Southern Ocean Heat and Carbon Uptake

An Update on the Progress by the:
JOINT U.S. CLIVAR/OCB WORKING GROUP

Co-Chairs:
Igor Kamenkovich (U. Miami)
Joellen Russell (U. Arizona)

Ocean Carbon & Biogeochemistry

U.S. CLIVAR Climate Variability & Predictability

JOINT U.S. CLIVAR/OCB WORKING GROUP: Heat and Carbon Uptake by the Southern Ocean

Southern Ocean Working Group	
Igor Kamenkovich, co-chair	University of Miami
Joellen Russell, co-chair	University of Arizona
Cecilia Bitz	University of Washington
Raffaele Ferrari	Massachusetts Institute of Technology
Sarah Gille	University of California, San Diego/SIO
Bob Hallberg	NOAA/GFDL
Ken Johnson	Monterey Bay Aquarium Research Institute
Irina Marinov	University of Pennsylvania
Matt Mazloff	University of California, San Diego/SIO
Jorge Sarmiento	Princeton University
Kevin Speer	Florida State University
Lynne Talley	University of California, San Diego/SIO
Rik Wanninkhof	NOAA/AOML

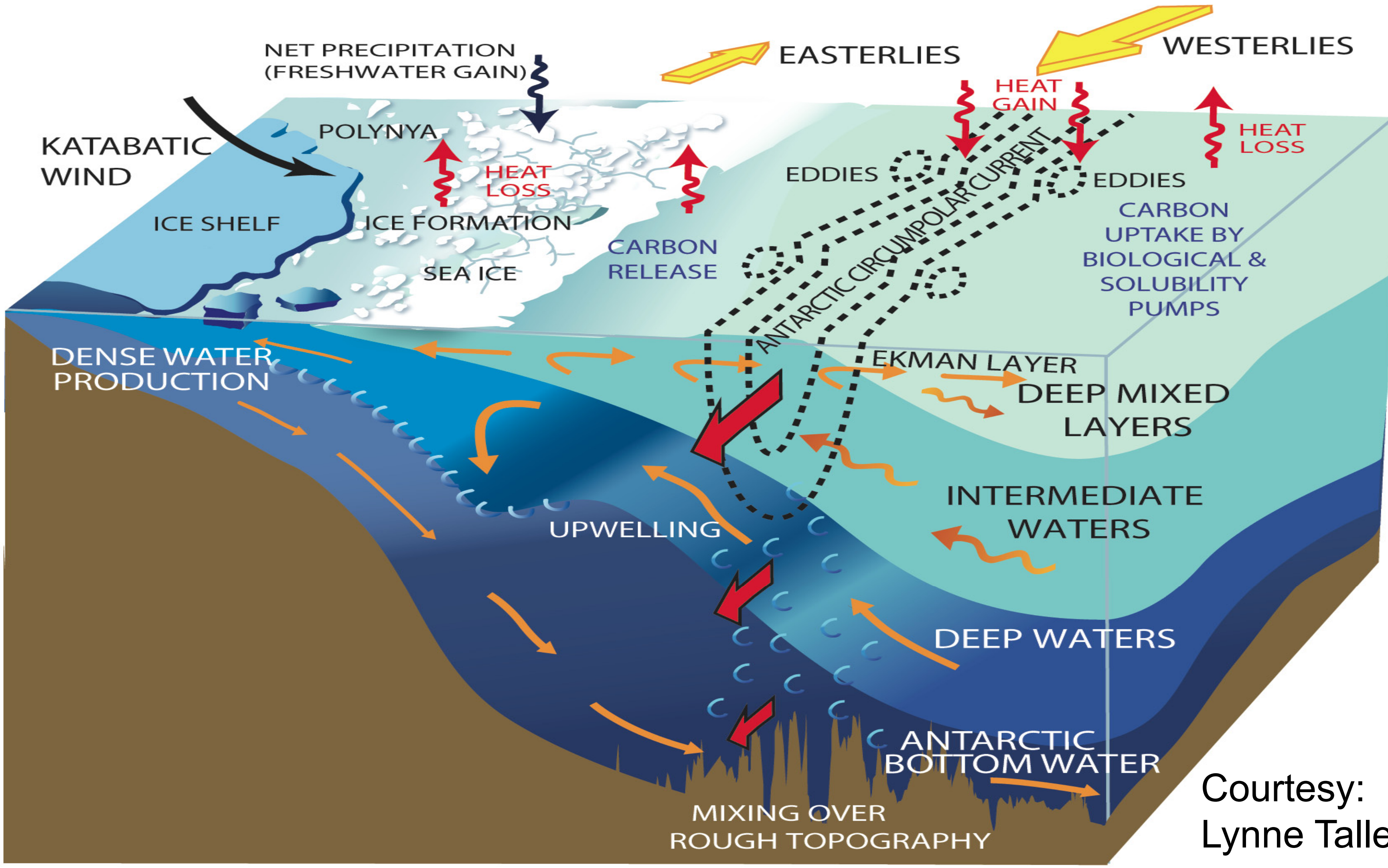
Goals:

- Improve understanding of the role of mesoscale eddies in the heat and carbon uptake by the Southern Ocean.
- Improve understanding of how the Southern Ocean stratification, circulation and heat and carbon uptake will respond to a changing climate.

What is the role of the Southern Ocean in the global climate system?

1. It may account for up to half of the annual oceanic uptake of anthropogenic carbon dioxide from the atmosphere (cf., Gruber et al., 2009)
2. Vertical exchange in the Southern Ocean is responsible for supplying nutrients that fertilize three-quarters of the biological production in the global ocean north of 30°S (Sarmiento et al., 2004)
3. It may account for up to 70 ± 30% of the excess heat that is transferred from the atmosphere into the ocean each year (see analysis of IPCC AR4 models)
4. Southern Ocean winds and buoyancy fluxes are the principal source of energy for driving the large scale deep meridional overturning circulation throughout the ocean (e.g., Toggweiler and Samuels, 1998; Marshall and Speer, 2012)

The Antarctic Circumpolar Current System



Courtesy:
Lynne Talley

SOWG Outcomes and Deliverables

- Observationally-based data/model metrics for the consistent evaluation of modeling efforts by Southern Ocean and Antarctic scientists.

- A White Paper that:
  (i) assesses the state of our understanding of the role of eddies in the Southern Ocean in both the data and the models;
  (ii) identifies the most critical observational targets needed to fill in gaps in our understanding of the role of the Southern Ocean in present and future climate.

- A Workshop/Conference jointly sponsored with the Oceanic Carbon Uptake Working Group, with the goal of:
  (i) sharing the developed metrics for model evaluations;
  (ii) identifying important biases in the AR5/CMIP5-type model simulations of present and future climate, stemming from the lack of mesoscale eddies;
  (iii) providing guidance for estimating and reducing uncertainty in climate projections.

- A summary of WG activities/products for the U.S. CLIVAR and OCB

SOWG Planned Activities

- ***Spring/Summer 2012*** – Bi-monthly teleconferences: progress on development of targets and model assessment
- ***Fall 2012*** – 1st WG Meeting to: a) discuss/propose potential targeted process or measurement campaigns that will allow alignment of model-derived and observational evidence; and b) discuss/propose targeted process or sensitivity studies in available models with appropriate tracers and outputs to match our observational colleagues efforts
- ***Spring 2012/2013*** – Bi-monthly teleconferences: progress on development of measurement campaigns and modeling studies
- ***Summer 2013*** – Bi-monthly teleconferences: plan and arrange a larger workshop/conference to frame science questions motivated by new measurements, to evaluate the ability of high-resolution models to reproduce these effects, and to foster climate model improvements.
- ***2012-2013*** – conference calls every 6 months involving co-chairs of this WG (I. Kamenkovich and J. Russell) and the WG on "Oceanic carbon uptake in the CMIP-5 models" ("Carbon Uptake WG", cochairs: A. Bracco, C. Deutsch and T. Ito), to collaborate on the interpretation of model analysis in the Southern Ocean
- ***Fall/Winter 2013*** – Monthly teleconferences: write/submit white paper, summarizing key results from WG and workshop/conference.
- ***Spring/Summer 2014*** – 2nd WG Meeting and workshop/conference, joint with the Carbon Uptake WG, to update wider community on progress

Responsiveness to agency concerns:

This Working Group addresses key concerns of three supporting agencies, in particular:

NOAA: Describing and understanding the state of the climate system through integrated observations and analysis. Improving climate predictive capability from weeks to decades.

