Southern Ocean Model Intercomparison Project

Perturbation Experiments in the Southern Ocean

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Matt England & Benjamin Bronselaer

Southern Ocean Model Intercomparison Project (SOMIP)

Drafting Committee:

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Goal and Overview of the MIP Experiments

SOMIP is primarily focused on the CMIP6 scientific question "How does the Earth System respond to forcing?" with the aim of reducing uncertainties in climate projections by defining the role of the oceans in climate with regards to the Southern Ocean. As with most MIPs the goal is to understand the causes of differences in the models' responses and to compare models to observations. The purpose is to increase our understanding of the important processes influencing model response and to use that understanding to improve the models. Our plan is to closely align SOMIP with FAFMIP, using an adaptation of the FAFMIP wind forcing anomaly, and complementing their study by including an additional fresh water forcing anomaly around Antarctica.

The Southern Ocean is responsible for 67-98% of the oceanic uptake of anthropogenic heat (Roemmich et al. 2015, doi:10.1038/nclimate2513) and 43±3% of the oceanic uptake of anthropogenic carbon over the CMIP5 historical period (Frölicher et al. 2015, doi:10.1175/JCLI-D-14-00117.1), but simulations of the Southern Ocean continue to show significant inter-model differences (Russell et al., 2006, doi:10.1175/JCLI3869.1, Downes and Hogg, 2013, doi:10.1175/JCLI-D-12-00504; Meijers, 2014, doi:10.1098/rsta.2013.0296; Ito et al., 2015, doi:1 0.1002/2015GL064320, Farneti et al., 2015, doi:10.1016/j.ocemod.2015.07.009, Downes et al., 2015, doi:10.1016/j.ocemod.2015.07.022). A significant remaining uncertainty is how the

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

1

It accounts for **67-98%** of the excess heat that is transferred from the atmosphere into the ocean each year.

Roemmich et al. 2015

2

It accounts for **up to half** of the annual oceanic uptake of anthropogenic carbon dioxide from the atmosphere.

Gruber et al. 2009, Landschützer et al. 2015

3

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

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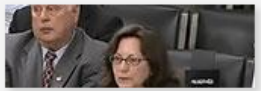
Unlocking the mysteries of the Southern Ocean

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.

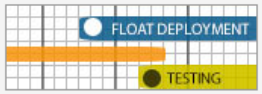
NEWS



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

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Princeton, New Jersey
08540-6654

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.

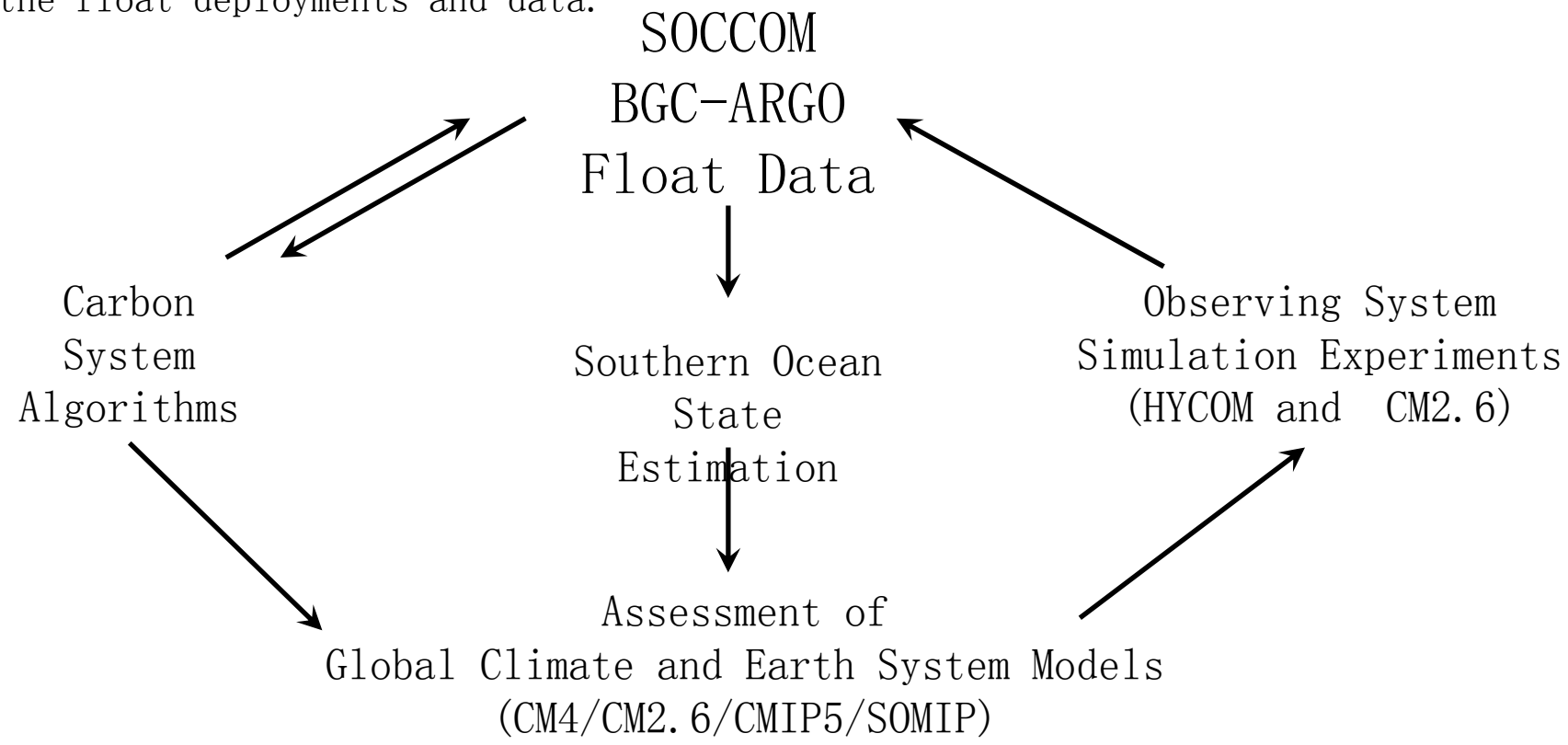
SOCCOM Dashboard

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

SOCCOM Partners

The SOCCOM Modeling Plan

The various components of the SOCCOM Modeling Plan all interact and relate to one another (below). The SOCCOM float program informs several of the modeling projects and the modeling projects are helping with the planning, design and quality control of the float deployments and data.



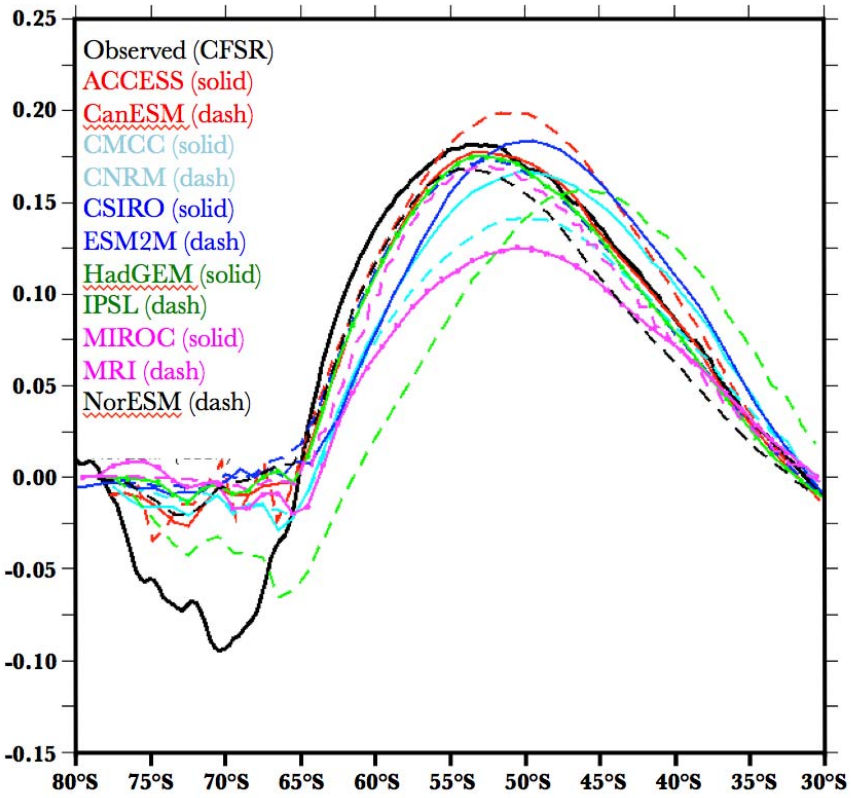
SOMIP

1. Why did we decide to do this - what do we want to know?
2. How did we come up with the procedure?
3. What are other MIPS doing?
4. What are we going to do specifically?
5. What have we learned so far?

