Scale Dependence of Ocean-Atmosphere Coupling in CCSM3.5 and Observations

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Key Points

- Observed variability in sea-surface height (SSH) and turbulent heat flux (THF) in the vicinity of Western Boundary Currents (WBC) and ocean fronts is more realistically simulated in a coupled model integration with an eddy resolving ocean, compared to one with a non-eddy resolving ocean

- Correlations between SSH and/or heat content (HC) and THF are dominated by ocean variability forcing an atmospheric response at small scales and the atmospheric variability forcing an oceanic response at large scales and the transition between the two regimes occurs at ~10^{o}

- Small scale heat content anomalies are more strongly and extensively correlated with precipitation in a coupled model simulation with an eddy resolving ocean, suggesting a mechanism whereby internally driven ocean variability may influence the deep atmosphere

Experiments & Data

	LR	HR
Atmos. Res.	~0.5° / 26L	~0.5° / 26L
Ocean Res.	~1.0° / 42L	~0.1° / 42L
Initial Condition	Coarse res. CCSM3.5 present day control	Coarse res. CCSM3.5 present day control
Integration Length	~155 yr last 100 yrs and 20 yrs analyzed	~155 yr last 100 yrs and 20 yrs analyzed
Ocean-Atmosphere Coupling	6 hour	6 hour

J-OFURO2 turbulent fluxes 1° horizontal resolution, 1993-2006 (14 years)

AVISO SSH anomalies for overlapping period, interpolated onto flux grid

All data are monthly means unless stated otherwise

Monthly climatologies are subtracted before any analysis of variability

Ocean data interpolated onto atmosphere grid

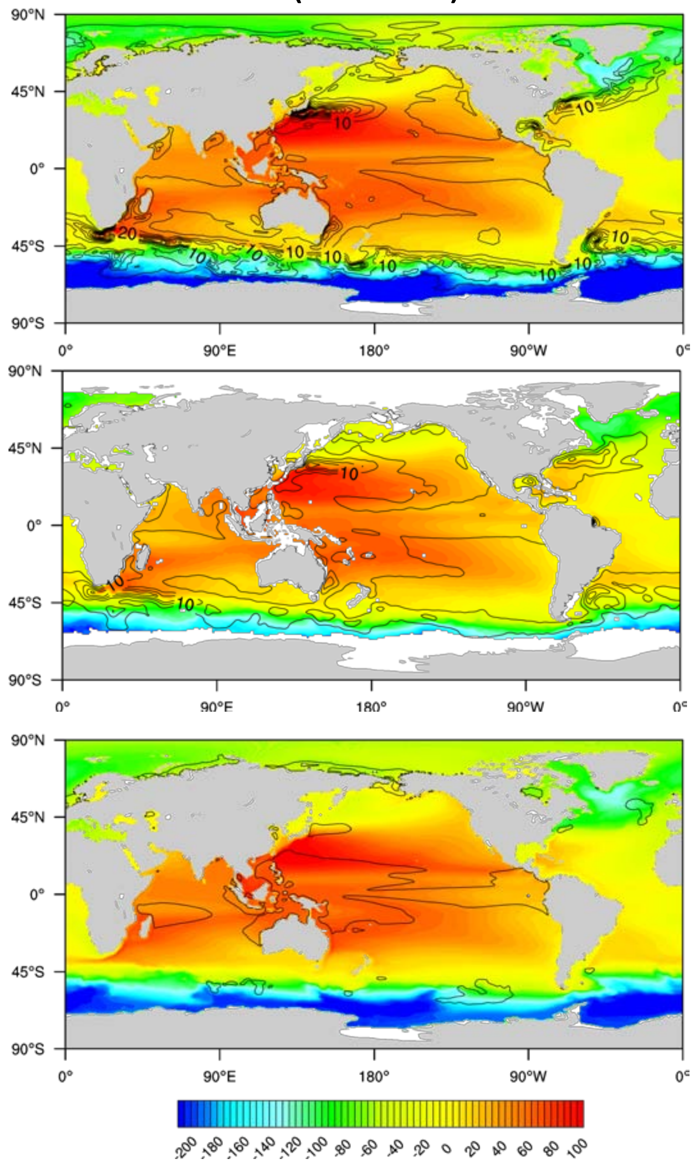
Mean and Standard Deviation of SSH

(CI: 5cm)

HR

OBS

LR

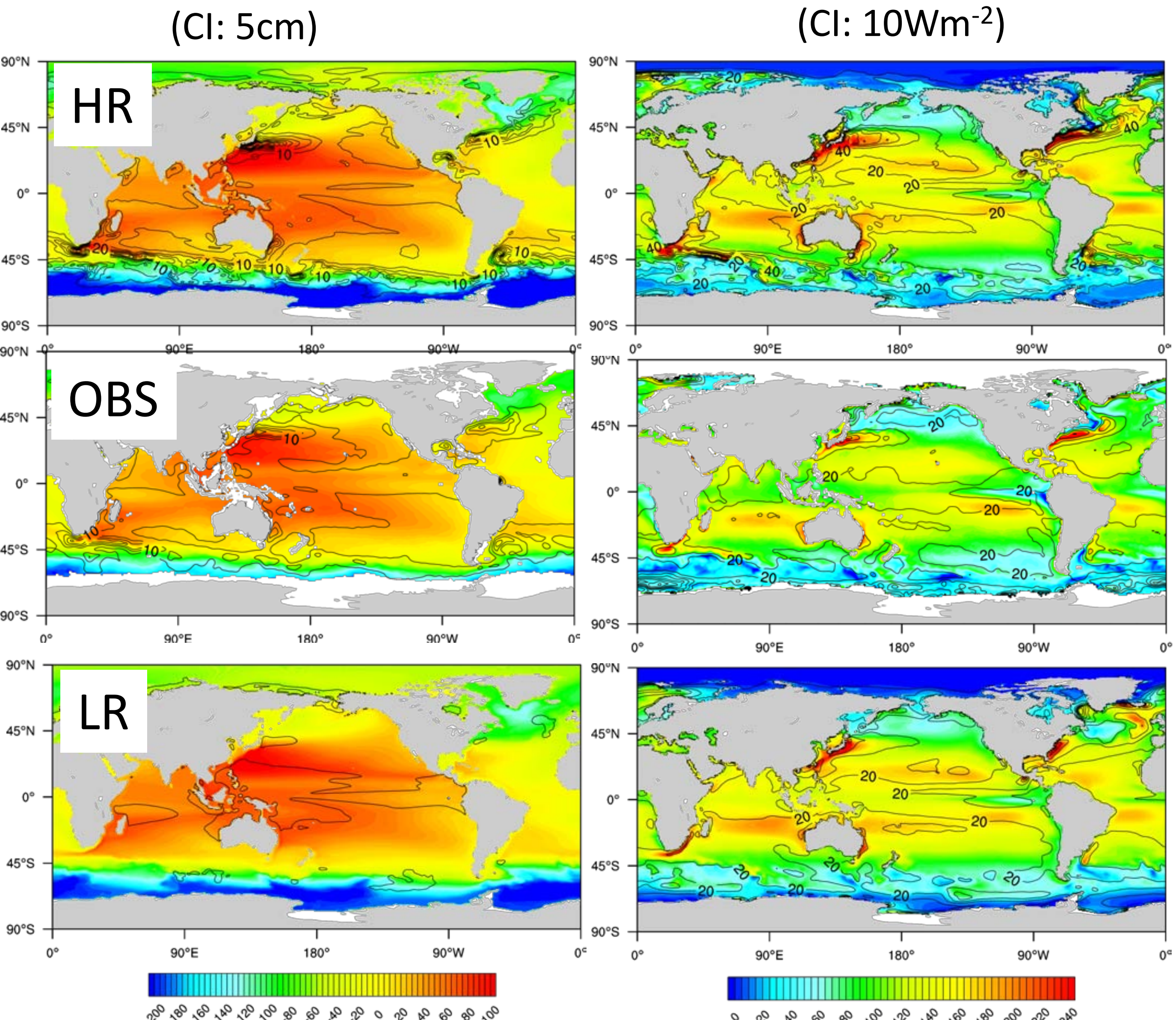


- The HR simulation and observations have SSH SD maxima in the mid-latitudes, vicinity of WBC’s and ACC, where there are large meridional gradients in the mean

- These features are muted or absent in the LR simulation

- HR ocean maybe too energetic and/or observations do not capture enough variability, or significant LF variability not in observations

