Some Aspects of

Mesoscale Air-Sea Interaction

As Manifested in Contemporary Global Climate Models

Frank Bryan

Climate and Global Dynamics Laboratory

National Center for Atmospheric Research

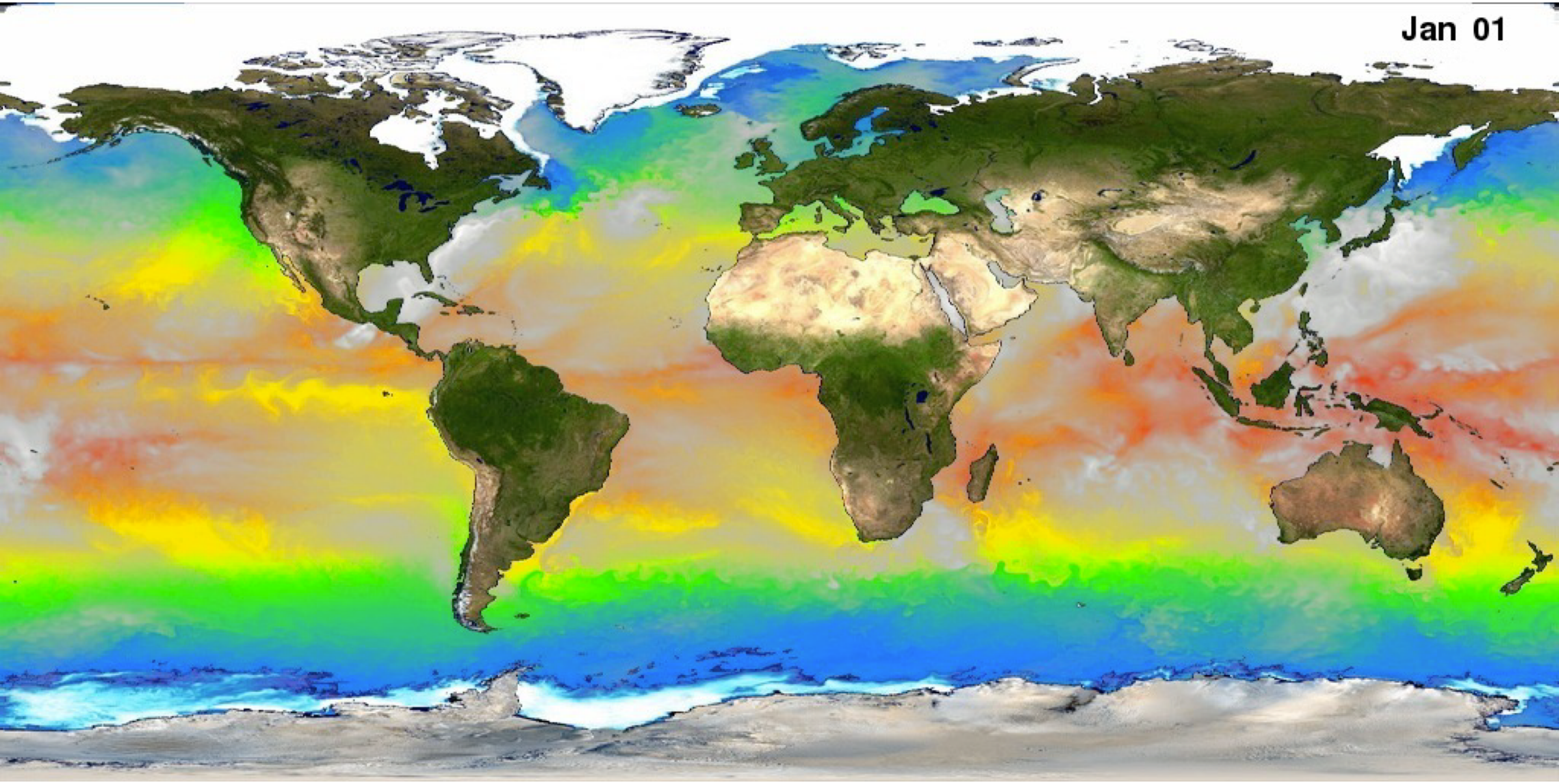
Thanks to:

Bob Tomas & Justin Small (CGD), Stu Bishop (NCSU)

How does the climate system differ when both ocean and atmosphere have "weather"?

Even if we could perfectly parameterize the integrated transport effects of ocean eddies, what feedbacks or coupled system behaviors would we miss by not explicitly representing the scales and variability they imprint on the air-sea interface?

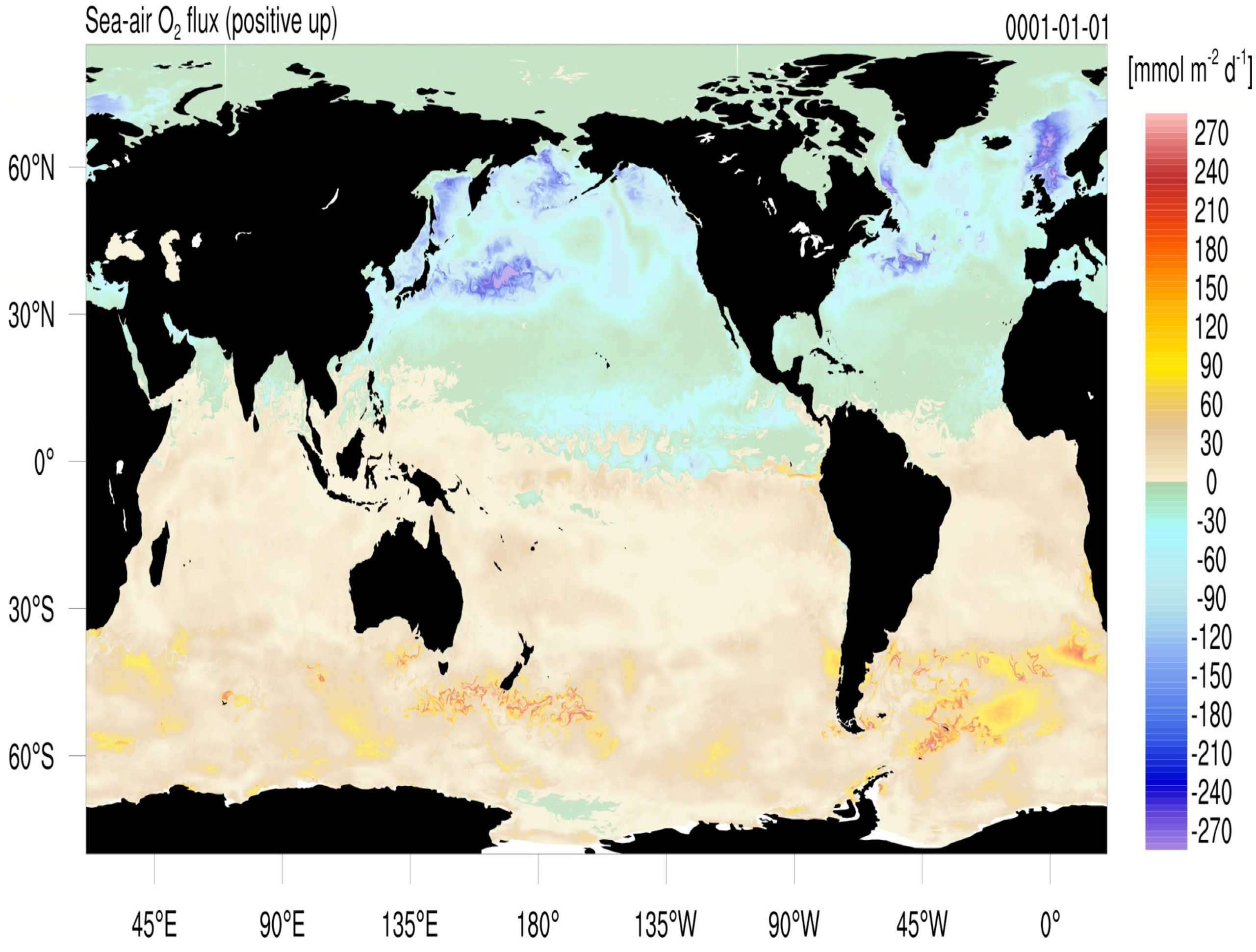
Simulated SST & Latent Heat Flux



0.25° ATM / 0.1° OCN

Small et al (2014) JAMES

Air-Sea Oxygen Flux

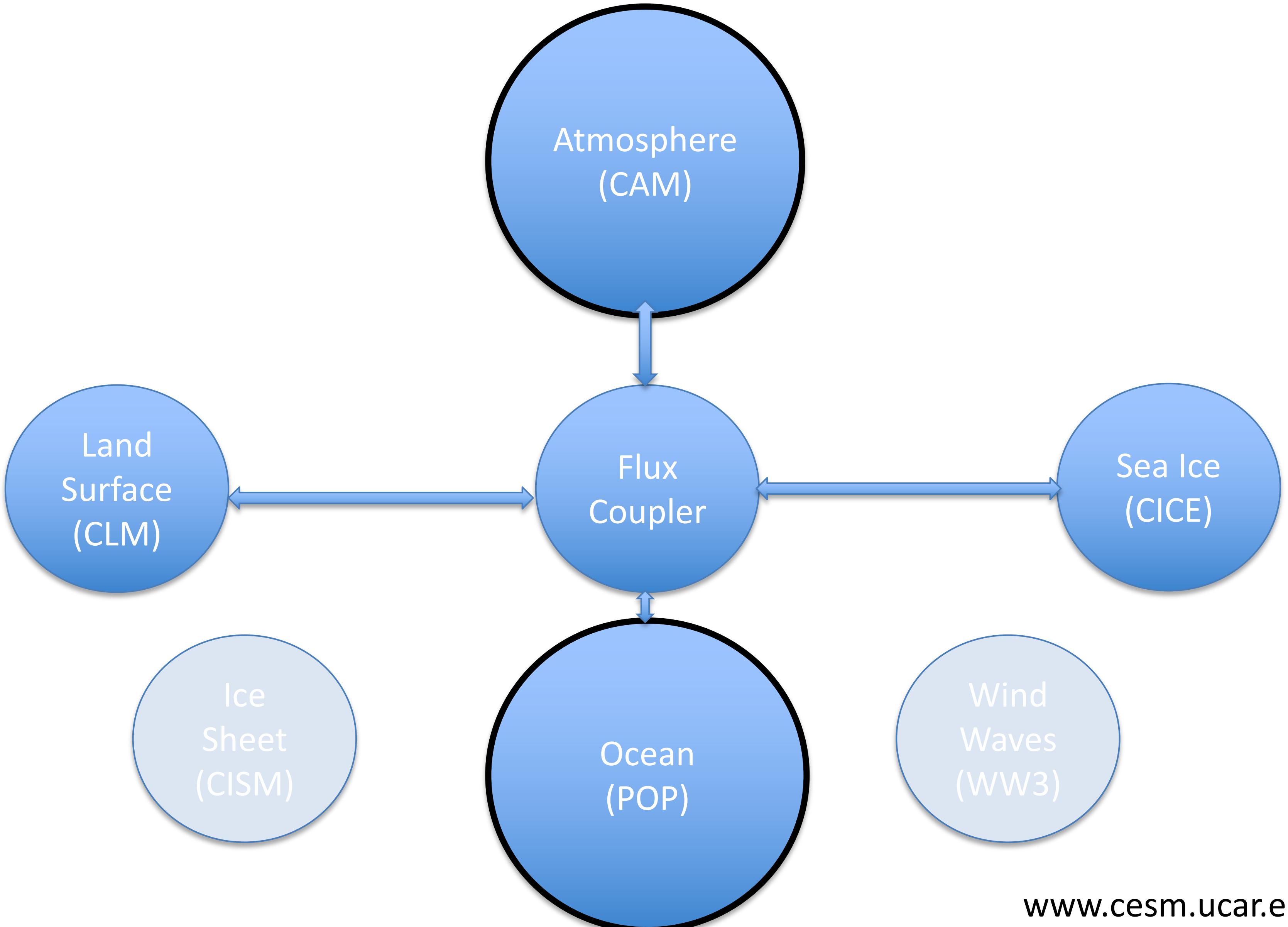


Provided by Matt Long

Outline

1. The Model and its Fidelity
2. Response of low-level winds to mesoscale structure in the SST field
3. Differences between $\tau, \nabla \cdot \tau, and\ \nabla \times \tau$
4. Some consequences outside the PBL

