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

Southern Ocean Working Group	
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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?

- Hypothesis 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)

- Hypothesis 2: 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)

- Hypothesis 3: Southern Ocean winds largely control the upwelling and meridional overturning strength not only in this region but also for North Atlantic overturning (Toggweiler and Samuels, 1998)

Energy Content in the Climate System

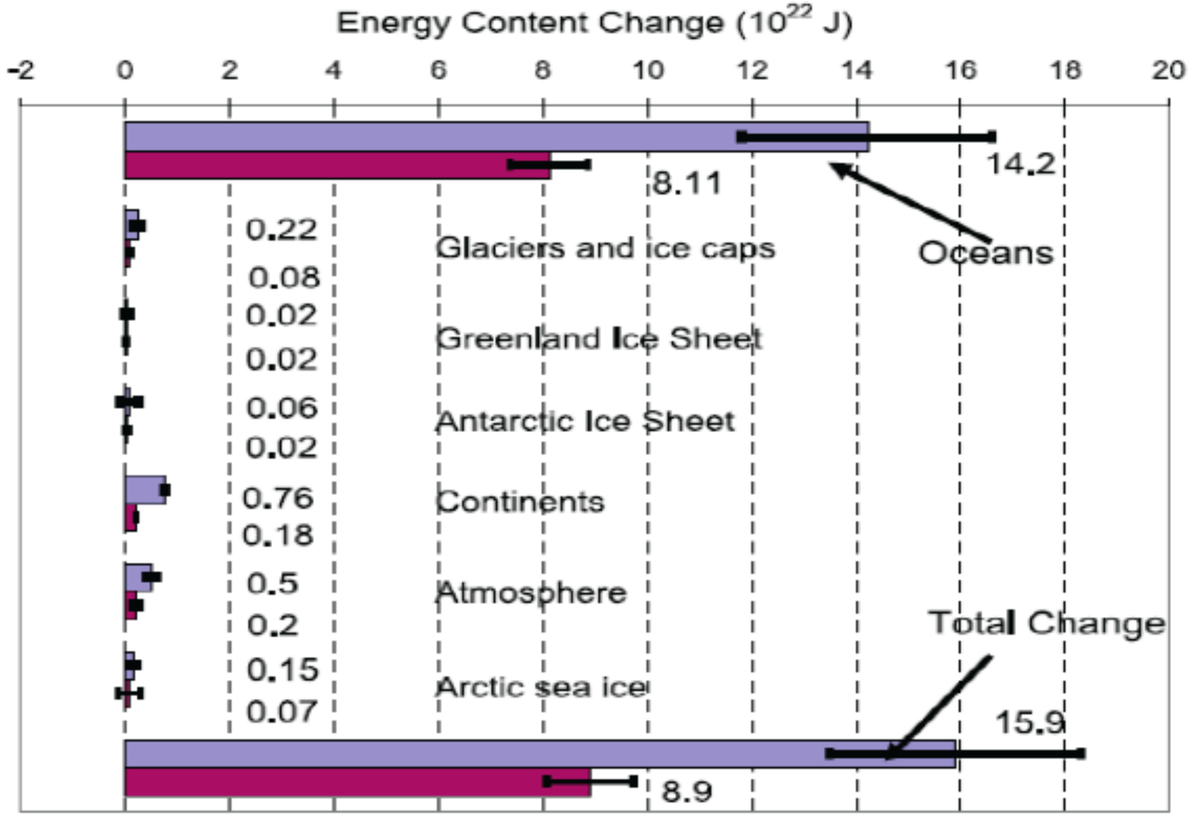


Fig. 2. Energy content changes in different components of the Earth system for two periods (1961–2003 and 1993–2003). Blue bars are for 1961 to 2003; burgundy bars are for 1993 to 2003. Positive energy content change means an increase in stored energy (i.e., heat content in oceans, latent heat from reduced ice or sea ice volumes, heat content in the continents excluding latent heat from permafrost changes, and latent and sensible heat and potential and kinetic energy in the atmosphere). All error estimates are 90% confidence intervals. No estimate of confidence is available for the continental heat gain. Some of the results have been scaled from published results for the two respective periods. From (IPCC 2007, Fig. TS.15 and Fig. 5.4).

