# Ocean and Ice Sheet Modeling and Sea-level Rise

Presented by

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Geophysical Fluid Dynamics Laboratory Review

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# GFDL's Ocean-Climate Models in Service to NOAA and the World

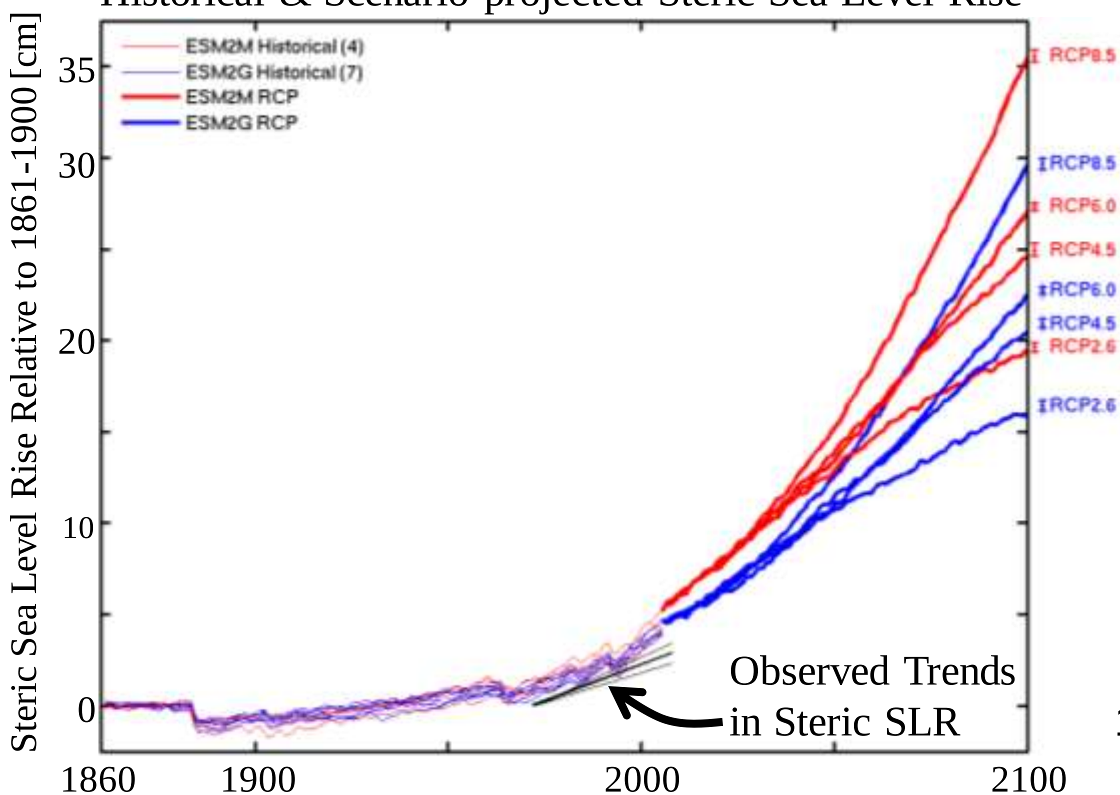
- MOM series of models is widely used & will continue to be so
  - MOM4.1 had many active users worldwide
  - MOM5 is the latest public release of MOM (October, 2012)
  - GOLD (GFDL's isopycnal coordinate ocean) now incorporated into MOM6
  - *All GFDL ocean & climate model development is focused on* ***MOM6***
- Aim for MOM6 is to capture the complete range of climatically important physical processes in the ocean, with robust diagnostics, and effective and efficient numerics (Talk by Adcroft)
- Key element of all GFDL coupled climate models
- Used for important operational products in NOAA and abroad
  - E.g., NCEP using MOM4.1 in seasonal predictions; CM2.1 is a part of CFS2.0 ; MOM5 is currently being ported for use in NCEP/CFS3.0
  - E.g., MOM4/MOM5 used for operational and research applications in Australia, Brazil, India, South Africa, …

# The Ocean's Role in Climate Change

*Exploring the dynamics of Sea Level Rise*

**ESM2M** & **ESM2G** – same atmosphere & ecosystems, different ocean models.

Historical & Scenario-projected Steric Sea Level Rise



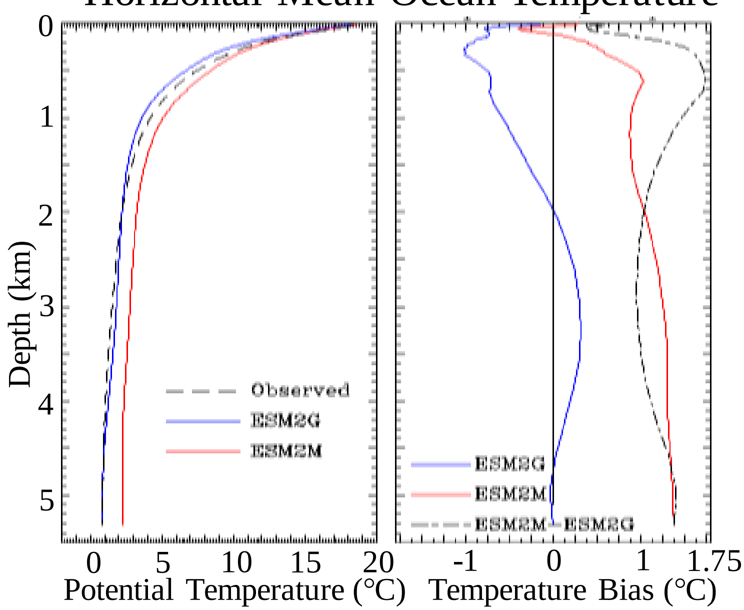

Ref: Hallberg et al., 2013, *J. Climate*

Projecting sea-level rise is prominent in NOAA's Next Generation Strategic Plan:

- Adaptation to Climate Change
- Resilient Coastal Communities

ESM2G & ESM2M 1980-2000

Horizontal-Mean Ocean Temperature




18% larger steric SLR in ESM2M

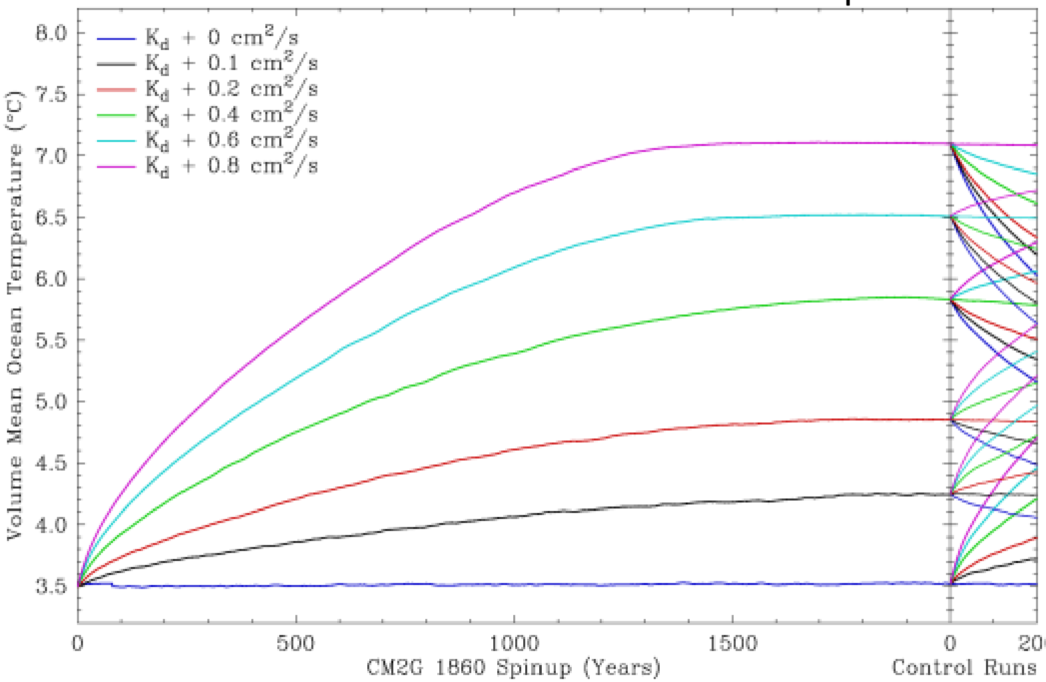
9% due to more & deeper heat uptake

7% due to warmer spun-up ocean

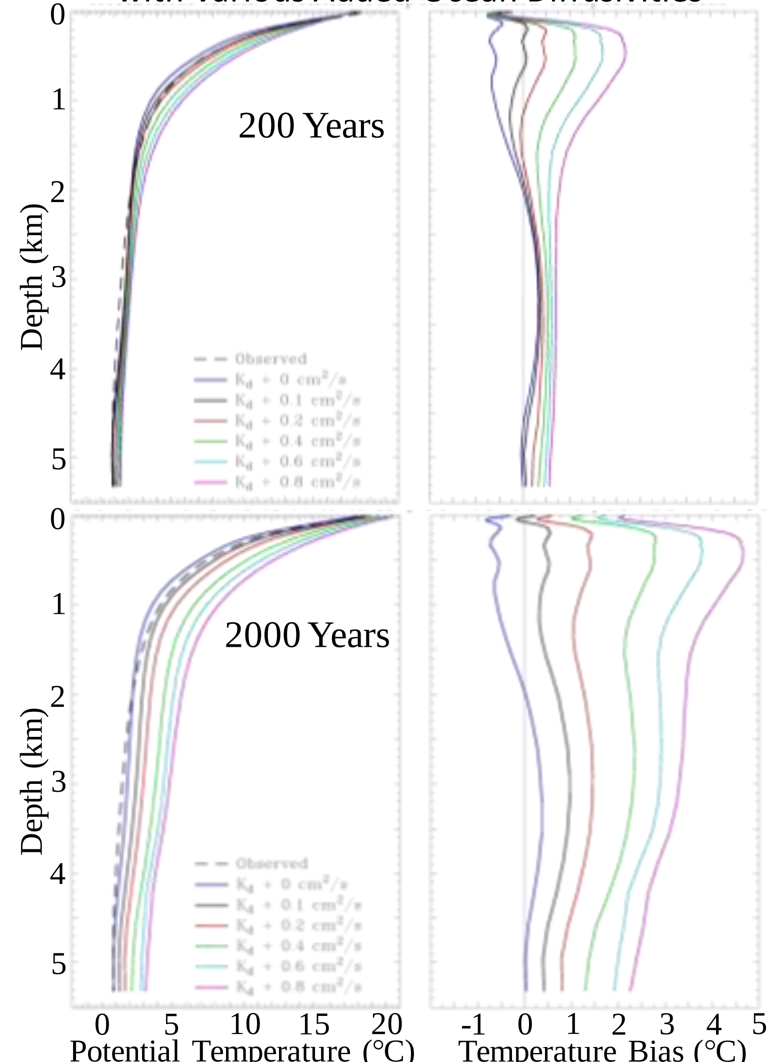
# Sensitivity of the Ocean State and Steric Sea Level Rise to Diapycnal Mixing in the Ocean

Coupled model ocean drift and equilibrium bias are sensitive to the magnitude of diapycnal diffusion (mixing) in the ocean.

ESM2G Volume-mean Ocean Potential Temperatures

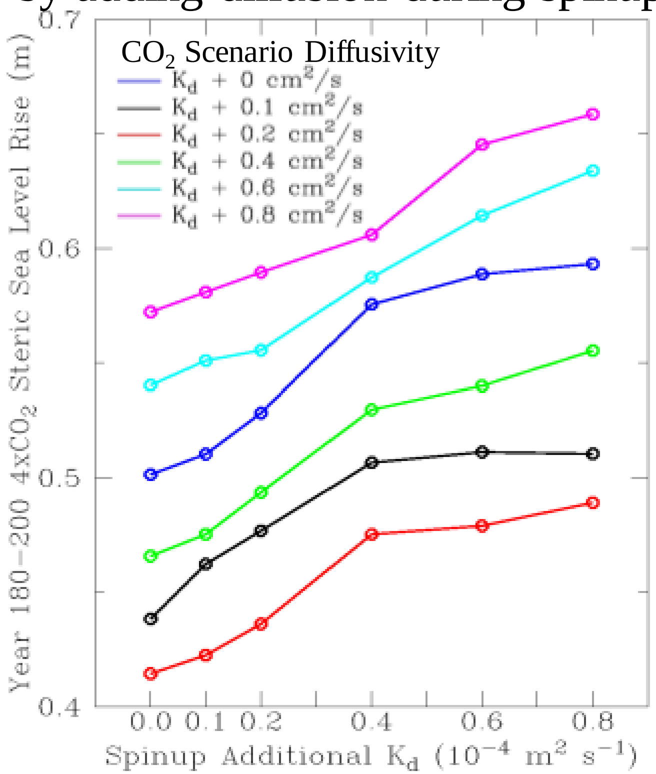



Horizontal Mean Ocean Temperature and Bias with Various Added Ocean Diffusivities

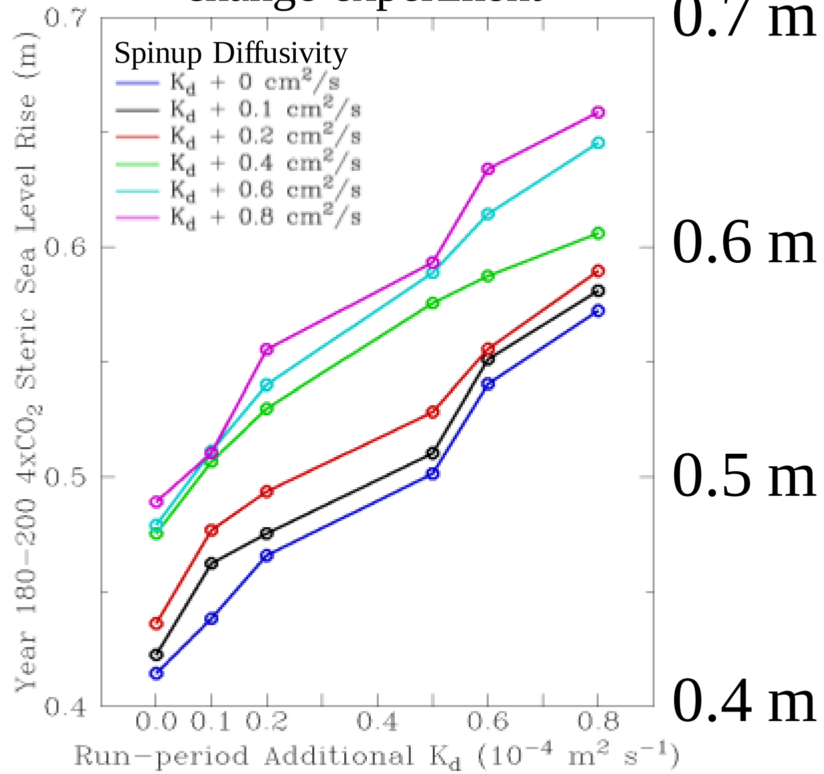


## Steric Sea-Level Rise after 200 Years in 1%/year to 4x $CO_2$ Run, Relative to Control

Changing initial conditions by adding diffusion during spinup




Adding diffusion during the climate change experiment



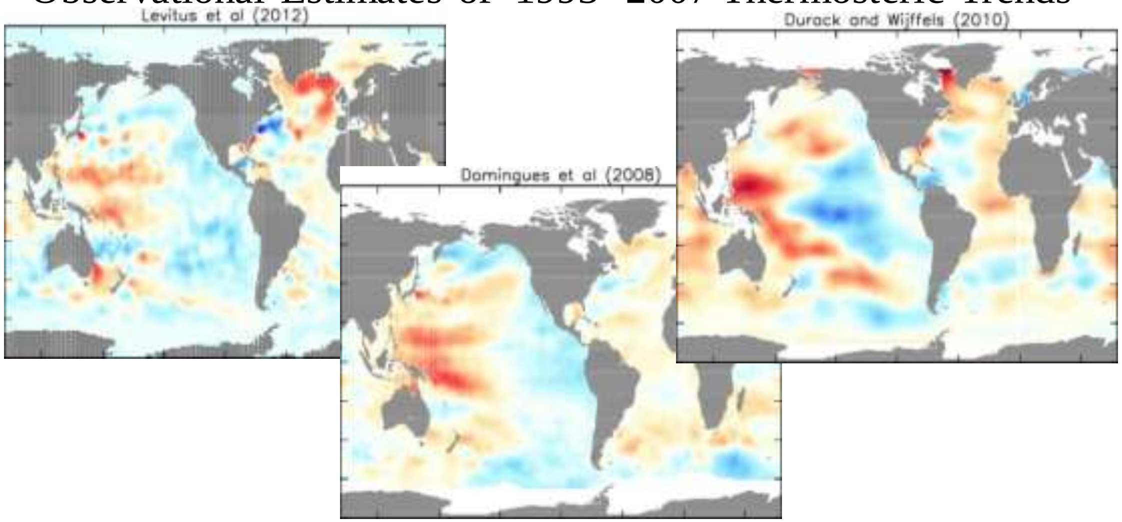

Adding diapycnal diffusion increases steric sea level rise both by increasing heat uptake and by warming the ocean (warmer water expands more when heated).

Both the initial conditions and mixing during the run contribute significantly.

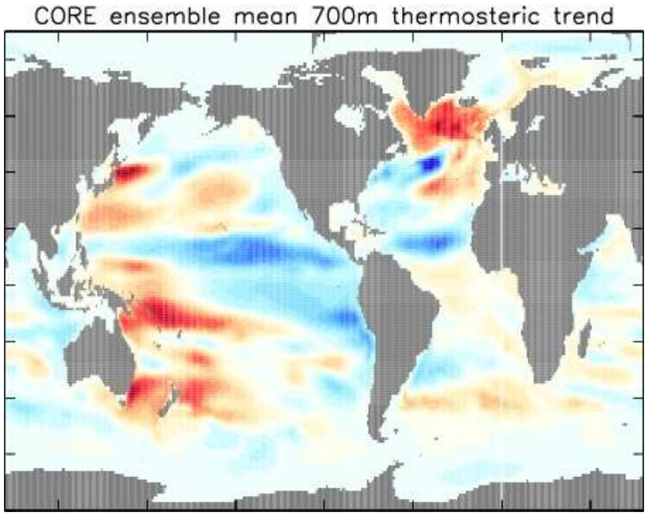
# Steric sea level studies

- Griffies and Greatbatch (2012):
  - Developed a theoretical framework for global mean steric sea level.
  - Emphasized role of ocean thermal expansion variations in determining how heating and mixing impact steric sea level.
- Griffies + 40 co-authors (2014):
  - Assessed sea level trends in 13 historically forced (CORE-II) global ocean-ice models.
  - Models generally capture recent linear trends in West Pacific and North Atlantic thermosteric sea level, both associated with natural variability in atmospheric forcing.

