Climate Variability and the Tropical Oceans During the Satellite Era: Integrating Observations and Reanalyses

F. R. Robertson

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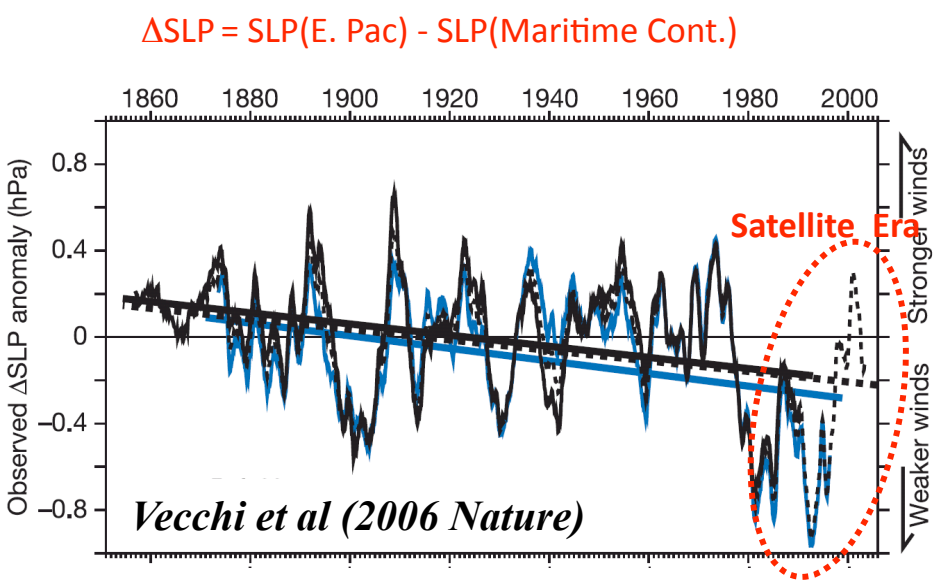
- What evidence do we have that satellite derived estimates of water and energy fluxes can capture, quantify climate variability during the satellite era (~1979 →)?

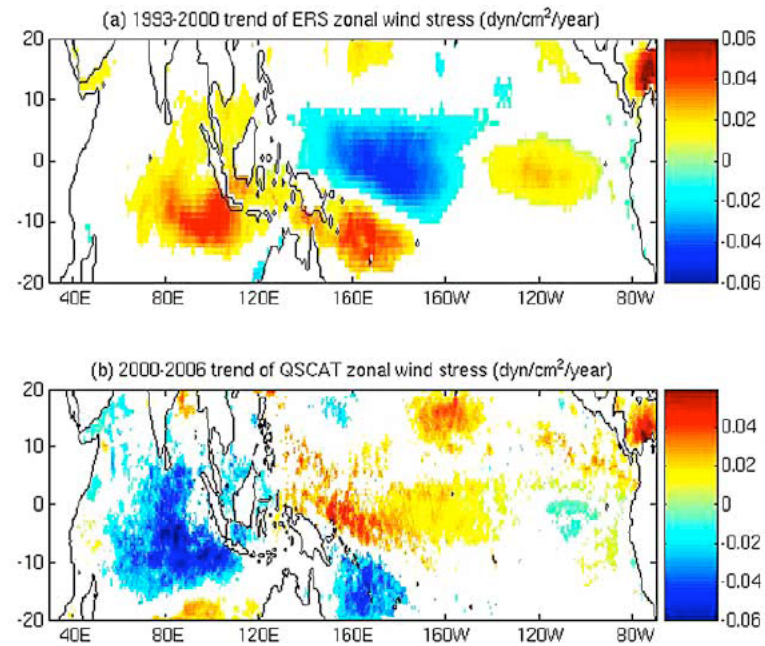
-Is it likely that MERRA will help in confirming flux variability, ferreting out sensitivities / feedbacks and scaling relationships?

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).

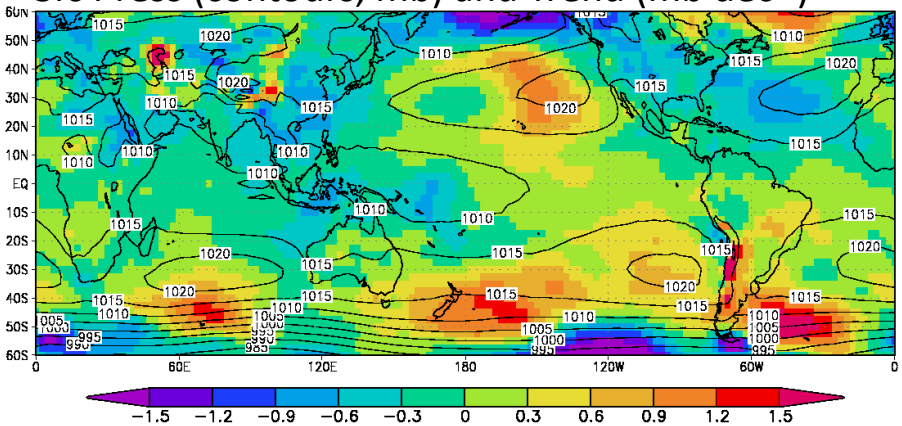
Evidence for Strengthening of Walker Circulation
1988-2006 Linear trends

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

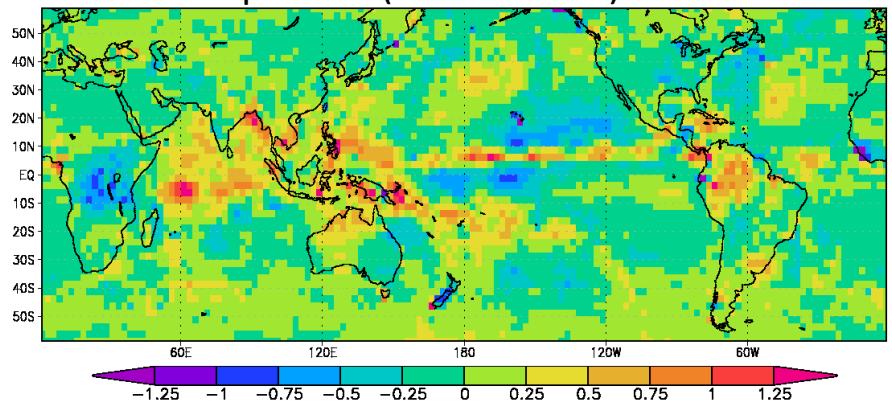
-Precipitation (GPCP) focuses over warm pool, E. Pac ITCZ narrows

