Initial Results from Coupled High Resolution Climate Models

Julie L. McClean
Scripps Institution of Oceanography

David C. Bader (LLNL), Mark A. Taylor (SNL), Mathew E. Maltrud (LANL), Carmela Veneziani (LANL), Qi Tang (LLNL), John Ritchie (SIO), Marcia Branstetter (ORNL), Katherine J Evans (ORNL) and Salil Mahajan (ORNL)

High-Resolution Ocean Modelling for Coupled Seamless Predictions Workshop
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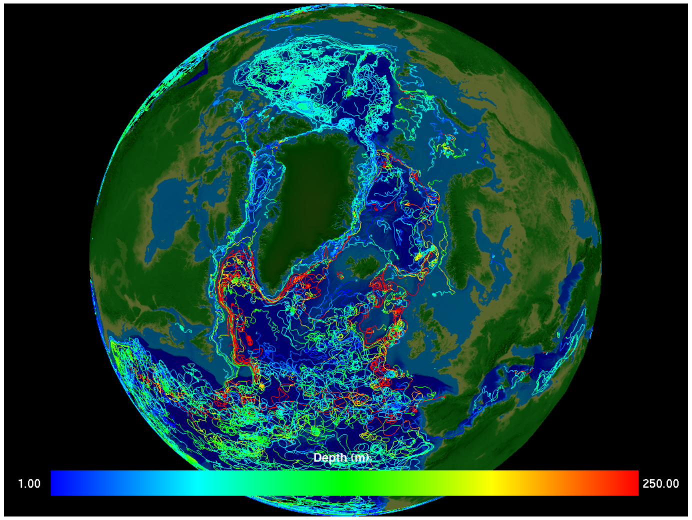
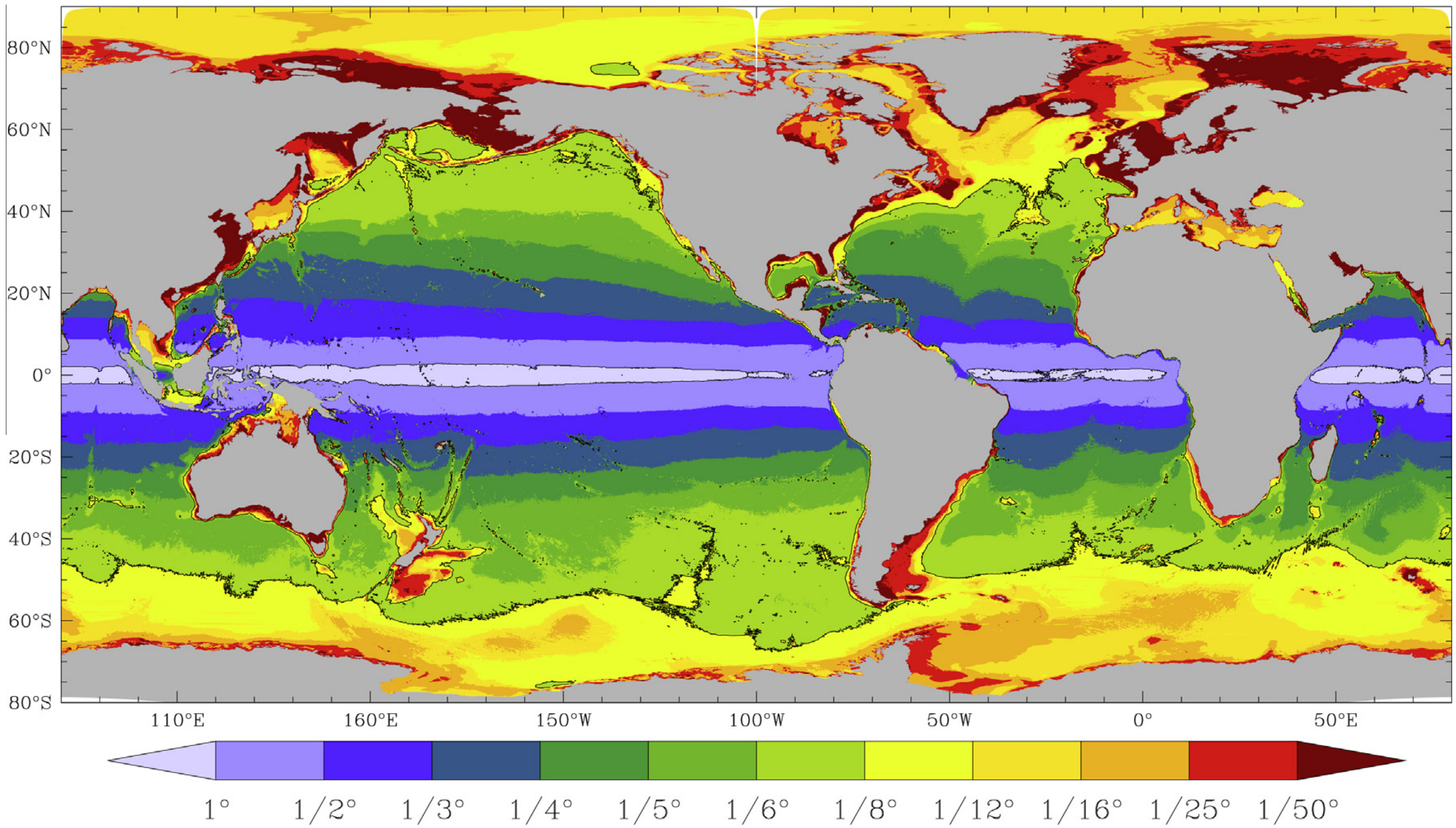
Overarching Goal



Capability to execute fully coupled simulations of the Earth System for up to multi-decadal prediction where oceanic and atmospheric mesoscale phenomena with scales of 10s and 100s of kilometers, respectively, are largely resolved.

