The development of the new GEOS-MITgcm atmosphere-ocean model for coupled data assimilation system

Ehud STROBACH[1,2], Andrea MOLOD[2], Atanas TRAYANOV[2,3], William PUTMAN[2], Gael FORGET[4], Jean-Michel CAMPIN[4], Chris HILL[4], Dimitris MENEMENLIS[5], Patrick HEIMBACH[6]

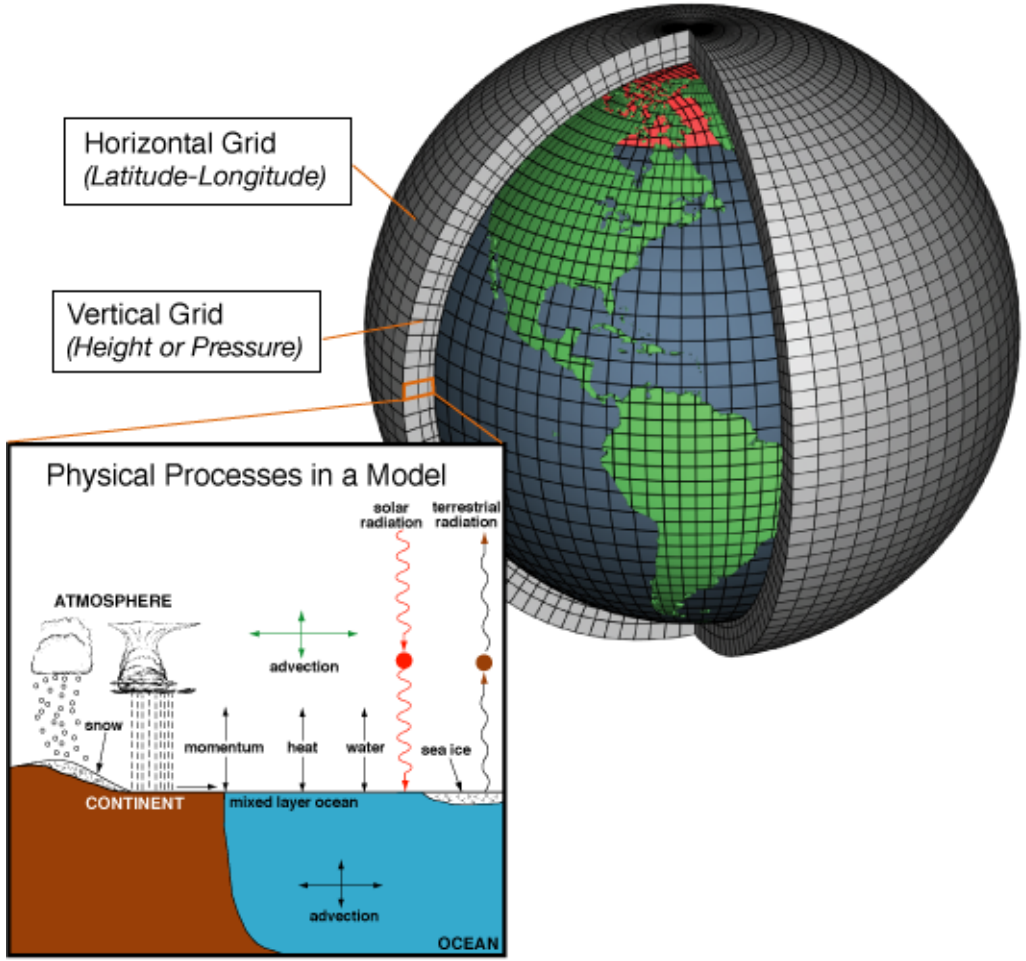
[1]University of Maryland, United States, [2]NASA / GMAO, United States, [3]Science Systems and Applications, Inc., [4]Massachusetts Institute of Technology, United States, [5]Jet Propulsion Laboratory, California Institute of Technology, United States, [6]University of Texas at Austin, United States

Overview

- Part I: Earth System models and data assimilation
- Part II: Air sea interactions in the high resolution GEOS-MIT

Earth System Models

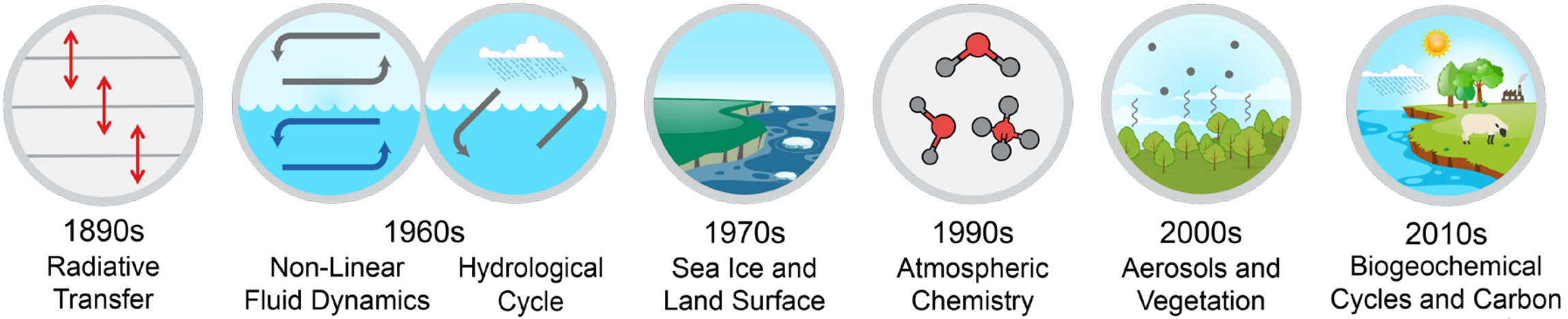
- Numerical models representing physical processes in the atmosphere, ocean, cryosphere and land surface.
  - The planet is divided into a 3-dimensional grid.
  - A set of differential equations describing the circulation is defined.
  - Variables such as temperature, wind and pressure are predicted for each of the grid cells at different times.



Source: https://en.wikipedia.org/wiki/General_circulation_model

Modeling Timeline

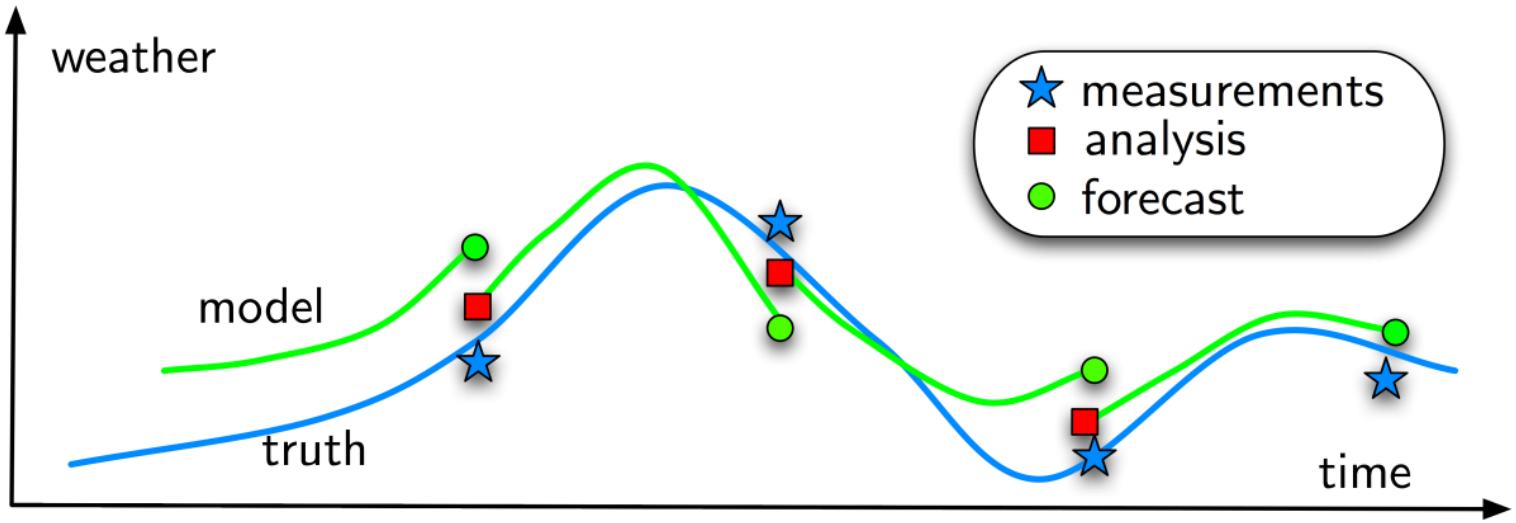
(When Various Components Became Commonly Used)