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

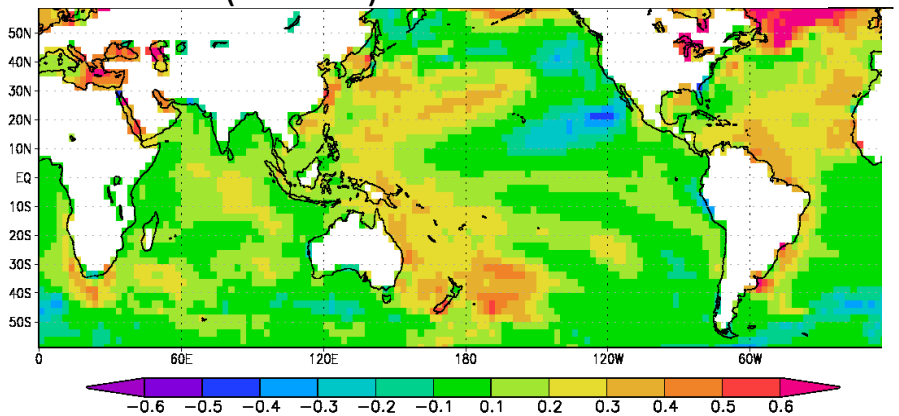
Sfc Press (contours, mb) and Trend (mb dec^{-1})



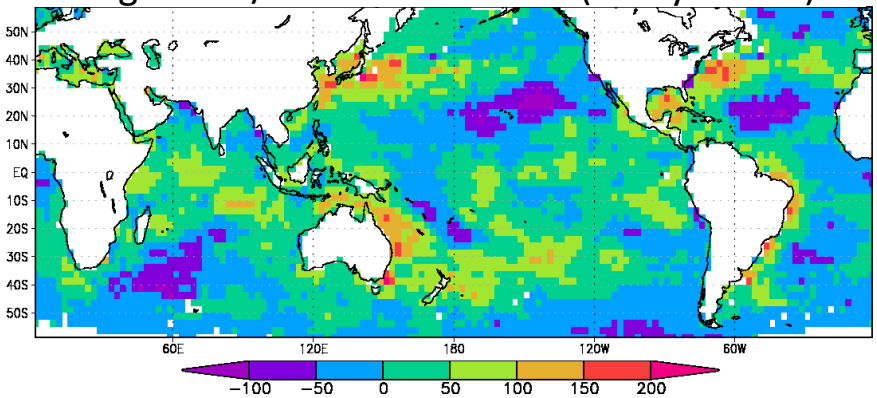
GPCP Precip Trend (mm d^{-1} dec^{-1})



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

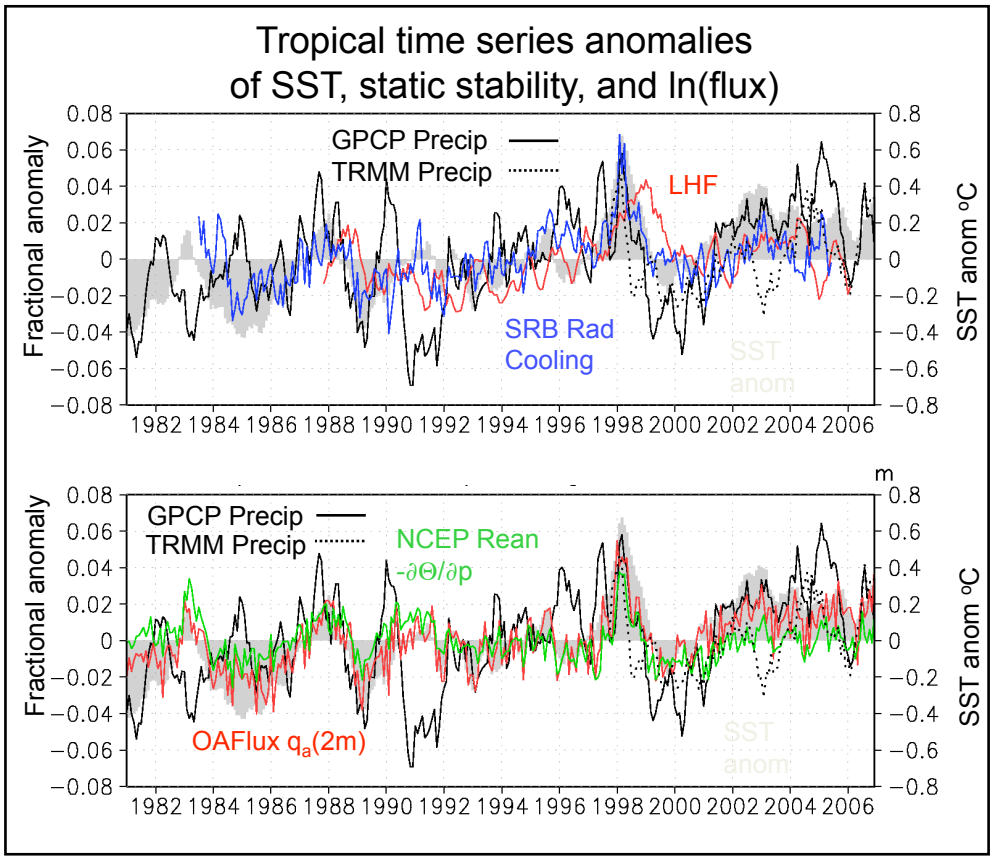


Merged RSS/OAFlux LHF Trend (mm y^{-1} dec^{-1})



Scaling Relationships for Water and Energy Flux Coupling to SST Changes

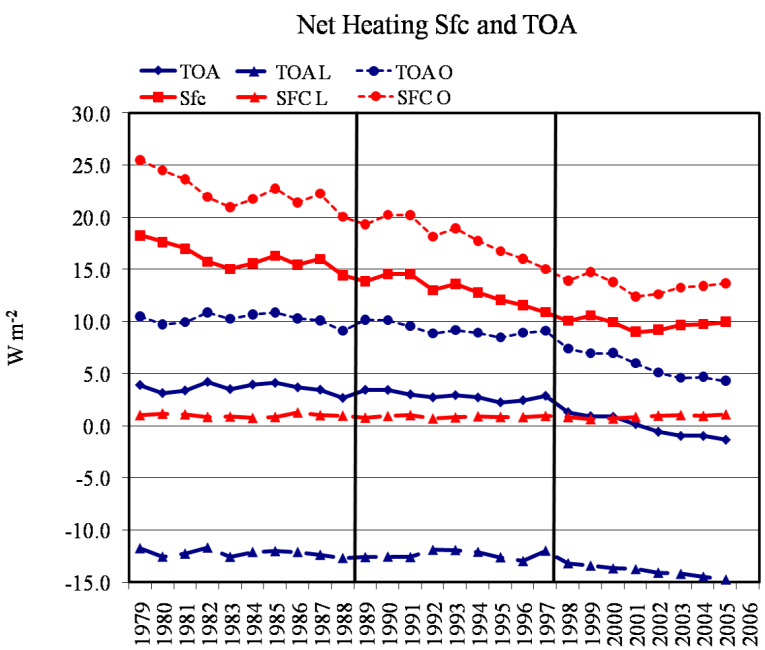
In a warmer climate it is generally expected that the convective mass cycling rate must decrease to accommodate stronger static stability and water vapor lapse rates (Betts and Ridgeway, 1989; Held and Soden 2007). In terms of fractional variations, the approximate water balance is: $\delta M/M \approx \delta P/P - \delta q/q \approx \delta P/P - .07\delta SST$ where M, P, SST and q are convective mass flux, precipitation, sea-sfc temp and boundary layer specific humidity, respectively.