Horizontal resolution needed to resolve the 1st baroclinic deformation radius with two grid points, based on a 1/8° ocean model on a Mercator grid.



Solid lines: where the deformation is resolved with 2 grid points at 1° & 1/8° resolutions.

Hallberg, 2013, Ocean Modelling

Why High Resolution for Climate Prediction?

- Mesoscale air-sea interactions: western boundary currents (WBCs) & their extensions, ACC, & Agulhas eddies. Modify atm/ocean surface circulations through feedbacks.
- Eddy-mean flow interactions: jet stream/storm tracks, WBCs, ACC. Acceleration/de-acceleration of mean flow due to mesoscale eddy forcing.
- Mesoscale mixing processes: Cross-stream mixing of properties *i.e.* in the ACC and WBC extensions.

Fine resolution grids will also encourage more realistic representation of:

- Strength and pathways of WBCs, ACC, open-ocean zonal jets.
- Positioning of frontal structures i.e. air-sea interactions. Large SST errors result from path errors.
- Tropical cyclones and mid-latitude storms
- Energy in ocean circulation: majority of energy is due to mesoscale processes.
- Mesoscale eddy growth and decay time scales.
- Ocean-bottom bathymetry and coastal geometry.

Prototype High-Resolution Fully-Coupled Models

- Ocean/sea ice and atmosphere/land components ~ 5-10 and 2-4 times those in standard climate models.

- Present-day controls *i.e.* 1990 and 2000.

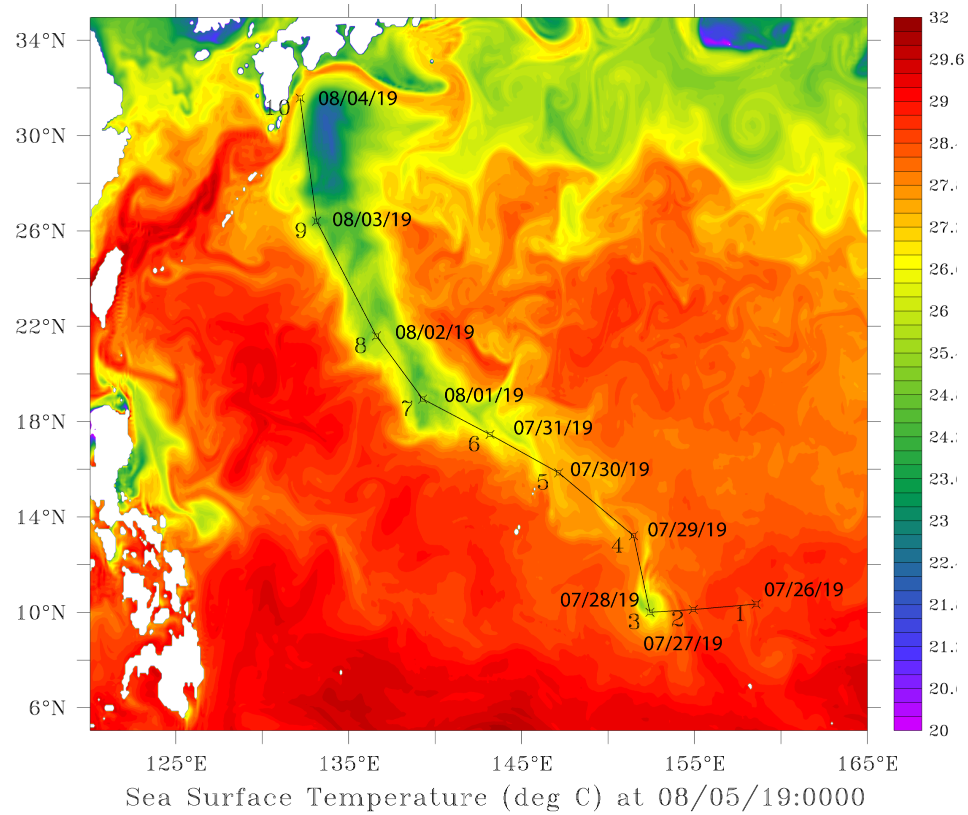
- CCSM3.5: Bryan et al. (2010), McClean et al. (2011), Kirtman et al. (2012). Models not "tuned". Initial conditions differ.