Source: https://science2017.globalchange.gov/chapter/4/

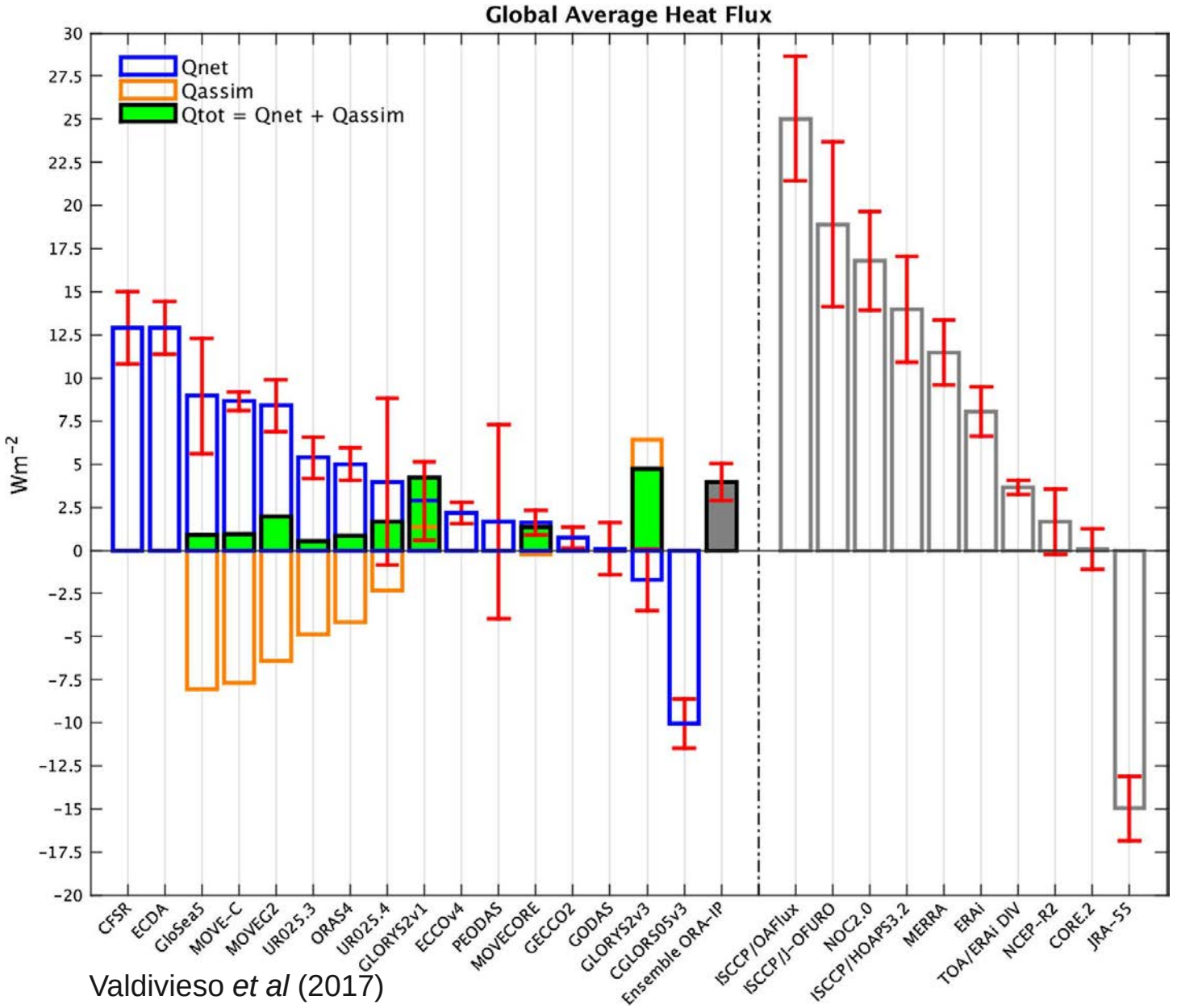
Data Assimilation

- Mathematical discipline that seeks to optimally combine theory (usually in the form of a numerical model) with observation. (Wikipedia)
- Data Assimilation Systems components:
  - Observation system
  - Model
  - Data assimilation algorithm
- Uses:
  - Initialization of GCMs.
  - Investigate past patterns of variability (Reanlysis).



Source: https://blogs.surrey.ac.uk/mathsresearch/2017/03/27/epsrc-awards-grant-to-naratip-santitissadeekorn-for-data-assimilation/

Net heat flux from various reanalysis datasets



Valdivieso *et al* (2017)

Overall motivation of the research program

- Couple the models underlying the MERRA-2 atmospheric reanalysis (GEOS) and the ECCO-v4 ocean state estimate (MITgcm).
- Develop a prototype ocean-ice-atmosphere coupled data assimilation system.
- Work toward closed budget global data assimilation system.

Applications

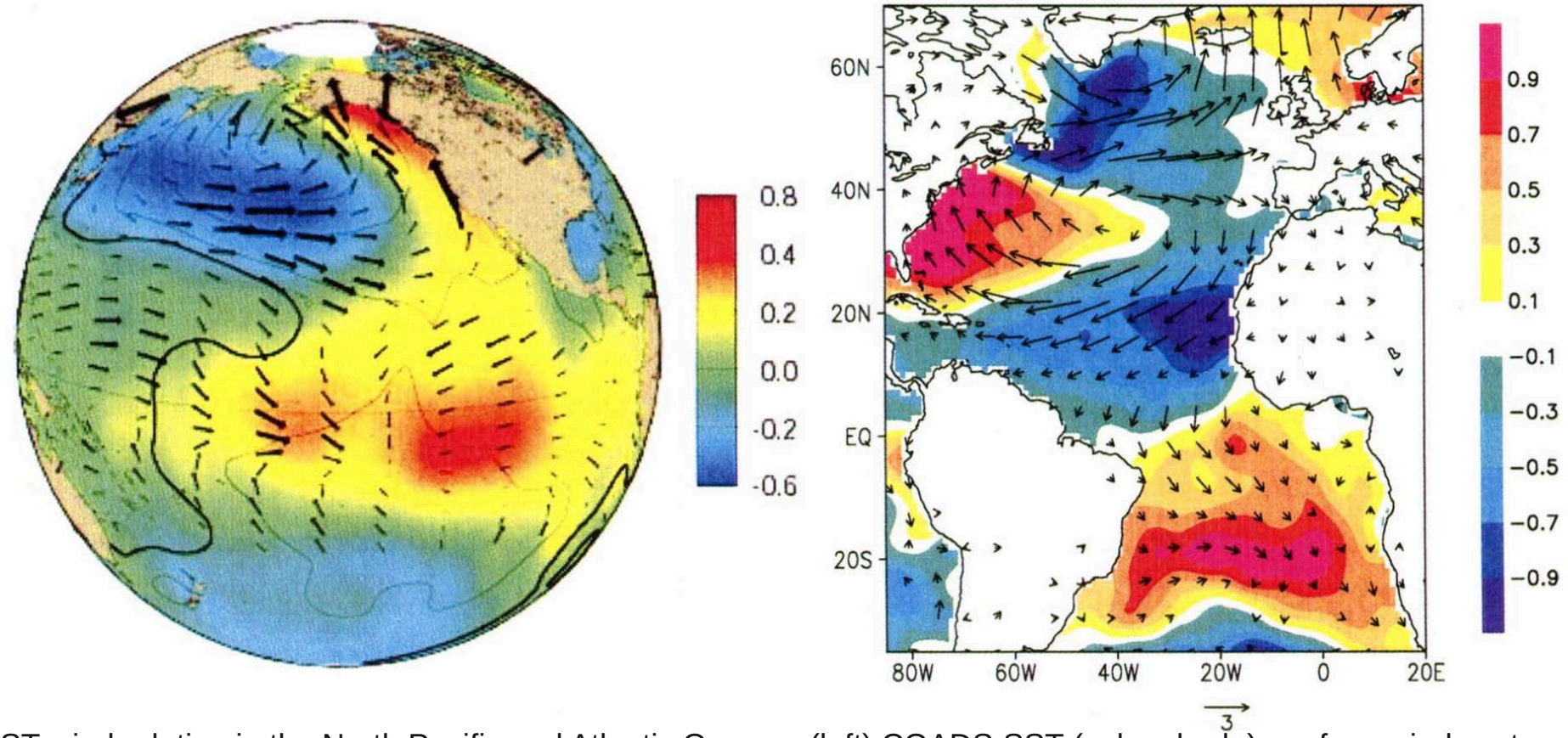
- Sub-seasonal to decadal climate predictions.
- Observation System Simulation Experiments (OSSEs).

Air sea interactions in the high resolution GEOS-MIT

Current objectives of this study

- Develop a high resolution coupled ocean-atmosphere run for studying air sea interactions and simulating an observation system.
- Investigate the ability of the coupled model to capture the strong observed positive correlations between SST and wind stress/speed.
- Compare near-surface diagnostics of the fully coupled ocean-atmosphere set-up to equivalent atmosphere-only simulations.