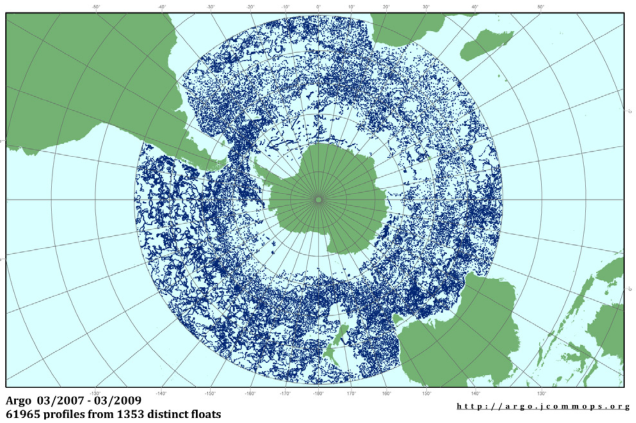
NASA: Understanding how climate variations induce changes in the global ocean circulation; improving predictions of climate variability and change [using satellite observations]; understanding the role of slowly varying components of the earth system (e.g. ocean and ice) in climate.

NSF: Advancing discovery, knowledge and understanding in climate science; understanding processes and exploiting new observing techniques; analyzing process studies to address known deficiencies in climate models; identifying critically important questions and the facilities and research required to address them; providing feedback on long-range scientific priorities.

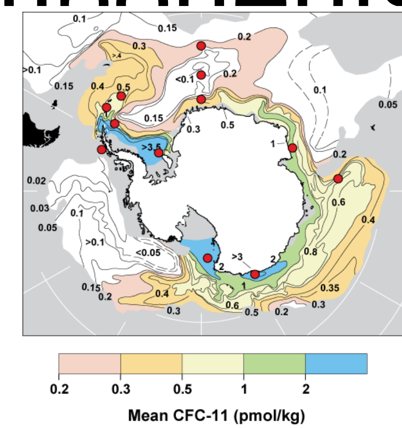
New Tools:

1) Southern Ocean Observations
2) Southern Ocean State Estimate
3) Mesoscale-Resolving Models

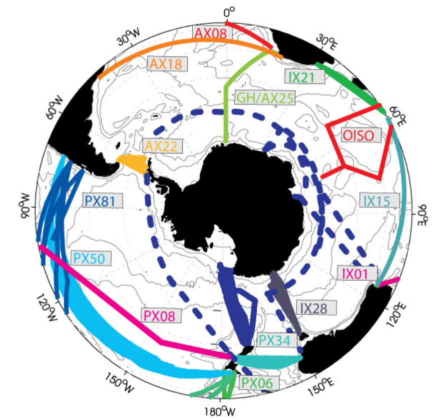
SOOS Observing System Components



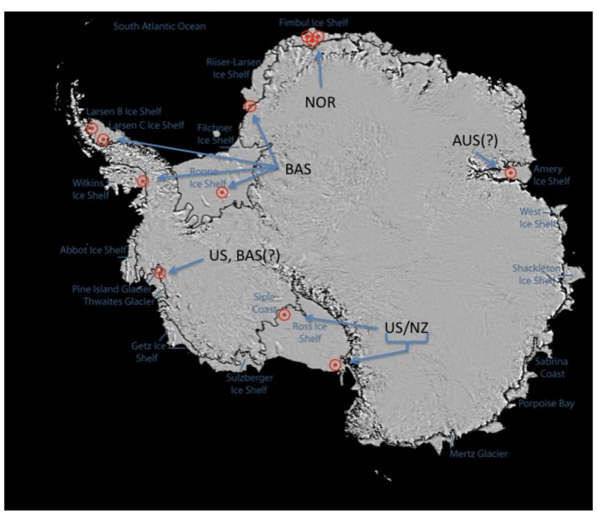
The locations of more than 60,000 Argo profiles of temperature and salinity collected during the 24 months of the IPY. Courtesy of Mathieu Balbeoch, JCOMMOPS



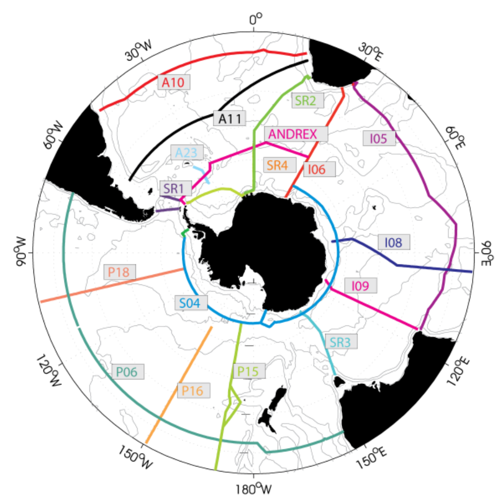
Map of proposed moored arrays (red circles) to sample the primary Antarctic Bottom Water formation and export sites



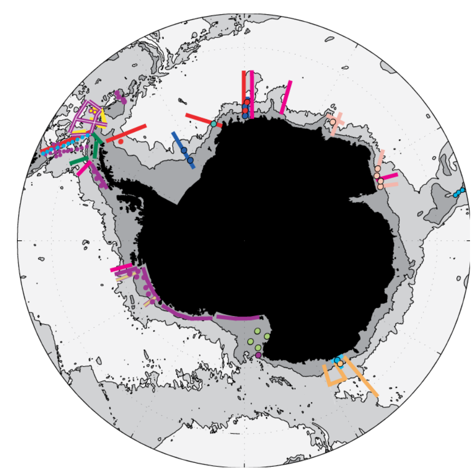
The ship-of-opportunity lines in the Southern Ocean that contribute to SOOS.



White circles indicate location of current or planned drill holes through ice shelves, allowing sampling of underlying ocean waters. .



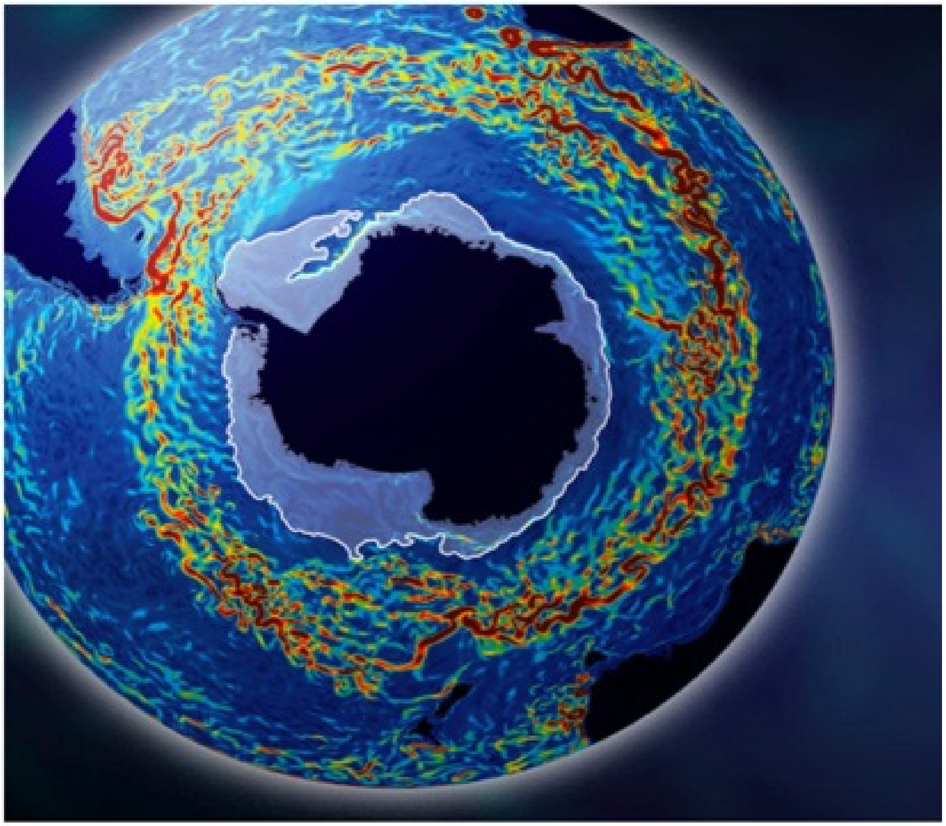
Repeat hydrographic sections to be occupied by SOOS. Symbols indicate the WOCE/CLIVAR designations for each line



Hydrographic sections (lines) and moorings (circles) occupied as contributions to the IPY SASSI program.