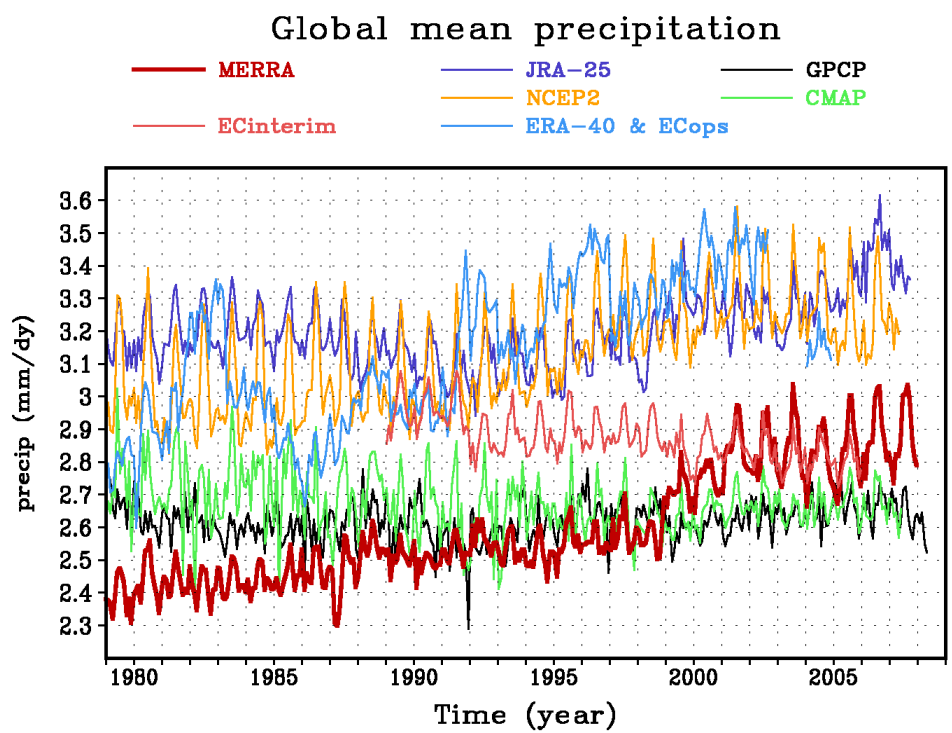


- OAFlux 2m q_a follows Clausis-Clapeyron scaling (~7 %/ °C δSST) very closely.
- Note, however, GPCP precipitation variations are systematically *larger* than those of q_a suggesting that convective mass flux variations cannot have changed significantly in response to SST variations.
- From the heat budget perspective, SRB radiative cooling variations are also of the same size as static stability variations, consistent evidence that the vertical mass flux variations are not decreasing with increased SST.
- ENSO-scale LHF variations tend to lag precipitation amounts due to ENSO-induced remote SST warming in other basins and subsequent recovery of tropical easterlies after ENSO SST anomaly peak.

Impact of Time-Varying Observational Data Streams on MERRA Fluxes

- Time-dependent biases in q_v, T, u, v analysis increments result from varying satellite information content interacting with a constant but imperfect GEOS5 assimilation model
- Model physics respond to this varying "forcing" with artifacts in fluxes



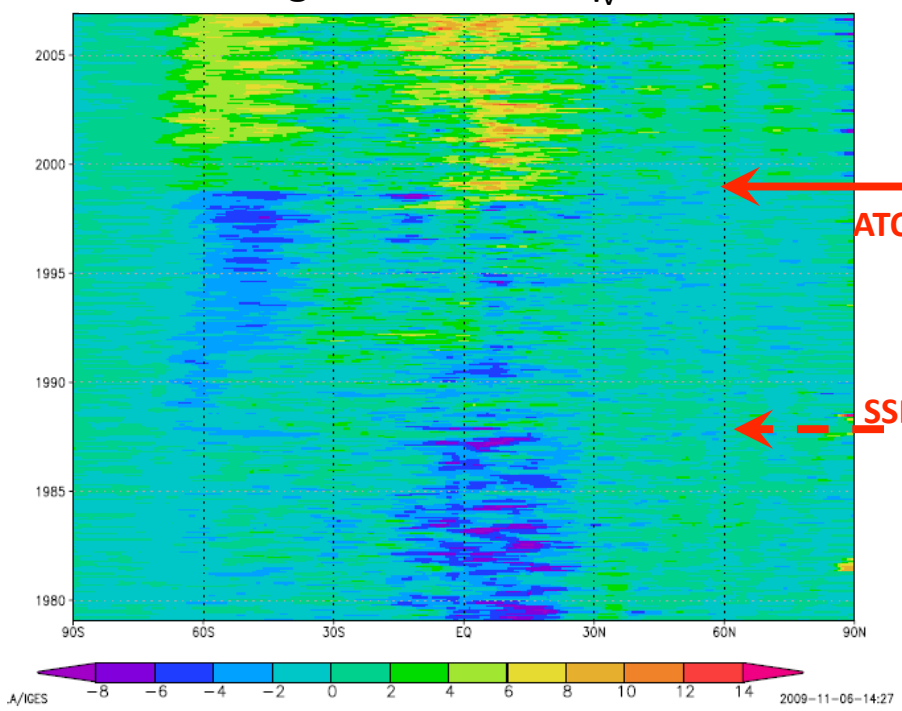


Time Dependent q_v Analysis Increments Affect Rainfall

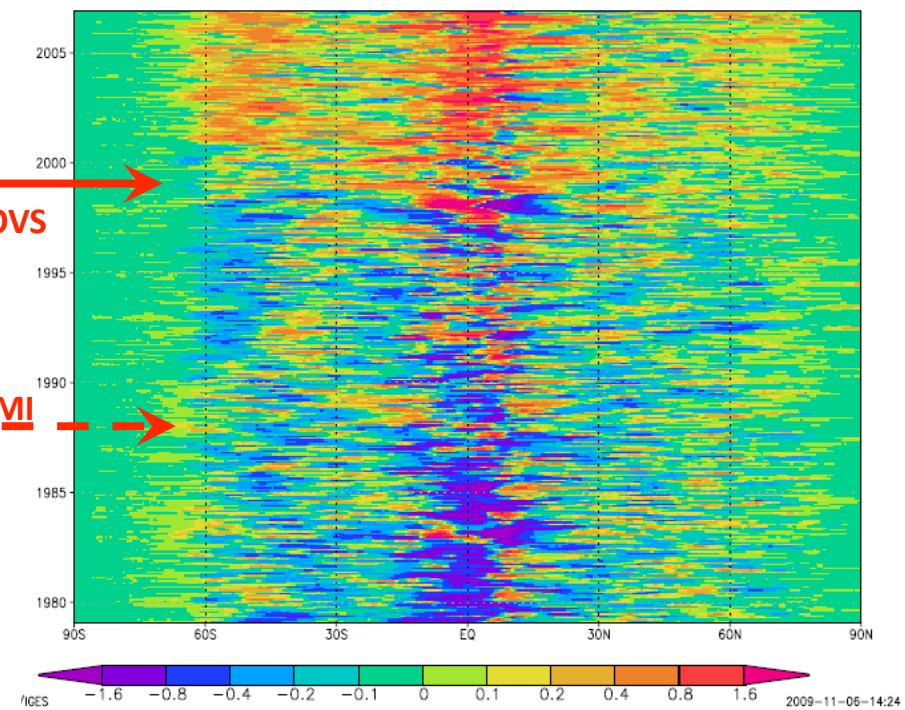
Zonal Mean Time Series (Mean Annual Cycle Removed)