Background: observed SST/wind speed anomaly correlations

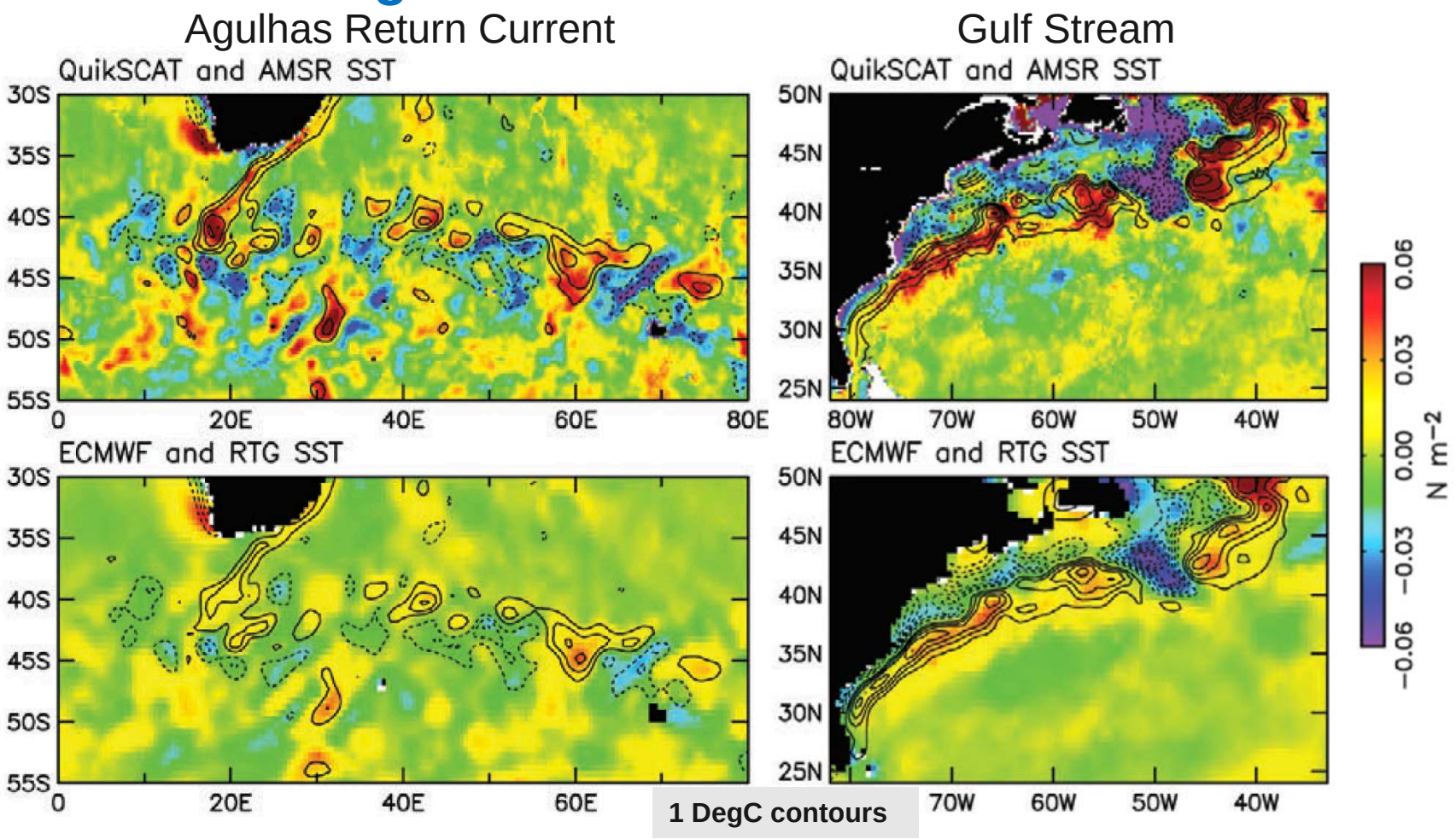


"Most often negative correlations between SST and surface wind speed variability are observed in the extra-tropics for seasonal means and on the basin scale"

Xie *et al* (2004)

SST-wind relation in the North Pacific and Atlantic Oceans, (left) COADS SST (color shade), surface wind vectors, and SLP regressed upon the Pacific decadal oscillation index (Mantua et al. 1997). (right) COADS SST (color in ◦C) and NCEP surface wind (m s^{-1}) composites in Jan-Mar based on a cross-equatorial SST gradient index (Okumura et al. 2001).

Background: observed SST/wind stress anomaly correlations

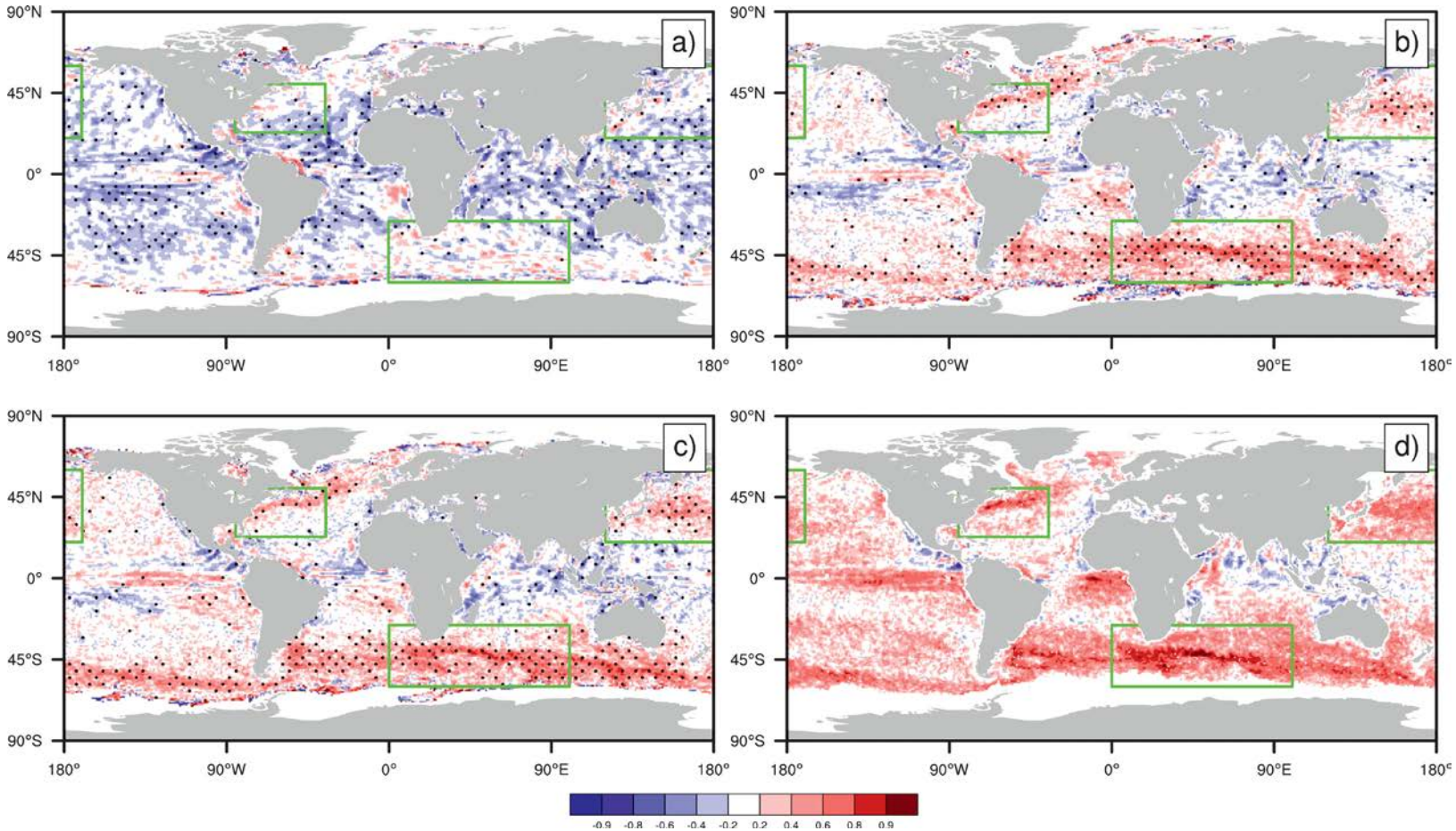


Two-month averages (January–February 2008) of **spatially high-pass-filtered sea surface temperature (SST)** overlaid as contours on **spatially high-pass-filtered wind stress.**

"Satellite observations have revealed a remarkably strong positive correlation between sea surface temperature (SST) and surface winds on oceanic mesoscales of 10–1000 km."

