Interannual to Decadal Variability of Ocean Evaporation in Climate Reanalyses: Efforts at Refined Estimates

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A Hierarchy of Global Ocean LHF Estimates

←More Observ Constrained

AGCMs w/ Specified SSTs (AMIPs) GEOS-5, ERA-20CM Ensembles

Incorporate best historical estimates of SST, sea ice, radiative forcing Atmospheric "weather noise" is inconsistent with specified SST so sfc fluxes can be wrong sign (e.g. Indian Ocean Monsoon, high latitude oceans). Averaging over ensemble members helps isolate SST-forced signal.

Reduced Observational Reanalyses: NOAA 20CR V2C, ERA-20C, CERA-20C

Incorporate observed Sfc Press (20CR) and Marine Winds (ERA-20C, CERA-20C) to recover much of the evaporation induced by true synoptic or weather "noise".

Comprehensive Reanalyses (MERRA-2, JRA-55, ERA-I, CERA-SAT)

Full suite of observational constraints- both conventional and remote sensing. But… substantial uncertainties owing to evolving satellite observing system.

Multi-source Statistically Blended OAFlux, LargeYeager

Blend reanalysis, satellite, and ocean buoy information. While climatological biases are removed, non-physical trends or variations in components remain.

"Observations"

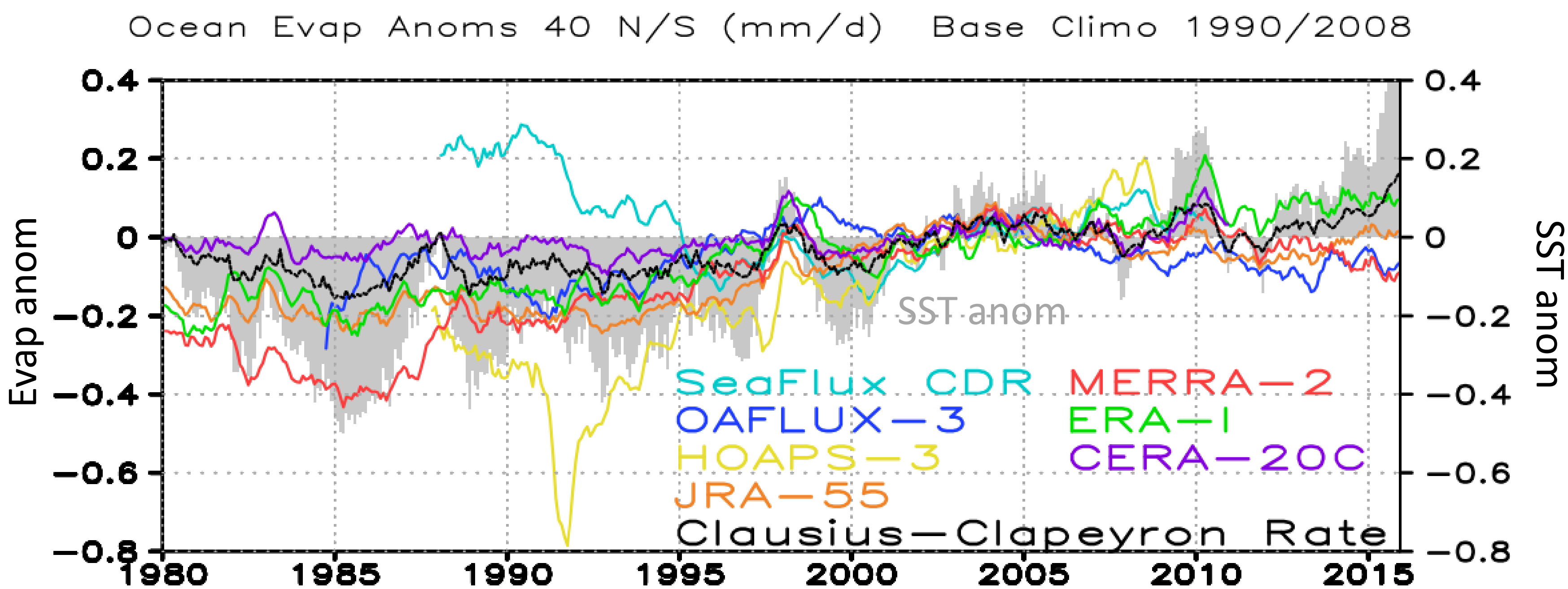
Satellite Retrievals GSSTF3, SeaFlux, HOAPS3…

Global coverage. Retrieved near sfc wind speed, & humidity used with SST to drive accurate bulk aerodynamic flux estimates. Satellite inter-calibration, spacecraft pointing variations crucial. Short record (1987-present).

In situ Measurements ICOADS, IVAD, Res Cruises

VOS and buoys offer direct measurements. Sparse data coverage (esp south of 30S. Changes in measurement techniques (e.g. shipboard anemometer height).

Substantial Disparities Exist in Global Ocean Evaporation Estimates



- Wide disparities in values, especially pre-2000s when SSMI sensor population is increasing. (Starts in Aug 1987)
- Slopes / trends of various estimates generally exceed C-C rate. How much is Decadal Variability? How much is artifact from changing satellite assimilation constraints?