Southern Ocean Model Intercomparison Project

Specific Interests

- Models differ widely in their simulations of the Southern Ocean: all of the models have their mean annual southern hemisphere westerly wind position northward of the observations.
- The baseline circulation of the Southern Ocean will affect how the heat and carbon uptake in each model responds to increased wind forcing and/or stratification.



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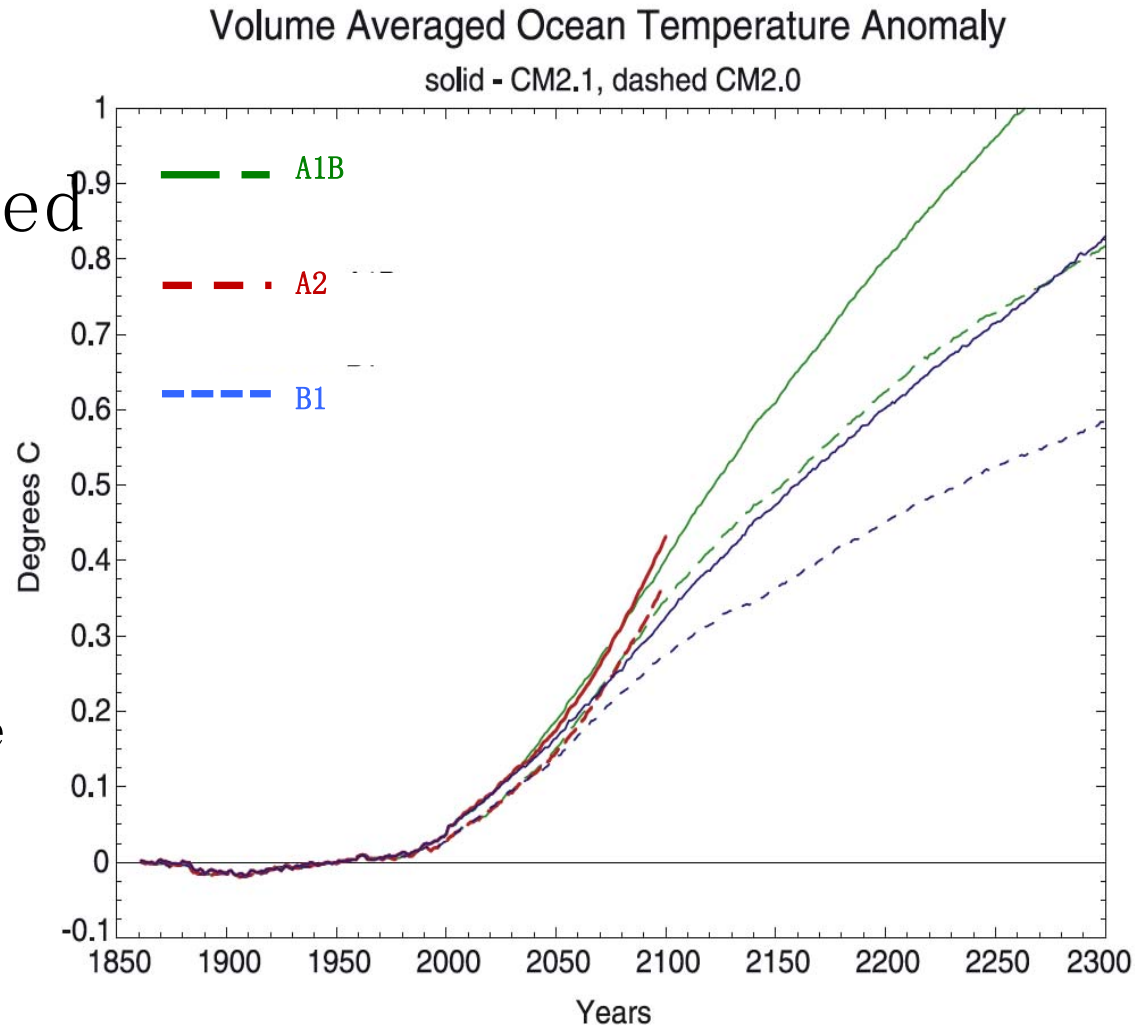
Effects of Poleward-Shifted of the Southern Hemisphere Westerlies

Simulated Ocean Heat Uptake

Solid lines = poleward winds

Dashed lines = equatorward winds



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Stouffer et al., 2006

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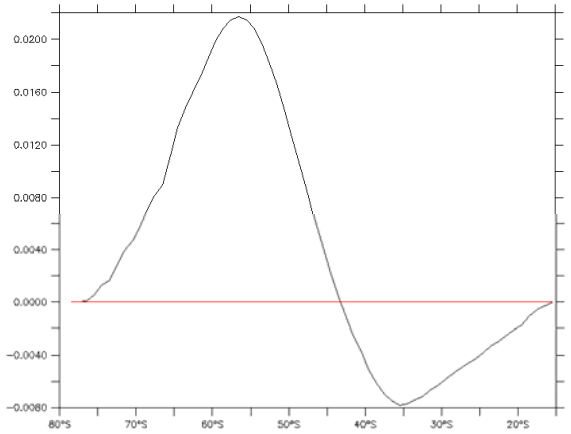
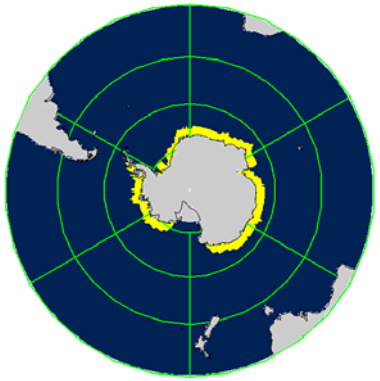
OVERALL GOAL: SOMIP is primarily focused on the CMIP6 scientific question “How does the Earth System respond to forcing?” with the aim of reducing uncertainties in climate projections by defining the role of the oceans in climate with regards to the Southern Ocean.



Proposal: Wind and Fresh water perturbations



OBJECTIVES:

- understand the causes of differences in the models’ responses
- compare models to observations
- increase our understanding of the important processes influencing model response

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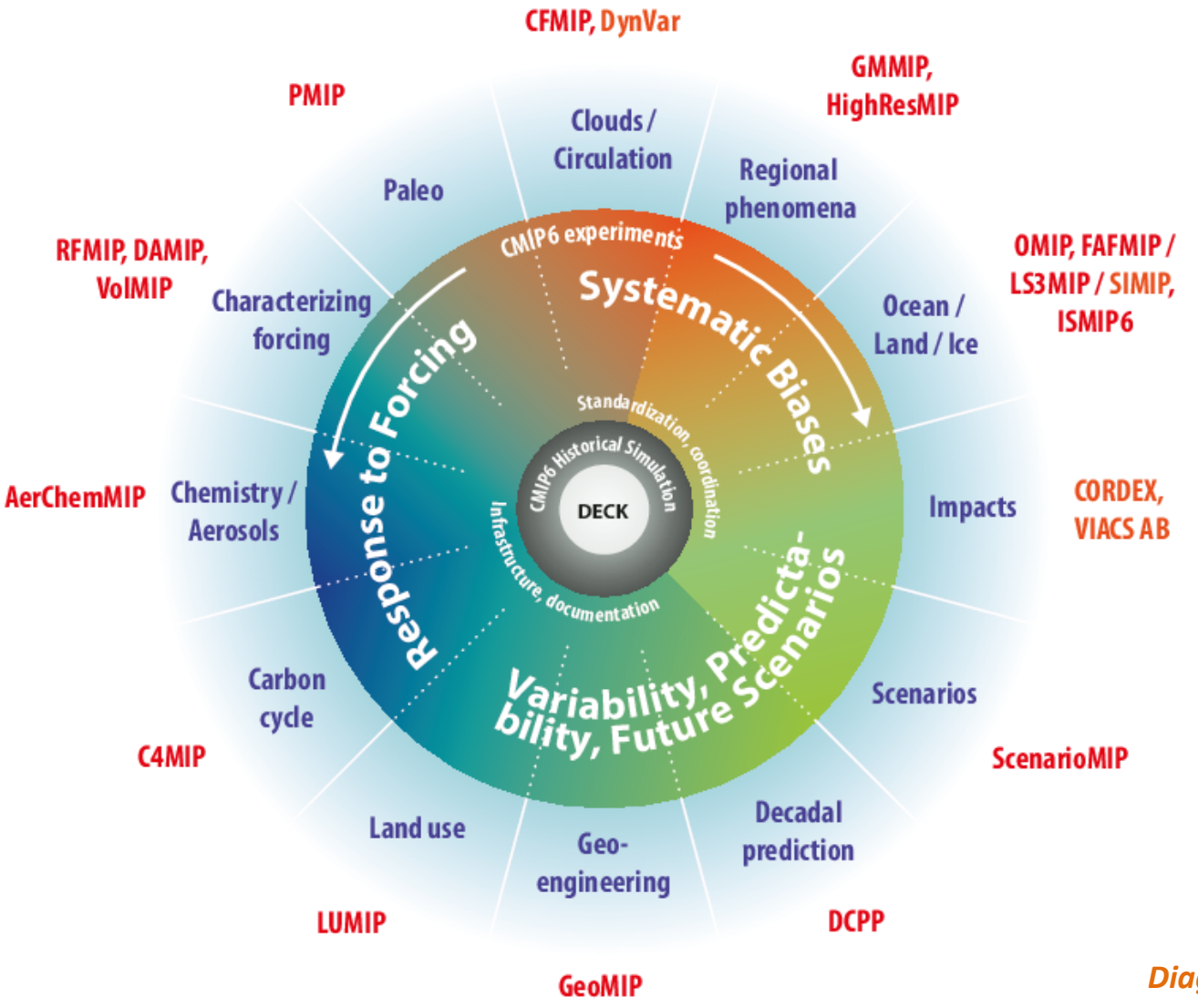
WCRP World Climate Research Programme

