US CLIVAR/OCB Southern Ocean Working Group Annual Report (2014-2015)

Joellen Russell (U. Arizona)
Igor Kamenkovich (U. Miami)

Southern Ocean Working Group:
Joint U.S. CLIVAR/OCB Working Group

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.

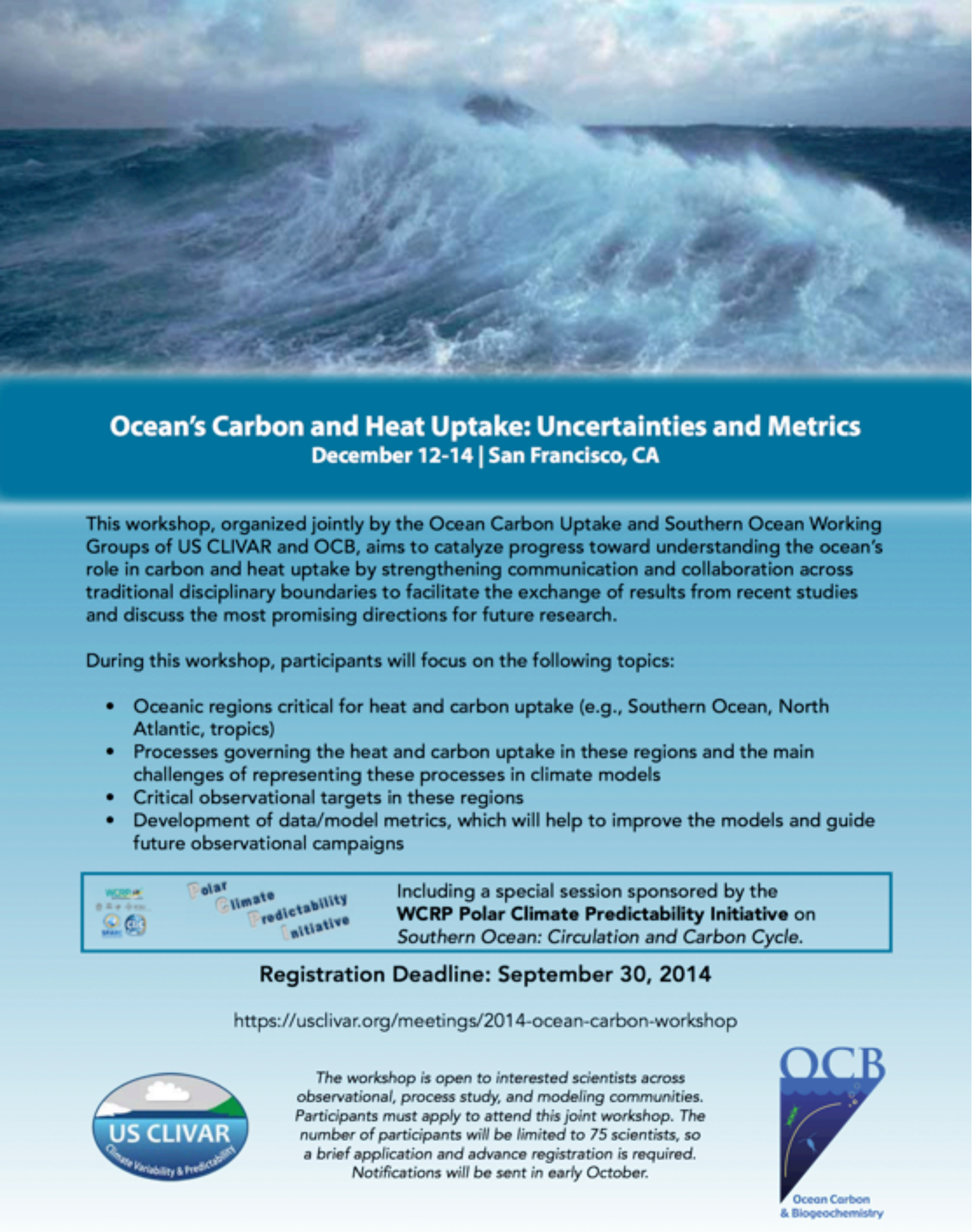
SOWG Outcomes and Deliverables

- A Workshop/Conference jointly sponsored with the Oceanic Carbon Uptake Working Group at **Fall AGU 2014**, 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 Manuscript for the Journal of Climate 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.

- Observationally-based data/model metrics for the consistent evaluation of modeling efforts by Southern Ocean and Antarctic scientists. Will be available on UA-hosted Southern Ocean Climate Model Atlas website. (available this summer)

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



Joint Workshop

Workshop Organizing Committee:

- **Joellen Russell**, Chair, University of Arizona
- **Heather Benway**, OCB/Woods Hole Oceanographic Institution
- **Annalisa Bracco**, Georgia Tech
- **Curtis Deutsch**, University of Washington
- **John Fyfe**, Environment Canada/ WCRP Polar Climate Predictability Initiative
- **Taka Ito**, Georgia Tech
- **Igor Kamenkovich**, RSMAS/ University of Miami
- **Mike Patterson**, US CLIVAR Project Office
- **Kristan Uhlenbrock**, US CLIVAR Project Office

The goals of this workshop were to:

- Build upon and synthesize the Working Groups efforts to develop metrics for evaluating biases in CMIP-5 model simulations;
- Estimate uncertainties in model projections of heat and carbon uptake;
- Inform future observations, model development, and analysis strategies for addressing biases and uncertainties (including protocols of CMIP-6)

The workshop was organized into five main sessions covering the following themes:

- **Model Biases and Uncertainties in CMIP5 Models**
- **Observational Gaps and Uncertainties**
- **Process Studies: Gaps, New Measurements, and Parameterizations**
- **Southern Ocean: Circulation and Carbon Cycle**
- **New Initiatives**

The 82 attendees included academic, government and non-governmental scientists and program managers including at least 20 from non-US organizations representing 9 different countries.

Recommendations from the Workshop:

Modeling Session Recommendations

- **Derive observational metrics** that cross boundaries between atmosphere, ocean, land and cryosphere and can identify biases in coupled dynamics and associated feedbacks
- **Evaluate and address model biases** by identifying processes/mechanisms, not simply documenting the model errors. Among the important properties mentioned are the hydrologic cycle amplification, water mass structure (SAMW/AAIW, AMOC), continental shelf processes (upwelling and outflows/overflows), large-scale tropical features (cold tongue, ITCZ, upwelling), spatial variations in carbon uptake and atmospheric biases
- **Need comprehensive CMIP5 analysis packages** (CMIPVAL tool, PCMDI metrics), such as newly established CMIP panel within GFDL, CLIVAR REOS webpage for one-stop shop (observational data sets/metrics to evaluate ocean models)
- **The community should conduct idealized sensitivity simulations** to establish key processes; the results can be used to validate the parameterization of these processes before adding more complexity to climate models
- **Coordinated observations and modeling efforts** can go a long way toward identifying biases and reducing uncertainty in climate simulations

Recommendations:

Observations Session Recommendations

- **Calibration, calibration, calibration** – it's critical and newly emerging programs like OOI don't have readily available, well documented procedures. It's difficult to calibrate rates, and there is a strong need to fully document methodologies and changes in methodologies
- **Need standardized** climate-quality biological measurements
- **More data synthesis/analysis efforts** – these are critical to fully exploiting rich data sets but many of efforts to date have been done on shoestring (e.g., GLODAP and GLODAP2), agencies need to prioritize this to get full return on their investment in the observations!!
- **More coordinated efforts** to observe atmospheric and oceanic process concurrently
- **More deep ocean measurements** (Expand Deep Argo!)
- **Measurements under the ice**

Recommendations:

Southern Ocean Session Recommendations

- The use of **observationally-based standardized metrics** is the best way to evaluate and compare models and to move toward reducing uncertainty in out projection of future climate.
- A **rigorous assessment of input of wind energy** into the ocean and the uncertainties (spatial and seasonal) associated with the observing system is needed.
- A **coordinated program to observe and model** both oceanic and atmospheric biogeochemical parameters at the same place and time is needed for both improved understanding and for model validation.
- There is an increasing need for both **top-down tracers** that reveal sinking (like CFCs) and **bottom-up tracers** that reveal ventilation (like radiocarbon).
- We need to **assess the role of the winds in changes in the strength of the Antarctic Circumpolar Current and the role of eddies both in the ocean and in the models**; why variability in the strength and position of the simulated winds is larger than observed across models and within individual models; and how carbon uptake is sensitive to the interaction between the simulated winds and the simulated (or parameterized) eddies.