Observational Estimates of 1993- 2007 Thermosteric Trends

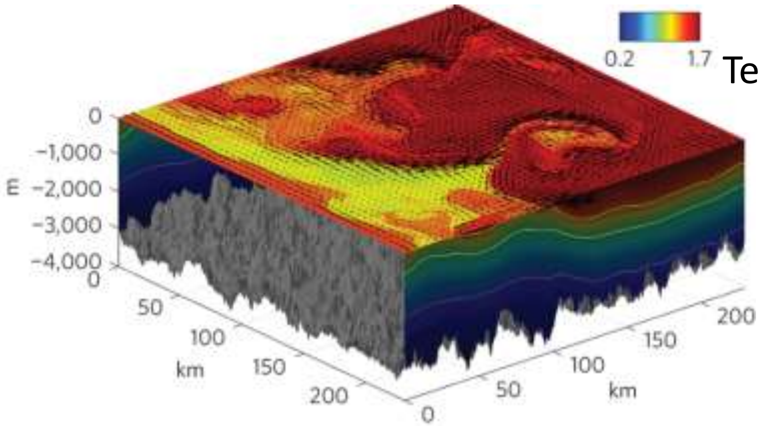



Mean of 13 CORE-forced Ocean Models



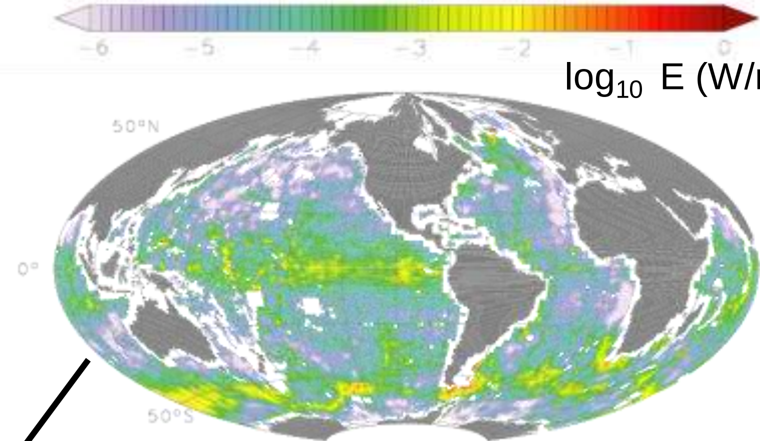
# Parameterization of ocean lee waves

Mesoscale eddies transmit energy to lee-waves at rough bottom topography, which break and cause mixing



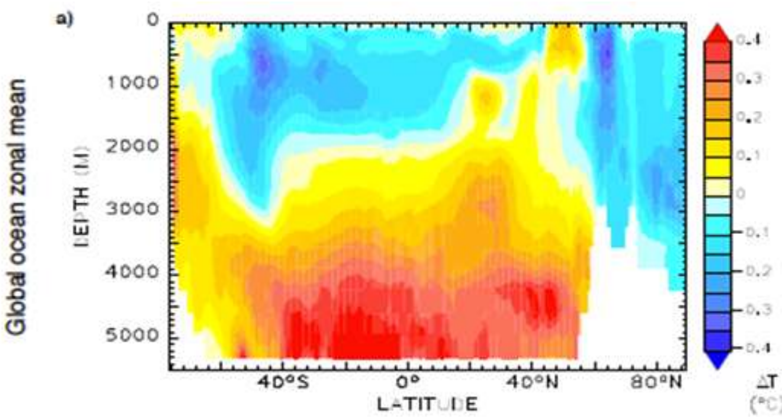

*Nikurashin, Vallis and Adcroft, 2013*

Estimate of energy transferred from eddies to lee-waves




*Nikurashin and Ferrari, 2011*

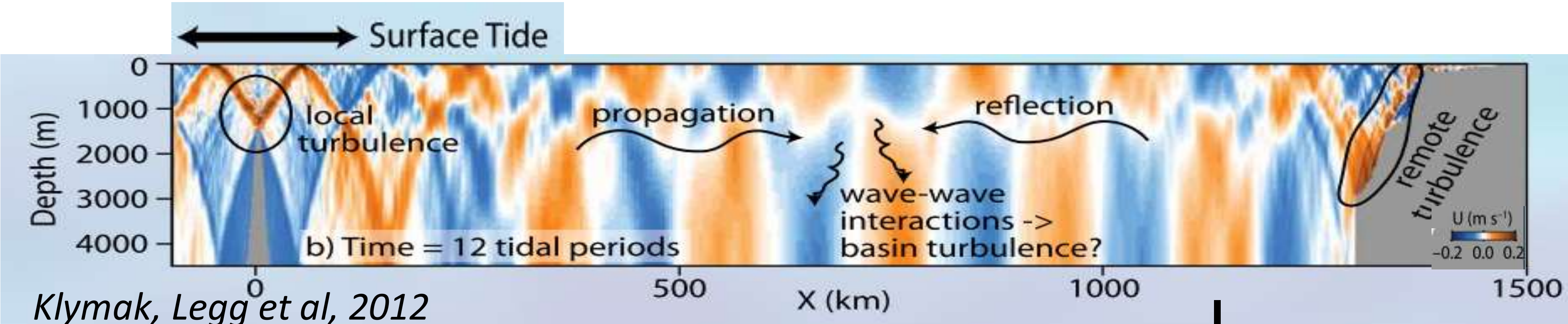
Addition of lee-wave driven mixing parameterization leads to warmer deep ocean, cooler upper ocean.




Impact of this extra supply of energy for mixing in ESM2G

*Melet, Hallberg, Nikurashin and Legg, 2014*

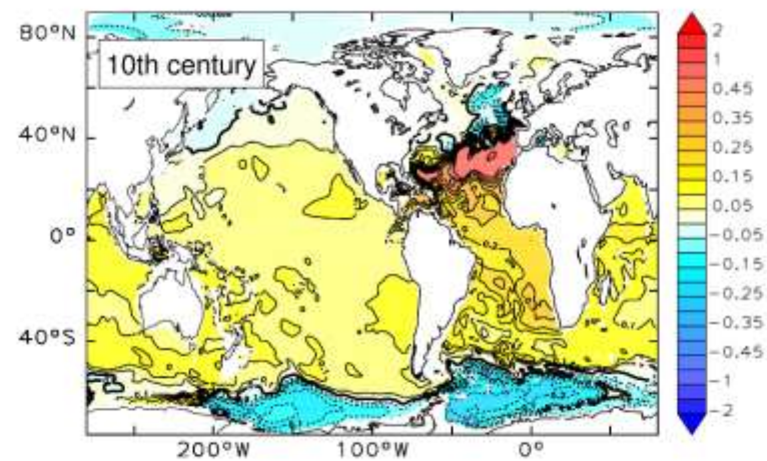
# Parameterization of mixing by internal tides




*Klymak, Legg et al, 2012*

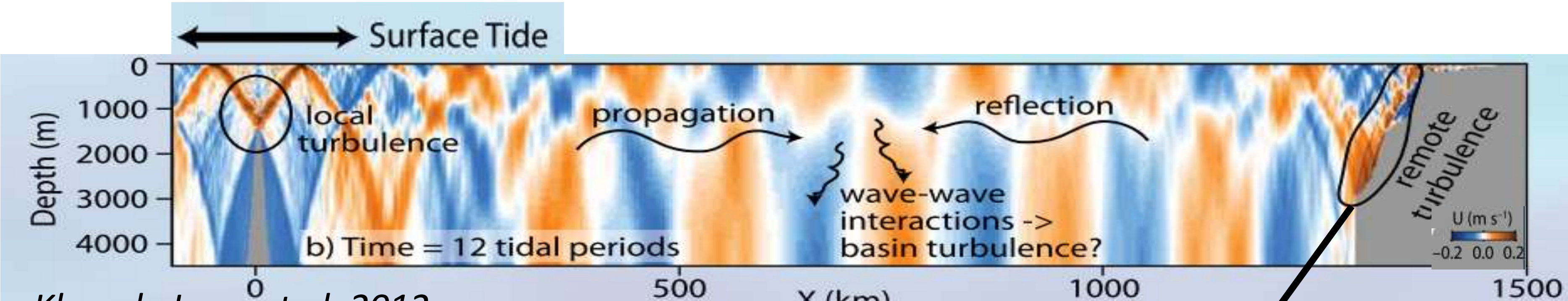
Improved energetically consistent parameterizations are developed in collaboration with academic partners in the NOAA/NSF funded Internal Wave Driven Mixing Climate Process Team.

