Prospects for High-Resolution to Improve Small-Scale Ocean Processes and Ocean-Atmosphere Interactions

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Contributions From

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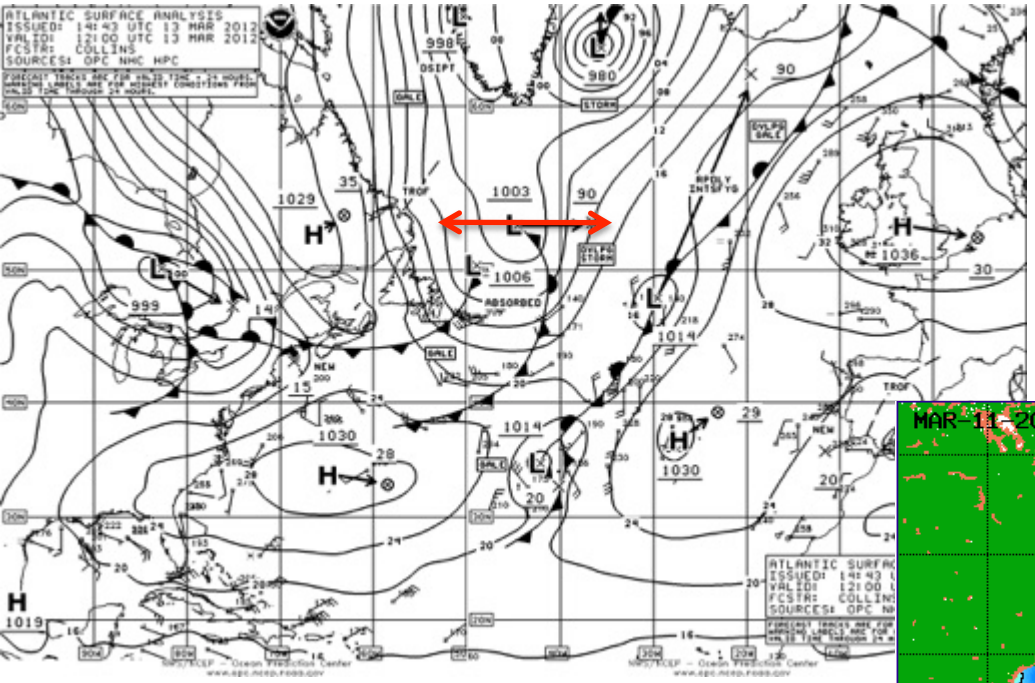
Outline

- What constitutes a “high-resolution” ocean model?
- Small-scale features/processes newly resolved
  - SST coupling with low-level winds
  - Intrinsic variability in upper ocean heat content & surface fluxes
- Interactions small-scale/large-scale
  - Modulation of the N. Pacific storm track
  - Initiation of tropical convection
  - Sea ice polynas and water mass formation
- Large-scale features: bias reduction/amplification
  - Eastern boundary current SST biases

Resolving The Synoptic Scale: Atmosphere vs. Ocean

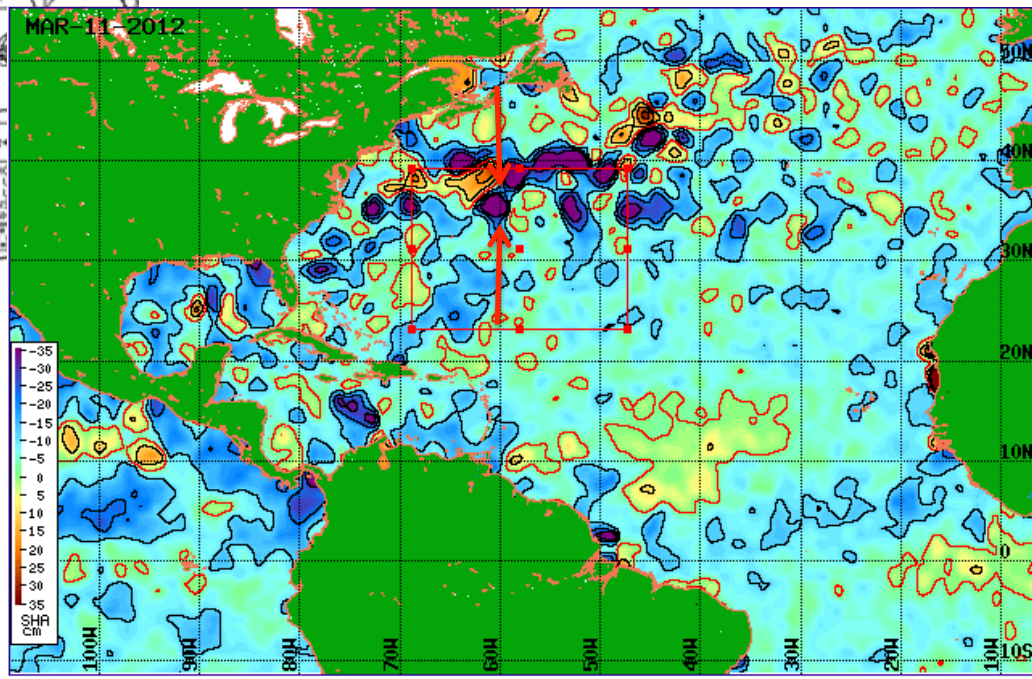
Mean Sea Level Pressure: O(1000 km)



Troposphere

$$R_1 = \frac{NH}{f} \approx \frac{(10^{-2}\,s^{-1})(10\,km)}{10^{-4}\,s^{-1}} = 1000\,km$$

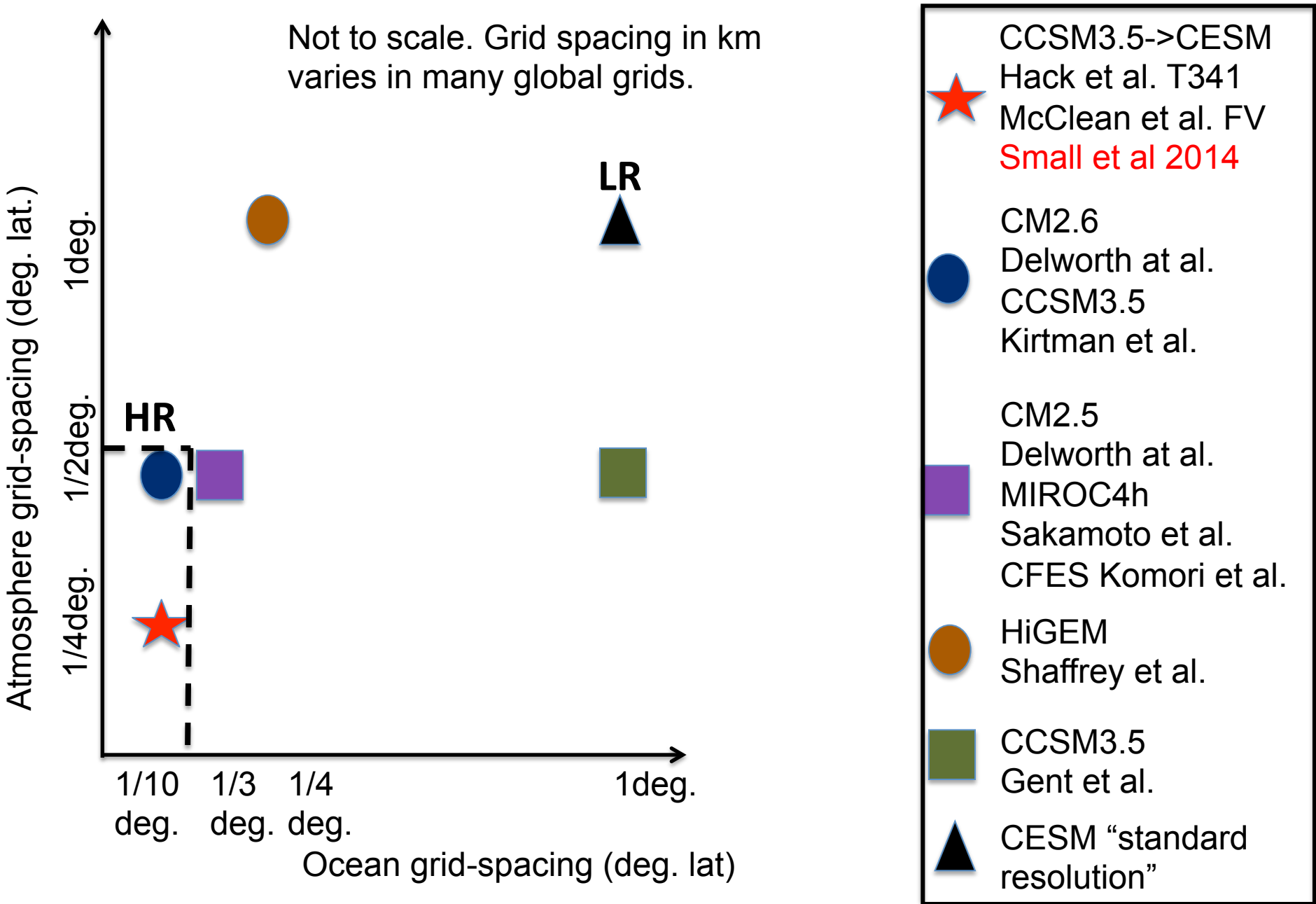
Sea Surface Height Anomaly: O(100 km)



Open Ocean

$$R_1 = \frac{NH}{f} \approx \frac{(10^{-3}\,s^{-1})(4\,km)}{10^{-4}\,s^{-1}} = 40\,km$$

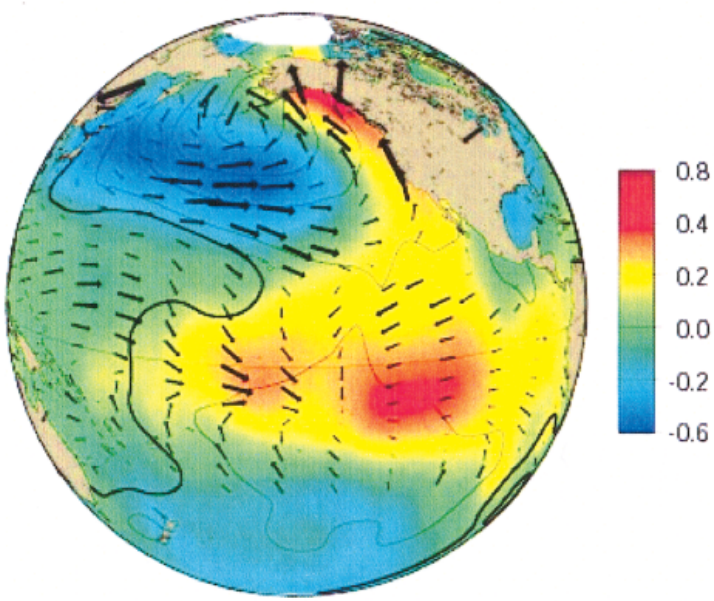
Scales of high-res global simulations



1. Response of Low-level Winds to SST

Basin Scale
(-ve Corr.)

