Dominance of ENSO / PDO - Like Variability in Controlling Tropical Ocean Surface Latent Heat Fluxes in the Satellite Era

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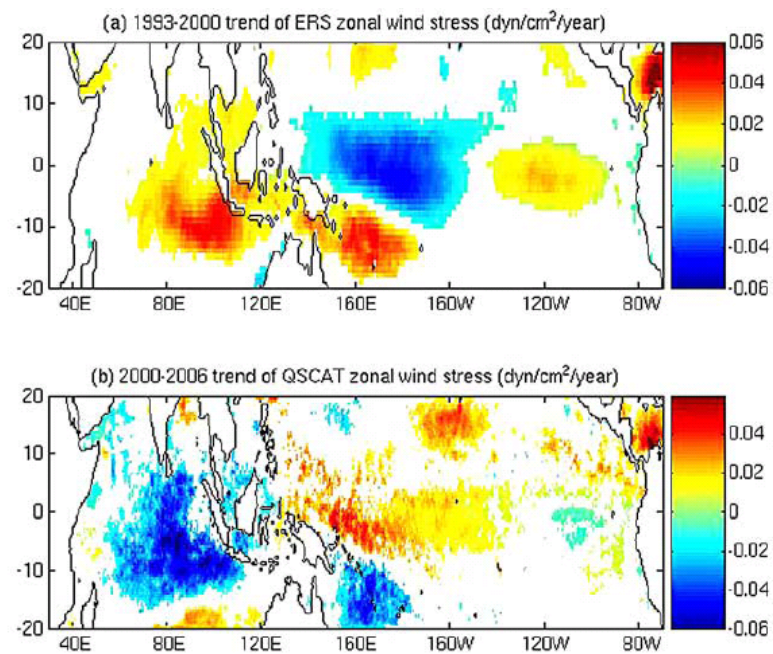
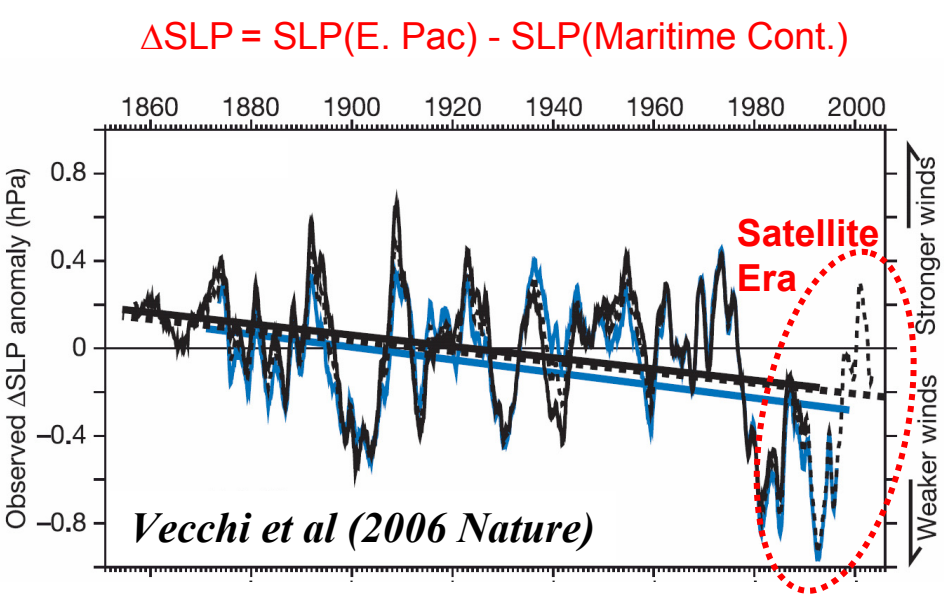
Motivation:

Multi-decadal perspective: Some observational and modeling studies find consistency with anthropogenic effects weakening Walker circulation / vertical mass fluxes, different P, E vs WV scaling with δSST.

Interannual to decadal perspective: Ocean surface wind speed variability found to exhibit significant amplitude, evidence for recent Walker Circulation strengthening tied to MOC in Pacific.





From Lee and McPhaden (2007 GRL): Reversal in trend of scatterometer-derived zonal wind stress forcing meridional overturning circulation, MOC, (or subtropical cell, STC, McCreary and Lu, 1994).

In the context of water and energy cycle changes, questions logically arise…

How is evaporation changing over the (tropical) oceans?

What role does ENSO and other natural variability play?

What are the relative uncertainties in our flux estimates?

In this study we will:

- *examine / compare interannual to decadal signals in two state-of-the-art LHF data sets,*
- *highlight / explain their differences, and*
- *put these results into context of NEWS*

Attributes of two LHF Data Sets

Remote Sensing Systems (RSS), Wentz et al., (2007)

- 2.5 degree monthly mean fluxes computed daily using bulk aerodynamic algorithm from NCAR / CCM3
- Driven by SSM/I Version 6 10m wind speeds built logarithmically from τ and adjusted via buoy comparisons
- $\Delta q = q_s$(Reynolds SST) – q_a(built from Reynolds SST and ICOADS-based $\Delta T = T_{air}$ - SST and RH monthly climatology) → Δq anomalies from climatology come only from SST changes with no independent atmospheric variability taken into account.

