

Temperature changes along the 1000m isobath

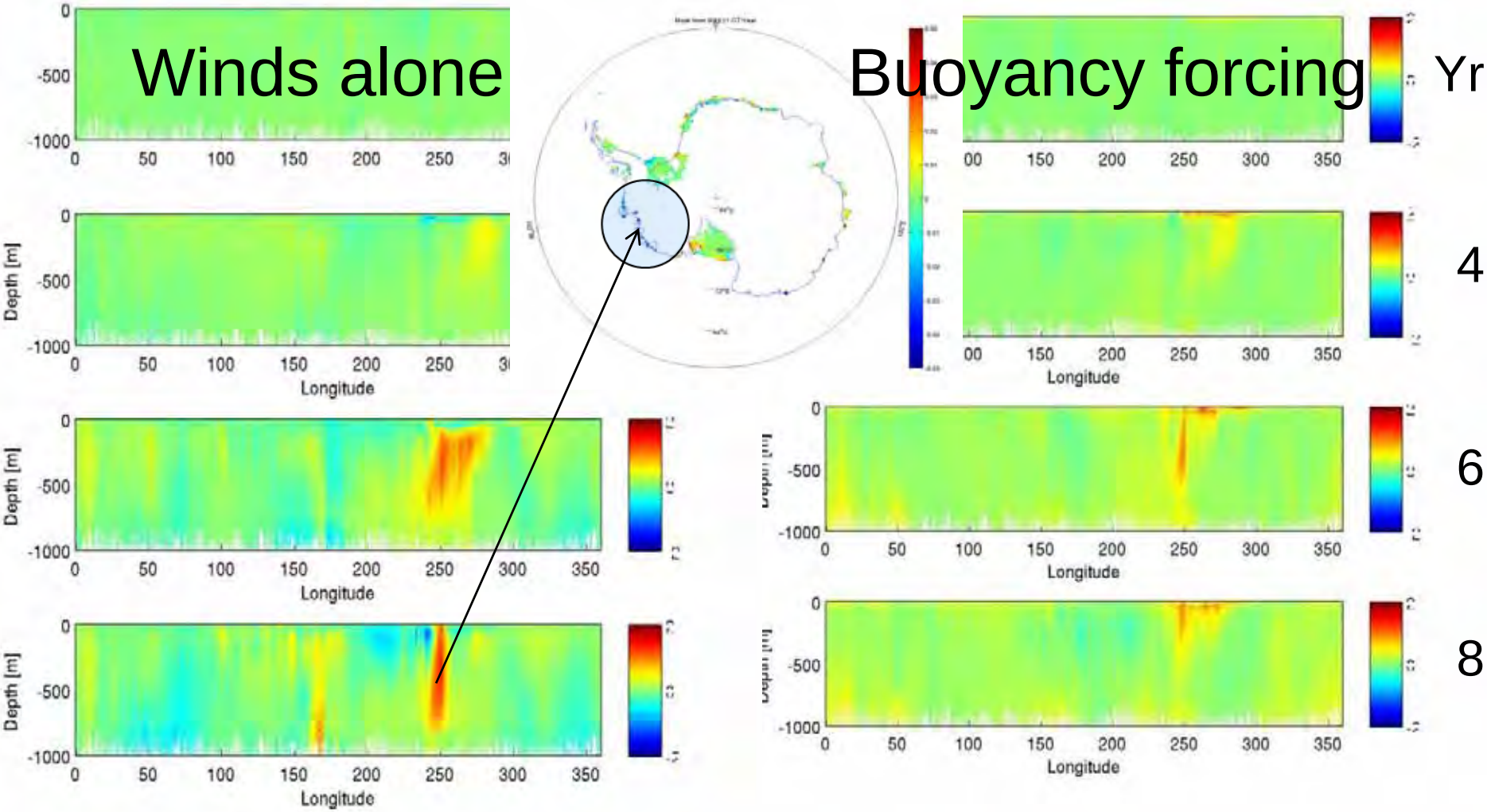
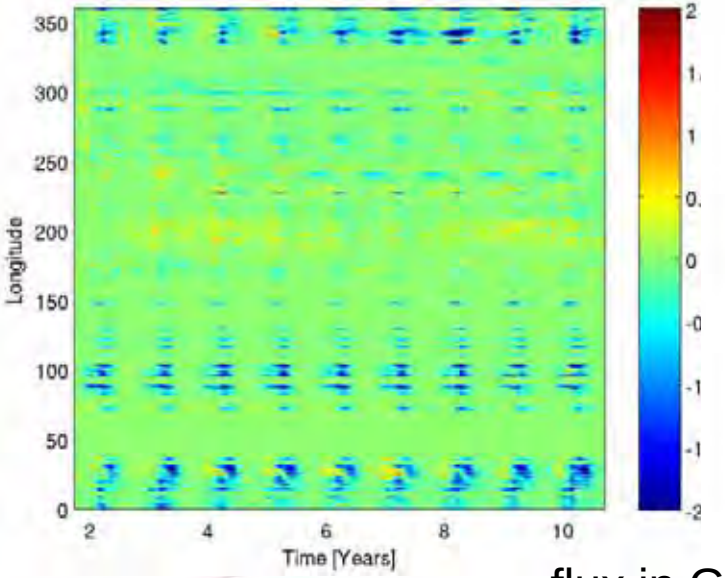
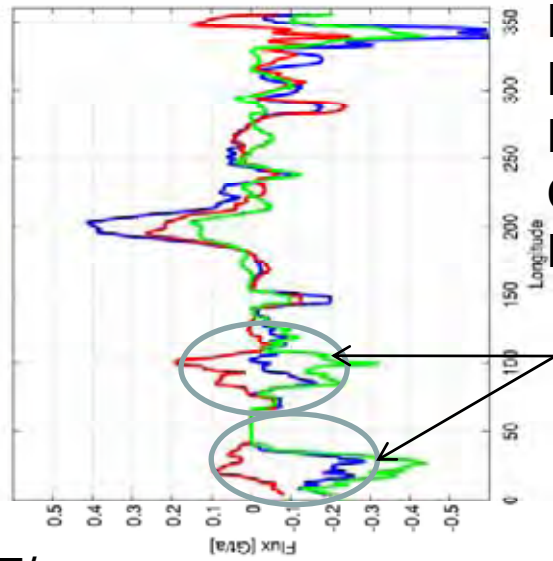