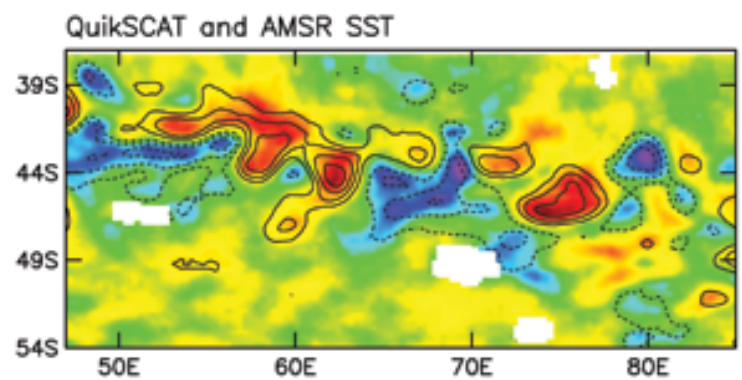
High Winds ➔
High latent and sensible heat flux, entrainment➔
Cool SST



Mantua (1998)

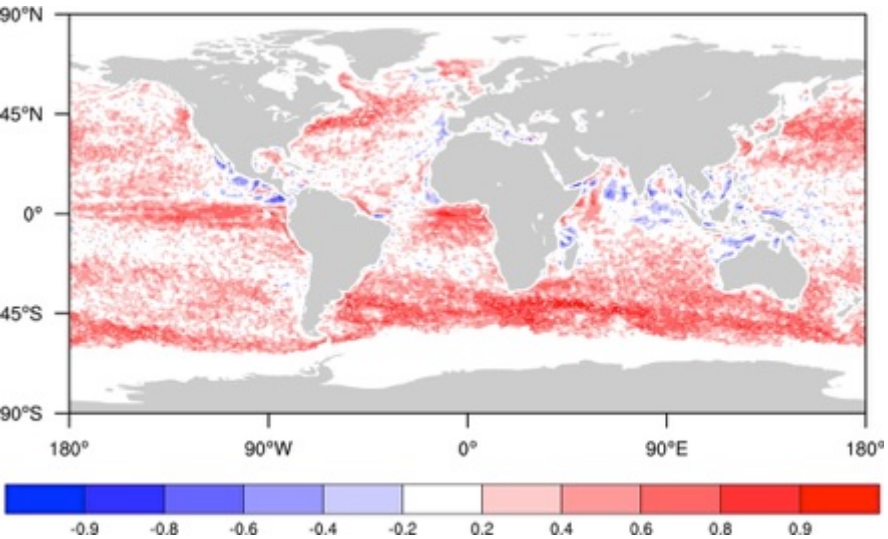
Frontal Scale
(+vs Corr.)

High SST➔
High Winds

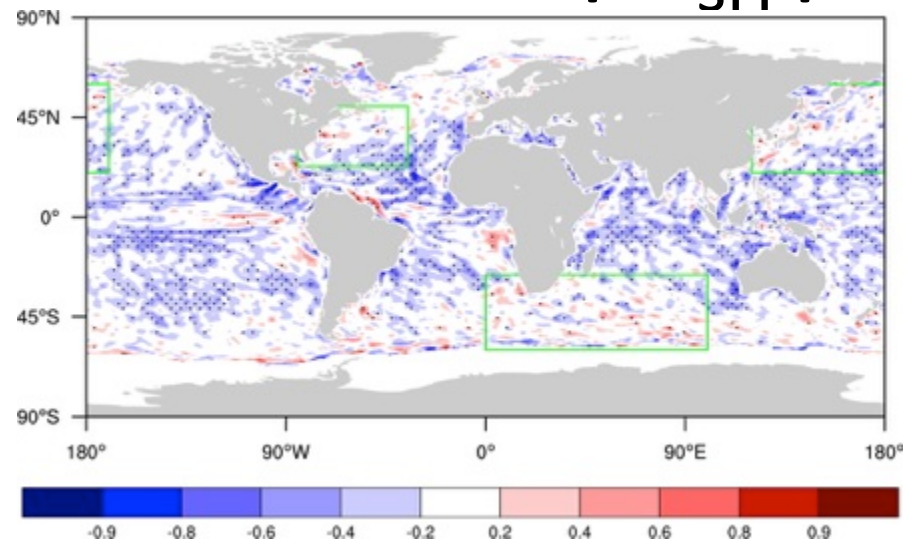


Chelton and Xie (2010)

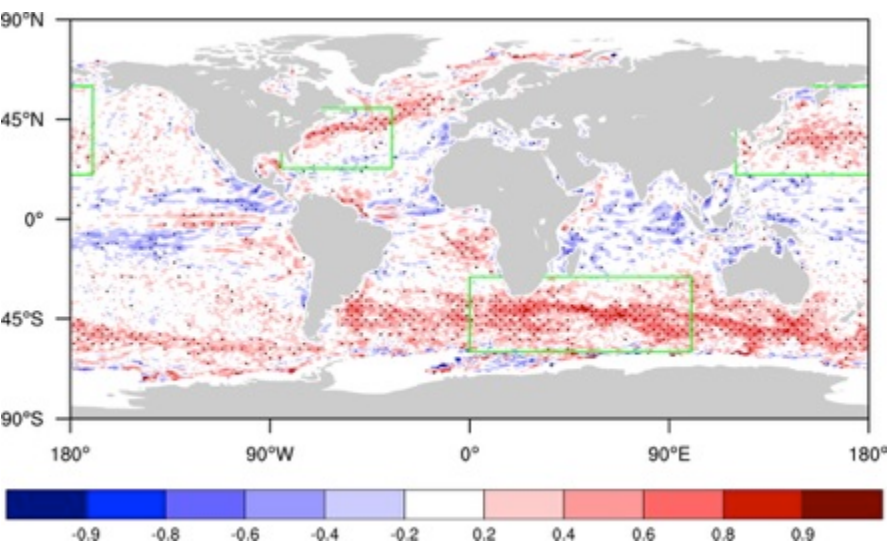
Correlation High-Pass SST w/ $|\mathbf{U}_{srf}|$



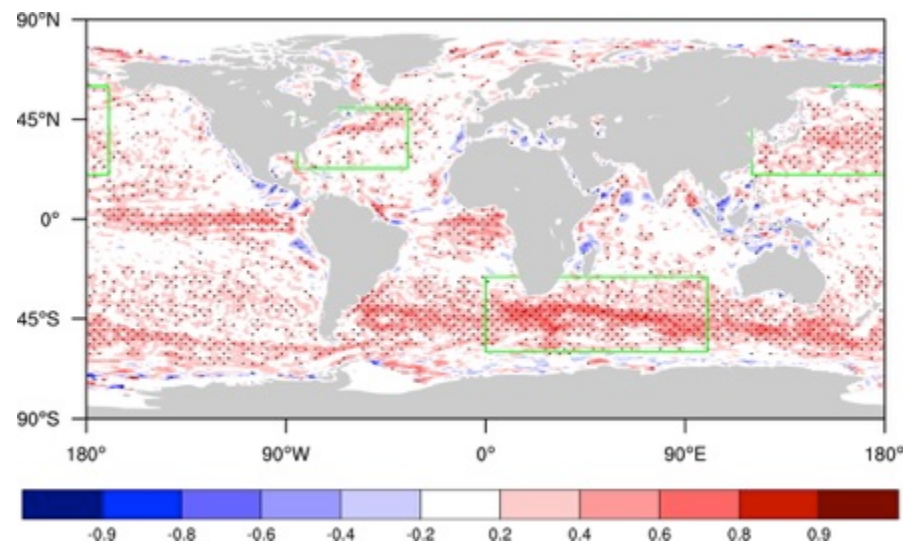
QuickScat + AMSR



CCSM 0.5° atm / 1° ocn

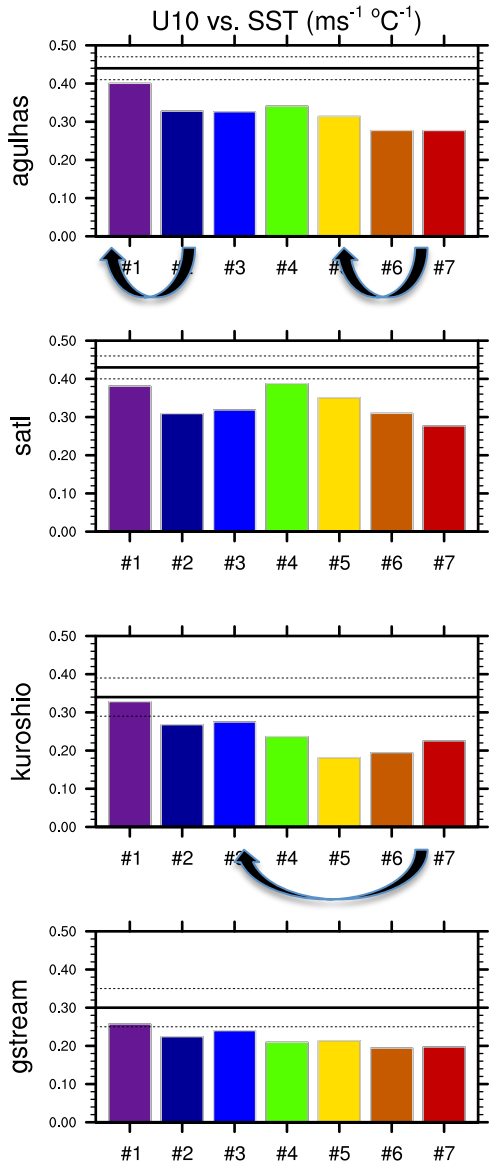


CCSM 0.5° atm / 0.1° ocn



CAM5 0.5° w/ 0.25° Observ. SST

Resolution Dependence of Wind-SST Coupling Coefficient



Experiments w/ CAM5

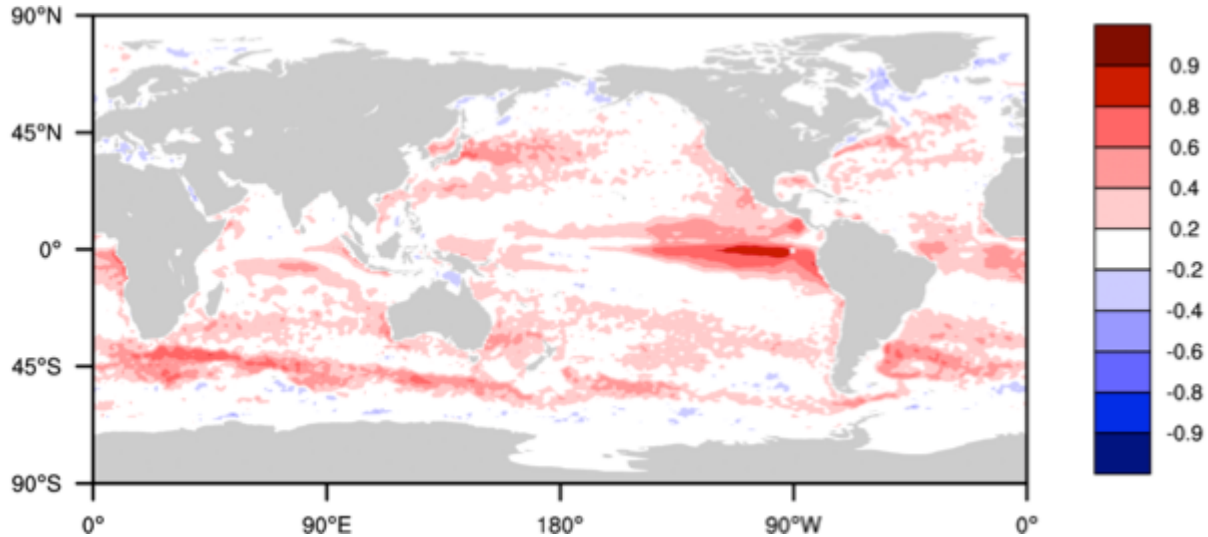
#1) 0.25 deg daily SST, ne120 atm, 61 levels
#2) 0.25 deg daily SST, ne120 atm, 30 levels
#3) 0.25 deg daily SST, ne30 atm, 30 levels
#4) 1 deg monthly climo SST, ne30 atm, 61 levels
#5) 1 deg monthly climo SST, ne30 atm, 31 levels
#6) 1 deg monthly climo SST, ne30 atm, 30 levels
#7) 1 deg monthly climo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

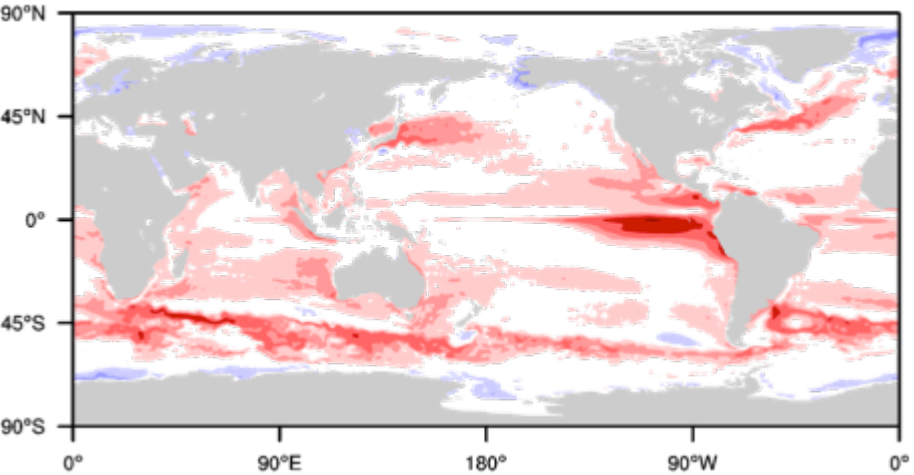
2. Coupled Variability in Surface Heat Fluxes