Recommendations:

Process Studies Session Recommendations

- The **role of eddies** at low and high latitudes
- The **dynamics in coastal upwelling zones**, including the role of Eastern Boundary Currents
- **Ocean convection, overflows** from marginal seas and shelf, and the interior pathways of dense water masses
- **Mechanisms** of iron (Fe) input to the ocean

The workshop report is being edited by the organizing committee, and should be available this summer

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

Metrics for the Evaluation of the Southern Ocean in Coupled Climate Models and Earth System Models

Joellen L. Russell[1], Igor Kamenkovich[2], Cecilia Bitz[3], Raffaele Ferrari[4], Sarah T. Gille[5], Robert Hallberg[6], Kenneth Johnson[7], Irina Marinov[8], Matthew Mazloff[5], Jorge Sarmiento[9], Kevin Speer[10], Lynne D. Talley[5] and Rik Wanninkhof[11]

Affiliations: (1) University of Arizona; (2) Rosenstiel School of Marine and Atmospheric Science, University of Miami; (3) University of Washington; (4) Massachusetts Institute of Technology; (5) Scripps Institution of Oceanography, University of California, San Diego; (6) National Oceanic and Atmospheric Administration, Geophysical Fluid Dynamics Laboratory; (7) Monterey Bay Aquarium Research Institute; (8) University of Pennsylvania; (9) Princeton University; (10) Florida State University; (11) National Oceanic and Atmospheric Administration, Atlantic Oceanographic and Meteorological Laboratory

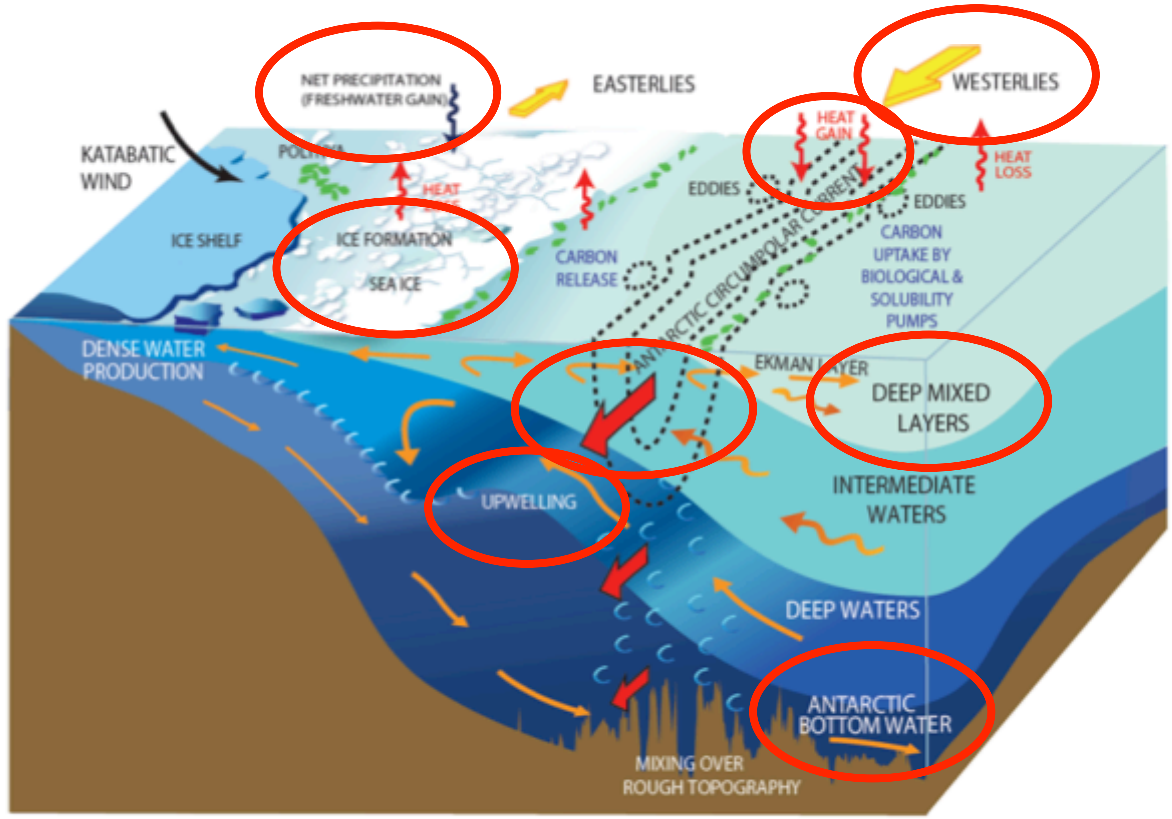
Abstract

The Southern Ocean Working Group, jointly sponsored by US CLIVAR and Ocean Carbon and Biogeochemistry, was formed to develop observationally-based data/model metrics for the consistent evaluation of modeling efforts of the ocean, atmosphere and cryosphere in the Southern Ocean. Specifically, the oceanic uptake and storage of heat and carbon make the Southern Ocean a key component of the Earth climate system, and variables related to these processes are the main focus of this study. We brought together theoretical, observational and numerical oceanographers as well as atmospheric and ice scientists in order to establish what are the "most useful" metrics for assessing a model simulation of the Southern Ocean. This report is not strictly an intercomparison, although we will present results from a subset of the available CMIP5 models. This report is a distillation of those metrics that can provide a reliable way to

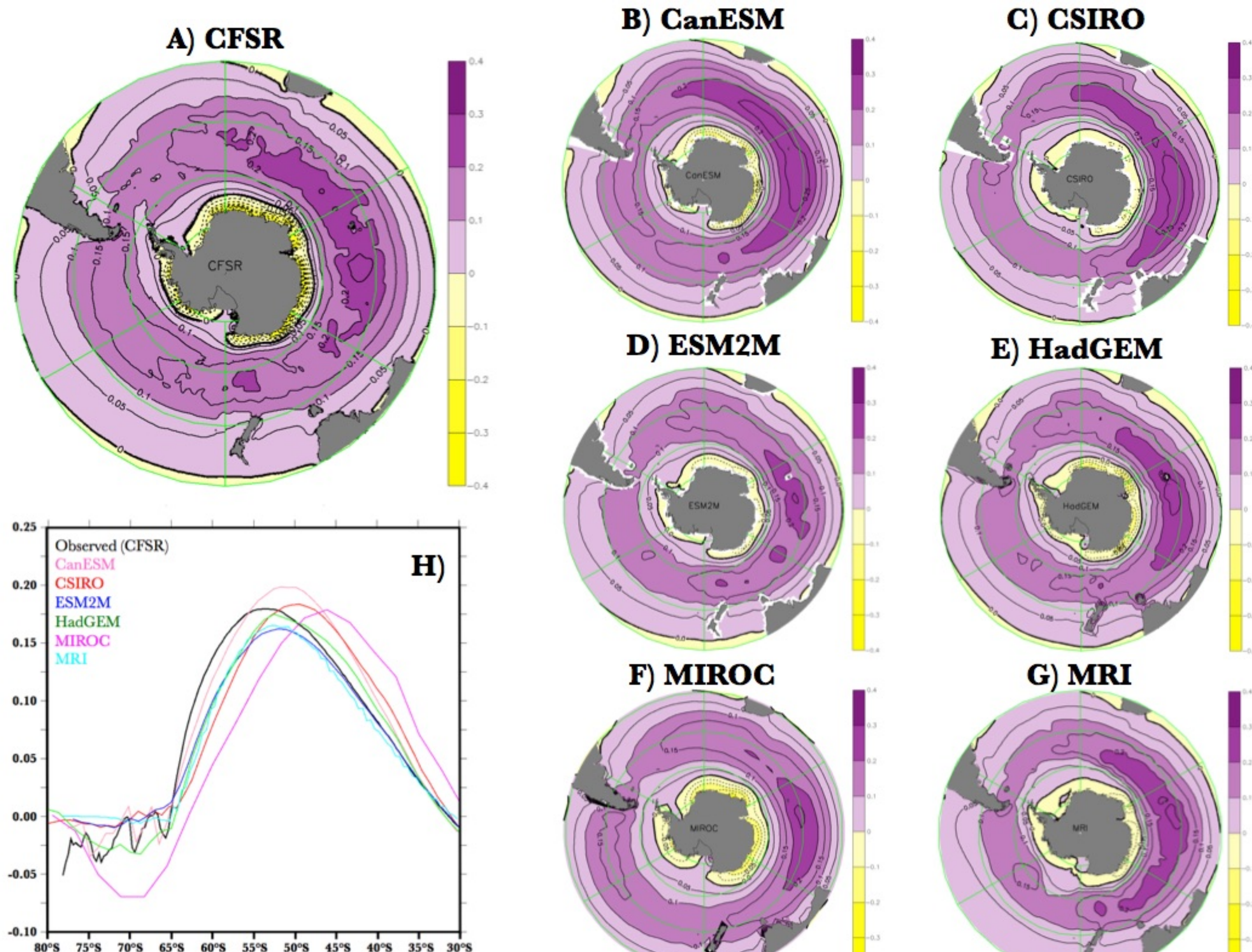
Southern Ocean Metrics and the Door to the Deep Ocean