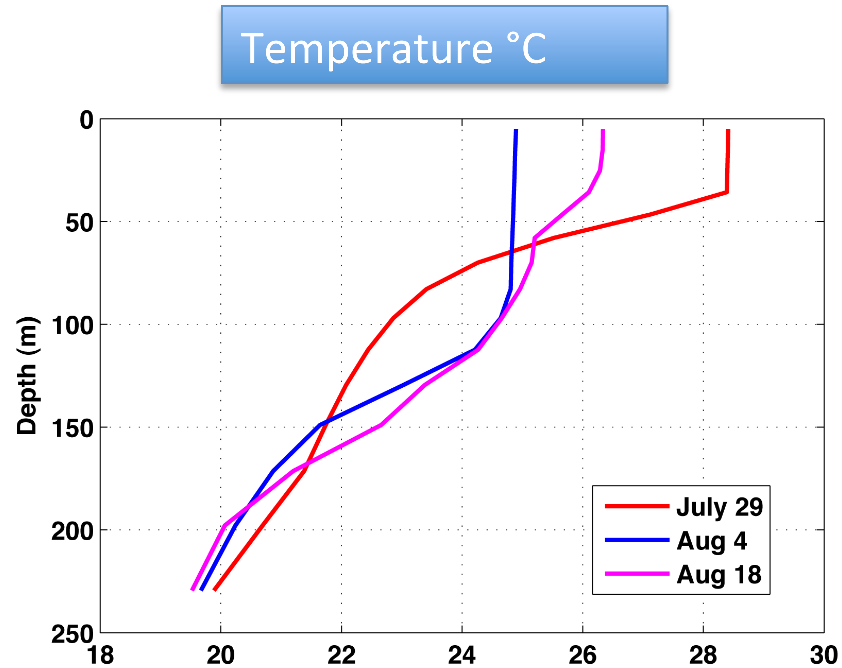
- GFDL CM2-O suite: Delworth et al. (2012), Griffies et al. (2015).

- MIROC4h: Sakamoto et al. (2012)

- HadGEM3: Hewitt et al. (2011)

CCSM4 Typhoon Track 07/08 of Yr 19 of CCSM3.5 (0.1° POP2 & 0.25° CAM3.5) "ATLAS" simulation.



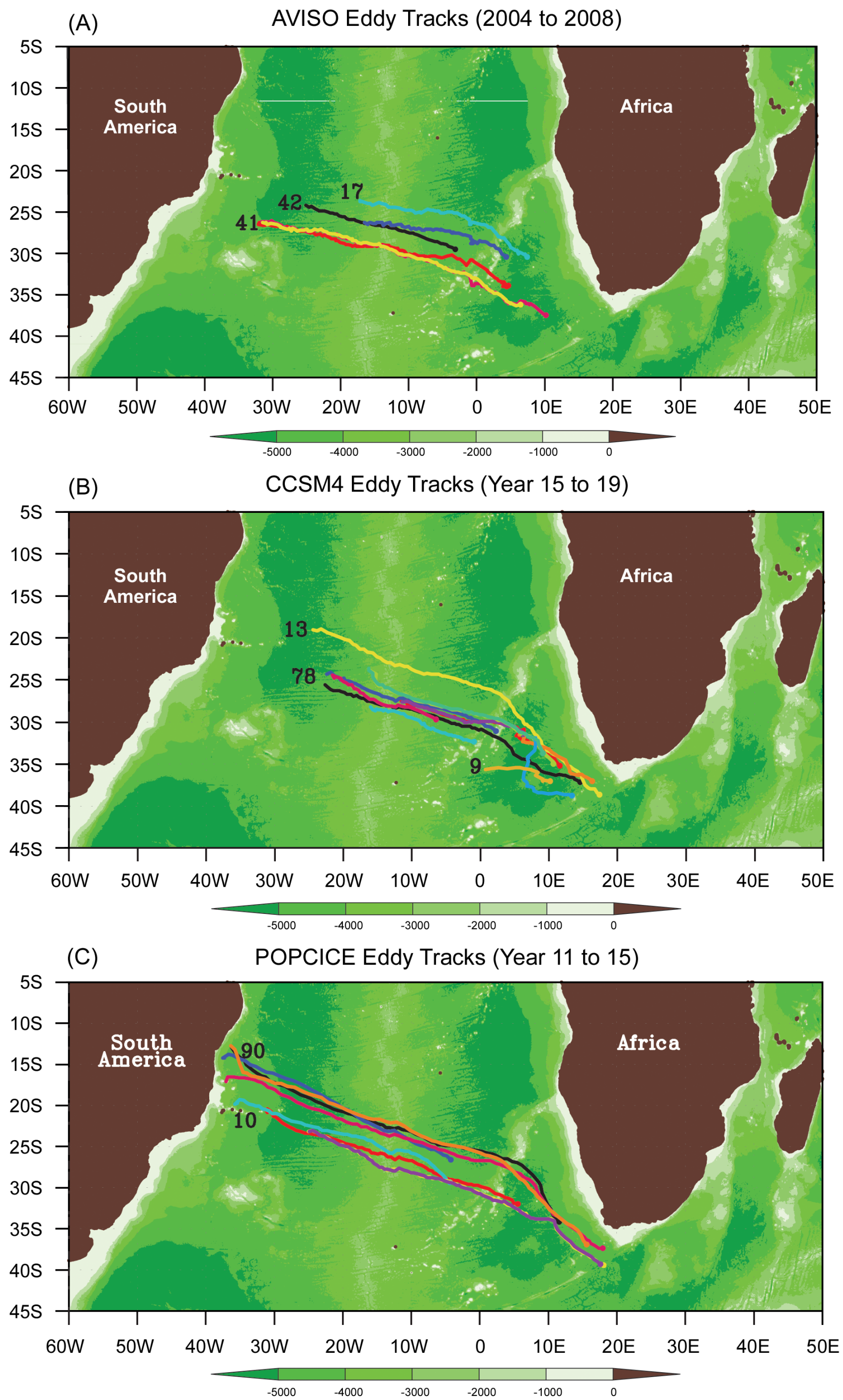


Category 4 (Saffir-Simpson)

Max. wind speeds of 66.5 m/s (239 km/hr)

McClean et al. 2011

Vertical profiles of temperature (°C) at station 9 (133°E, 26°N) that correspond to pre-storm conditions (07/29/19), a day after the passage of the storm's center (08/04/19), and the water column 2 weeks later (08/18/19).