Figure 4: Anomalous temperature for years 2, 4, 6, 8, (from top to bottom) along the 1000m isobath around the Antarctic continent. Anomalous wind forcing is included (left) excluded (right). Note the different vertical and horizontal patterns of the response.

BOUY IPCC - BASE





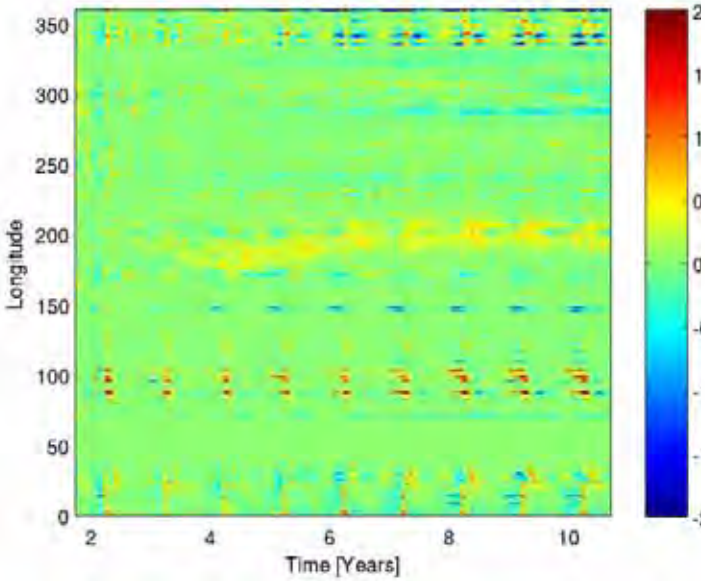
Blue: All IPCC- BASE RUN
Red: Wind IPCC – BASE RUN
Green: Bouy IPCC – BASE RUN