- Observationally-based metrics associated with Southern Ocean circulation, biogeochemistry and heat and carbon uptake have been formulated based on observations derived from:

- WOA
- GLODAP/CDIAC
- AVISO
- ISCCP
- CFSR/NCEP reanalyses
- and more
- (Russell et al.,
  J. Climate, in prep)



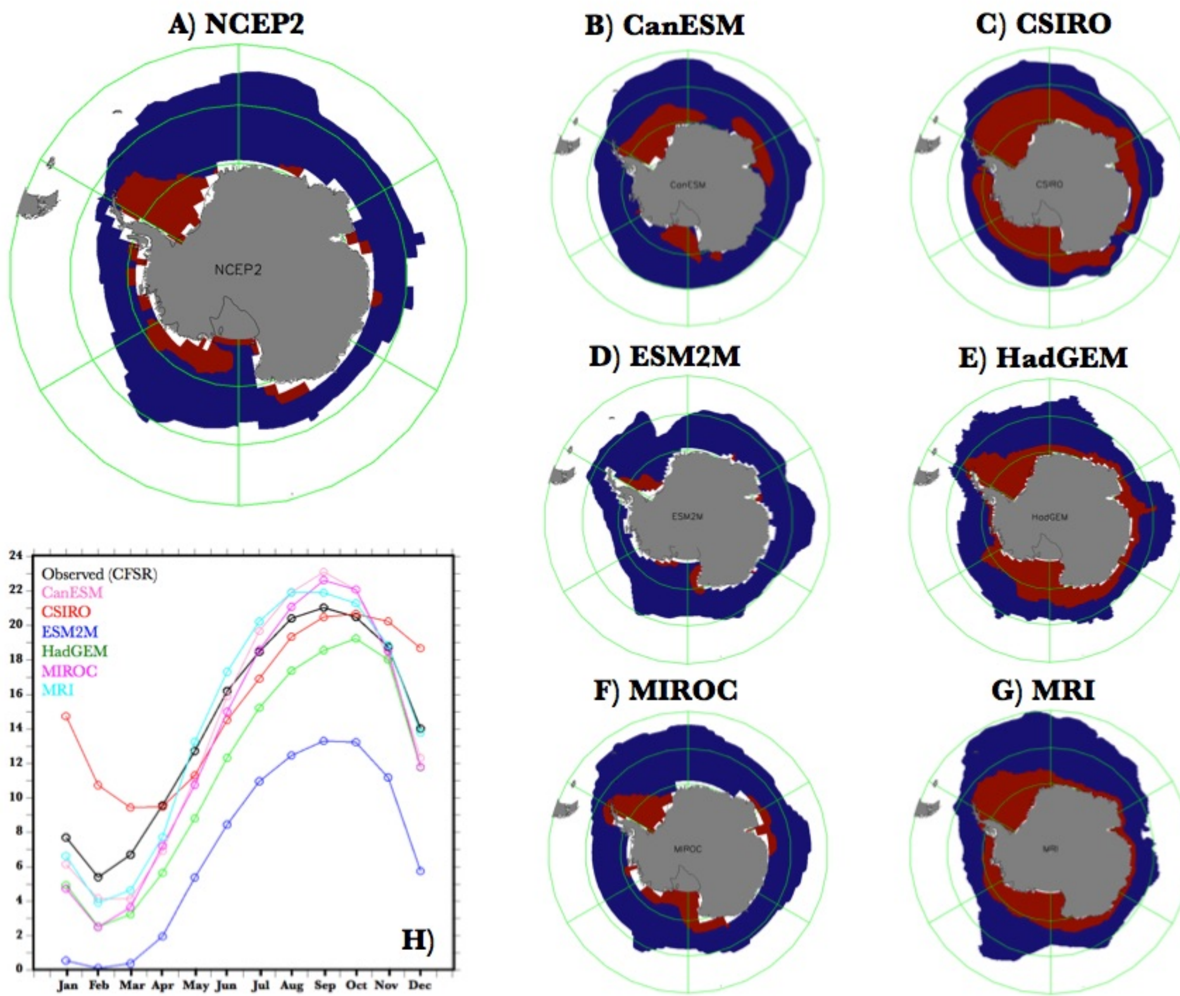
Metrics



Westerly winds –

- source of virtually all of the momentum in the Southern Ocean (ACC)
- effects depend critically on the latitudinal structure
- drives upwelling/downwelling
- play a key role in balancing density structure: act to weaken stratification
- models continue to exhibit a northward bias in the location of the maximum of the wind stress.

Metrics



Integrated area is given in 10^6 km^2

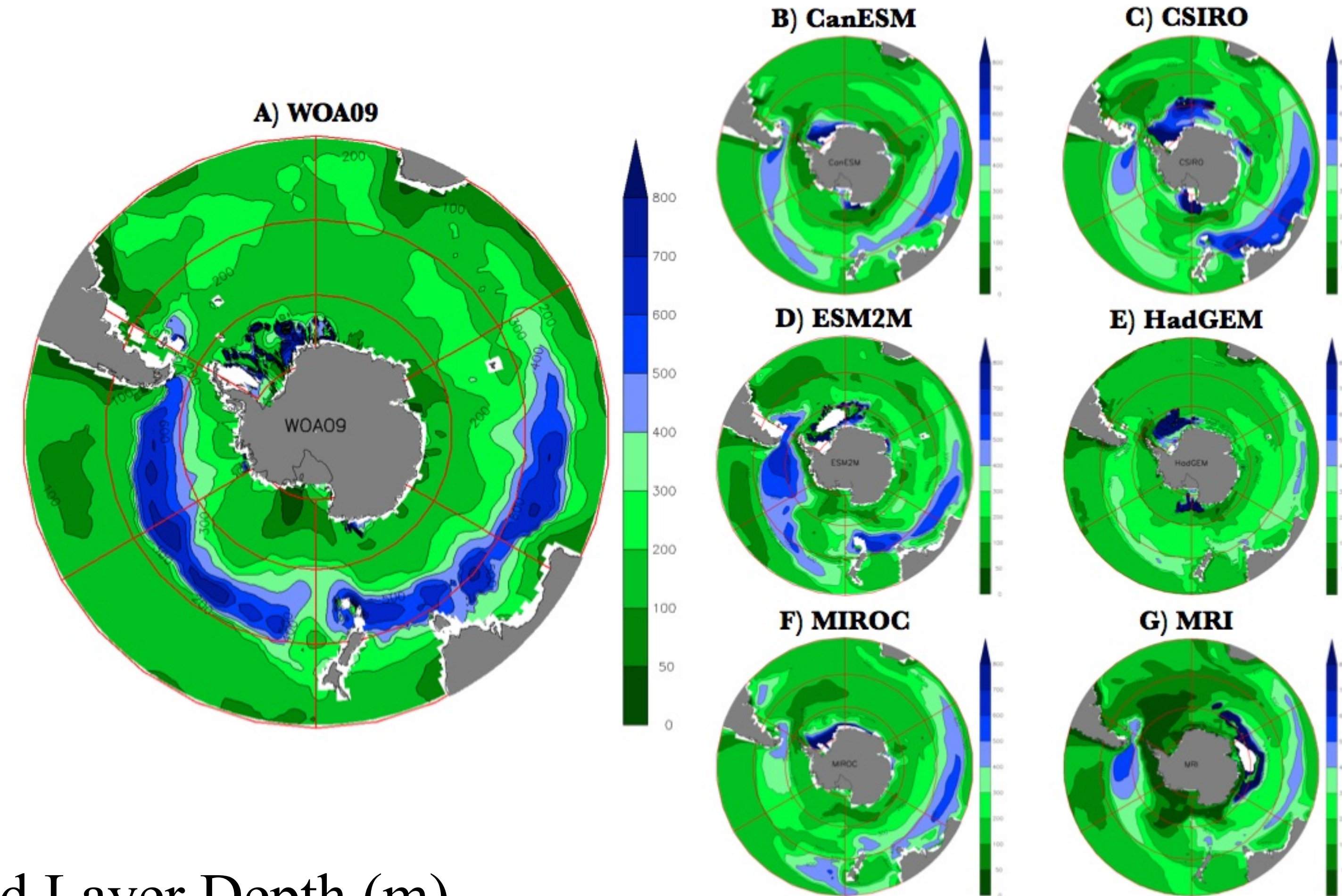
The ice edge is defined as the 15% coverage contour (NSIDC)