The Community Earth System Model



www.cesm.ucar.edu

CESM: Low- vs. High-Resolution

- Low Resolution: Ocean weather parameterized
- High-Resolution: Ocean weather explicitly represented

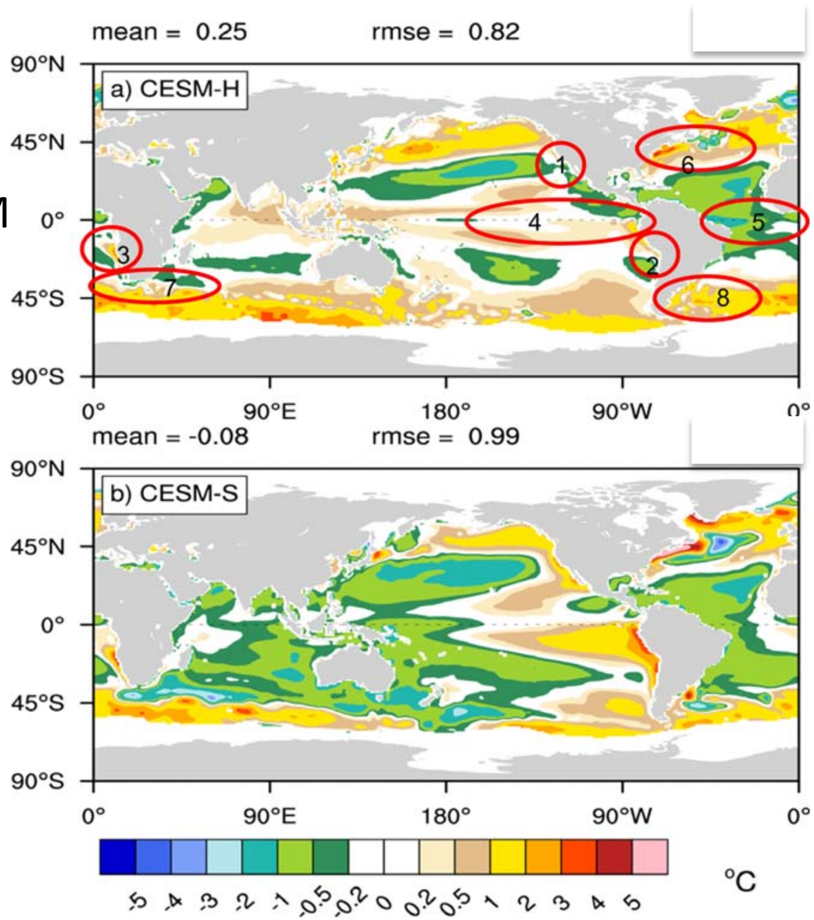
	Low Resolution	High Resolution
Ocean Grid / Resolution	Dipole ~1.0°	Tripole 0.1°
Ocean Tracer Lateral Subgridscale Closure	Gent-McWilliams w/ diagnostic $\kappa(\mathbf{x},t)$	Biharmonic $\kappa \propto \Delta^3$
Ocean Momentum Subgridscale Closure	Anisotropic harmonic viscosity	Biharmonic $\nu \propto \Delta^3$
Ocean Topography	Full Cell (ETOPO5)	Partial Cell (ETOPO2)
Atmos. Resolution	0.5° , 1°	0.25° , 0.5°
Ocean-Atmosphere Coupling Interval	6 hours	6 hours

Large-Scale Annual Mean Biases

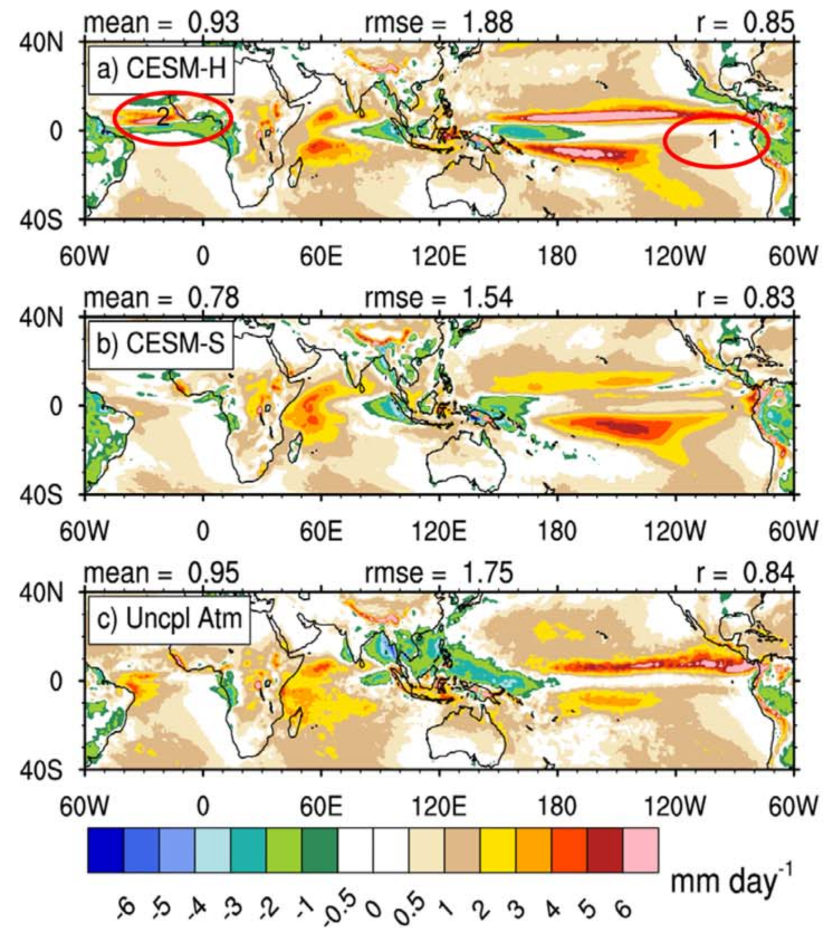
SST (vs OISST)

HR
0.25° ATM
0.1° OCN

LR
1.0° ATM
1.0° OCN

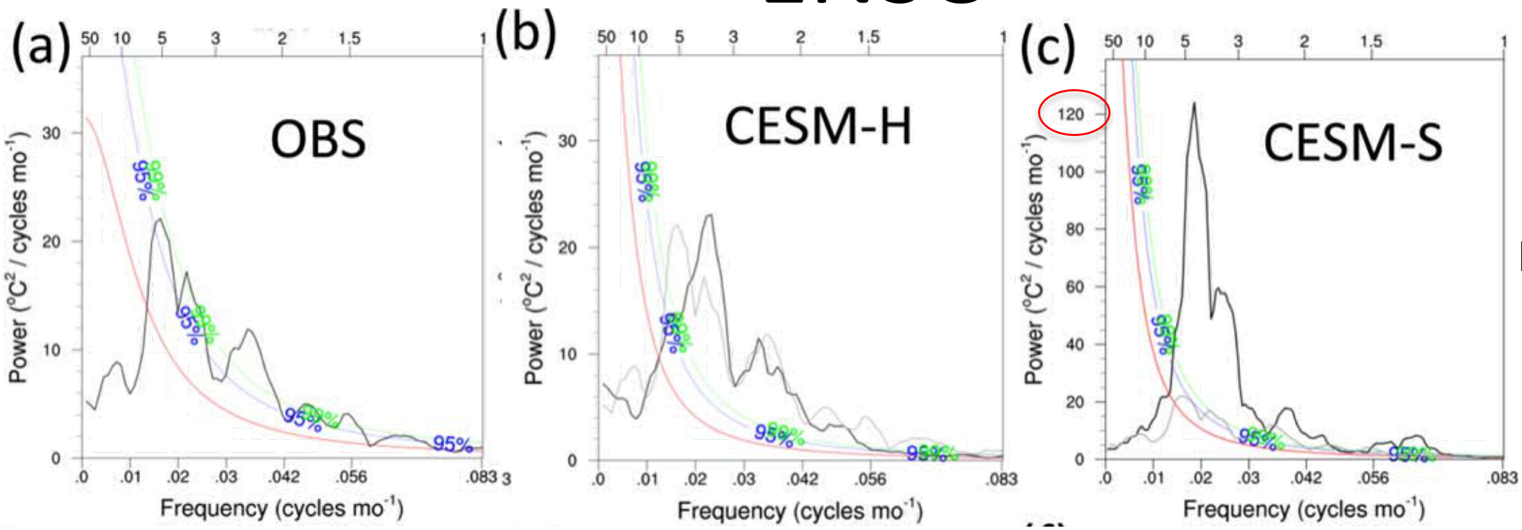


PRECIP (vs TRMM)