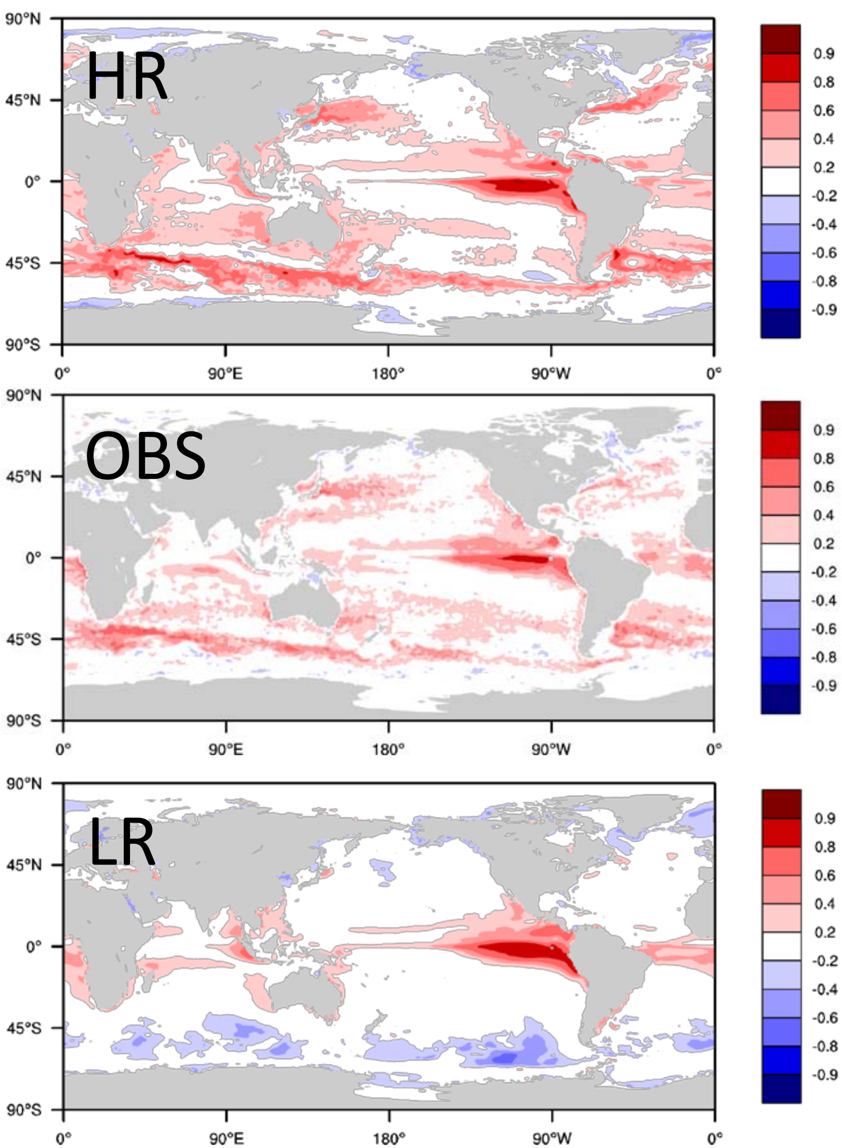
Mean and Standard Deviation of Turbulent Heat Fluxes



THF = LHFLX + SHFLX upward; out of ocean, into the atmosphere

- The HR simulations and observations have SD maxima in the THF collocated with maxima in the mean THF and also with maxima in the SSH SD
- In the LR simulation, the mean maxima are confined to near continents and variance maxima are weaker

Correlation of SSH and THF: Positive in HR Simulation



THF= LHFLX + SHFLX > 0 upward; out of ocean, into the atmosphere

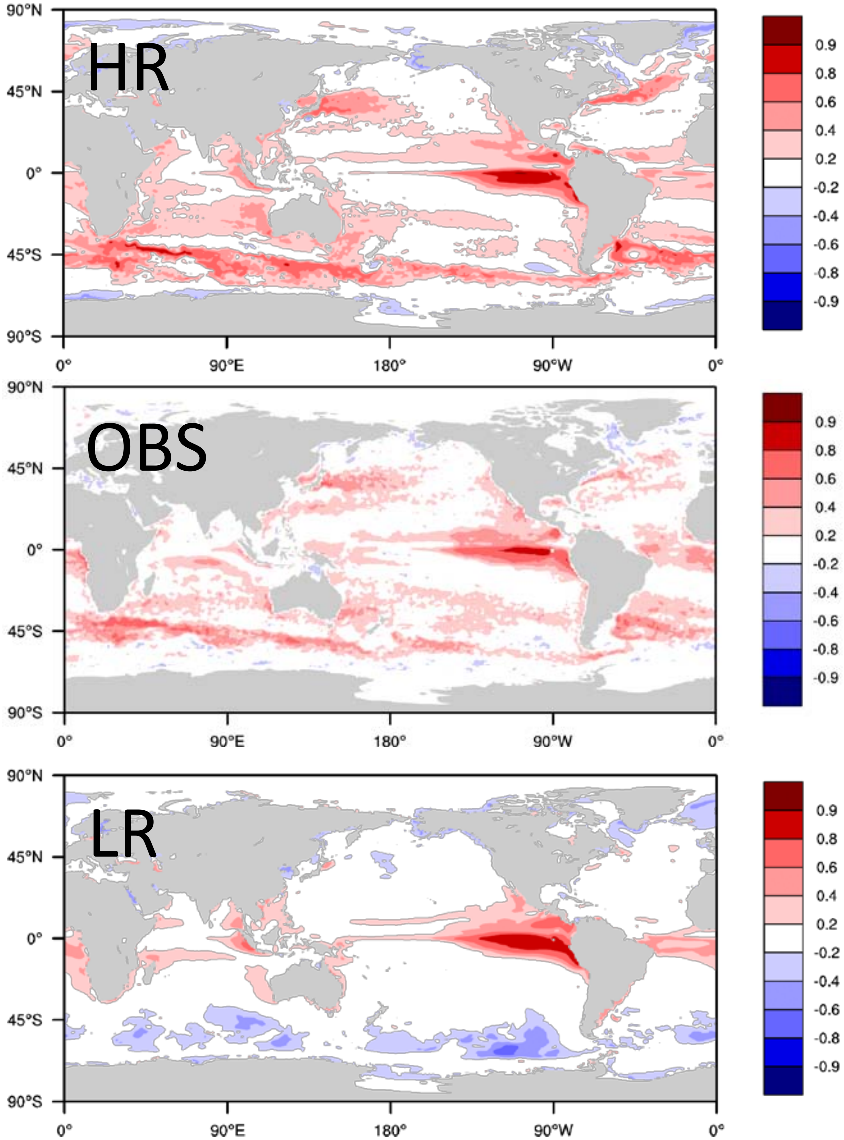
- In the extra-tropics, HR and OBS are more similar to each other than the LR

- + correlations suggest ocean forcing atmosphere in mid-latitudes, HR and OBS

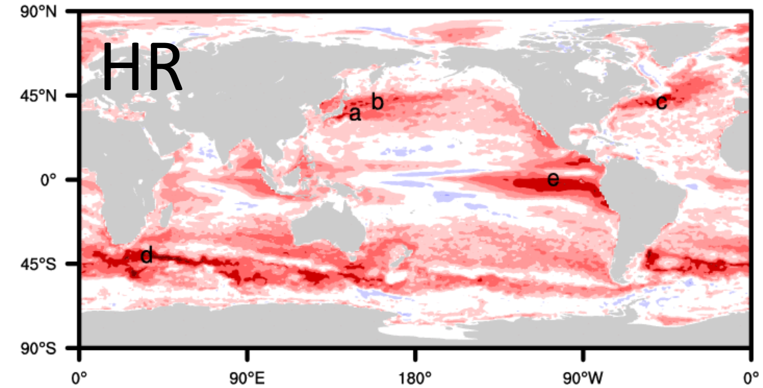
- All are similar in the tropics

Correlation HC(400m)& THF

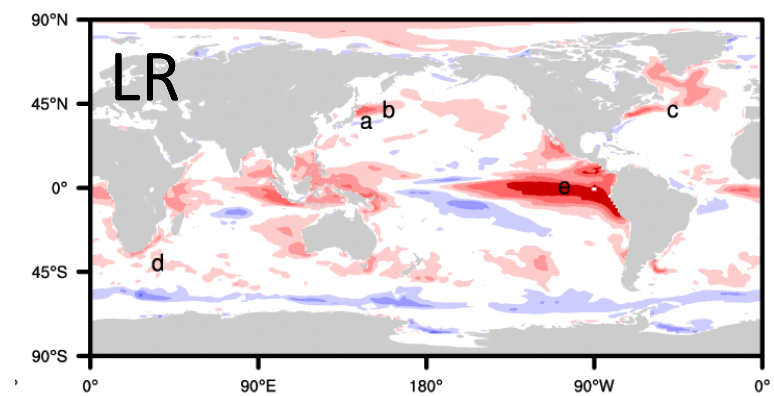
Correlation SSH and THF



Correlation HC(400m) and THF



- Qualitative agreement in vicinity of WBC, ACC and other frontal regions



Simple Stochastic EB Model to Attribute the Sources of Air-Sea Fluxes

$$\frac{dT_a}{dt} = \alpha\left(T_o - T_a\right) - \gamma_a T_a + N_a \quad (1)$$

$$\frac{dT_o}{dt} = \beta\left(T_a - T_o\right) - \gamma_o T_o + N_o \quad (2)$$

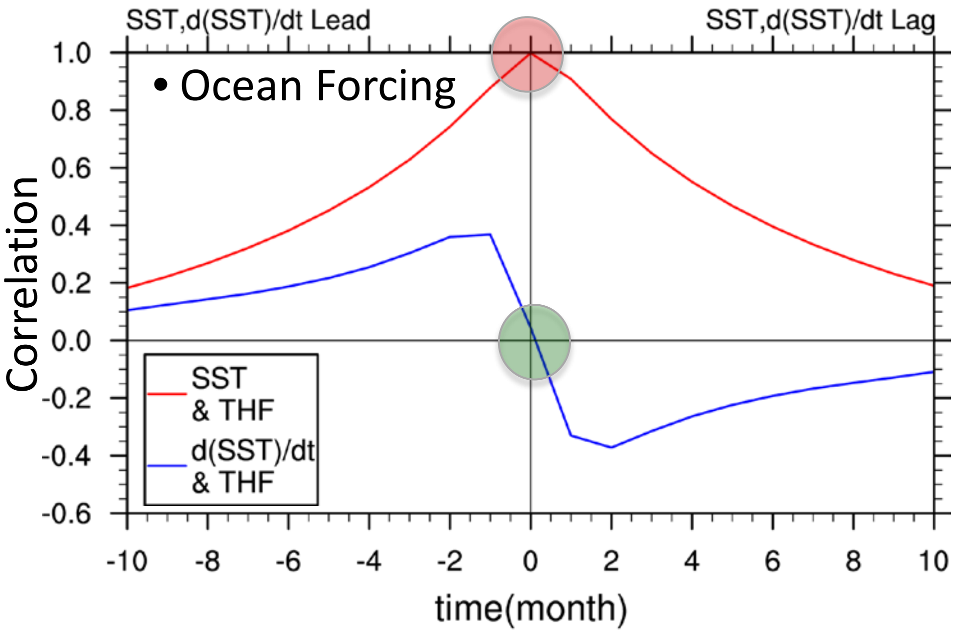
- Wu et al., 2006 + Υ_a; Barsugli and Battisti, 1998