Correlation of Surface Turbulent Heat Flux and SSH

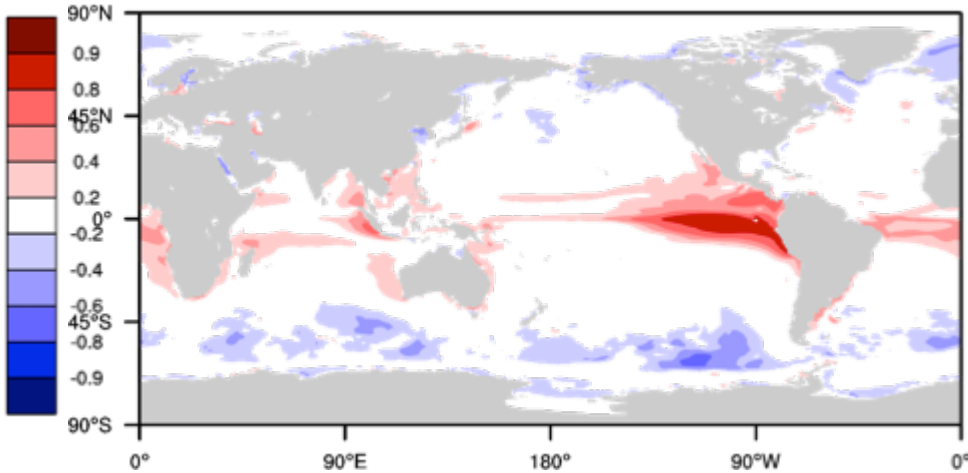


OBS (JOFURO+ AVISO)

HR Model



LR Model



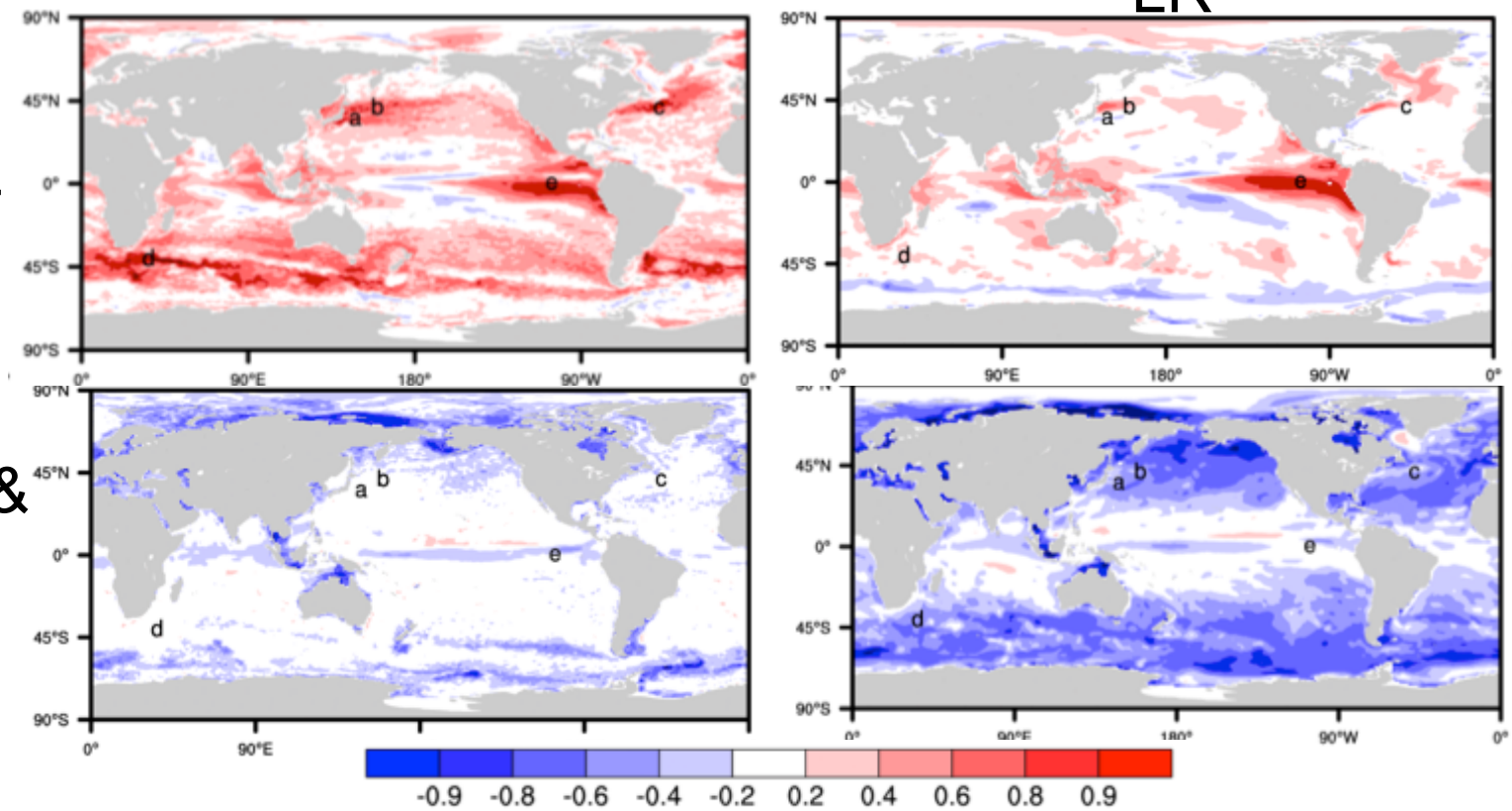
Correlations between HC & THF, d(HC)/dt & THF in Coupled Simulations

HR

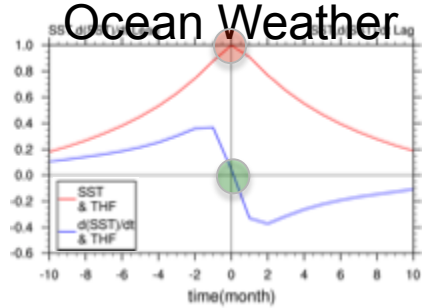
LR

HC & THF

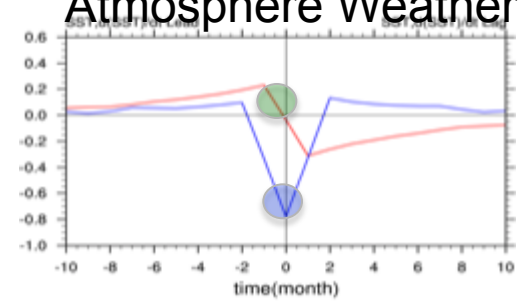
d(HC)/dt & THF



Ocean Weather



Atmosphere Weather



von Storch (2000)
Wu and Kirtman (2006)

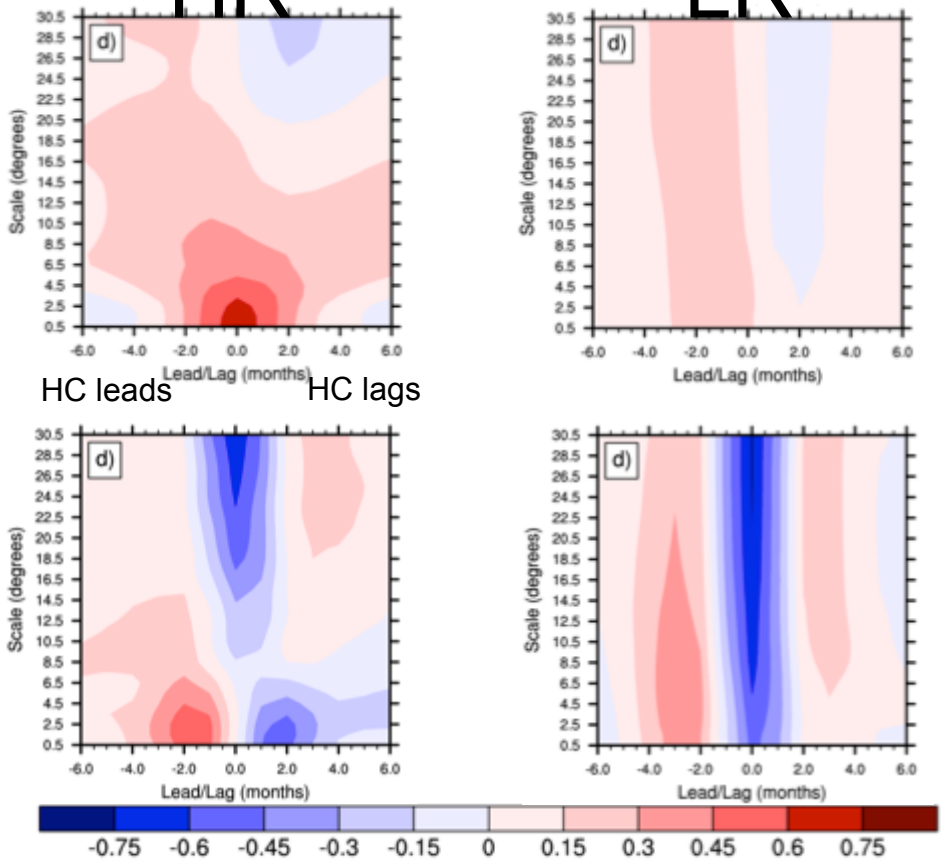
Scale Dependence of Lagged Correlation

HR LR

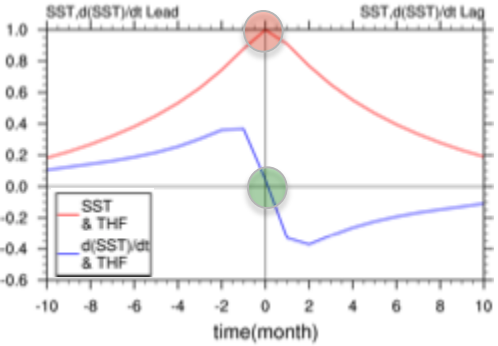
(Agulhas Region)