To what extent can we understand, estimate, and remove these spurious signals?

A Taylor Series Expansion of Bulk Aerodynamic Evaporation Around Monthly Climatology

As in Richter and Xie (2008), Lorenz et al (2010) we first write the bulk formula for evaporation as a function of SST, Relative Humidity, Wind Speed, and Stability:

near-sfc q_a

$$E = C_E \rho_a U q_o \left[q_s(SST) - RH \cdot q_s(SST + S) \right]$$

where we use the analytical expression for saturation specific humidity,

$$q_s(SST) = q_o e^{b(SST)} \quad b = e^{(a - b/SST - c\ln(SST))} \qquad S = T_{air} - SST$$

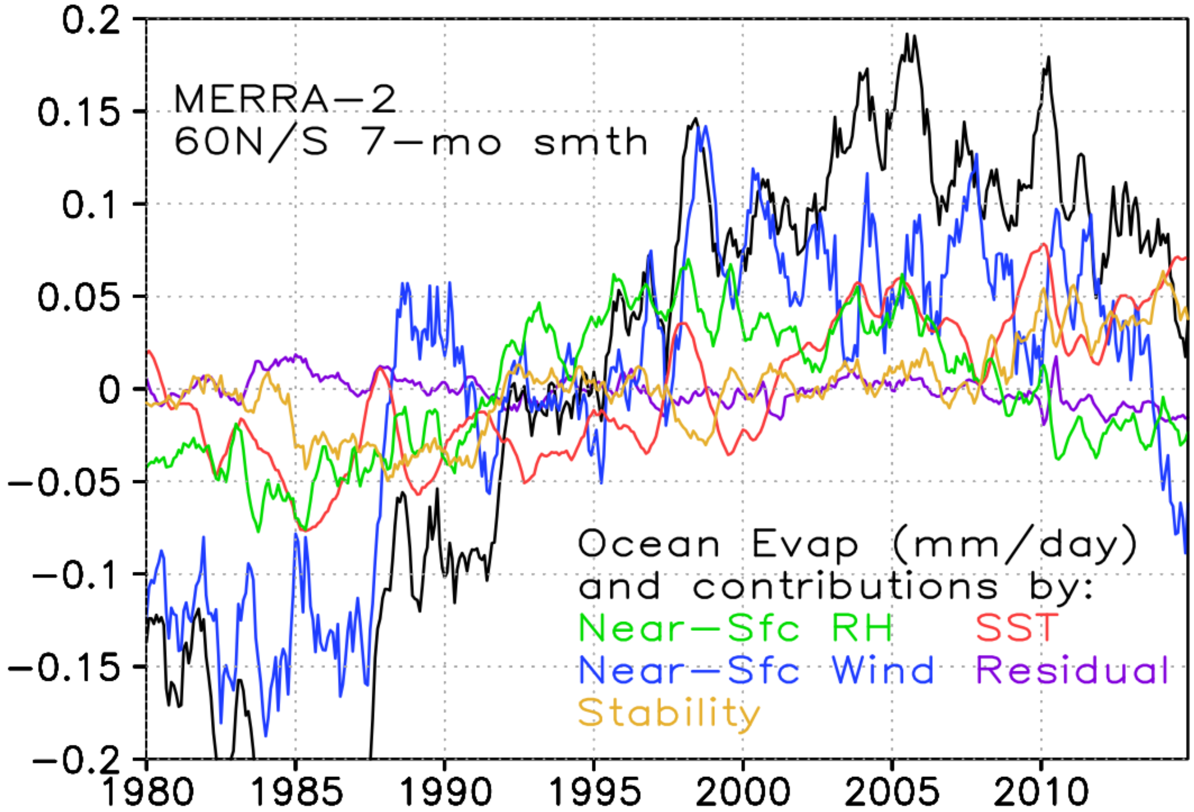
and q_o, a, b, c are constants.

Evaporation anomalies, δE, are expressed as

$$\delta E = \frac{\partial E}{\partial SST}\delta SST + \frac{\partial E}{\partial U}\delta U + \frac{\partial E}{\partial RH}\delta RH + \frac{\partial E}{\partial S}\delta S + \frac{\partial E}{\partial C_E}\delta C_E + res$$

where he partial derivatives are "sensitivities" built from monthly resolved climatology and $\delta(\ )$ denotes a monthly anomaly.

MERRA-2 R-X Evaporation Decomposition (mmd^{-1})



- Note jumps / discontinuities in wind speed contribution as SSMI becomes available.
- RH impacts are more prominent after 1991/92 as more sensors become available. Near surface moisture is reduced by increments in subsidence regions but then this drying weakens after 2006 as SSMIs age off (no SSMIS moisture assimilation).