- Onset of ATOVS data in 1998 increases convective moisture source (SSMI in 1988 less so). Temperature tendency (not shown) also impacts precipitation
- Leading mode of precipitation variability is non-physical trend, strongly coupled to the moisture increment

Vert Integ zonal mean $dq_v dt$-ana



Zonal mean MERRA precip



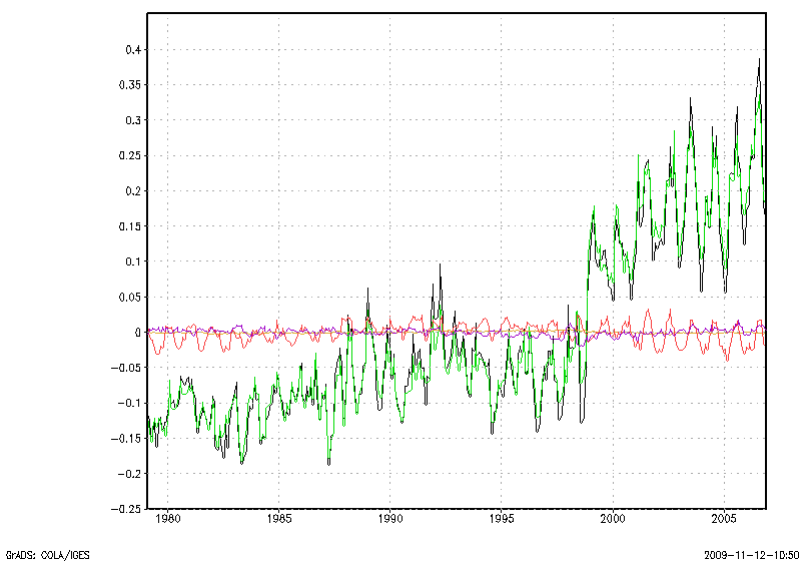
ATOVS

SSMI

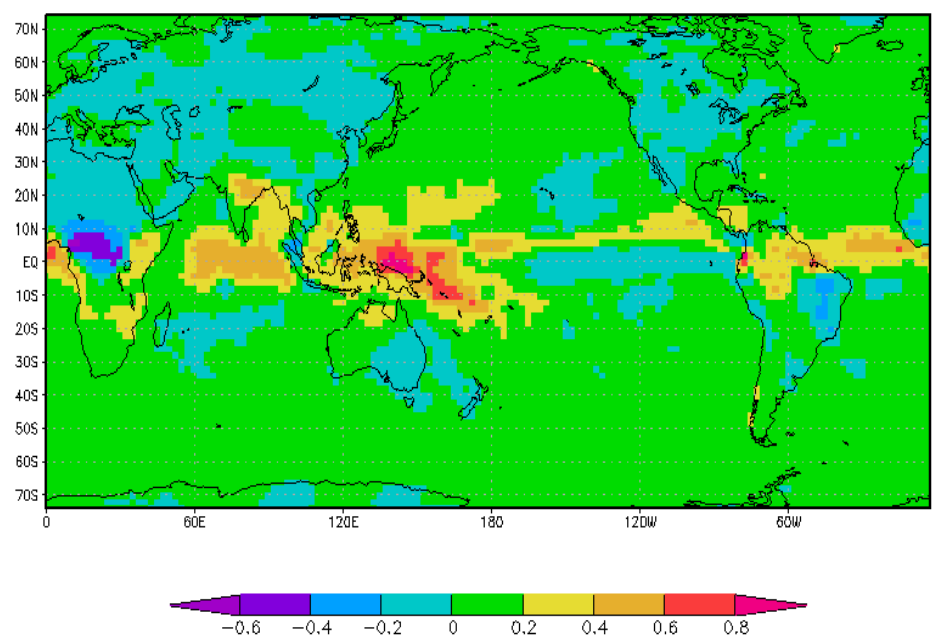
SVD Analysis May Enable Removal of Spurious Precip Signal to First Order

1. Perform singular value decomposition (SVD) analysis of zonal mean vertically-integrated dq_v/dt and precipitation. This largely isolates the artifact common to both
2. Regress precipitation <u>fields</u> onto the leading <u>zonal</u> singular vector of dq_v/dt mode
3. Time-dependent correction field is the product of the zonal singular vector and regression pattern that is then eliminated from the precipitation.