HC and THF

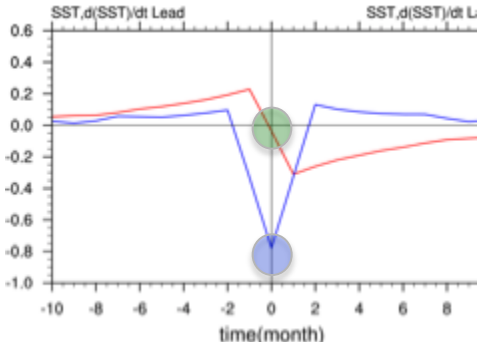
d(HC)/dt & THF



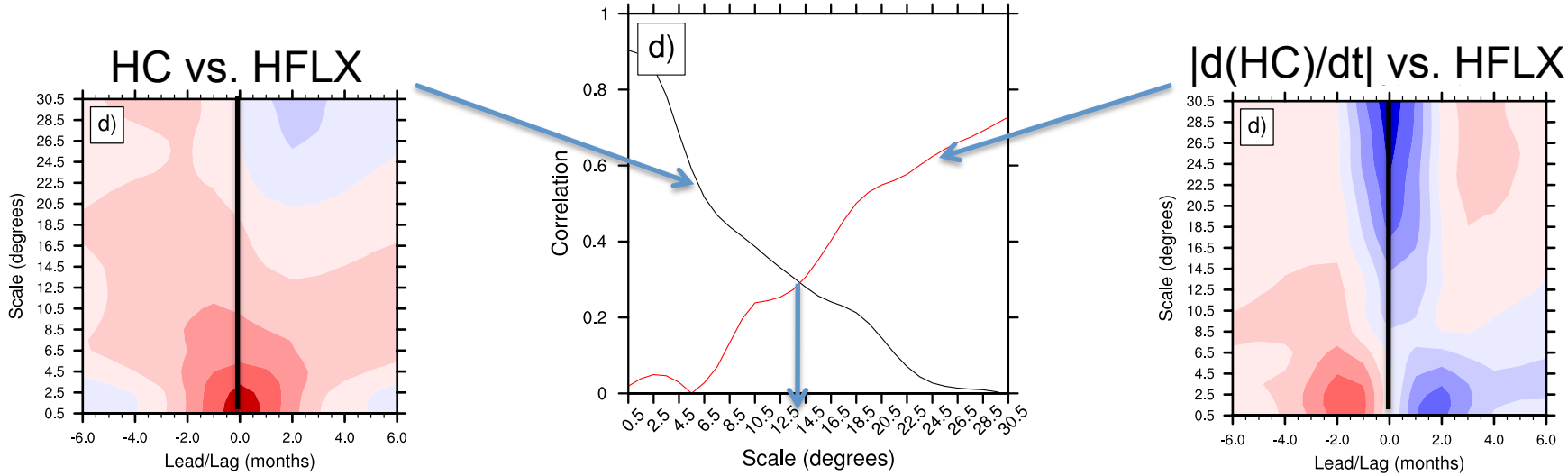
Ocean Weather

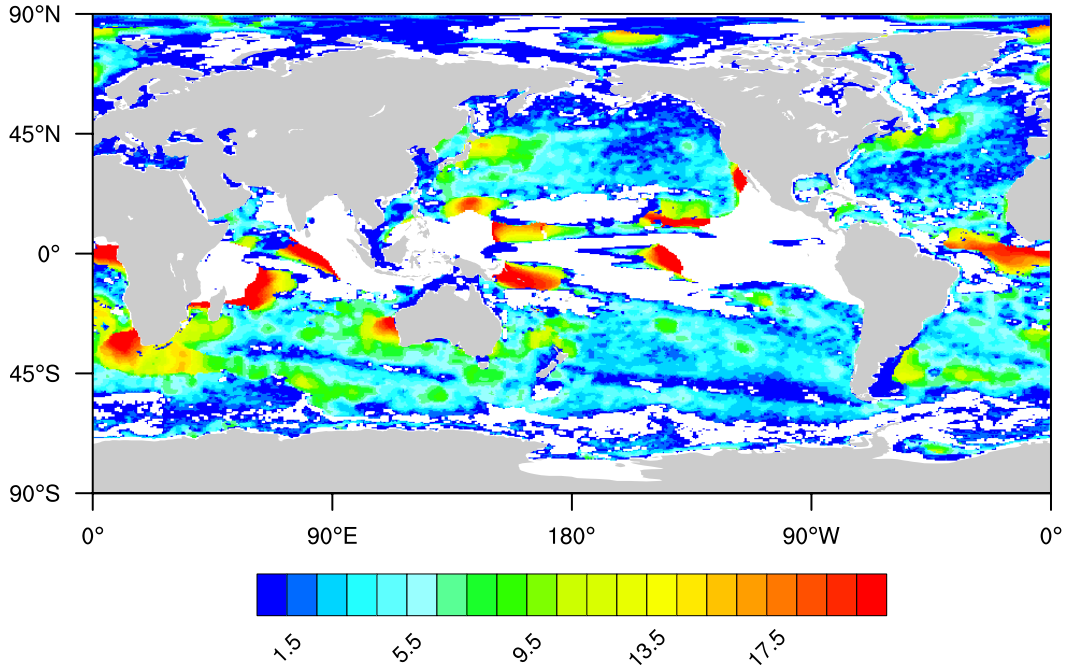


Atmosphere Weather



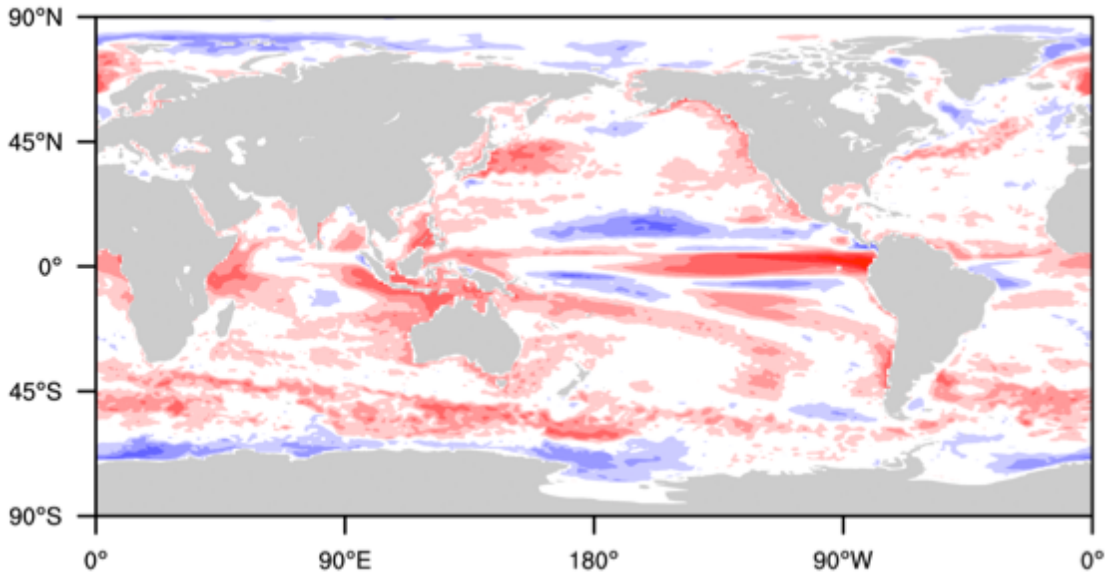
Transition Scale:
Ocean Dominance to Atmosphere Dominance



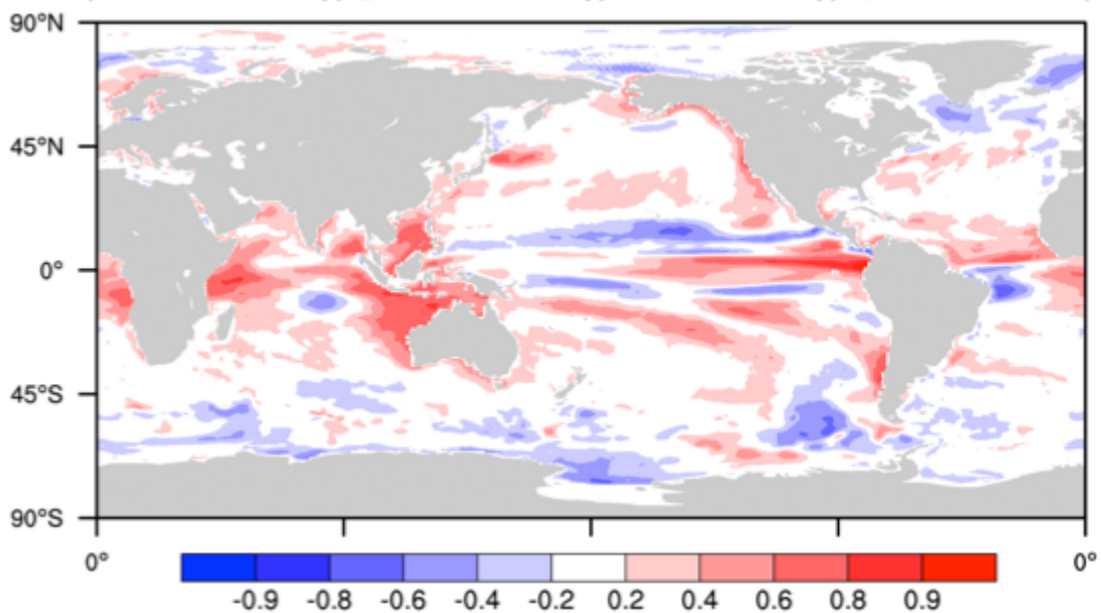


Does Intrinsic Ocean Variability Influence the Free Troposphere?

Correlation Annual SSH and Convective Precipitation



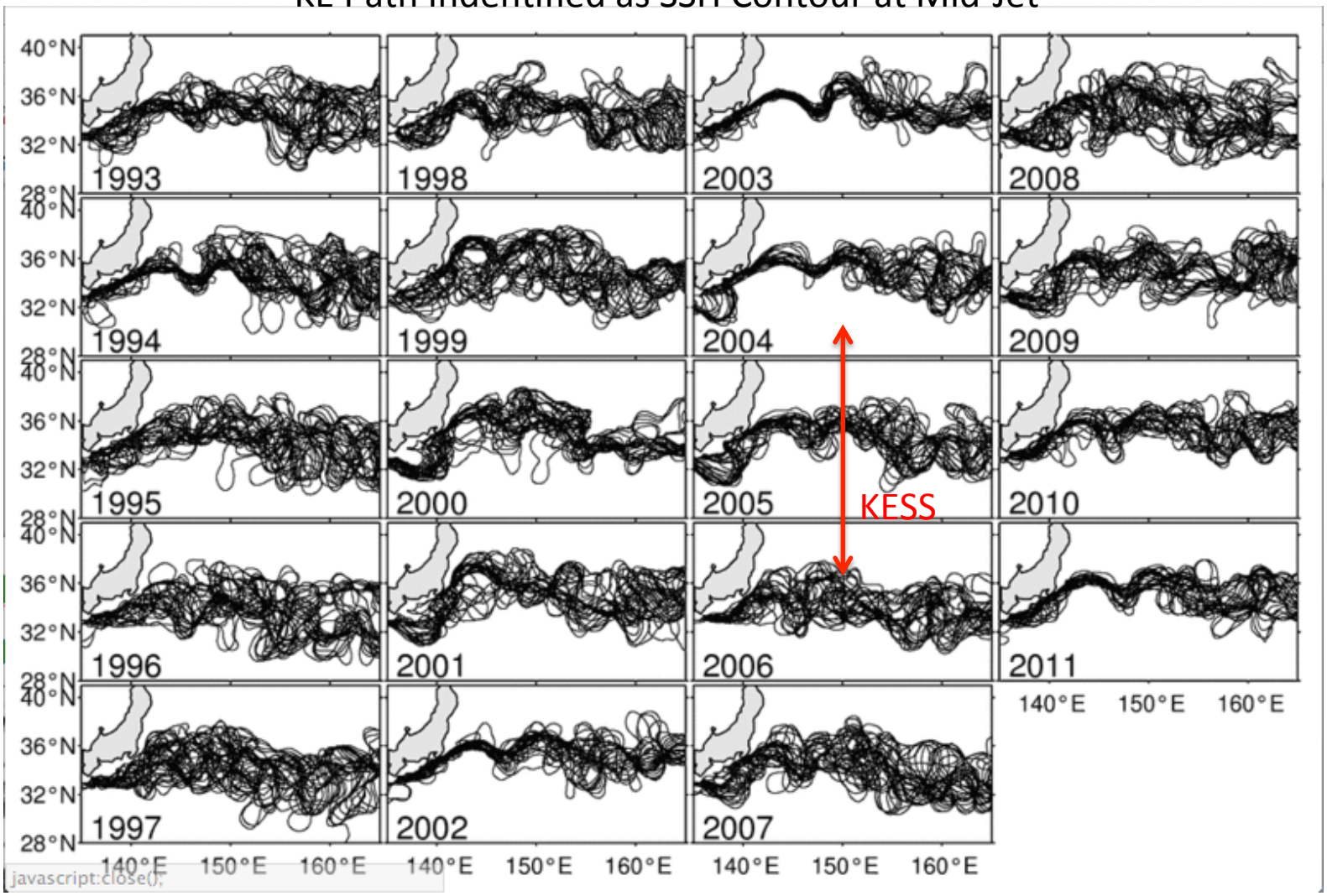
HR



LR

3. Decadal variability in the Kuroshio Extension

KE Path Indentified as SSH Contour at Mid-Jet

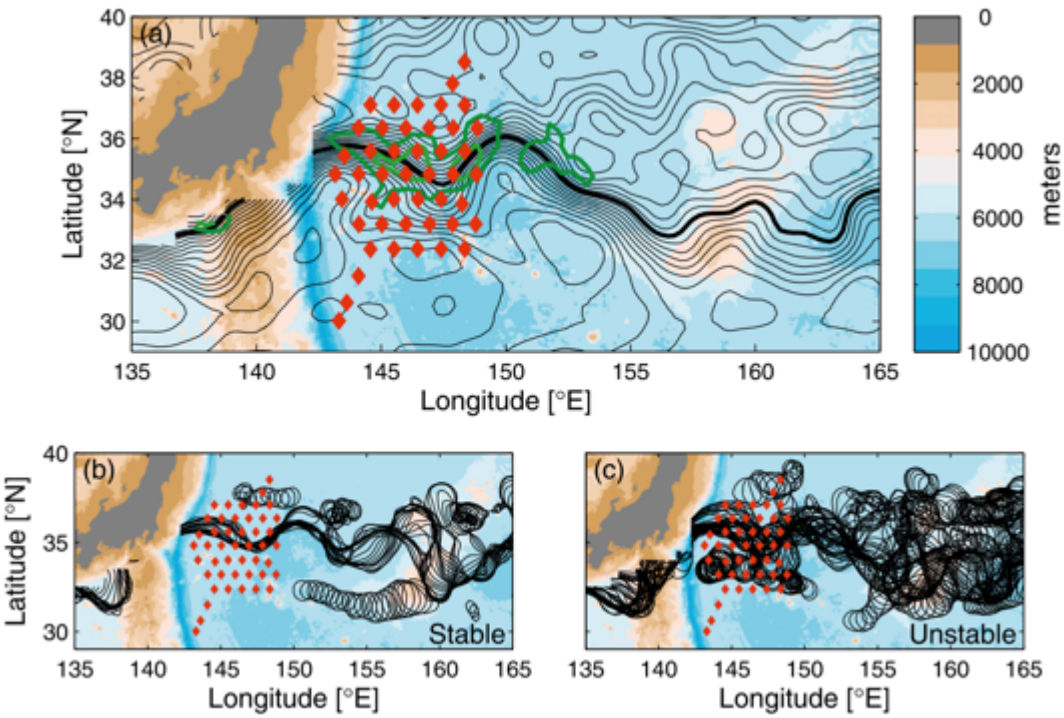


After Qiu and Chen (2005)

http://www.aviso.altimetry.fr/en/news/idm/2012/mar-2012-following-kuroshio-paths.html