Sea Ice Extent (max/min) –

- forms a physical barrier to the air/sea exchanges of heat and carbon
- brine rejection believed to be an essential part of Antarctic Bottom Water formation
- biases in the sea-ice cover most likely caused by errors in the simulated heat budgets of the upper ocean

Metrics

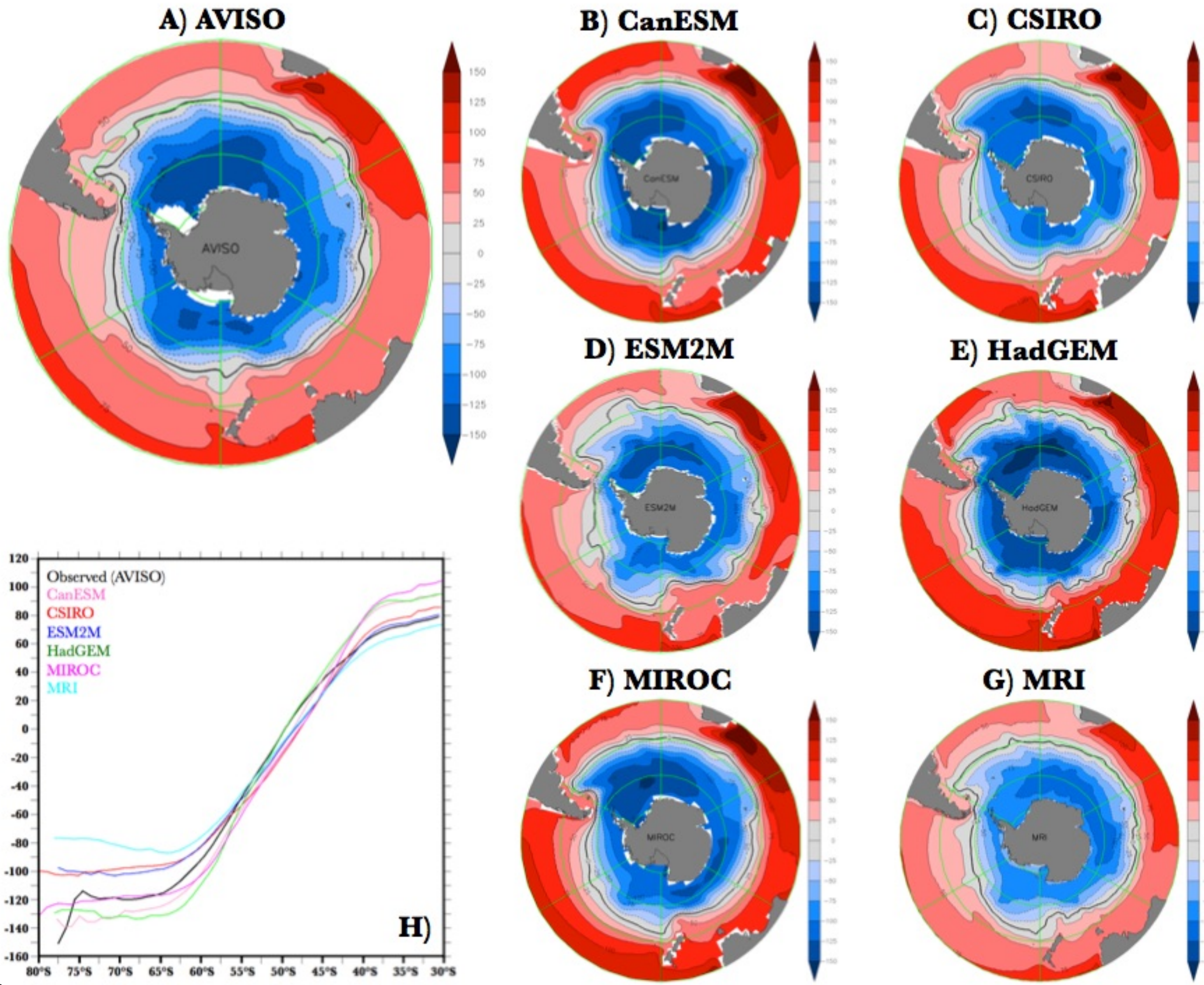
MLD defined as depth of density at 0.125 kg/m^3 above the surface value (Levitus 1982; Monterey & Levitus 1997)



Maximum Mixed Layer Depth (m) –

- indication of the stratification of the water column and the depth to which wind forcing can penetrate into the ocean
- deep winter-time mixed layer south of Australia that is associated with the Subantarctic Mode Water
- Several of the models have excessively deep mixed layers in the Weddell Sea and/or the Ross Sea due to persistent convection.