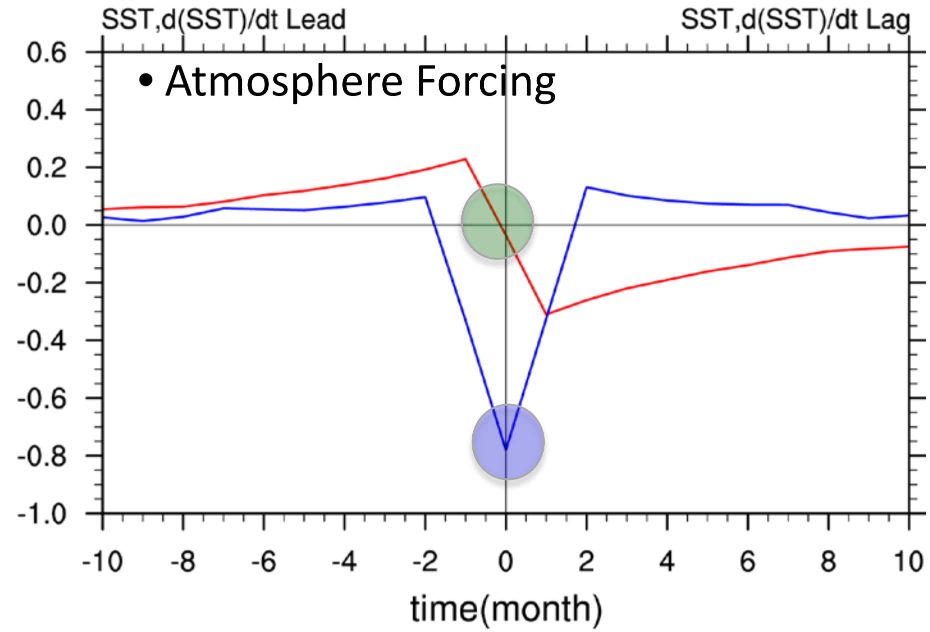
- T_a and T_o are the air temperature and SST anomalies, air-sea fluxes are proportional to their difference

- N_a and N_o are Guassian White Noise – internal variability

- Parameters chosen to be appropriate for mid-latitudes (Wu et al.)

Correlation Signatures of Ocean or Atmosphere Forcing of THF





Circles indicate simultaneous correlations

Correlation signature of Ocean Variability forcing THF:

- Positive for SST and THF
- Neutral for d(SST)/dt and THF

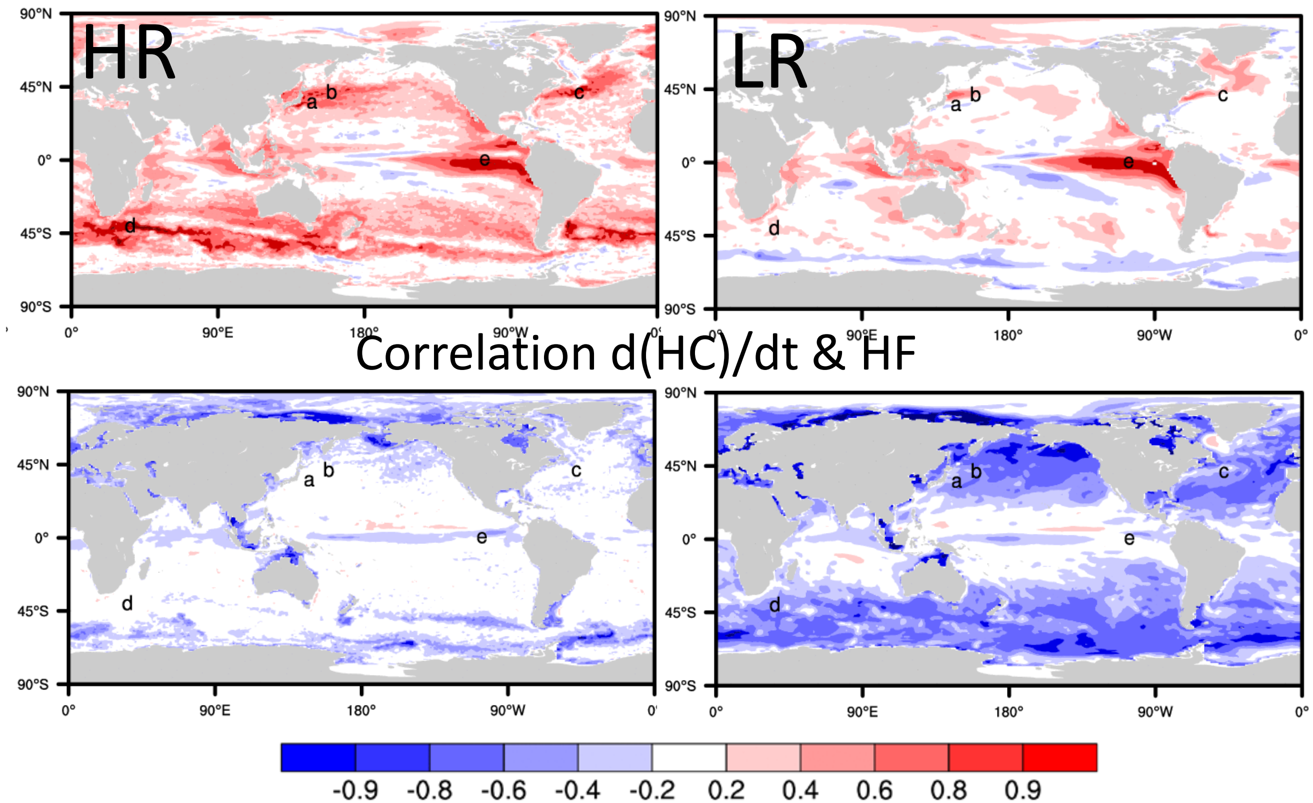
Correlation signature of Atmospheric Variability forcing THF:

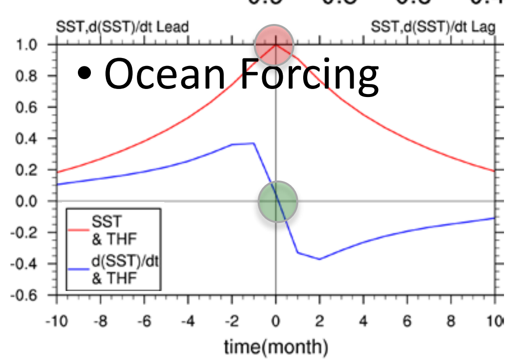
- Neutral for SST and THF
- Negative for d(SST)/dt and THF

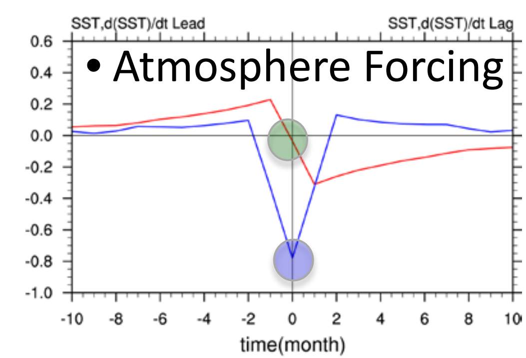
Correlations in the Coupled Simulations and Simple Model

- In the HR simulation mid-latitudes, ocean variability is dominant in forcing THF
- In the LR simulation mid-latitudes, atmosphere variability is dominant in forcing THF
- In the tropics, ocean variability is dominant in forcing THF in both simulations