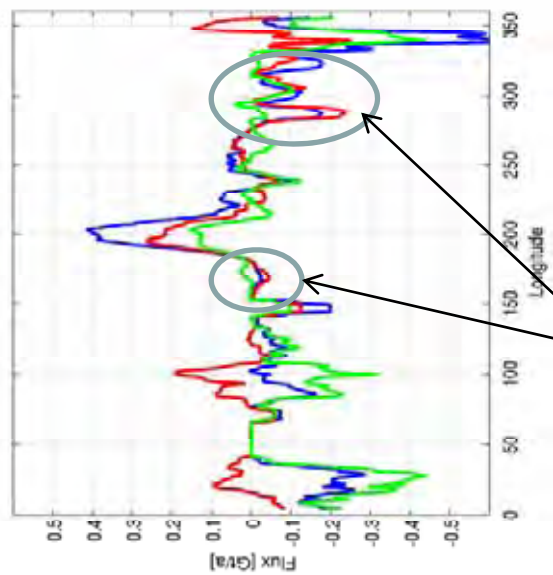
Buoyancy Melt

flux in GT/a

Time series are smoothed with a 10deg running mean

WIND IPCC - BASE

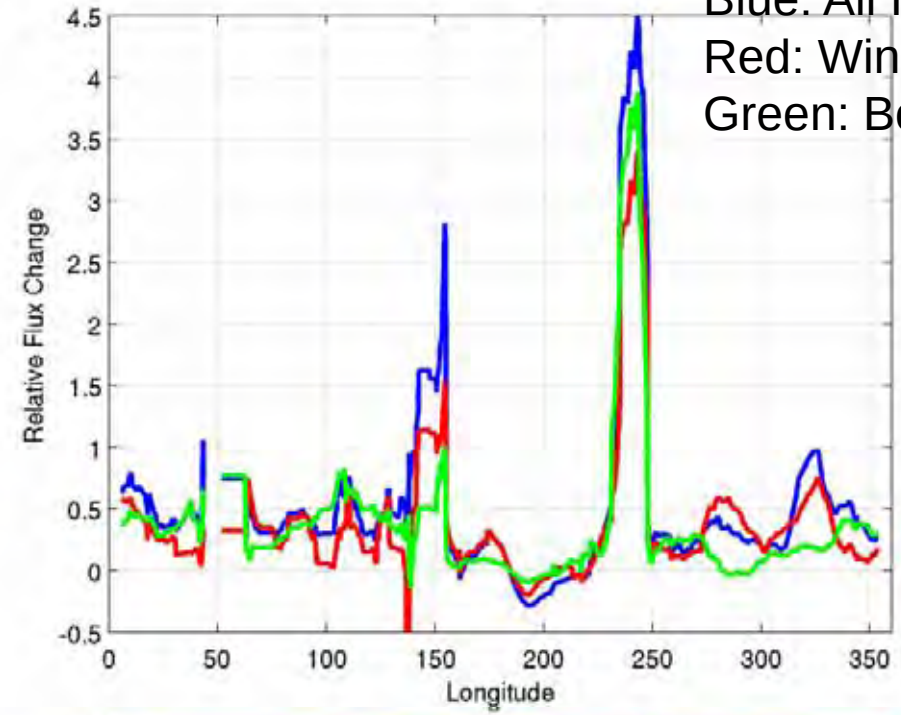


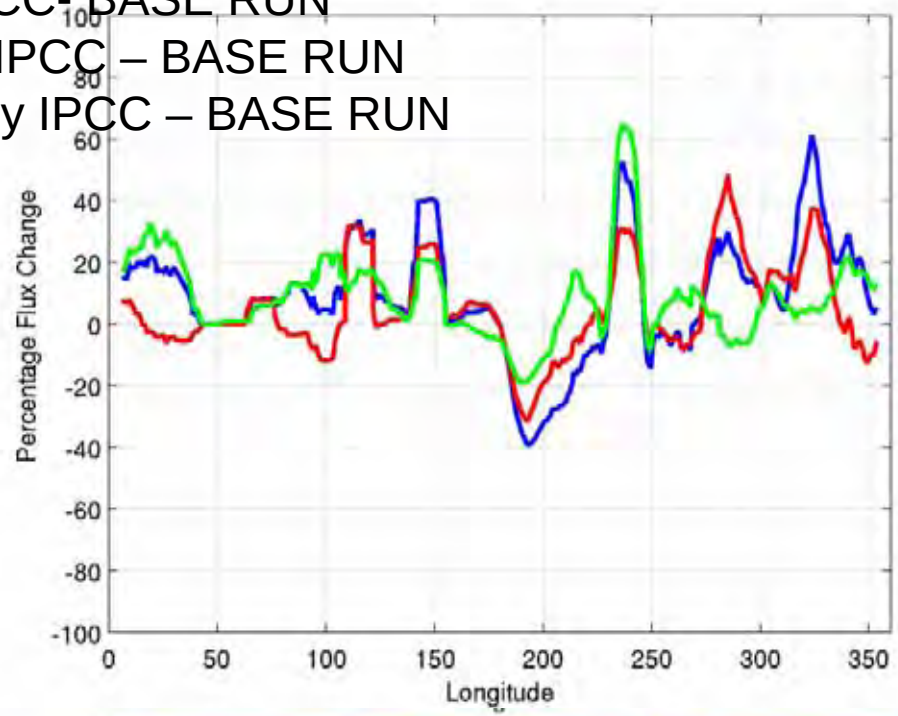


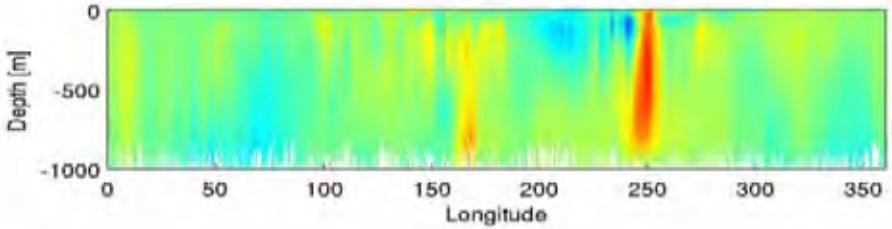
Circles indicate areas of enhanced melting due to bouyancy (upper) or wind forcing (lower)