1500m Temperature difference due to improved vertical profile for internal tide driven mixing




*Melet, Hallberg, Polzin and Legg, 2013*

# Parameterization of mixing by internal tides

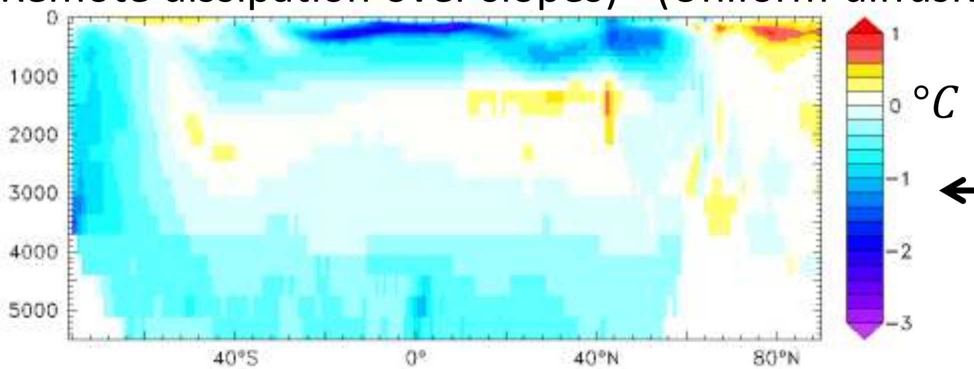



*Klymak, Legg et al, 2012*

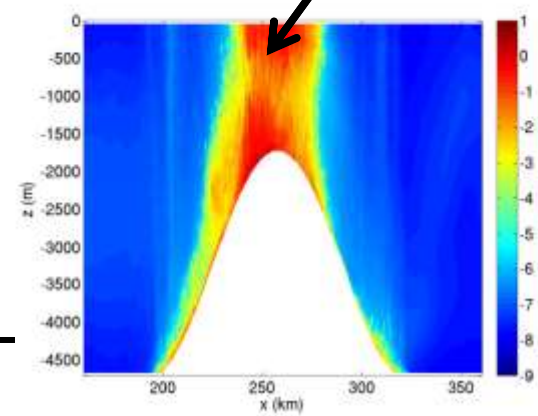
Zonally-averaged temperature difference:

Same energy input, different wave-breaking locations

(Remote dissipation over slopes) - (Uniform diffusivity)




*Melet, Hallberg and Legg, 2014*




$\varepsilon/(\frac{U^2}{T})$

log10

Internal wave shoaling leads to enhanced dissipation over tall ridges and continental slopes

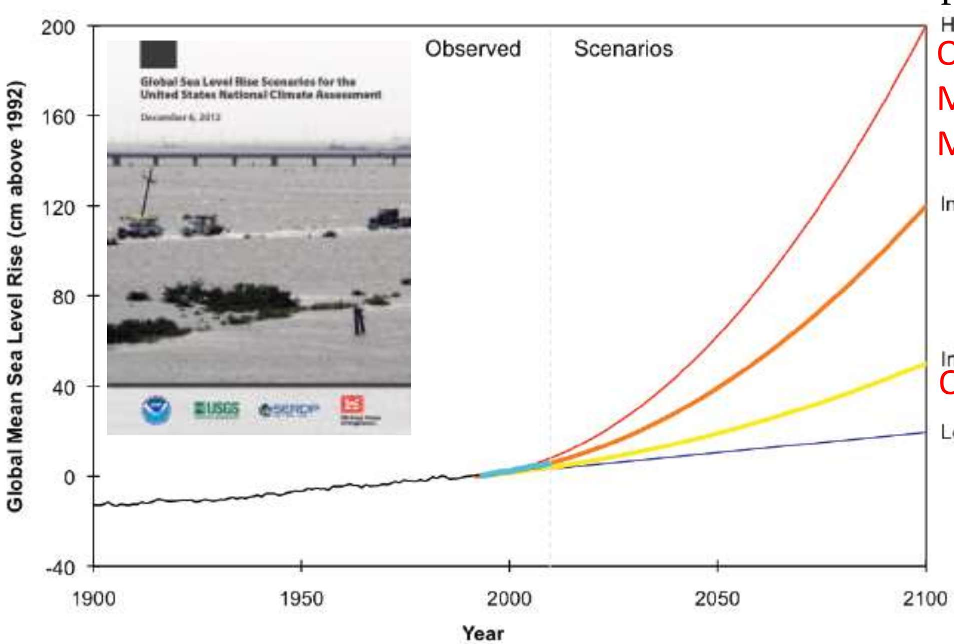
*Legg, 2014*

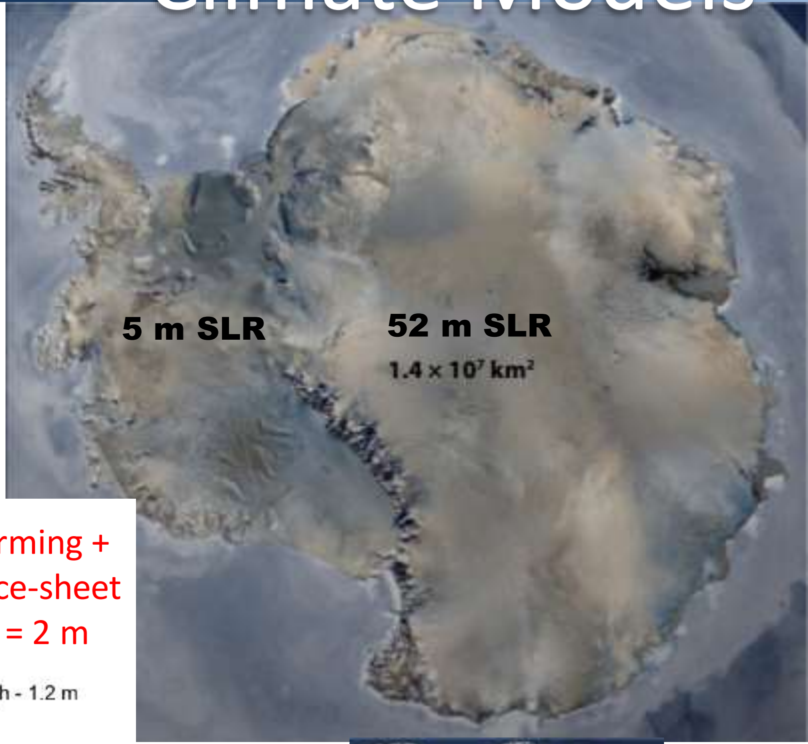
## Location of mixing matters to large-scale ocean and climate

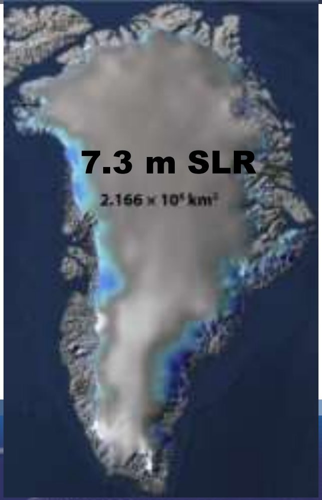
# Coupling Dynamic Icesheets into GFDL's Climate Models

- Icesheet mass loss is the largest term and largest source of uncertainty in 21st century sea level rise projections.
- GFDL is addressing this uncertainty by developing a fully coupled and dynamically evolving ice sheet modeling capability.