Observed Changes in Northward Ocean Heat Transport Between Stable and Unstable KE Regimes

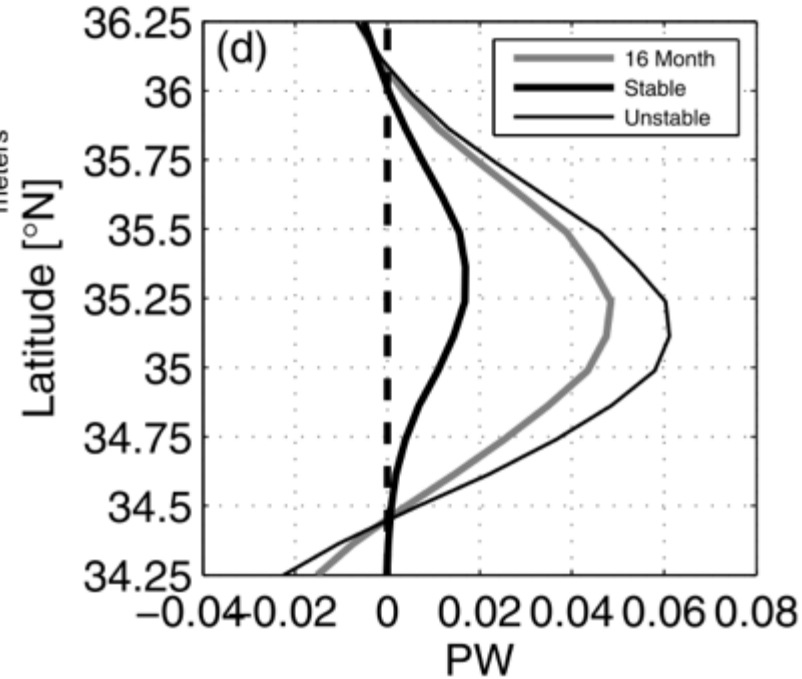
Mean SSH



Stable (2004-2005)

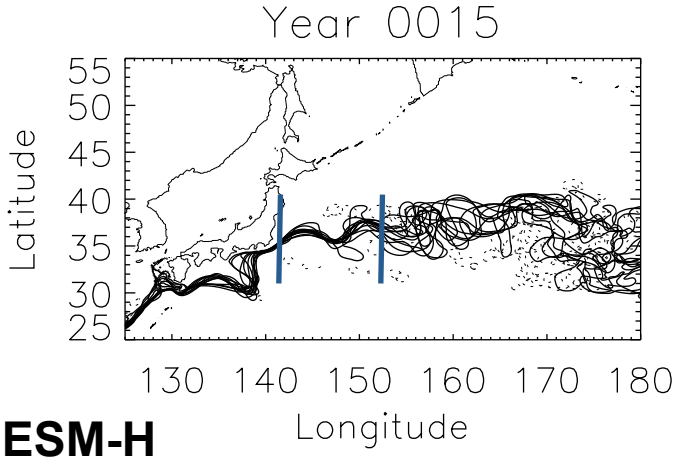
Unstable (2005-2006)

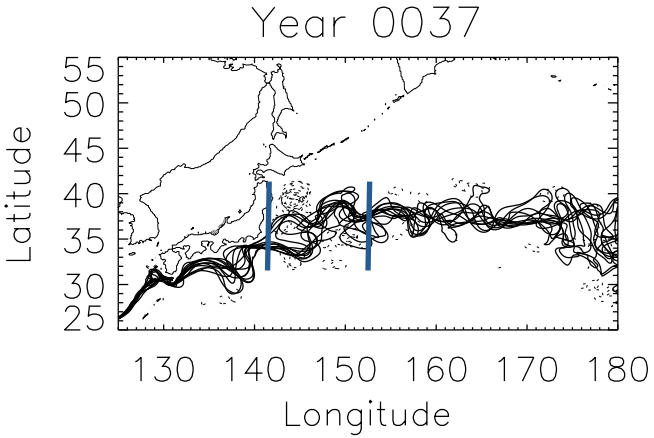
MHT



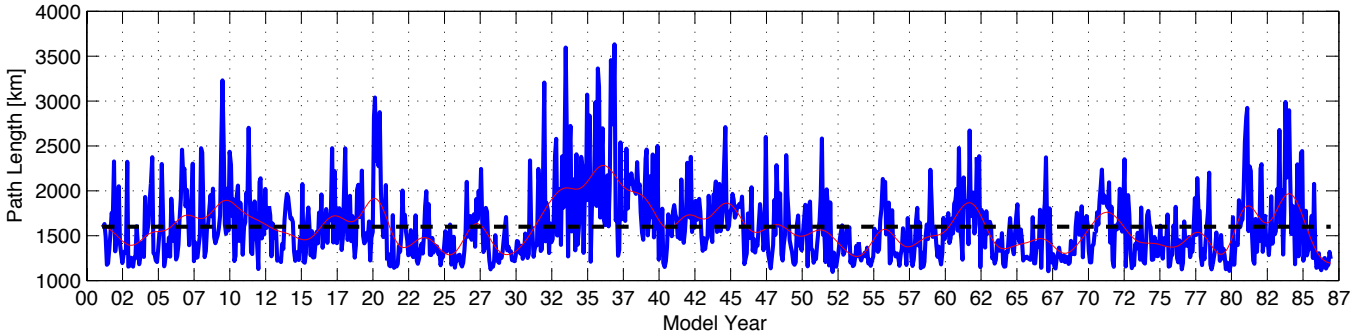
Bishop (2013) JPO

Simulated KE Path Length Variability

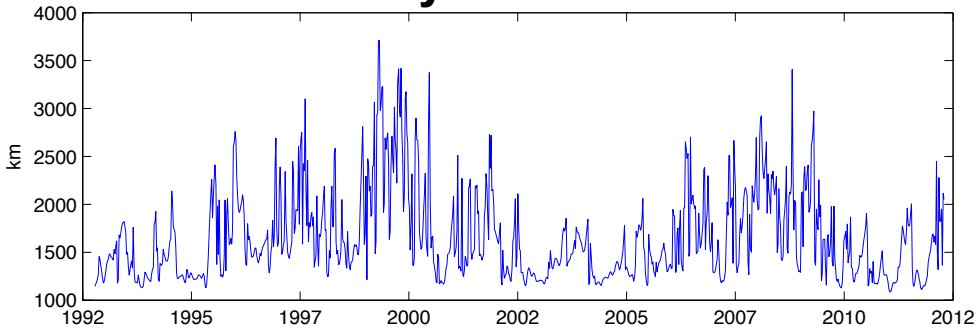




CESM-H



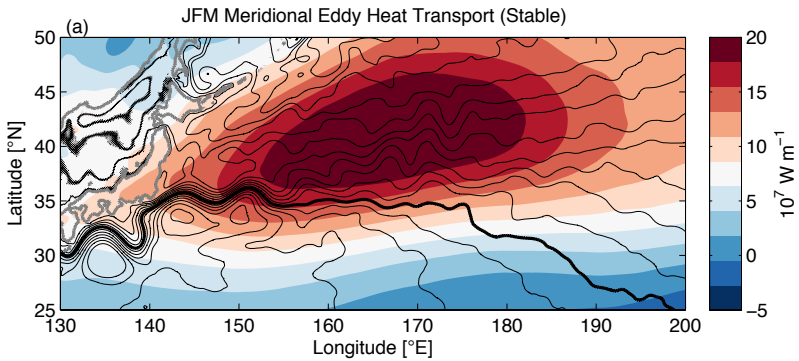
AVISO Altimetry Observations



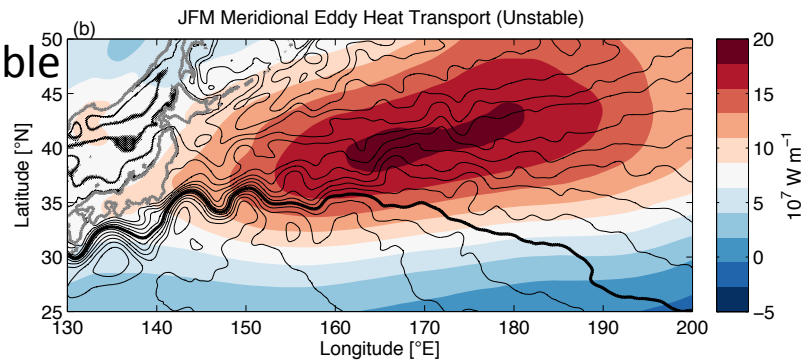
Bishop et al (2015)