Chelton *et al., Oceanography (2010)*

Background: modeled SST/wind speed correlation



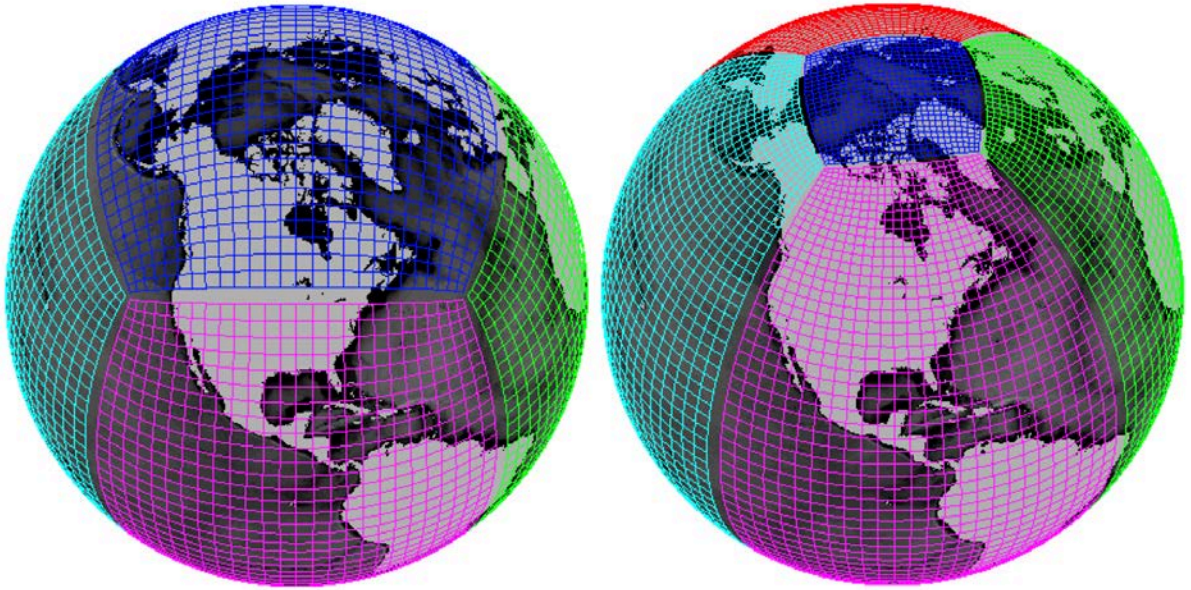
"… the output of a suite of Community Climate System Model (CCSM) experiments indicates that … correlation between SST and surface wind stress, is realistically captured only when the ocean component is eddy resolving."

Bryan *et al., J. Clim. (2010)*

Temporal correlation of **high-pass filtered surface wind speed with SST.** (a) 1.0° ocean and 0.5° atmosphere (b) 0.1° ocean and 0.5° atmosphere (c) 0.1° ocean and 0.25° atmosphere. (d) Satellite observations.

Methods - models

- Atmosphere – GEOS:
  - Horizontal grid type – Cubed sphere, 1/8° X1/8°
  - Vertical grid type – hybrid sigma-pressure, 72 levels
- Ocean – MITgcm
  - Horizontal grid type – Lat-Lon-Cap, 1/12° X1/12°
  - Vertical grid type – z^* rescaled height vertical coordinate, 90 levels

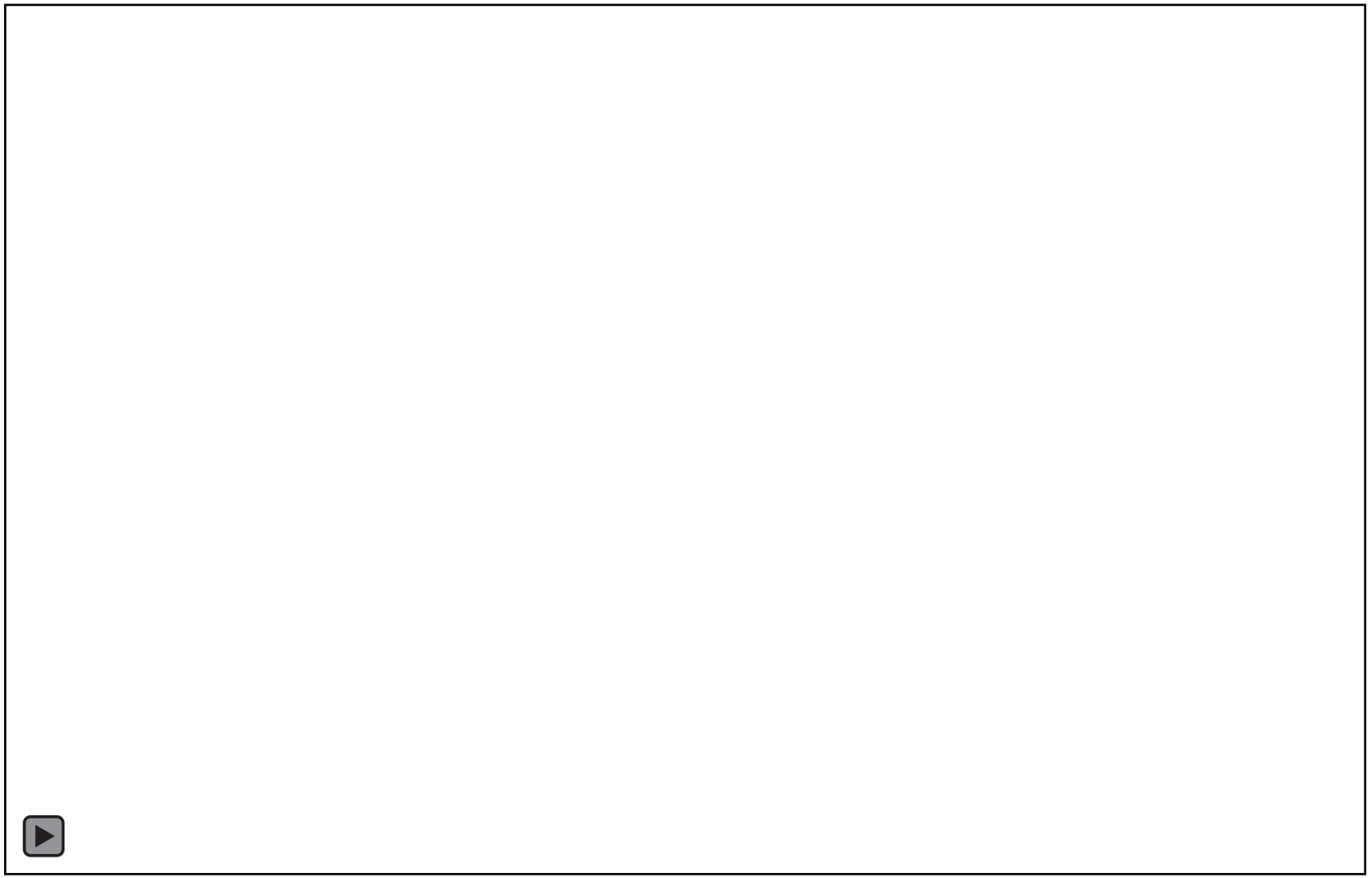


Cubed sphere grid (left) and Lat-Lon-Cap (right)

Methods - experimental setup

1) Ocean only – MITgcm (OGCM):
   - Jan, 1 – Jun 15, 2012
   - Forcing: 0.14°, 6 hourly ECMWF
2) Atmosphere Only – GEOS (AGCM)
   - Feb, 9 – Apr 9, 2012
   - Forcing: SST and ice fraction from run 1
   - Initial conditions: MERRA-2
3) Coupled – GEOS-MITgcm (AOGCM)
   - Feb, 9 – Apr 9, 2012
   - Ocean initial conditions: from run 1
   - Atmospheric initial conditions: MERRA-2 (same as the run 2)

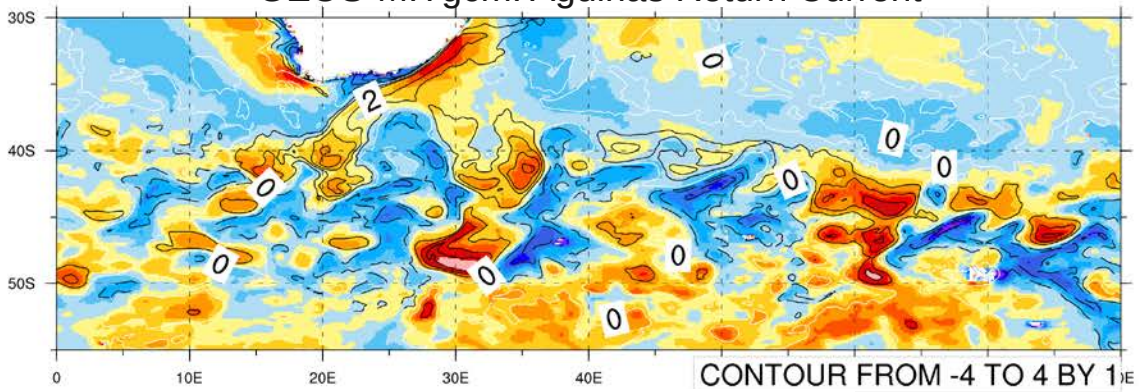
Ocean surface current



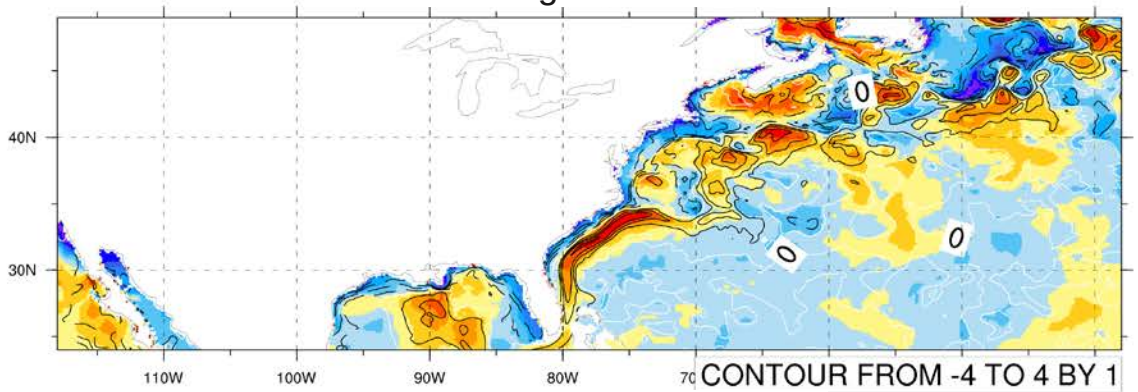
Precipitation

Wind stress (shading) and SST (contours)