The Southern Ocean State Estimate (SOSE)

(Nominal Resolution is 1/6°)

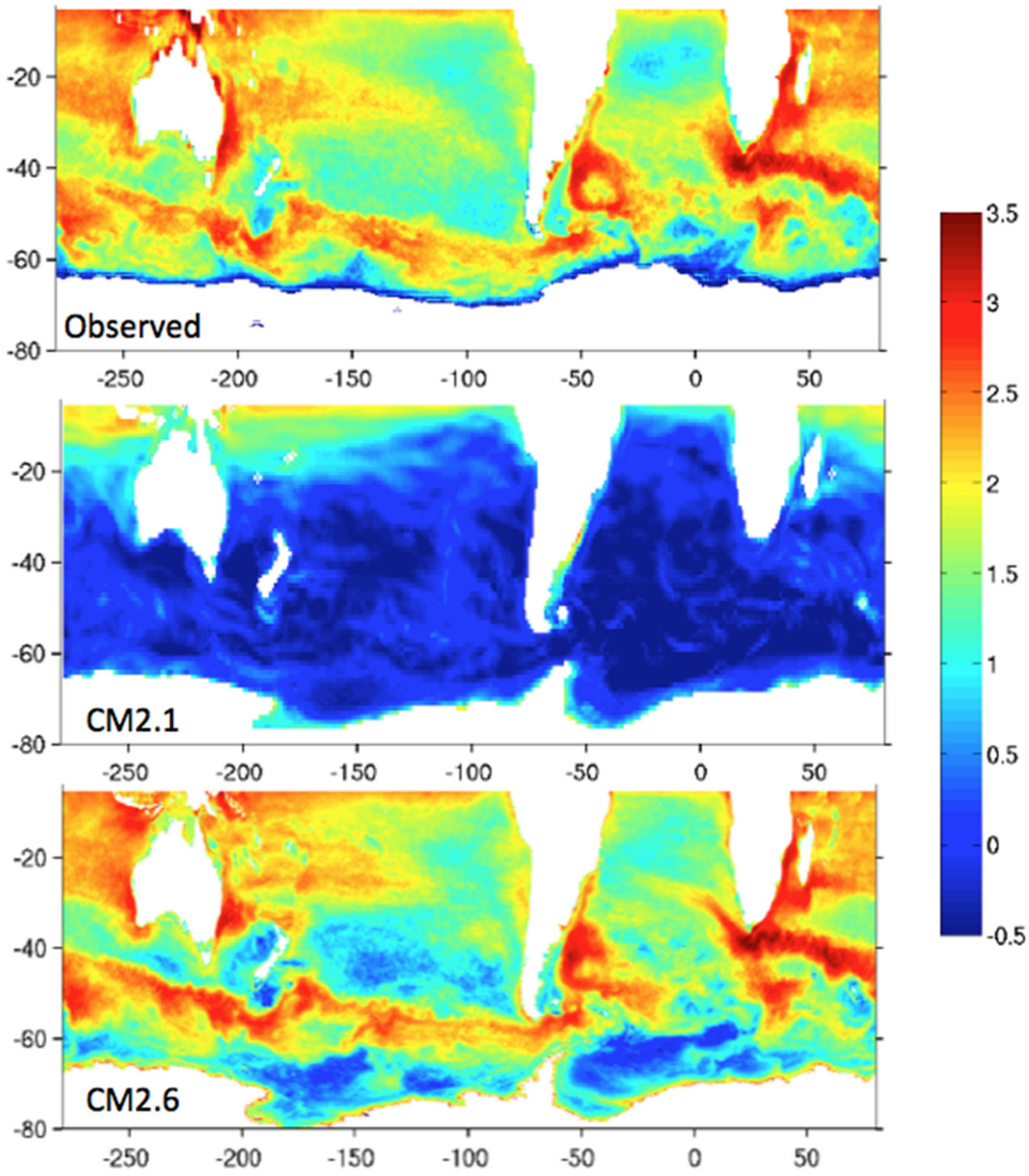


http://sose.ucsd.edu/

M. Mazloff, P. Heimbach, and C. Wunsch, 2010: "An Eddy-Permitting Southern Ocean State Estimate." *J. Phys. Oceanogr.*, **40**, 880–899. doi: 10.1175/2009JPO4236.1

Southern Ocean State Estimation
A modern general circulation model, the MITgcm, is least squares fit to all available ocean observations. This is accomplished iteratively through the adjoint method. The result is a physically realistic estimate of the ocean state. SOSE is being produced by Matthew Mazloff as part of the ECCO consortium and funded by the National Science Foundation. Computational resources are provided in part by the NSF TeraGrid.

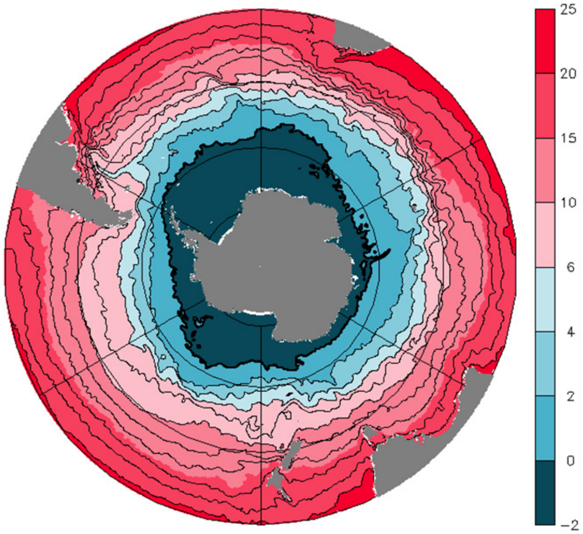
Eddy Kinetic Energy in the Southern Ocean



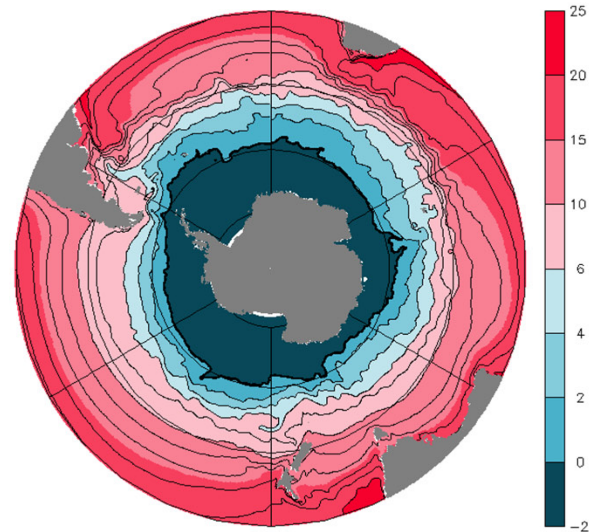
(Delworth et al., 2012)