Atmospheric Response: Poleward Heat Flux

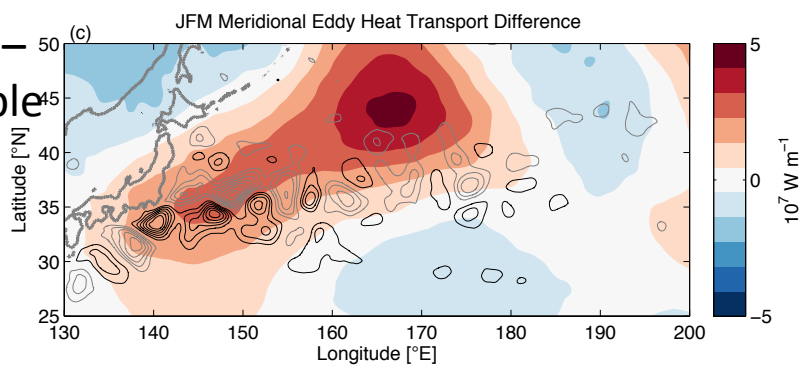
Stable



Unstable



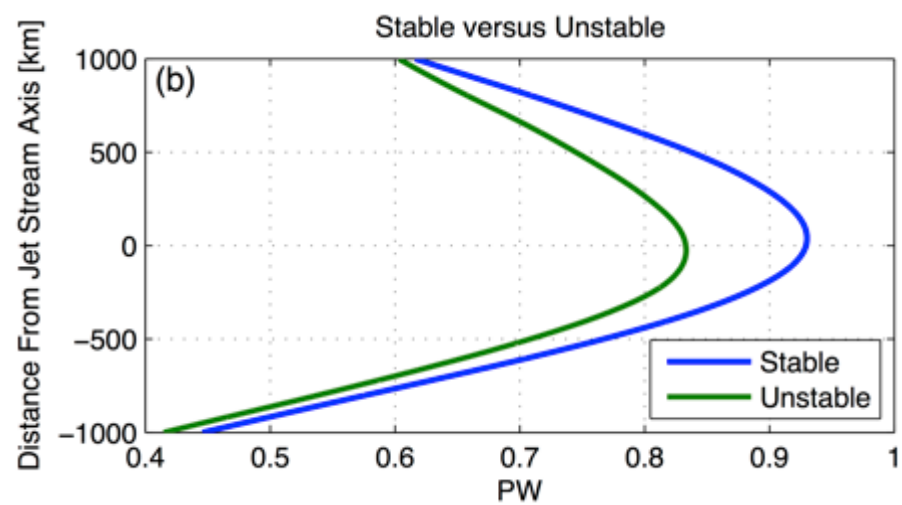
Stable – Unstable



Vertically-Integrated Transient Eddy Heat Flux

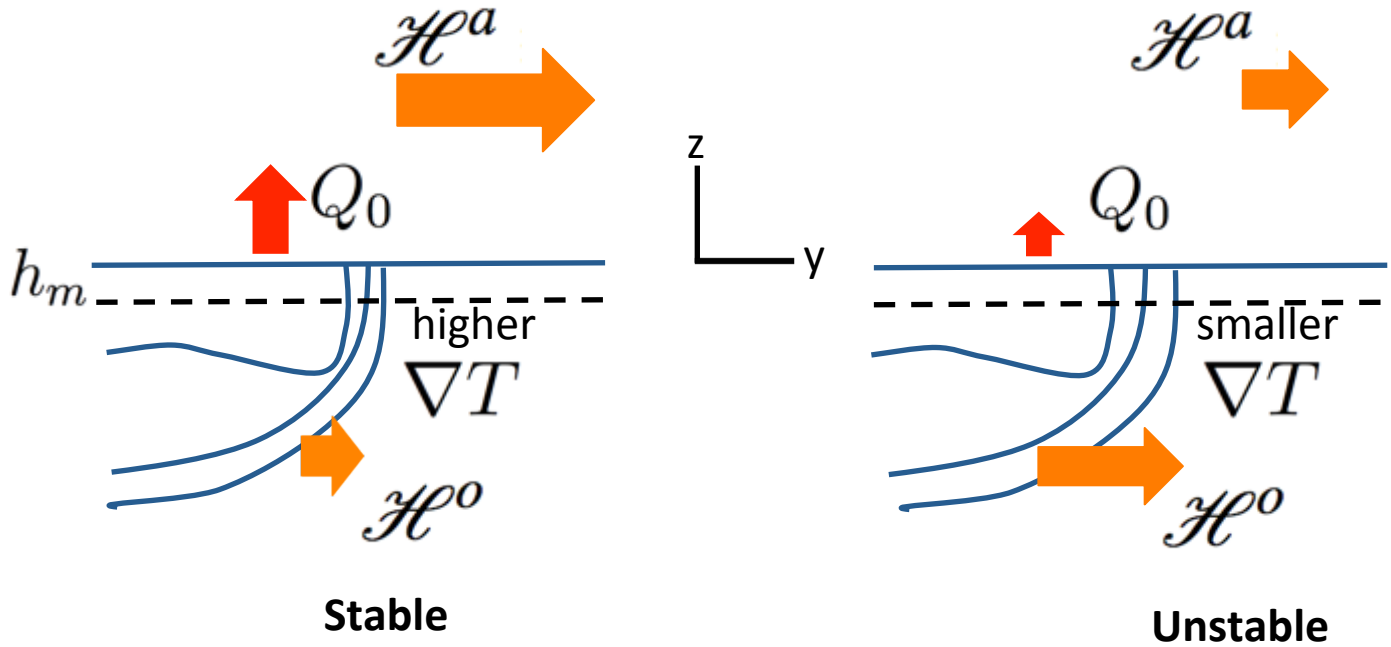
$$\frac{1}{g}\int_{p_0}^{p_s}(C_p\overline{v'T'}+L\overline{v'q'})dp$$

Pacific Sector Integrated MEHT



Schematic Summary:

"Local Bjerknes Compensation"



Stable

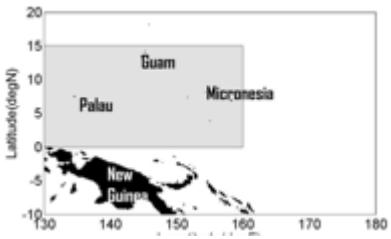
- Lower Ocean Heat Poleward Transport
- Strong SST Front
- Strong low-level baroclinicity
- High Ocean-Atmos. Surface Heat Flux S. of KE Axis
- High Atmos Transient Eddy Poleward Heat Transport

Unstable

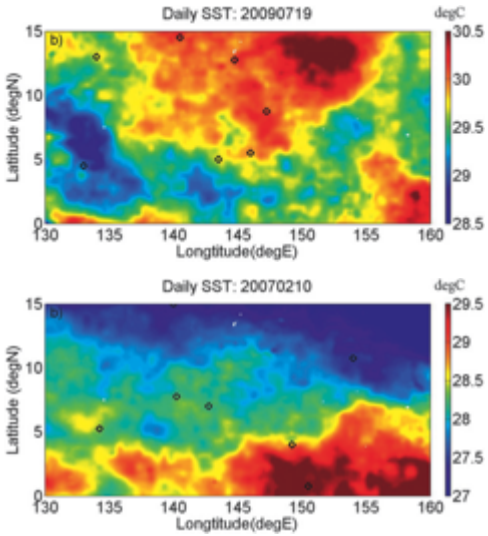
- Higher Ocean Heat Poleward Transport
- Weak SST Front
- Weak Low-level Baroclinicity
- Low Ocean-Atmos. Surface Heat Flux S. of KE Axis
- Low Atmos Transient Eddy Poleward Heat Transport

Onset of Tropical Convection

Li and Carbone, JAS (2012,2015)

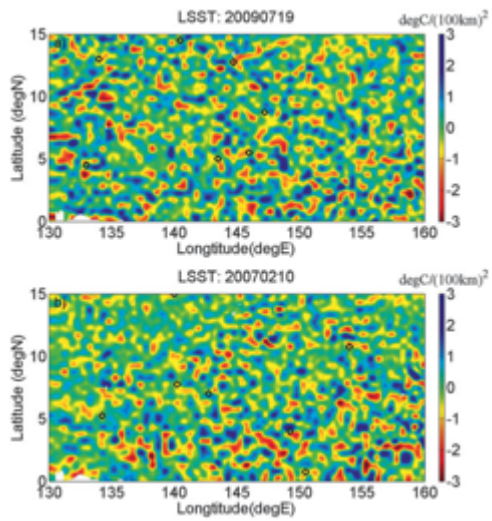


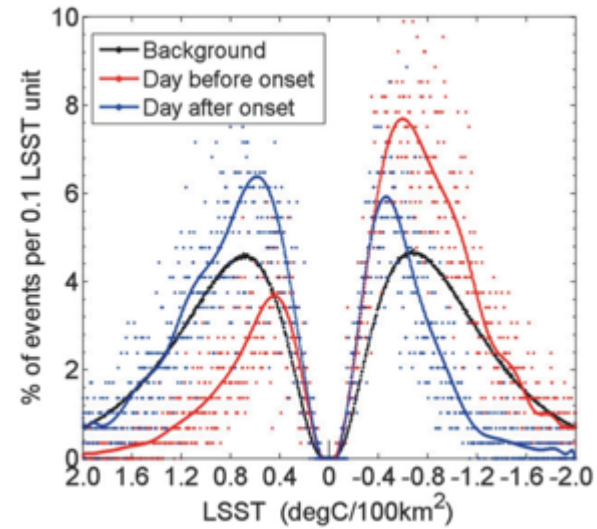
SST



GHRSST

$\nabla^2 SST$





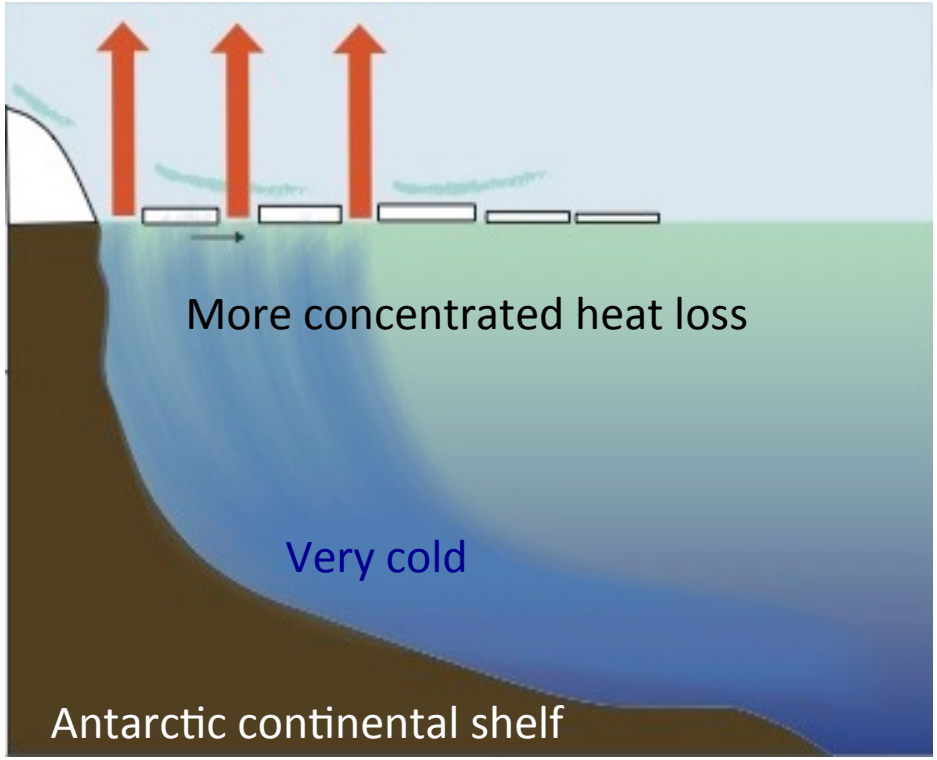
CMORPH Precip

$$\left(\nabla_h \bullet \vec{u}_h\right)_t \propto \nabla^2 p \propto \nabla^2 SST$$

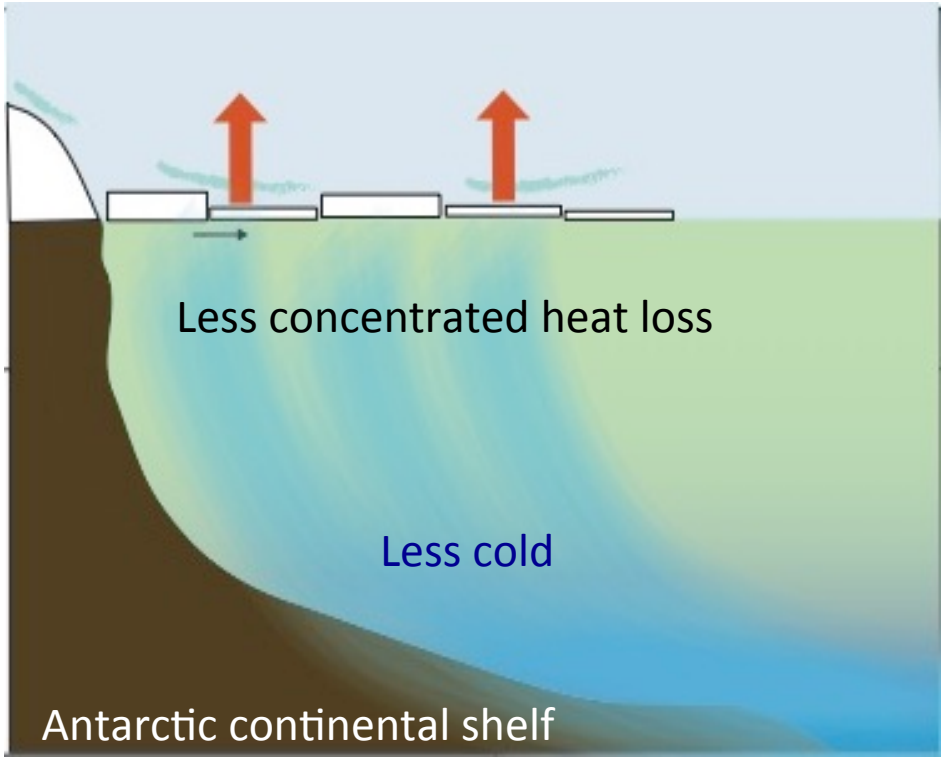
- Track O(10,000) precipitation events over 4 year period
- For 75% of events precipitation events onset co-located with convergent LSST
- Infer a Lindzen-Nigam type response on scales O(100 km)