MERRA-2 Adjustment Strategy:

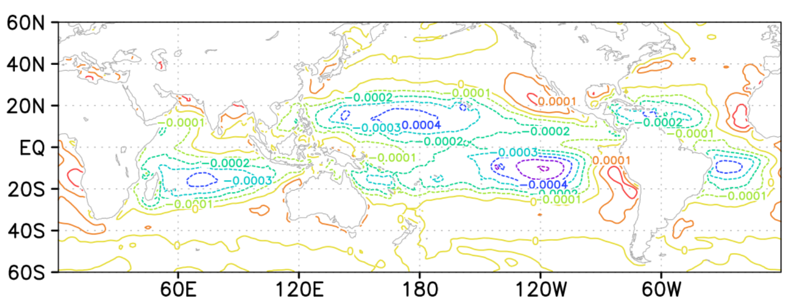
(1) Use EOF analysis of q, Ta, and wind speed-inc at 975 hPa to identify time-dependence R-X terms most likely associated with the changing satellite observations. (A 27-month smoother is applied to Q-inc beforehand to avoid affecting interannual variability since non-physical signals from satellite system changes, while discrete in nature, produce low-frequency variations on longer scales.)

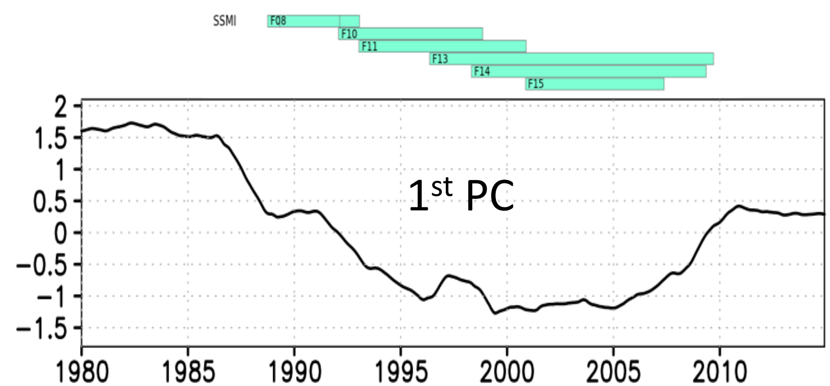
(2) Regress budget terms on these modes, and remove these spurious signals from the budget terms.

Advantage: Small number of modes is needed (~5)

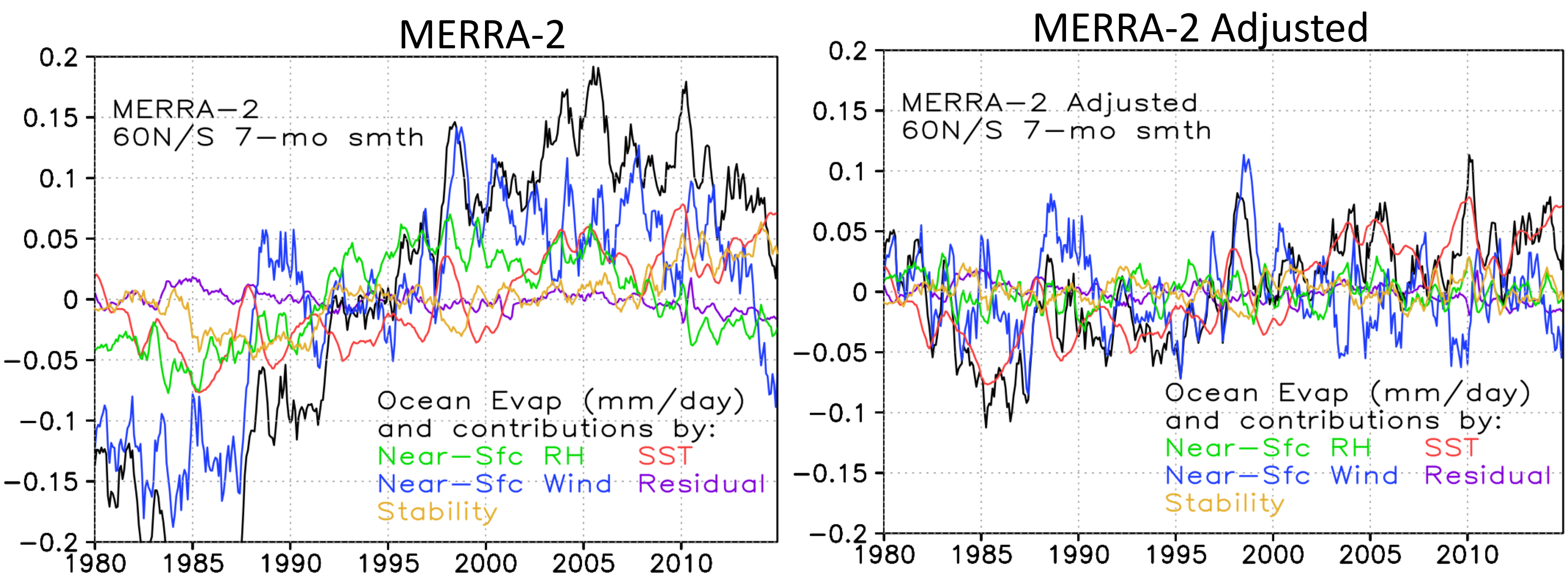
Disadvantage: Ultimately a subjective methodology

1st MERRA-2 Adjustment EOF





MERRA-2 R-X Evaporation Decomposition (mmd^{-1})



- After adjustments, each component has much smaller trends and result in a reduced global mean trend (SST component not affected).
- ENSO influence is major IA signal.