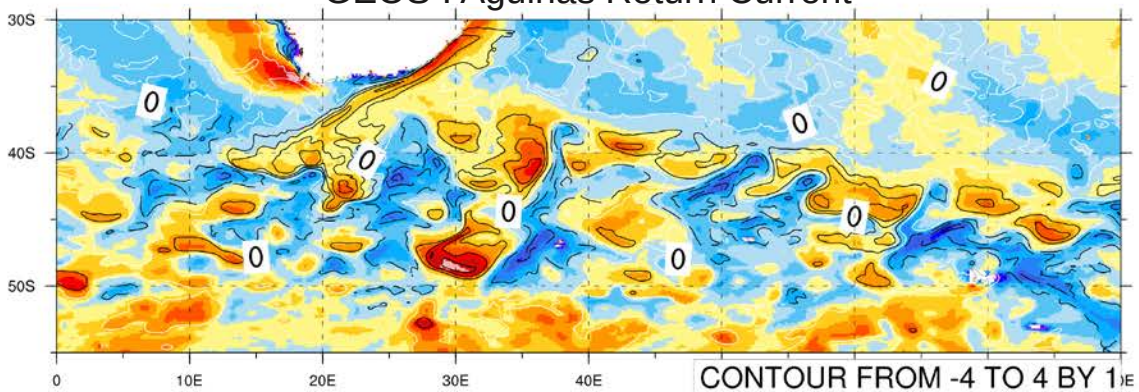
GEOS-MITgcm: Agulhas Return Current



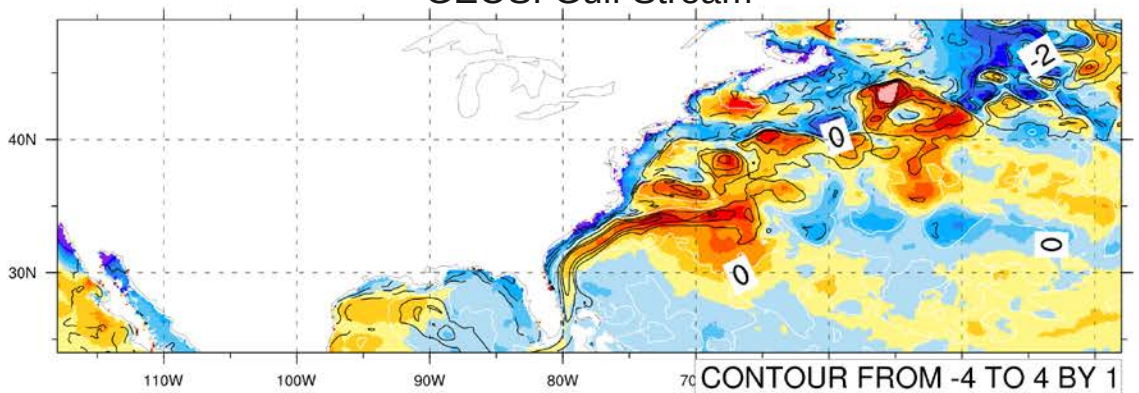
GEOS-MITgcm: Gulf Stream



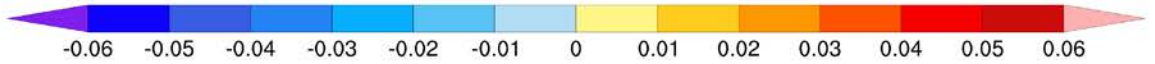
GEOS : Agulhas Return Current



GEOS: Gulf Stream



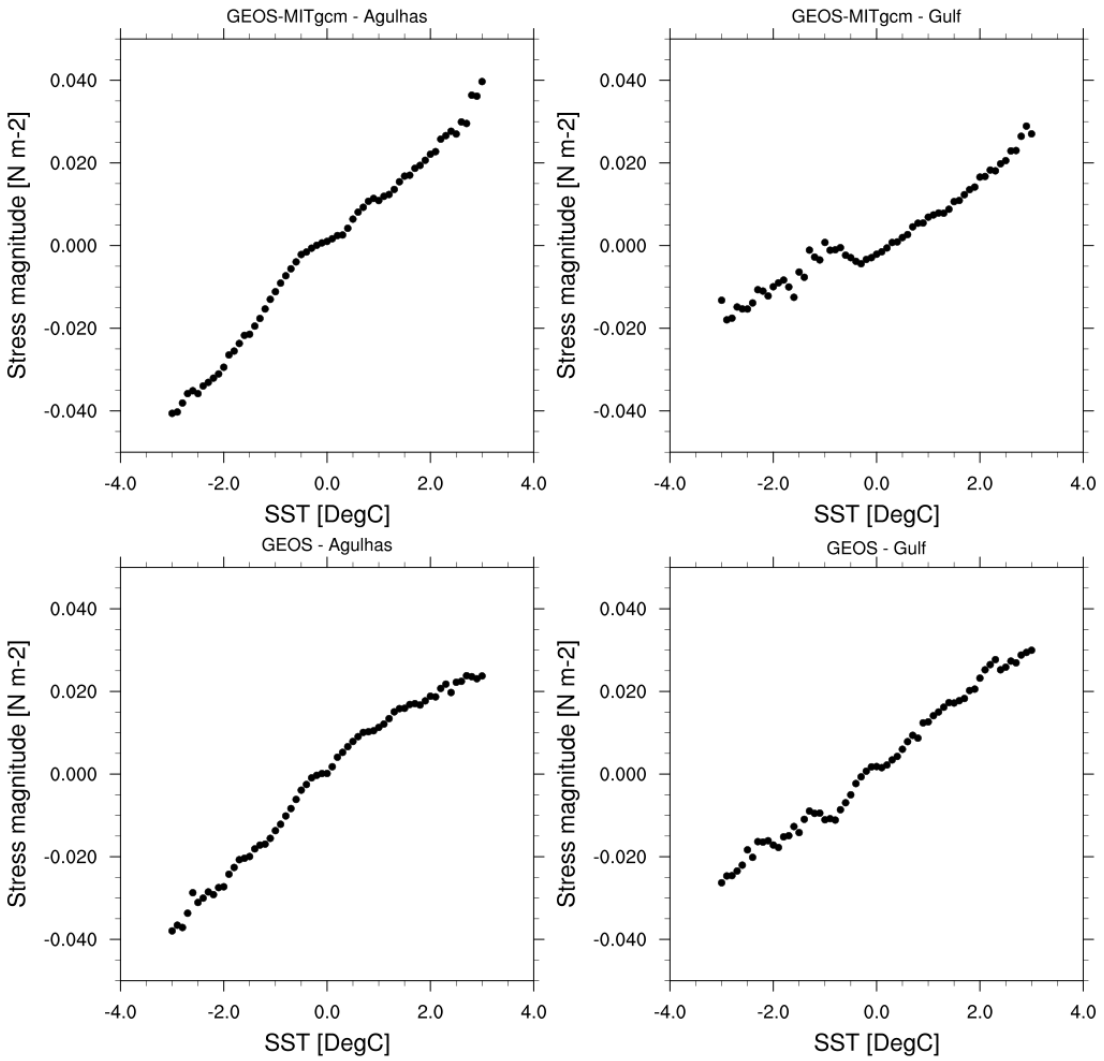
Solid Black – positive anomaly
White – zero
Dashed black – negative anomaly