Heat loss though sea ice

Well Resolved Leads/Polynyas



Coarse Resolution

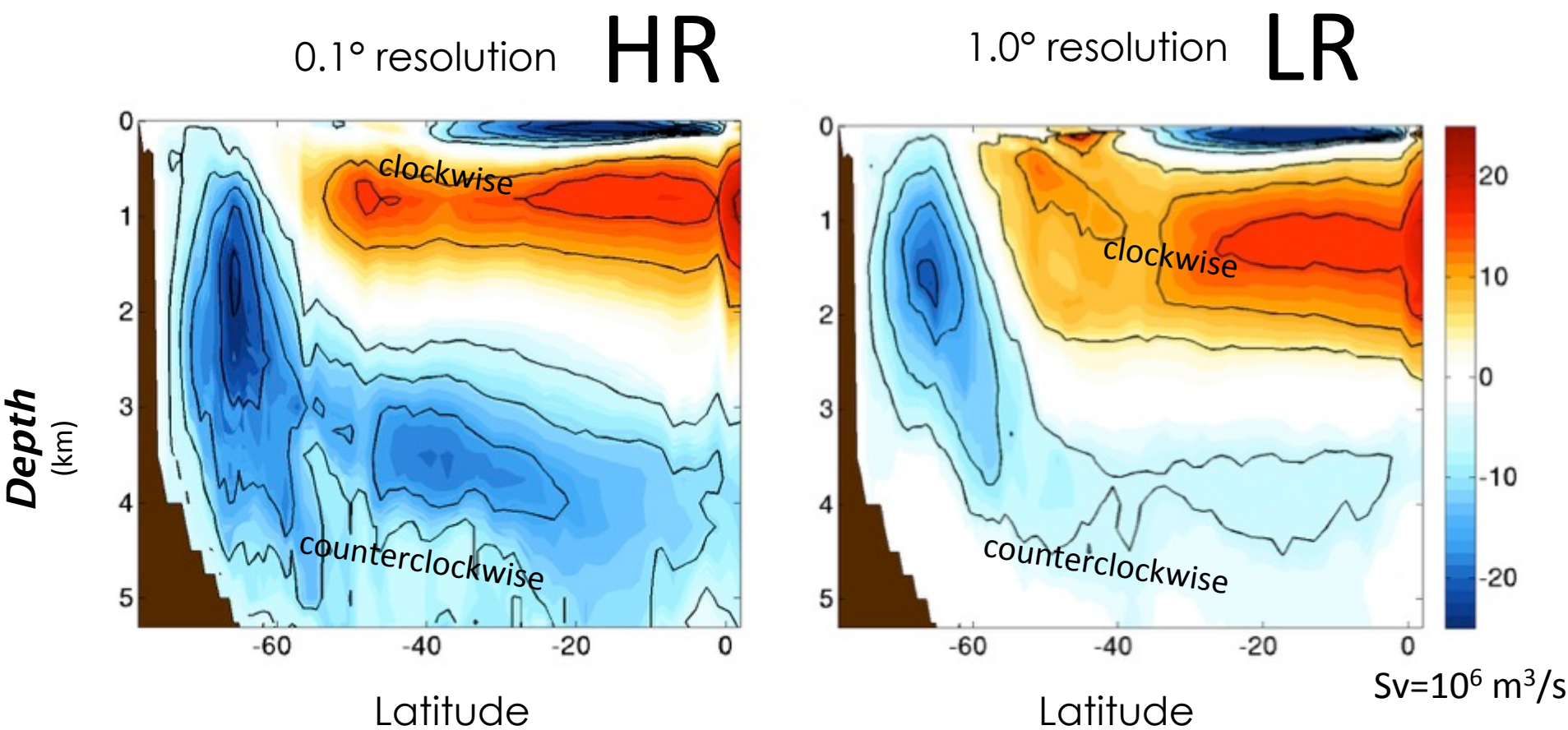


Better sea ice resolution allows for more concentrated heat loss, increasing the drive of surface waters to densify, and forming more, and colder, AABW

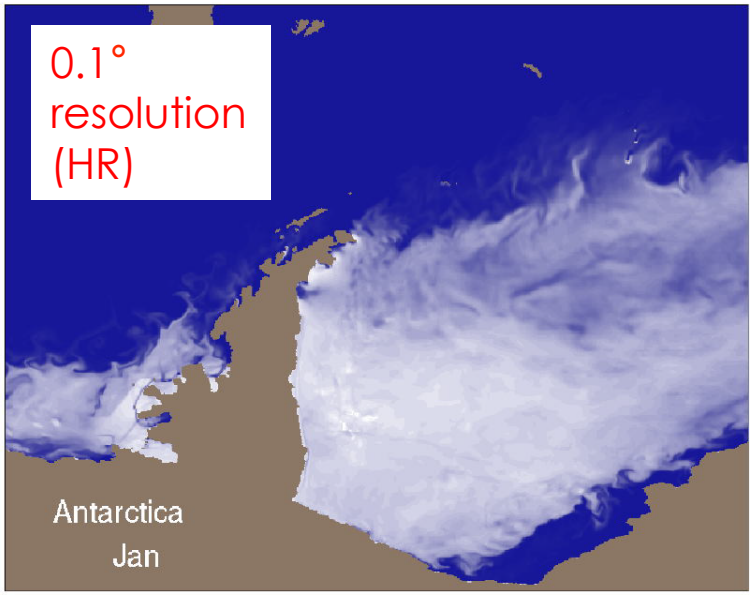
Newsom et al J. Clim. (in review)

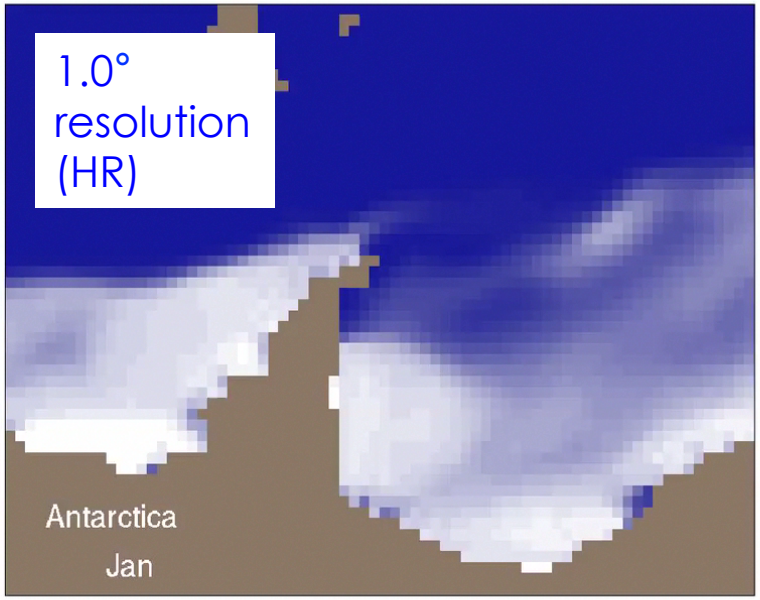
Isopycnal MOC ψ^{σ}

The Lower Cell is stronger, deeper, and extends more northward at fine resolution



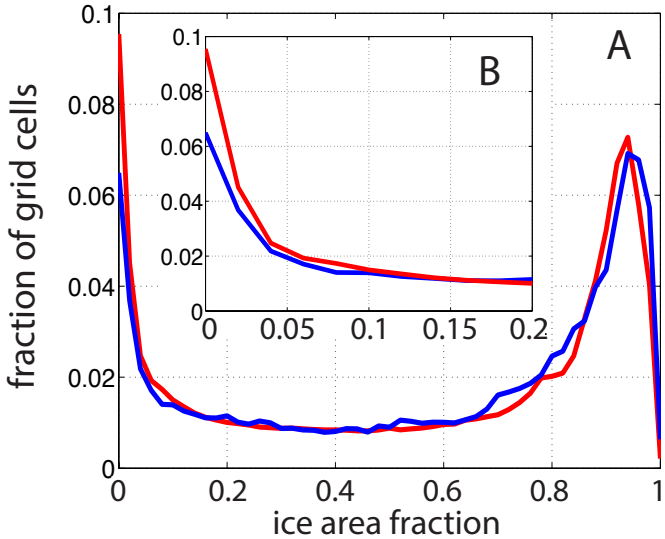
Heat loss though sea ice

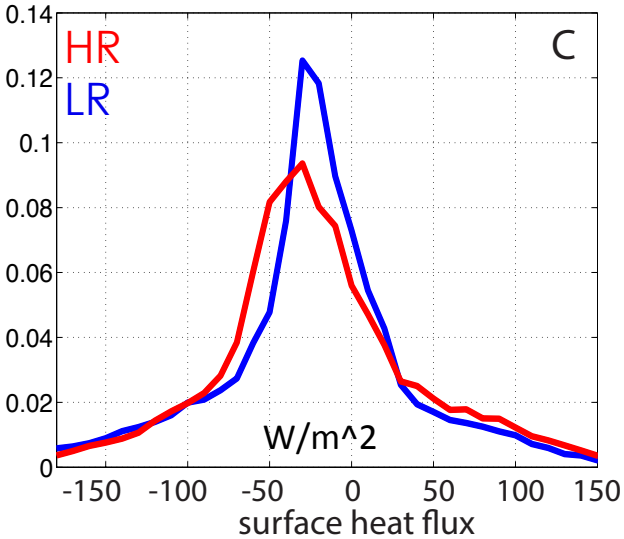




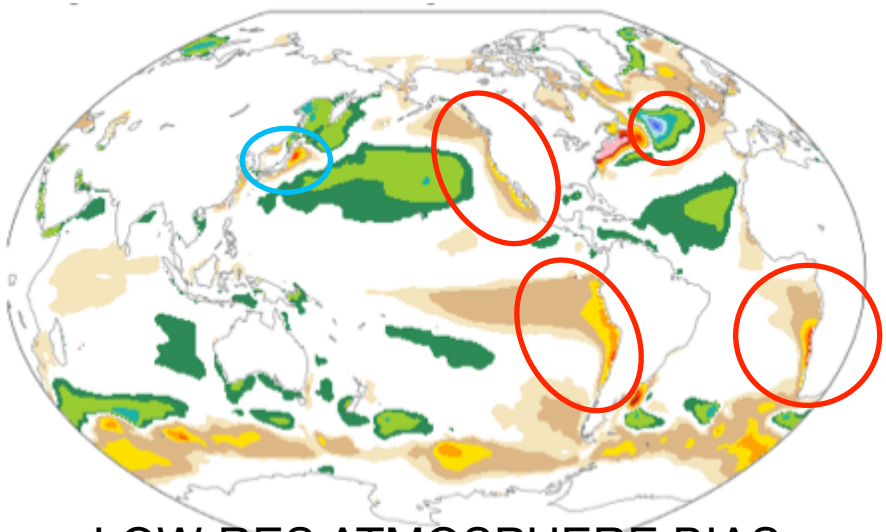
0.1°
resolution
(HR)

1.0°
resolution
(HR)