Sea Level Rise Scenarios from 2012 NOAA/CPO Report

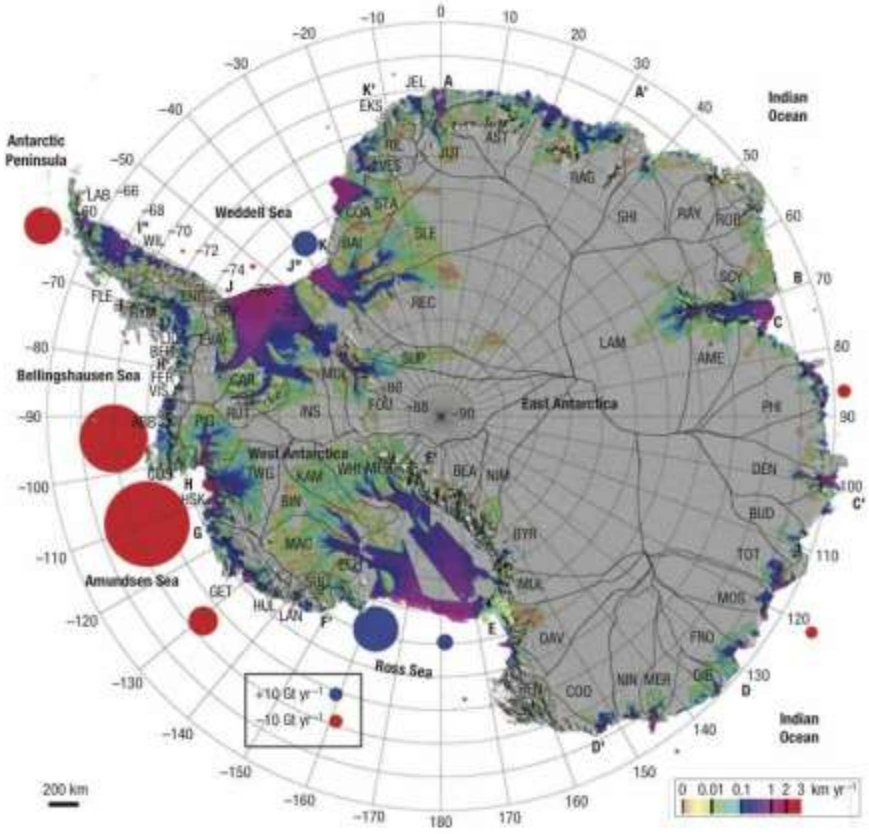


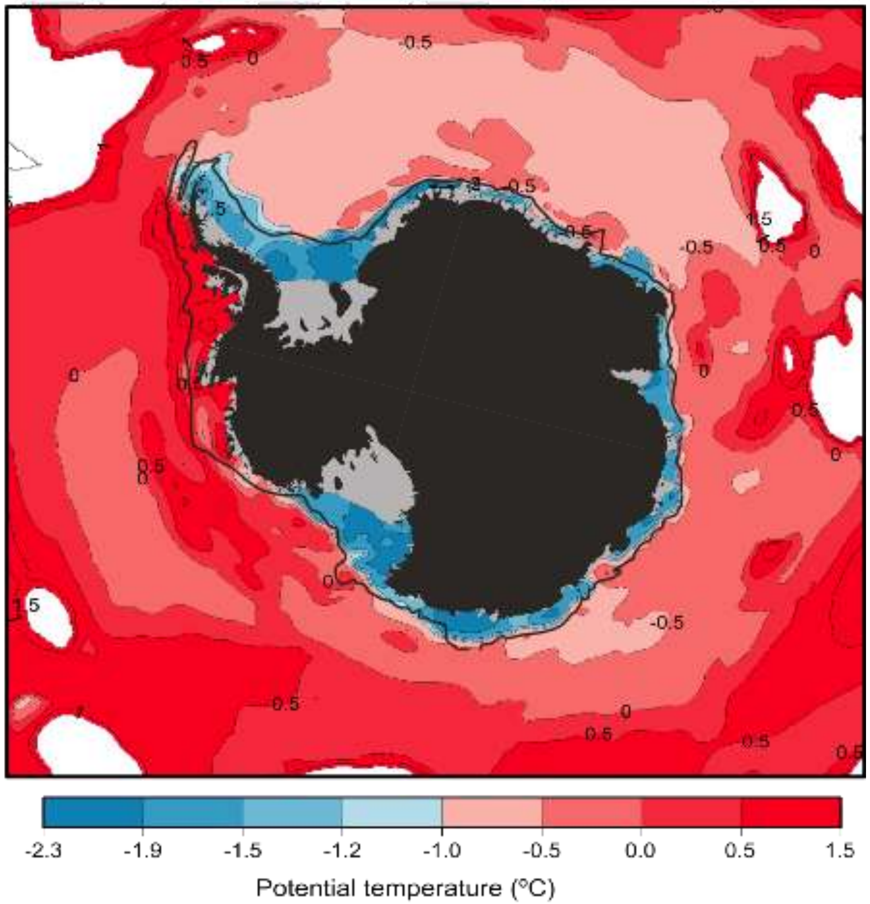
# Coupled Ice-shelf-ocean Interaction

Antarctic mass balance (1992-2005)



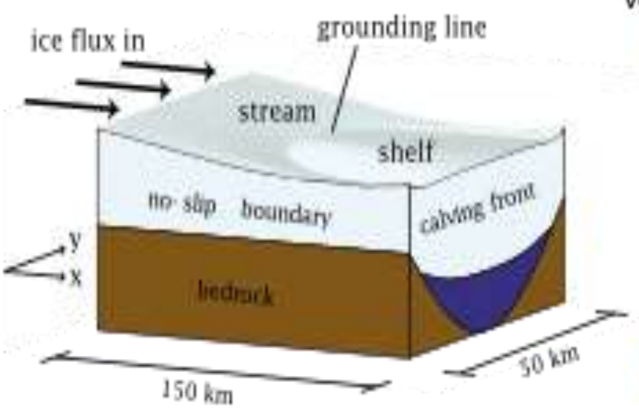
Rignot et al (2008)

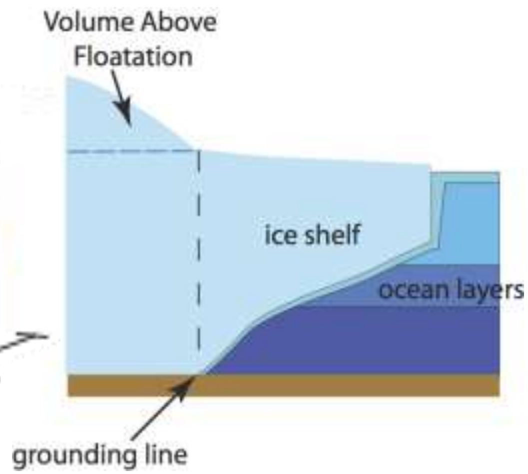
Ocean bottom temperature

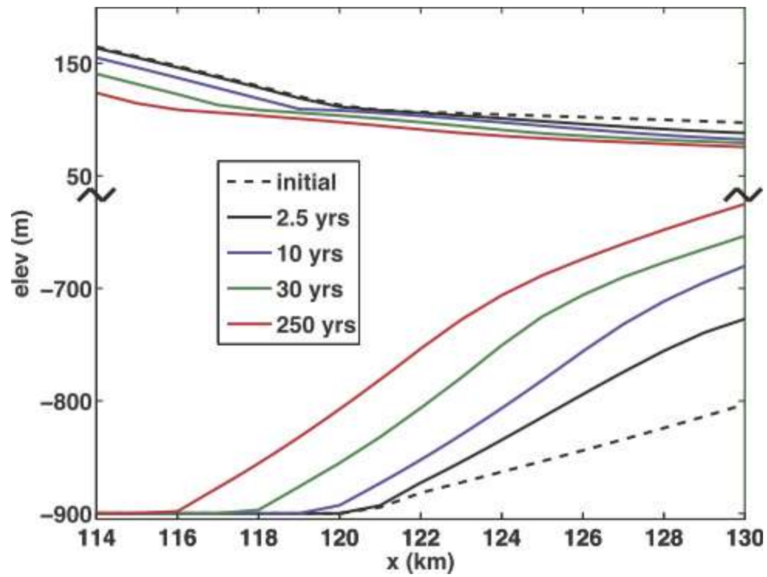



Nichols et al (2005)

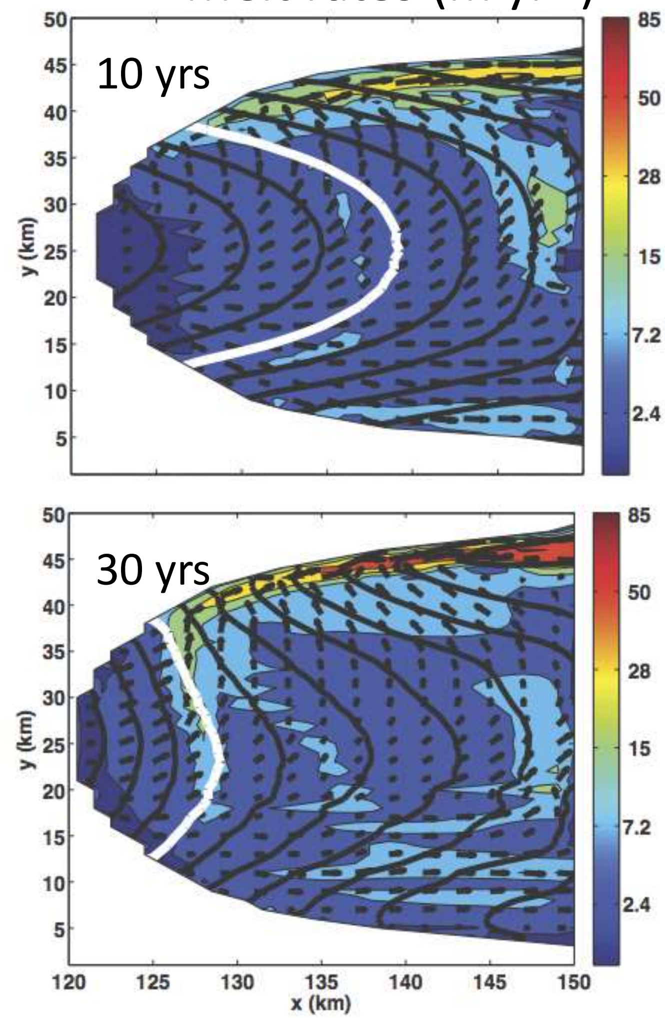
# **Dynamic** Ice-shelf-ocean Interaction