Trenberth & Fasullo 2011

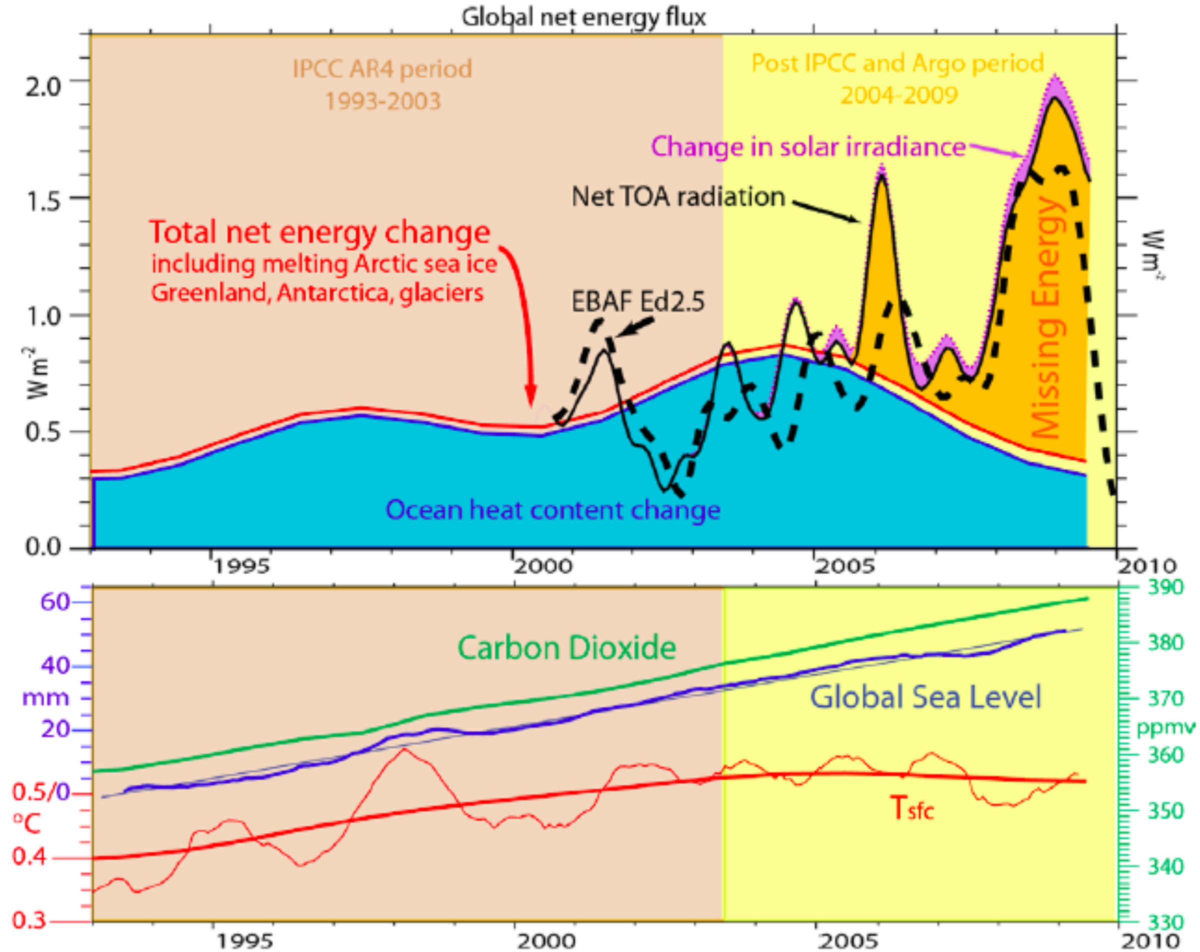
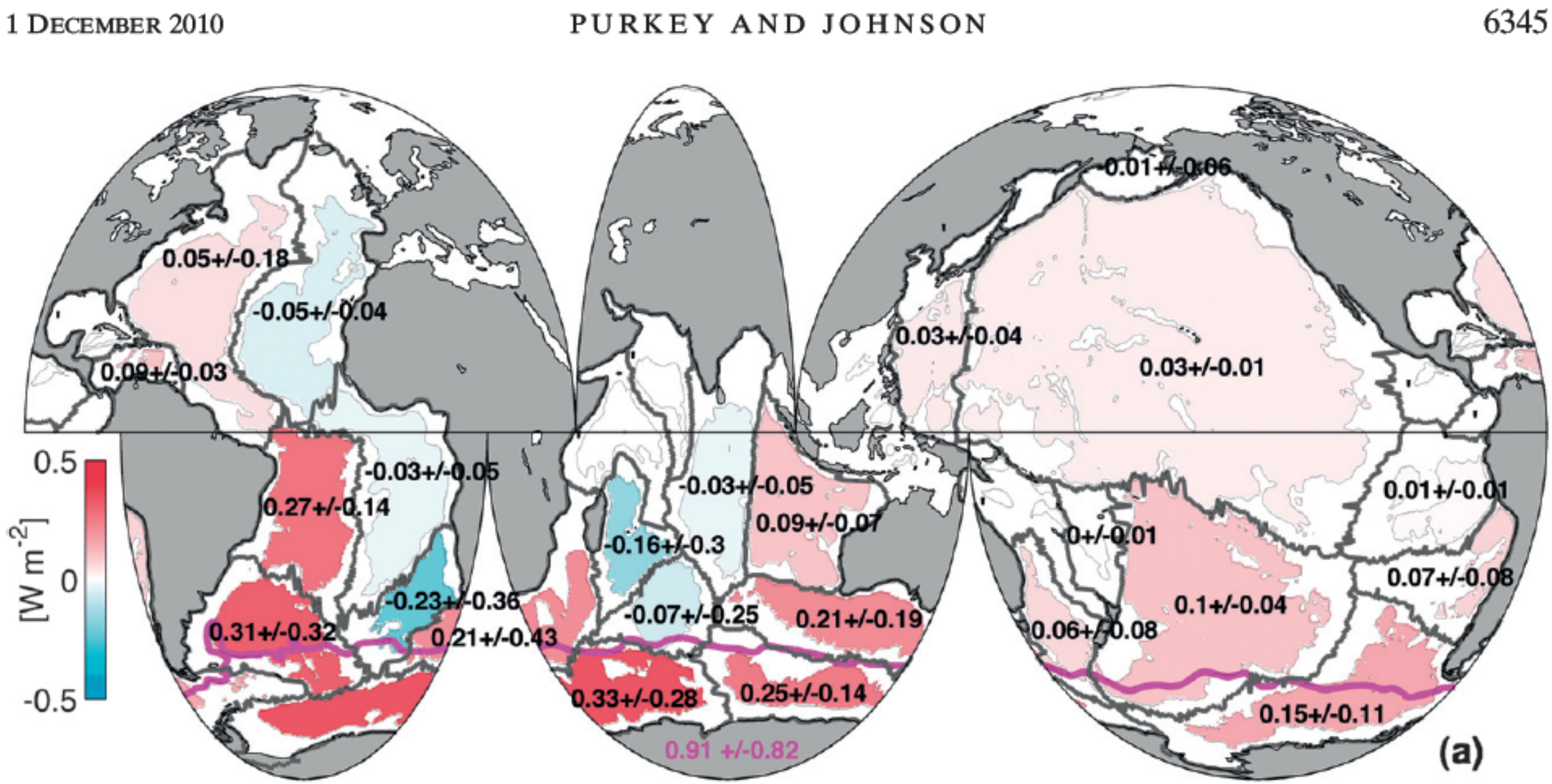


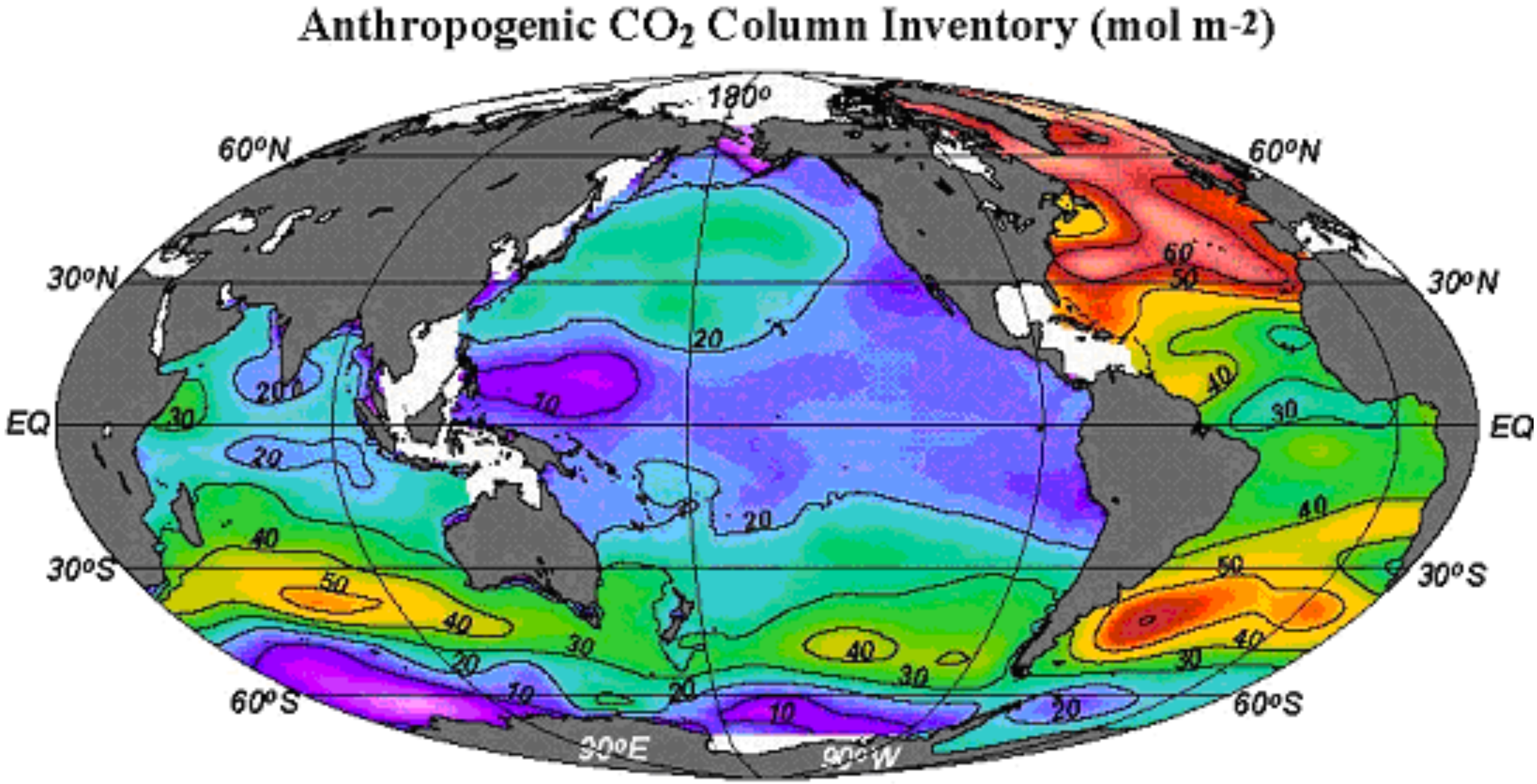
Figure 4. The disposition of energy entering the climate system is estimated. The observed changes (lower panel; Trenberth and Fasullo 2010) show the 12-month running means of global mean surface temperature anomalies relative to 1901-2000 from NOAA (red (thin) and decadal (thick)) in °C (scale lower left), carbon dioxide concentrations (green) in ppmv from NOAA (scale right), and global sea level adjusted for isostatic rebound from AVISO (blue, along with linear trend of 3.2 mm/yr) relative to 1993, scale at left in millimeters). Rates of change of global energy in W m^{-2} (top panel) are contrasted between the AR4-IPCC era 1993-2003 and the post-2003 Argo era. From 1992 to 2003 the decadal ocean heat content changes (blue) along with the contributions from melting glaciers, ice caps, Greenland, Antarctica and Arctic sea ice plus small contributions from land and atmosphere warming (red) suggest a total warming for the planet of 0.6±0.2 W m^{-2} (95% error bars). After 2000, preliminary observations from TOA (black) referenced to the 2000 values, as used in Trenberth and Fasullo (2010), show an increasing discrepancy (gold) relative to the total warming observed (red). The quiet sun changes in total