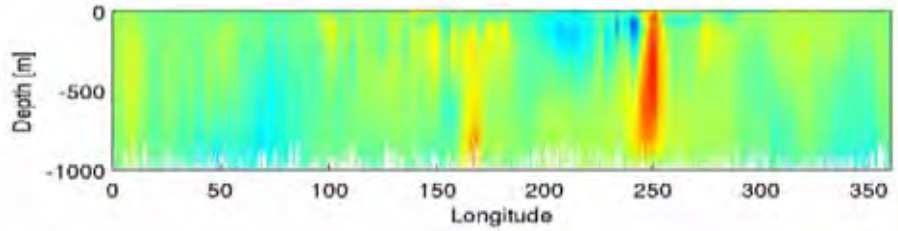
Wind Melt

Blue: All IPCC- BASE RUN
Red: Wind IPCC – BASE RUN
Green: Bouy IPCC – BASE RUN





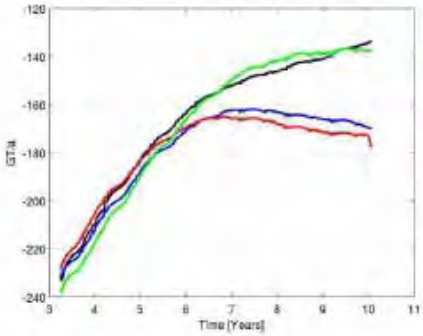




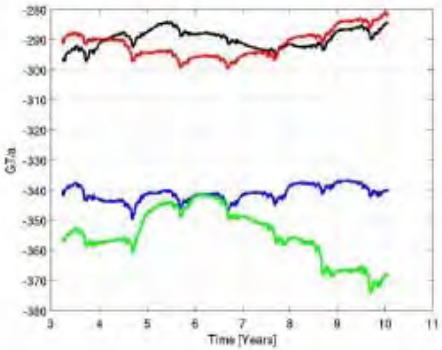
Upper: Relative change: (1) (IPCCRUN-BaseRUN)/BaseRUN
Two different ways to calculate
(1). All timeseries are smoothed with a 10degree running mean
Lower: Temperature anomaly.

Spatial Distribution of Melt

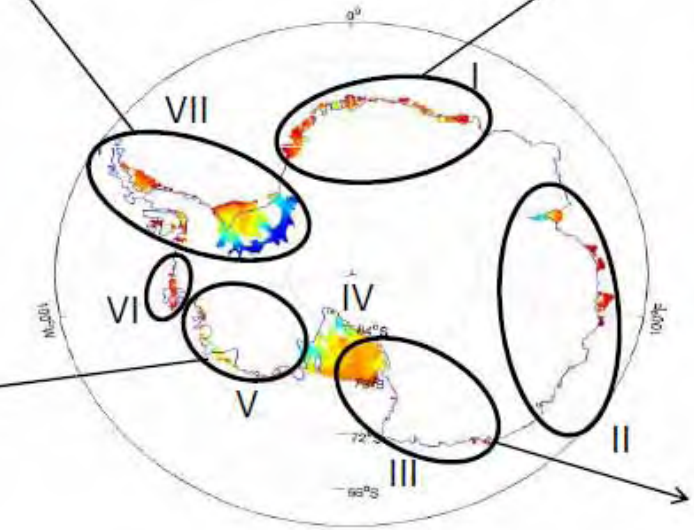
Black: base run
Blue: all IPCC forcing
Red: wind IPCC forcing
Green: buoyancy IPCC forcing