Adjustment Strategy cont:

At present we don't have access to corresponding analysis increment data from JRA-55 or ERA-I. We use "Reduced Obs" reanalyses in making approximate corrections:

JRA-55

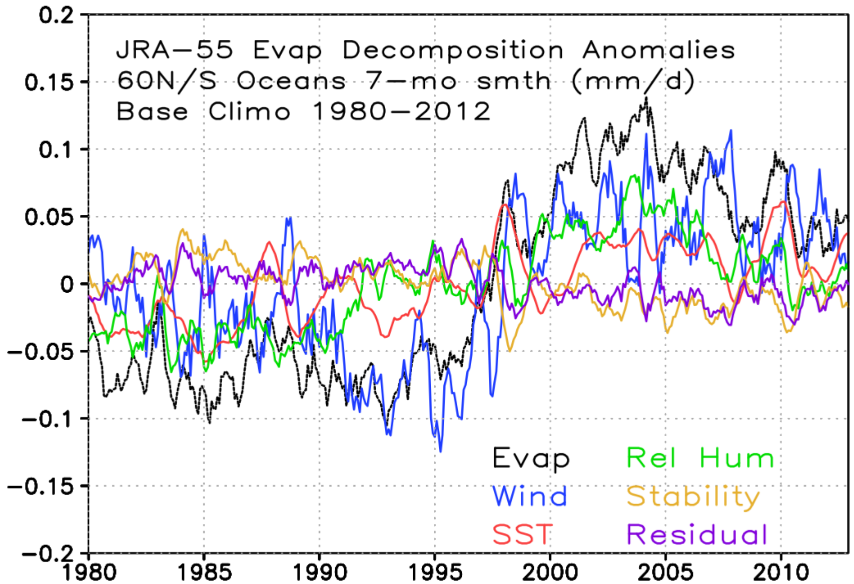
1) JRA-55C reanalysis uses conventional data only (RAOB, Sfc, Marine, Aircraft) and is free of satellite change-induced signals.
2) Combine 27-mon smoothed JRA-55C data with corresponding hi-passed JRA-55 fields as corrected estimates.

ERA-I

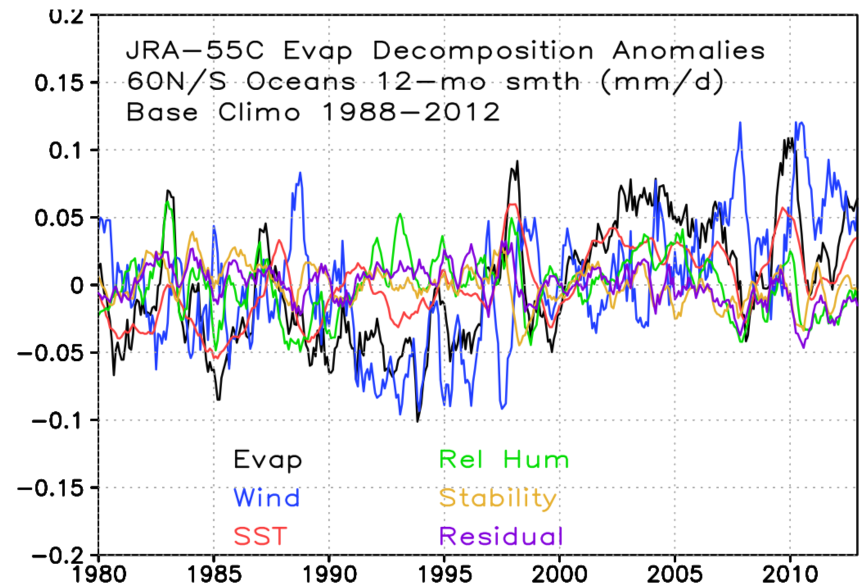
1) We simply use PC time series from EOF analysis of 27-mon smoothed RH and stability terms. No adjustment of winds at this time.
2) ERA-20C or CERA-20C assimilation only of Sfc Pressure and Marine Winds could provide an opportunity for correction analogous to JRA-55C.