Metrics

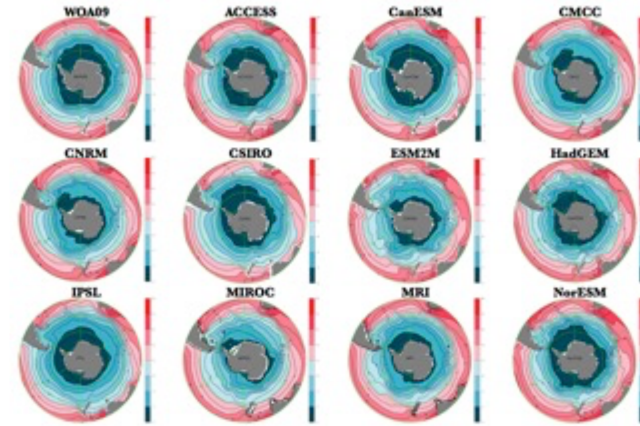


Area average SSH south of 30°S has been subtracted from each figure

Sea Surface Height (cm) –

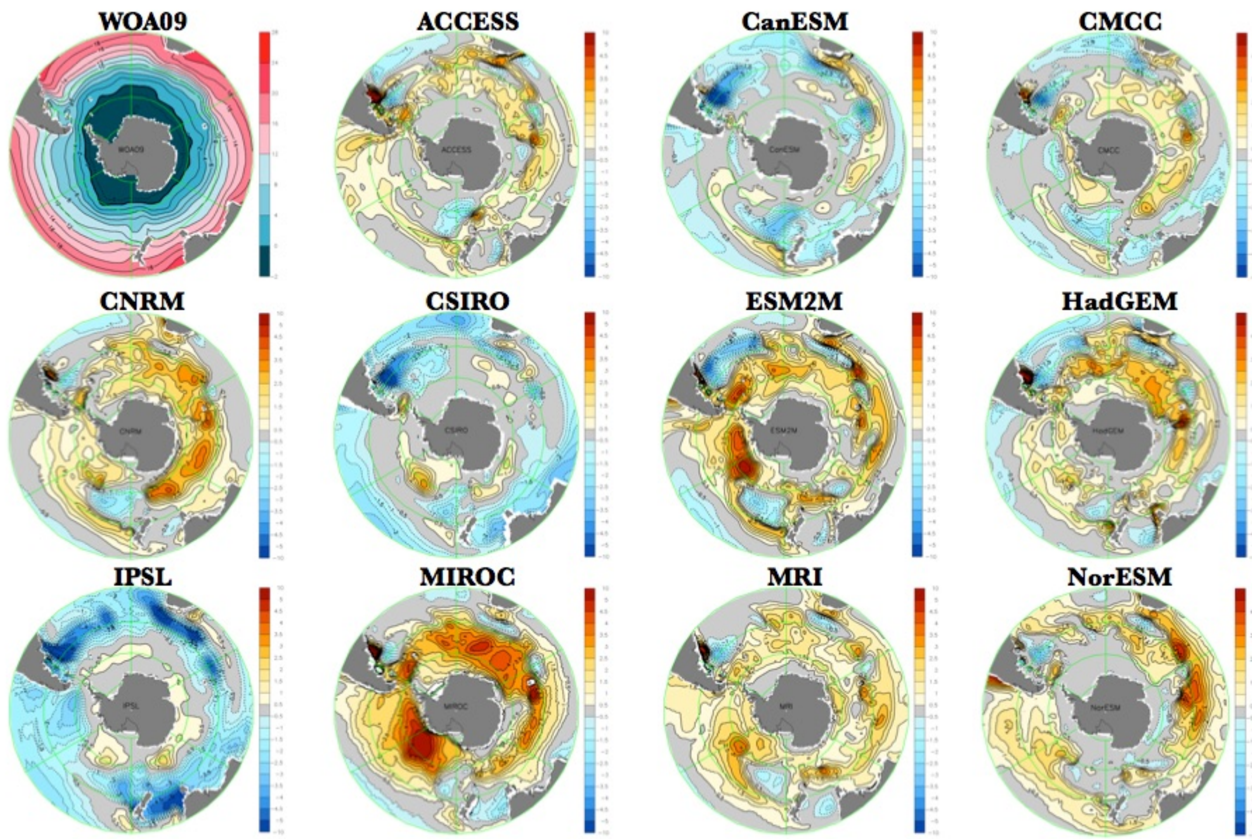
- indication of the **barotropic** circulation around Antarctica
- affected by density and steric height anomalies so an indicator of heat content as well as winds and velocity
- significant flow along the bottom, so direct connection between the SSH gradient and the total flow may be skewed, especially in models with idealized topography and/or significant differences in the stratification on both sides of the ACC

Metrics



Sea Surface Temperature Simulation Errors –

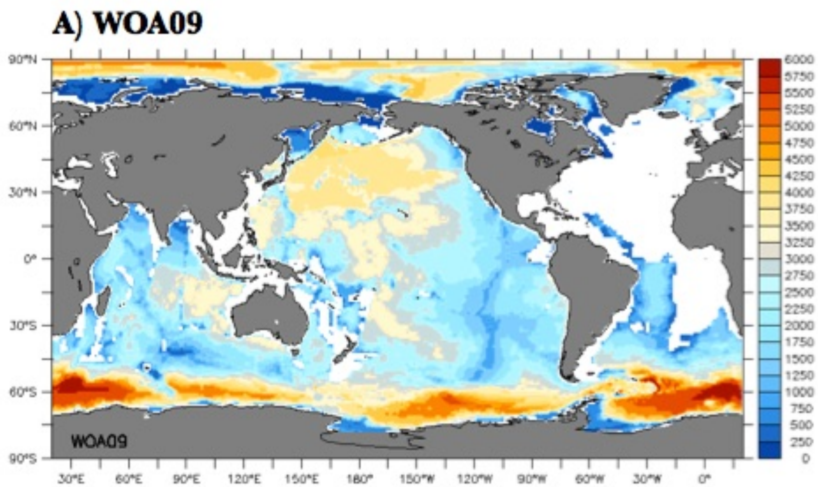
- Models are generally warm, especially near the coast (not enough <0° water)
- As expected, SST anomalies are well correlated with sea ice anomalies
- differences are primarily due to circulation and or wind biases and not due to net air/sea heat fluxes
- anomalies can affect heat uptake