WMO

IOC

ICSU International Council for Science

21 CMIP6-Endorsed MIPs



Diagnostic MIPs

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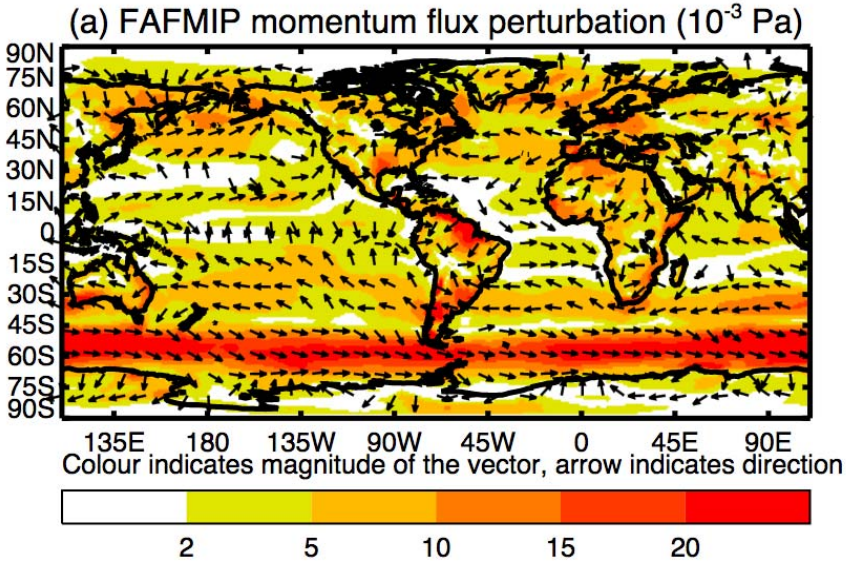
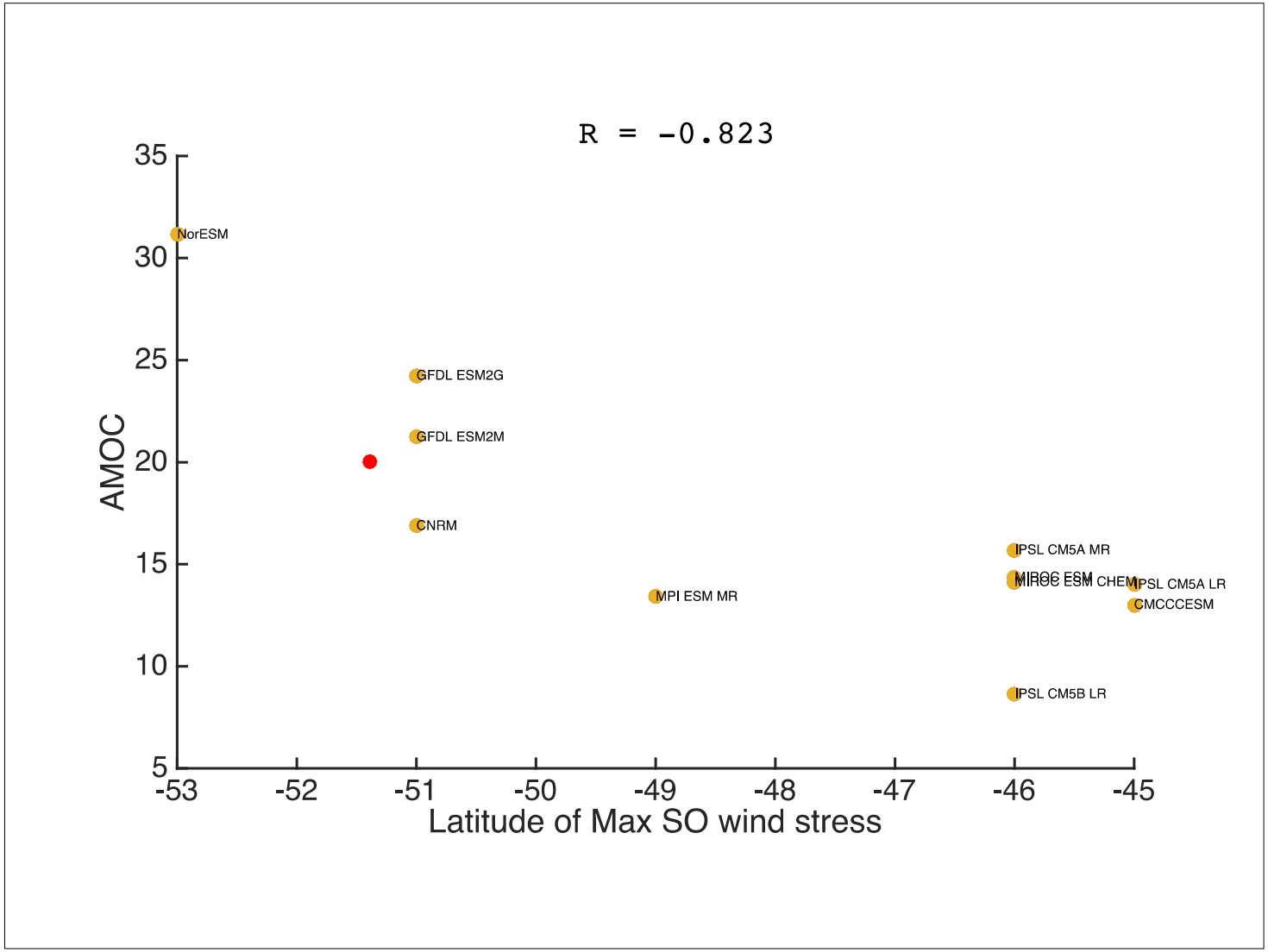
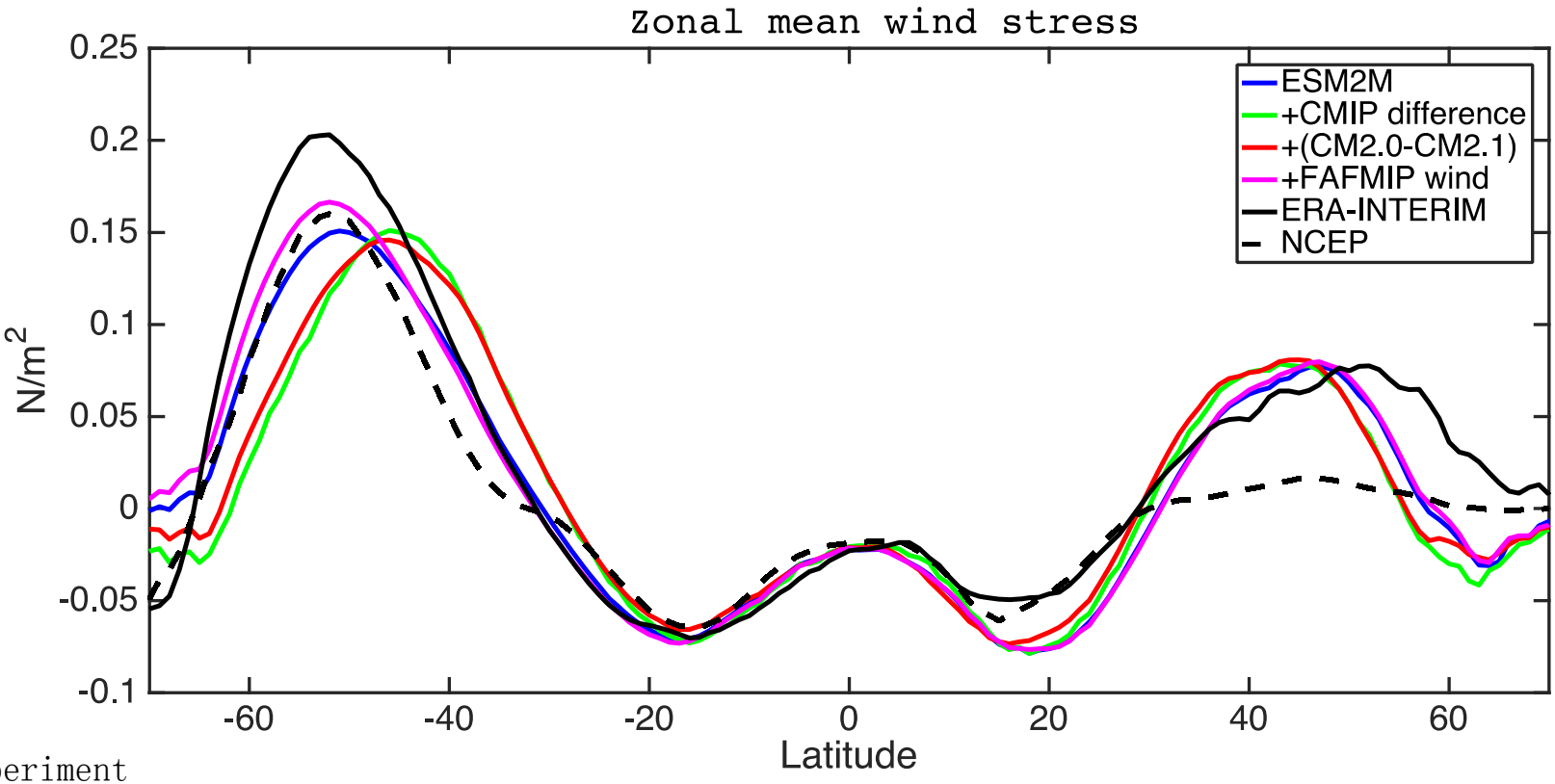
Goal for SOMIP:



As with most MIPs the goal is to understand the causes of differences in the models' responses and to compare models to observations. The purpose is to increase our understanding of the important processes influencing model response and uncertainty to improve the models. Our plan is to closely align SOMIP with FAFMIP, using an adaptation of the FAFMIP wind forcing anomaly, and complementing their study by including an additional fresh water forcing anomaly around Antarctica.

understanding


R = -0.823
AMOC
Latitude of Max SO wind stress
35
30
25
20
15
10
5
-53
-52
-51
-50
-49
-48
-47
-46
-45
NorESM
GFDL ESM2G
GFDL ESM2M
CNRM
MPI ESM MR
IPSL CM5A MR
MIROC ESM
MIROC ESM CHEM
IPSL CM5A LR
CMCCCESM
IPSL CM5B LR



4. Experiment

- The patterns to be applied is the difference in pre-industrial zonal mean wind stress between CMIP5 models that have a more Northern-than-average wind stress and the models with more Southern-than-average wind stress in the Southern Ocean. Slides show this pattern applied to the ESM2M zonal mean wind stress, as well as the FAFMIP perturbation.

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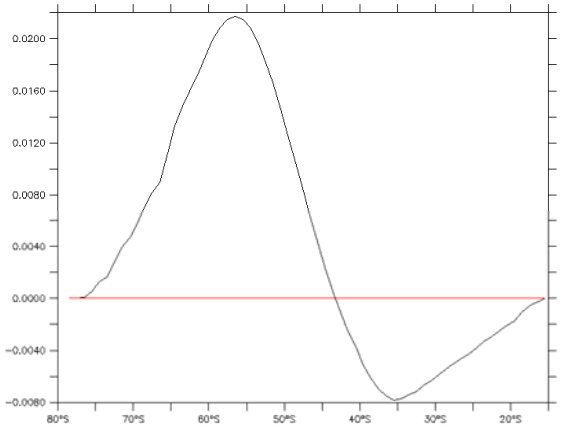
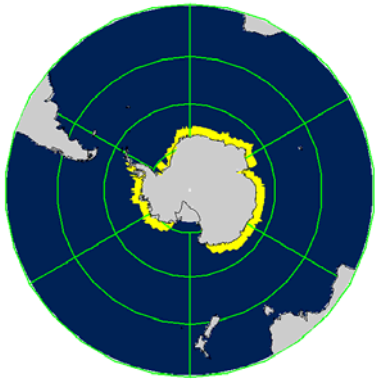
PLAN: The initial phase will be to perform idealized experiments trying to understand the differences in models' response to common changes in forcings, especially how the relationship between wind forcing and stratification influences on the circulation and heat (and carbon) uptake in and by the Southern Ocean.



Proposal: Wind and Fresh water perturbations



3 EXPERIMENTS (300 years - up to 900 if willing/able) :

1) An experiment that increases the winds over the Southern Ocean and shifts them poleward. Implications: 1 run (100-300 years).

2) An experiment where the stability of the Southern Ocean is changed via an external source of fresh water (so-called water hosing). Implications: 1 run (100-300 years).

3) An experiment that will use both the increased wind

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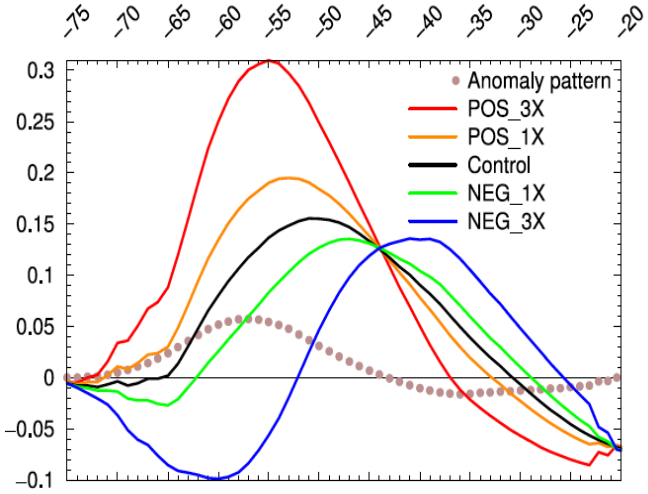
Methodology for the experiments

Winds:



We will apply the method of Delworth and Zeng (2008), in which a fixed wind stress perturbation pattern will be added to the internally-calculated wind stress over the Southern Ocean. In the perturbation experiments, when this internally-calculated surface momentum flux exchange occurs, an additional wind stress perturbation pattern is added to the ocean, thereby making the model ocean "feel" the Southern Hemisphere winds. The amplitude and sign of this pattern are altered for various experiments, as described below. **It is crucial to note that the atmosphere has no direct knowledge of these altered winds.** The atmosphere is only affected through changes to the ocean that the wind stress perturbations induce. The latitudinally-varying wind stress perturbation applied in these experiments will be constant at all longitudes over the Southern Ocean and constant in time.

altered

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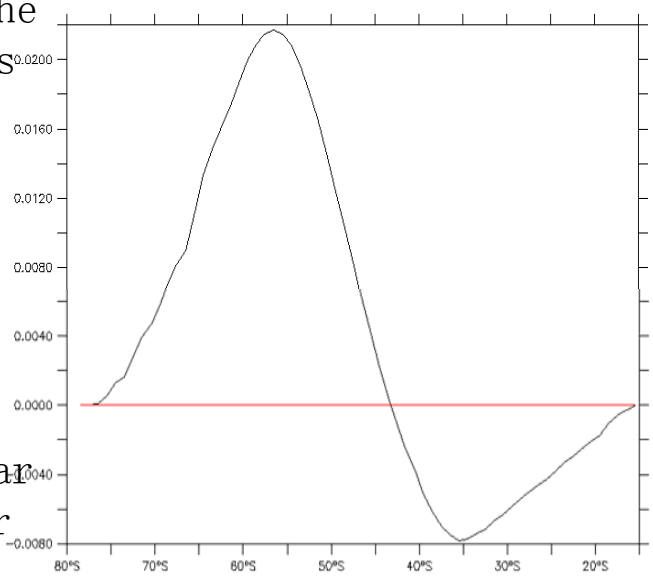
The wind perturbations are the zonal and annual mean of the zonal wind perturbations applied as part of FAFMIP. For the purposes of our initial, idealized phase of this MIP, this will make our results comparable to theirs.



- from the end of the preindustrial control simulation,
- apply strong poleward increase in the wind stress
- assess the ability of wind forcing to both mix surface properties downward in the water column and bring interior properties to the surface.
- assess the momentum balance in the Antarctic Circumpolar Current especially with respect to eddies (simulated or parameterized).
- Assess upwelling of Circumpolar Deep Waters along the Antarctic coast that has been hypothesized to lead to changes in the ice shelves

Changes in the net heat and carbon uptake due solely to wind forcing changes should allow an assessment of the plumbing of the Southern Ocean free from inter-model biases or initial condition biases.

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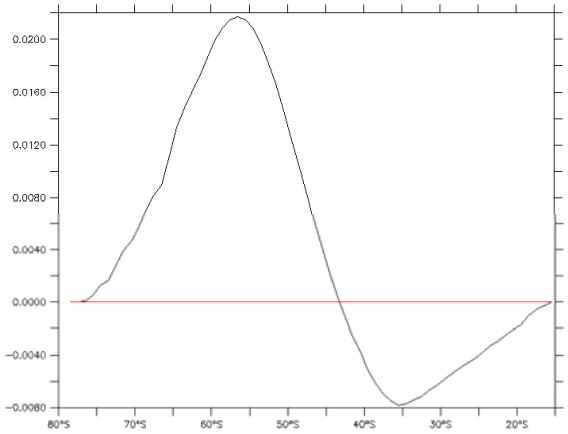
How will the 3 Tier-1 SOMIP experiments be conducted?