JRA-55 R-X Evaporation Decomposition (units mmd^{-1})

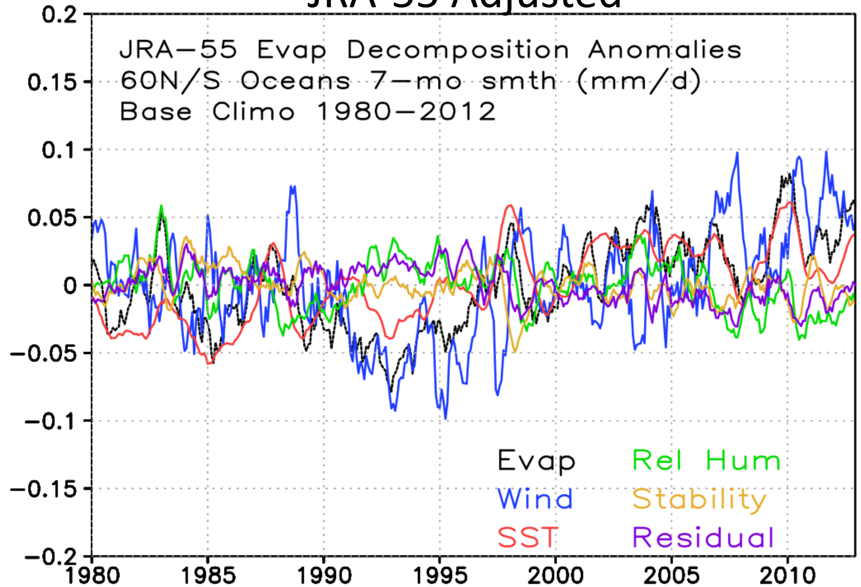
JRA-55



JRA-55C



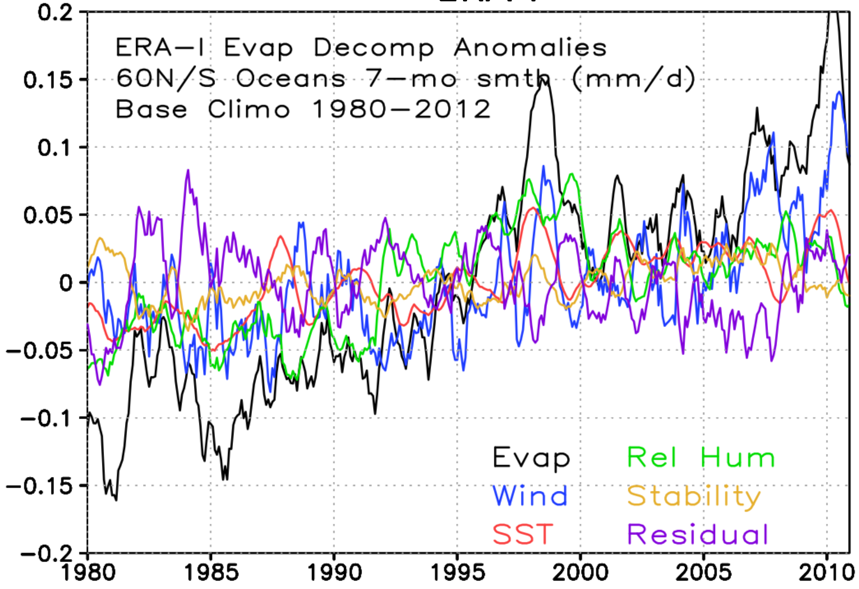
JRA-55 Adjusted



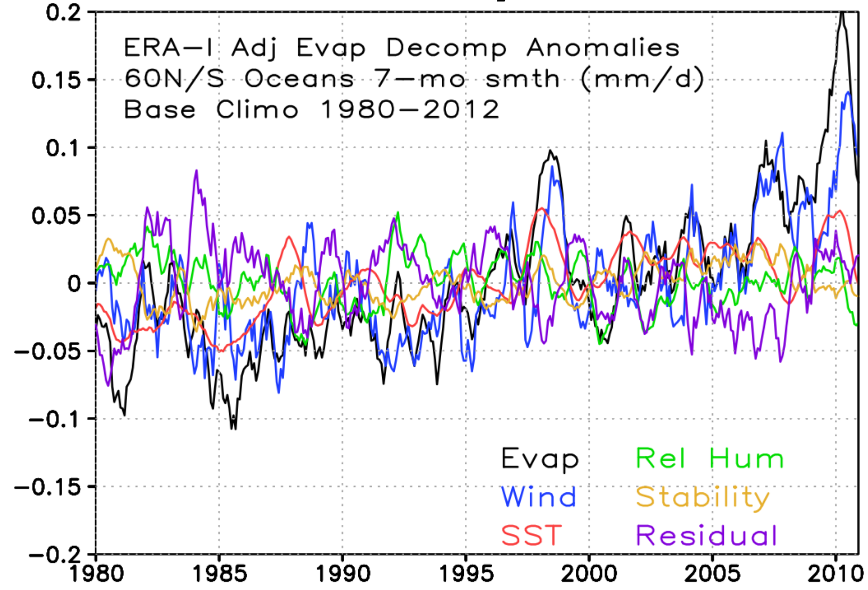
- Largest JRA55/55C difference is in the RH term. RH changes (drying) in JRA55 contribute to Evap increases after 1990 and especially the late 1990s. The former (latter) is likely an impact of SSMI (ATOVS).
- JRA-55C has no influence from satellite assimilation so the adjustment uses JRA-55C low frequency patterns to adjust JRA55.