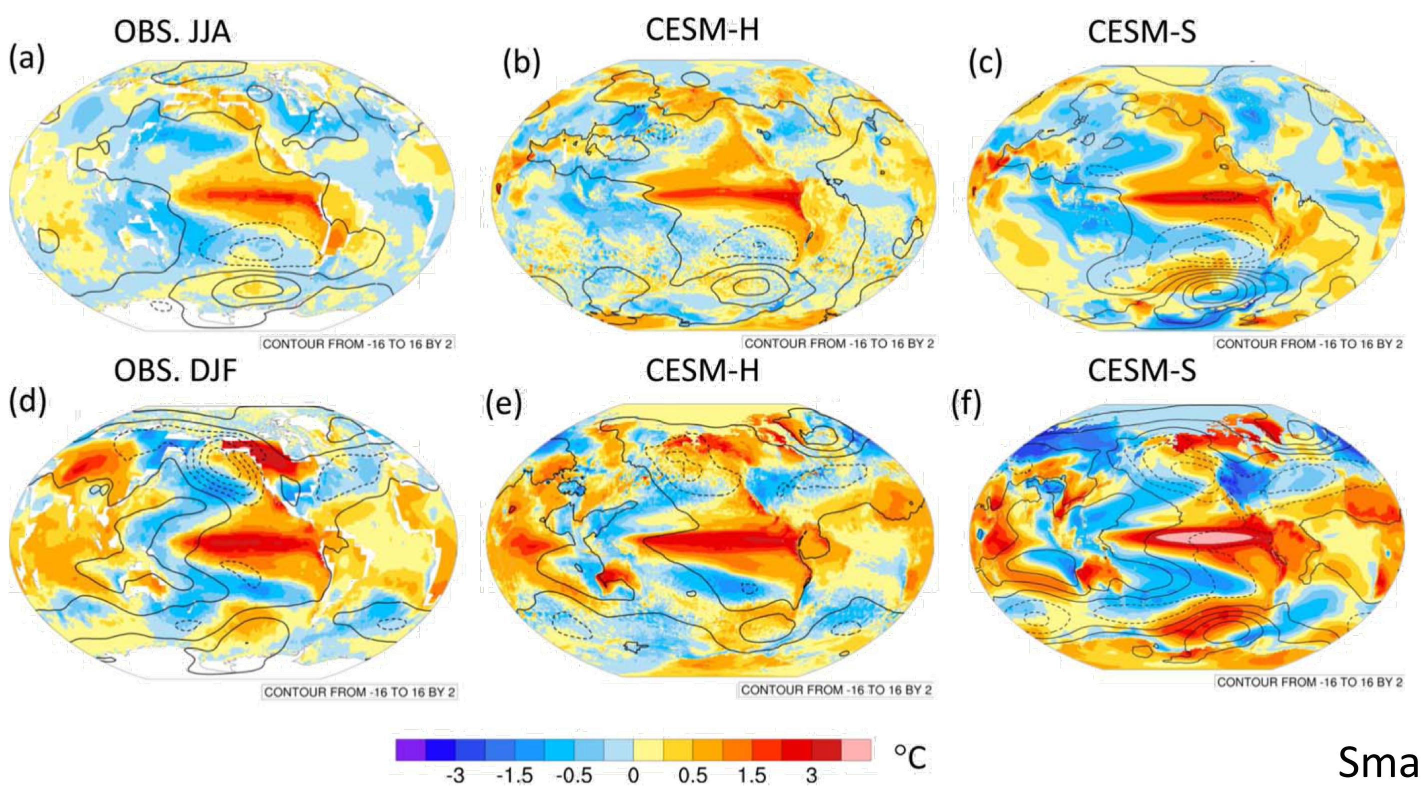


Small et al (2015) JAMES

ENSO



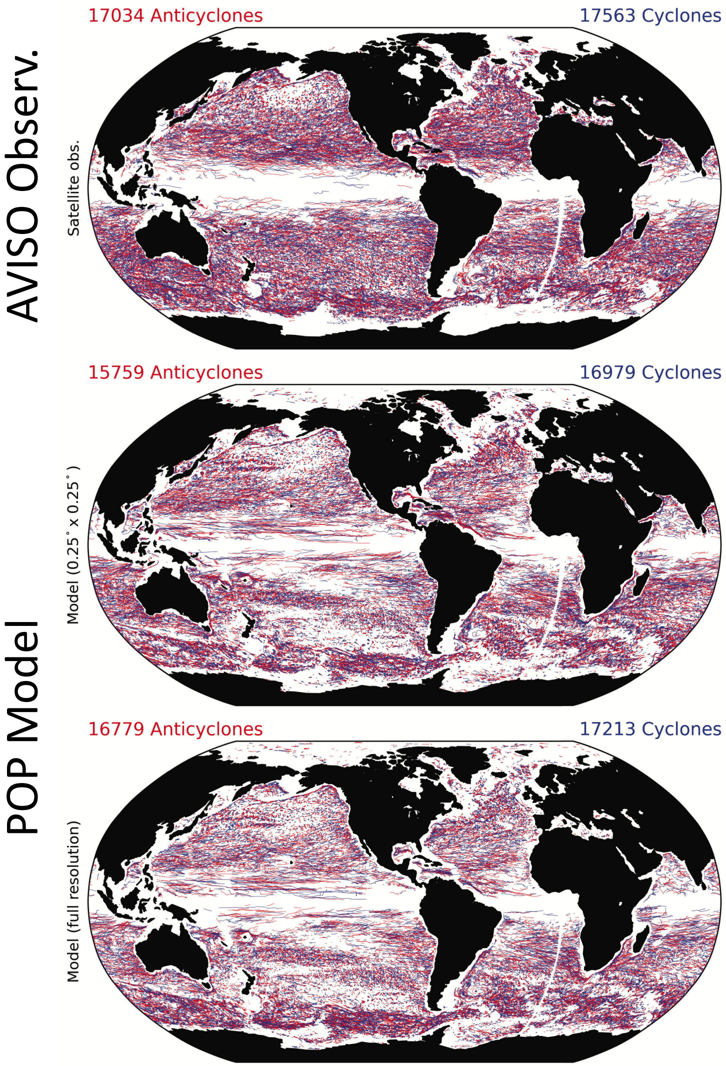
NINO3.4 SST Freq. Spectrum



SST / SLP ENSO Seasonal Composites

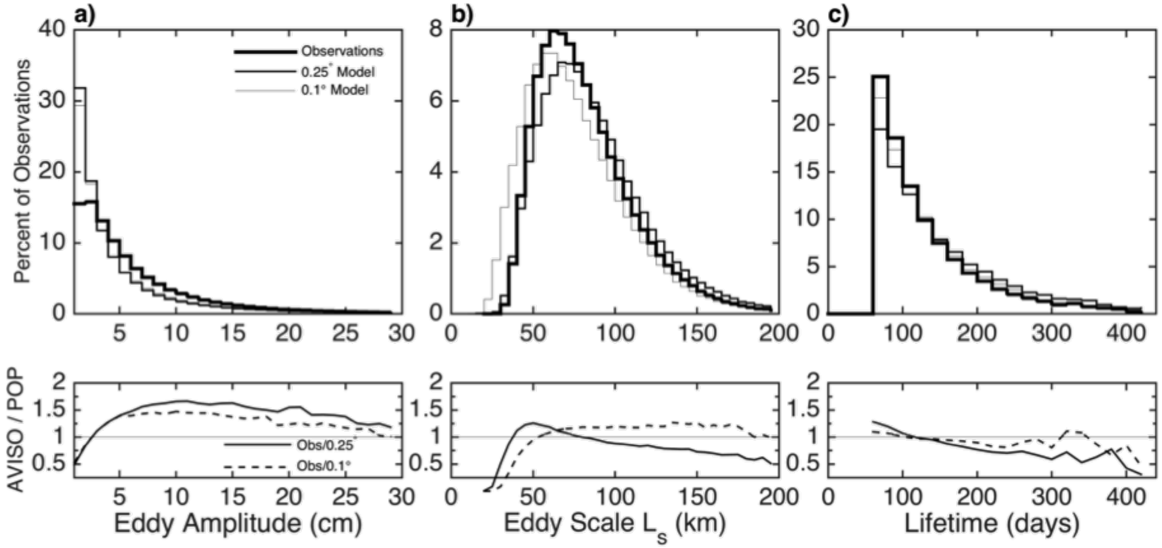
Small et al (2015) JAMES

Mesoscale Eddy Demographics (CORE NY Ocean-Ice Simulation)



- Chelton (2011) Eddy Tracking Algorithm
- 5 years data / model output

Amplitude | Length Scale | Life Time

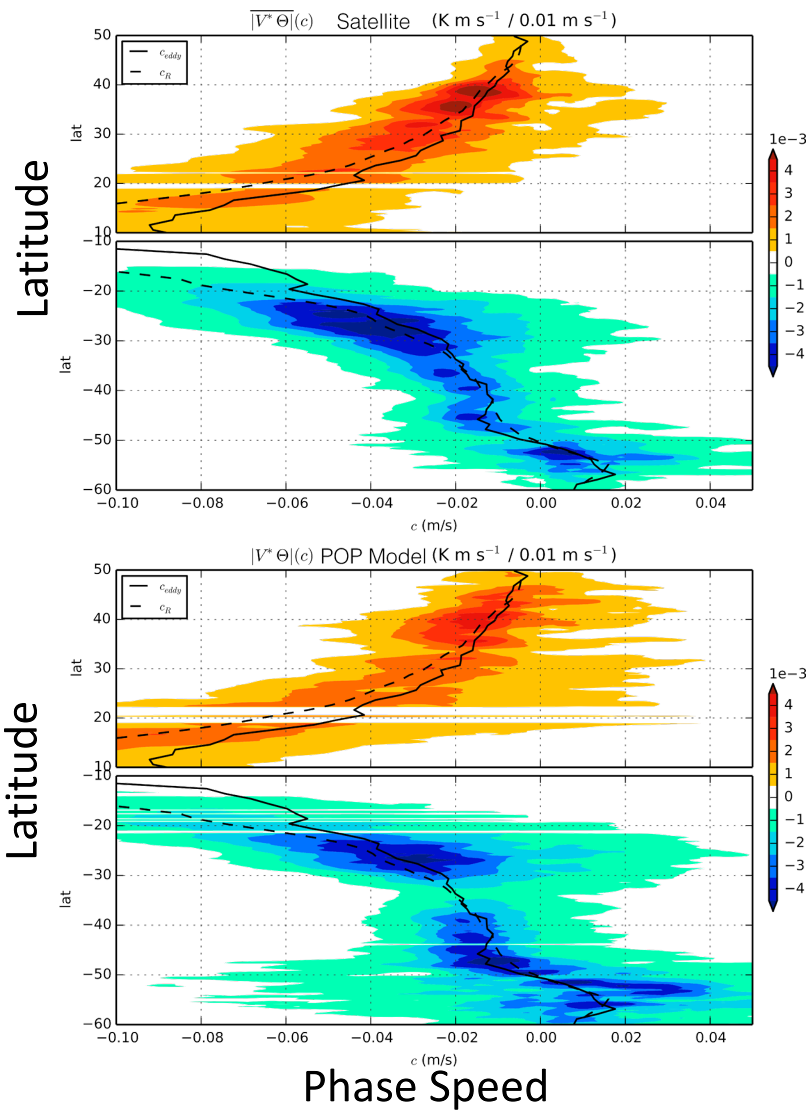


Long et al (2017) (*in review*)

Phase Speed of Eddies Transporting Heat

- Wavenumber-Frequency Cross Spectra v, T
- Eastern Pacific sector (180°E - 130°W)