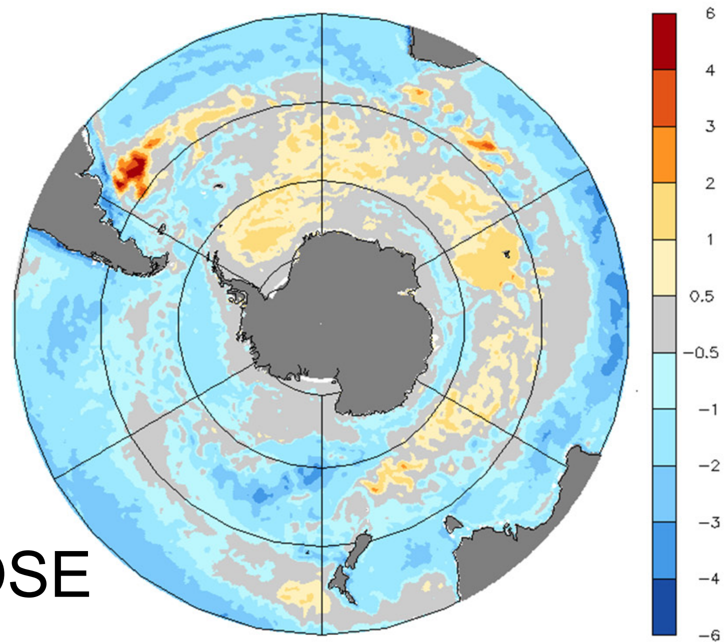
SST

SOSE



CM2p5





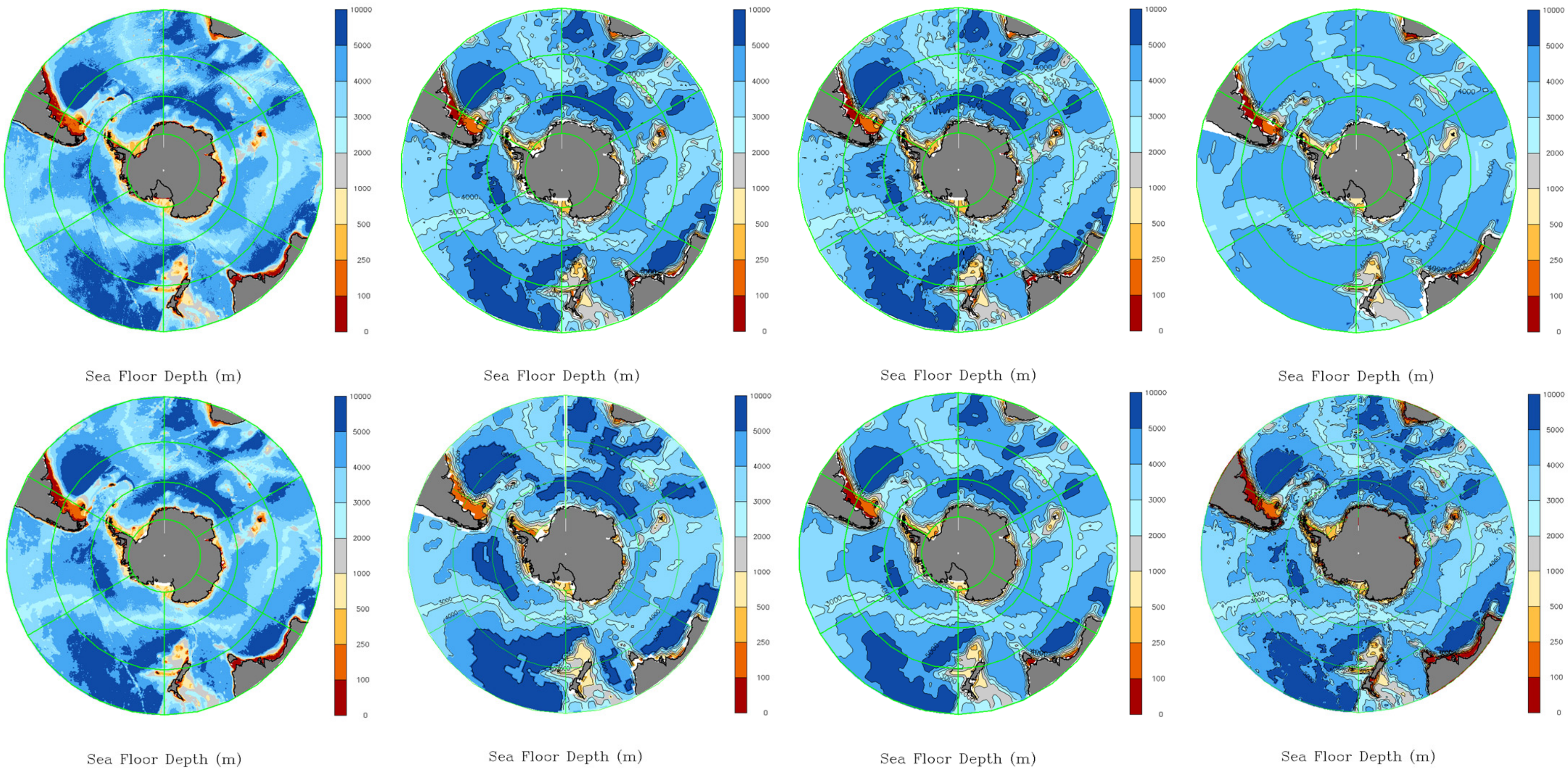
CM2p5 - SOSE

New Metrics

Person	Affiliation	Area of Interest	Metric(s)
Cecilia Bitz	U. Washington	Role of Sea Ice in Climate	Sea Ice Extent/Volume/Seasonality
Raffaele Ferrari	MIT	Ocean Turbulence	Eddy Kinetic Energy; Eddy-induced diffusivities and heat transport/uptake
Sarah Gille	UCSD/SIO	Air/Sea Exchange	Mixed-layer depth; Heat Content (400m) Non-solubility pCO_2 variance
Robert Hallberg	NOAA/GFDL	Ocean Dynamics	Water mass properties (upper 2000m and abyssal); Age tracer distribution; Drake Passage transport
Ken Johnson	MBARI	Chemical Sensors/ Biogeochemical Cycles	Seasonal cycle of nitrate
Igor Kamenkovich	U. Miami	Mesoscale Eddies/ Role of SO in global MOC	Stratification at the northern flank of the SO; Eddy-induced diffusivities
Irina Marinov	U. Pennsylvania	Carbon Cycle/Ecology	Oxygen, Temperature, Salinity Precipitation; Background nutrients
Matt Mazloff	UCSD/SIO	State Estimates	Mean dynamic topography; Temperature transport through the Drake Passage
Joellen Russell	U. Arizona	Role of Ocean in Climate	Strength and position of SO Westerly Winds Area of deep-water outcrop; Depth of AAIW isopycnal
Jorge Sarmiento	Princeton U.	Biogeochemical Cycles	Fractional uptake of heat and carbon by the SO
Kevin Speer	Florida State U.	Large-Scale Circulation	Stratification north and south of ACC (esp. SAMW) Mean flow/shear in SE Pacific; tracer spreading rates
Lynne Talley	UCSD/SIO	Physical Oceanography	Repeat hydrography inventories
Rik Wanninkhof	NOAA/AOML	Inorganic Carbon Cycle	Aragonite saturation state

Bathymetry – Depth of the Sea Floor (m)