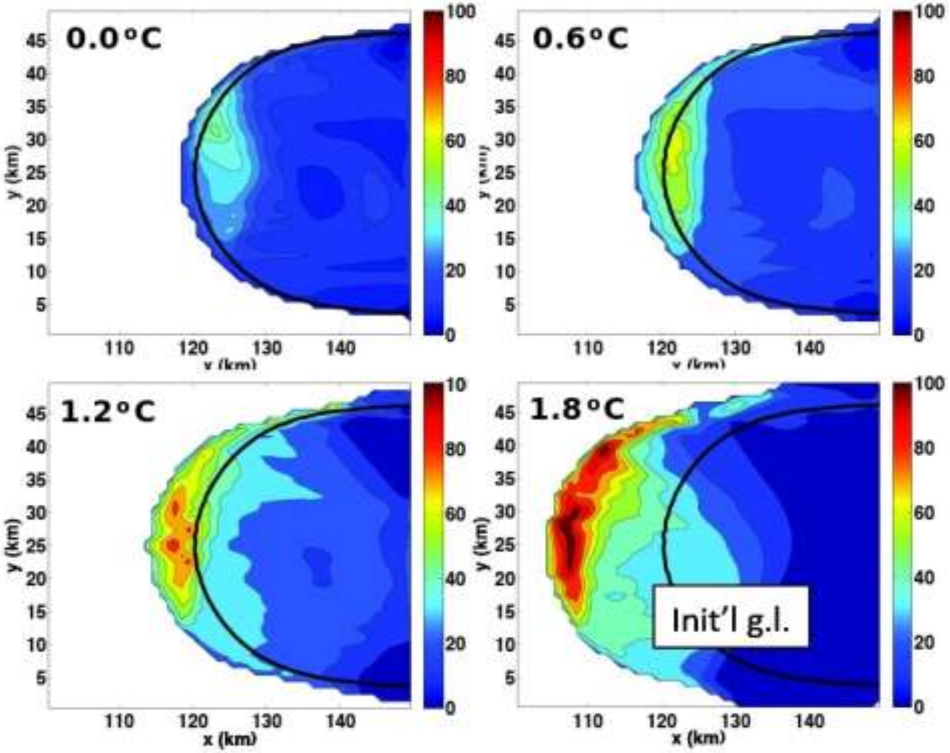

Melt rates (m $yr^{-1}$)



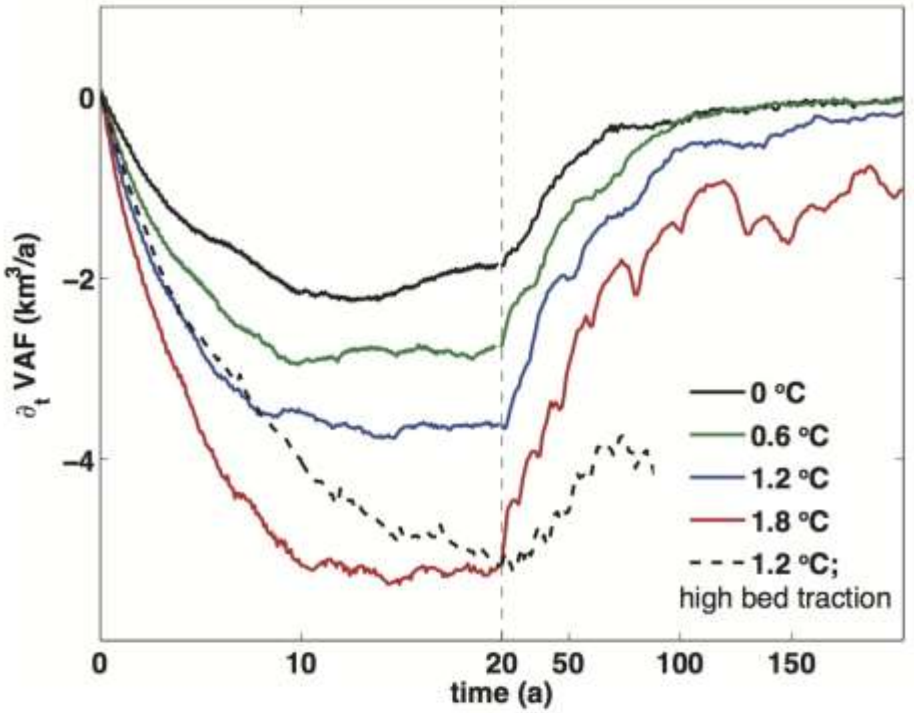

Goldberg et al *JGR* (2012)

# **Dynamic** Ice-shelf-ocean Interaction

Melt rates (m yr$^{-1}$)

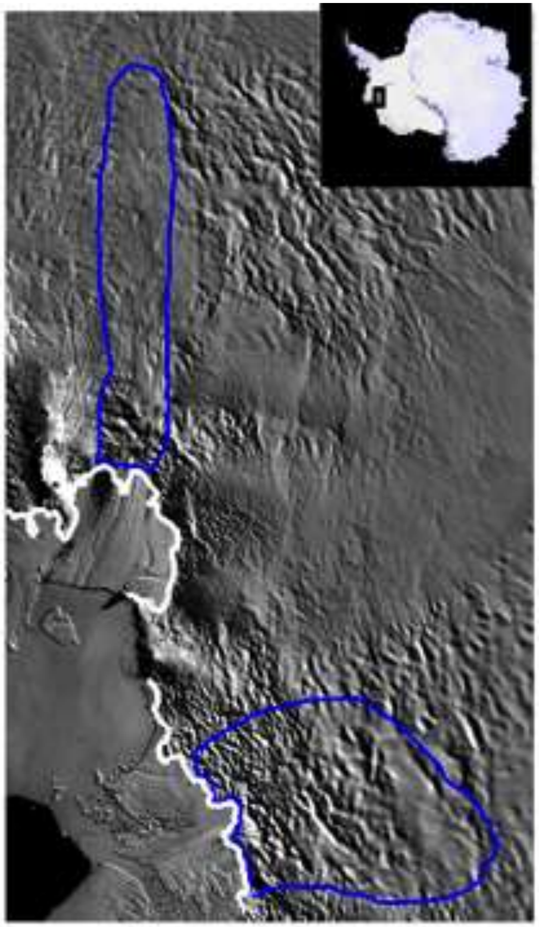



Rate of change of
Volume Above Flotation



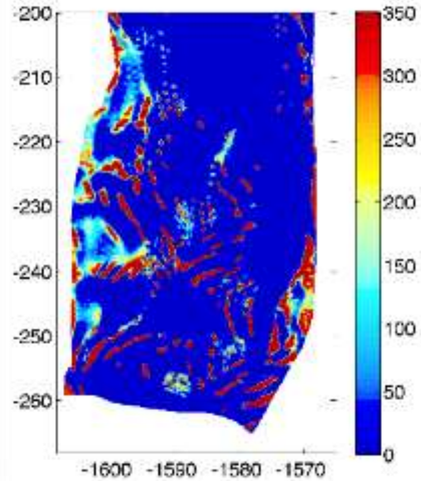

Goldberg et al *JGR* (2012)

# Basal conditions under ice streams

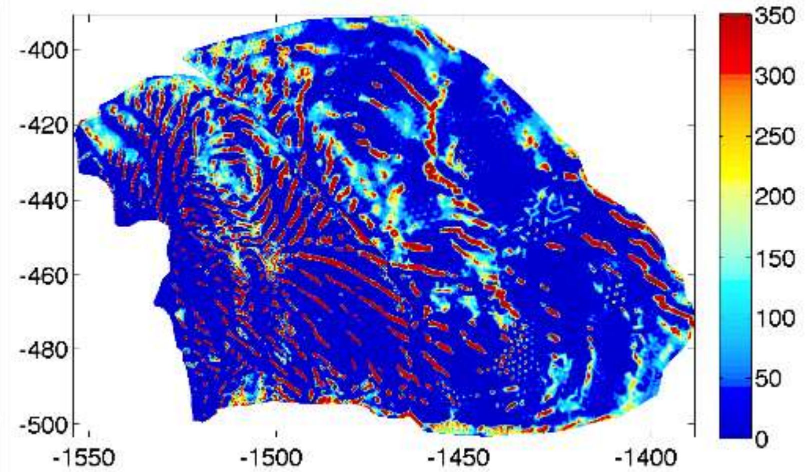


Inverted basal shear stress (kPa)