Increased Winds (Experiment #1)

- Coupled Climate Models and Earth System Models should start with a "reasonably equilibrated" preindustrial control simulation
- For OGCMs, initialization should take place after no less than five cycles of the CMIP6/OMIP atmospheric forcing.
- Keep radiative forcing factors (aerosols, atmospheric concentrations, solar irradiance, etc.) held at constant preindustrial levels
- Apply the positive perturbation pattern imposed on the ocean to simulate the effect of strongly increased and poleward-shifted winds (based on the curve to the right, and applied south of 15°S)
- Specifically, at each time step, after the internally-generated wind stress from the atmosphere onto the ocean is determined, add in the latitude-dependent wind perturbation at all longitudes before applying to the ocean
- Run the simulation for 100 model years. Resources permitting, run the simulation for an additional 100-200 years without the imposed perturbation to allow the coupled system to recover.



Proposal: Zonally uniform wind perturbation, focused on Drake Passage, based on the imposed annual-mean, zonal wind stress anomaly from FAFMIP

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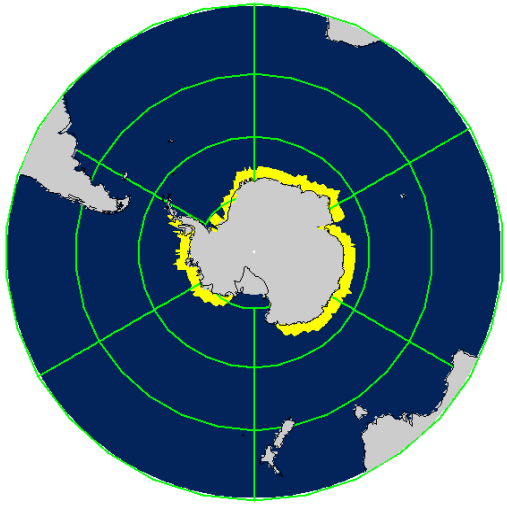
Methodology for the experiments

Freshwater:

In parallel to the method of Delworth and Zeng (2008), a fixed freshwater flux perturbation will be added to the surface and/or mixed layer over the Southern Ocean, either in a targeted area (e.g. as shown) or to discrete locations by an increase in the iceberg calving rate.



Some previous anomalous freshwater forcing experiments in the Southern Ocean (Stouffer et al. 2007; Seidov et al. 2005) applied a fairly large influx of 1 Sv applied to the surface south of 60° S for a century; Richardson et al. 2005 applied a enough water instantly to lower the salinity of the water above 666m south of 65° S by 1 psu. These experiments were designed to provoke an extreme response.

As with the wind experiments, the atmosphere has no direct knowledge of the perturbation freshwater flux. The atmosphere is only affected through changes to the ocean that the freshwater perturbation induces.

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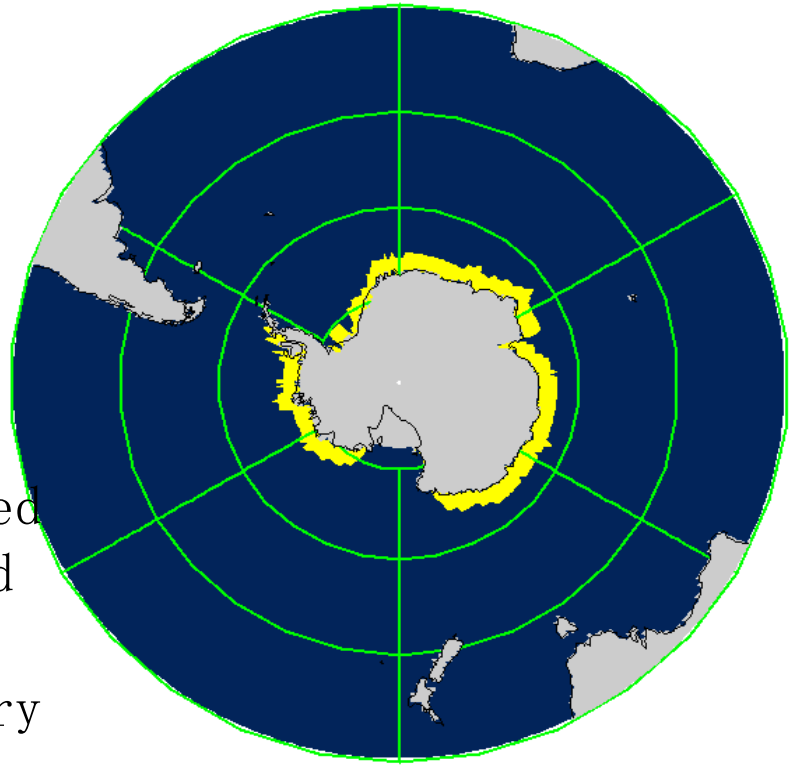
In the freshwater perturbation experiments, we will impose a standard size perturbation equivalent to an anomalous freshwater input of 0.1 Sv applied as:



- uniform anomalies around Antarctica,
- more realistic ice-melt scenarios where locations and amounts are based on the existing patterns of melt and flow, or
- via icebergs as a freshwater delivery mechanism:

We will address the basic questions of wind vs stratification

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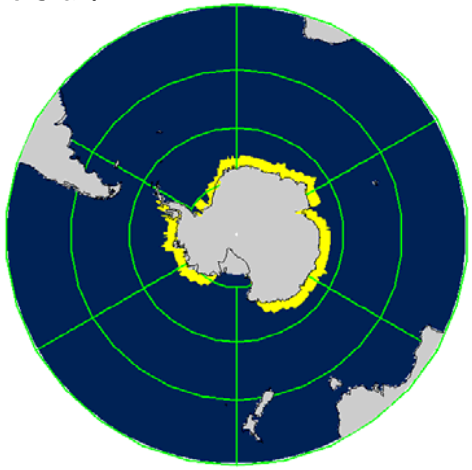
How will the 3 Tier-1 SOMIP experiments be conducted?

Fresh Water Input (Experiment #2)

- Initialize with “reasonably equilibrated” preindustrial control simulation or after no less than five cycles of the CMIP6/OMIP atmospheric forcing.
- Keep radiative forcing factors (aerosols, atmospheric concentrations, solar irradiance, etc.) held at constant preindustrial levels
- Apply a positive perturbation of 0.1 Sv to the fresh water budget in the high-latitude Southern Ocean



Proposal: One possible realization of the area over which the fresh water perturbation will be added.

Specifically, each group will be allowed to determine how they want to add the fresh water perturbation:

Either as additional water to the surface (i.e. rain/melt) at discrete locations or over targeted areas of ocean, an increase in the iceberg calving rate - the icebergs will then be advected by the current and melt normally.

- Regardless of the method, it is critical that the perturbation be added AFTER the model has determined all of the normal internally-generated fluxes.
- Run the simulation for 100 model years. Resources permitting, run the simulation for an additional 100-200 years without the imposed perturbation to allow the coupled system to recover.

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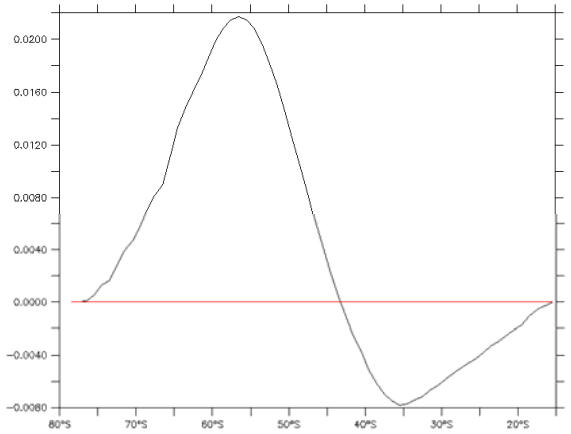
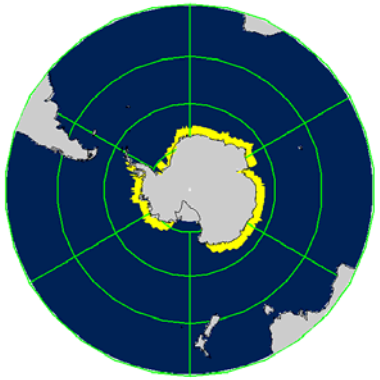
How will the 3 Tier-1 SOMIP experiments be conducted?

Wind and Fresh Water (Experiment #3)

- Initialize with “reasonably equilibrated” preindustrial control simulation or after no less than five cycles of the CMIP6/OMIP atmospheric forcing.
- Keep radiative forcing factors (aerosols, atmospheric concentrations, solar irradiance, etc.) held at constant preindustrial levels
- Apply both the wind perturbation (as given above) and the total fresh water perturbation (0.1 Sv as indicated above)
- Regardless of the method, it is critical that the perturbations be added AFTER the model has determined all of the normal internally-generated fluxes.
- Run the simulation for 100 model years. Resources permitting, run the simulation for an additional 100-200 years without the imposed perturbation to allow the coupled system to recover.