Correlations HC & HF





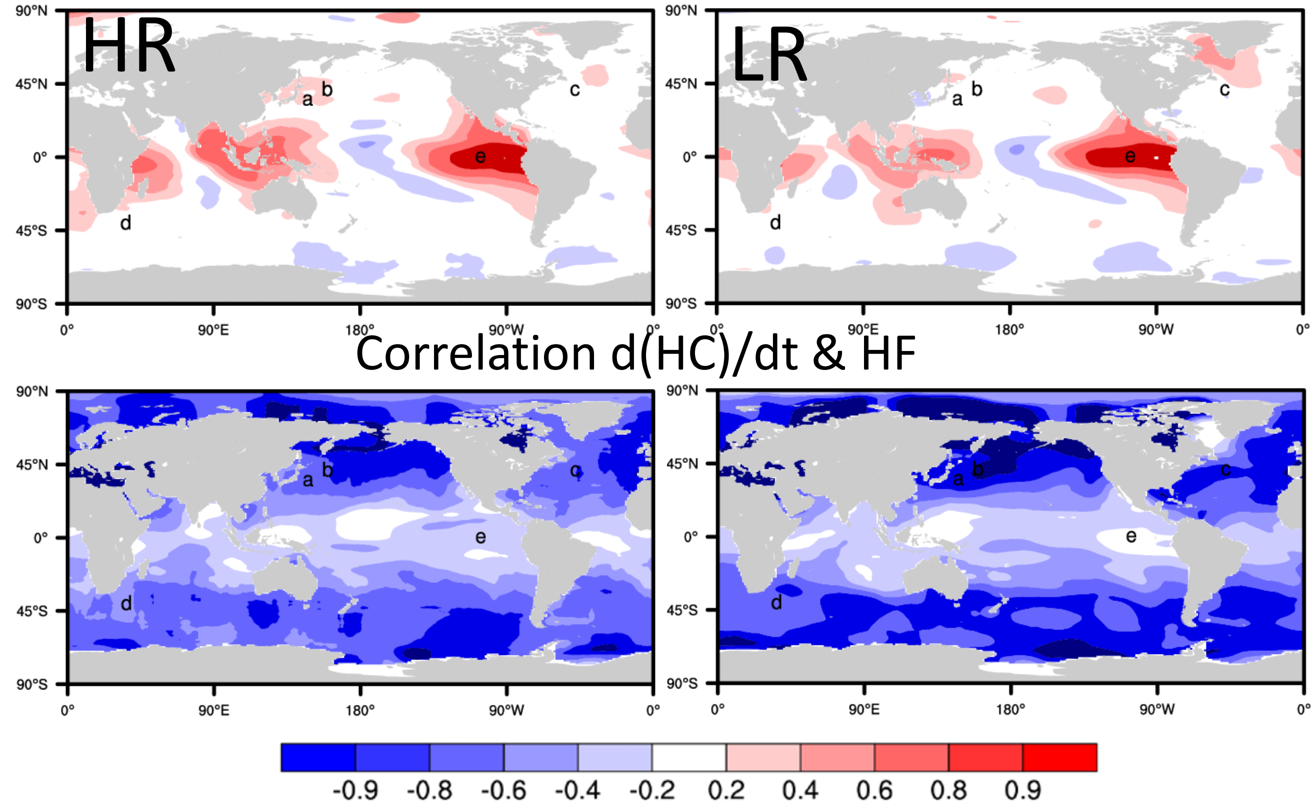


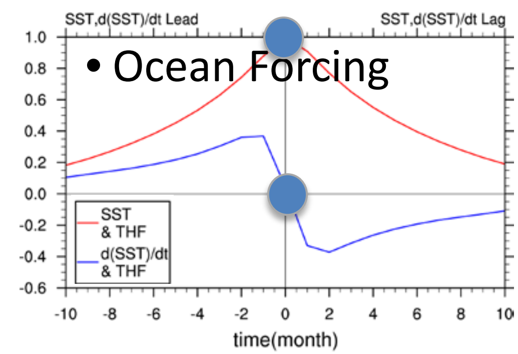
Note locations a,d,e

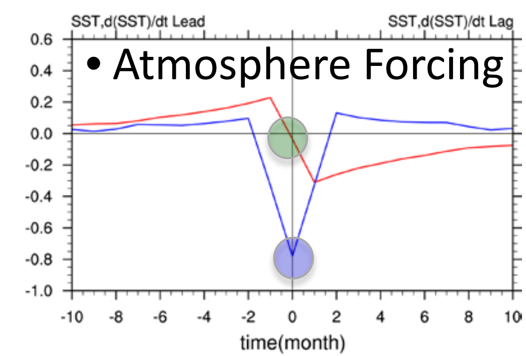
Correlations in the Coupled Simulations (Large Scale Only) and Simple Model

- Filtered to remove small scales < 10°
- Correlations in both simulations are similar and in the mid-latitudes indicate atmospheric variability forcing THF and in the tropics ocean variability forcing THF

Correlations HC & HF

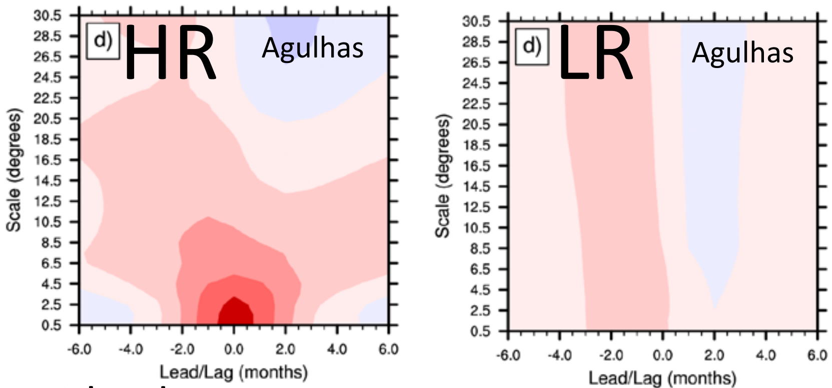






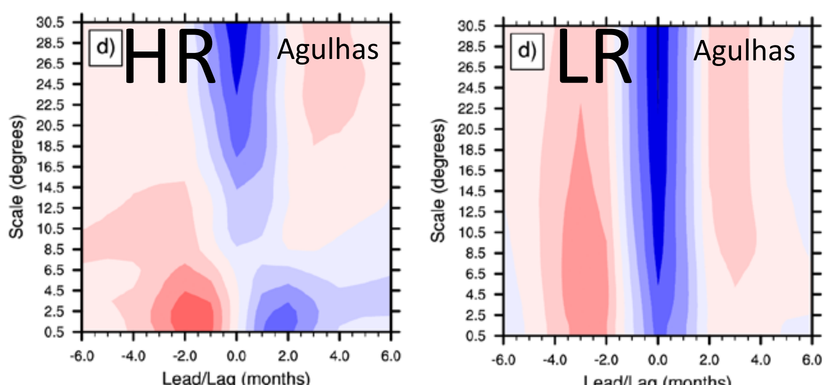
Scale Dependence in Lead/Lag Correlations