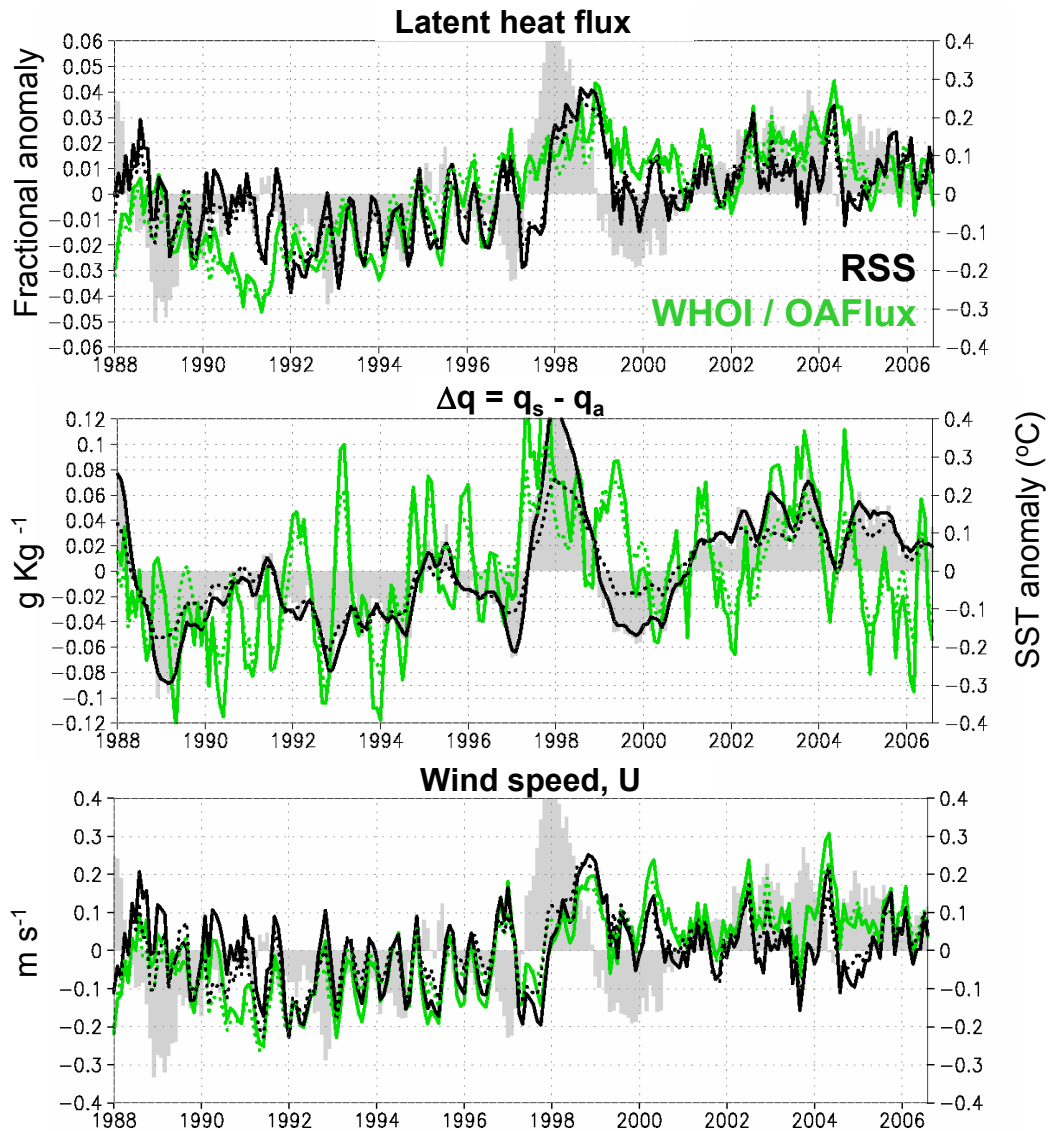
Woods Hole Oceanographic Institution (WHOI / OAFlux) Version 3, Yu and Weller (2007), Yu, Jin and Weller (2008)

- Variational least squares blending of near surface U, q_a, T_a, SST from reanalyses, satellite winds including RSS V6, NSCAT, QuikSCAT, AMSR-E.
- Fluxes derived using COARE V3.0 bulk algorithm
- Analysis weights determined from statistical comparisons to buoys and Southhampton Oceanographic Center climatology