- C_{eddy}: from Chelton (2011)
- C_R: Doppler shifted Rossby Wave Phase Speed



Satellite Observ.
AVISO SSH -> v_{geo}
Reynolds OISST

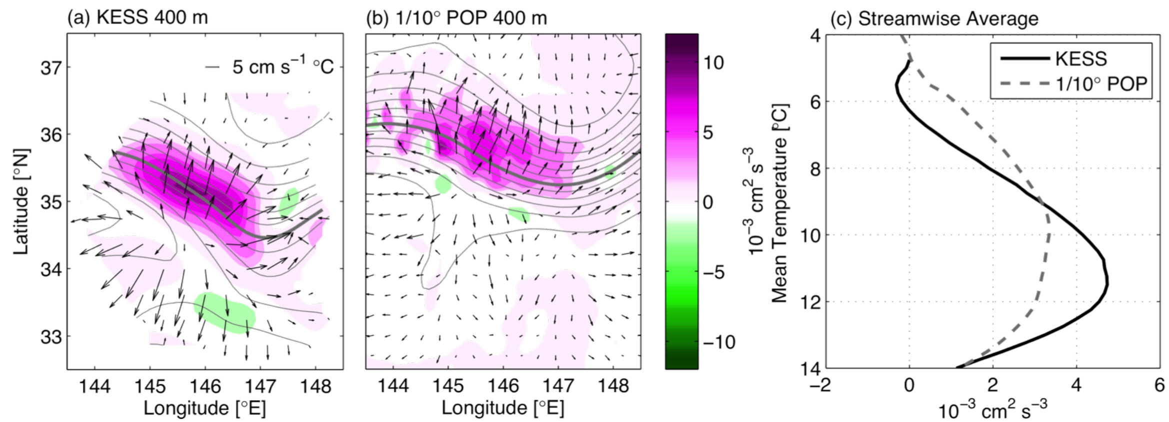
HR CESM

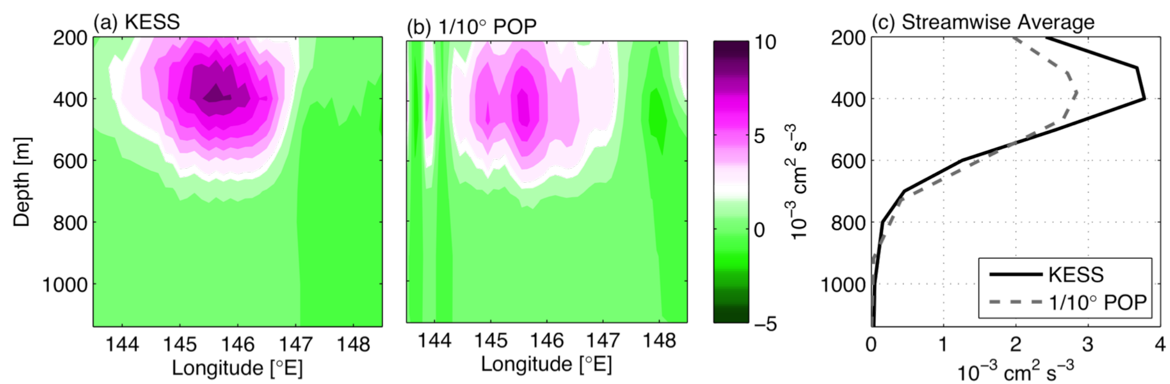
Abernathy and Wortham (2015) JPO

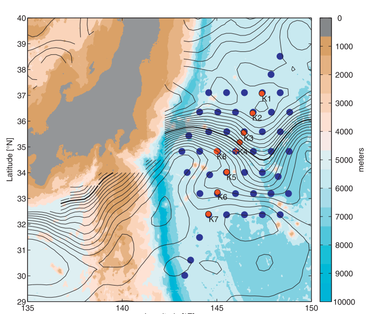
Eddy Baroclinic MPE→EPE Conversion Rate

$$BC = -\frac{\alpha g}{\Theta_z}\overline{\mathbf{u}'T'}^{div} \bullet \nabla \overline{T}$$

- This is the process GM is designed to emulate in LR models
- How well is it represented by the resolved flow in HR models?
- KESS Array provides *local* observational estimate



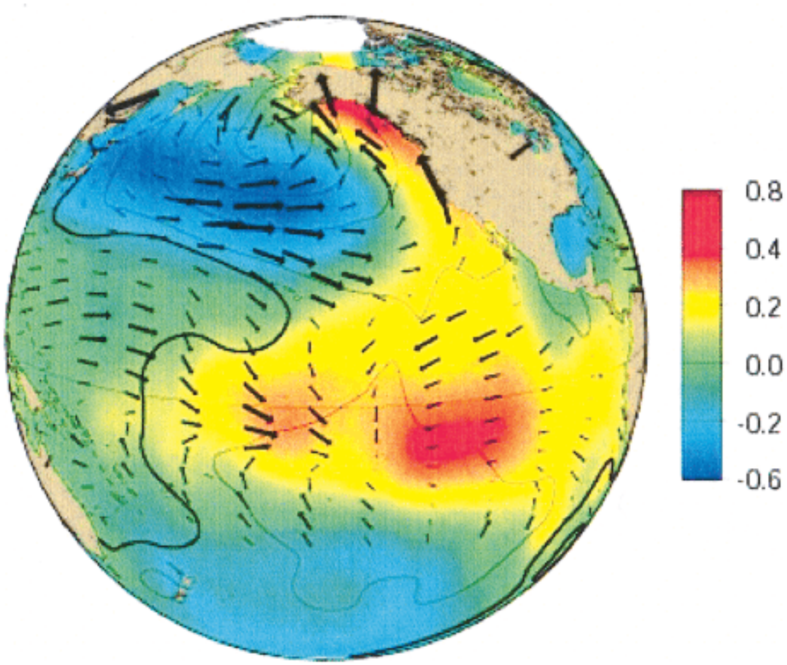




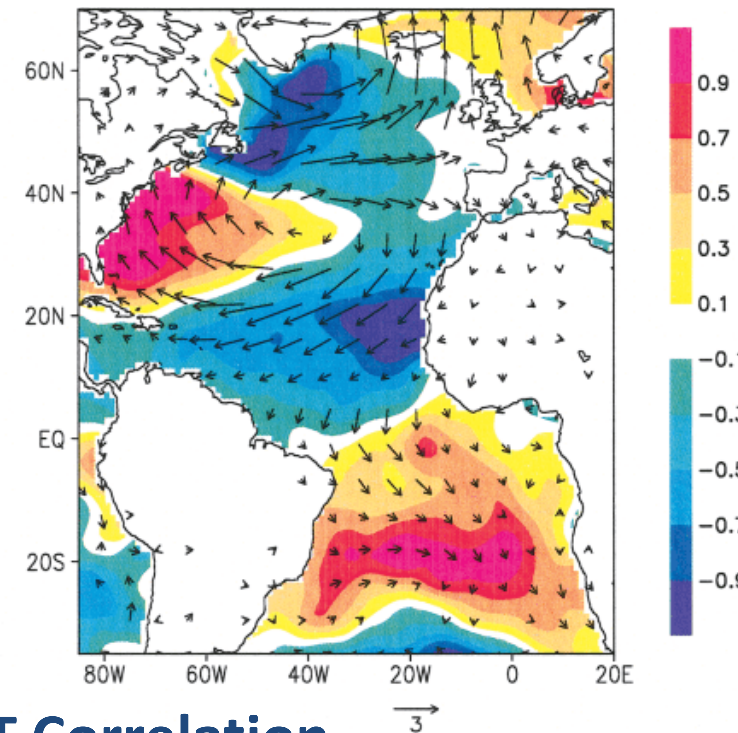
Bishop and Bryan (JPO 2013)

Coupling of Wind and SST

PDO



AMO



NEGATIVE Wind-SST Correlation

High Winds → Increased turbulent heat loss → Colder SST

High Winds → Increased mixed-layer entrainment → Colder SST

Xie (2004); Mantua (1998), Okamura (2001)

FIG. 10. Aerial photograph of sea condition over the cold slope water, 6 December 1979.

Gulf Stream North Wall

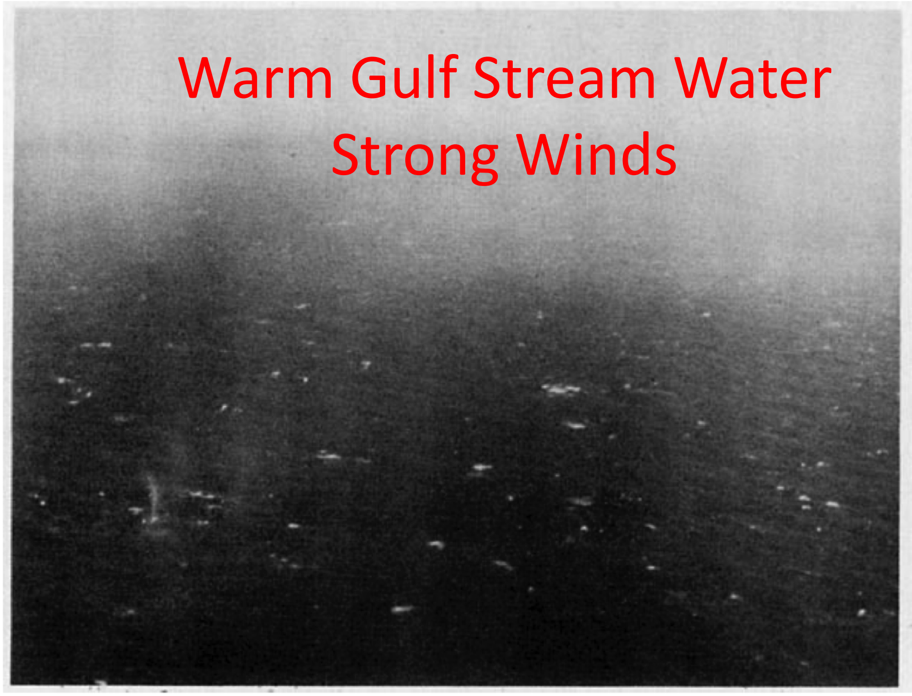


FIG. 11. Aerial photograph of sea condition over the warm Gulf Stream, 6 December 1979.

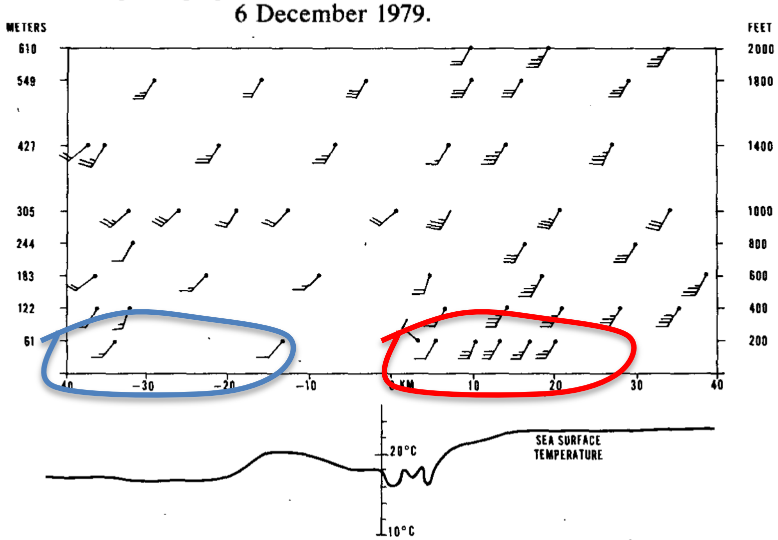


FIG. 9. Winds as determined from the inertial navigation system for the eight flight altitudes, 6 December 1979. One full barb ~ 5 m s⁻¹ (10 kt).

POSITIVE SST-Wind Correlation

"However, air-sea temperature differences, contributing to greater instability over the Gulf Stream also act to favor a turbulent transfer of stronger winds to the sea surface in that area, producing rougher seas in comparison to the Slope Water area."