Trenberth & Fasullo 2011

Heat Trend Distributions

Purkey and Johnson (2010)

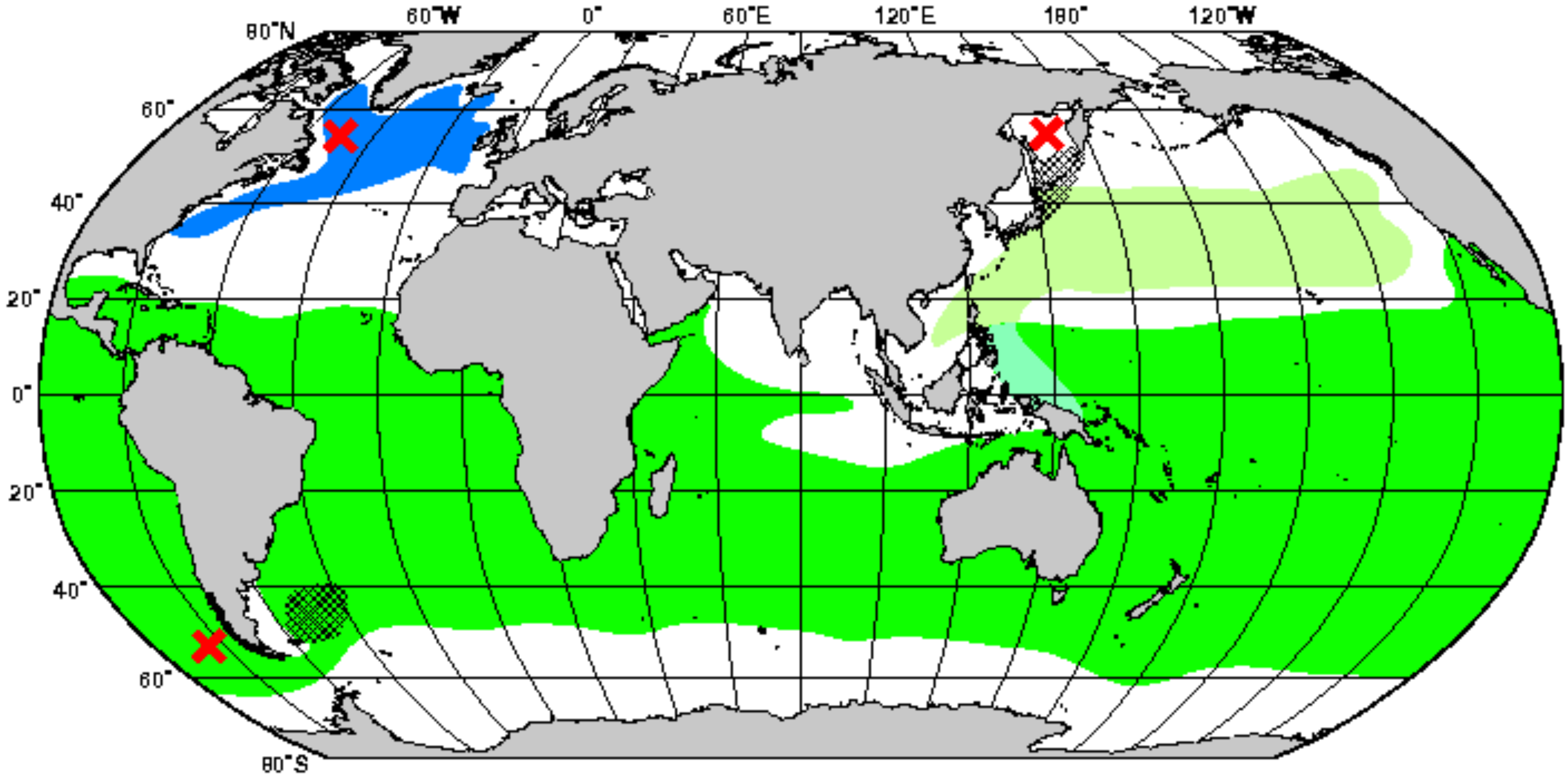




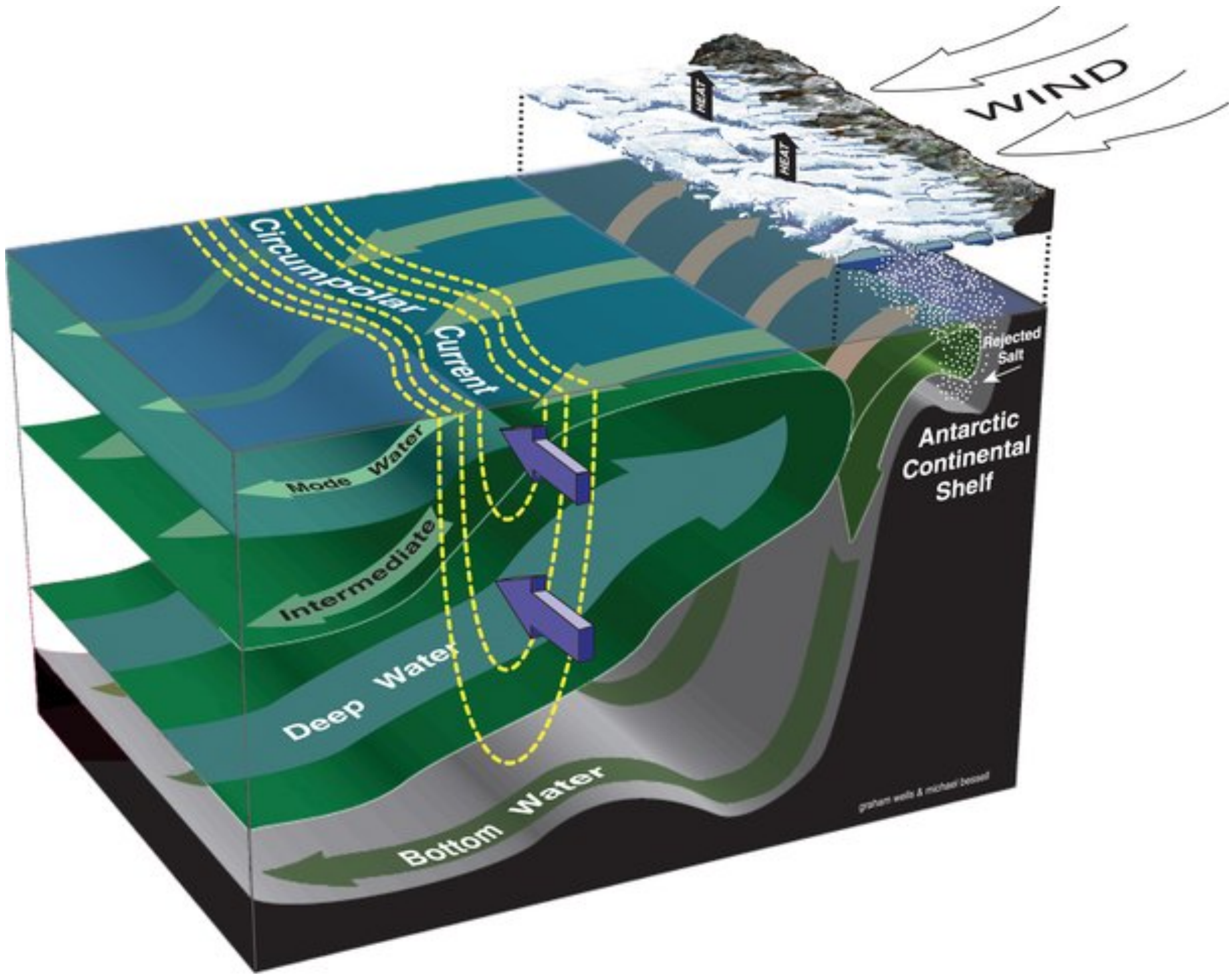
Column inventory of anthropogenic CO_2 in the oceans (after Sabine et al. 2002). High inventories are associated with deep water formation in the North Atlantic and intermediate and mode water formation between 30°S and 50°S