Time Series of Ocean LHF, Δq, U Anomalies

Solid 30°N/S, Dotted 60°N/S *Tropical Avg SST anomalies shaded*

3-month smoother applied *LHF normalized by respective climatology*

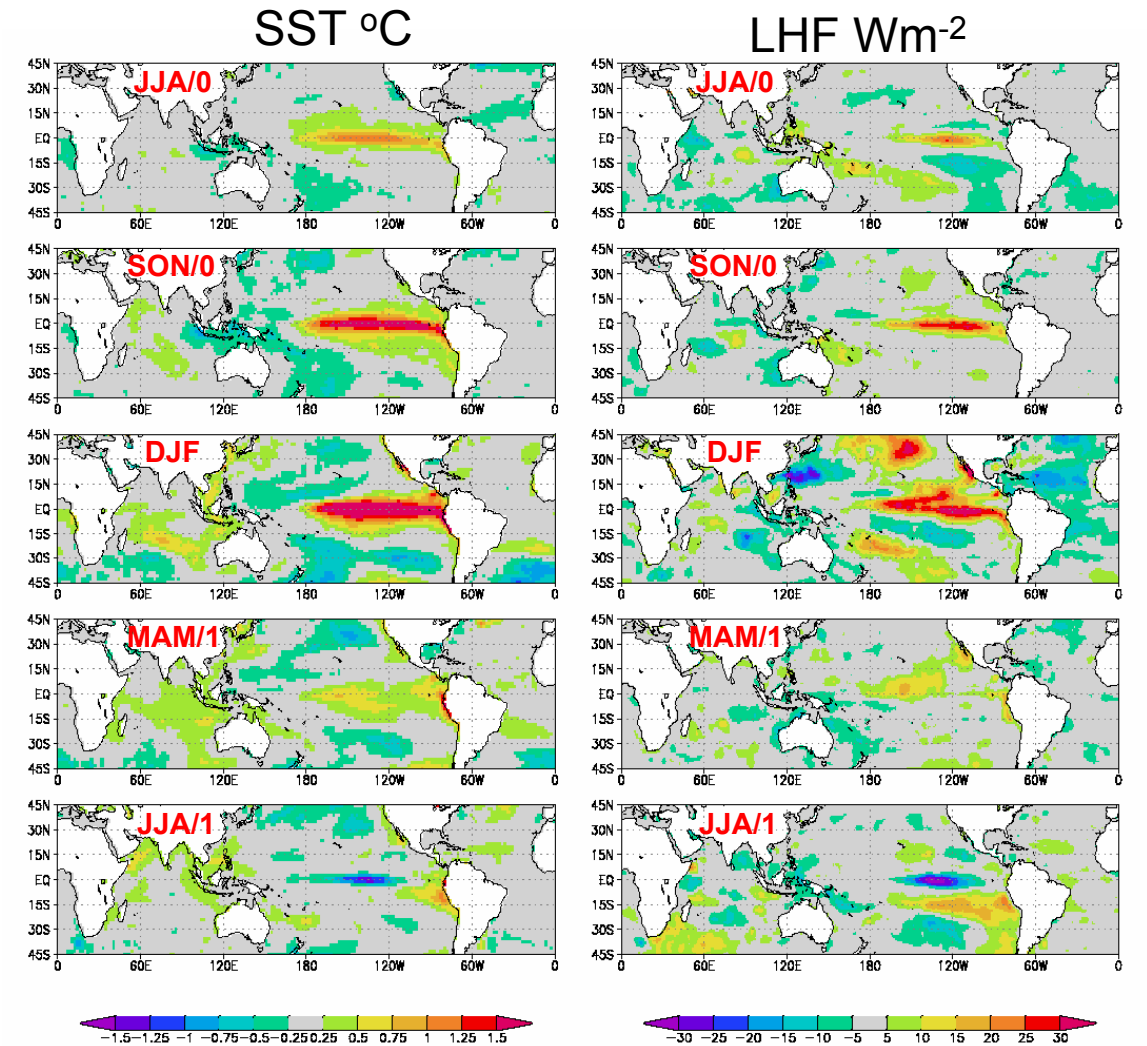


- ENSO, near-decadal and trend variations apparent
- LHF increases with time (RSS= 1.2 % dec^{-1}; WHOI = 2.4 % dec^{-1})
- RSS Δq ties much more closely to SST than WHOI, but both increase at ~0.04 g $Kg^{-1}dec^{-1}$ or 1.0 % dec^{-1}.
- Strong correlation between LHF and U (RSS=0.97, WHOI = 0.88)
- RSS winds have smaller increase (0.04 $ms^{-1}dec^{-1}$or 0.6% dec^{-1}) than WHOI (0.13 $ms^{-1}dec^{-1}$or 2.0 % dec^{-1})