SE Trades Response to E. Equatorial Pacific Cold Tongue

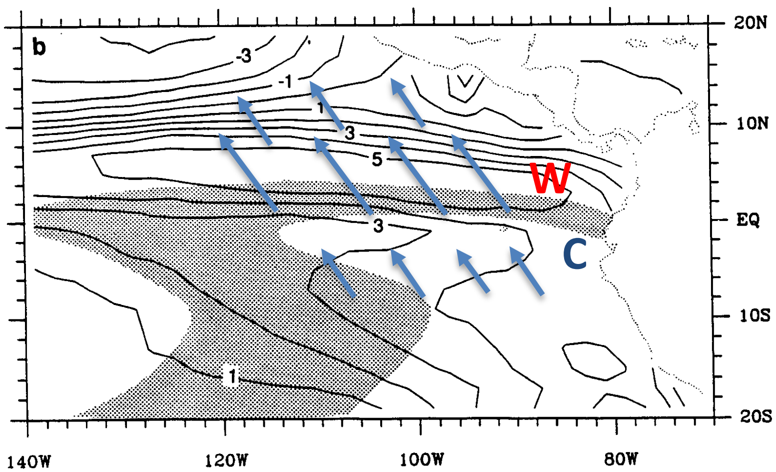
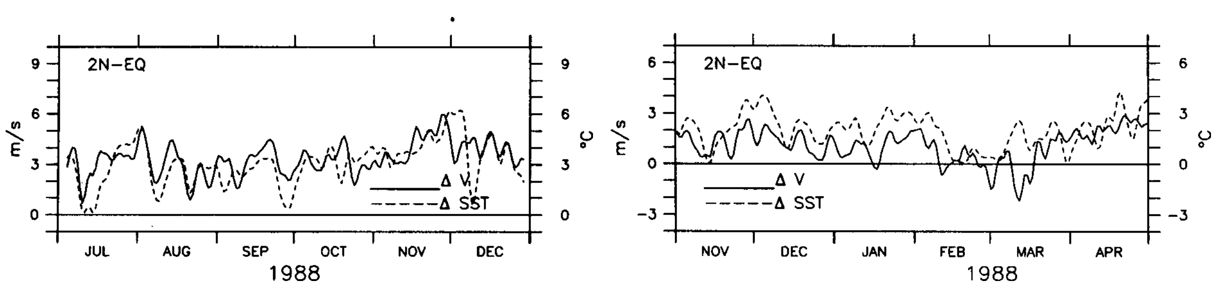


FIG. 6. Magnitude of the meridional wind component during the cold seasons of (a) the warm years, and (b) the cold years. Contour interval 1 m s^{-1}. Shading in (b) denotes sea-surface temperatures between 22° and 25°C, which delineate the oceanic frontal zone.

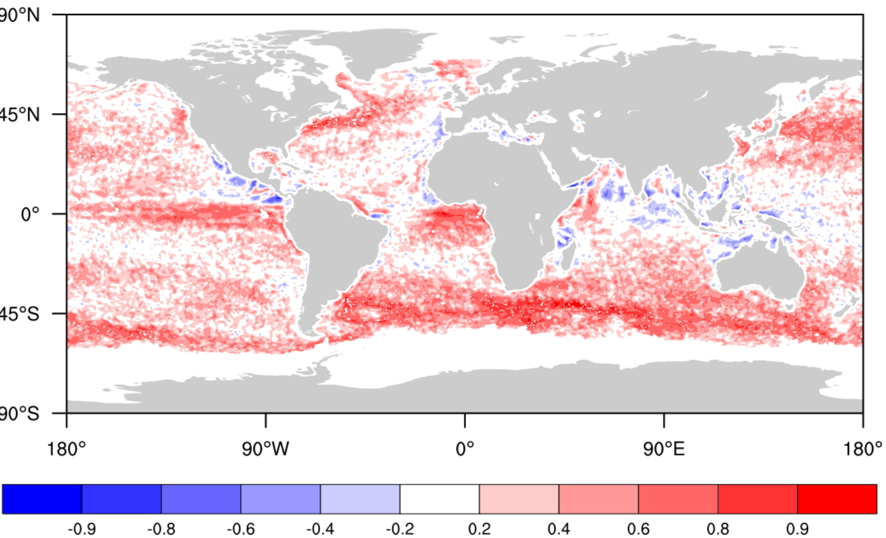
"We suspect that the wind profile might change substantially as the air flows northward over the oceanic frontal zone and the boundary layer becomes destabilized."

POSITIVE SST-Wind Correlation

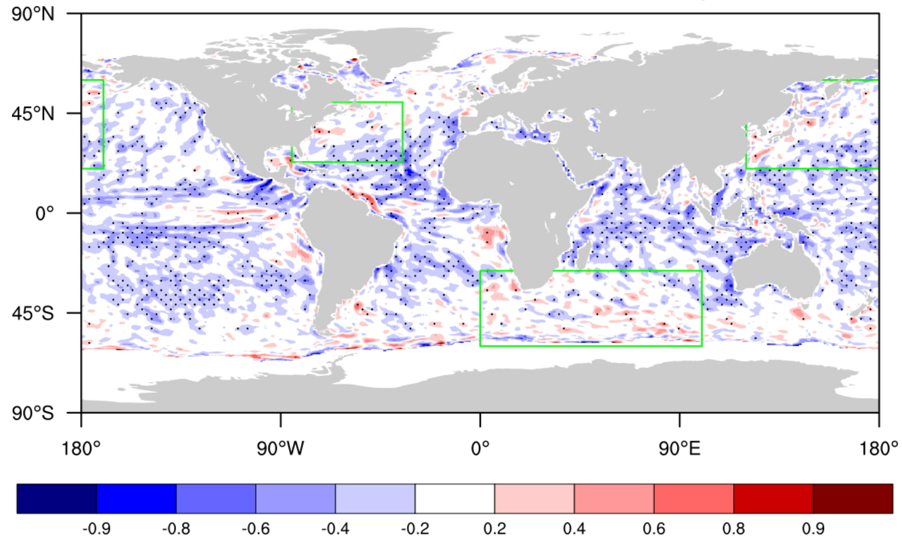


"The strong correlations we have observed indicate a rapid and direct response to SST perturbations."

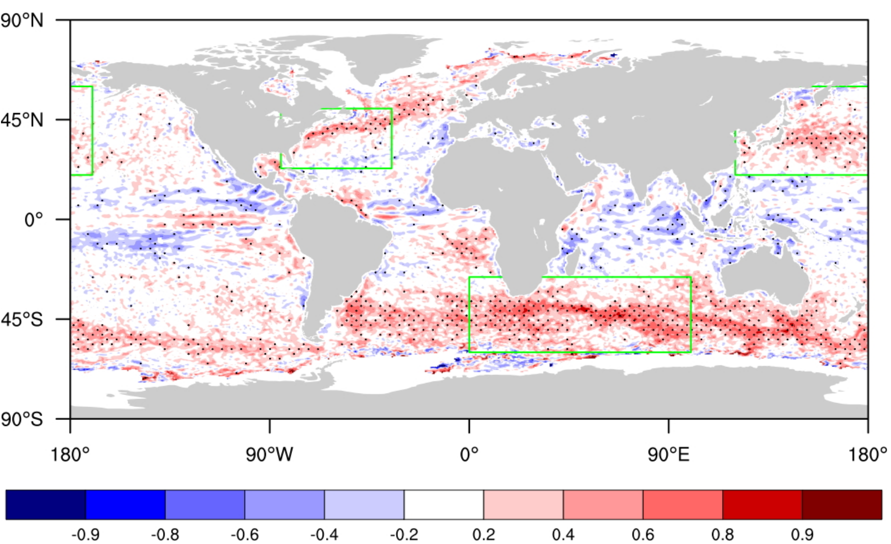
Correlation High-Pass SST w/ $|\mathbf{U}_{srf}|$