(Feely and Sabine, http://www.pmel.noaa.gov/co2/PressConference.html)

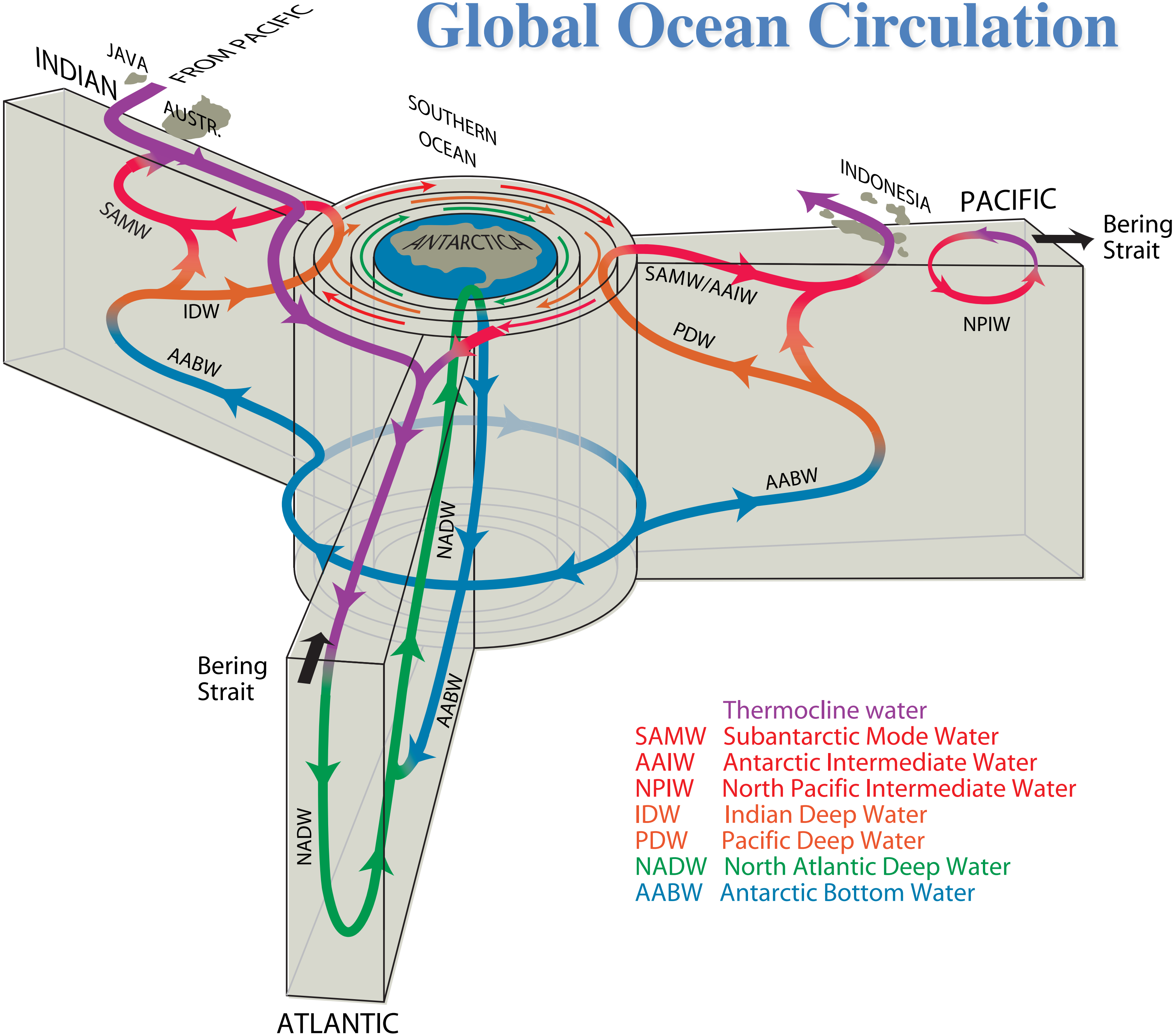
Antarctic Intermediate Water Influence

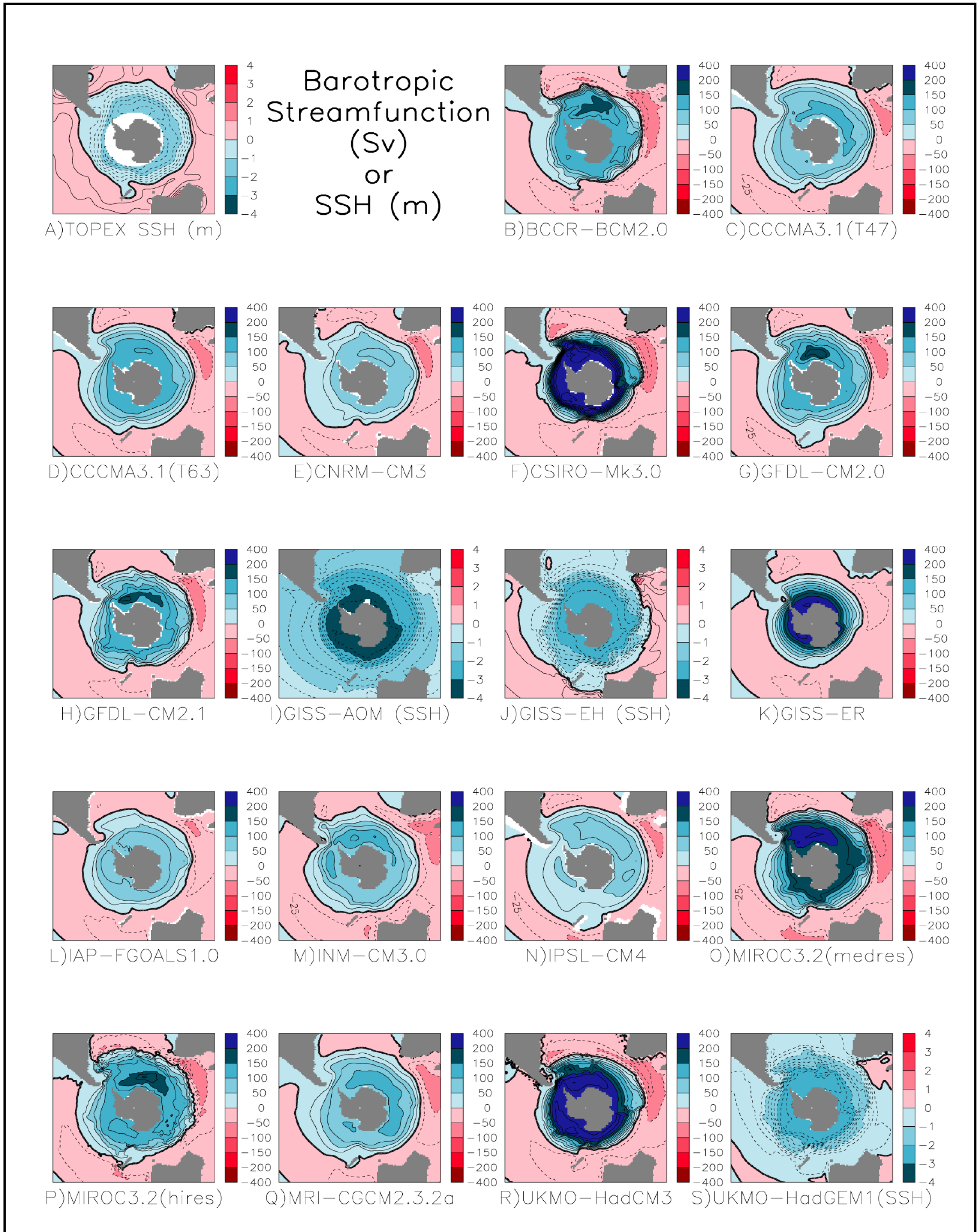


Southern Ocean Circulation



Global Ocean Circulation





Barotropic Streamfunction (Sv) & Sea Surface Height (m)

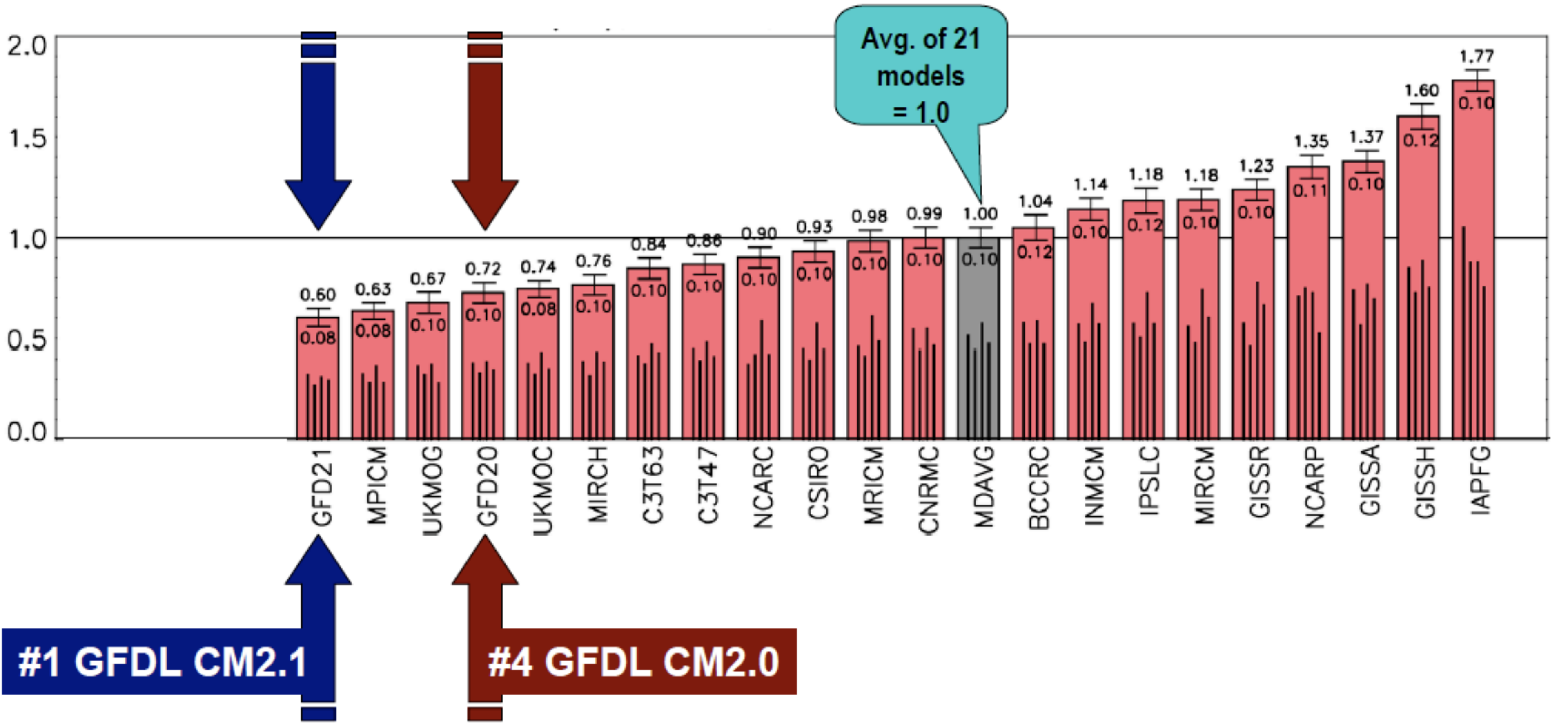
Russell et al., *2006a*

Overall Performance Index $\overline{\overline{I_m^2}}^{v,s}$

courtesy Thomas Reichler & Junsu Kim, Univ. of Utah

A combined measure of how well 21 different global climate models simulate 35 different observed climate features (time averaged, large scale quantities).

Normalized so that the average model score = 1.0; Values less than 1.0 are better.
Lower Values = Smaller Errors (i.e., greater agreement btwn the model simulation & observations)