ERA-I R-X Evaporation Decomposition (units mmd^{-1})

ERA-I

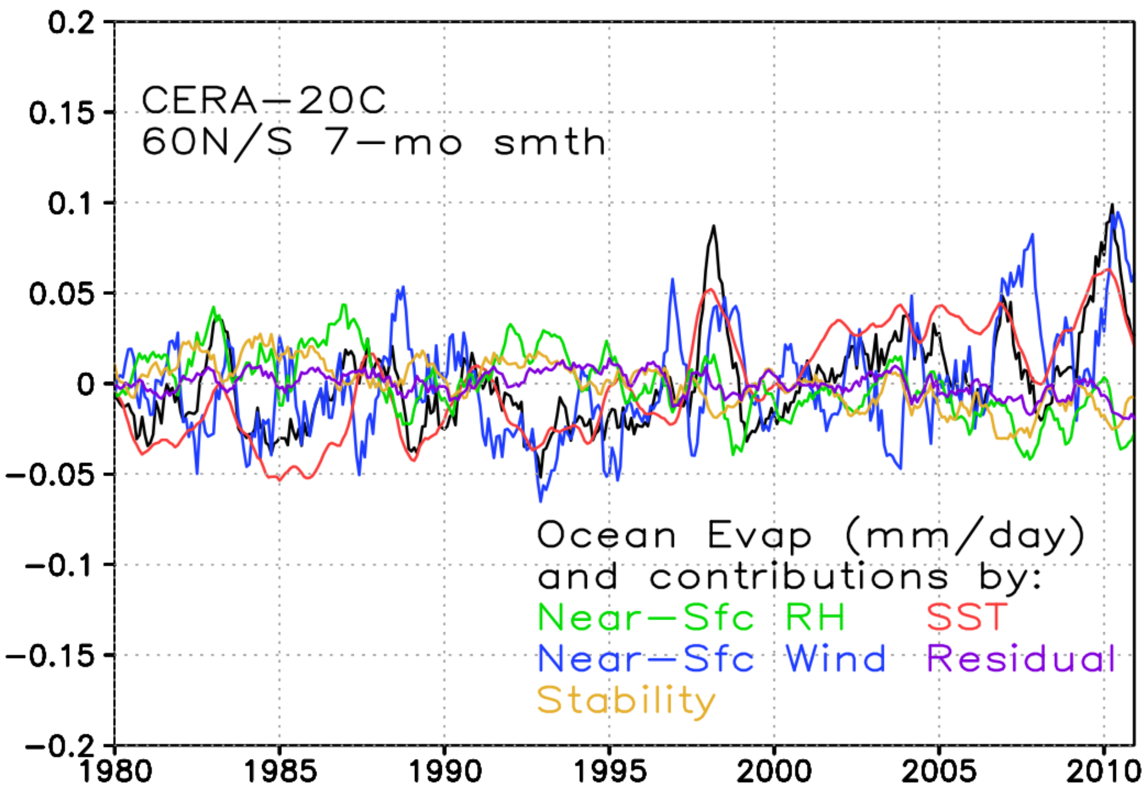


ERA-I Adjusted



- Large residual is present which anti-correlates strongly with the stability (SST-Ta) component. Since no exchange coefficient is provided by ECMWF, this term may be reflected in residual.
- RH term (drying jump in 1992, down in 2000) contributes to trend. Its low frequency behavior is the only attribute altered in adjusting the Evap.

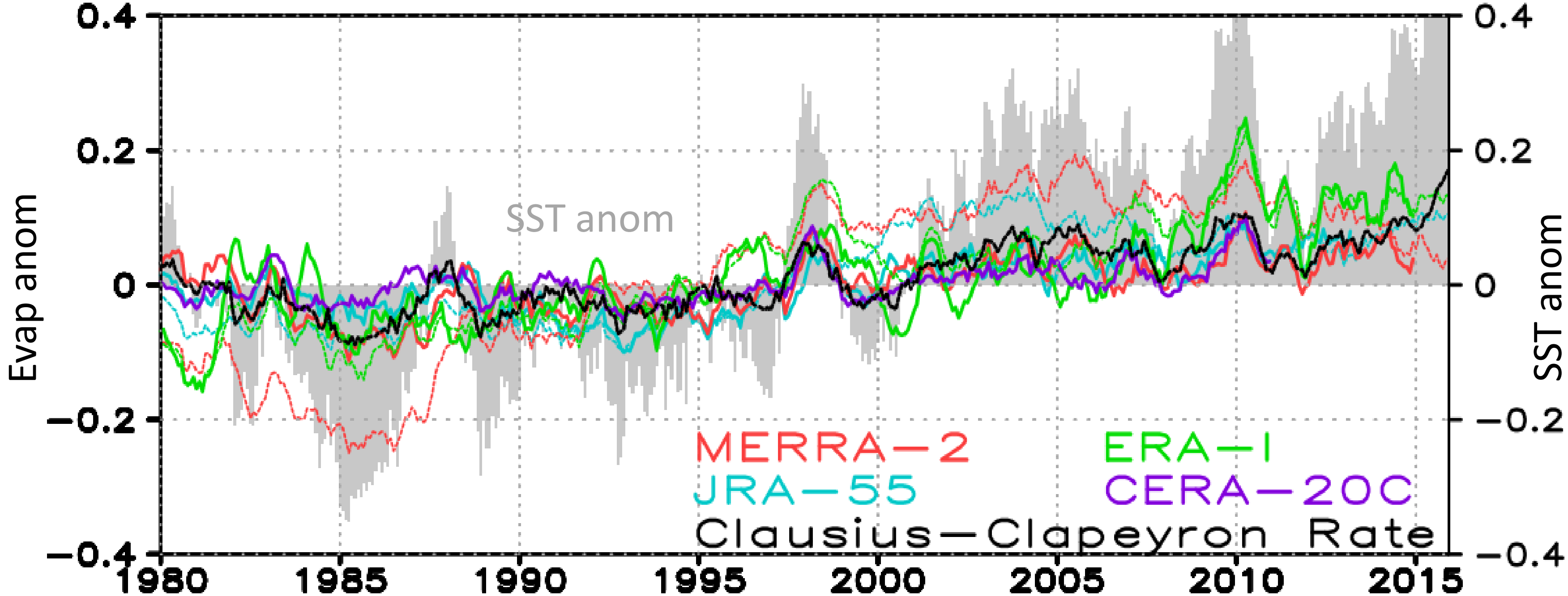
CERA-20C Evaporation Decomposition (units mmd^{-1})