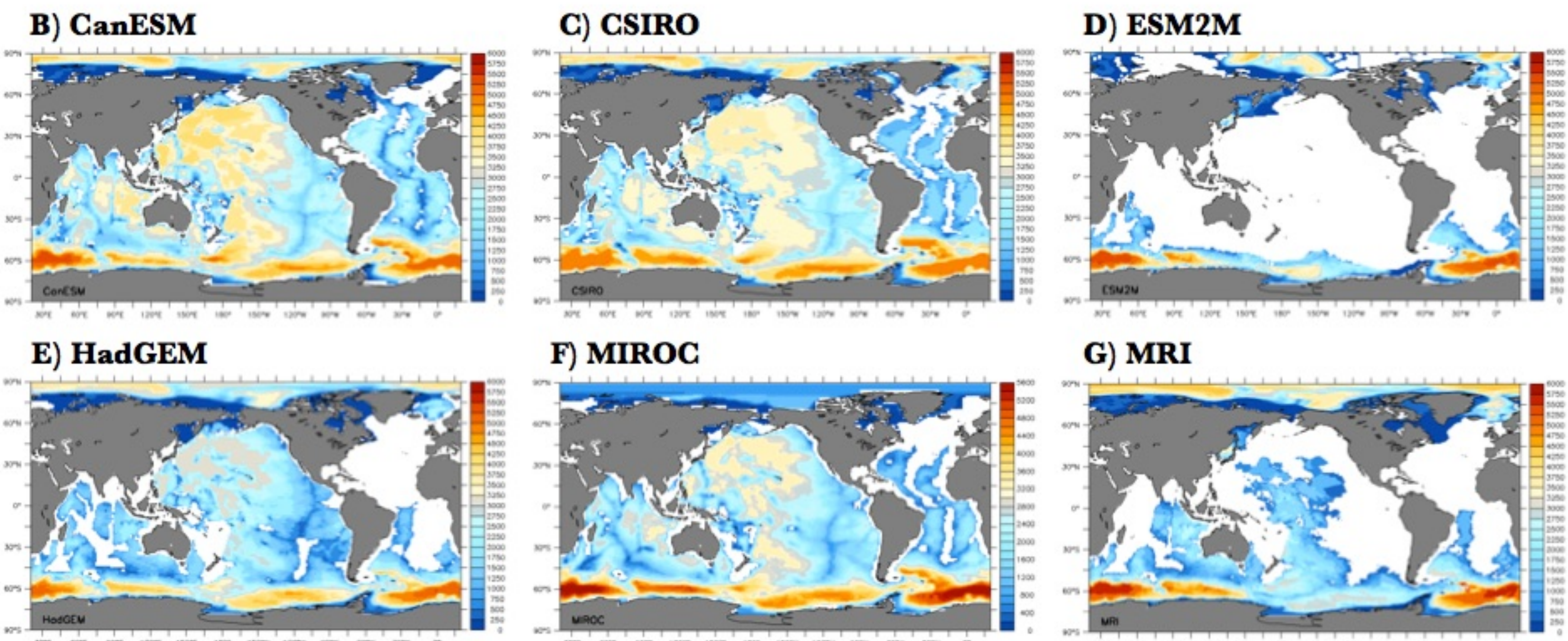


Metrics

Thickness of the <2° layer

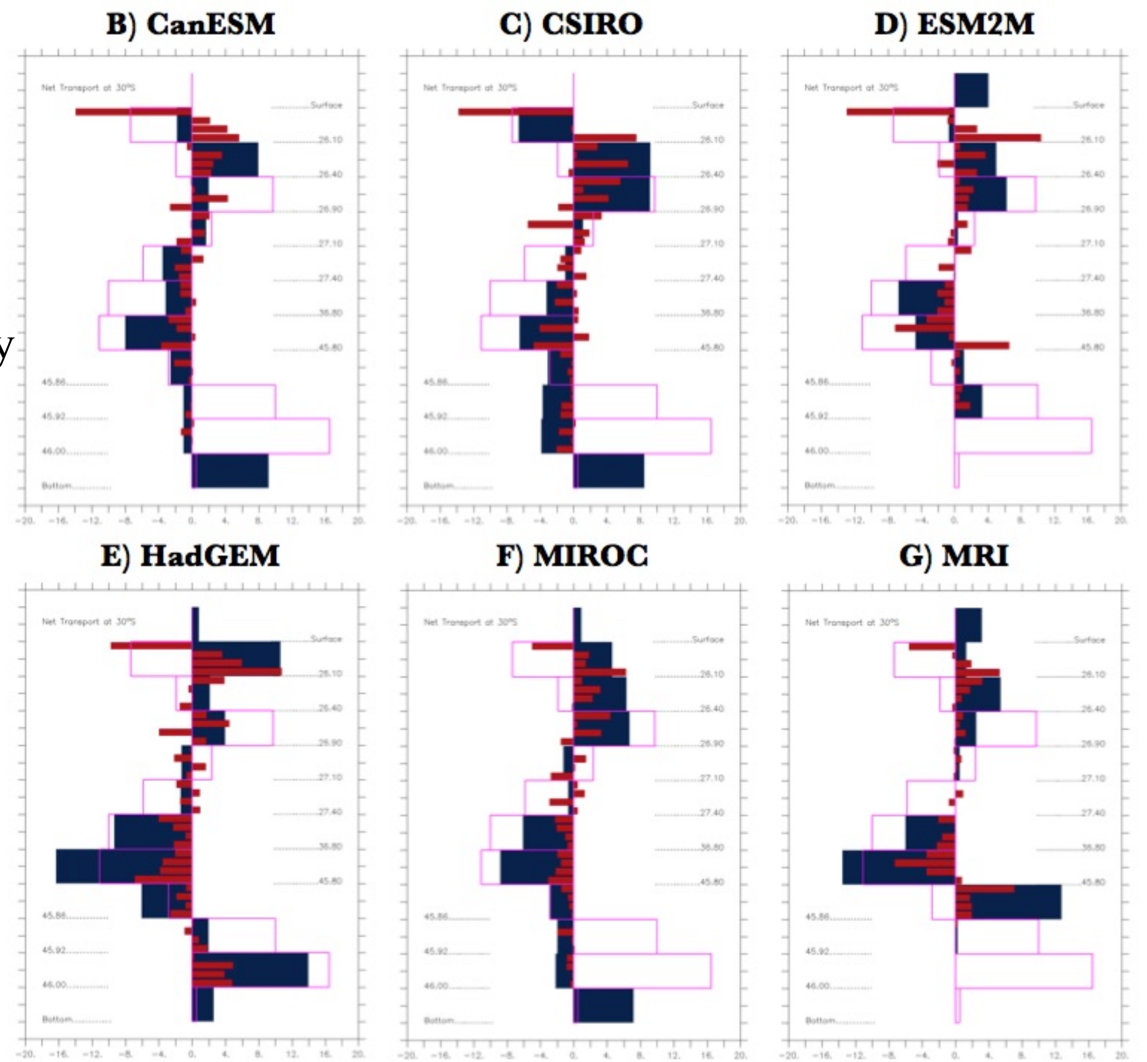
- nominal Antarctic Bottom Water layer is a good indicator of potential heat and carbon uptake in warming scenarios.
- Simulations with a thick cold-water layer in the Southern Hemisphere have a robust connection between the surface and the deep.
- model simulations that simulate deep uptake of heat have been show to have relatively reduced atmospheric warming under increasing greenhouse gas scenarios





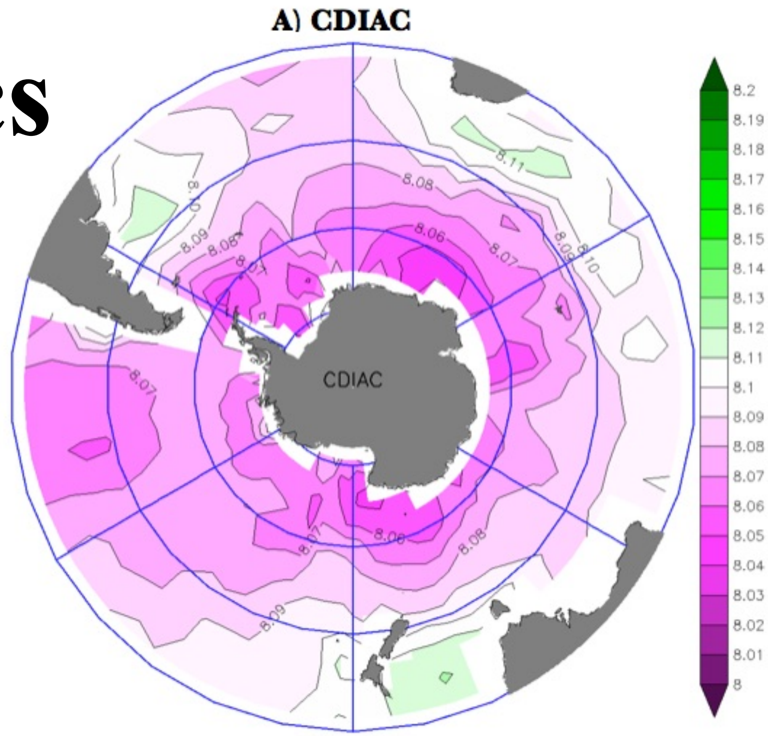
Metrics

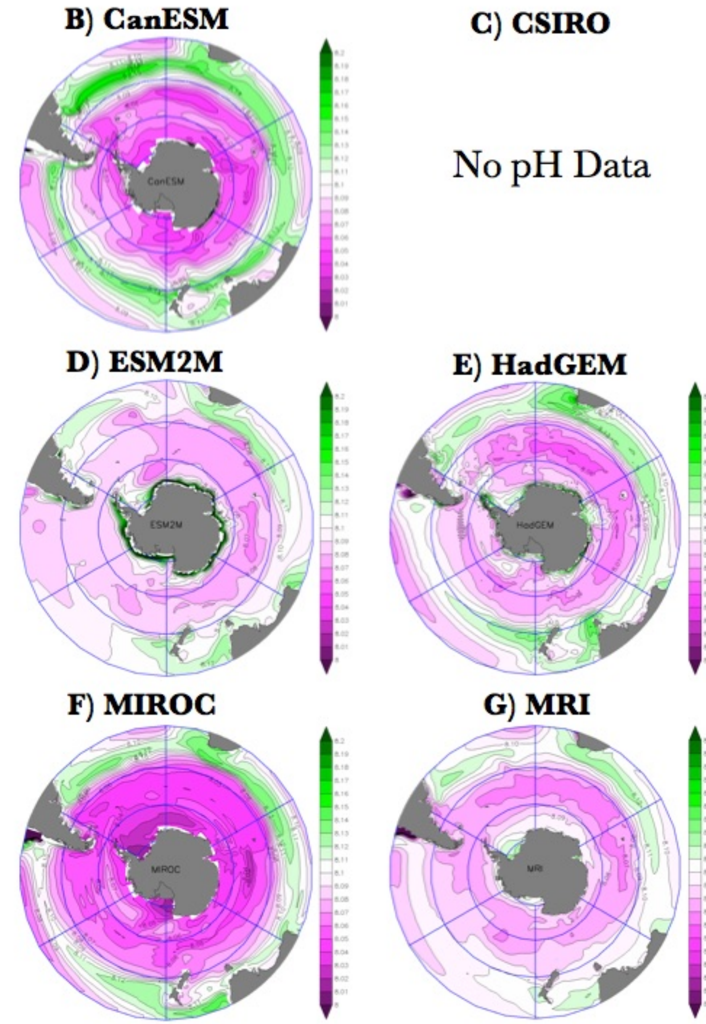
- An “inverse-type” analysis where volume flow is mapped onto density layers and then calculated across various sections.
- These analyses show more of the plumbing and the water mass transformations occurring in the model.
- This flow analysis, especially with the finer-resolution layers, reveals strengths and weaknesses of each simulation with respect to both its flow and its hydrography.



Density layer based heat/temperature transport (in PW/PWT) across 30°S based on the layer definitions in Talley (2008). The comparison with Talley (2008) assumes that the model’s water mass characteristics are similar to those observed in the real ocean, however, in some cases this leads to a somewhat incomplete representation of the computed transports from the model simulation. The dark blue bars are the integrated totals for each layer and can be compared to the magenta lines, which are the observed values from Talley (2008). The narrower red bars are approximately equal subdivisions of each layer. Unlike the Talley 2008 analysis, we have not separated out the Ekman transport (although we corrected the “observed” quantities (in purple) to reflect this). The topmost blue bar indicates the total heat transport across 30°S. Positive values are northward transport (out of the Southern Ocean).