Agulhas Eddy Tracks from ATLAS CCSM3.5 Simulation

AVISO: Satellite altimetry

CCSM3.5: Eddy signatures disappear between 20° and 30° W and ~ 25°S.

Global Coupled 0.1° POP/CICE on tripole grid with partial bottom cells. Eddies follow a too northwesterly path across the entire South Atlantic.

McClean et al. 2011

Temporal Correlations of High-pass Filtered Surface Wind Speed with SST

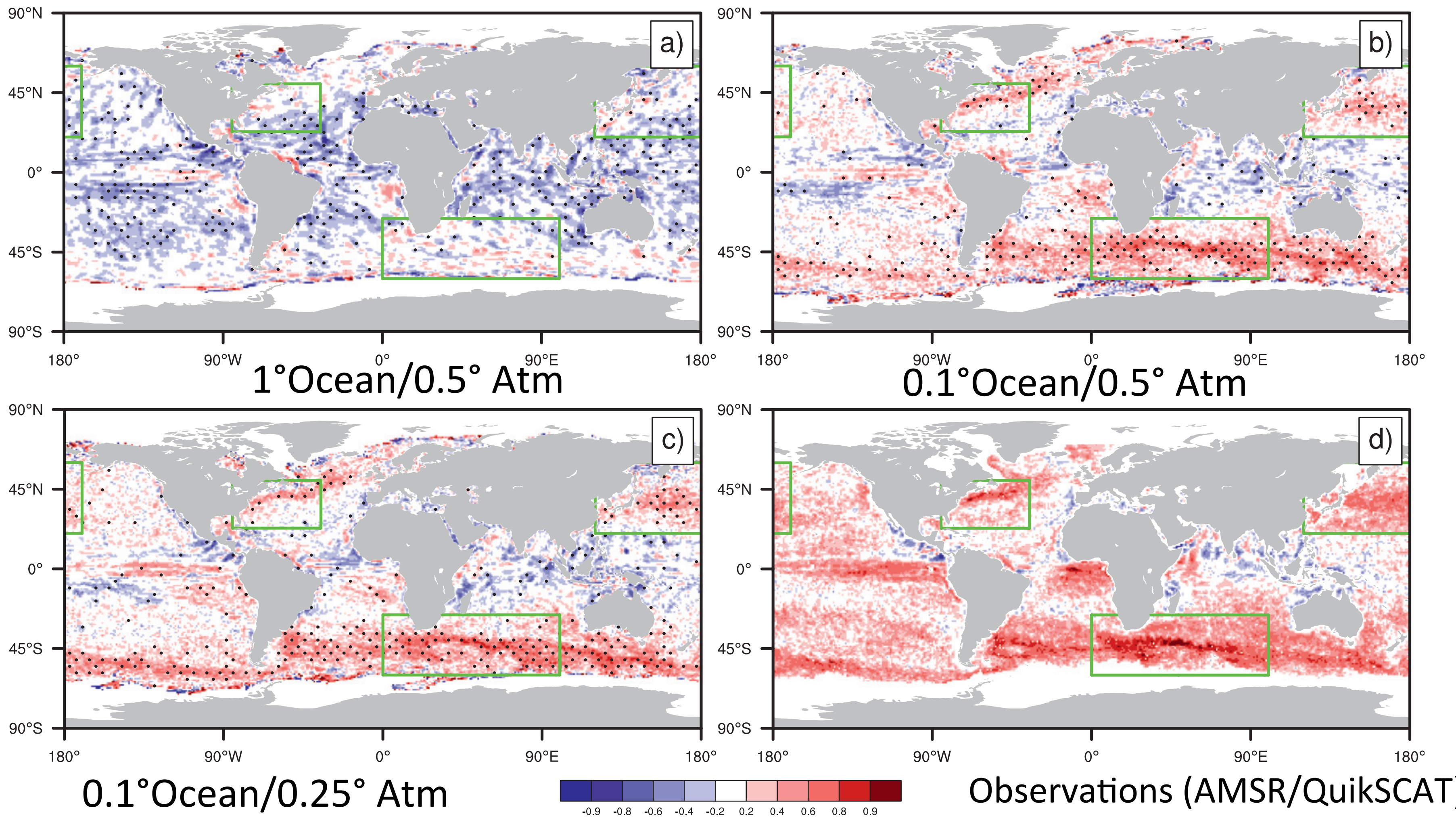
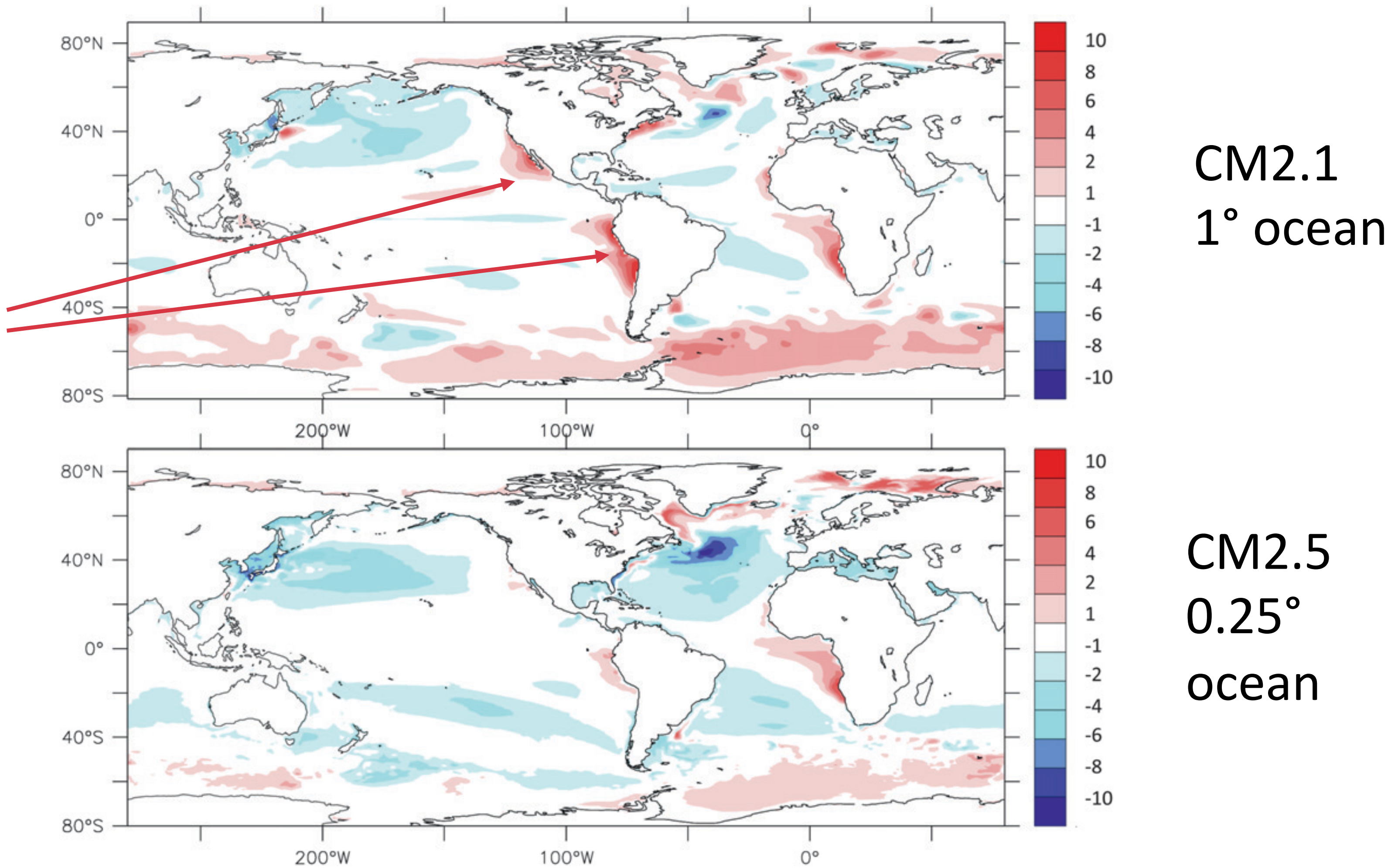