- CERA-20C evap trend is very small as is wind component trend
- Though diagnostics are built from the 10-member ensemble fields, individual members show very little spread.

Reanalyses Evap (mm/d) 60°N/S Ocean Original (dotted) and Adjusted (solid)

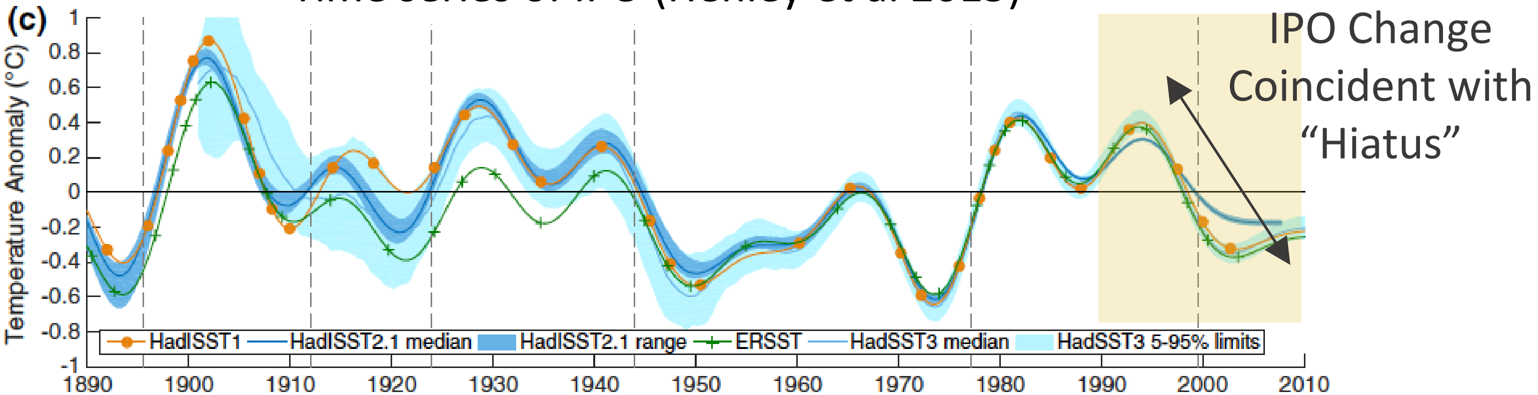
1980/2010 Base Climo



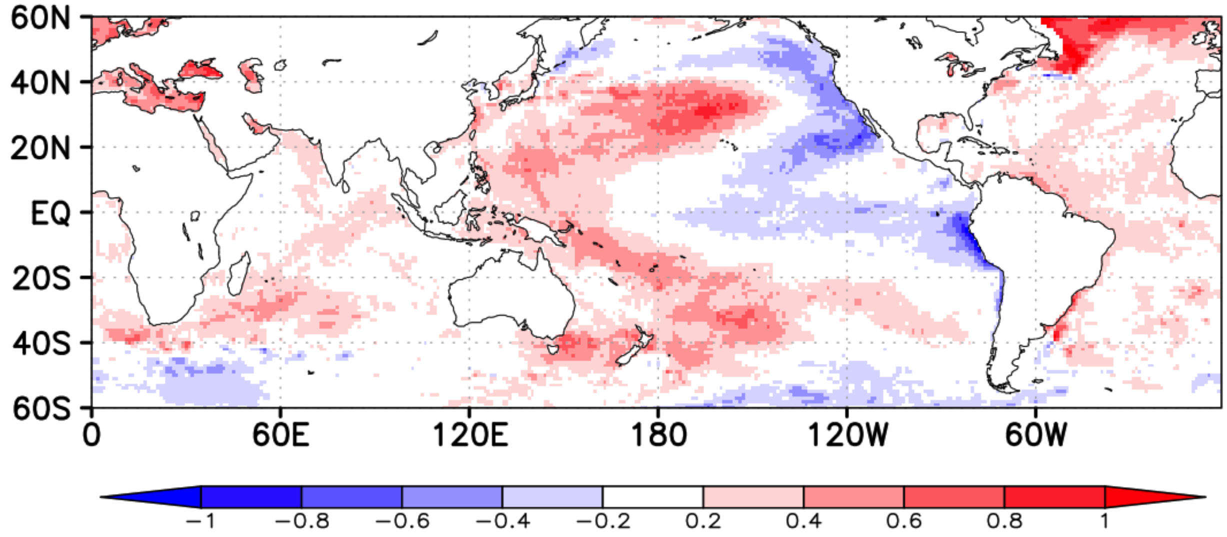
- Near-global averages of each adjusted rean evap are closer to C-C rate and bearer to CERA-20C (though not by design or constraint).
- ERA-I still has larger excursions.