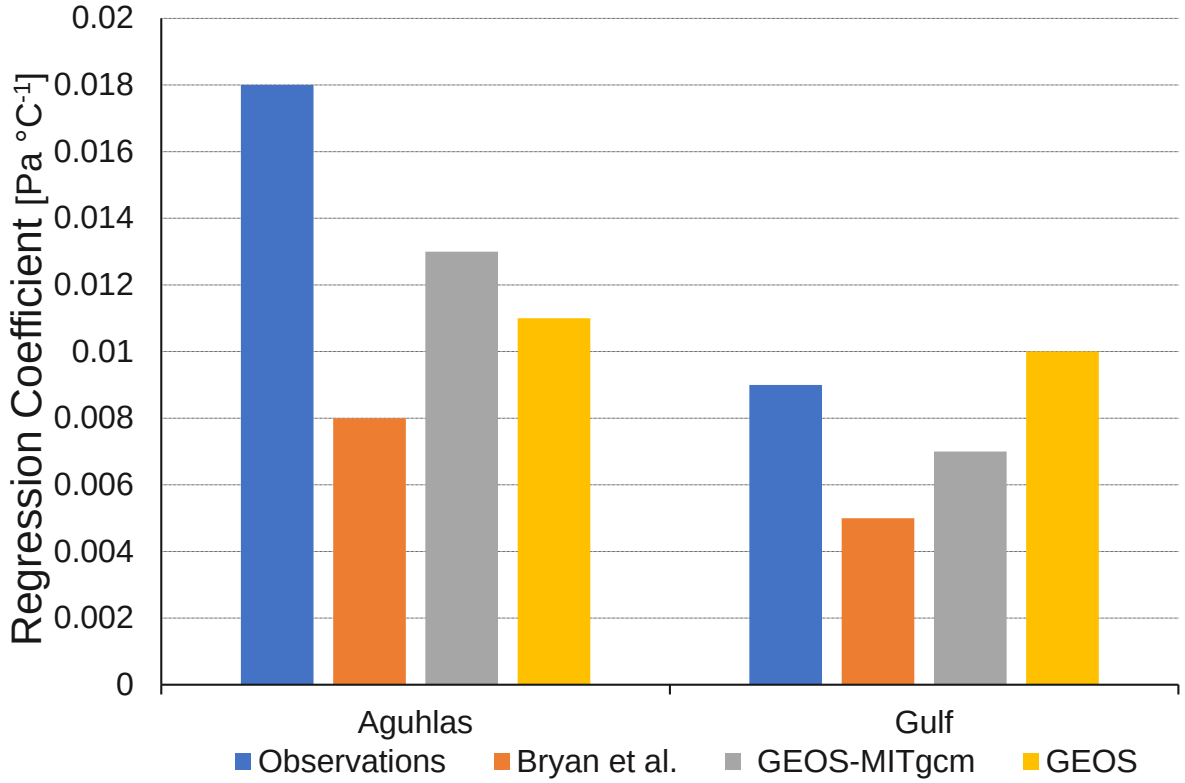


Wind Stress [N m-2]

Both GEOS and GEOS-MITgcm show positive correlation between wind stress and SST consistent with previous results

Linear relation between wind stress and SST

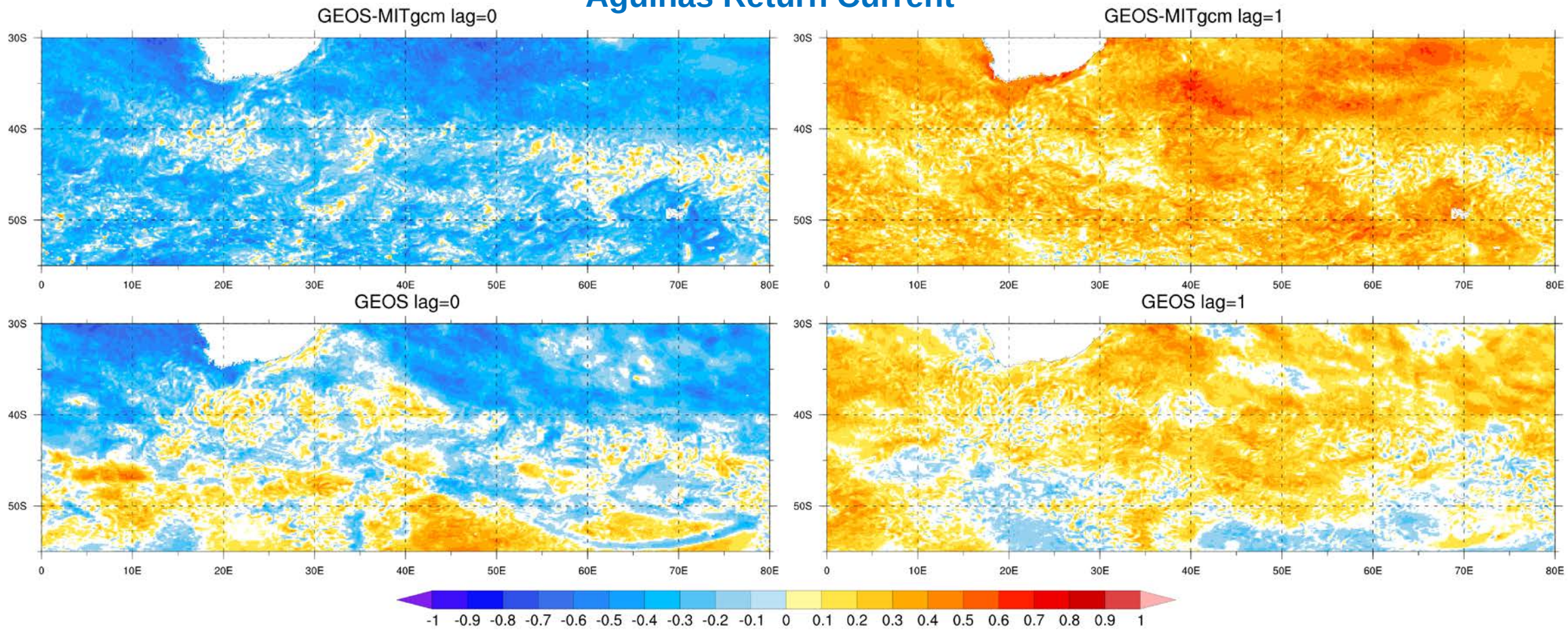




The linear relation between the stress and the SST in our coupled model is closer to the observed values compared to the previous modeling study.

Correlation between daily SST $\left(\frac{\Delta SST}{\Delta t}\right)$ and wind speed $\left(\frac{\Delta WS}{\Delta t}\right)$