FIG. 1. Temporal correlation of high-pass filtered surface wind speed with SST. Locations where ice appeared have been masked and stippling indicates statistical significance at the 95% level calculated using a two-sided *t*-test. (a) 1.0° ocean and 0.5° atmosphere (expt 1) (b) 0.1° ocean and 0.5° atmosphere (expt 2) (c) 0.1° ocean and 0.25° atmosphere (expt 3). (d) Satellite observations. Model analysis computed using four years of monthly averaged output (48 months), observational analysis using AMSR and QuikSCAT data for 2002–2006. Green boxes delineate the regions used for the statistics presented in Table 2.

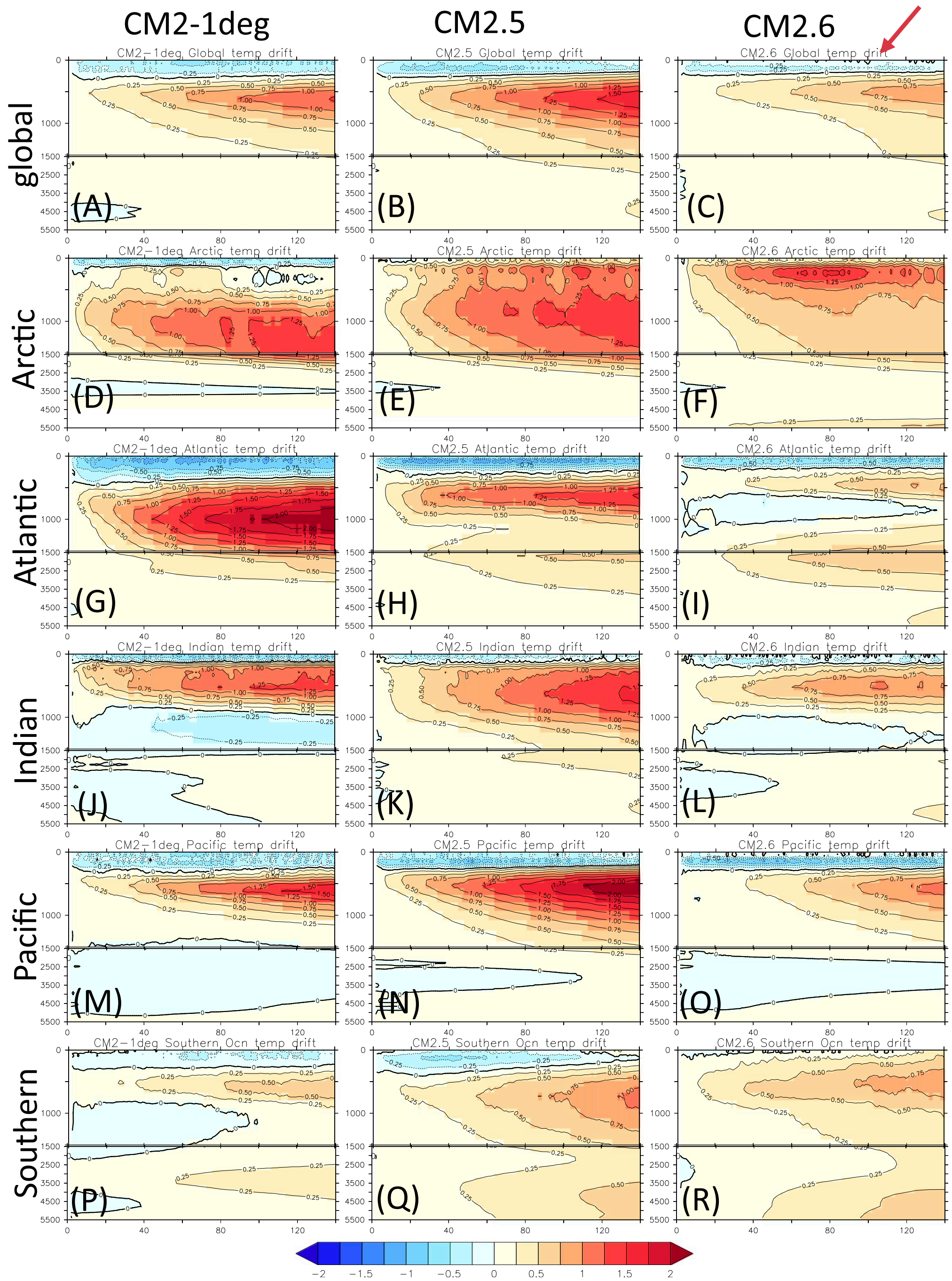
Bryan et al 2010, J. Climate

SST biases for annual mean: CM2.1 (top) and CM2.5 (lower).
Model (yrs 101-200) – observations (Reynolds). Units in K.
From Delworth et al. (2012, Fig. 2)



CM2-O Suite: Griffies et al. 2015

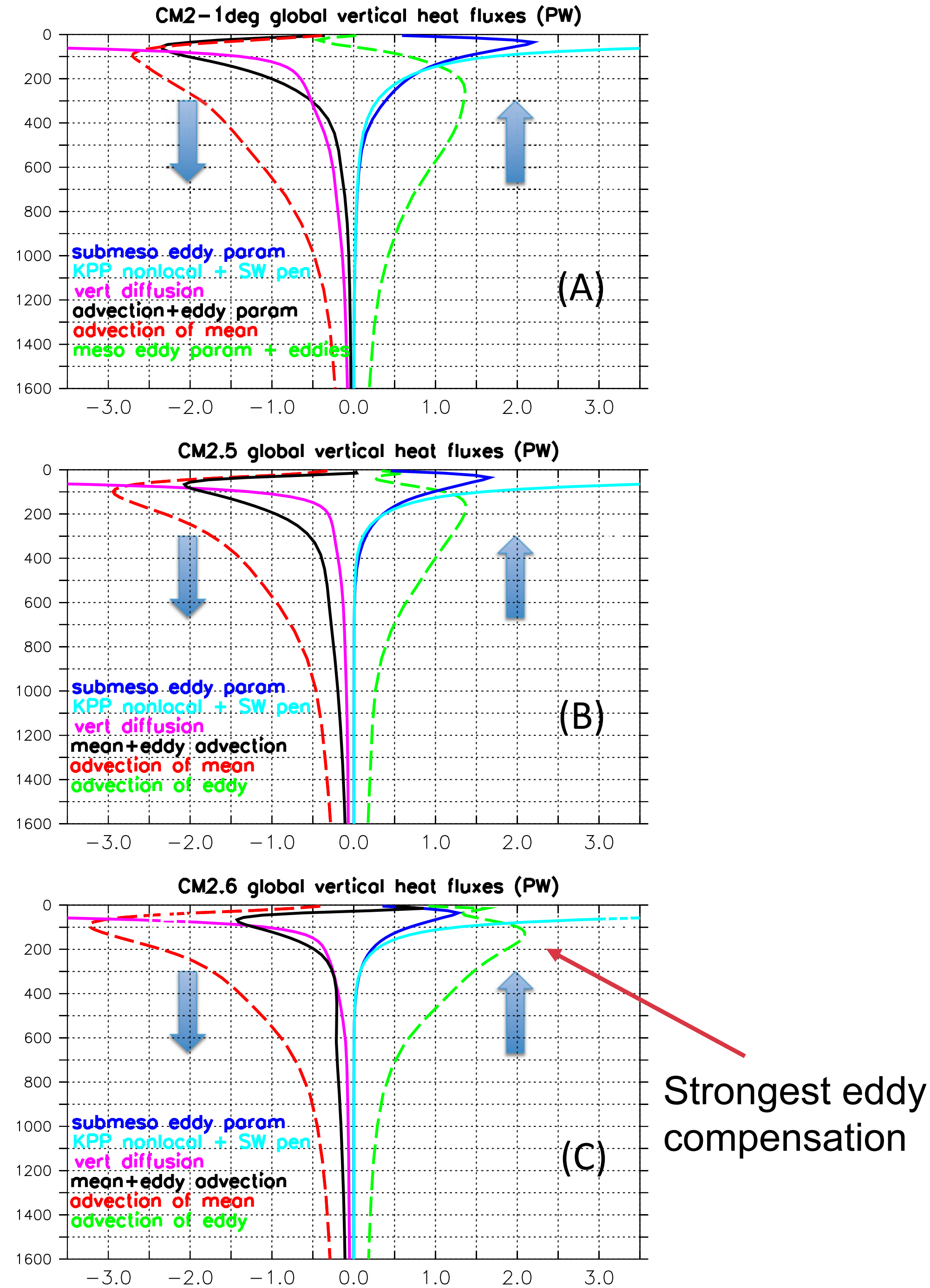
Global- and basin-averaged drift of the volume-weighted annual mean potential temperature as a function of depth, relative to the annual mean from the first year of the simulation.