Proposal: Wind and Fresh water perturbations



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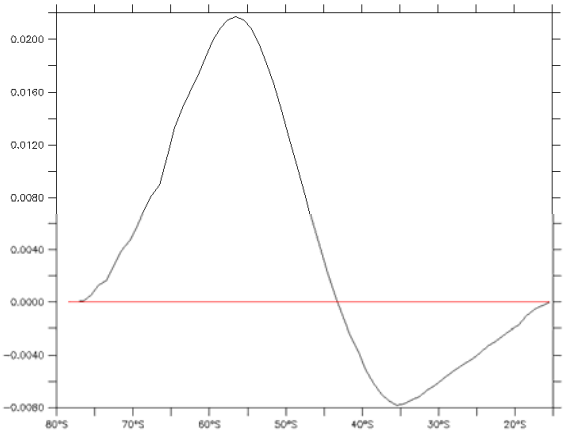
Additional Experiments:

Although not necessary to be included, any center with the inclination, time and resources could further the scope of this MIP by the following:

1. Run more than one Experiment 2 with different combinations of of rain/melt/icebergs to assess the sensitivity of the model to the details of the imposed forcing perturbation.
2. Run any/all of the Tier-1 experiments for 200-300 years with the imposed perturbation to assess the stability and variability in the perturbed system
3. Run an ensemble of perturbation experiments with differing initial conditions (with 5-member ensembles) to provide quantification of the size of the forced response to the perturbation and its significance relative to the pre-existing variability in each model.



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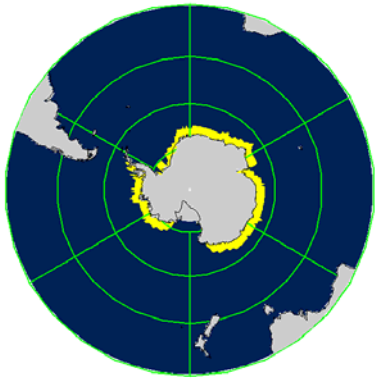

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Variables archived:

No changes to the standard CMIP set of diagnostics or CF, CMOR or ESG archived data sets are required. The analysis of the circulation, the stratification, and the heat and carbon uptake will use the same variables required by the CMIP6/OMIP standards.

Variables to retain	Interior	Surface
Heat-related	thetao,	hfds, rsds, rsus, rlds, rlus, hfss, hfls
Salt-related	so	pr,
Freshwater-related		evspsbl, pr
Wind-related		tauuo, tauvo
Carbon (BGC)-related	dissic, no3, o2, pH	fgco2, fgo2, fsn
Momentum-related	uo, vo	
Other (where available)	agessc	

thetao	Temperature	hfds	Downward heat flux at the surface
so	Salinity	rsds	Downward shortwave radiation at the surface
dissic	Dissolved Inorganic Carbon	rsus	Upward shortwave radiation at the surface
no3	Dissolved nitrate	rlds	Downward longwave radiation at the surface
o2	Dissolved oxygen	rlus	Upward longwave radiation at the surface
pH	pH	pr	Precipitation rate
uo	zonal velocity	evspsbl	Evaporation rate
vo	meridional velocity	tauuo, tauvo	Zonal and meridional wind stress
agessc	age since last surface contact	fgco2, fgo2	Flux of CO2 and O2 through the ocean surfa

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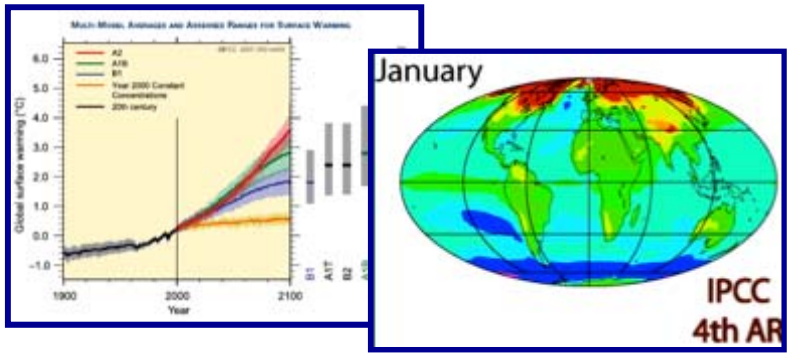
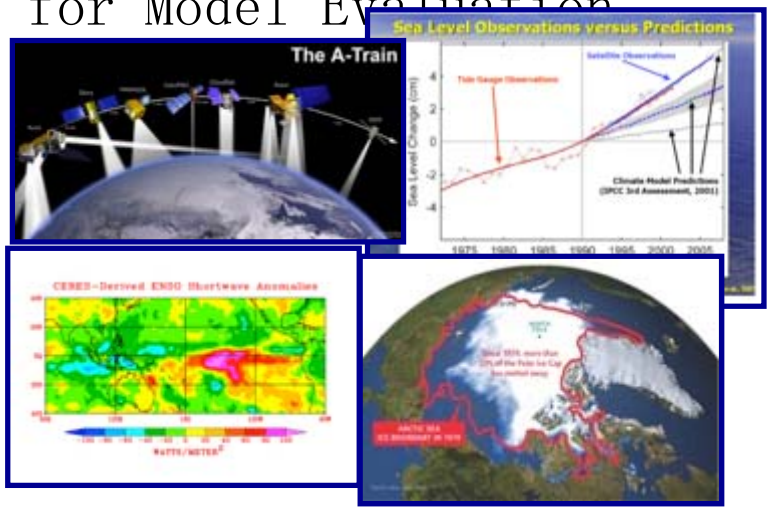
Under-Exploited Observations for Model Evaluation

Observations for Model Intercomparison Projects (obs4MIPs)

WDAC Task Team on Observations for Model Evaluation

CMIP6





How to bring as much observational scrutiny as possible to the CMIP/IPCC process?

How to best utilize the wealth of satellite observations for the CMIP/IPCC process?

- Obs4MIPs has defined a set of technical specifications and criteria for developing observational data sets that are technically aligned with CMIP model output (with common file format, data and metadata structure).
- Over 50 datasets that conform to these standards are now archived on the ESGF alongside CMIP model output (Teixeira et al., 2014), including ESA CCI data
- Data users have enthusiastically received Obs4MIPs

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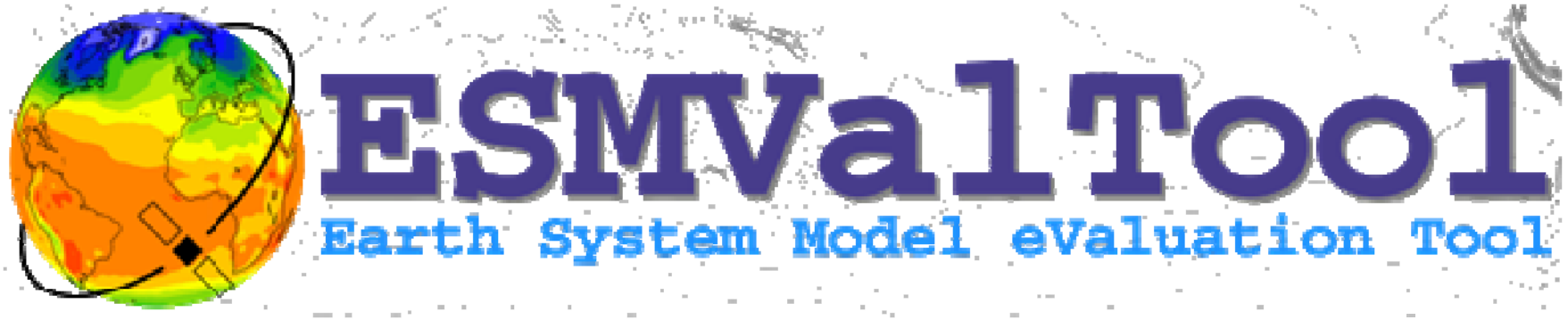
Shared Metrics: ESMValTool