Composite ENSO Warm Phase Anomaly Evolution

NCEP SST and WHOI OAFlux LHF

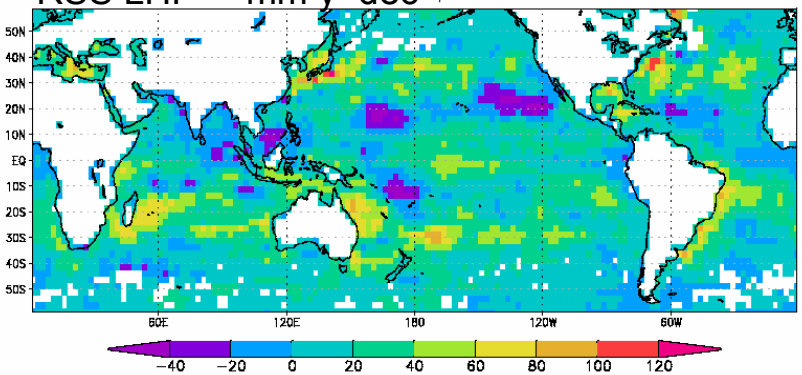
Events center on DJF 82/83, 86/87, 91/92, 94/95, 97/98, 02/03



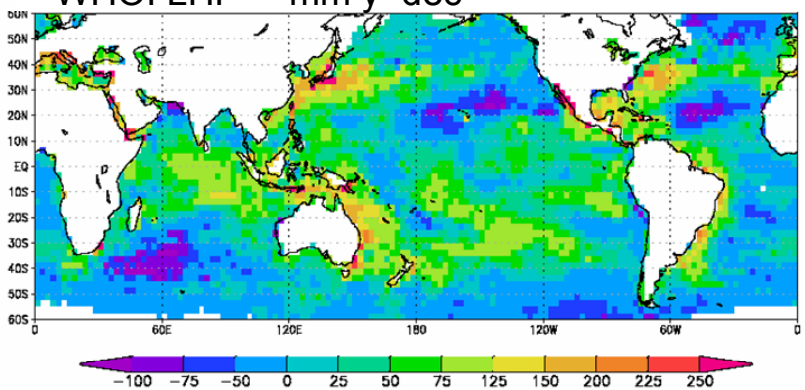
- E. Pacific elevated q_s-q_a and meridional winds increase LHF.
- Decreased trop N. ATL LHF with weakened ATL Hi press and reduced Hadley flow into Amazon
- Evolution of N. Pac cold SSTs in response to strengthened LHF.
- Warmer ATL SSTs and increased LHF following Summer.
- Initial cooling and increased LHF in E. IO followed by lagged warming of tropical IO