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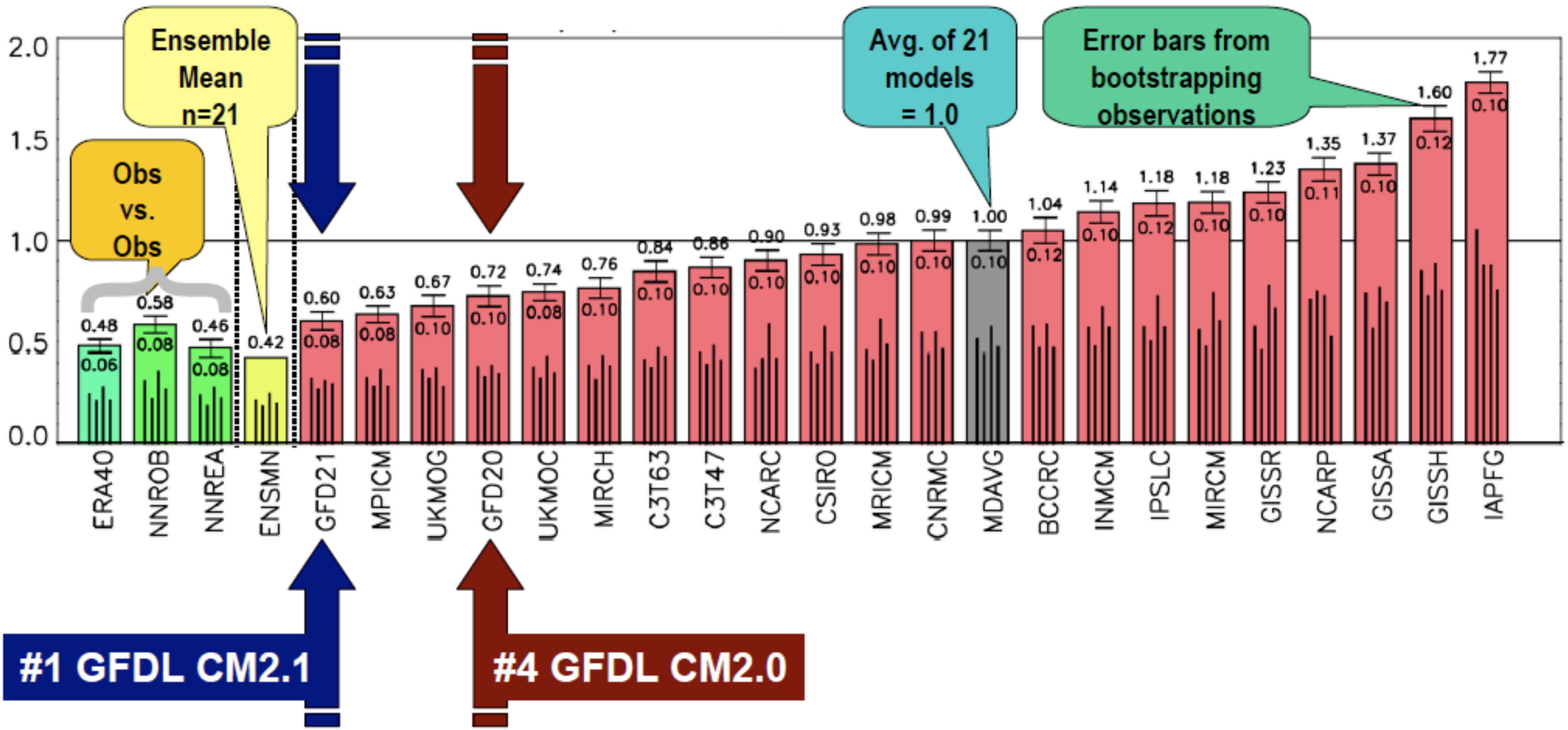
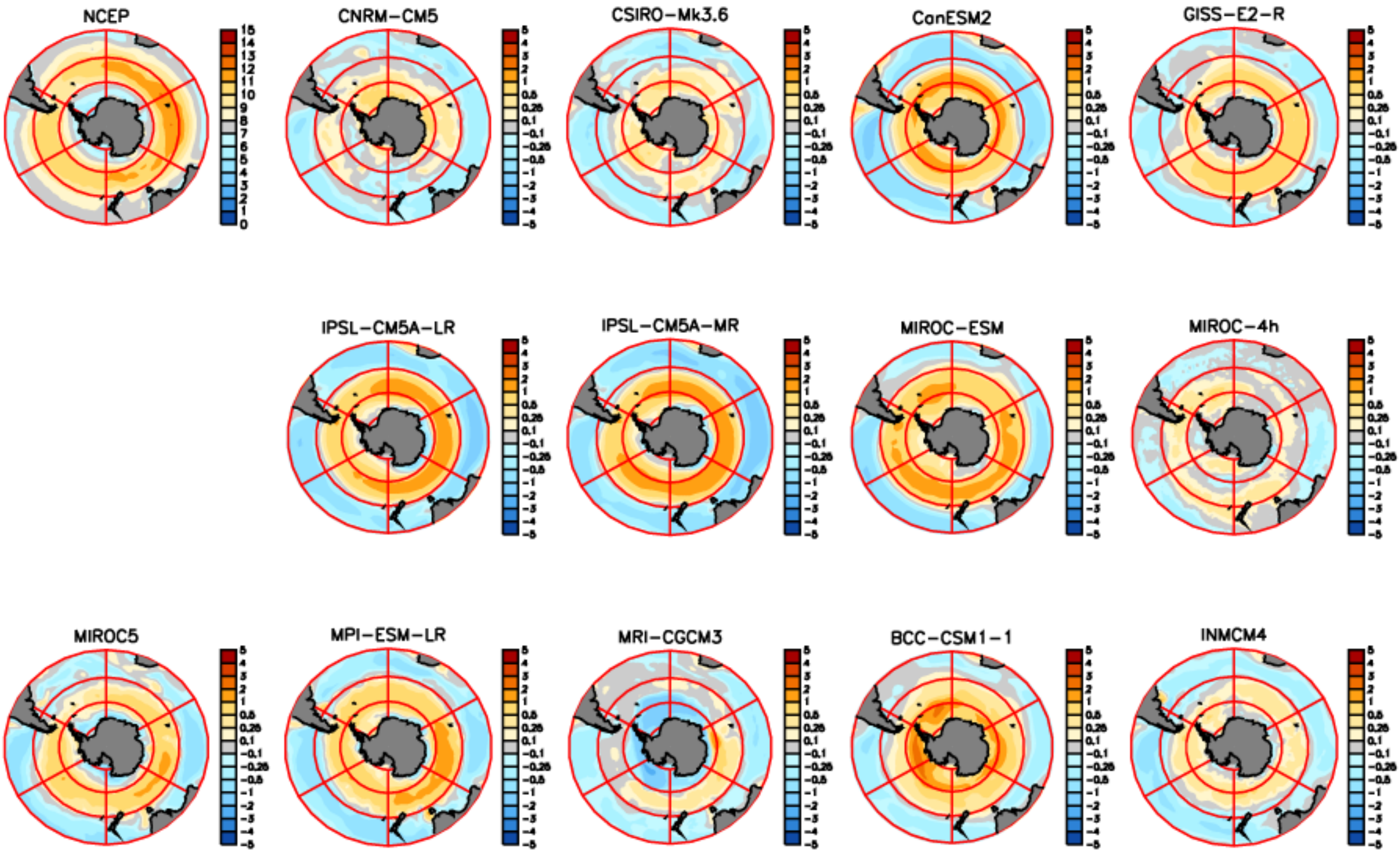


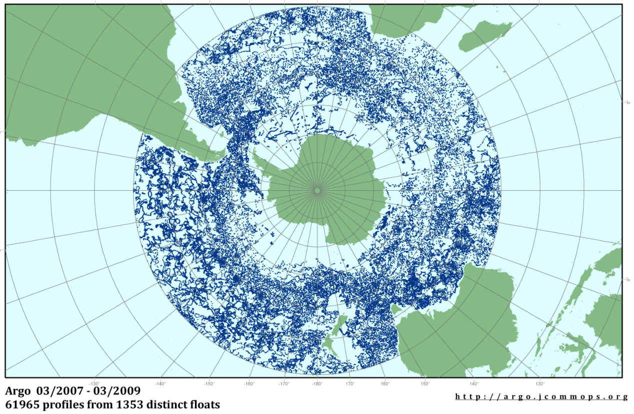
Change in Mean Wind Speed (m/s)