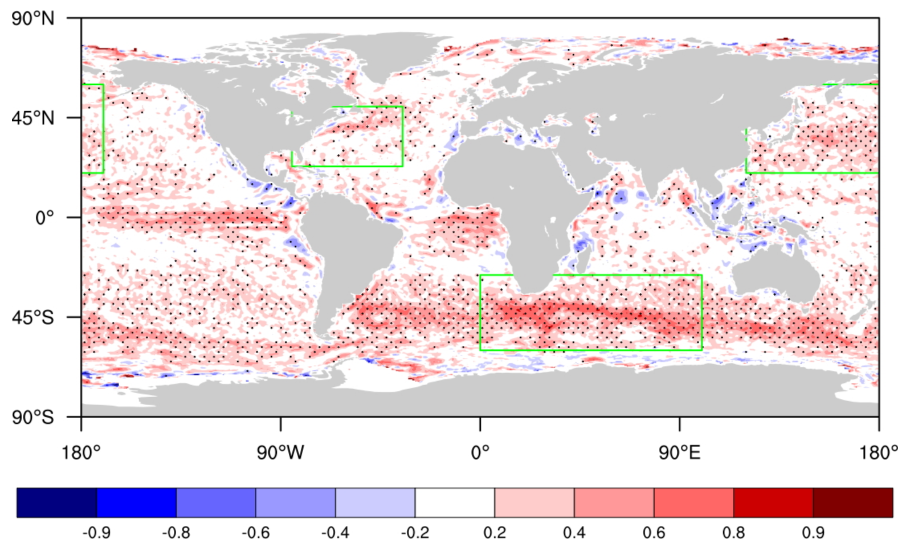
OBS: QuikSCAT + AMSR



CCSM 0.5° atm / 1° ocn



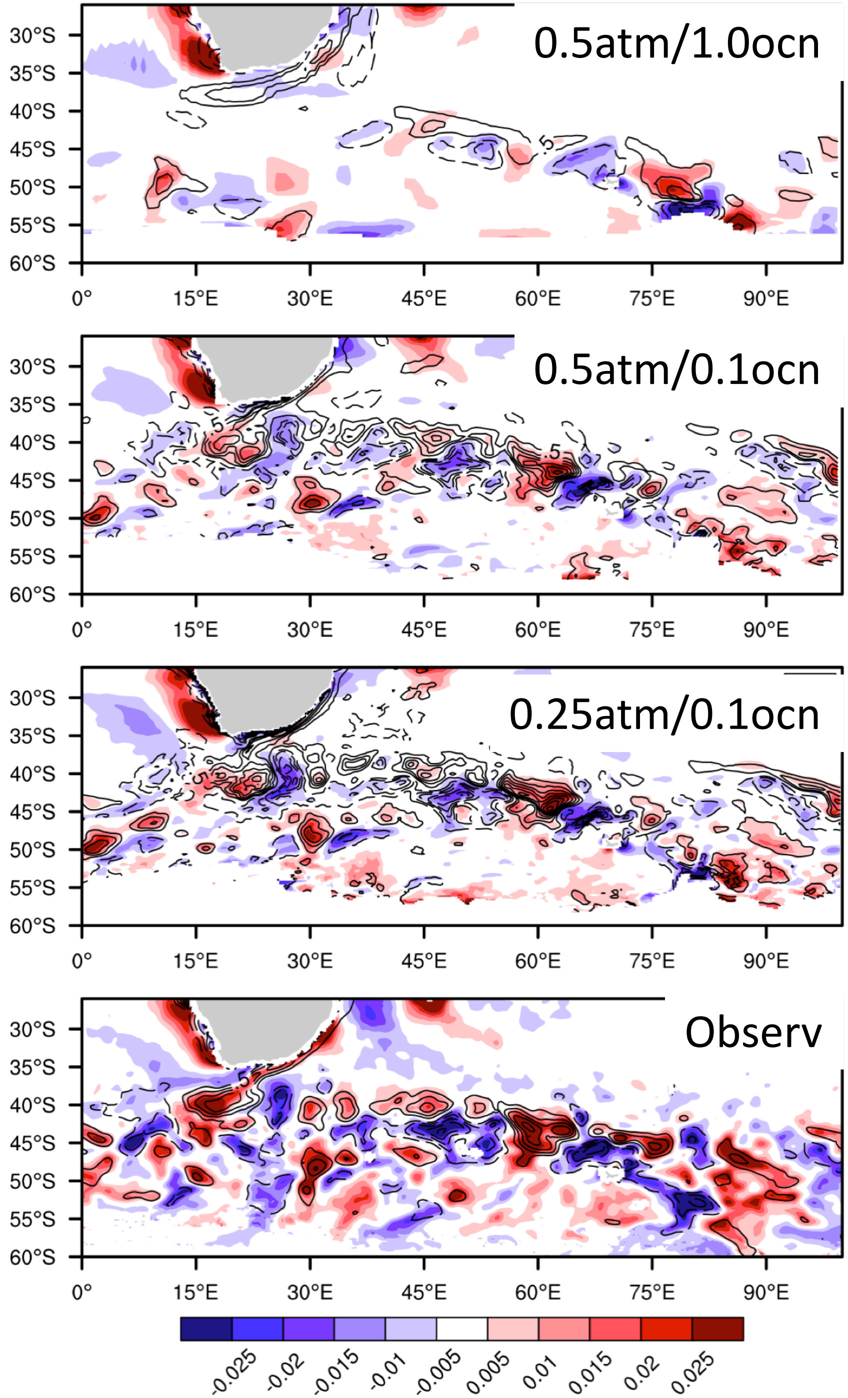
CCSM 0.5° atm / 0.1° ocn

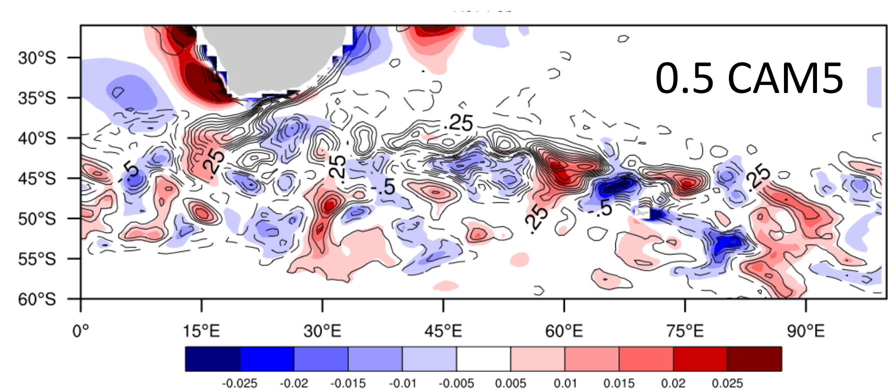


CAM5 0.5° w/ 0.25° Observ. SST

NDJF Climatalogical Mean Wind Stress (color) Vs. High-Pass SST(contour)

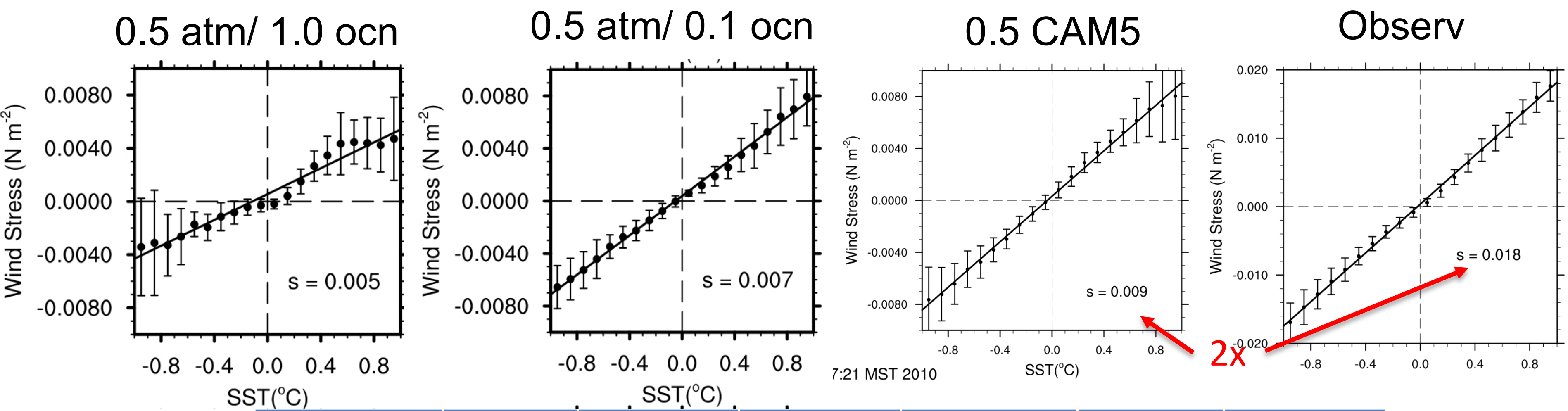
10° x6°





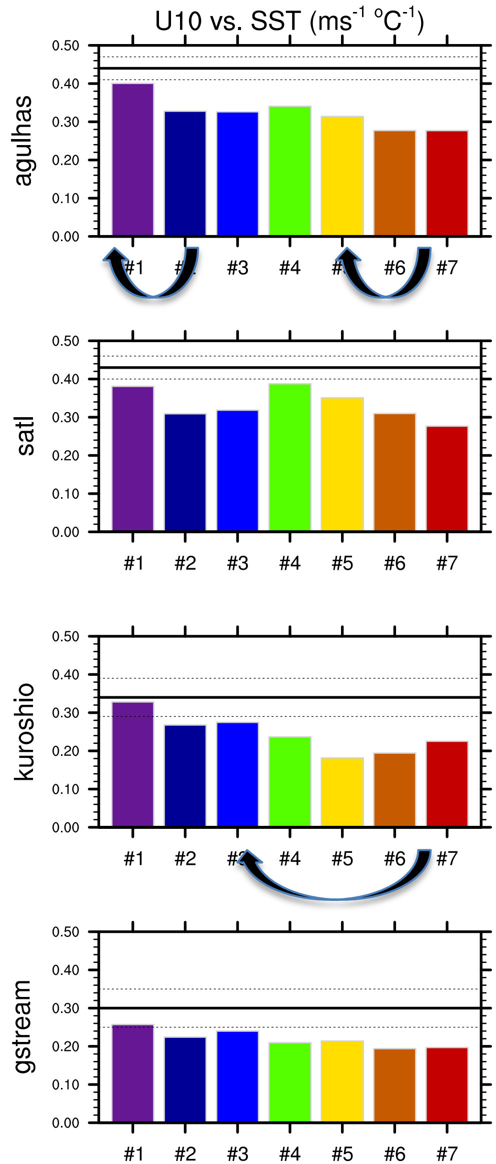
Bryan et al (2010)

Regional SST vs Stress Regressions



	Region	0.5A/1.0O	0.5A/0.1O	0.25A/0.1O	0.5A CAM5	QS/AMSR
|τ| vs. SST	KE	0.007	0.008	0.006	0.007	0.010
	ARC	0.005	0.007	0.008	0.009	0.018
	GS	0.006	0.004	0.005	0.005	0.009
div(τ) vs Downwind grad(SST)	KE	-0.16	0.83	0.75	0.84	0.64
	ARC	1.02	1.03	0.99	1.08	1.62
	GS	0.39	0.60	0.50	0.61	0.62
curl(τ) vs Crosswind grad(SST)	KE	-0.51	0.50	0.53	0.64	0.42
	ARC	0.75	0.82	0.84	0.77	1.33
	GS	-0.37	0.29	0.33	0.37	0.38

Resolution Dependence of Wind-SST Coupling Coefficient



Experiments w/ CAM5

#1) 0.25 deg daily SST, ne120 atm, 61 levels
#2) 0.25 deg daily SST, ne120 atm, 30 levels
#3) 0.25 deg daily SST, ne30 atm, 30 levels
#4) 1 deg monthly climo SST, ne30 atm, 61 levels
#5) 1 deg monthly climo SST, ne30 atm, 31 levels
#6) 1 deg monthly climo SST, ne30 atm, 30 levels
#7) 1 deg monthly climo SST, ne30 atm, 30 levels

- Stronger Dependence
  - Atm. VERT. Res. (#1 vs #2 or #5 vs #6)
  - HORIZ. Res. of SST (#3 vs #6)
- Weaker Dependence
  - Atm HORIZ. Res. (1° vs. 0.25°) (#2 vs. #3)

Provided by R. Tomas

Tropospheric Response along 40°

θ

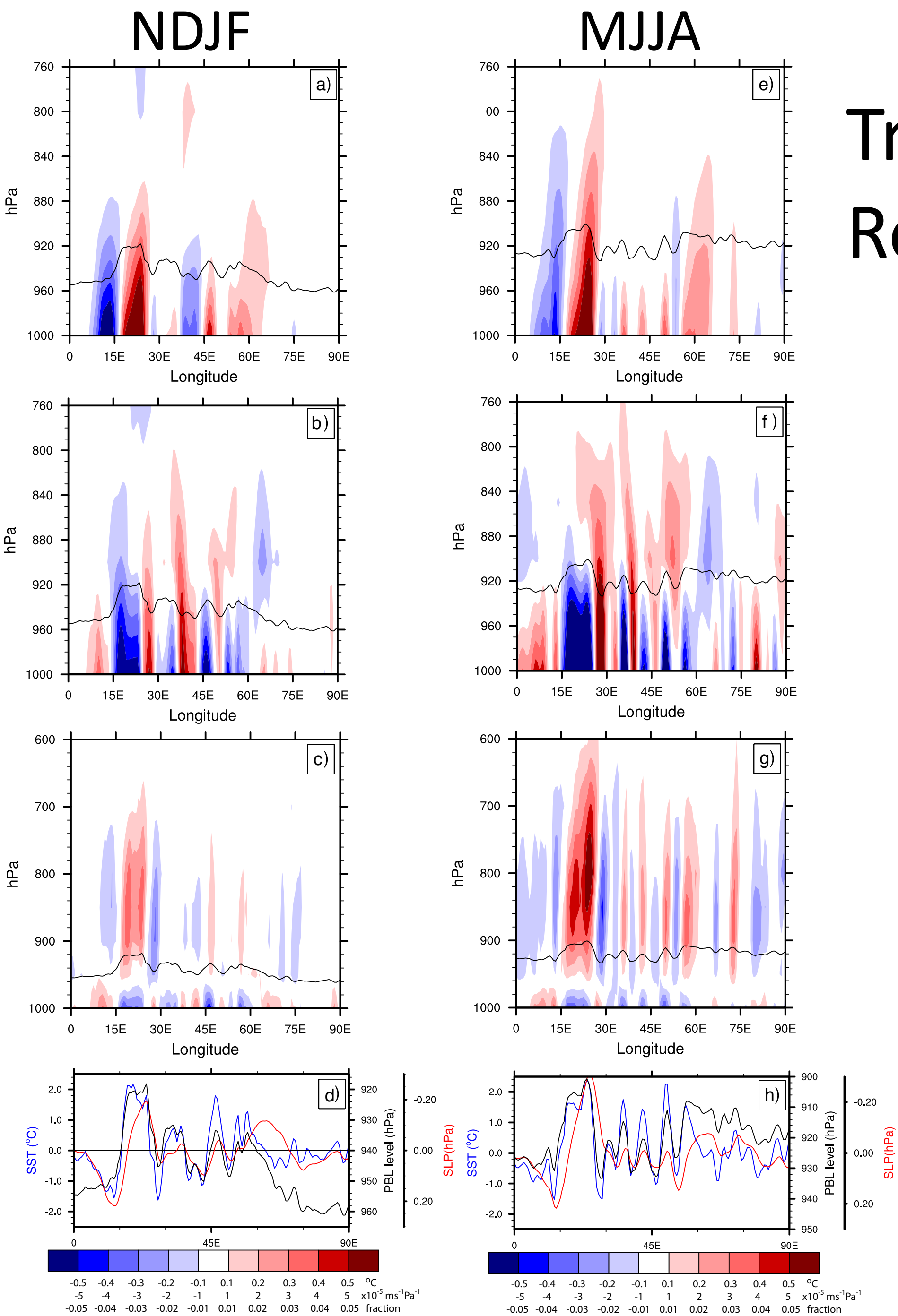
$-\frac{\partial u}{\partial p}$

Cld Frac

SST

SLP

H_{BL}



Pressure Adjustment Mechanism

Lindzen and Nigam (1987) Minobe, Takatama (2008,2010)