Correlation HC and HF

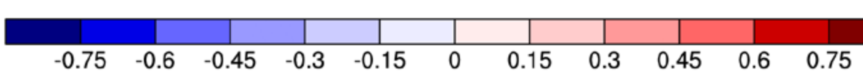


HC leads HC lags

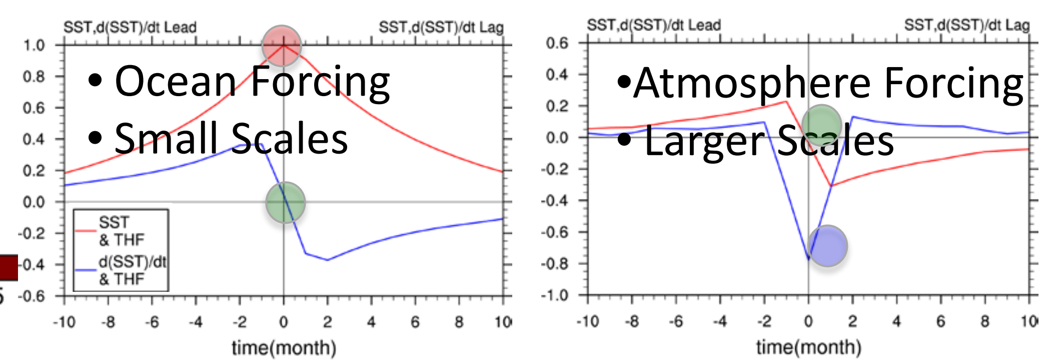
Correlation d(HC)/dt and HF



dHC/dt leads dHC/dt lags

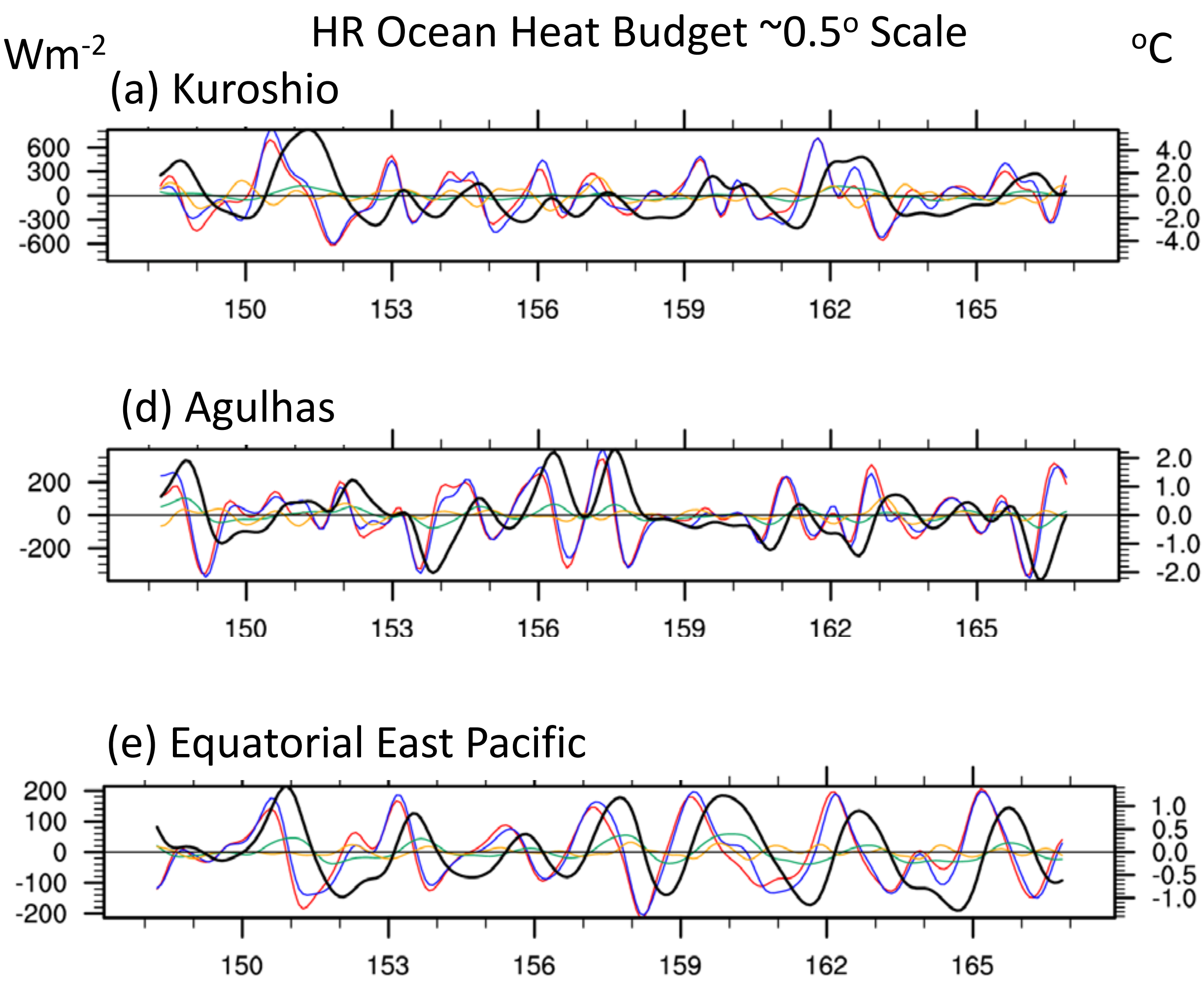


- HF and HC are in phase at small scales and in quadrature at large scales in HR simulation. In the LR simulation, in quadrature at all scales
- HF and d(HC)/dt are in quadrature at small scales and in phase at large scales in HR simulation. In LR, HF and d(HC)/dt are in phase at all scales
- Transition from small to large scale behavior occurs at scales well resolved by LR ocean
- Some regional dependence (not shown)



Heat Budget at Small Scales

$$\partial HC / \partial t = -C_p \rho_o \int_{400m}^{0} \nabla \cdot uT dz - HF + R$$

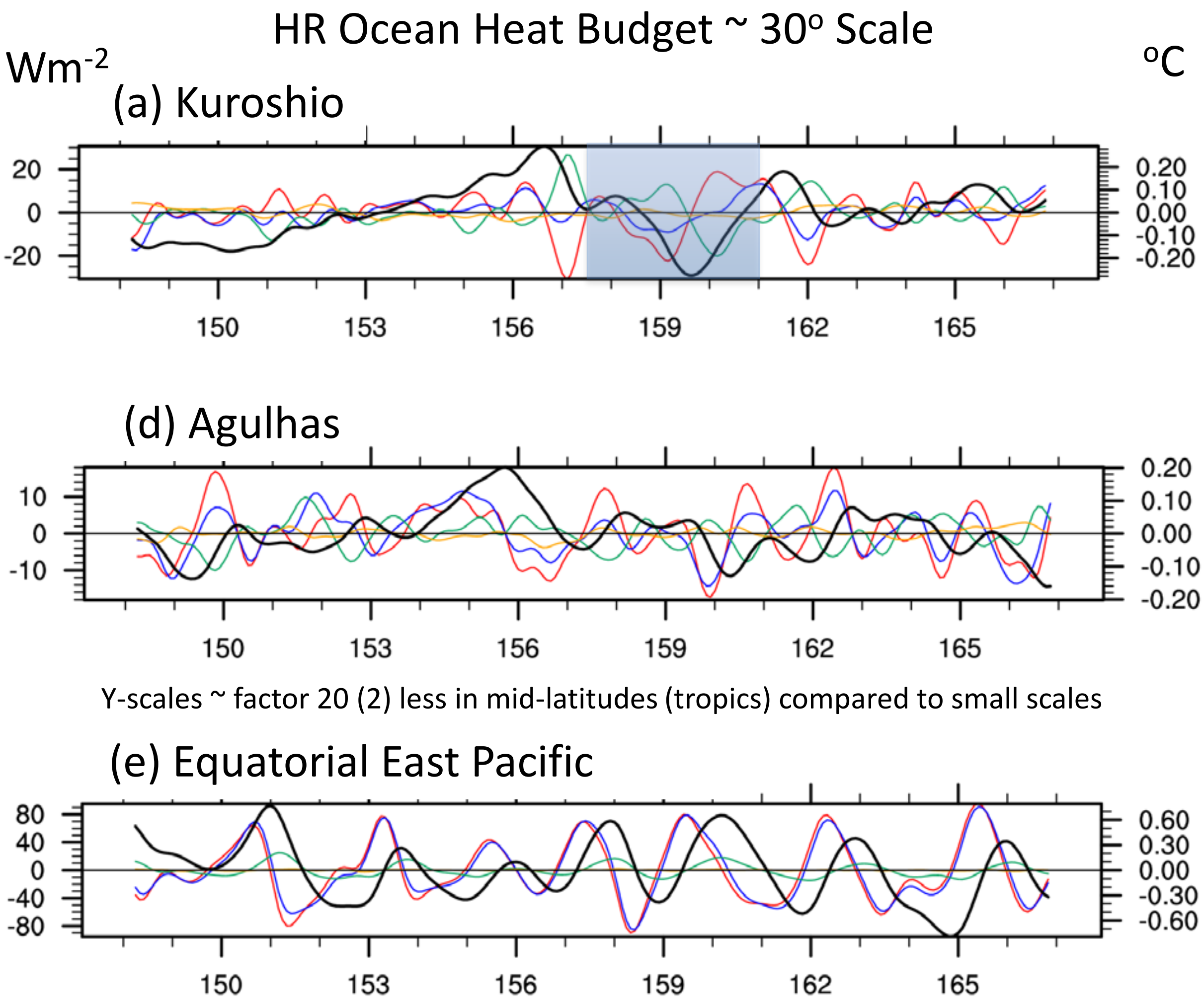


$T_{0\text{-}400m}$ - temp

- advec ~ tend; both >> HF
- Ocean dynamics create **T** anomalies
- **T** and HF anomalies are in phase with each other

Heat Budget at Large Scales

$$\partial HC/\partial t = -C_p\rho_o \int_{400m}^{0} \nabla\cdot uTdz - HF + R$$

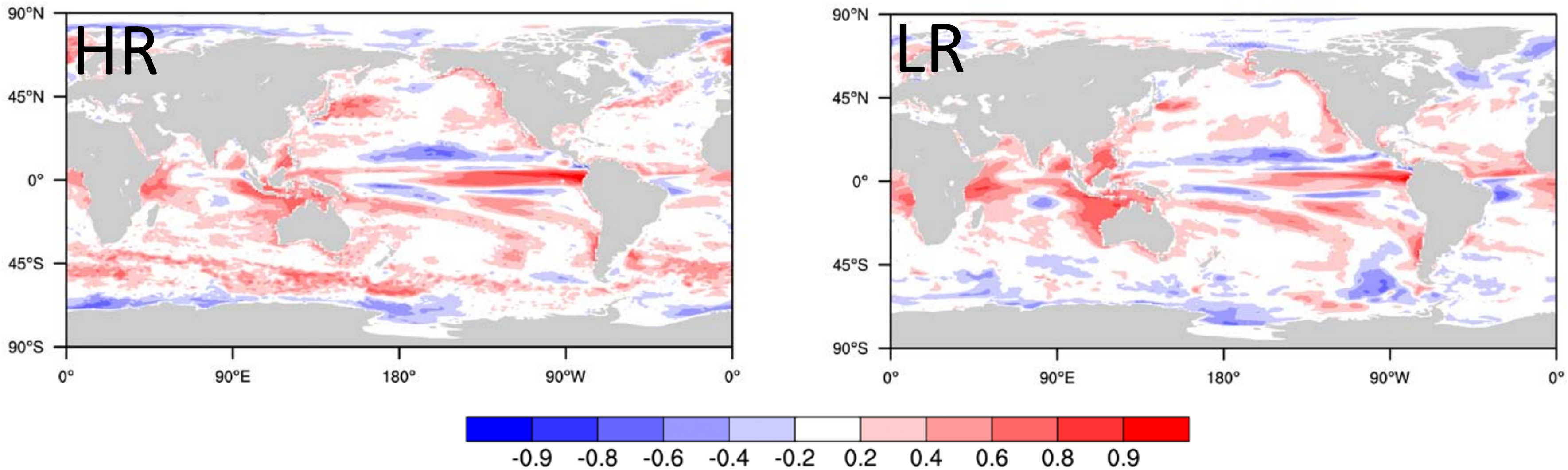


$T_{0\text{-}400m}$ - temp

- Mid-latitudes HF plays greater role in balance but advec still leading term
- HF not in phase **T** in mid-latitudes often leads 90º
- HF often 180º out of phase with tend-> atmos. creates ocean **T** and then damps the anomaly

Influence of Ocean Driven Eddies on the Deep Atmosphere

Correlation Annual SSH and Convective Precipitation



- Influence of ocean variability on the atmosphere extends beyond the vicinity of air-sea interface

- Possible mechanism where internally generated ocean variability may influence atmospheric circulation patterns