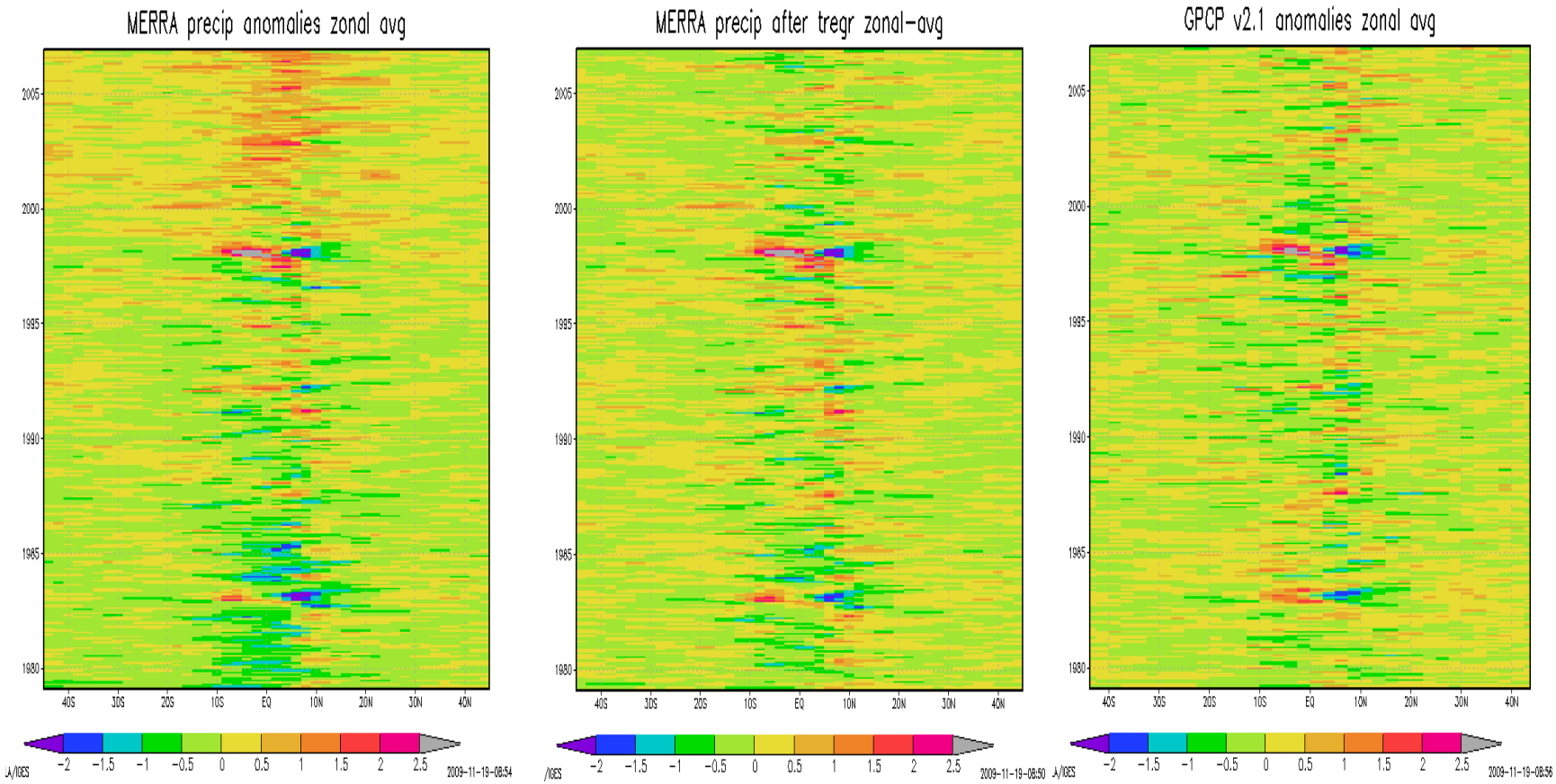
Zonal mean $dq_v dt$ (black) and SVD modes (green is 1st)



Precipitation regression map

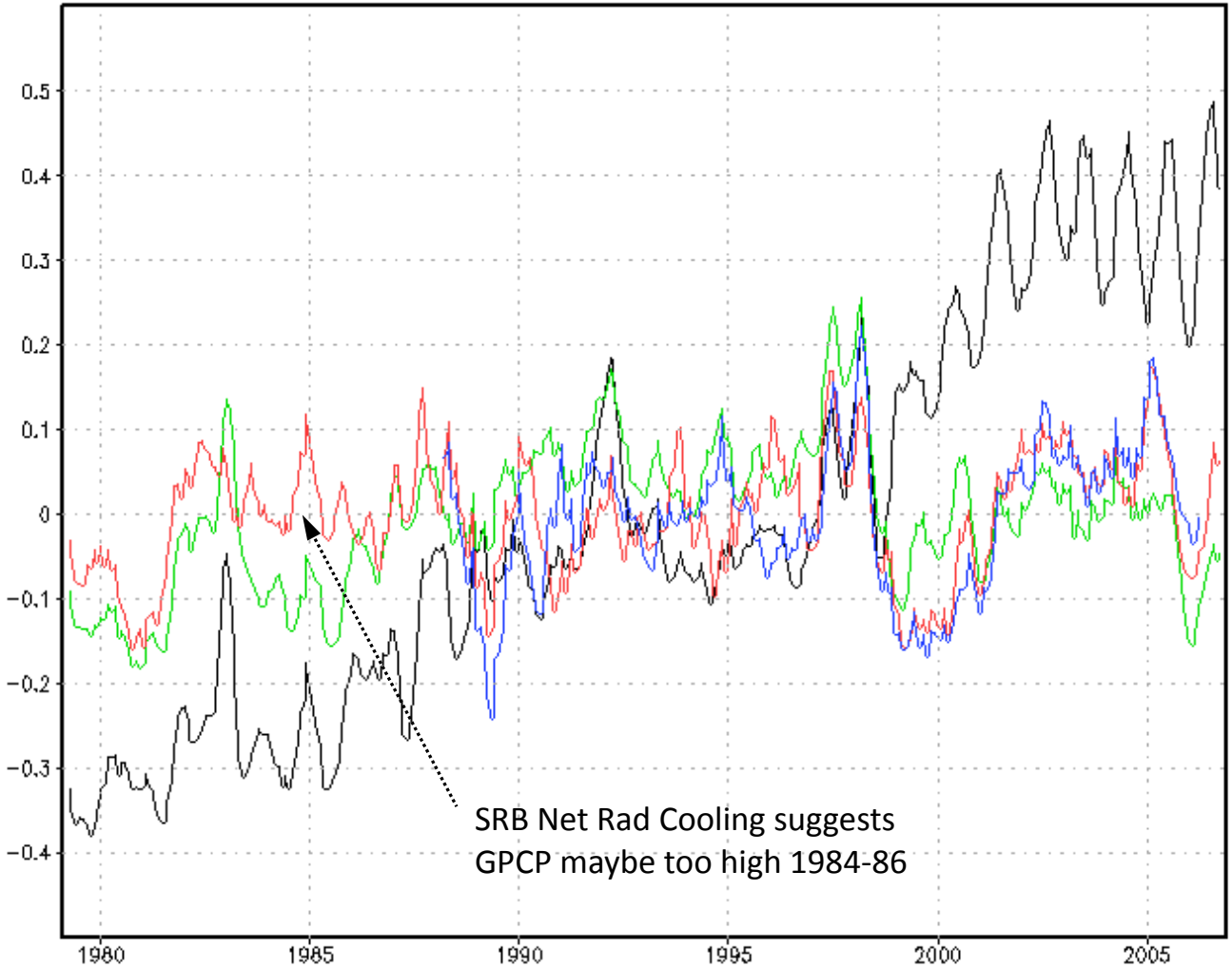


Results of Correction by Linear Regression to Remove Artifact with Leading $dq_v dt$-ana Mode



Ocean 45 N/S Precipitation mm d^{-1}

MERRA Corrected MERRA, GPCP, RSS Hilburn/Wentz



Integration / Context / Implications

- Ample evidence that precip, radiation, LHF retrievals have some consistent signals of climate variability over the satellite era. Intra-decadal to decadal scale LHF variations appear to be part and parcel of these ocean-atmosphere couplings spanning the Pacific basin.