Linear Trend Patterns 1988-2006

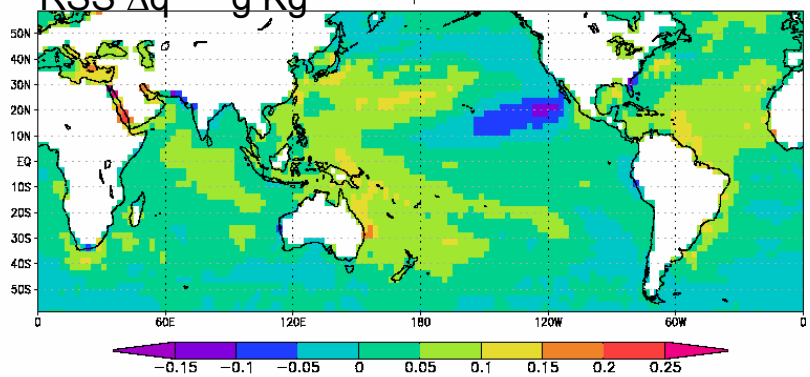
RSS LHF mm $y^{-1}dec^{-1}$



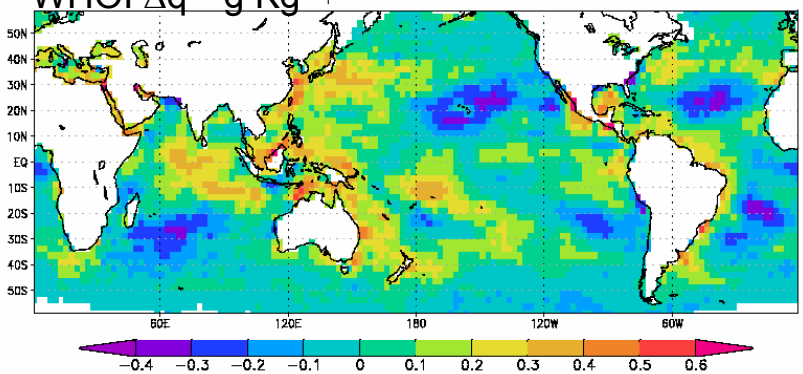
WHOI LHF mm $y^{-1}dec^{-1}$



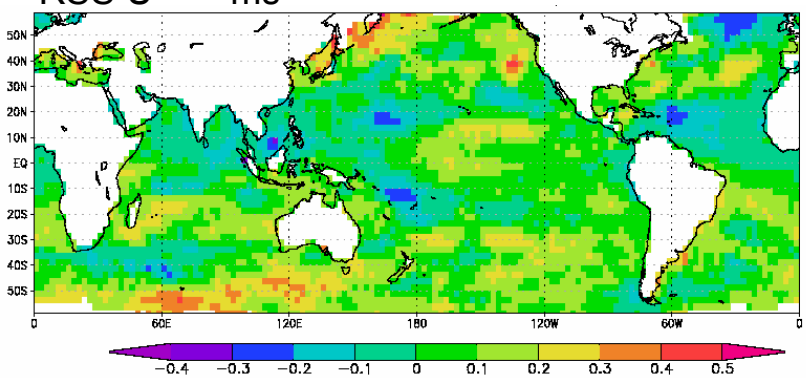
RSS Δq g Kg^{-1}



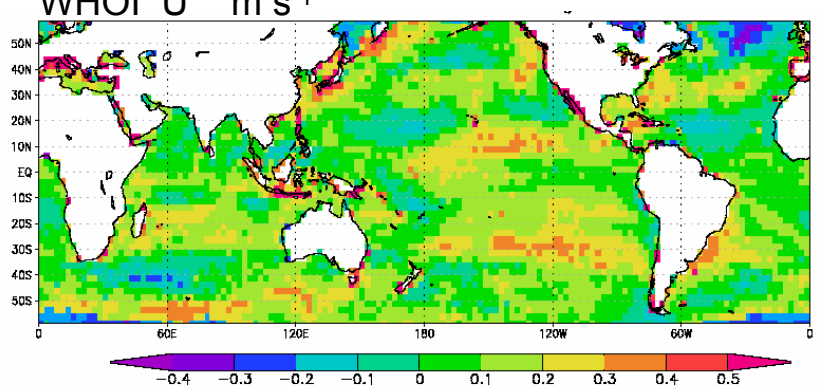
WHOI Δq g Kg^{-1}



RSS U ms^{-1}

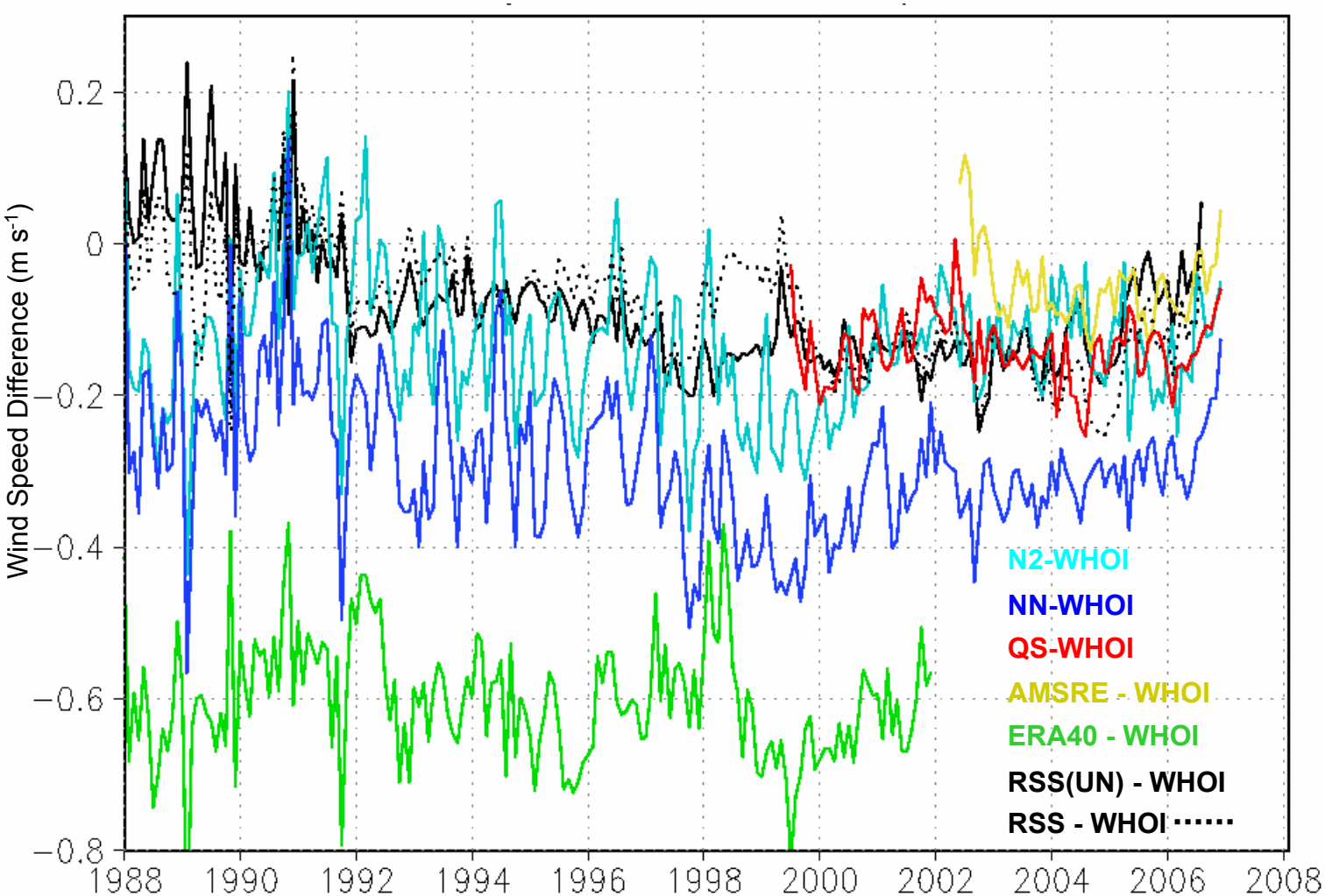


WHOI U m s^{-1}



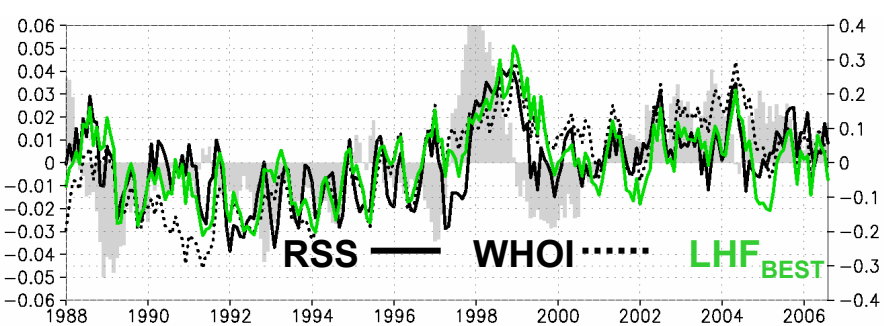
Wind Speed Differences with WHOI

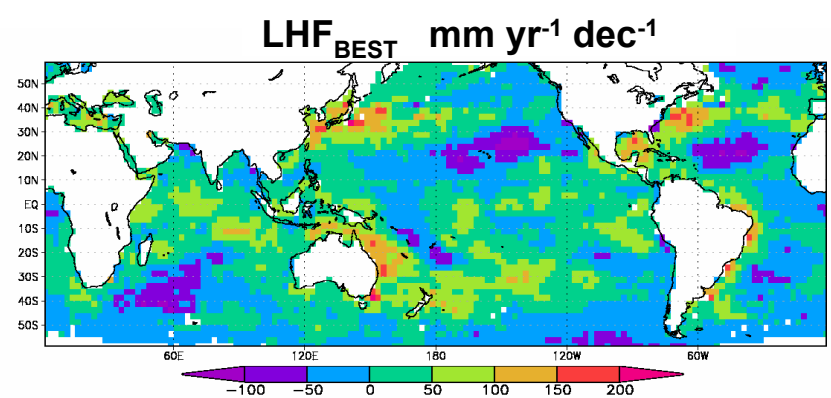
Tropical Average 30°N/S



Summary of RSS / WHOI Intercomparison:

- For tropical ocean averages, WHOI manifests a larger rate of increase in LHF, ~ 2.4 % dec^{-1} compared to 1.2 % dec^{-1} for RSS. This <u>*areal mean difference*</u> is driven by a larger increase in 10m wind speed for WHOI-- the origin of which is not yet clear.