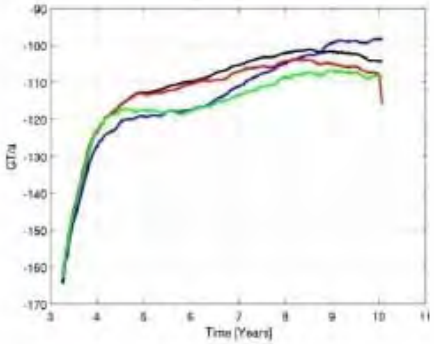
Wind driven melt



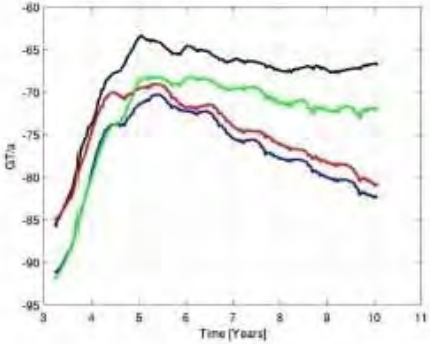
Buoyancy driven melt



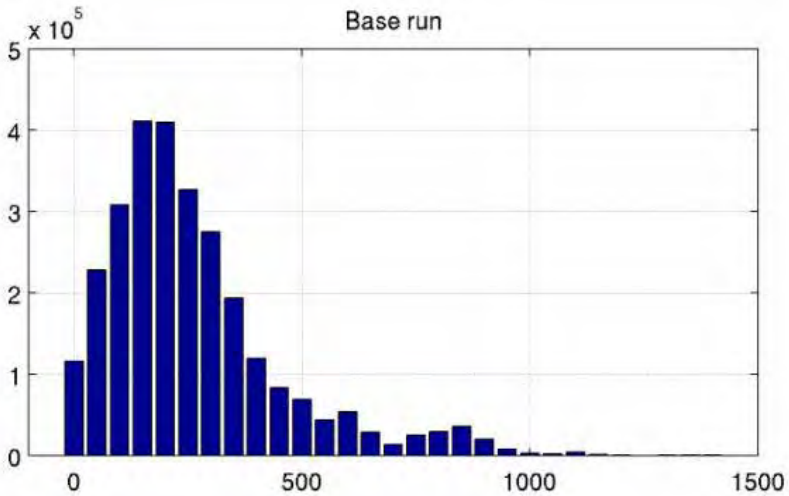
Buoyancy driven melt?