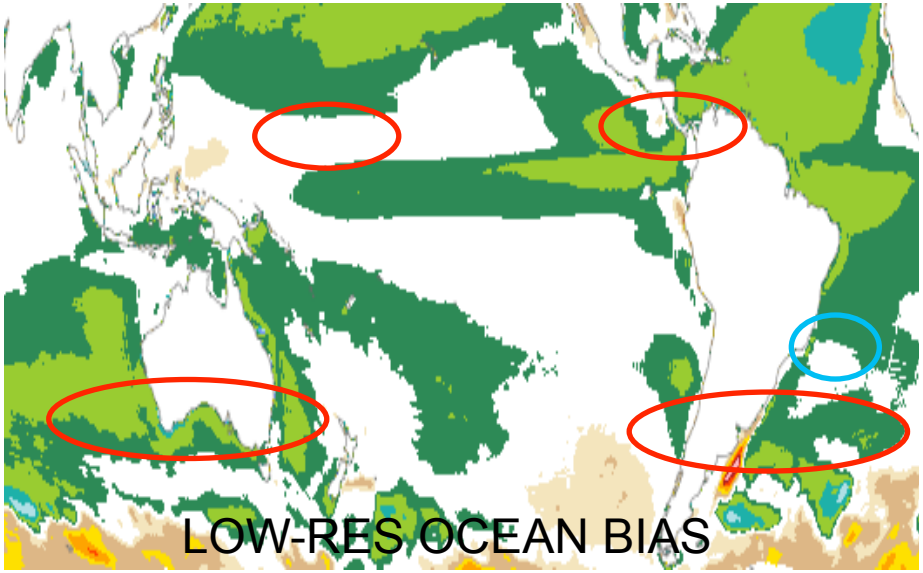




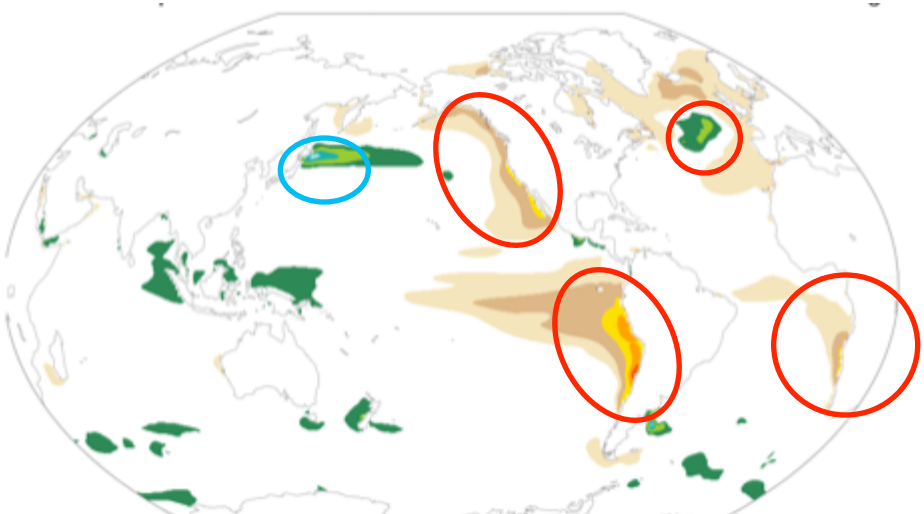
Eastern Boundary SST Biases



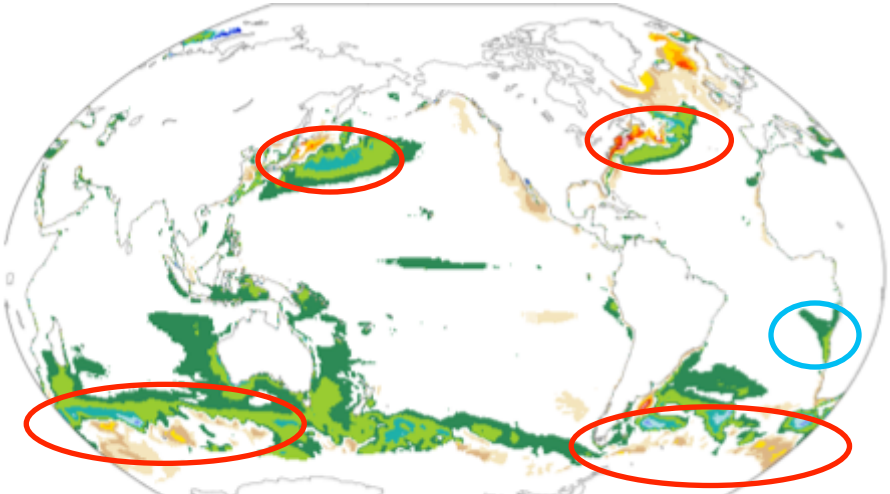
LOW-RES ATMOSPHERE BIAS



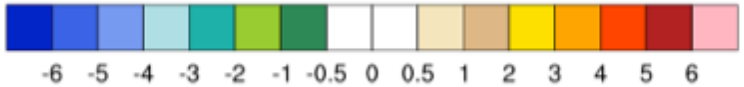
LOW-RES OCEAN BIAS

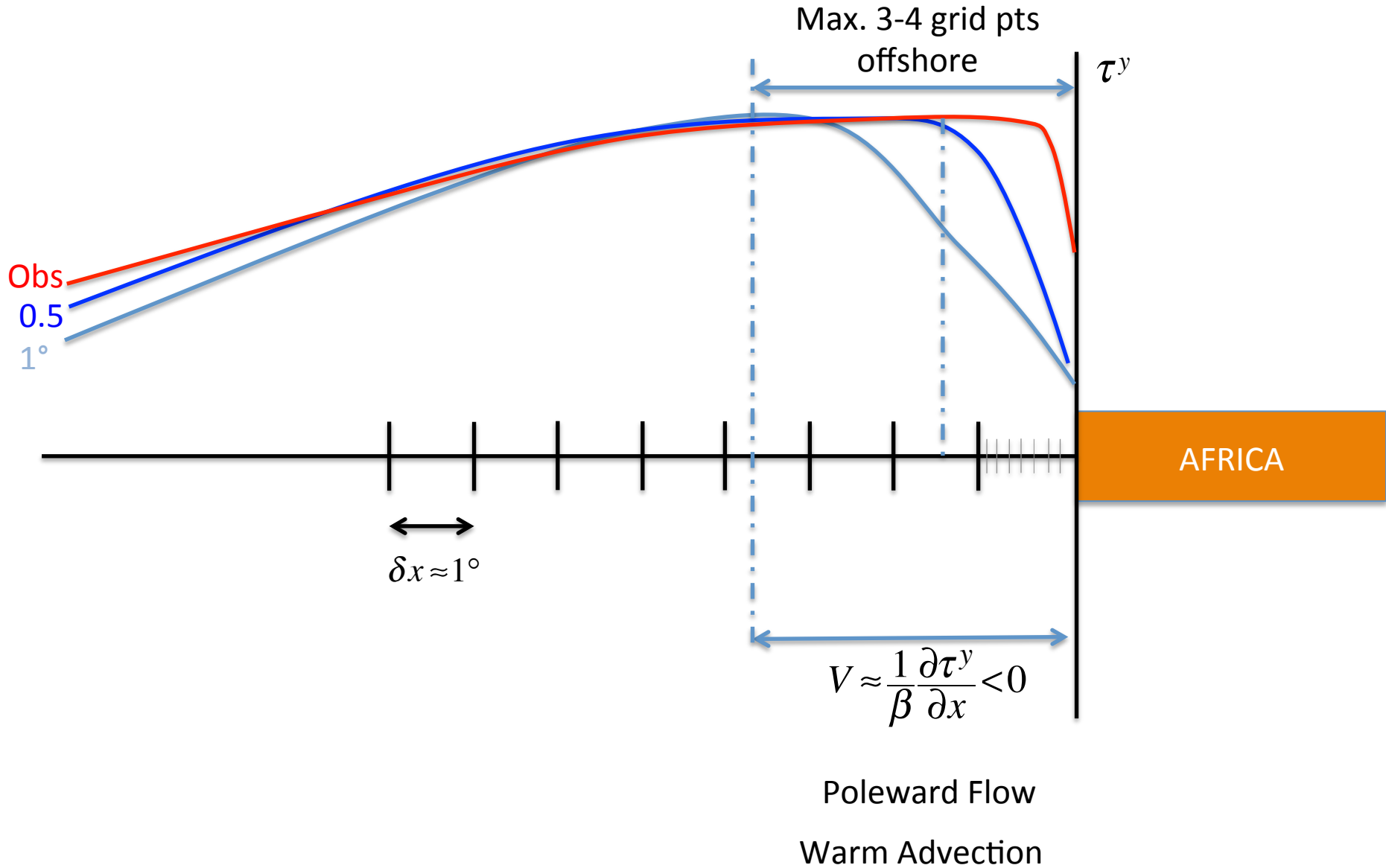


CHANGE DUE TO HIGH-RES ATMOSPHERE



CHANGE DUE TO HIGH-RES OCEAN



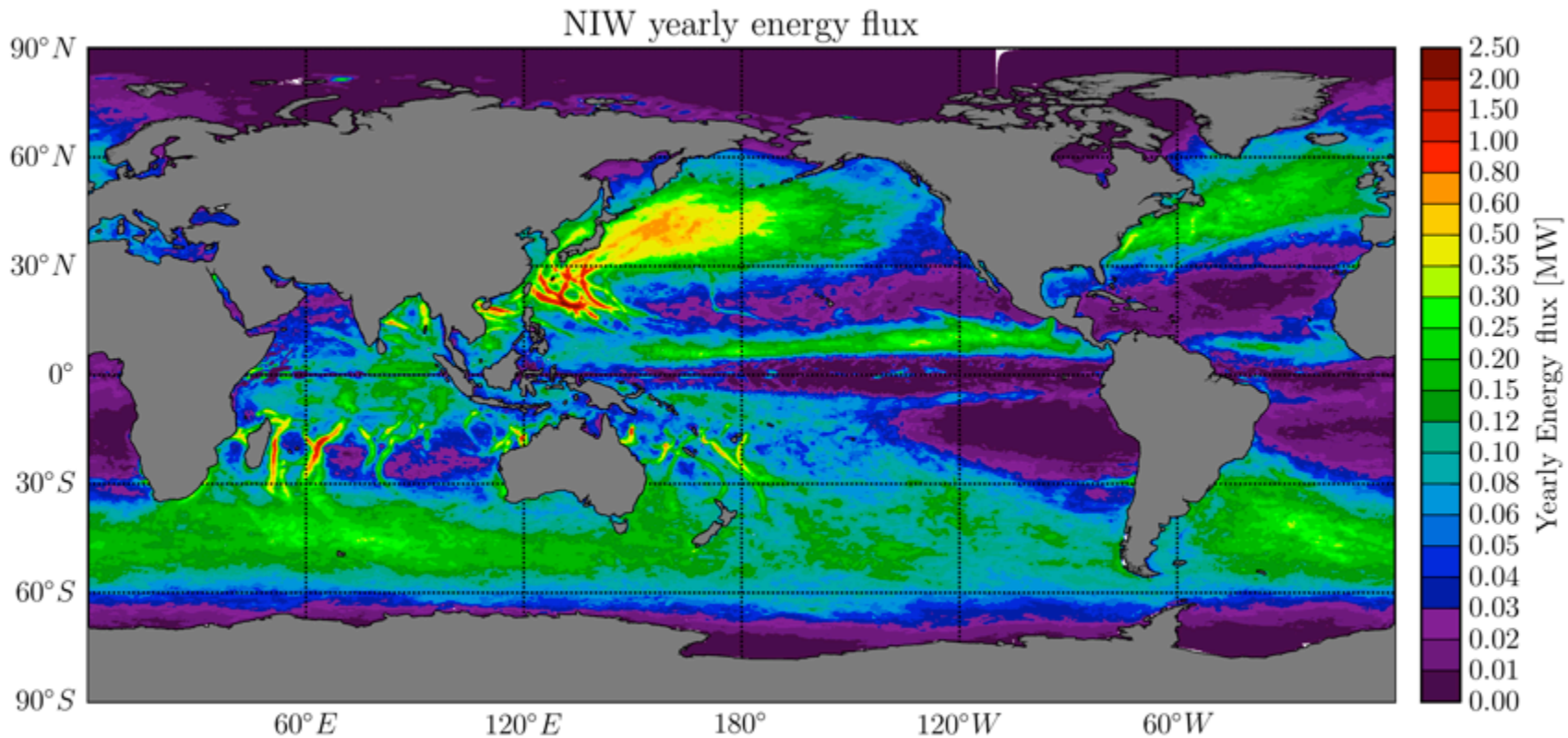


Resolution Dependence of Benguela Current Bias

Small et al (2015)

Conclusions

- Qualitative difference in mechanisms involved in ocean-atmosphere interaction when ocean eddies resolved
- 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
- Current high-resolution coupled models do a credible job of capturing this class of variability and ocean-atmos. Interaction. **PROSPECTS GOOD for improvement with increased resolution.**
- *Suggestive* of source of sub-seasonal to seasonal predictability, but as yet not demonstrated. Challenges for initialization of ocean mesoscale and hence improved predictions.
- Weak signatures of impact on larger-scale atmospheric state
  - Eastern boundary current/marine stratus deck systems
  - Some response in storm track statistics
- Improvement with resolution is non-uniform/non-monotonic especially when resolution of ocean and atmosphere are not increased in concert.

Postscript: Still to Be Explored

- Atmospheric Coupling/Interaction with the Oceanic Sub-mesoscale
  - Inertial wave generation
  - TC cold wake restratification
  - … ?