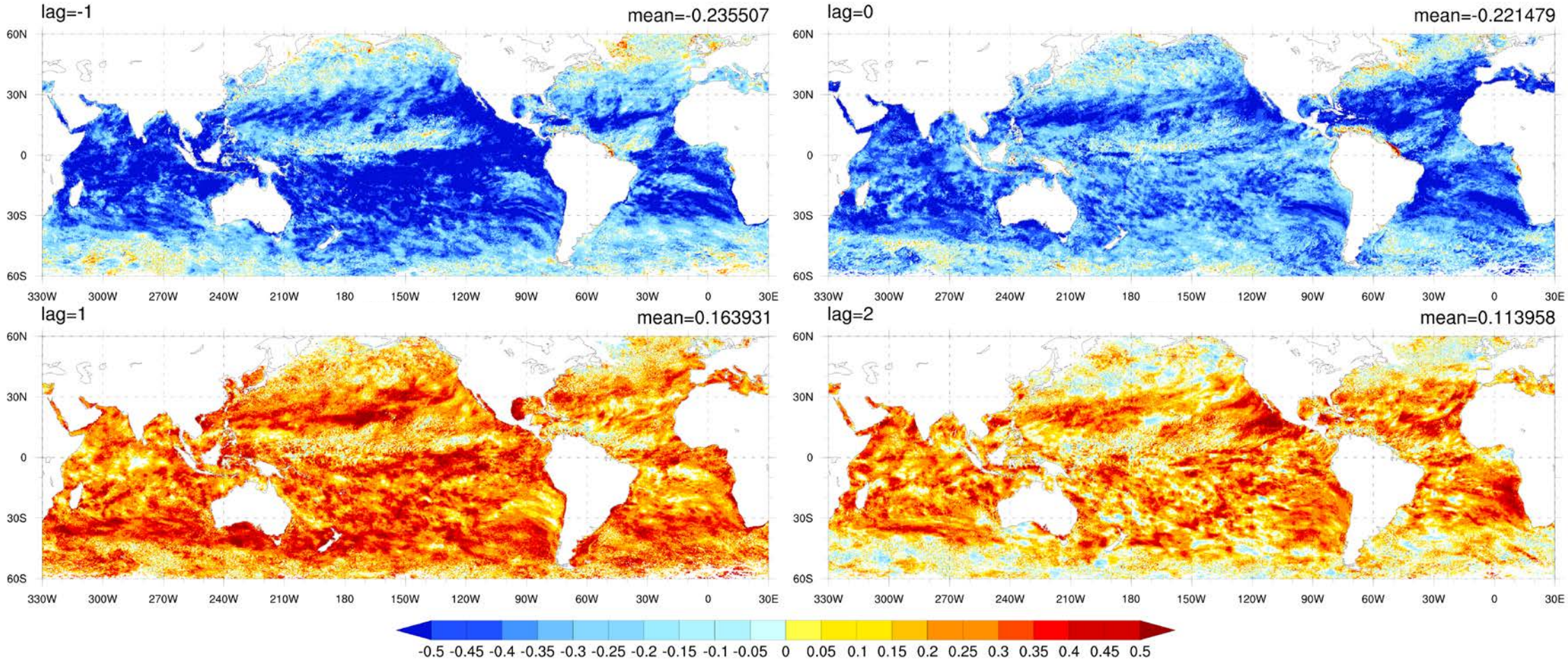
Agulhas Return Current



Wind speed is lagging the SST by ~1day

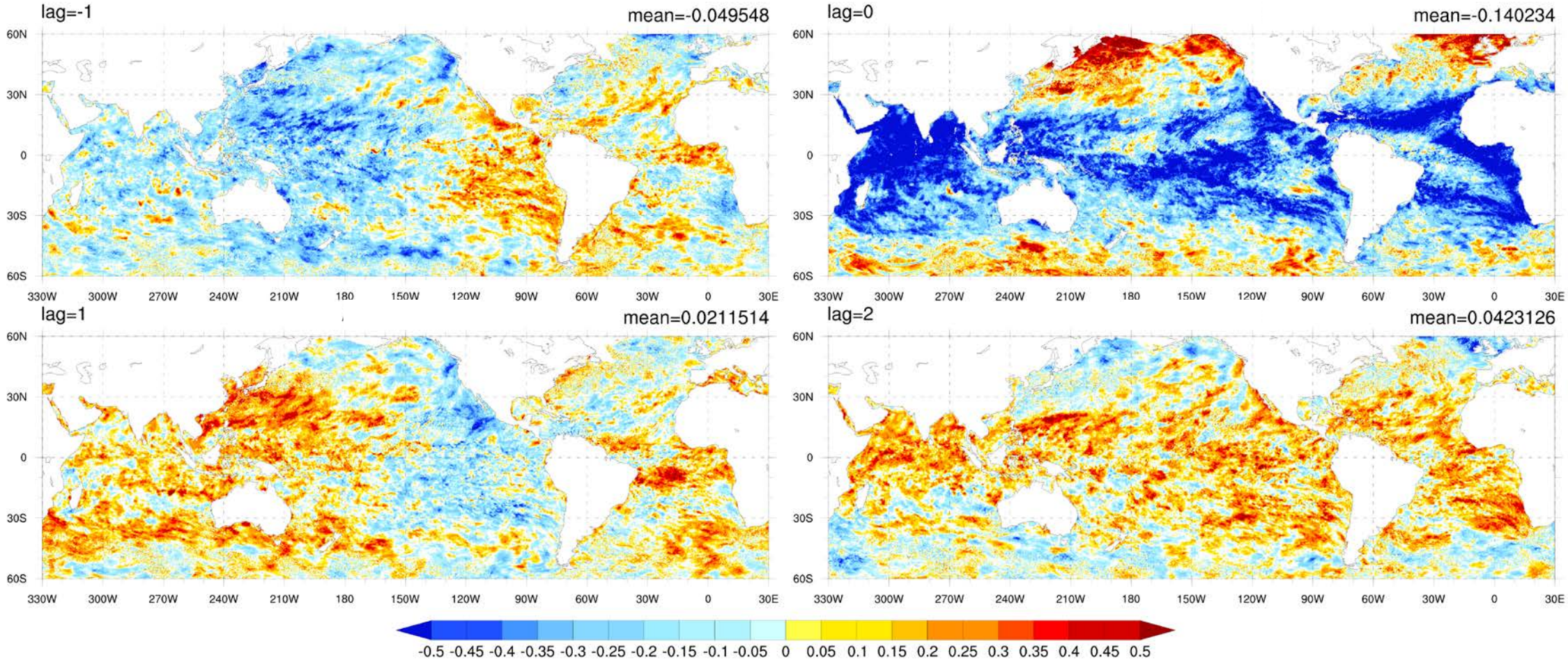
Correlation between daily SST $\left(\frac{\Delta SST}{\Delta t}\right)$ and wind speed $\left(\frac{\Delta WS}{\Delta t}\right)$

GEOS-MITgcm

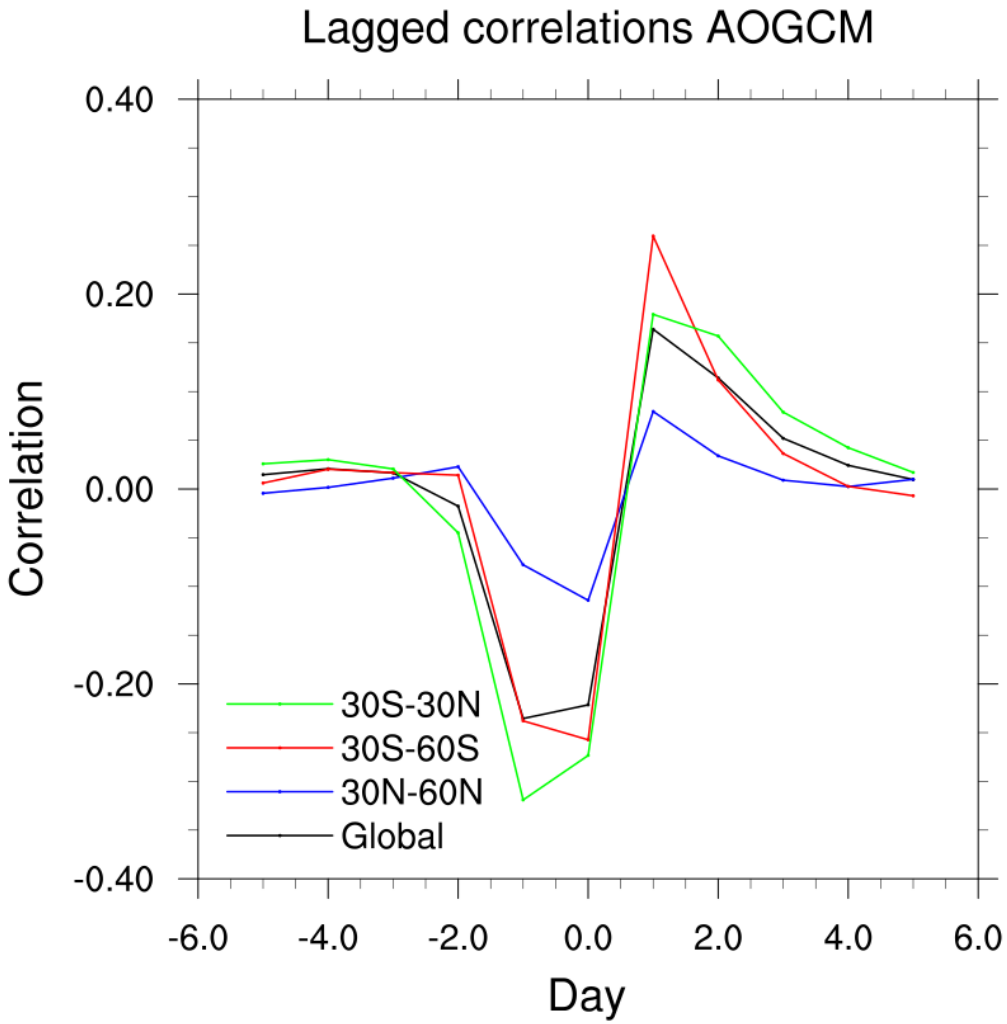


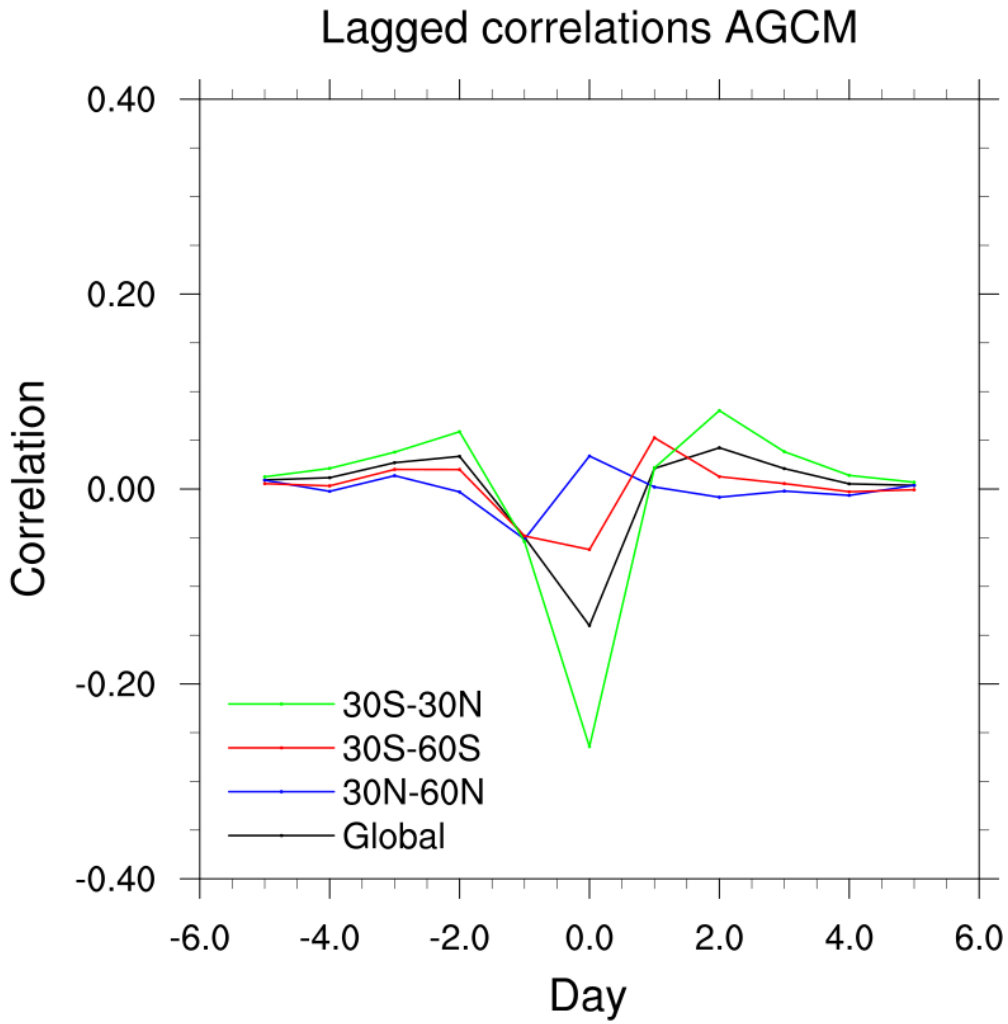
Correlation between daily SST $\left(\frac{\Delta SST}{\Delta t}\right)$ and wind speed $\left(\frac{\Delta WS}{\Delta t}\right)$