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

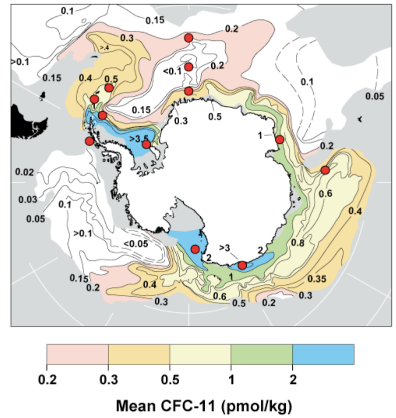


Mesoscale Resolving Models

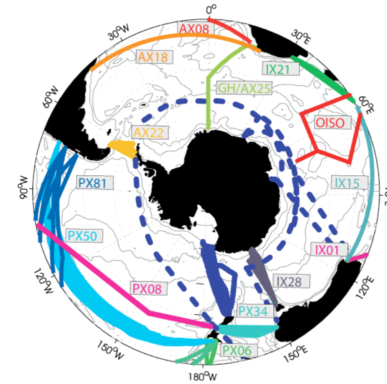
SOOS Observing System Components



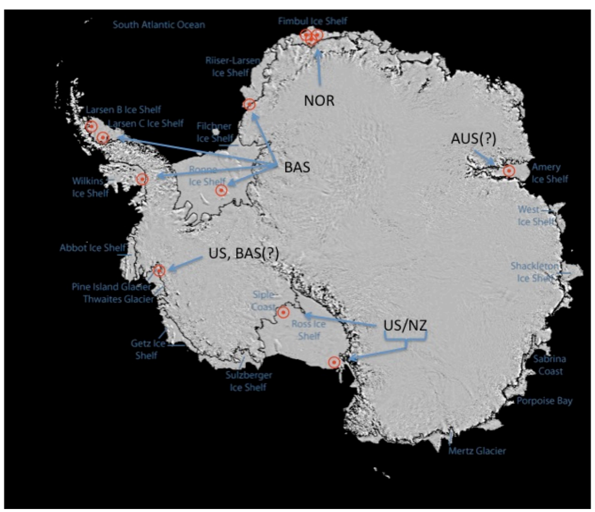
The locations of more than 60,000 Argo profiles of temperature and salinity collected during the 24 months of the IPY. Courtesy of Mathieu Balbeoch, JCOMMOPS



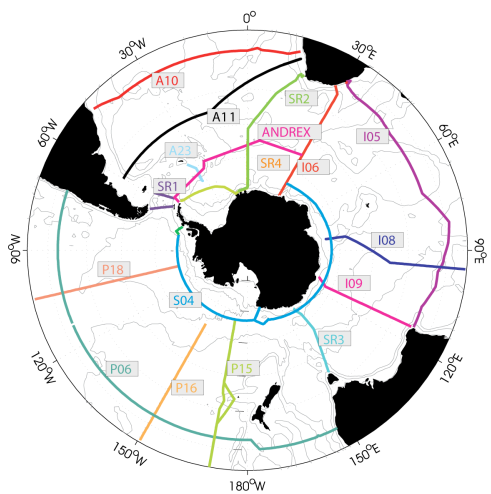
Map of proposed moored arrays (red circles) to sample the primary Antarctic Bottom Water formation and export sites



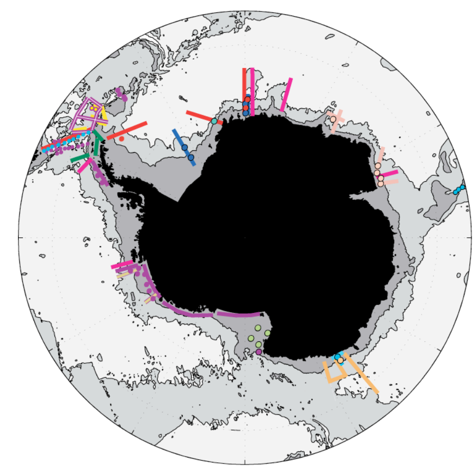
The ship-of-opportunity lines in the Southern Ocean that contribute to SOOS.



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



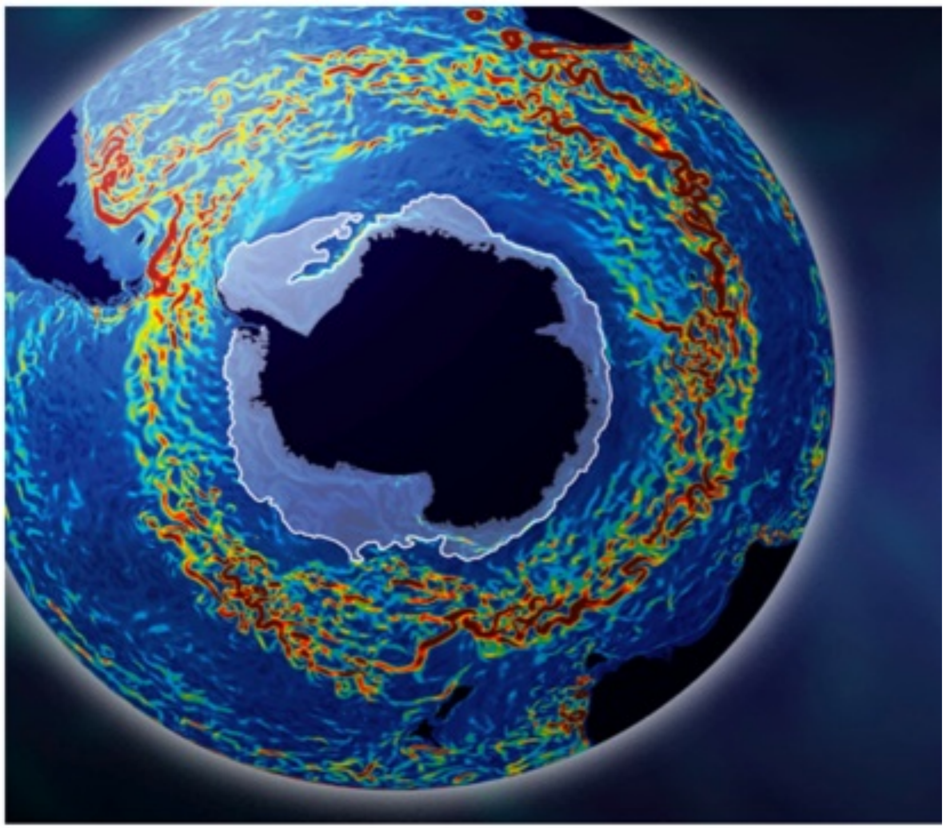
Repeat hydrographic sections to be occupied by SOOS. Symbols indicate the WOCE/CLIVAR designations for each line



Hydrographic sections (lines) and moorings (circles) occupied as contributions to the IPY SASSI program. Many of these lines are near Antarctic bases and could be repeated more regularly as a contribution to the SOOS.

The Southern Ocean State Estimate(SOSE)

(Nominal Resolution is 1/6°)