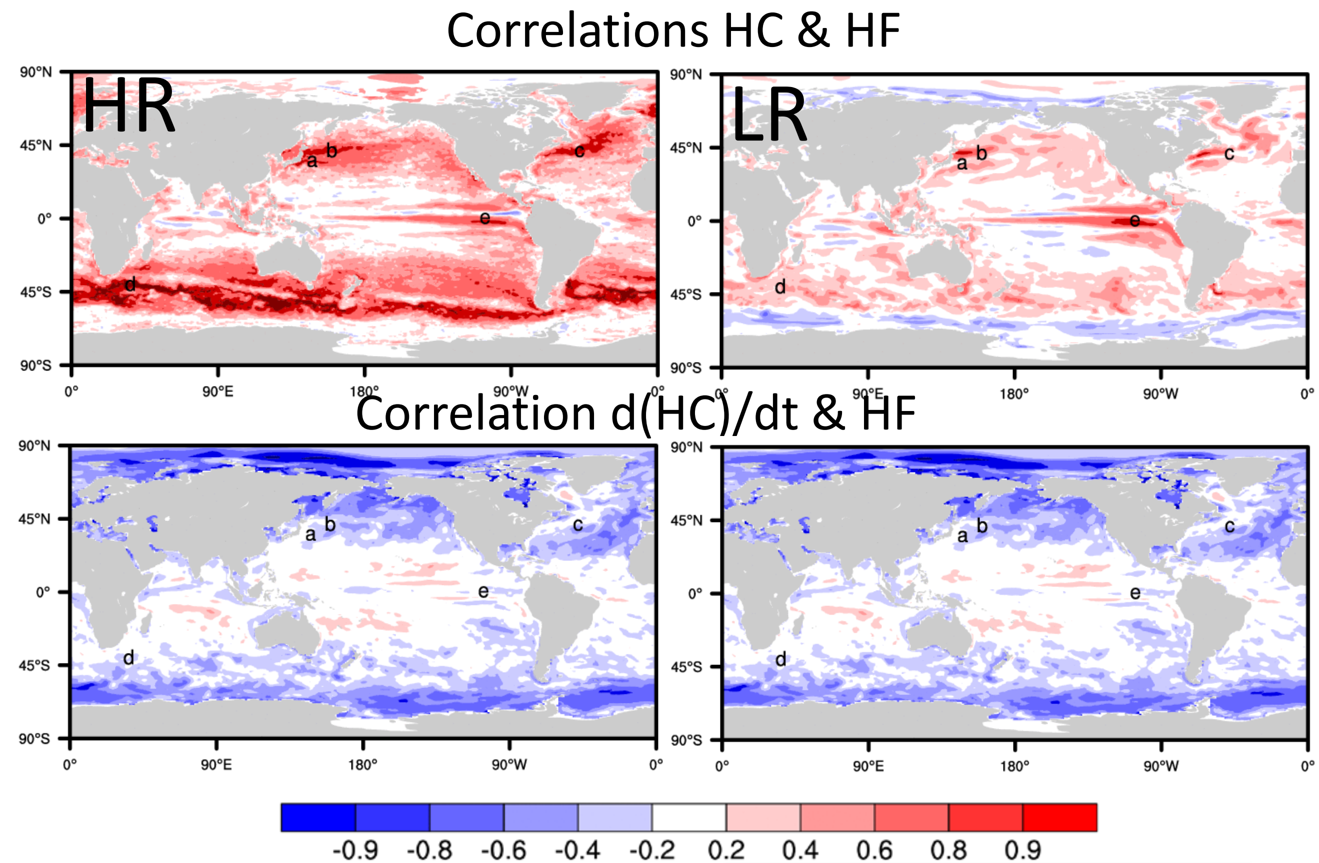
Key Points

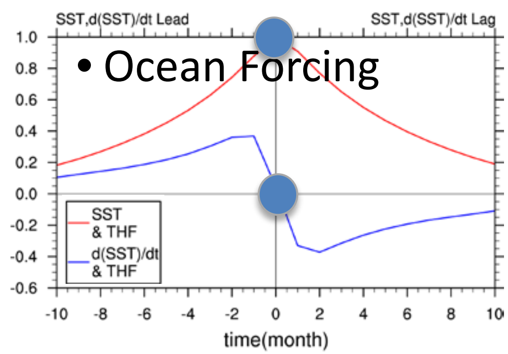
- Observed variability in sea-surface height (SSH) and turbulent heat fluxes (THF) in the vicinity of ocean fronts and on monthly and longer time scales is more realistically simulated by a coupled model simulation with an eddy resolving compared to a non-eddy resolving ocean componet.
- Correlations between SSH and/or heat content (HC) and THF are dominated by ocean forcing an atmospheric response at small scales and the atmospheric forcing an oceanic response at large scales and the transition occurs ~10^{o}
- Small scale heat content anomalies are correlated with precipitation in coupled model simulations suggesting a mechanism whereby internally driven ocean variability may influence the deep atmosphere

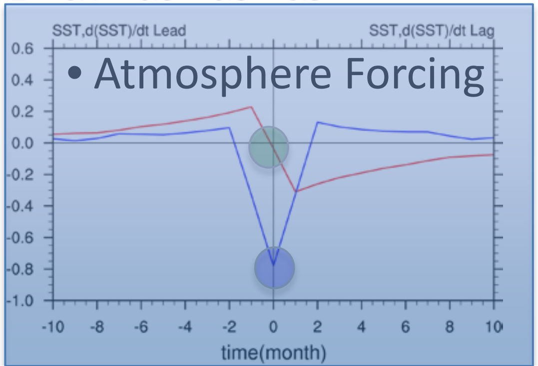
Extra slides

Correlations in the Coupled Simulations (Small Scale Only) and Simple Model

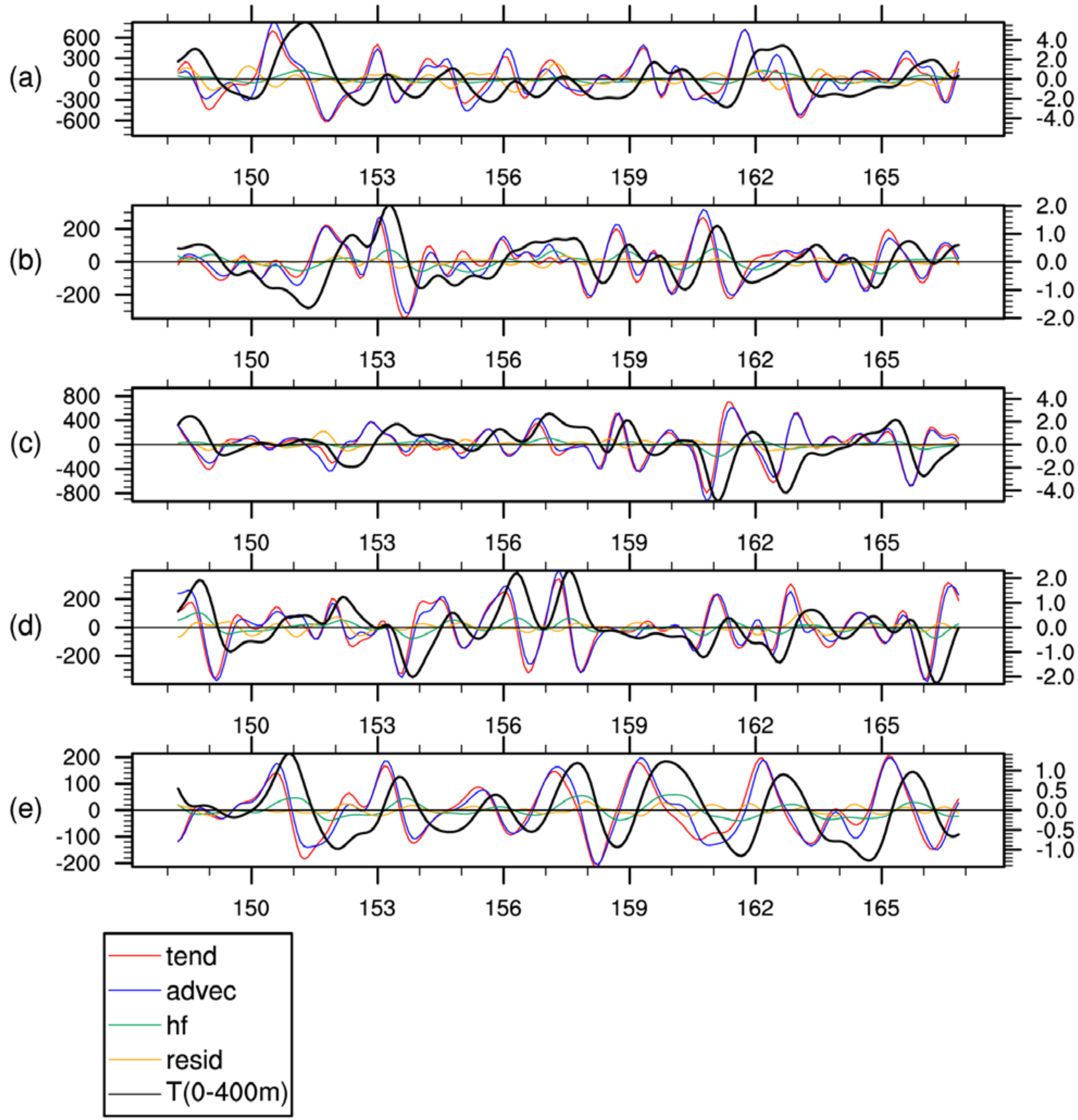
- Filtered to remove large scales > 10°
- Correlations in both simulations are similar and in the mid-latitudes and tropics indicate ocean variability forcing THF at small scales
- Note locations a,d,e