Metrics



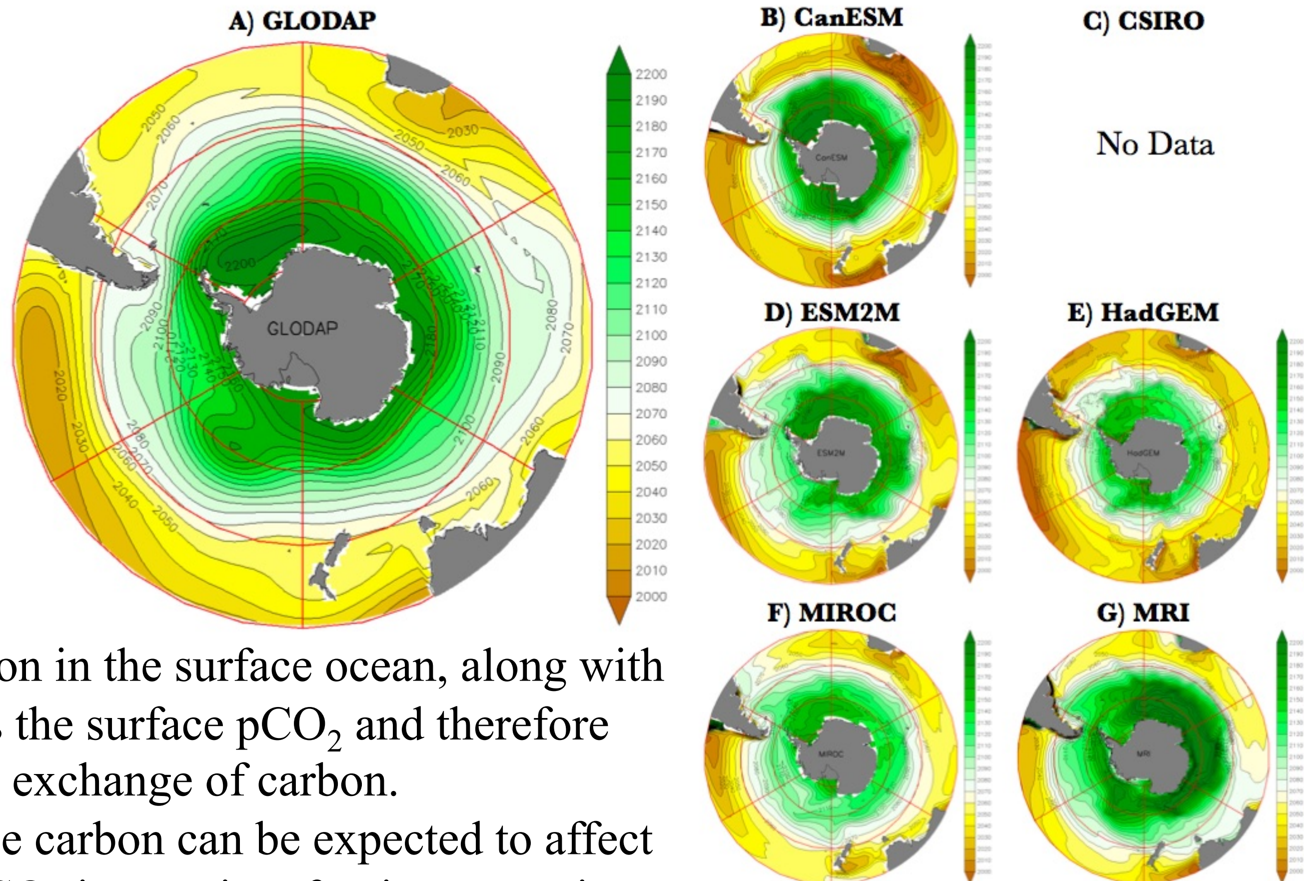


Surface pH (at the in situ temperature and total scale) calculated from pCO2 and Potential Alkalinity observations and the model simulations. Calculated pH are taken from the recent Takahashi et al. (2014) climatology for reference year 2005, available through CDIAC, which has a fairly coarse 5°-by-5° resolution.

Surface pH

- Ekman-driven surface divergence brings old, carbon-rich, low pH water to the surface:
- several of the simulations have excessively alkaline waters north of the ACC and several have too acidic water in the upwelling region.
- small differences can potentially have large effects on simulated acidification trends as calcification rates are especially sensitive to small changes in the pH

Metrics

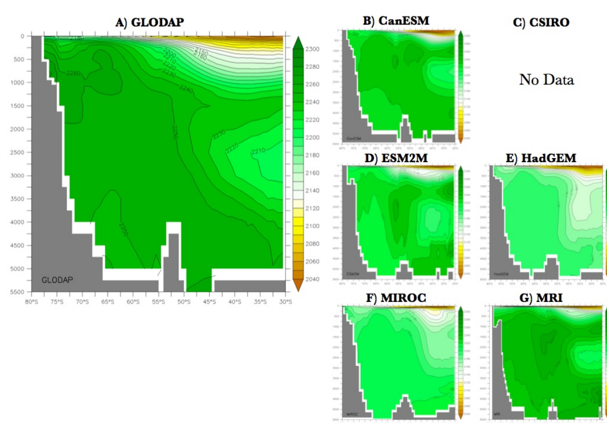


Surface DIC

- The total amount of carbon in the surface ocean, along with the alkalinity, determines the surface pCO_2 and therefore greatly affects the air/sea exchange of carbon.
- Simulations of the surface carbon can be expected to affect the simulated uptake of CO_2 in transient forcing scenarios, and therefore the global atmospheric temperature response to these scenarios.

Atlantic DIC (zonal mean)

- There are dramatically different carbon concentrations (globally and regionally) across the simulated oceans
  (note different scale from above)



SOCCOM

Unlocking the mysteries of the Southern Ocean

DRIFTERS DEPLOYMENT

Princeton University's Southern Ocean Carbon and Climate Observations and Modelling Program (SOCCOM) draws on talents of top scientists at leading institutions to unlock and communicate the mysteries of the Southern Ocean.

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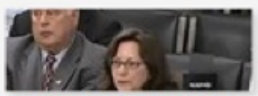
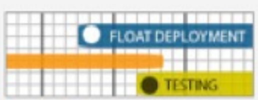
NEWS



Dr. Lynne Talley testifies before the Subcommittee on Fisheries

Dr. Lynne Talley testifies before the Subcommittee on June 13th, 2013

SOCCOM Timeline



See what our plans are

Follow SOCCOM

SOUTHERN OCEAN CARBON AND CLIMATE OBSERVATIONS AND MODELLING

The Southern Ocean Carbon and Climate Observations and Modelling Program (SOCCOM) is a candidate NSF Science and Technology Program focused on unlocking the mysteries of the Southern Ocean and determining its influence on climate.

Housed at Princeton University, SOCCOM would draw on the strengths of teams of investigators across the U.S. as well as participate in international observational and simulation efforts.