- For linearized momentum balance in PBL:

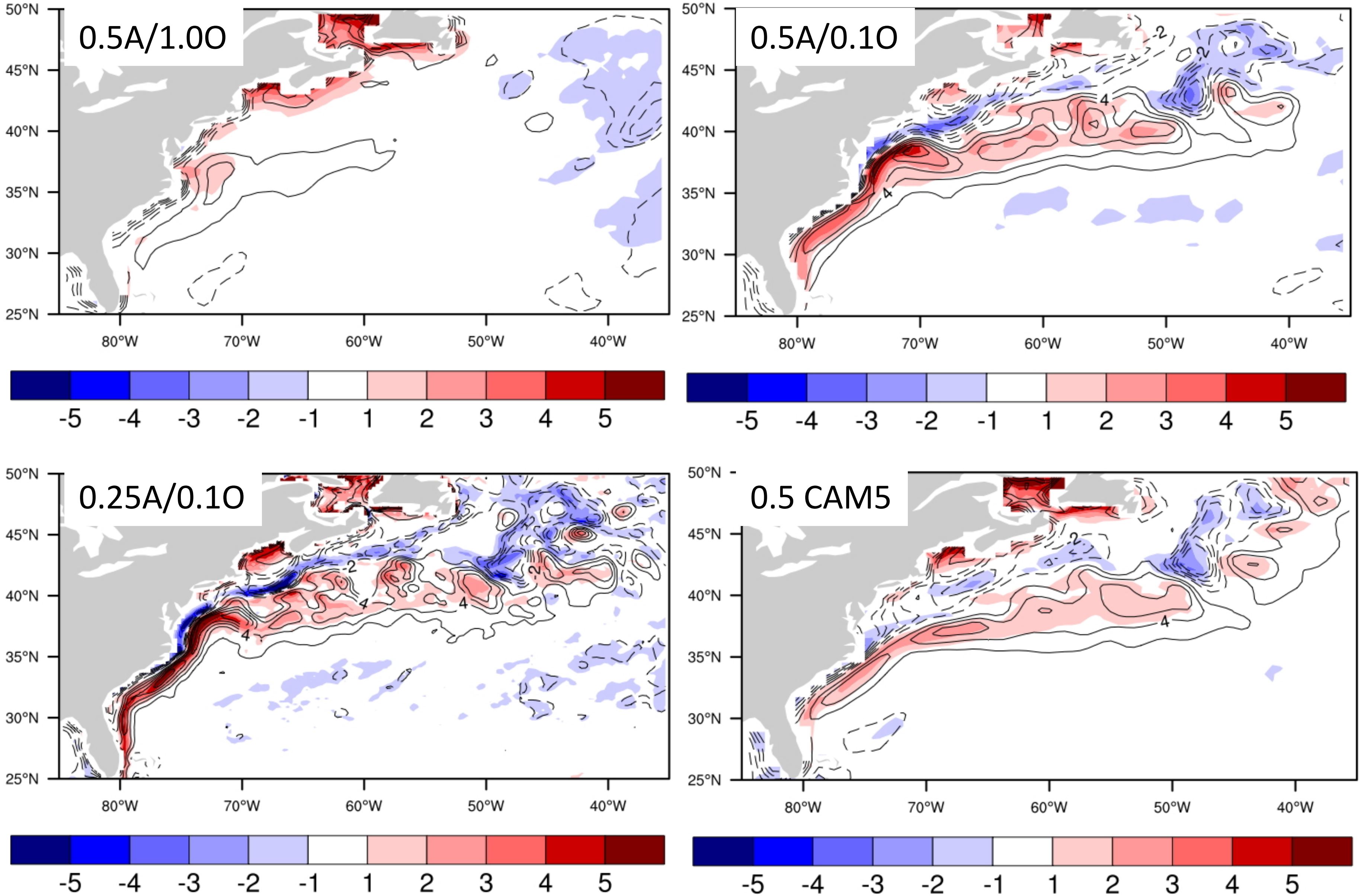
$$-fV = -\frac{\partial P}{\partial x} - \varepsilon U$$

$$fU = -\frac{\partial P}{\partial y} - \varepsilon V$$

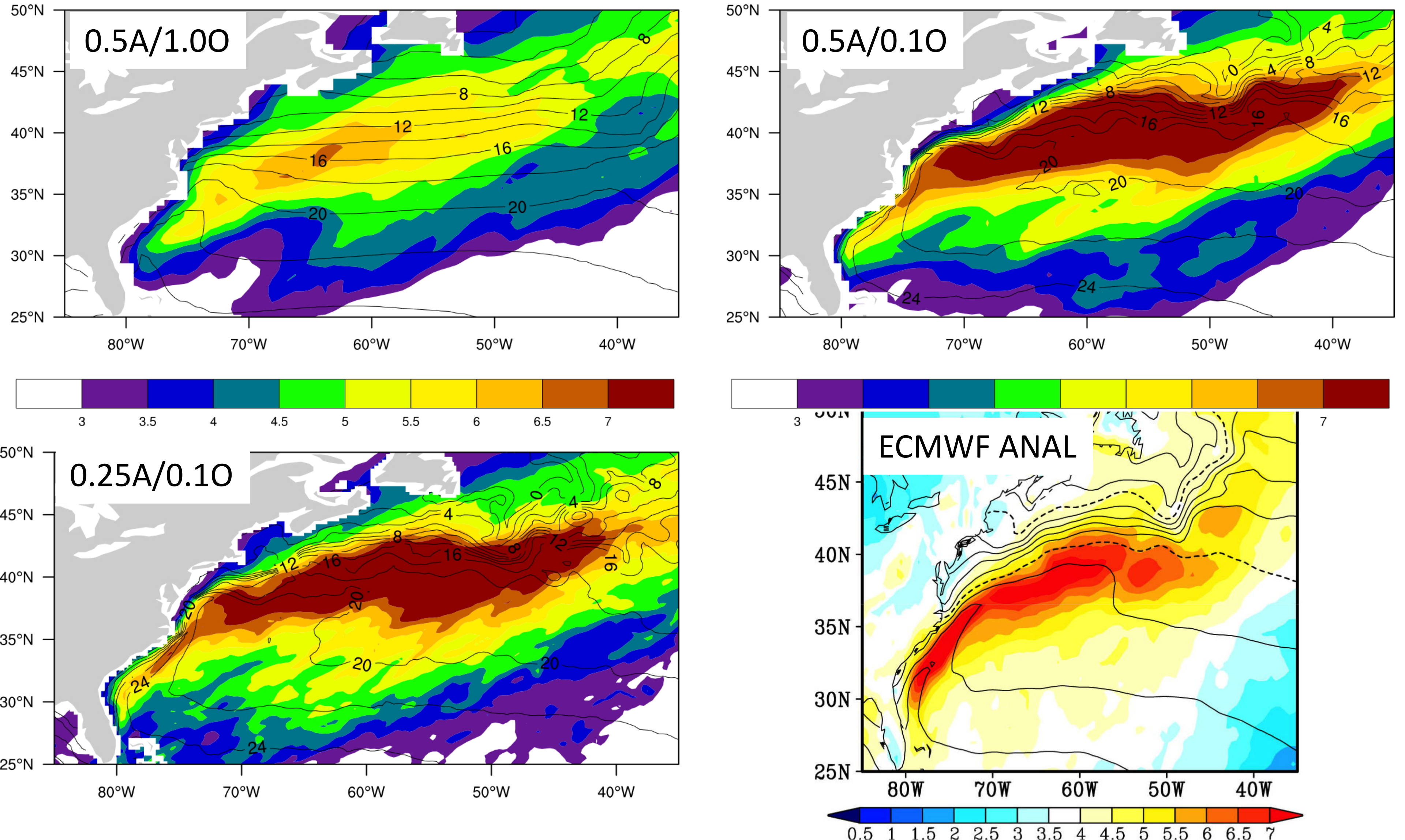
- Convergence ~ Laplacian pressure

$$-\nabla \bullet \vec{U} \approx \frac{\varepsilon}{\varepsilon^2 + f^2} \nabla^2 P$$

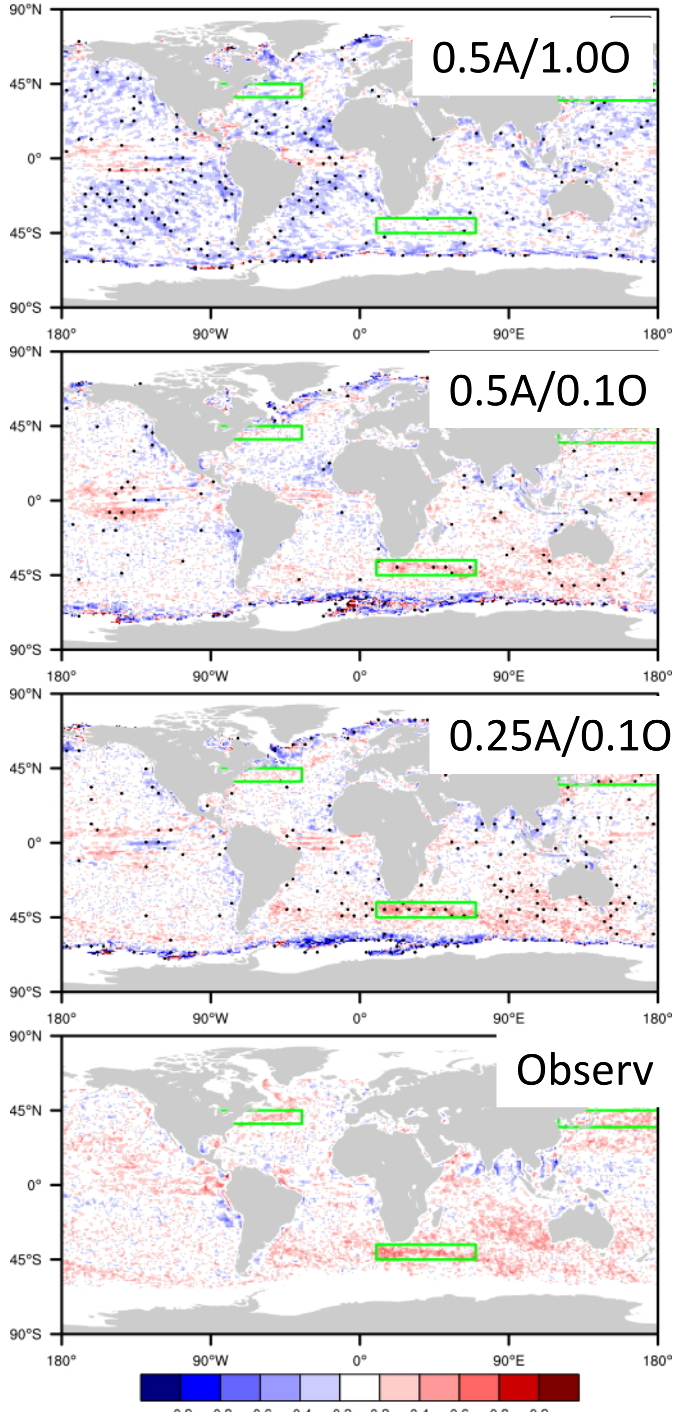
Winter Mean
Laplacian Pressure (color) vs. Convergence (contours)