ETOPO2 | GFDL-ESM2M | BCC-CSM2 | CSIRO-Mk3.6

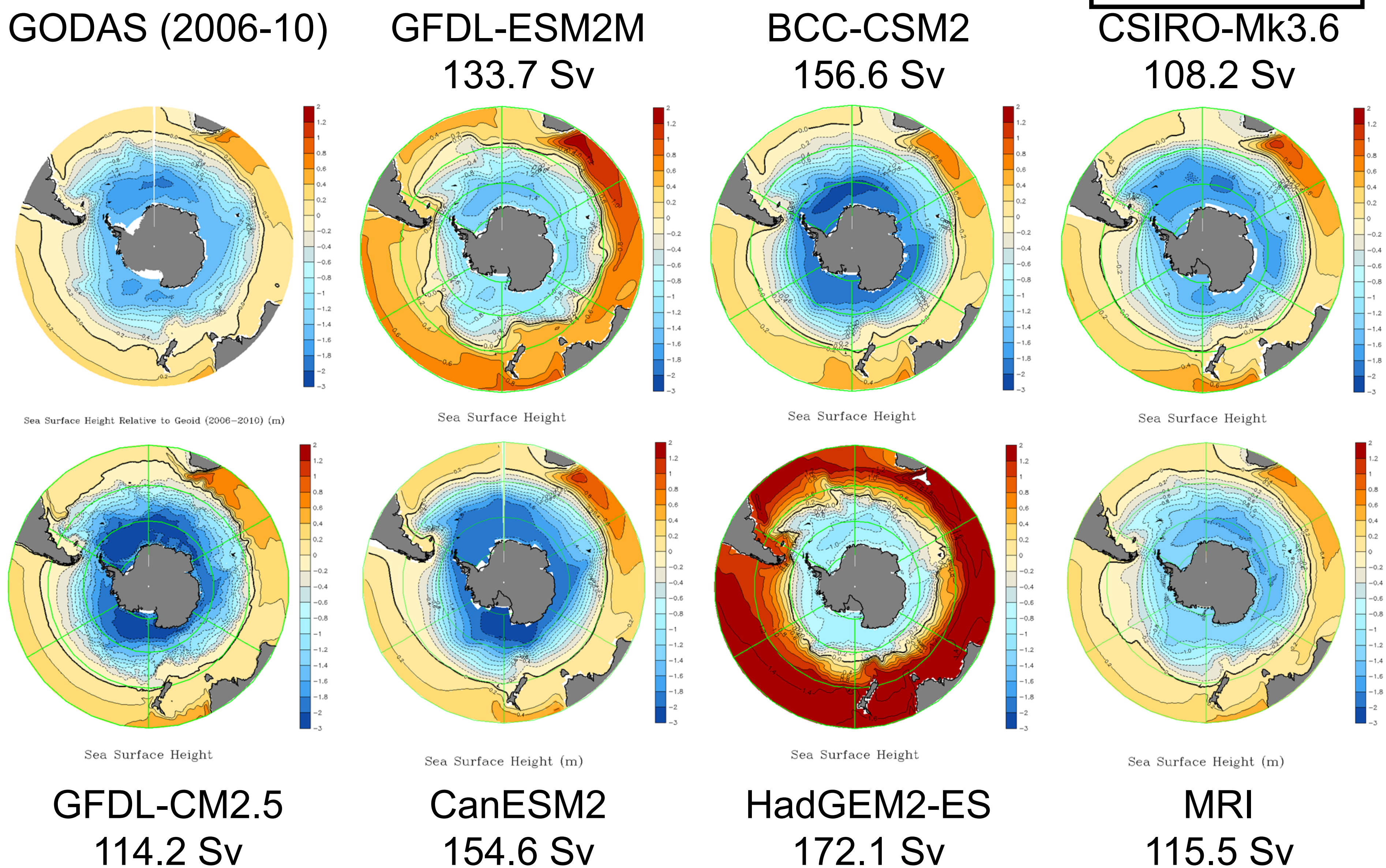


GFDL-CM2.5 | CanESM2 | HadGEM2-ES | MRI

CSIRO is much too smooth

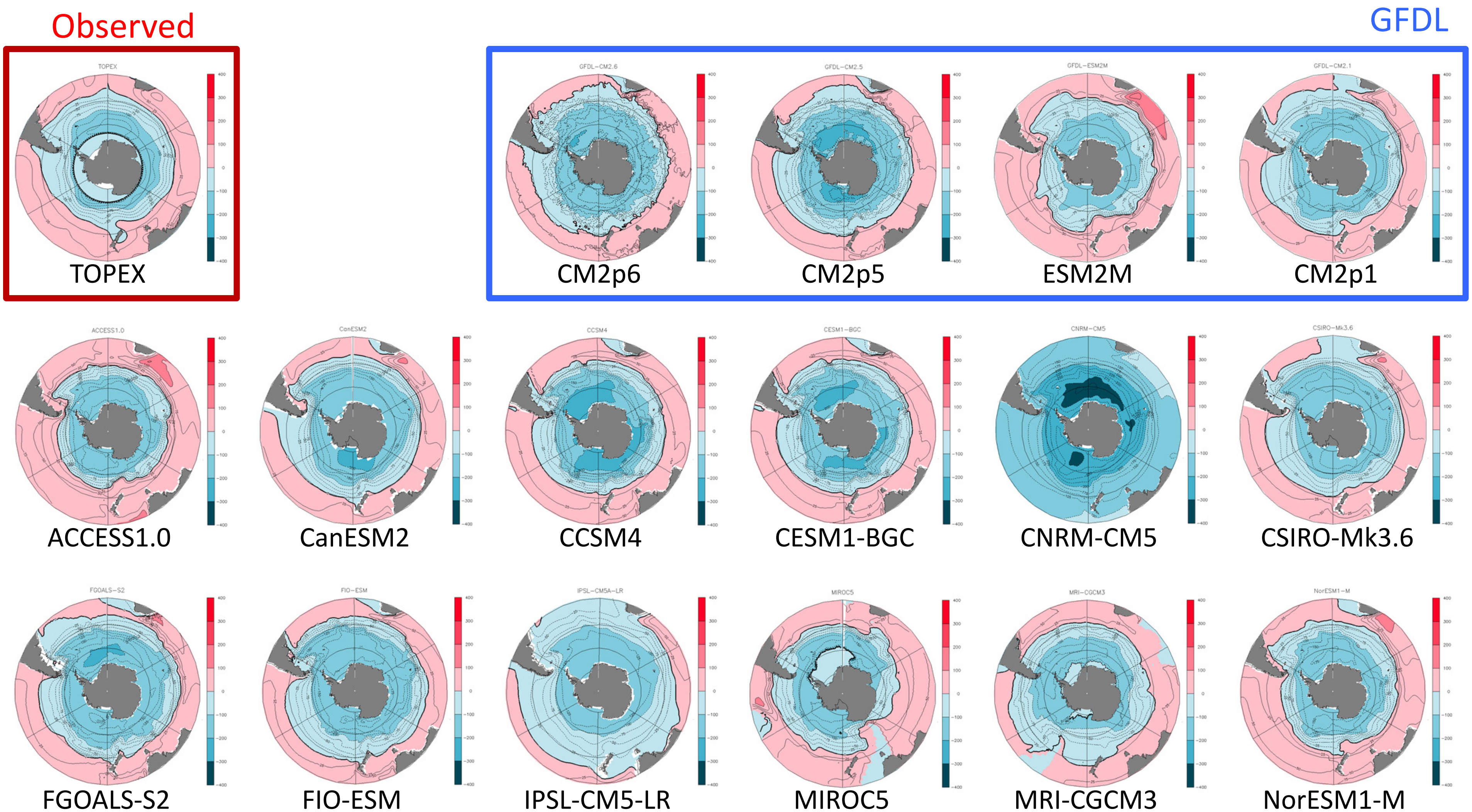
Sea Surface Height (m)

Annual mean, 2001-2005
Sea Surface Height
Values are net transport
through Drake Passage