- Δq values in RSS, by construction, contain variability related only to changes in SST and have about half the amplitude regionally as WHOI. This resulting RSS LHF regional trend patterns are likely weak and have too strong a resemblance to wind speed changes.
- In each analysis, however, there is strong regional cancellation of Δq contributions to tropically-averaged LHF changes.
- If we believe RSS winds to be more accurate we can rescaling monthly RSS flux maps by Δq(WHOI) / Δq(RSS) to gain a corrected flux estimate —similar in pattern to WHOI, but with a reduced tropical mean trend (1.2 % dec^{-1}).





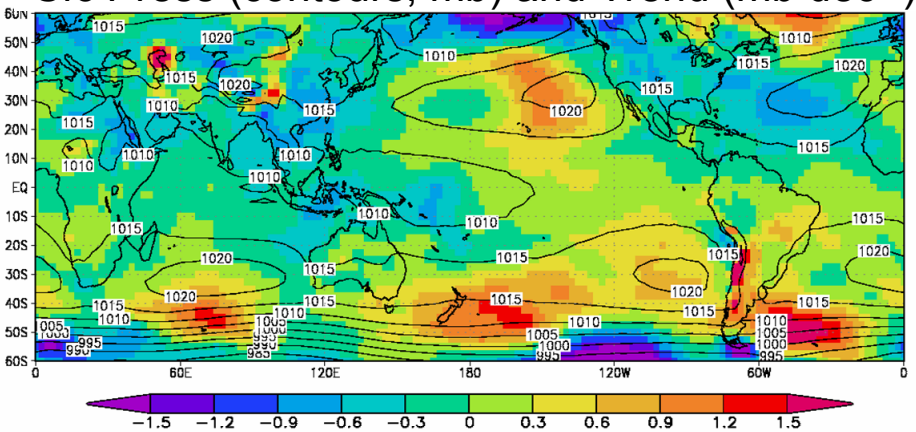
Evidence for Strengthening of Walker Circulation 1988-2006 Linear trends