SOCCOM Dashboard

- **Why study the Southern Ocean?**
- **Observations**
- **Models & Metrics**

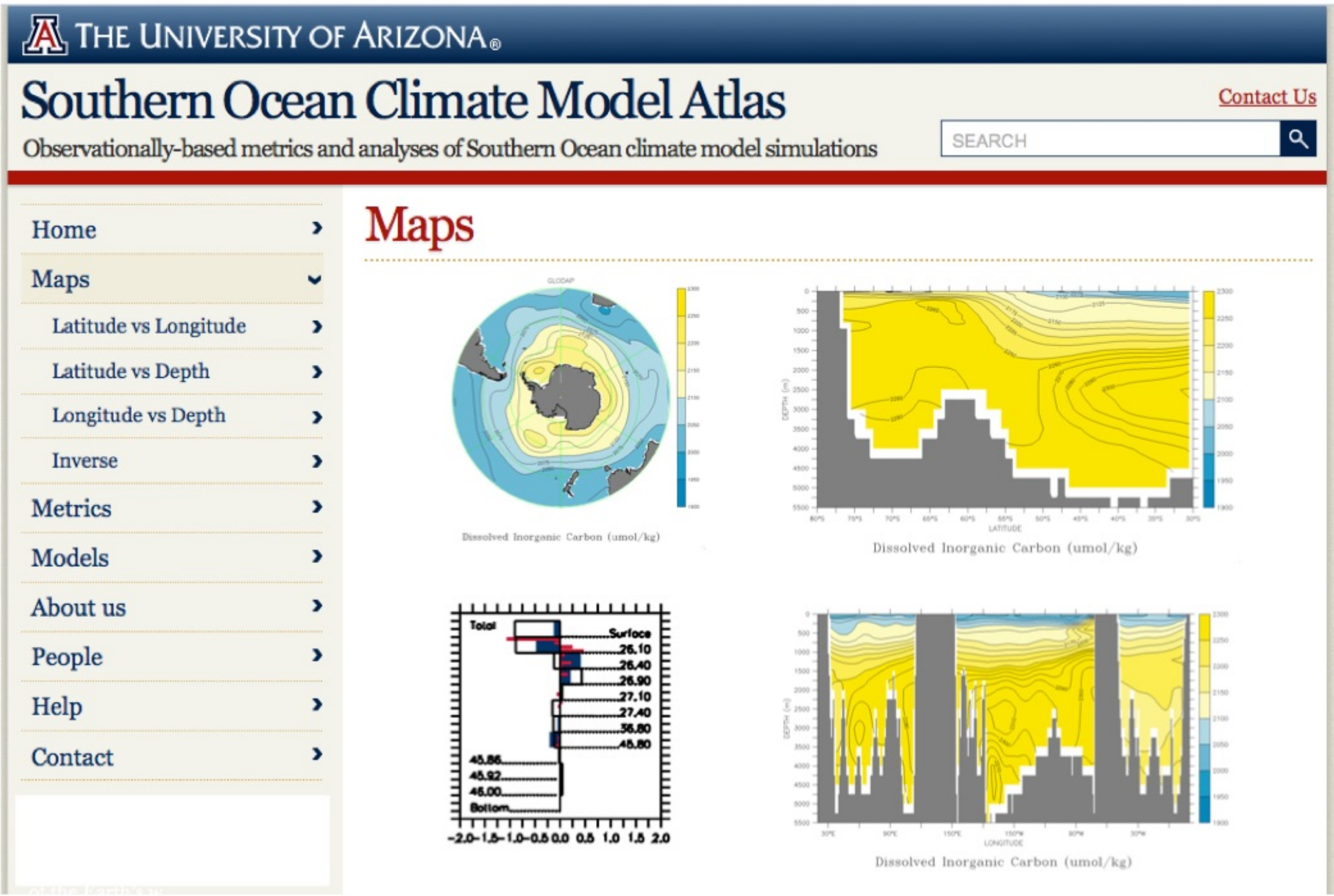
SOCCOM Partners

CLIMATE CENTRAL

SOCCOM
Princeton University
208 Sayre Hall
Forrestal Campus
Princeton, New Jersey
08540-6654

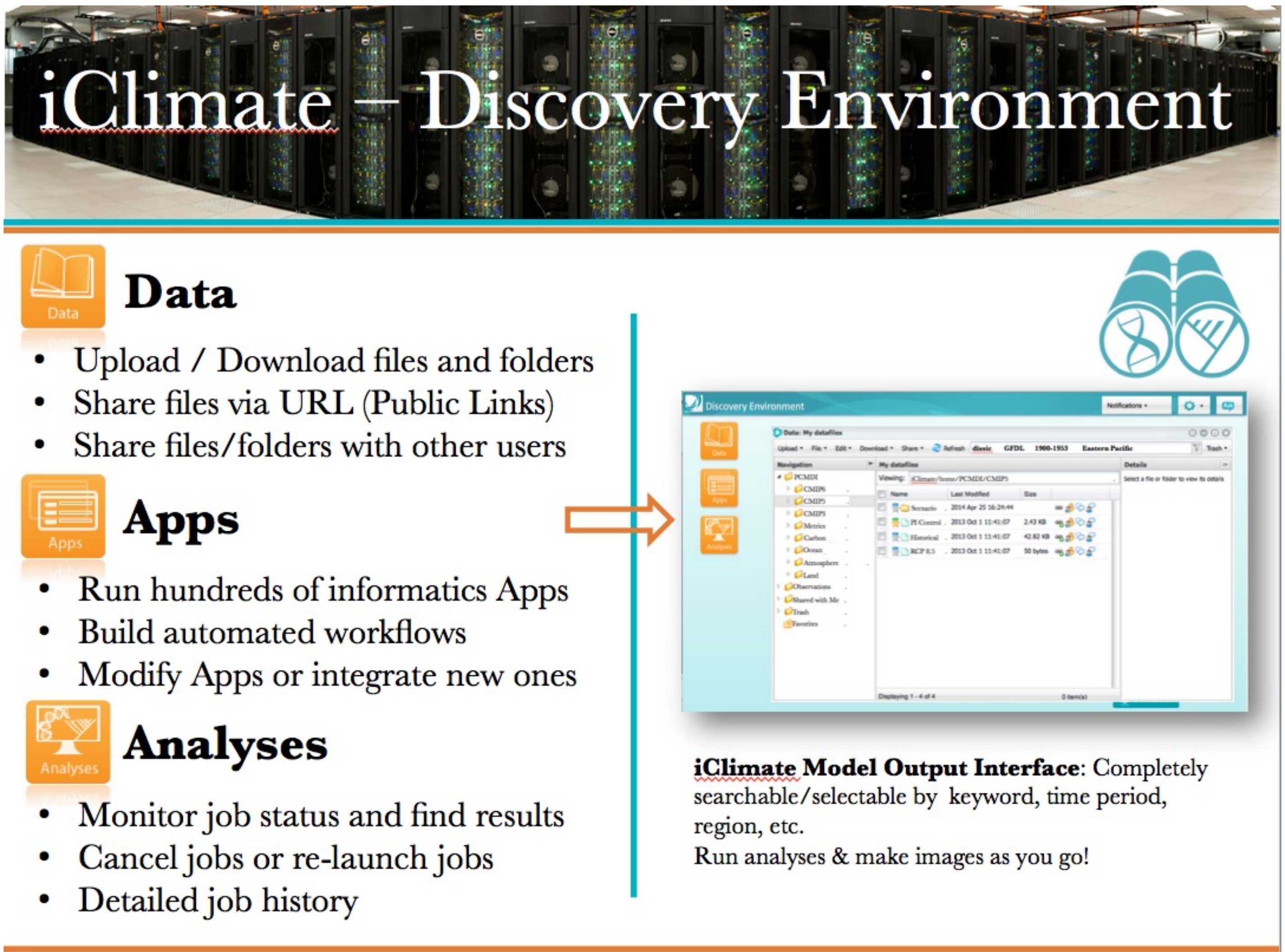
New Resources:

The Southern Ocean Climate Model Atlas will provide standardized images and metrics of the climate model and Earth System Model simulations conducted as part of the IPCC and CMIP processes. These maps, analyses and metrics will be available to researchers of all disciplines and members of the public. The Atlas will be made public shortly.



New Resources:

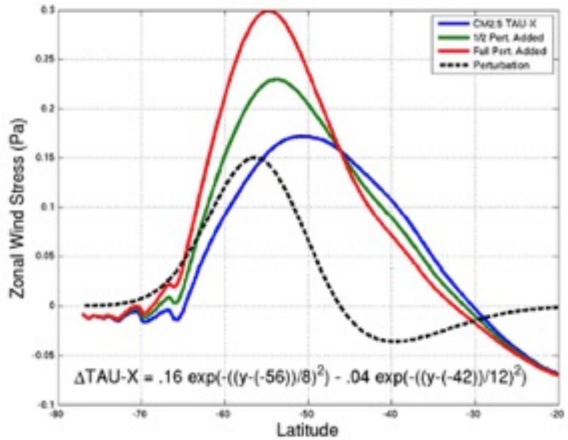
We are creating a climate data and analysis portal called iClimate. iClimate will allow users to upload and share climate model data and the observational datasets against which they are assessed, as well as analysis tools and scripts. iClimate is currently in a testing phase and should be available to the public in the Fall of 2015.



Southern Ocean Model Intercomparison Project

OVERALL GOAL: Reduce uncertainties in climate projections by defining the role of the oceans in climate with regards to the Southern Ocean, especially the role of winds, buoyancy and stratification in determining the global impacts of warming.

OBJECTIVE: Encourage the climate modeling community to use the newly created assessment tools (SOWG) by developing a protocol for an international, model intercomparison program (SOMIP)



Proposal: Zonally uniform wind perturbation, focused on Drake Passage

World Climate Research Programme

WMO

IOC

ICSU

International Council for Science

SOWG Conclusions:

We need to reduce the uncertainty in our projections of the Southern Ocean's role in climate.

1) We need more in situ biogeochemical observations of the Southern Ocean, including floats, ships, moorings, etc. (BGC-Argo)

2) We need more Southern Ocean Climate Process Teams

3) We need more Observationally-based climate model metrics

4) We need a Southern Ocean Model Intercomparison Project