GEOS

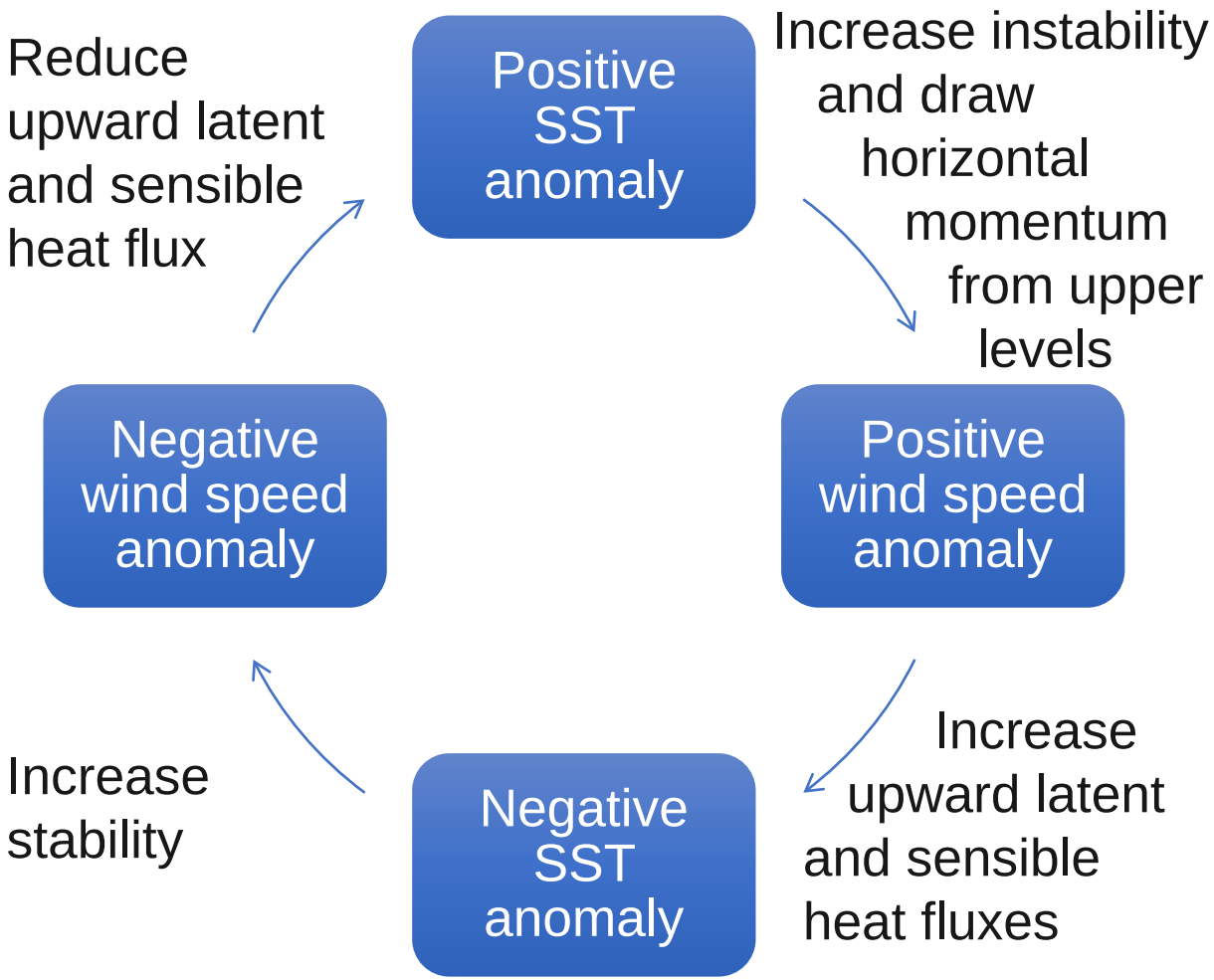


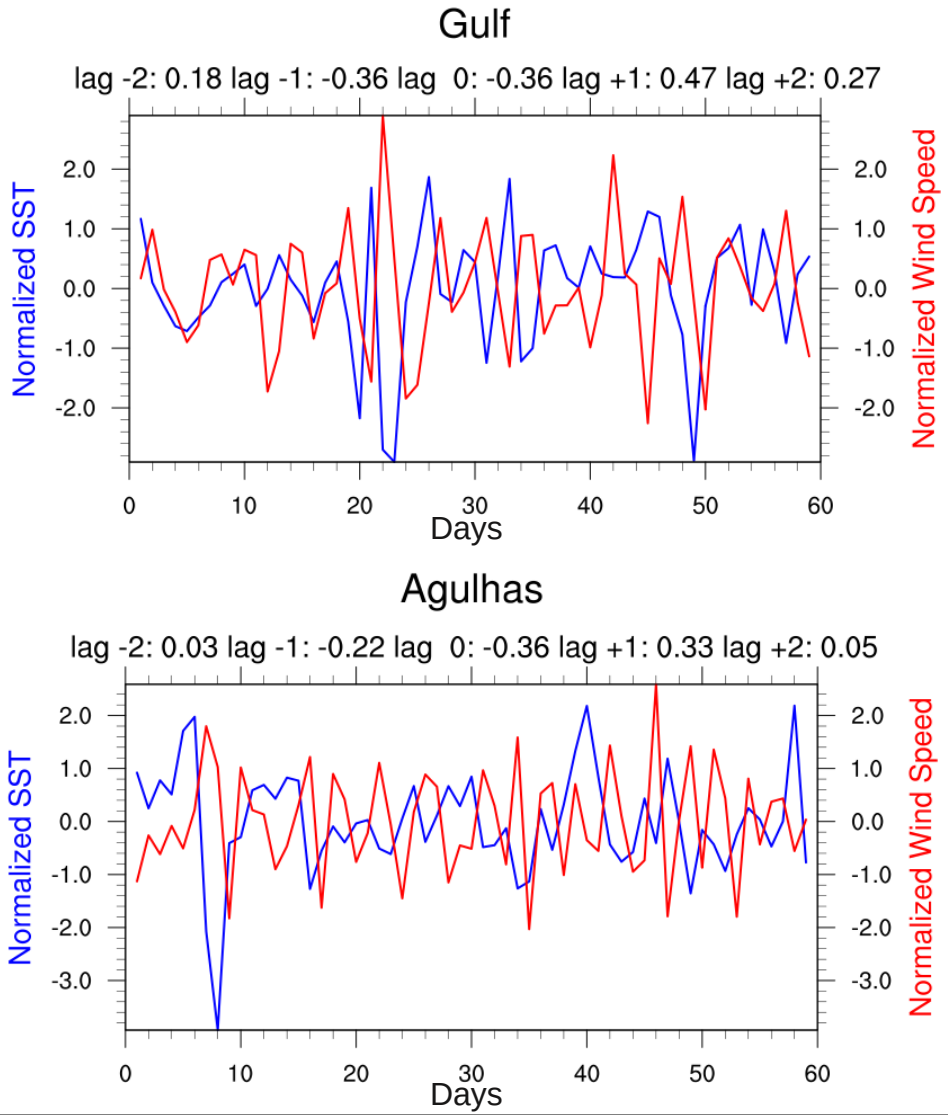
Correlation between daily SST $\left(\frac{\Delta SST}{\Delta t}\right)$ and wind speed $\left(\frac{\Delta WS}{\Delta t}\right)$





Possible mechanism





Conclusions

- First analysis of the ~10km coupled GEOS-MITgcm model reproduces realistic synoptic and mesoscale patterns.
- The coupled model shows positive correlations between SST and wind speed/stress, and the relation is slightly closer to observational estimates compared to previous simulations.
- The fact that the atmosphere-only experiment can reproduce the positive correlation suggests that the atmosphere responds to the ocean.
- Daily time series suggest a three-four-day cycle induced by air-sea feedbacks.

Next steps/future work

- Increasing horizontal resolution (~1km).
- Initialized sub-seasonal to decadal prediction system.
- Observation System Simulation Experiments (OSSE).