-Sfc pressure gradient from E. Pac. Subtropical Highs to Indo-Pacific Warm Pool reinforced

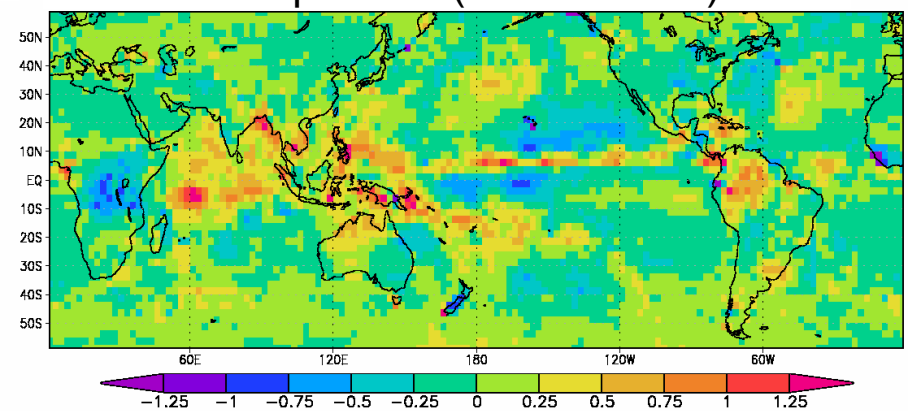
-Precipitation (GPCP) focuses over warm pool, E. Pac ITCZ narrows

-SST moves toward PDO-like configuration (negative phase)

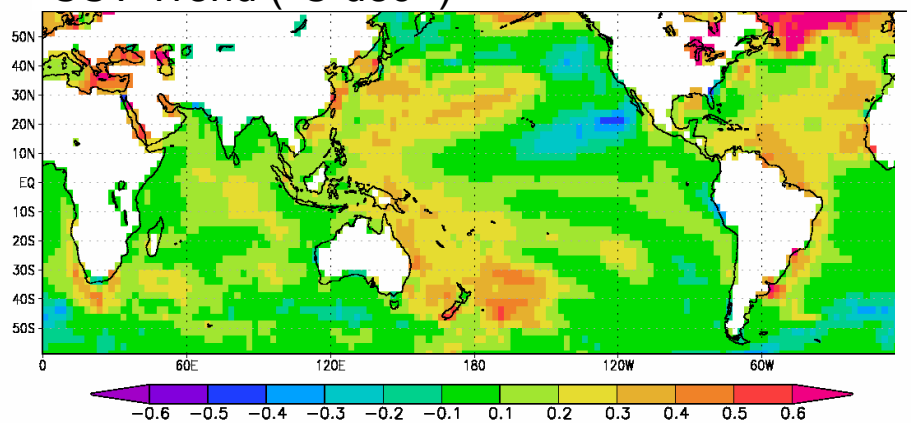
Sfc Press (contours, mb) and Trend (mb dec^{-1})



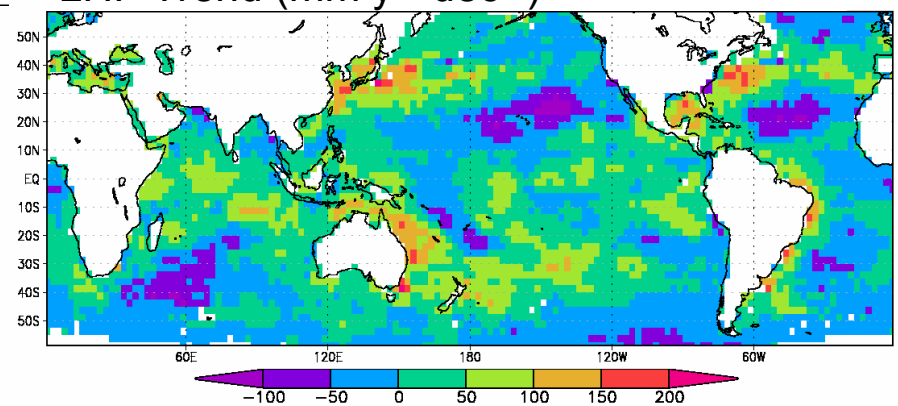
GPCP Precip Trend (mm d^{-1} dec^{-1})



SST Trend (^{o}C dec^{-1})