Heat Budget at selected points, HRC06.br avg over 0.5 degrees (Wm^{-2}) and T(0-400m) (^oC)



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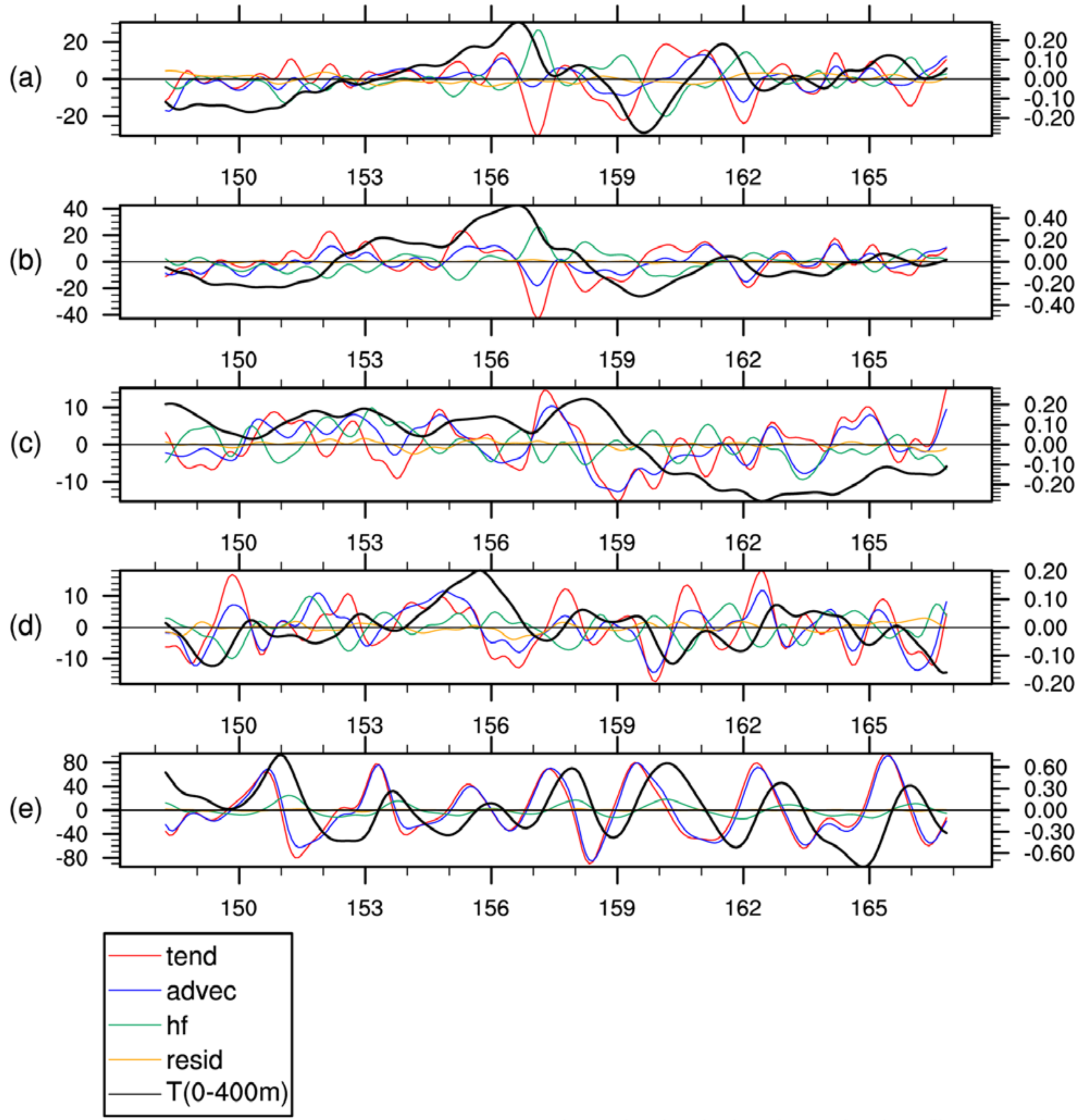
Heat Budget at selected points, HRC06.br avg over 30.5 degrees (Wm^{-2}) and T(0-400m) (^oC)



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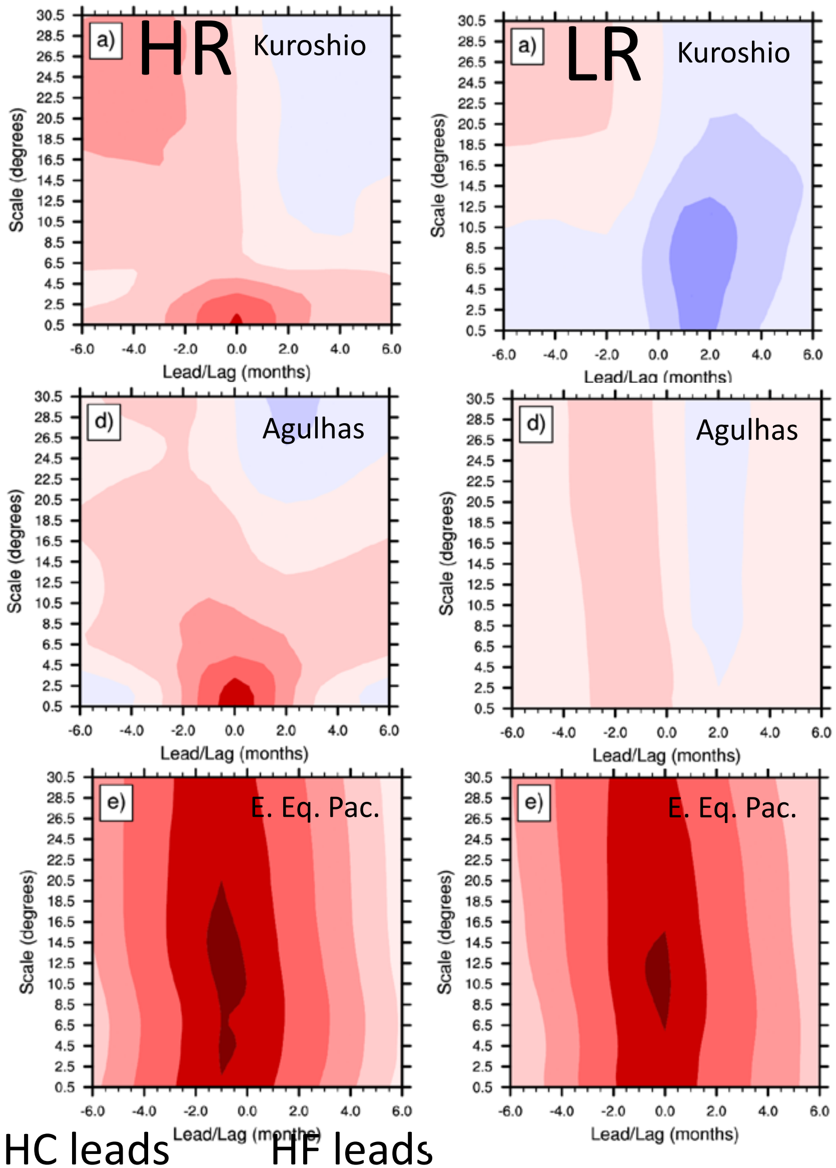
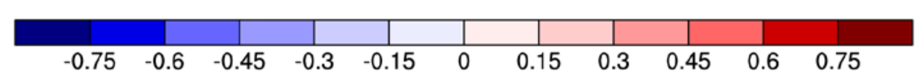
Temporal and Scale Dependence