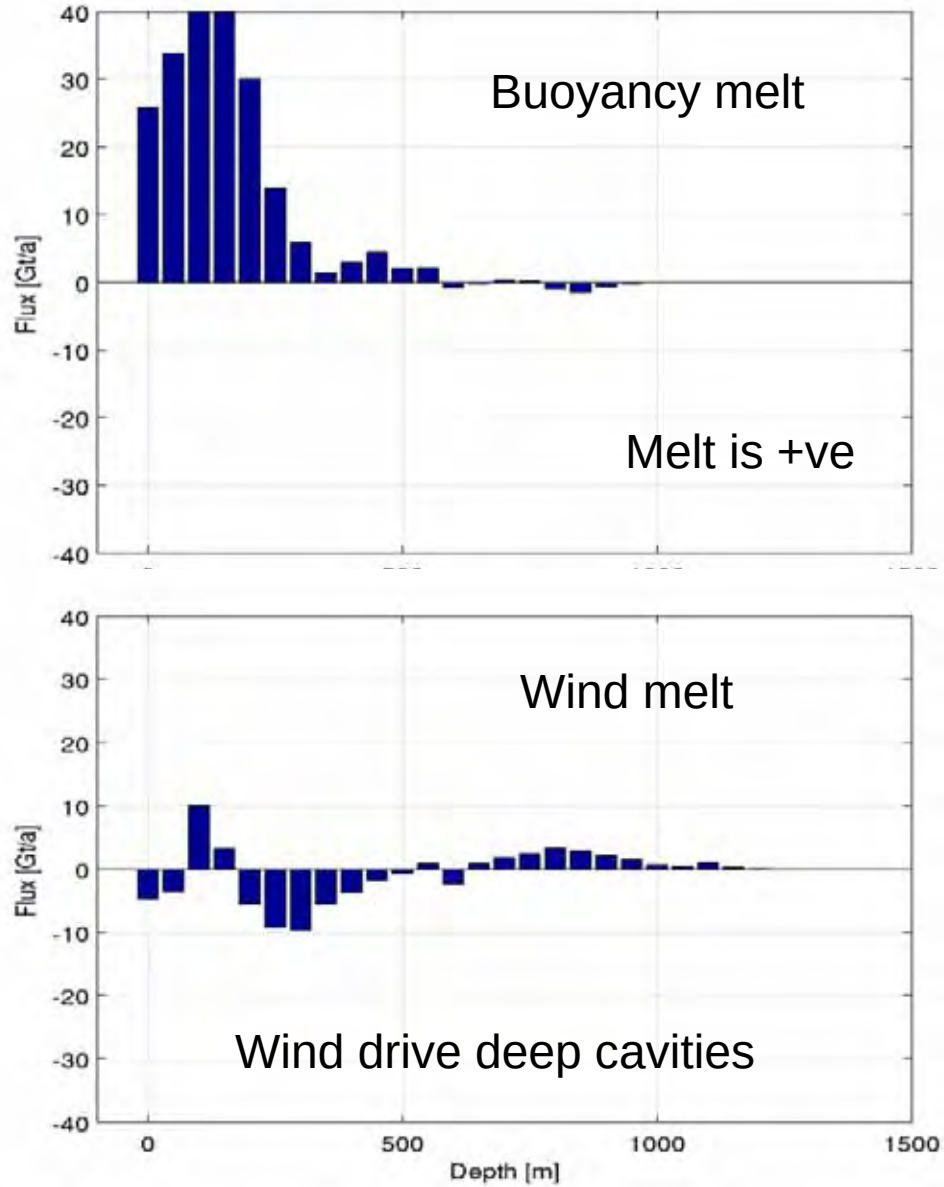


Wind driven melt



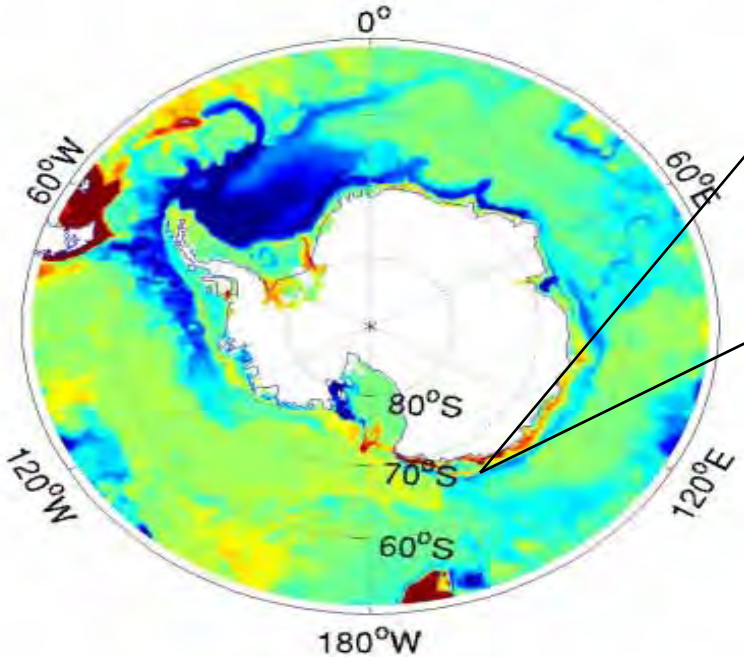
Melting as a function of depth

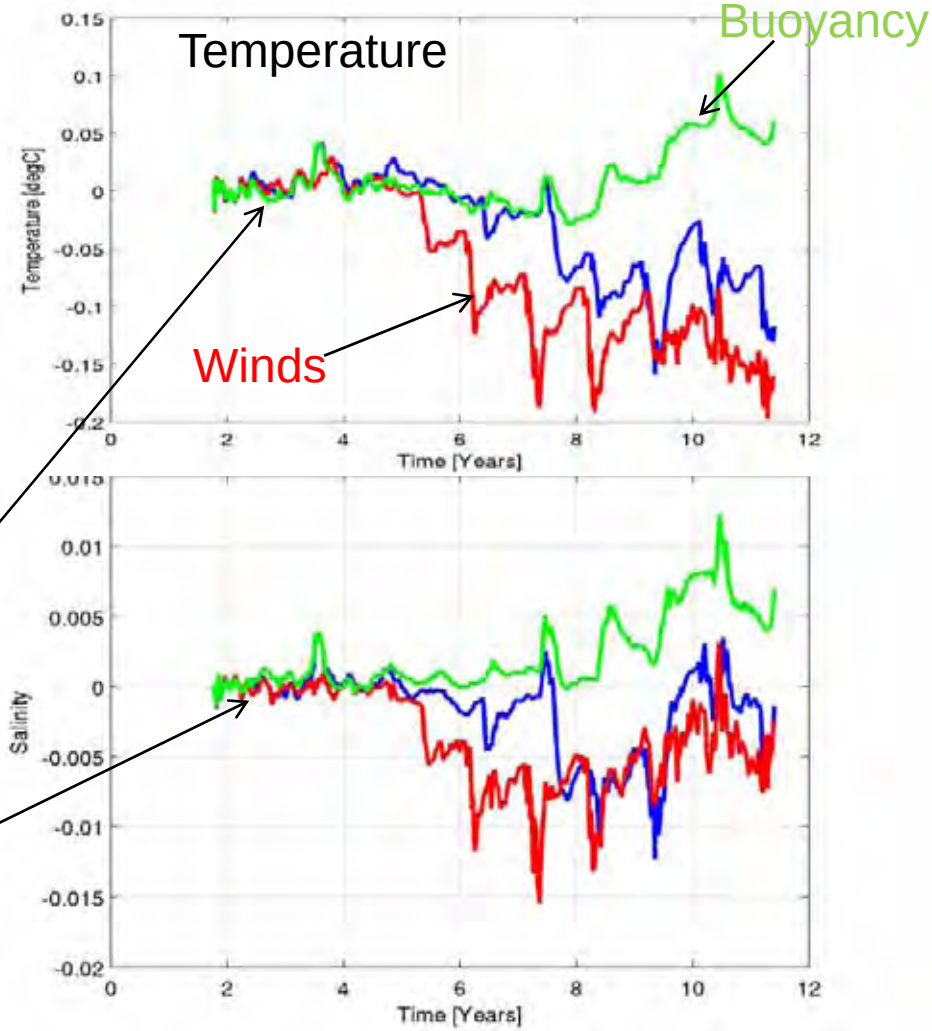




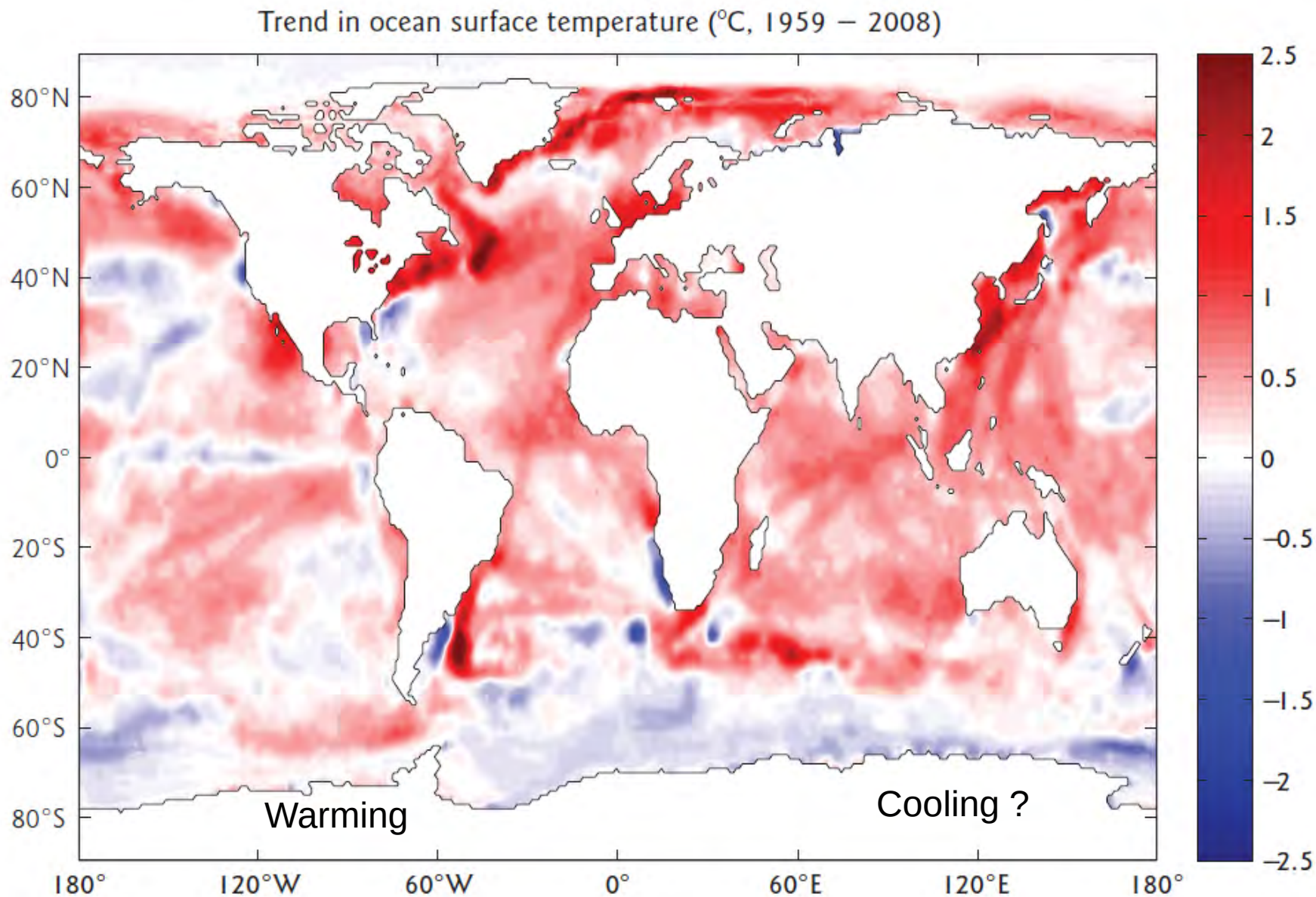
Most of the freshwater from the ice-shelves originates from depth between 0-500m. Deepe ice-shelves contribute litt to the overall freshwater budget.

Freshwater flux and bottom water





So why don't we see much melt in East Antarctica?