- CM2.5: 0.25° ocean
- CM2.6: 0.1° ocean
- Present-day 1990s controls

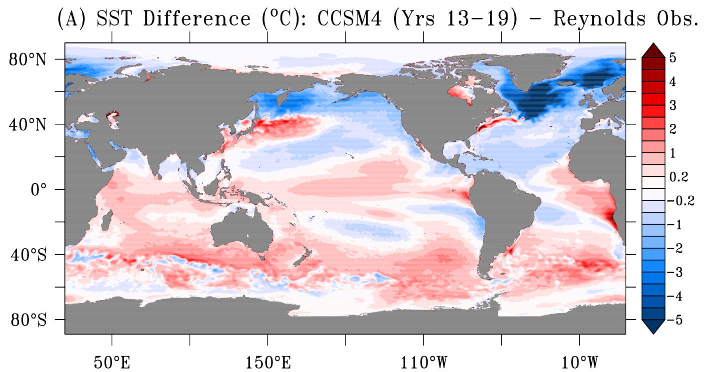
Global ocean vertical heat transport from CM2-O Suite (Griffies et al. 2015)

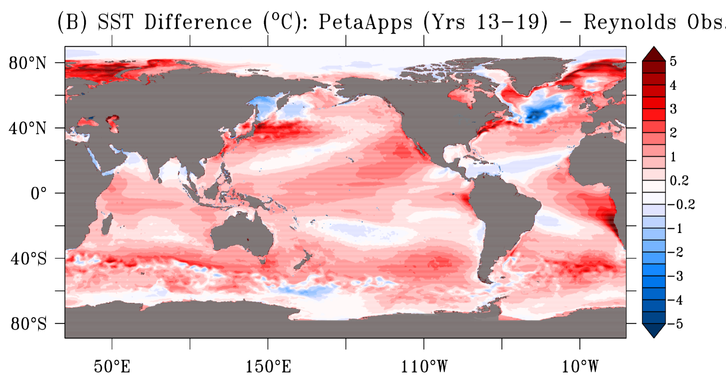
- Positive values: upward heat transport (upward arrows).
- Negative values from downward heat transport.
- Mesoscale eddies act to transport heat upward such that they partially compensate the downward heat transport from the time-mean currents.

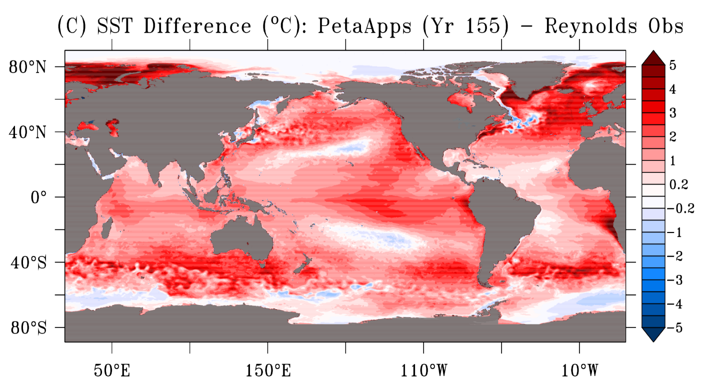


Sensitivity to Initial Conditions: CCSM3.5 1990 Controls

ATLAS: 0.1POP/CICE & 0.5° CAM/CLM
PetaApps: 0.1° POP/CICE & 0.5° CAM/CLM







(A) ATLAS SST – Reynolds SST (Yrs 13-19)

Initialized from 2 yr CCSM4 using 0.1° POP/CICE and 0.5° CAM/CLM. (McClean et al., 2011, OM)

(B) PetaApps SST – Reynolds SST (Yrs 13-19).

Initialized from multi-century CCSM3 Pre-industrial control interpolated to high resolution grid. (Kirtman et al., 2012, Clim. Dyn.)

(C) PetaApps SST – Reynolds SST (Yr 155)

PetaApps output courtesy, B. Kirtman (U. Miami)

Moving Forward

- 100-year 2000 control using fully coupled CESM5 for direct comparisons with recent observations (Small et al. 2014). Uses CAM5-SE (spectral element) as atmospheric dycore.
- Initialized from a 1-year 0.1° POP/CICE simulations forced with Coordinated Ocean Reference Experiment (CORE) atmospheric fluxes.
- Adjustment of model parameters “tuning” based on atm-only simulations at the same resolution or from low-resolution coupled runs for PI conditions, with minimal new tuning.
- Improvements, among others, in the representation of ENSO.