Correlation HF and HC

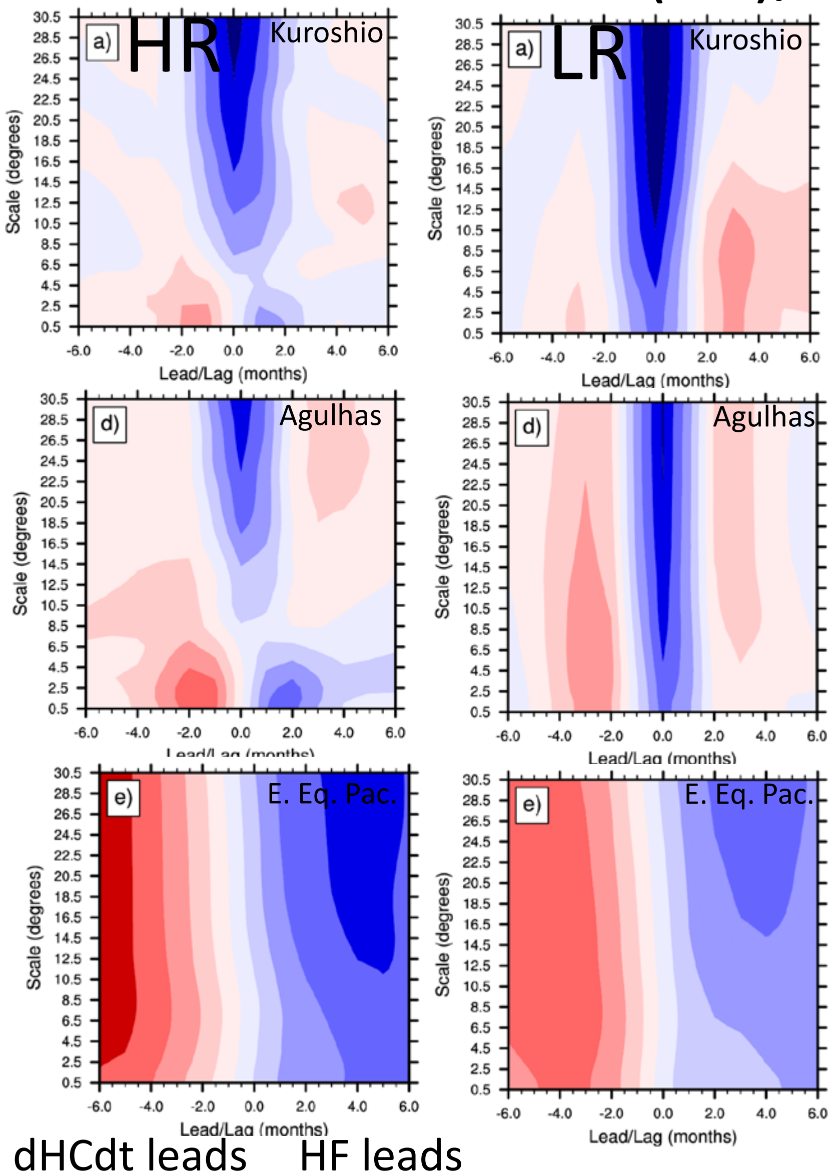


- Mid-latitudes small scales in HR shows HF and HC in phase
- At larger scales, HF and HC in quatrature; transition occurs at scale > scale resolved by LR
- LR shows HF and HC in quadrature at all scales
- In Tropics, HF and HC in phase at all scales in HR and LR
- Behavior in tropics similar to small scales in mid-latitudes HR



Temporal and Scale Dependence: d(HC)/dt

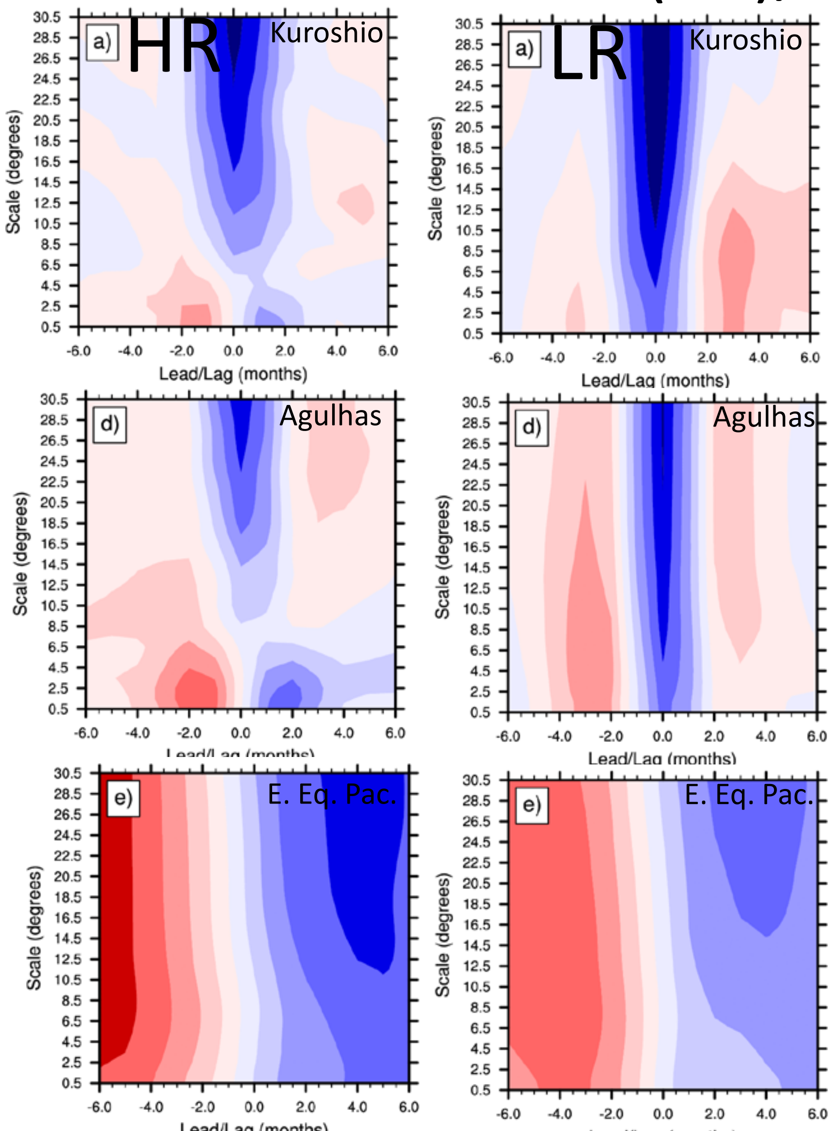
Correlation HF and d(HC)/dt



- Mid-latitudes small scales HR shows HF and d(HC)/dt now in quadrature
- At larger scales, HF and d(HC)/dt in phase; transition occurs scale > scale resolved by LR
- LR shows HF and d(HC)/dt in phase at all scales
- In Tropics, HF and d(HC)/dt in phase at all scales in HR and LR

Temporal and Scale Dependence: d(HC)/dt

Correlation HF and d(HC)/dt

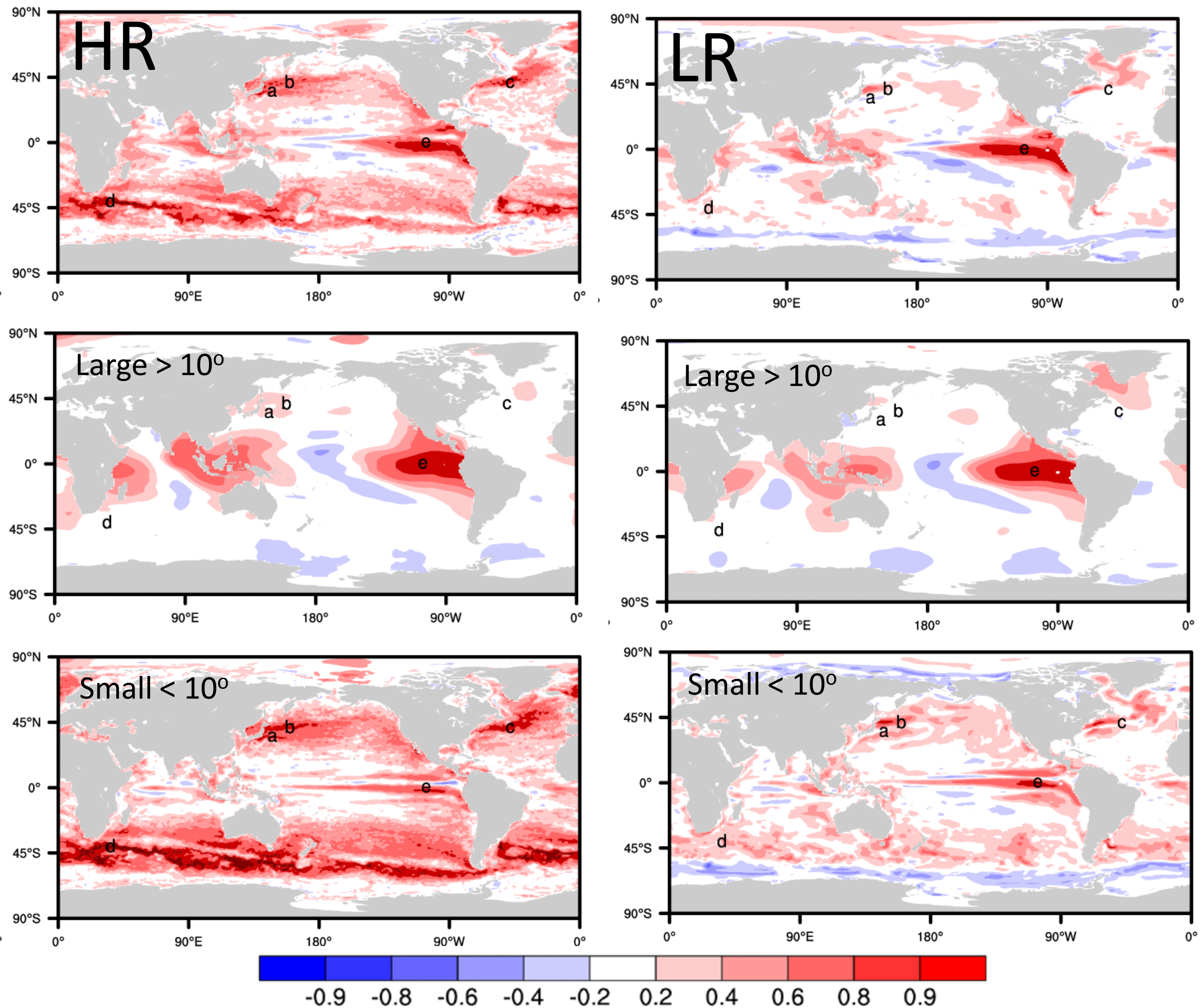


dHCdt leads   HF leads

- Mid-latitudes small scales HR shows HF and d(HC)/dt now in quadrature
- At larger scales, HF and d(HC)/dt in phase; transition occurs scale > scale resolved by LR
- LR shows HF and d(HC)/dt in phase at all scales
- In Tropics, HF and d(HC)/dt in phase at all scales in HR and LR

How does HF,HC Correlation Depend on Scale

Correlation HF and HC



- Patterns similar in tropics
- Large scale features dominate in the tropics
- Differences in mid-latitudes in total maps from small scales