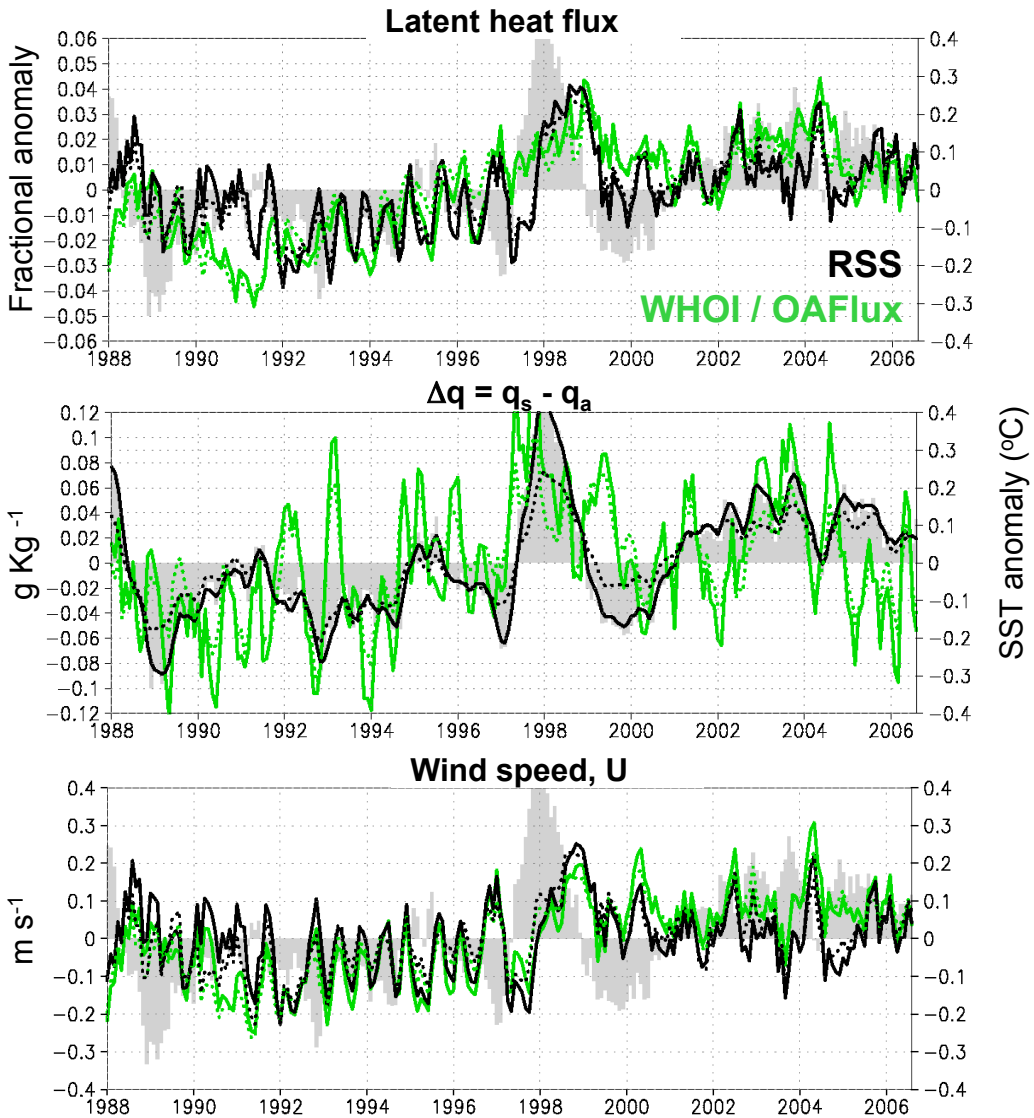
- Because of evolving observing system (e.g. evolution of passive microwave remote sensing of moisture) time dependent corrections to model first guess through analysis increment tendency have induced non-physical trends in fluxes. Techniques for isolating instrument-related step functions in fluxes and q, T increments show promise for greatly reducing these artifacts.

- **NEWS Challenge: To what extent can NEWS flux retrievals, reanalyses, and model experiments be integrated to comment on big questions: Is WEC changing regionally, globally? How has Walker / Hadley varied over the satellite record? Can we reconcile model / observed WEC scaling relationships?**

B A C K U P S

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*

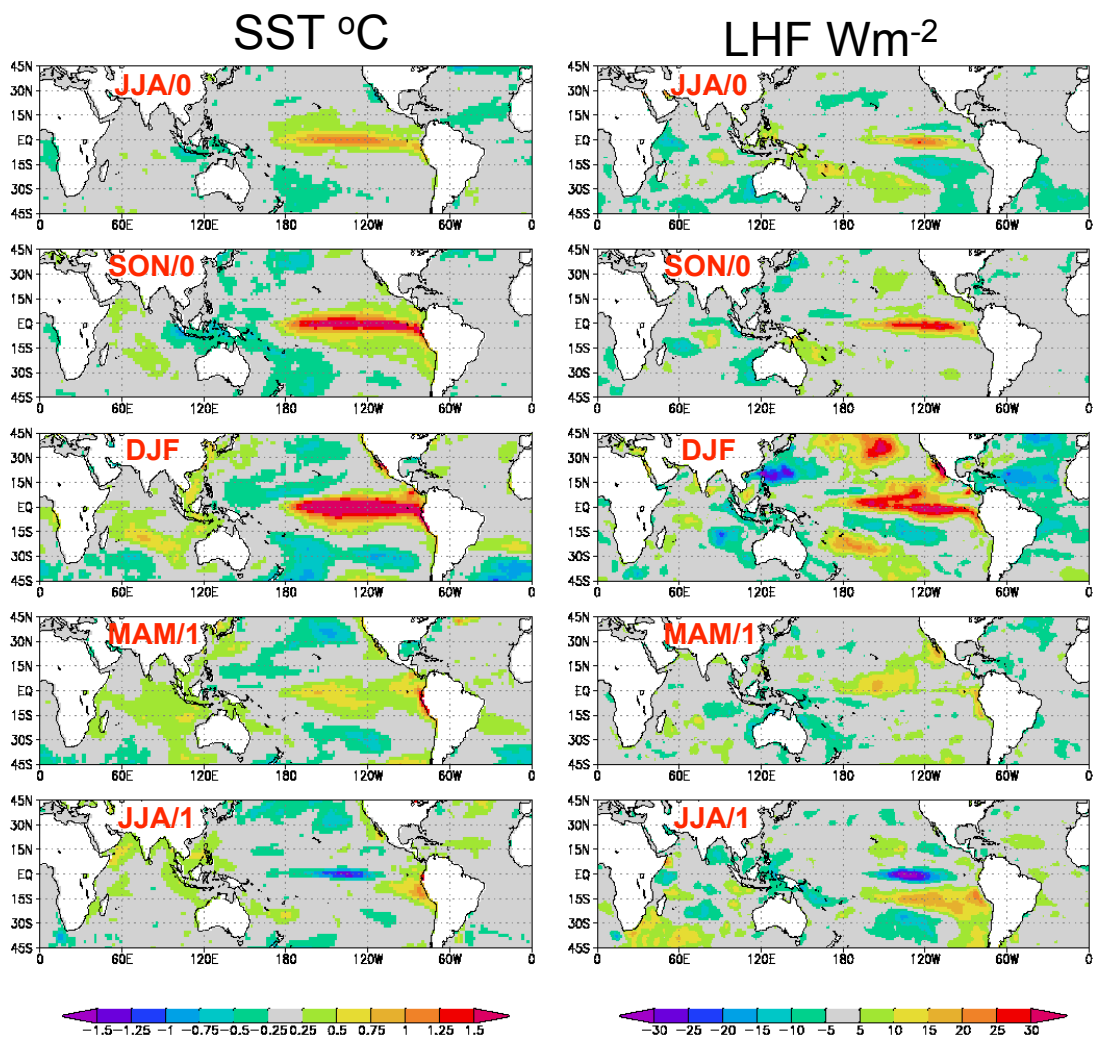


- ENSO, near-decadal and trend variations apparent
- LHF increases with time (RSS= 1.2 % dec^{-1}; WHOI = 2.4 % dec^{-1})
- RSS Δq ties much more closely to SST than WHOI, but both increase at ~0.04 g $Kg^{-1}dec^{-1}$ or 1.0 % dec^{-1}.
- Strong correlation between LHF and U (RSS=0.97, WHOI = 0.88)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