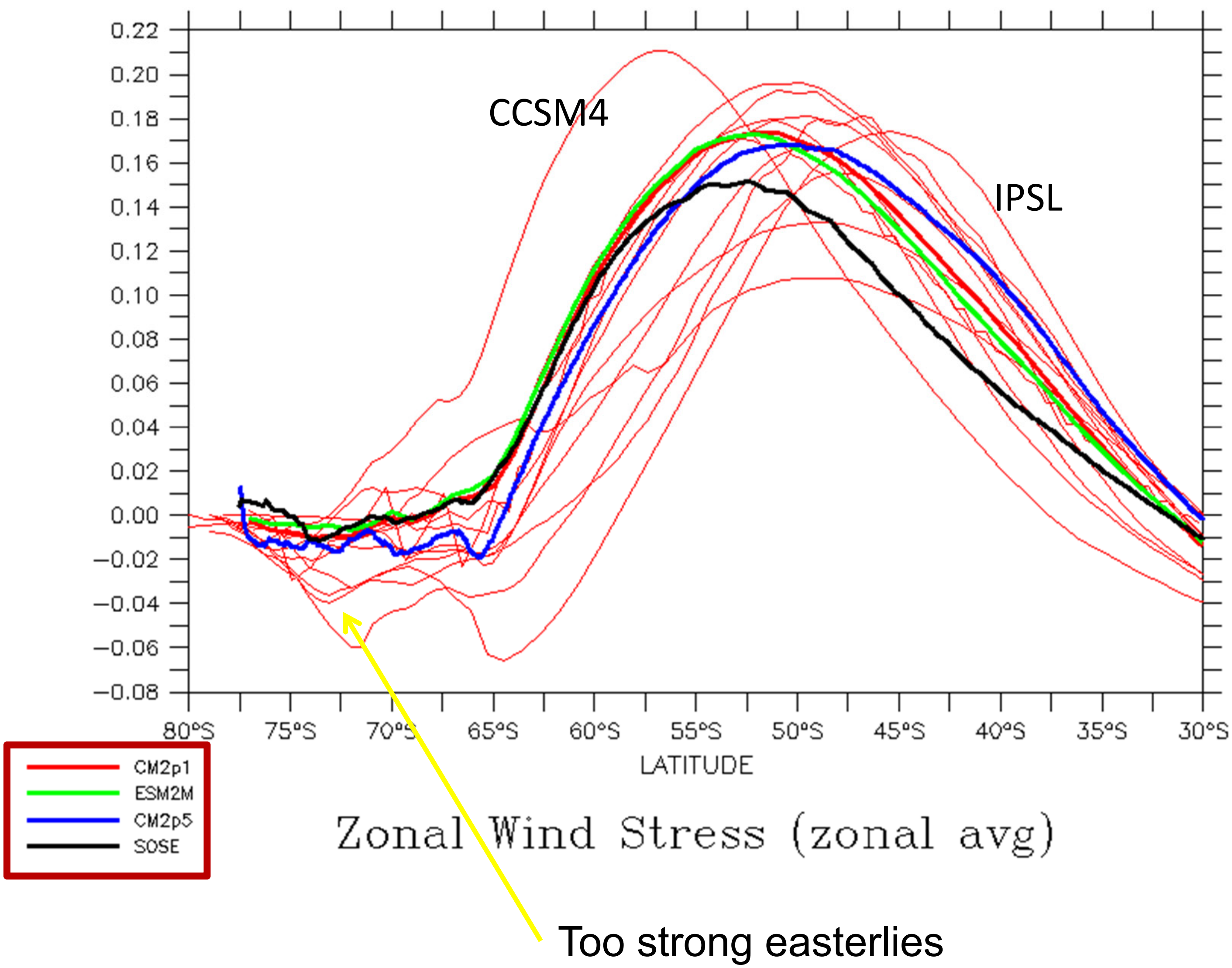
Russell – July 25, 2013

Simulated Sea Surface Height (cm) Annual mean, 2001-2005



This is a different subset of CMIP5 models

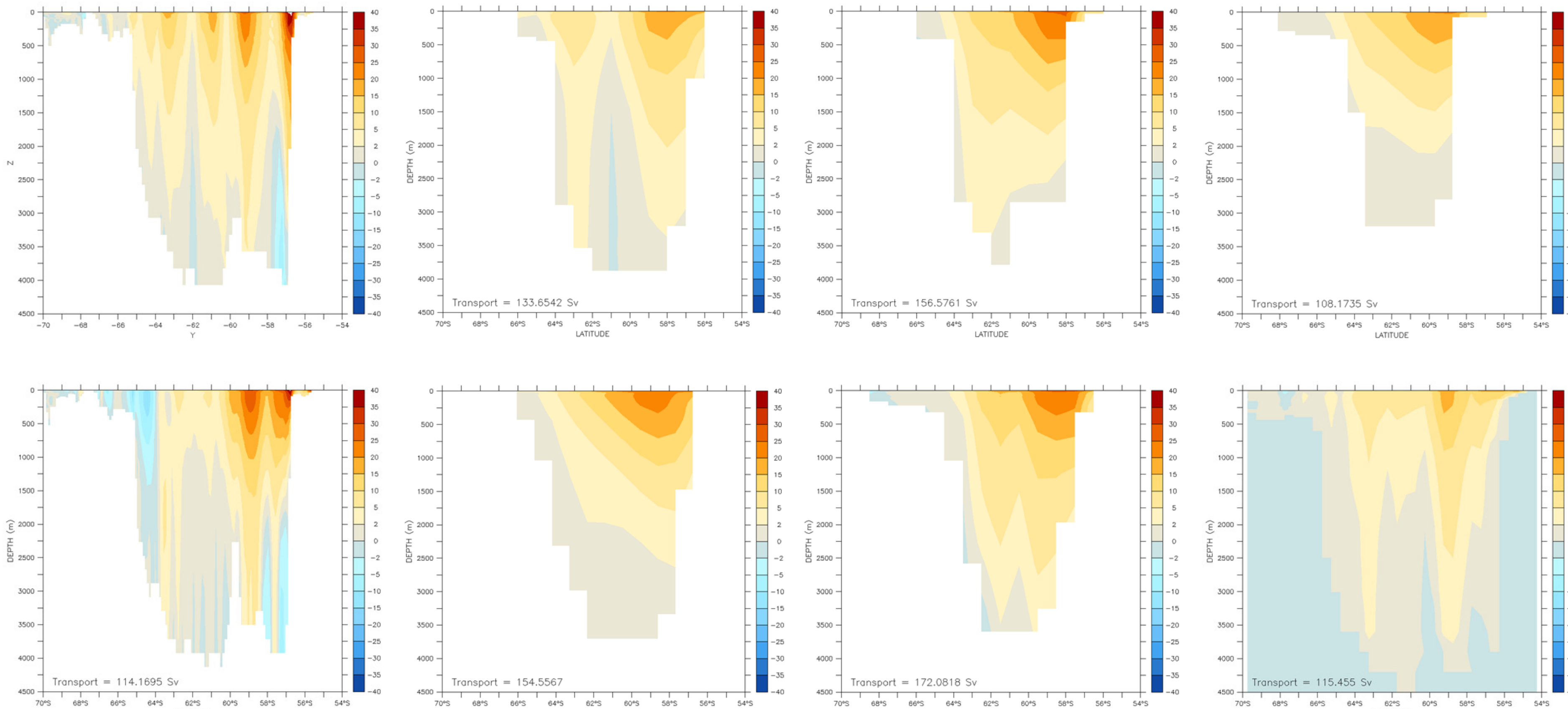
Simulated Zonal Wind Stress (N/m^2) Annual mean, 2001-2005



Drake Passage Transport: Zonal Velocity at 69°W

Annual mean, 2001-2005
Zonal Velocity
Values are net transport through Drake Passage

SOSE (2008) 148.1 Sv | GFDL-ESM2M 133.7 Sv | BCC-CSM2 156.6 Sv | CSIRO-Mk3.6 108.2 Sv

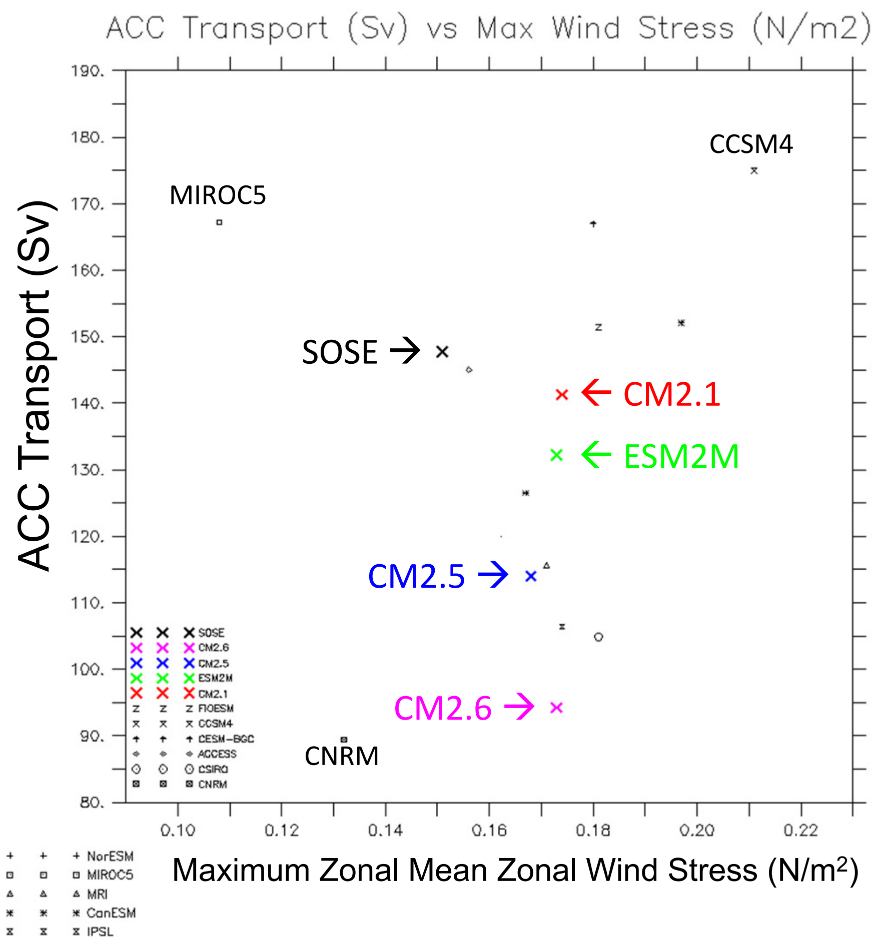


GFDL-CM2.5 114.2 Sv | CanESM2 154.6 Sv | HadGEM2-ES 172.1 Sv | MRI 115.5 Sv

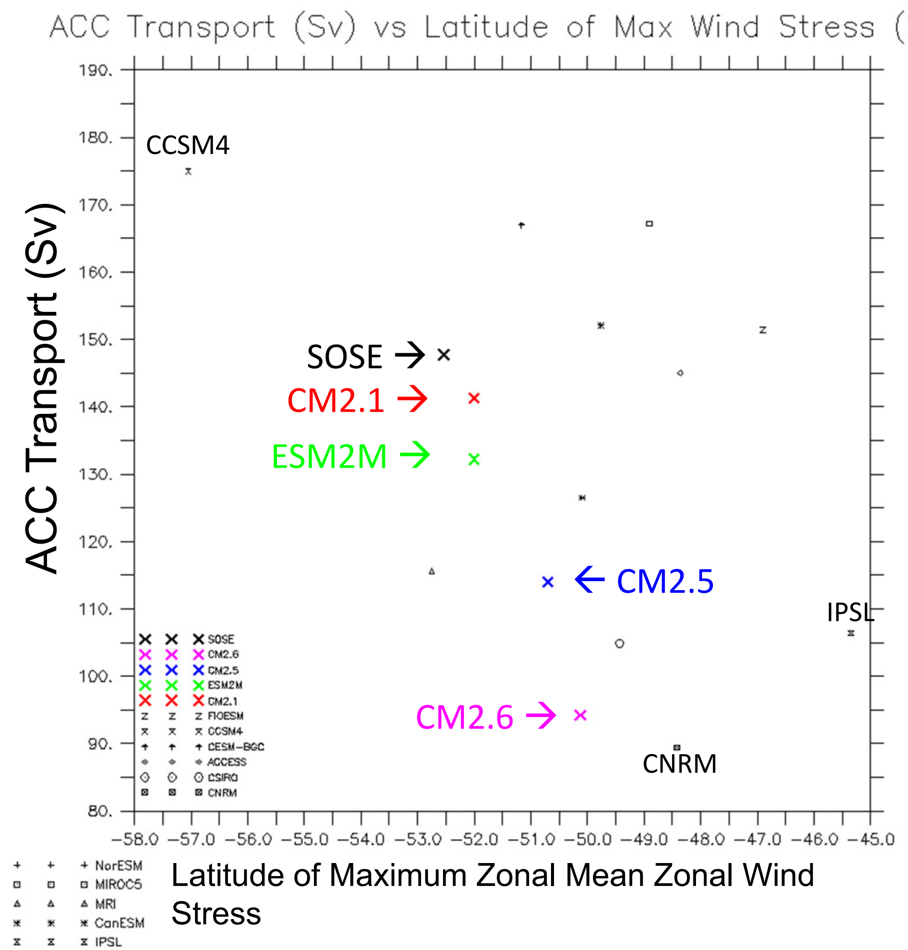
Frontal structure is not captured by lower resolution models