http://sose.ucsd.edu/

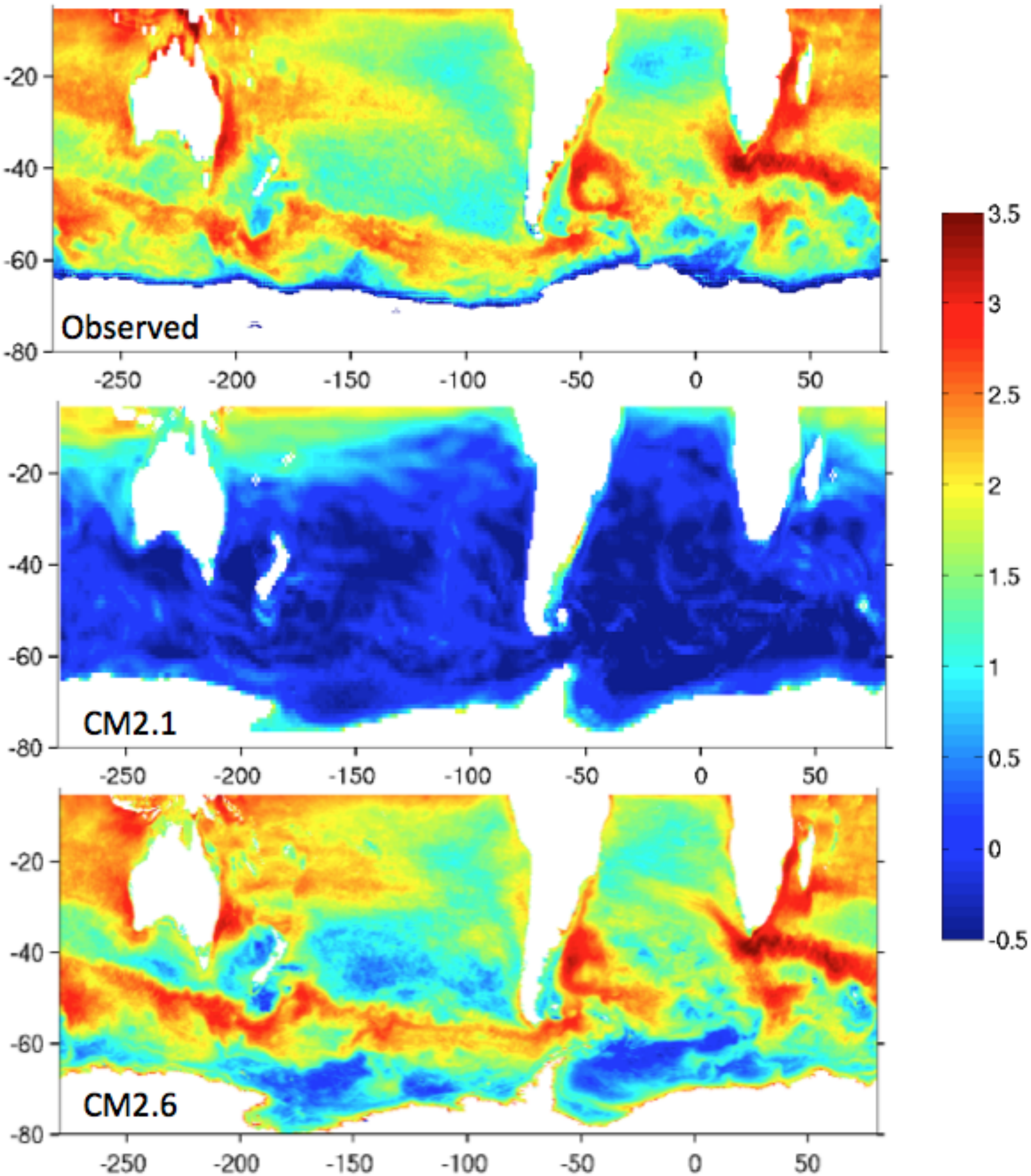
M. Mazloff, P. Heimbach, and C. Wunsch, 2010: "An Eddy-Permitting Southern Ocean State Estimate." *J. Phys. Oceanogr.*, **40**, 880–899. doi: 10.1175/2009JPO4236.1

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. (Nominal Resolution is 1/6°)

The NCEP Climate Forecast System Reanalysis (CFSR)

Saha, Suranjana, and Coauthors, 2010: The NCEP Climate Forecast System Reanalysis. *Bull. Amer. Meteor. Soc.*, **91**, 1015–1057. doi: http://dx.doi.org/10.1175/2010BAMS3001.1

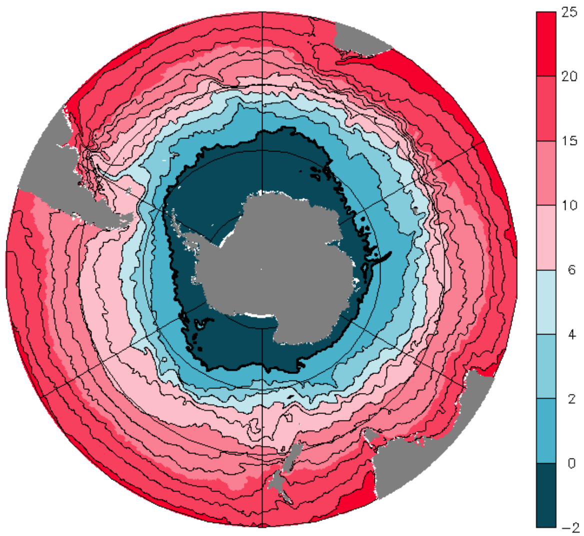
http://cfs.ncep.noaa.gov/cfsr/



Eddy Kinetic Energy in the Southern Ocean

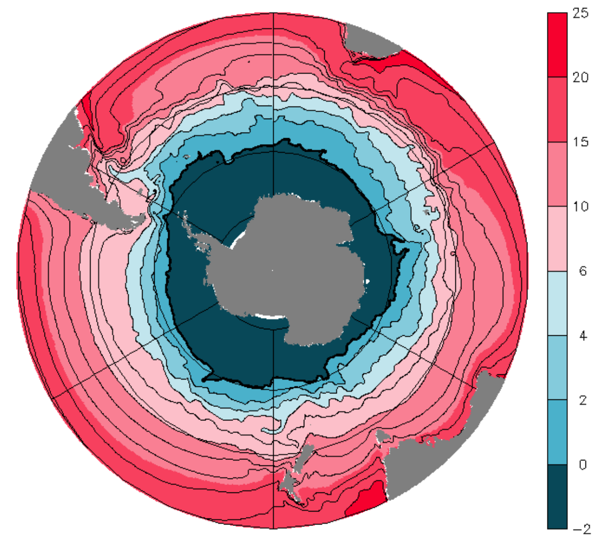
Delworth et al., 2012

SOSE

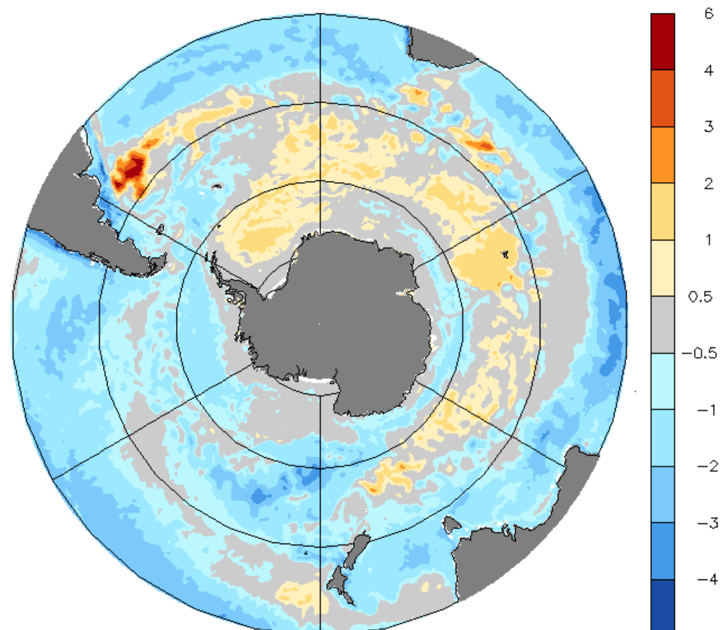


SST

CM2p5



CM2p5 - SOSE



SOWG Planned Activities

- ***Spring/Summer 2012*** – Bi-monthly teleconferences: progress on development of targets and model assessment
- ***Fall 2012*** – 1st WG Meeting (coincident with Fall AGU) 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
- ***Winter/Spring 2012/2013*** – Bi-monthly teleconferences: progress on development of measurement campaigns and modeling studies
- ***Spring/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 2013*** – 2nd WG Meeting (coincident with US CLIVAR Summit) and workshop/conference, joint with the Carbon Uptake WG, to update wider community on progress
- ***Fall/Winter 2013*** – Monthly teleconferences: write/submit white paper, summarizing key results from WG and workshop/conference.

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, possibly in two parts, for the scientific community and funding agencies that: (i) assesses the state of our understanding of the role of eddies in the Southern Ocean in both the data and the models; and (ii) identifies the most critical observational targets needed to fill in the 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, open to Southern Ocean and Antarctic scientists as well as carbon cycle scientists, 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 newsletters and websites.

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.