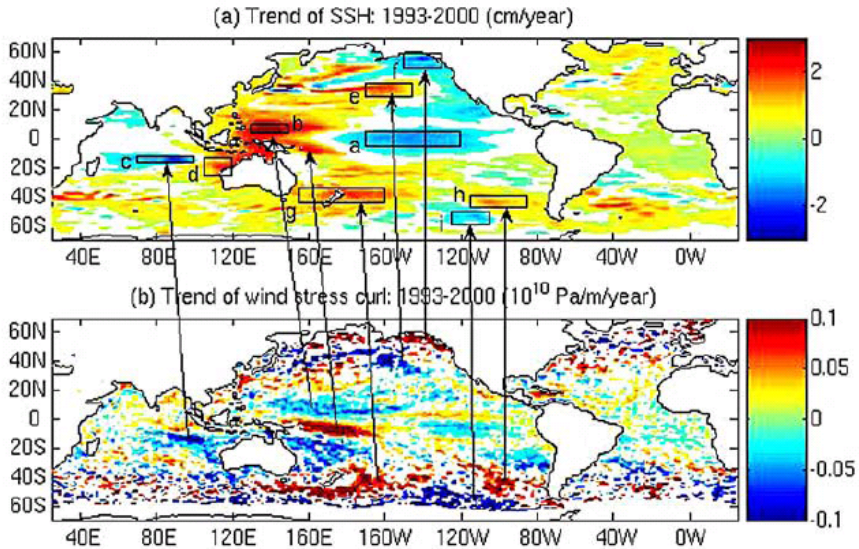
LHF Trend (mm y^{-1} dec^{-1})



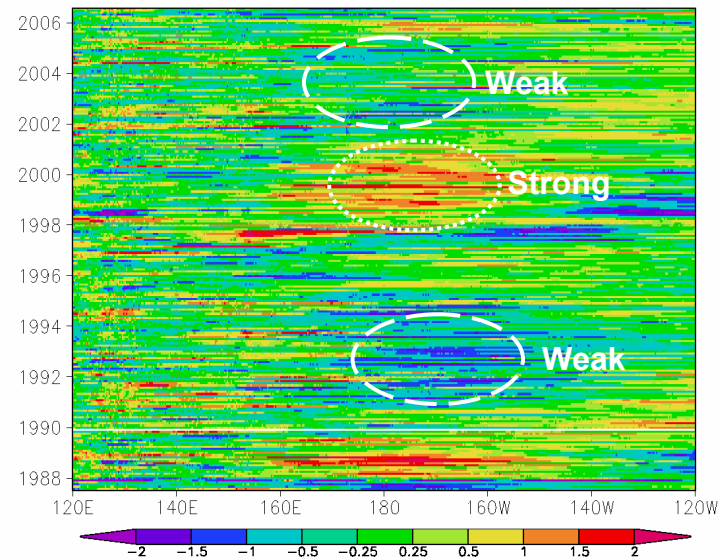
Decadal Variations in Near-Equatorial Wind Stress and Sea-Surface Height

- During mid-1990s stronger easterly trade winds in Equatorial Pacific recovered after prolonged warm SST period. Coherent changes in SSH also evolved.
- Post-2000 period exhibits relaxation of the prolonged strong easterlies, cooler SSTs.

1993-2000 trends in SSH (TOPEX/POSEIDON and JASON-1) and Wind Stress Curl (ERS-1, QuikSCAT) ***Lee and McPhaden (2007 GRL)***



SSM/I Surface Wind Speed Anomalies 5.0 º N/S ***(RSS V6)***



Integration / Context / Implications

- LHF increases over 1990s are linked to coherent SST, Δq, U and precipitation changes that are all consistent with a recent strengthening of the Walker circulation. (This contrasts with a multi-decadal weakening signal.)

- Independent scatterometer wind stress and altimeter SSH measurements are consistent with SST, surface pressure variation during this period. Intra-decadal to decadal scale LHF variations appear to be part and parcel of these ocean-atmosphere couplings spanning the Pacific basin.

- Several studies (e.g. Barlow et al., 2001; Schubert et al., 2004; Meehl and Lu, 2004) have related associated PDO-like SST configurations to hydrologic anomalies over the continental U.S.

- It is now the prevailing view (Wheeler et al., 2003; and Schneider and Cornuelle, 2007), that the PDO is not an independent dynamic mode of variability (e.g. as ENSO). Rather it's the result of reddening of the SST spectrum by ENSO, Kuroshio ocean dynamics, and atmospheric internal variability.

NEWS Challenge:

Entrain expertise & insights of ocean modeling community (especially those assimilating wind stress, altimetric measurements) to aid in:

- Determining / understanding how / when / where ocean forces atmosphere and vice versa. (Go beyond just tropical ocean forces atmosphere, mid-lat atmosphere forces oceans.) Quantify net surface flux components.
- Leveraging this knowledge to guide use / improvement of coupled modeling in NEWS objectives.