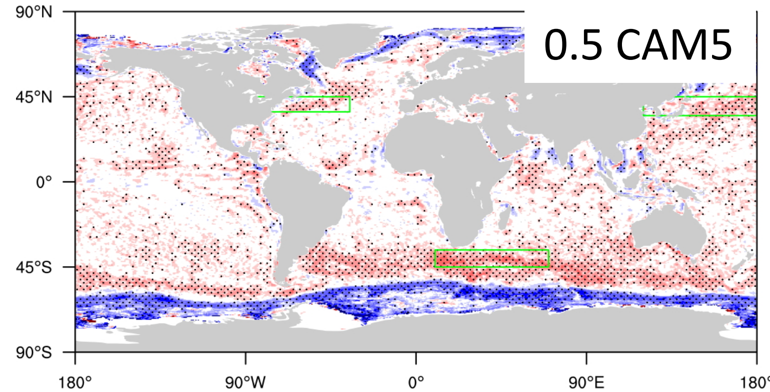


Winter Mean Precipitation

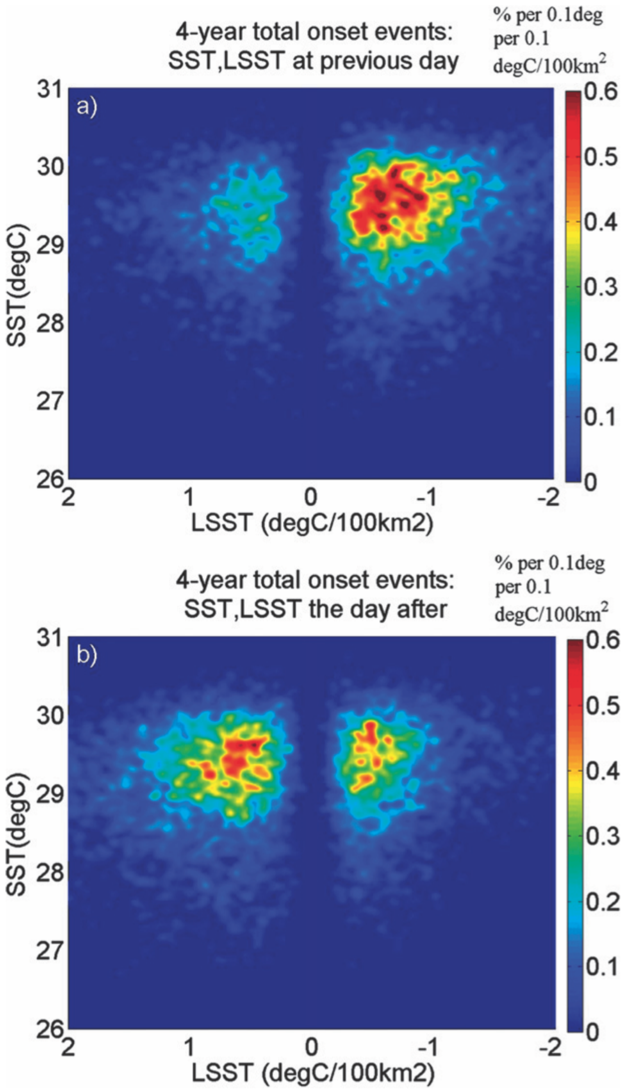


Planetary Scale Impact on Energy Balance: Correlation High-Pass SST vs. All Sky Albedo



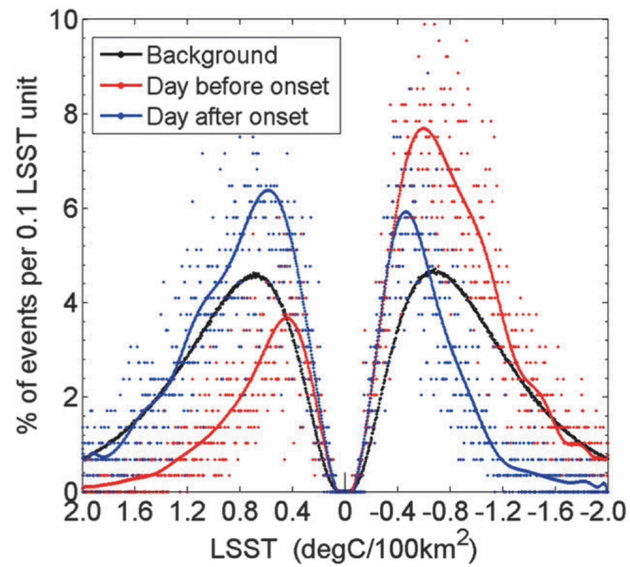


Association of Convective Initiation & ∇^2SST



Convective initiation within western Pacific warm pool favored over convergence favorable ($\nabla^2 SST < 0$) on scales O(100km)

Approx 75% of observed events



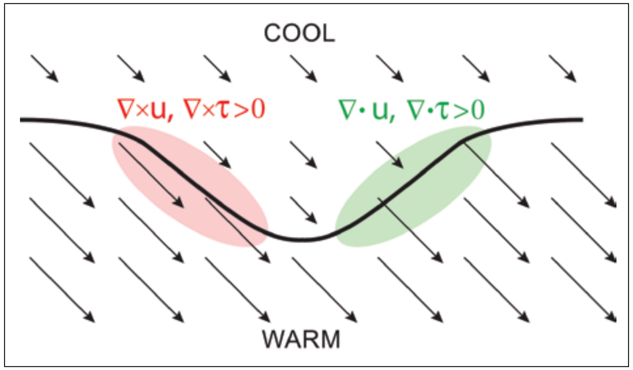
Li and Carbone (2012)

Oceanic Feedbacks

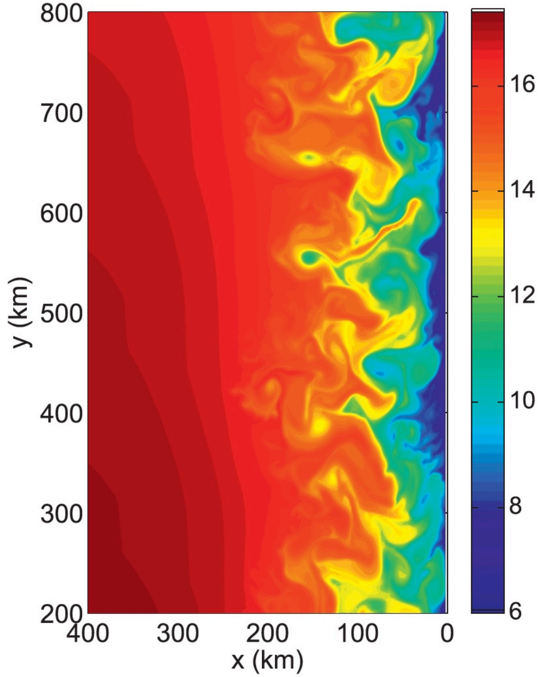
Jin et al (2009) JPO

$$\nabla\times\tau' \propto \nabla SST \times \frac{\tau}{|\tau|}$$

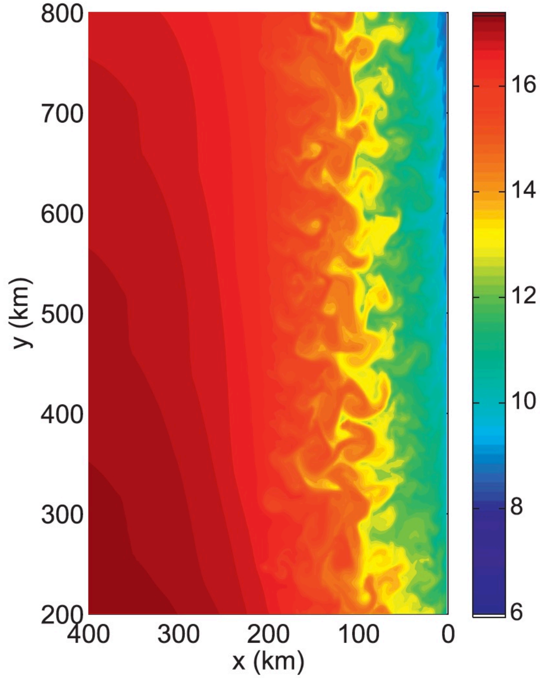
$$\nabla\cdot\tau' \propto \nabla SST \cdot \frac{\tau}{|\tau|}$$

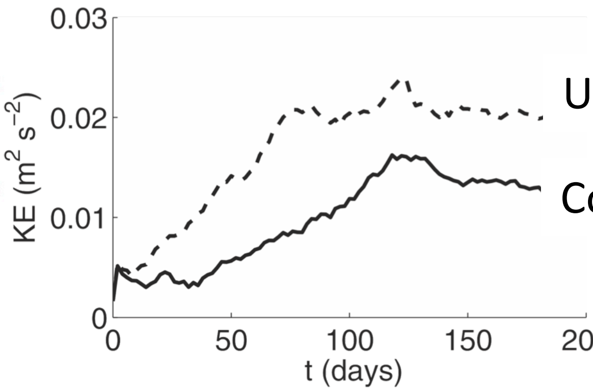


Uncoupled



Coupled





Ucoupled

Coupled

- Strong observational and computational evidence for role of intrinsic ocean variability as an important source of variability in air-sea interaction at scales below about 1000km
- Conventional climate models are missing this source of variability because they lack intrinsic variability in SST on these scales
- Higher resolution models capture these processes qualitatively, but underestimate the strength of the coupling
- A variety of mechanisms are invoked, all invoking some form of baroclinic modification of the marine atmospheric PBL
- Does it matter?
  - Depends on your question
  - At the least it provides an integral measure of the fidelity of PBL representation in GCMs (coupling coefficients)
  - Can be significant (though probably < first order) effect locally