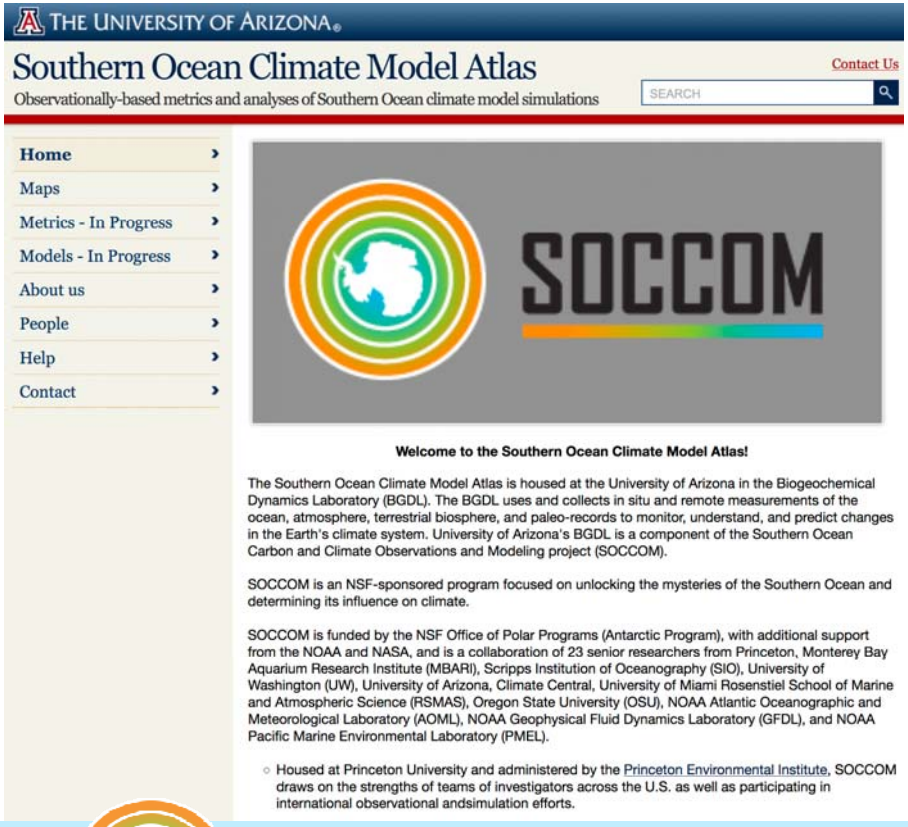


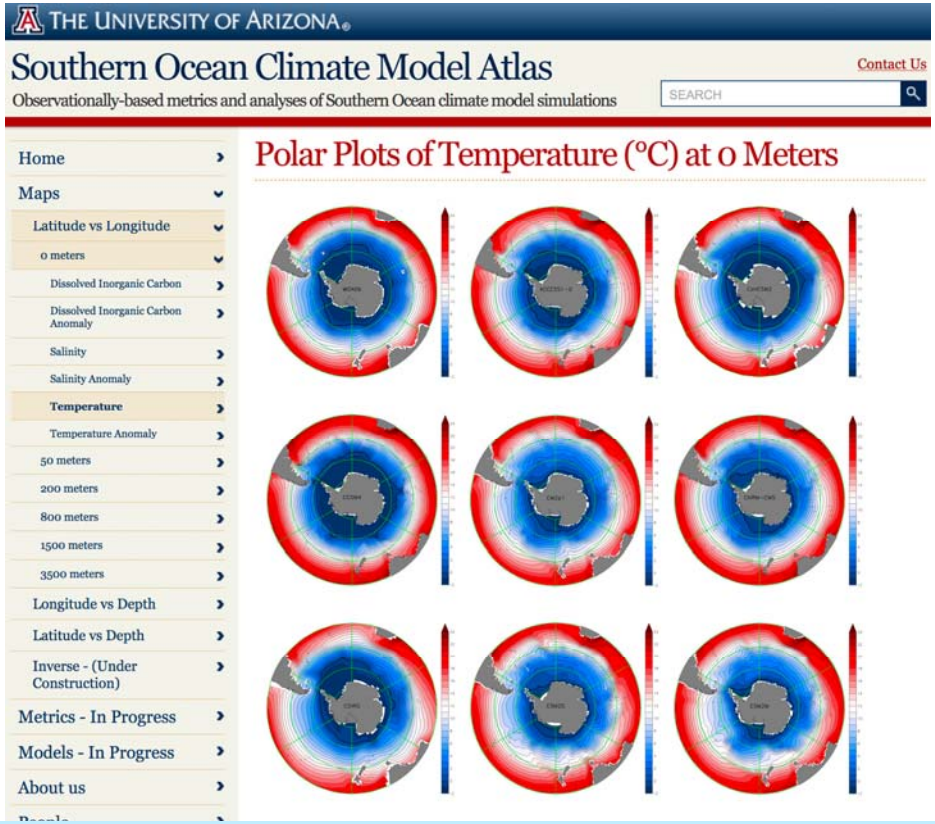
The Earth System Model eValuation Tool (ESMValTool) is a **community diagnostics and performance metrics tool for the evaluation of Earth System Models (ESMs)** that allows for routine comparison of single or multiple models, either against predecessor versions or against observations. Priority has been to focus on selected Essential Climate Variables, a range of known systematic biases common to ESMs, such as coupled tropical climate variability, monsoons, Southern Ocean processes, continental dry biases and soil hydrology-climate interactions, as well as atmospheric CO_2 budgets, tropospheric and stratospheric ozone, and tropospheric aerosols.

Southern Ocean Climate Model Atlas

- http://southernocean.arizona.edu/

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.





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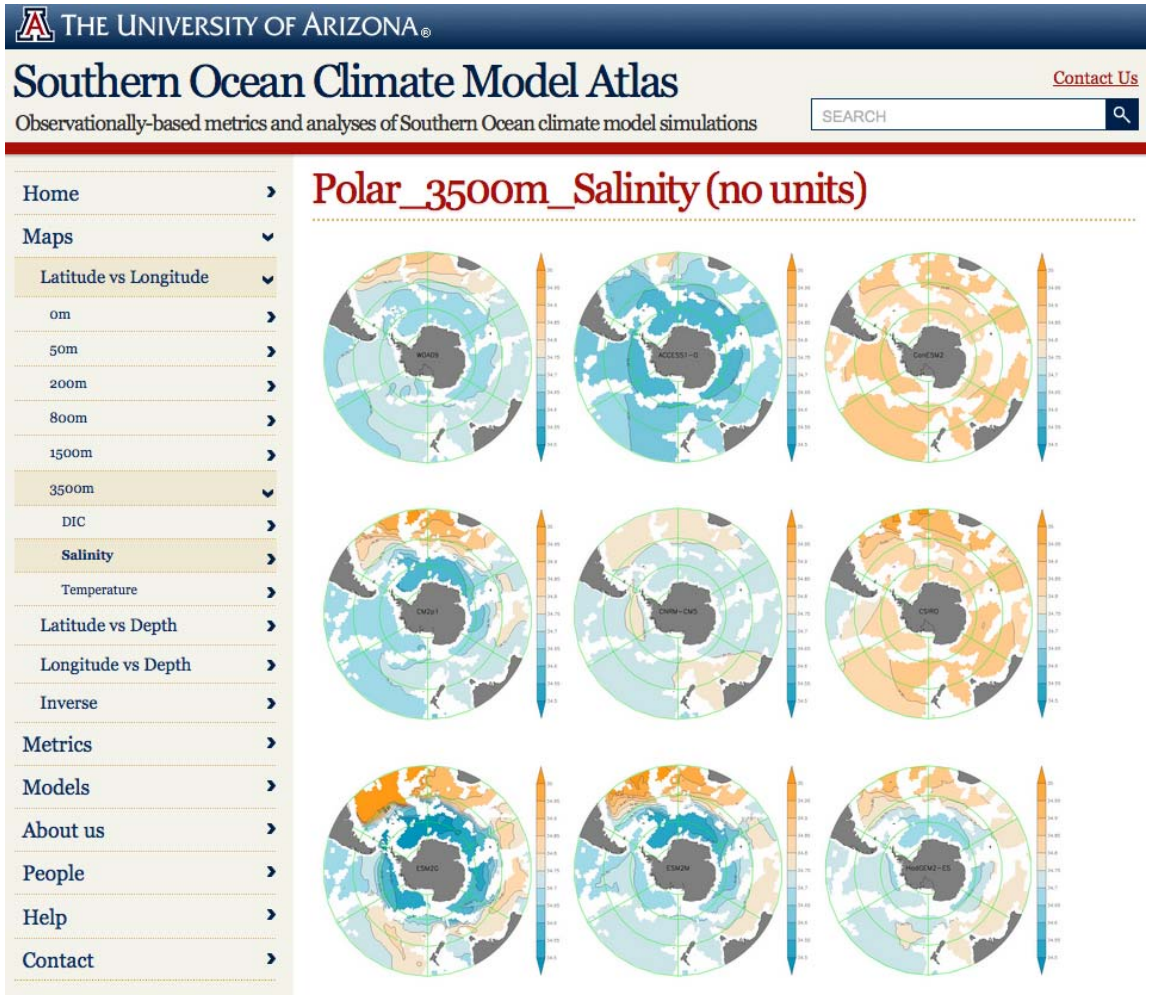
Southern Ocean Climate Model Atlas

- This is Salinity at 3500m

Pages will include processed variables as well: heat content, mixed layer depth, depth of 0° isotherm, etc.

We are doing CMIP5 first, and will then shift to CMIP3. We will also do the GFDL models, and any other significant ones outside of the CMIP.