Pine Island Glacier



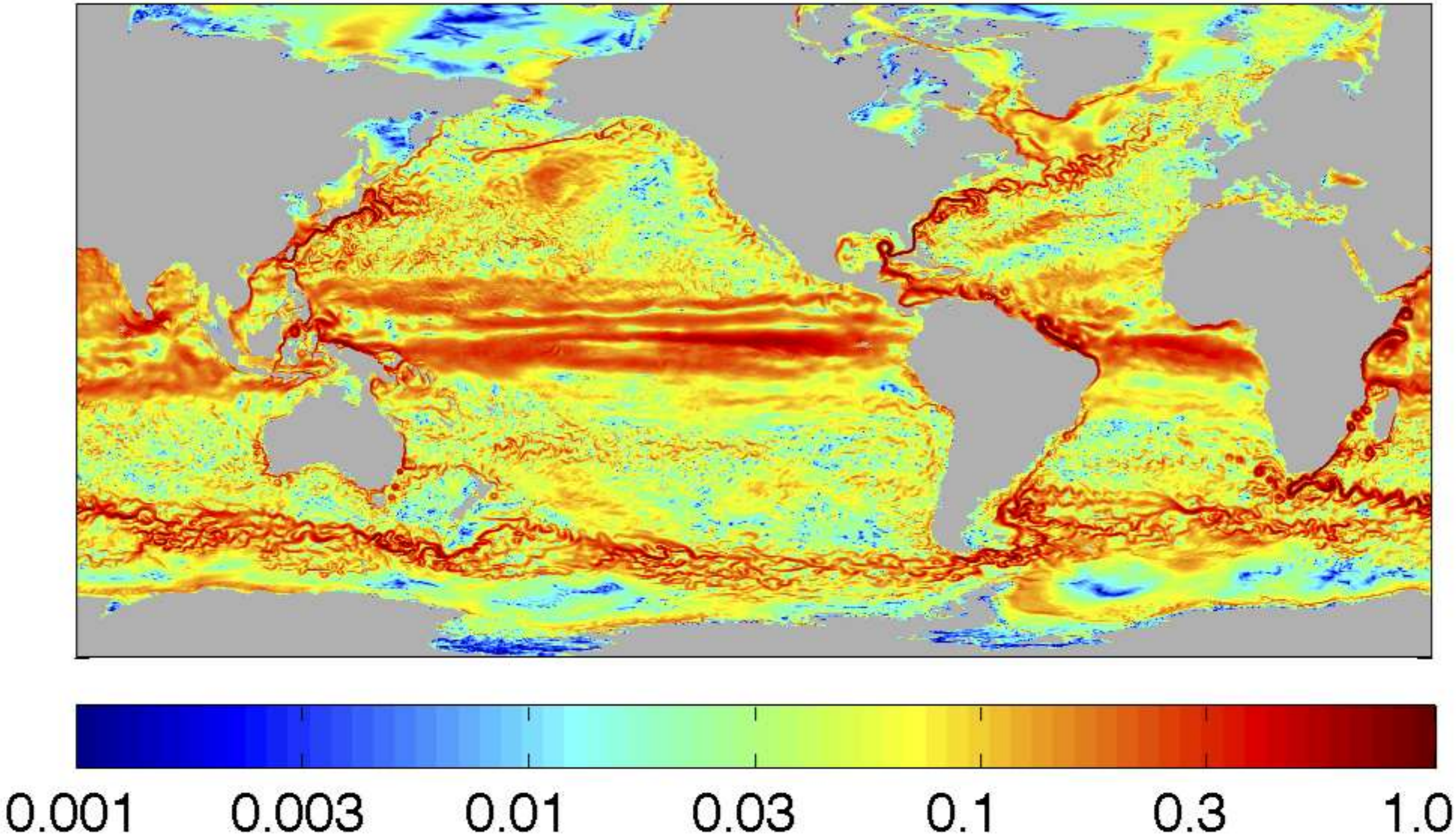

Thwaites Glacier




Sergienko & Hindmarsh, *Science* (2013)

# **Coupled** Ice-shelf-ocean Interaction

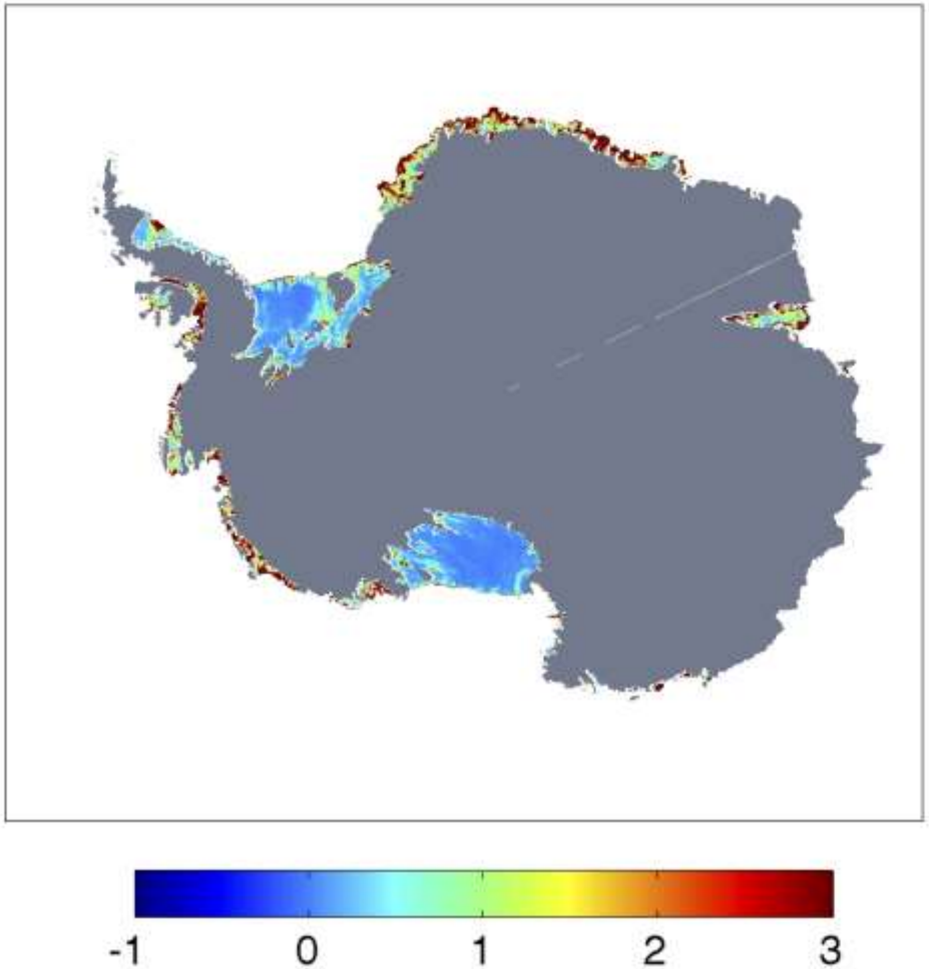
## MOM6 ⅛ deg **Global** Ocean Model




Ocean Mixed Layer Speed (m $s^{-1}$)

# **Coupled** Ice-shelf-ocean Interaction

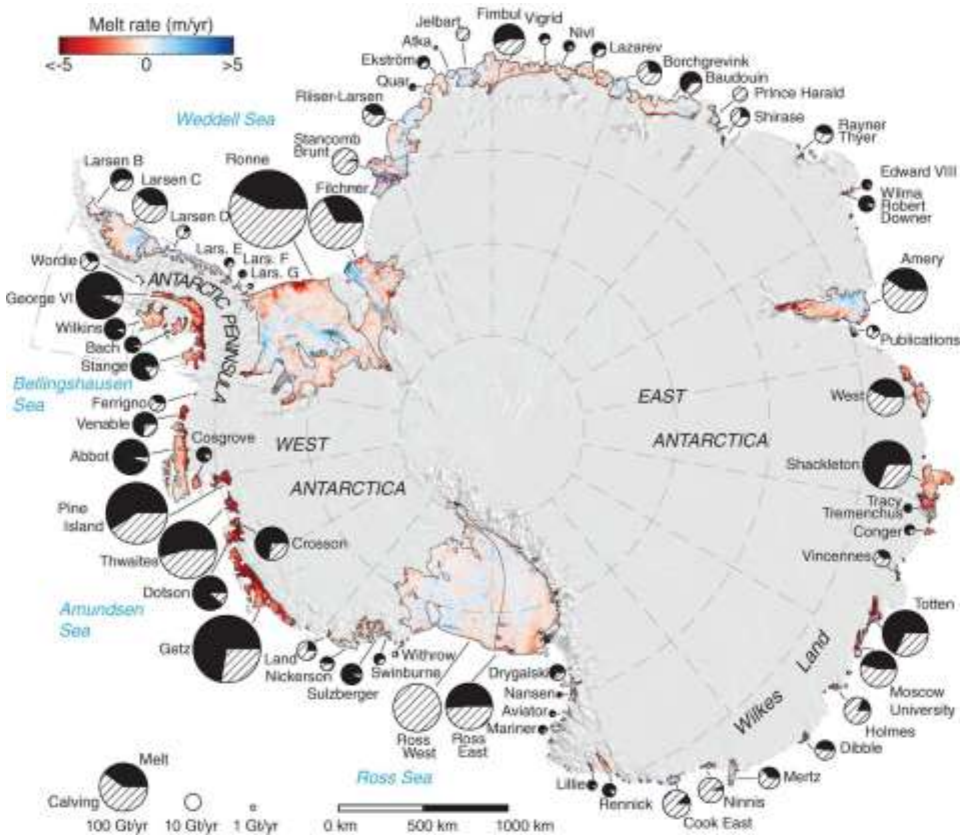
## MOM6 ⅛ deg **Global** Ocean Model




Modeled Melt Rates (m $yr^{-1}$)

# Calving and Icebergs Climate Process Team

## Antarctic mass loss




# Melting 45% Calving 55%

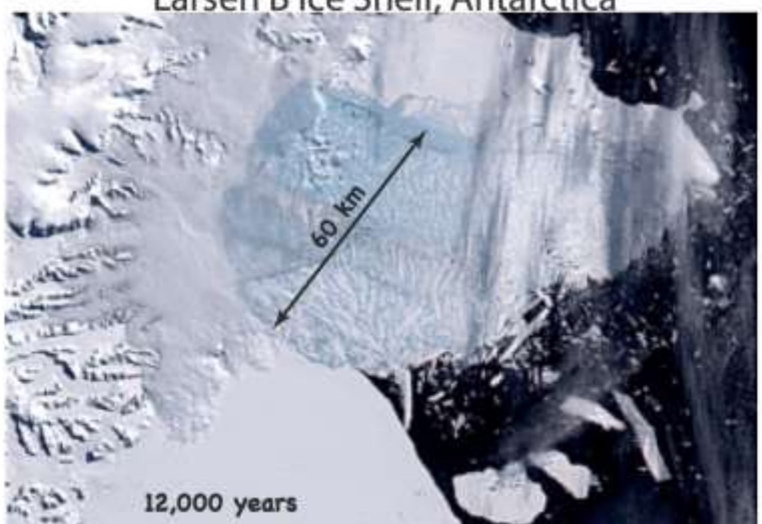
Rignot et al. (2013)