ACME V0

- 1850 Pre-industrial Control using CESM5: CAM5-SE/ CLM5 and POP2.0/CICE4.0

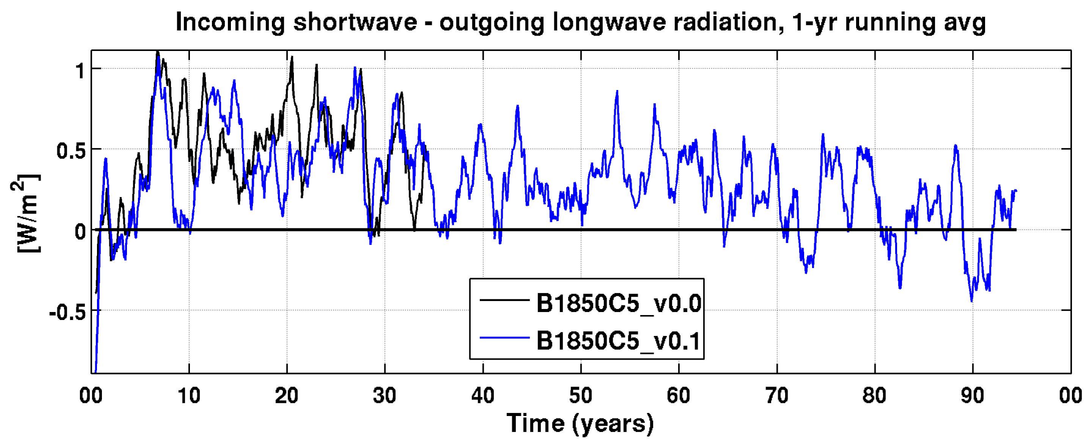
- Run for 95+ years

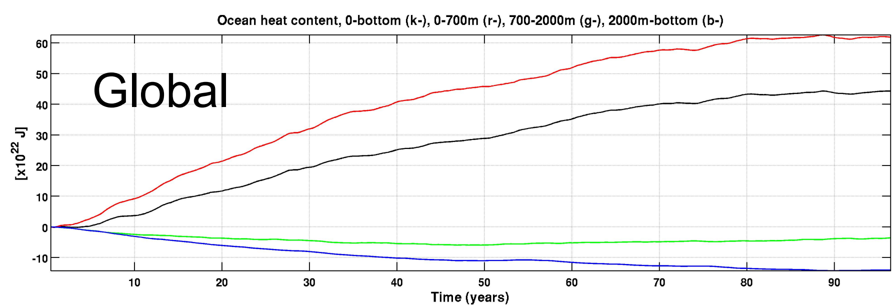
- Initial Conditions: 0.1° POP/CICE restarts from 1 January of 1973 to allow for the adjustment of the initial transients but avoiding drift due to reanalysis forcing. POP/CICE was initialized from rest & WOCE climatology in January 1970 and was forced with CORE-II interannually-varying fluxes (IAF).

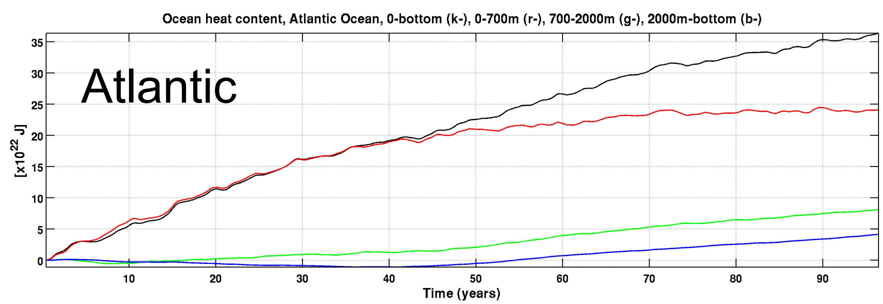
- "Tuned" in coupled mode to achieve an acceptable top of atmosphere (TOA) radiation balance.

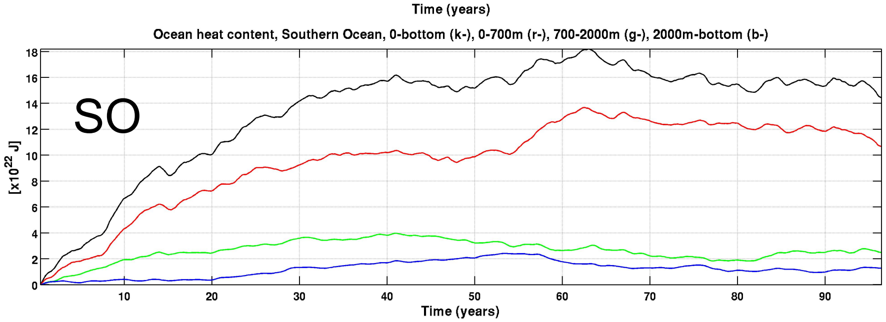
ACME V0.1: 1850 Pre-Industrial Control

TOA net radiation
(Wm^{-2})









Annual time series of global, Southern Ocean, & Atlantic Ocean heat content (J) relative to year 1 annual average.

Black: total depth, red: 0=700 m
Green: 700-2000m; blue: 2000-bottom

Conclusions

- Fine resolution coupled models have been run for a century or more using constant present day or preindustrial climate forcing.

- Mesoscale air-sea interaction processes are realistically depicted as well as tropical cyclones and winter storms.

- Mesoscale ocean eddies have been shown to partially compensate the downward heat transport by time-mean currents. The compensation is strongest in highest resolution (0.1°) ocean components. This compensation explains the significantly smaller temperature drift in a strongly eddy active ocean model relative to an eddy-permitting ocean model.