Simulated Winds vs ACC Transport

Annual mean, 2001-2005
Zonal Mean Wind Stress
between 80° S-30° S



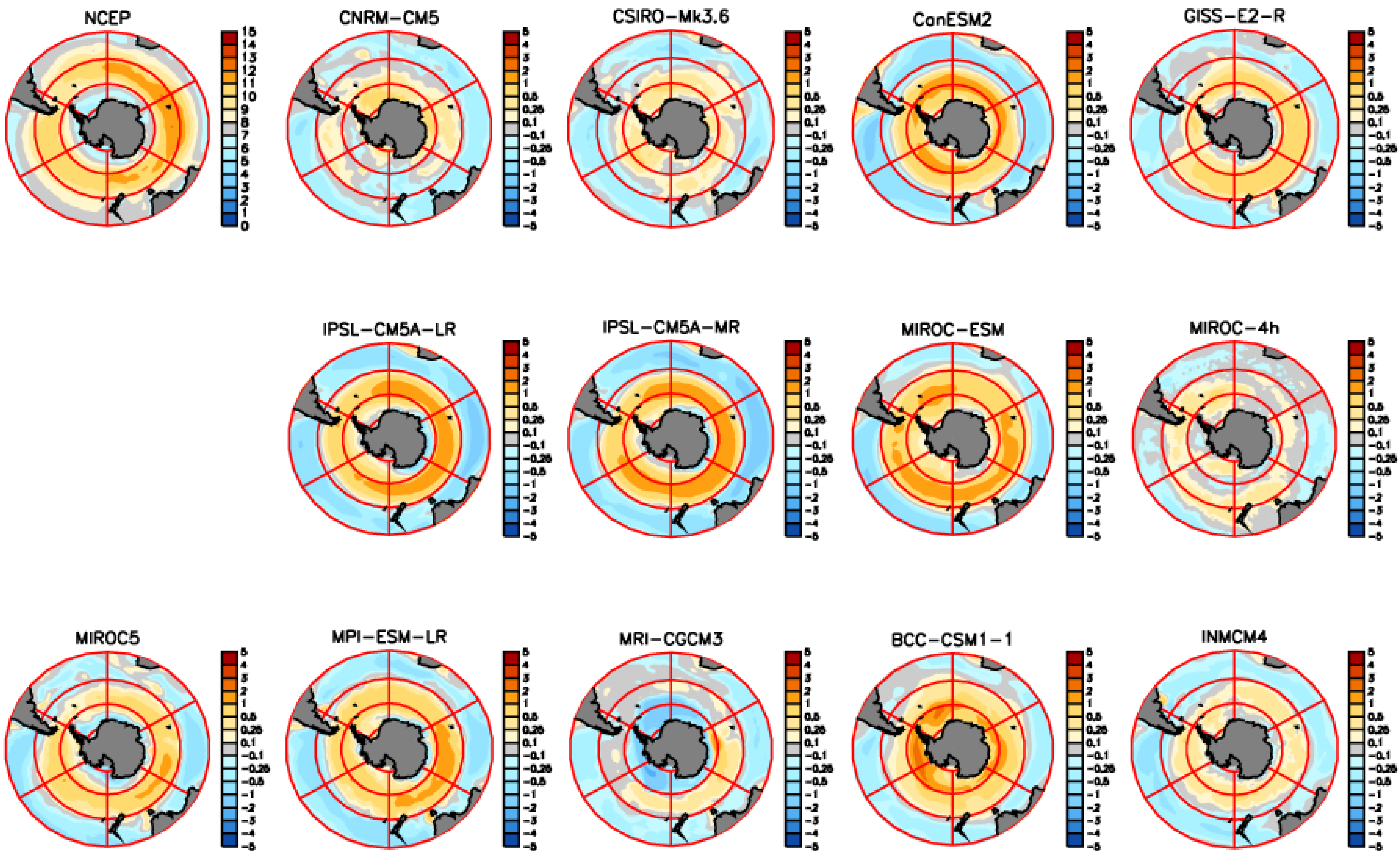
Maximum Zonal Wind Stress



Latitude of Maximum Stress

Change in Mean Wind Speed (m/s)

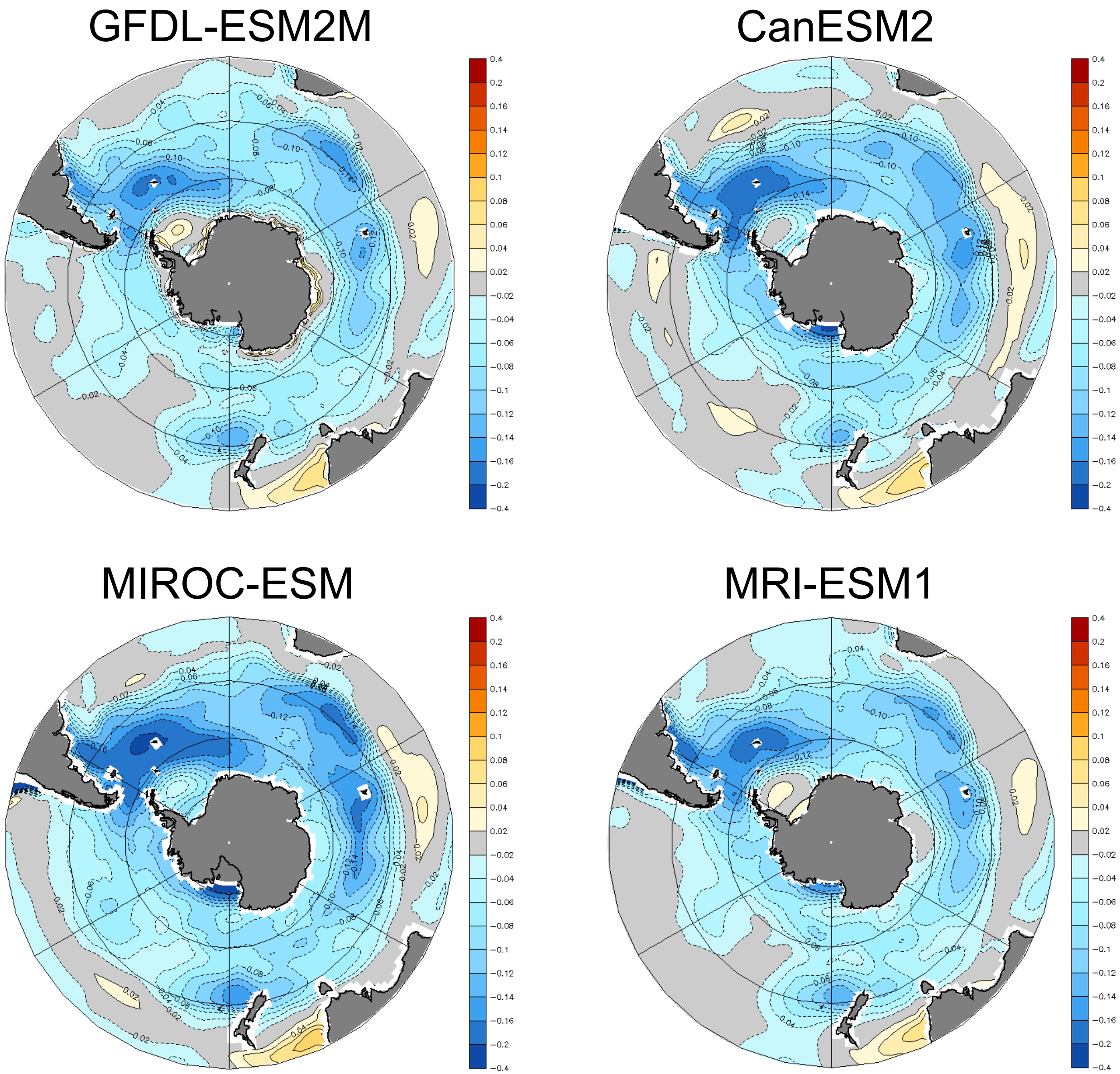
RCP8.5 (2080-2100) – Historical (1980-2000)