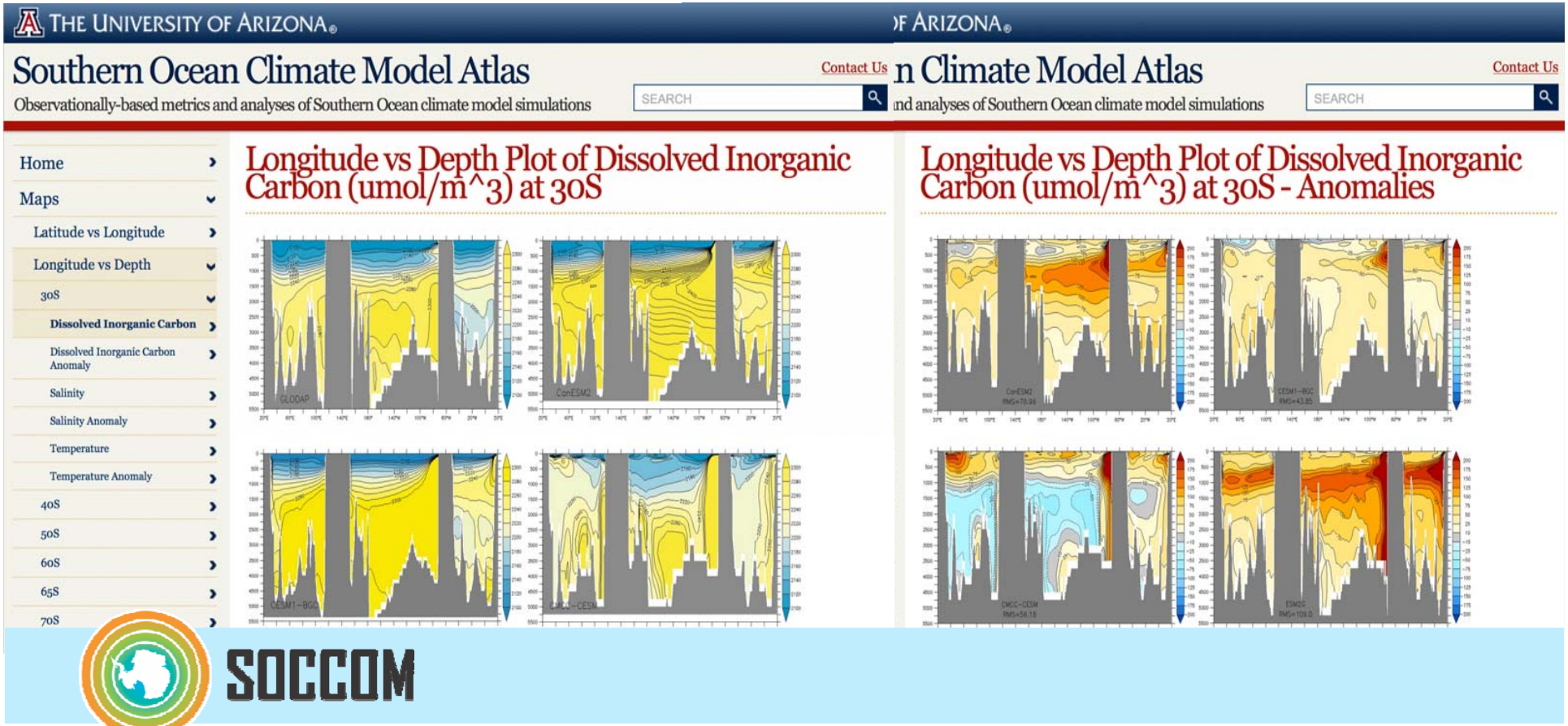


SOCCOM

Southern Ocean Climate Model Atlas

- Longitude vs Depth along 30° S for DIC

We now have pages for differences from observed, and will soon have different groupings, so you could see one model at all depths, etc. The scripts to generate the images will also be linked.



AntarcticClimate21

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The Scientific Committee on Antarctic Research

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Science

Standing Scientific Groups (SSGs)

- GeoSciences
- Life Sciences
- Physical Sciences

Scientific Research Programmes (SRPs)

- Astronomy & Astrophysics from Antarctica (AAA)
- Antarctic Climate Change in the 21st Century (AntClim21)
- State of the Antarctic Ecosystem (AntEco)
- Antarctic Thresholds - Ecosystem Resilience and Adaptation (AnT-ERA)
- Past Antarctic Ice Sheet Dynamics (PAIS)
- Solid Earth Response and influence on Cryosphere Evolution (SERCE)

Other Groups

- Humanities
- ICED (climate & ecosystem)
- Former Groups

Science Themes

- Antarctica & Climate
- Ice Sheets & Under the Ice
- Ecosystems & Biodiversity
- Poles as a Vantage Point
- Observing Systems

Home ▸ Scientific Research Programmes (SRPs) ▸ Antarctic Climate Change in the 21st Century (AntClim21)

Antarctic Climate Change in the 21st Century (AntClim^{21})

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The goals of AntClim^{21} are to deliver improved regional predictions of key elements of the Antarctic atmosphere, ocean and cryosphere for the next 20 to 200 years and to understand the responses of the physical and biological systems to natural and anthropogenic forcing factors. A primary form of data that we see being used by AntClim^{21} are the global coupled atmosphere-ocean model runs that form the basis of the Fifth Assessment Report (AR5) of the Intergovernmental Panel on Climate Change (IPCC). Palaeo-reconstructions of selected time periods, recognised as past analogues for future climate predictions, will be used to validate model performances for the Antarctic region.

AntClim^{21} incorporates ITASE (the International Trans-Antarctic Scientific Expedition).

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Antarctic Climate Change in the 21st Century (AntClim^{21})

Explore:

About

The overarching question of this proposal is: How will the Antarctic1 environment change over the 21st Century? This is an important issue both within Antarctic region and globally. To achieve this goal, AntarcticClimate21 will focus on three themes of research:

- Theme 1. Quantification of Antarctic climate variability.
- Theme 2. Climate model verification for the Antarctic region.
- Theme 3. Antarctic climate projection to 2100 AD

The Antarctic region has already experienced substantial changes with impacts on global sea level and ocean carbon uptake. To understand the significance of recent trends in the context of natural variability, it is important to consider change on a multi-century time scale. This proposal will focus on the past 2,000 years. In addition, we will take advantage of data and model outputs from earlier key time periods as they become available, such as the mid-Holocene, glacial terminations, warm interglacials, and the mid-Pliocene. Moreover, attribution of the causes of environmental change is a high priority. Assessment of how realistically climate models capture key forcings to help constrain climate model projections of future change. The overall aim is to provide improved projections of the magnitude and patterns of change to Antarctica's physical environment as a result of global change over the next 100+ years. The assessment will be based on Intergovernmental Panel on Climate Change (IPCC) Assessment Report Five (AR5) Representative Concentration Pathways (RCP) and updated scenarios as they become available.

AntarcticClimate21

#GreatAntarcticClimateHack

Workshop at Scripps: October 2017

Goals:

1) More metrics for ESMValTool
2) Grow the community using observations to evaluate climate simulations

Southern Ocean Model Intercomparison Project

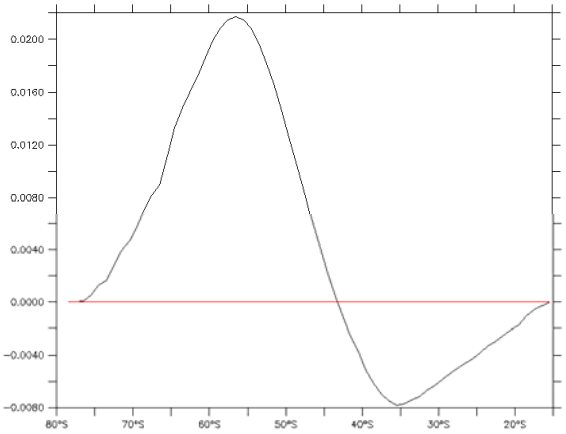
Where to find information/data/metrics:

We are proposing to create a website similar to the FAFMIP site:
http://www.met.reading.ac.uk/~jonathan/FAFMIP/

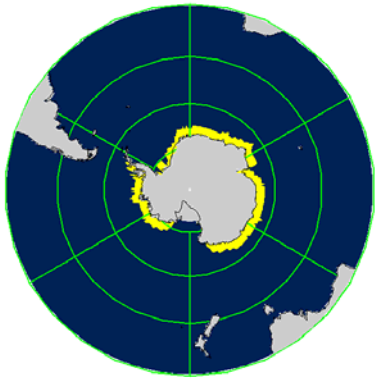
where the details of SOMIP will be available including the:

1. Goals/Overview
2. Relevant papers
3. Experiment design
4. Forcing files
5. Methodology
6. Diagnostics
7. Proposed timing

The site will likely be found at
http://soccom.princeton.edu



Proposal: Wind and Fresh water perturbations



SOCCOM


Comments? Questions? Volunteers?