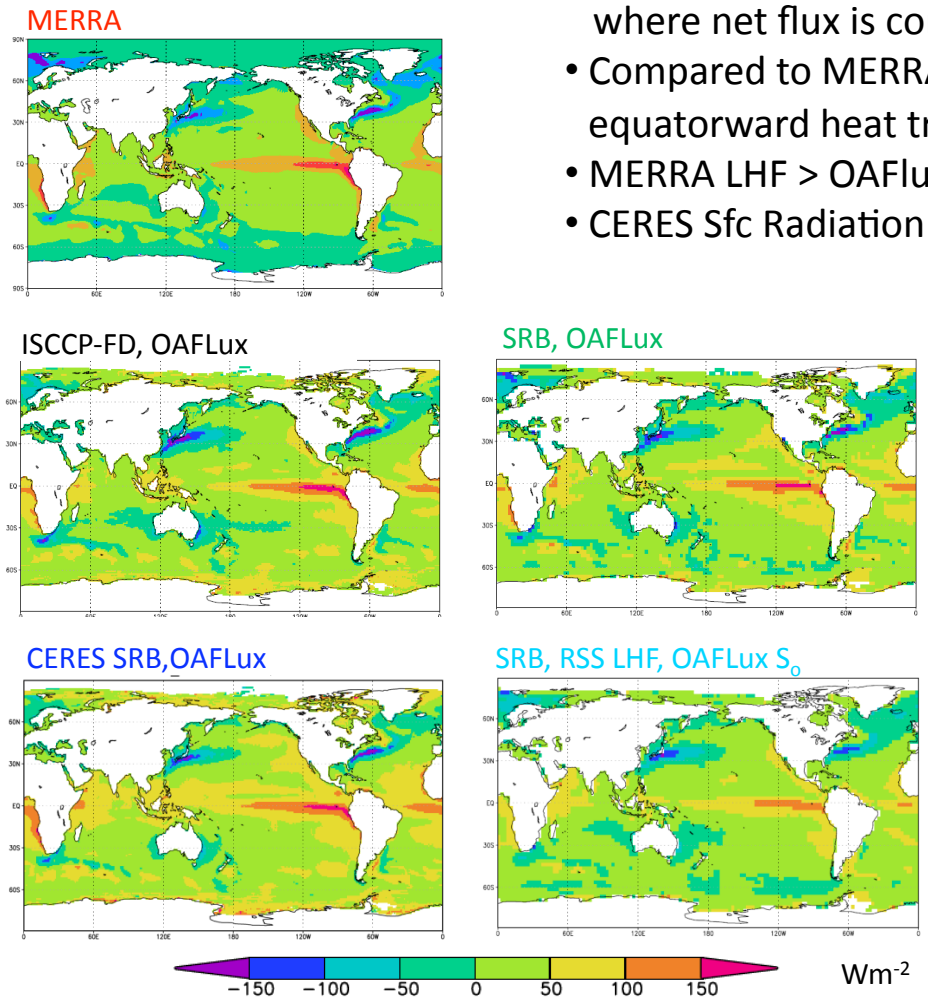


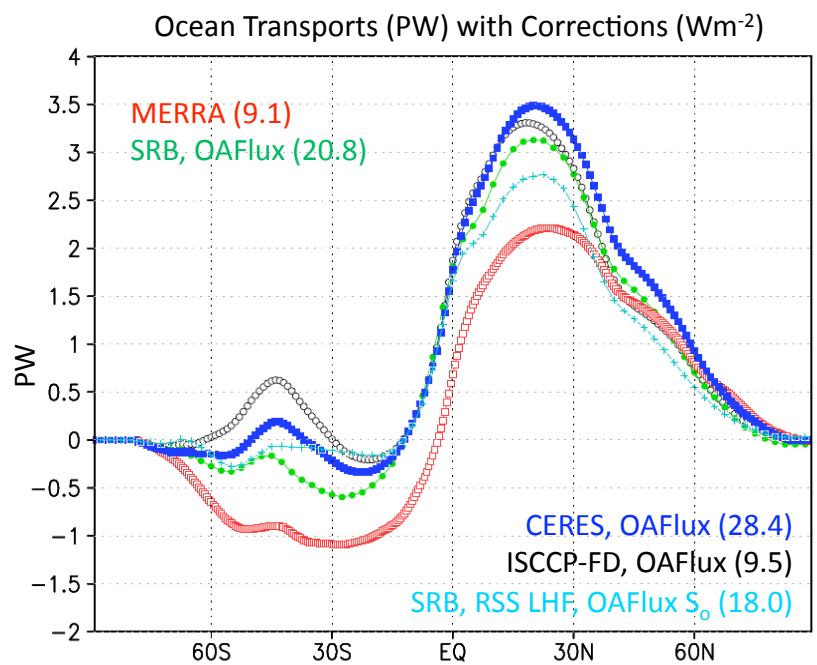
- E. Pacific elevated q_s-q_a and meridional winds increase LHF.
- Decreased trop N. ATL LHF with weakened ATL Hi press and reduced Hadley flow into Amazon
- Evolution of N. Pac cold SSTs in response to strengthened LHF.
- Warmer ATL SSTs and increased LHF following Summer.
- Initial cooling and increased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

Net Surface Heat Flux and Implied Northward Ocean Heat Transport 1999-2005

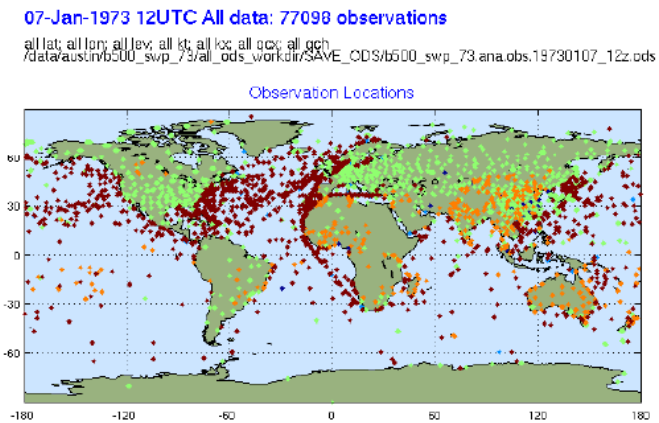
Flux uncertainties yield transport uncertainties of order 1 PW