Hadley SST, from Rayner et al 2006

Impacts of ocean currents on ice-sheet melting

Summary

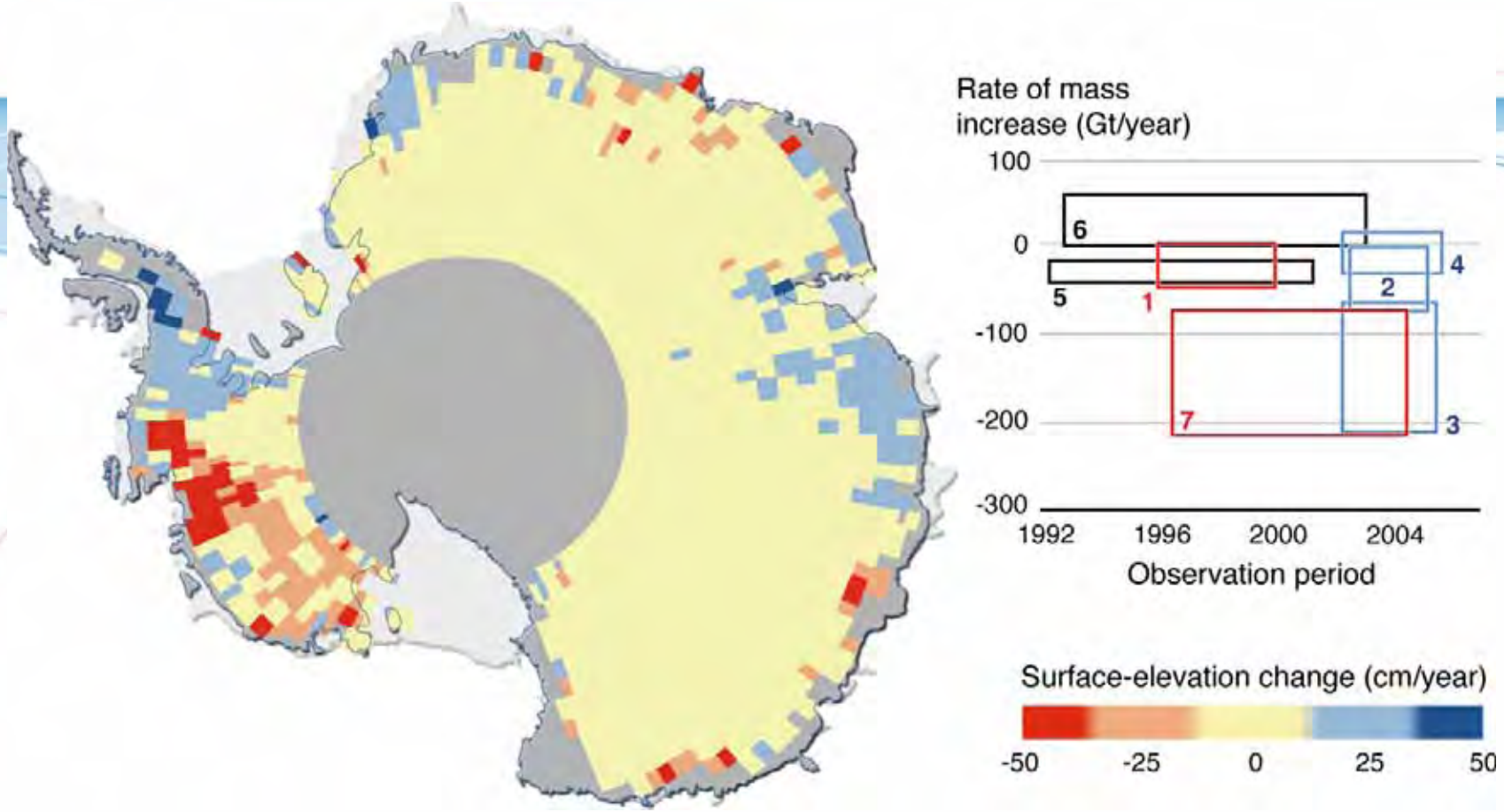
- Including full suit of IPCC forcing anomalies results in a net increased freshwater flux from ice-shelves (~200Gt/a) and comparable to observed change
- Winds are the driver of melt in West Antarctic Ice Sheet (Pine Glacier)
- Deep shelf cavities are wind driven on average
- Buoyancy changes drive shallower ice melt
- Recent bottom water properties changes driven by winds melting ice shelves in Ross and Mertz Glacier regions
- Bottom water properties are sensitive to anomalous wind forcing only
- East Antarctica has reduced melt rates from winds (weakening of easterlies?)

Impacts of ocean currents on ice-sheet melting

Caveats.....

- Do easterlies really weaken around east Antarctica

Mass Balance of Antarctica



Antarctica, showing rates of surface-elevation change derived from satellite radar-altimeter measurements. The graph shows rates at which the ice-sheet mass was estimated to be changing based on radar-altimeter data (black), mass-budget calculations (red), and satellite gravity measurements (blue). Rectangles depict the time periods of observations (horizontal) and the upper and lower estimates of mass balance (vertical).

Sources (corresponding to numbers on rectangles): 1 Rignot and Thomas 2002; 2 Ramillien and others 200632; 3 Velicogna and Wahr 2006a3; 4 Chen and others 2006a;31; 5 Zwally and others 20055; 6 Wingham and others 2006a6; 7 Rignot and others

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Impacts of ocean currents on ice-sheet melting

References

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