Surface Water pH Difference

(From GLODAP/WOA2001)

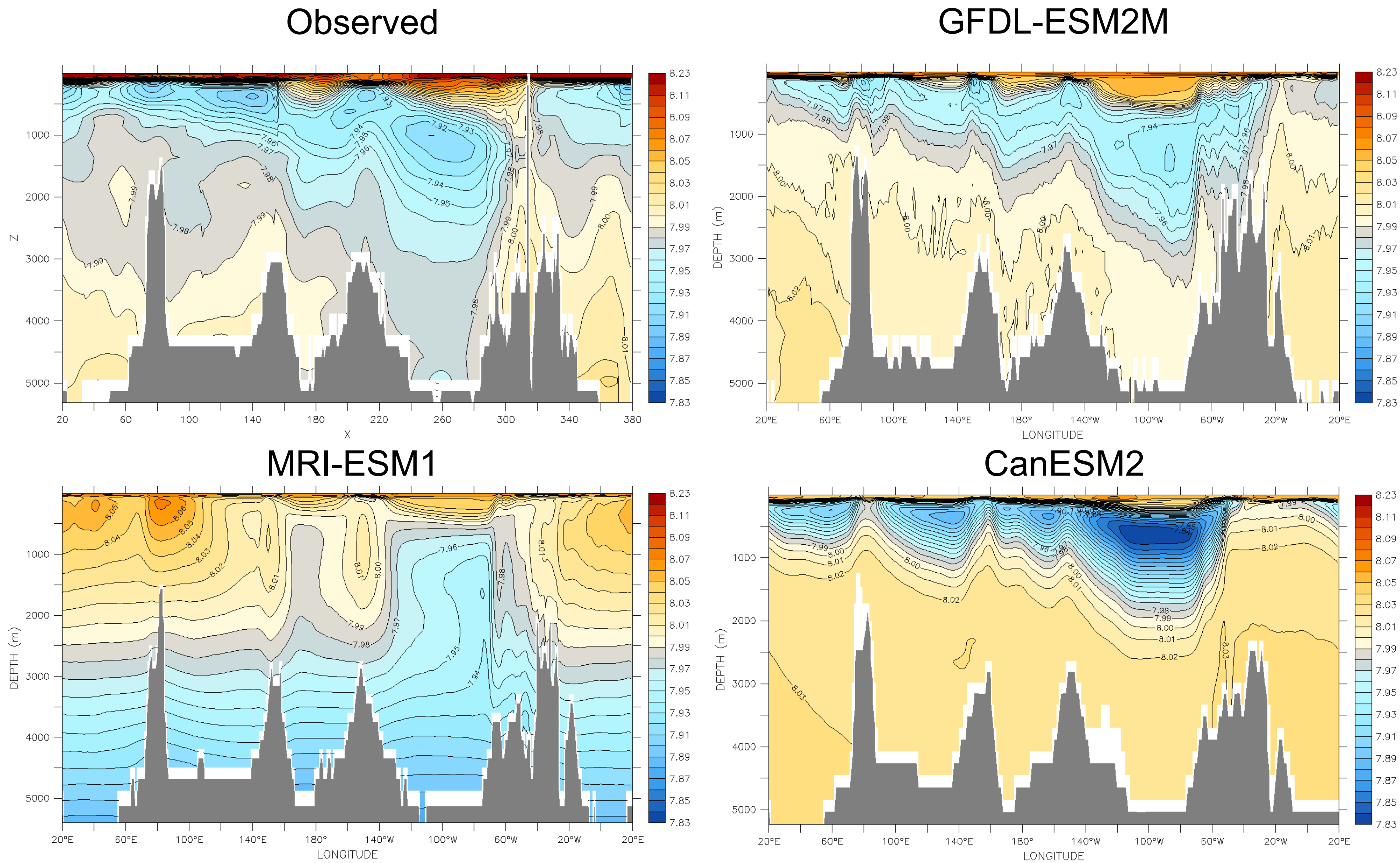
Annual mean (2001-2005)



Observed pH was calculated from the GLODAP TCO_2 and Alkalinity and the World Ocean Atlas (2001) Temperature and Salinity using the formulas from Dickson (2007)

Southern Ocean pH at 60°S

Annual mean (2001-2005)



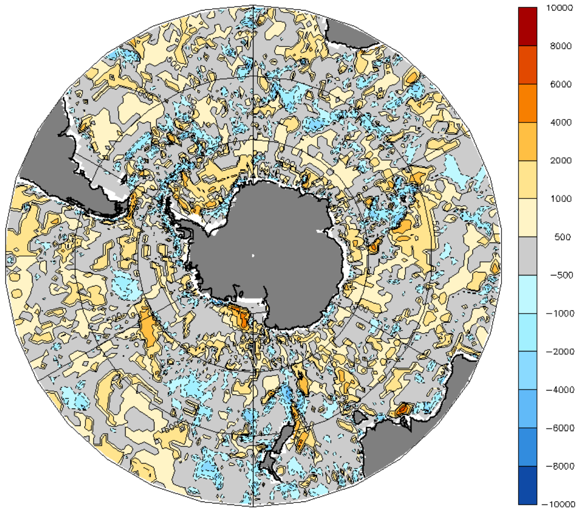
Observed pH was calculated from the GLODAP TCO_2 and Alkalinity and the World Ocean Atlas (2001) Temperature and Salinity using the formulas from

Colum Inventory DIC Difference

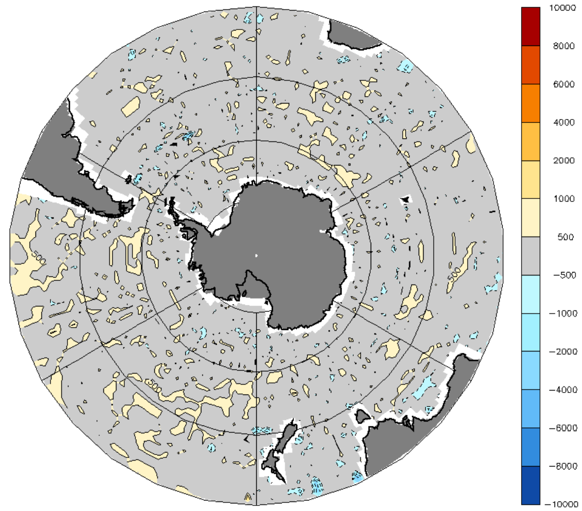
(mol/m^2; Difference From GLODAP)

Annual mean (2001-2005)

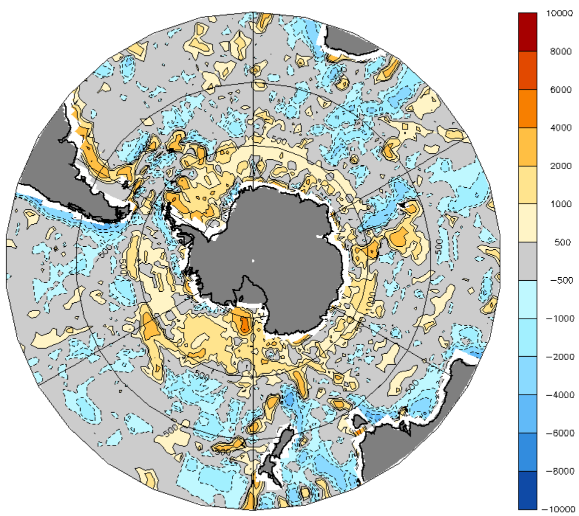
GFDL-ESM2M



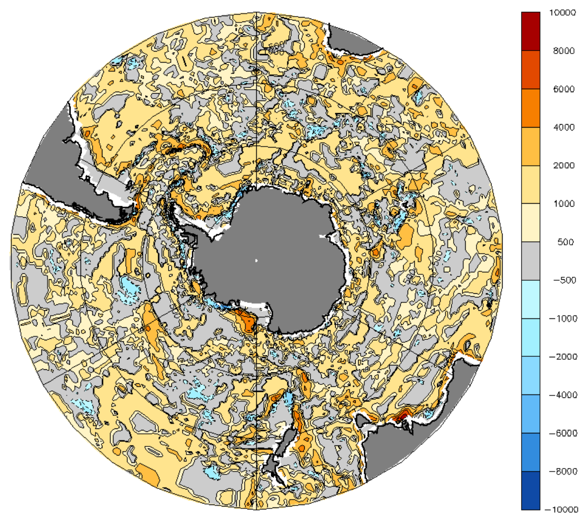
CanESM2



MIROC-ESM



MRI-ESM1



Some of the column inventory difference may reflect differences in the model bathymetry from observed