- Transport calculation: $T_o(\phi) = 2\pi a \int_{-\pi/2}^{\phi} (\langle N(\phi) \rangle - \alpha) \cos(\phi') d\phi'$
  where net flux is corrected by a constant offset , α
- Compared to MERRA, satellite retrievals biased toward equatorward heat transport in Southern Ocean (SO)
- MERRA LHF > OAFlux in SO; RSS LHF > OAFlux in tropics
- CERES Sfc Radiation > SRB, ISCCP

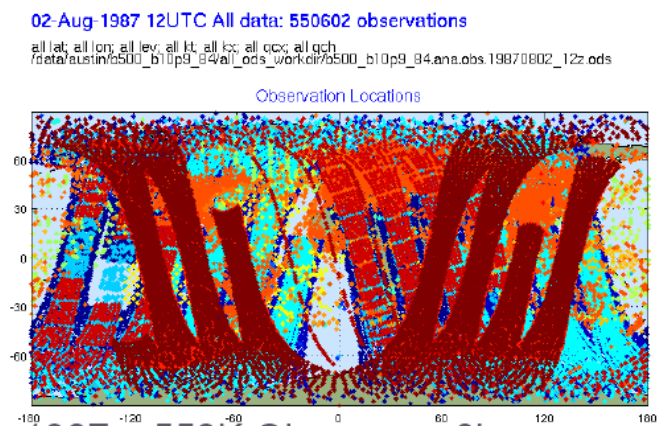




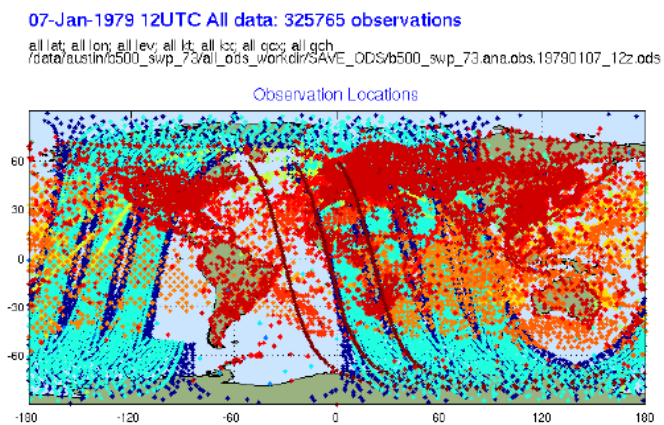
The Changing Observing System



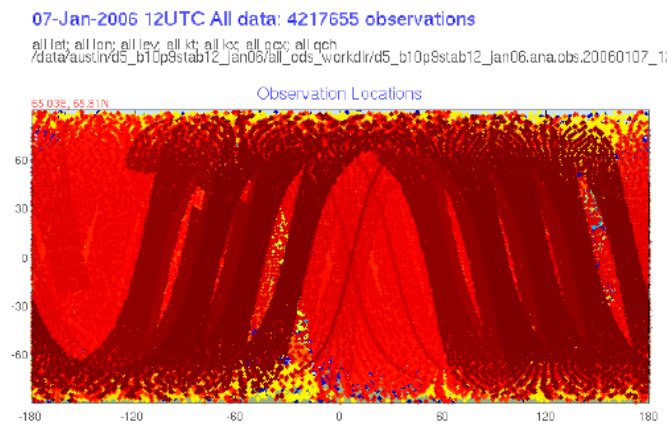
1973 – 77K Obs every 6hrs



1987 – 550K Obs every 6hrs



1979 – 325K Obs every 6hrs



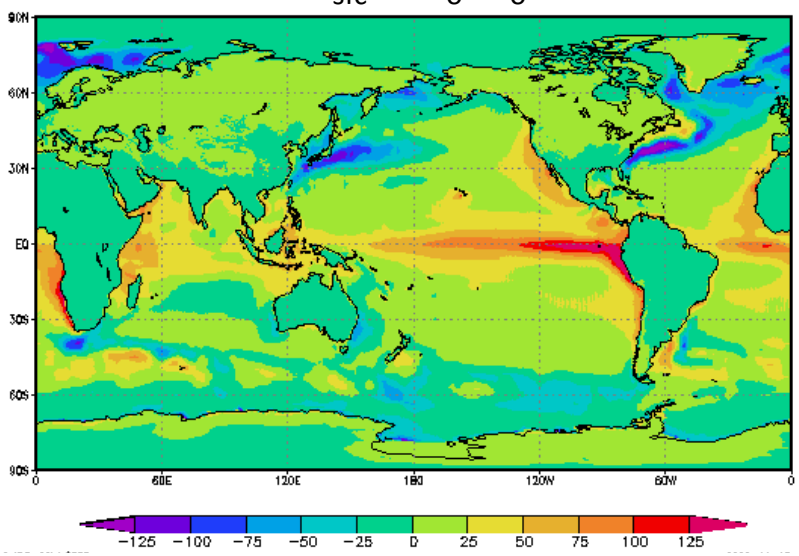
2006 – 4.2M Obs every 6hrs

MERRA Surface Water and Energy Flux (Wm^{-2}) 2000-2006 Climatology

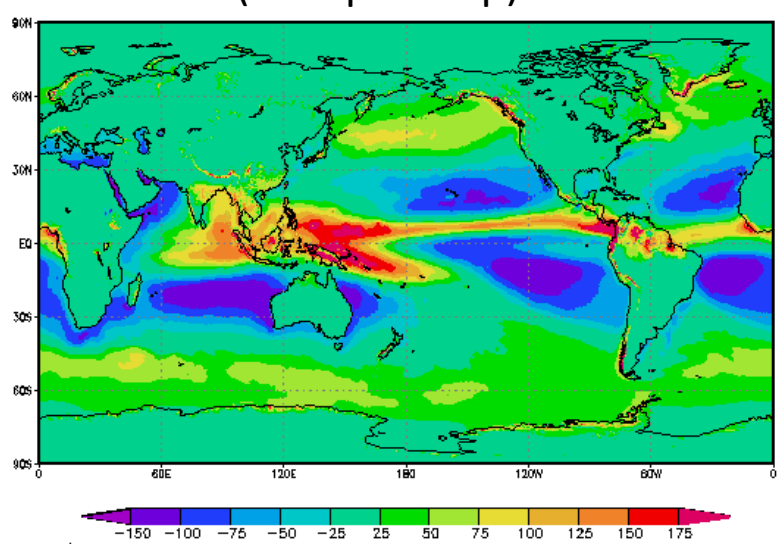
- Net ocean heat flux shows reasonable patterns but positive storage bias. ~No net storage over land is good sign.
- P-E ~ moisture convergence is realistic over oceans (weak over land?).

Net down sfc energy flux

$Rn_{sfc} - LE_o - S_o$



L(Precip – Evap)



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

- Pursue correction for MERRA fluxes & develop methodology for heat and moisture transport
- 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.