# Calving and Icebergs Climate Process Team

Ross Ice Shelf, Antarctica


Jakovshavn Isbræ, Greenland

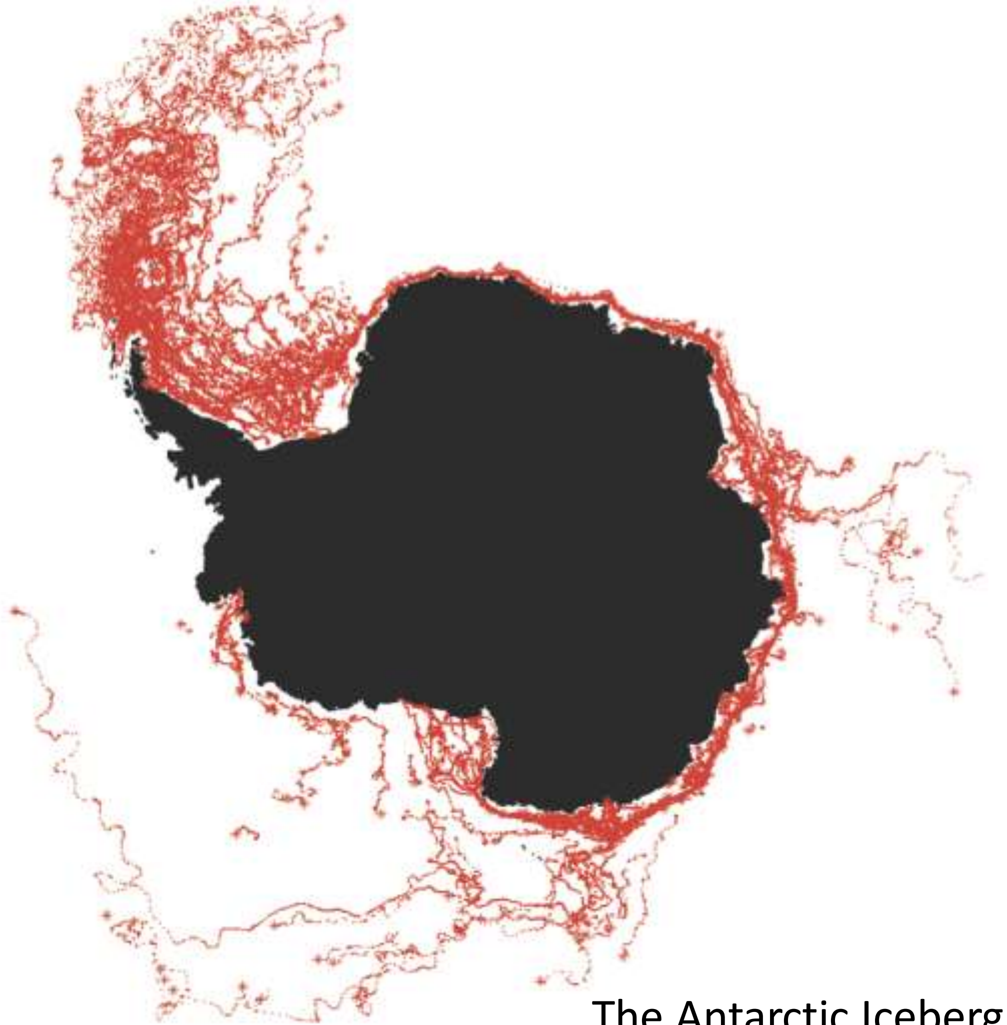

Larsen B Ice Shelf, Antarctica




Columbia Glacier, Alaska

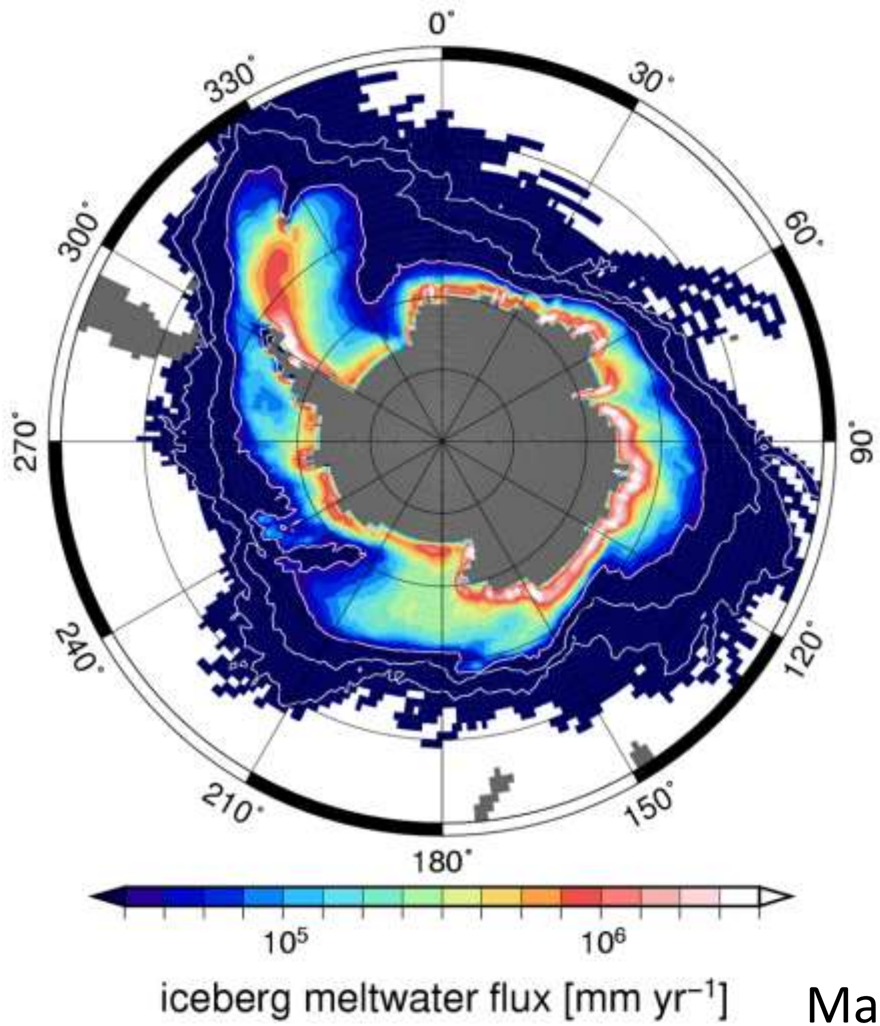
# Calving and Icebergs Climate Process Team

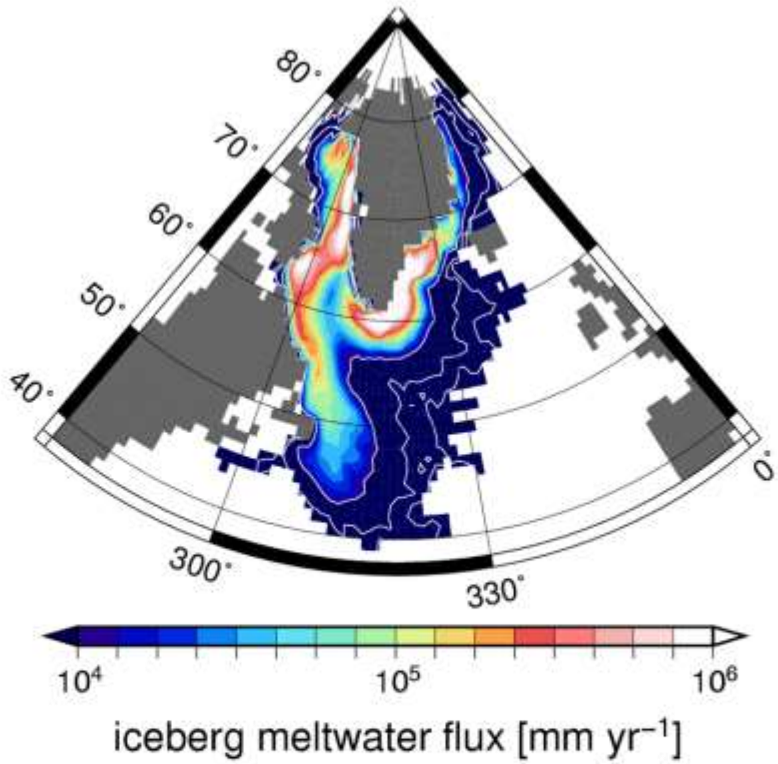
## Icebergs tracks 1999-2010



The Antarctic Iceberg Tracking Database

# Iceberg representation in GFDL climate models




Martin and Adcroft, *Ocean Modelling* (2010)

# Calving and Icebergs Climate Process Team

## Team

- Princeton CICS (Lead)
- GFDL
- University of Alaska
- University of Michigan
- Kansas University
- Penn State

## Goals

- Calving parameterizations
- Iceberg-ocean interactions
- Compile available data on calving and icebergs

Calving and Icebergs Climate Process Team Supported by NOAA/MAPP via NOAA/CPO

# Summary

- GFDL has unified its ocean model development efforts behind MOM6.
- Sea level rise exhibits significant sensitivity to the representation of the ocean and ocean mixing.
- GFDL is developing and adopting increasingly physically based representations of ocean mixing processes.
  - Success also requires limiting spurious numerical mixing
- Coupled ice-sheet / ocean interactions are central to societally important questions about Sea Level Rise.
  - GFDL is at the forefront in the development of the required fully coupled ice-sheet / ocean modeling capabilities.