Does the Inter-decadal Pacific Oscillation Have a Robust Signal?

Time series of IPO (Henley et al 2015)

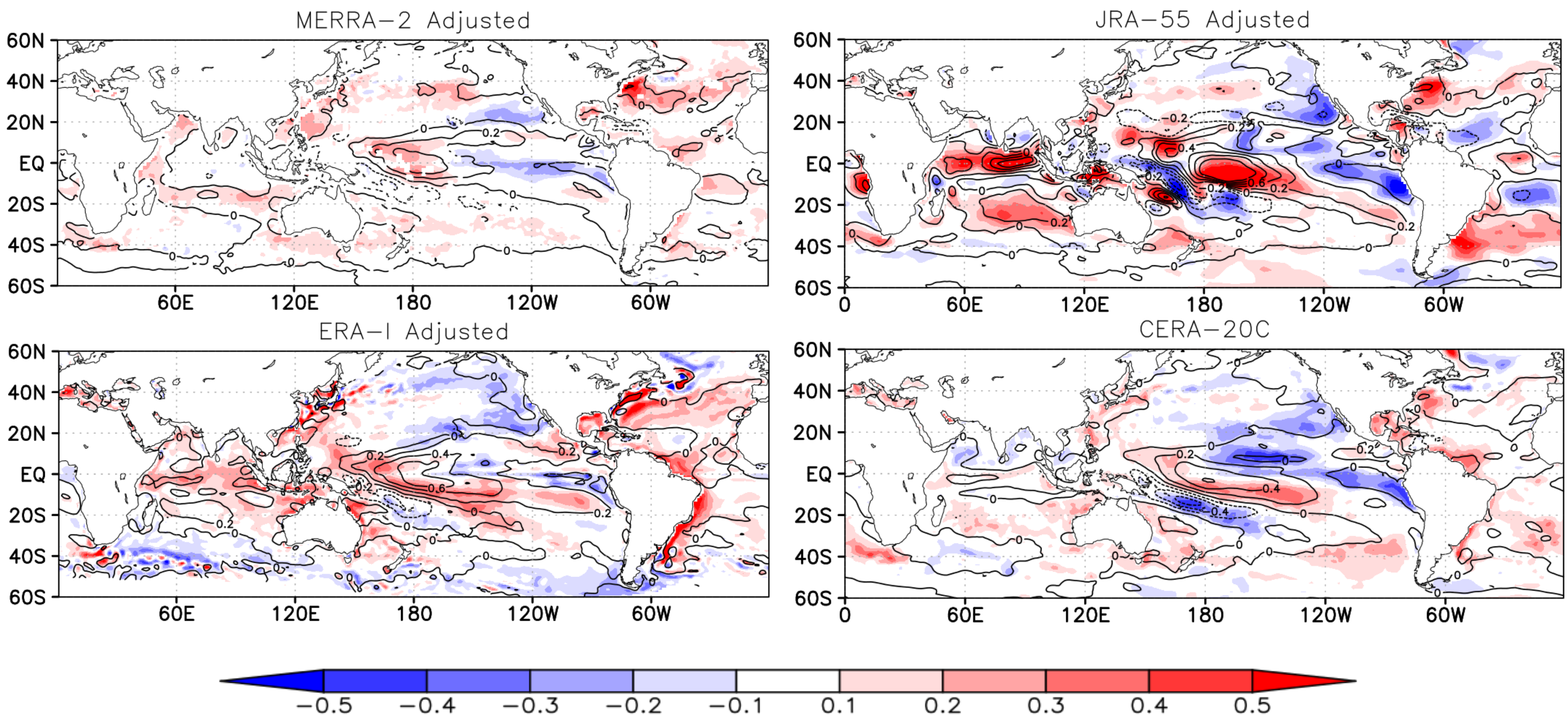


ERA-20C SST (°C) 1999/2009 minus 1990/1999



Trend Maps _Adjusted_ 1990 / 2010 (mm/day)

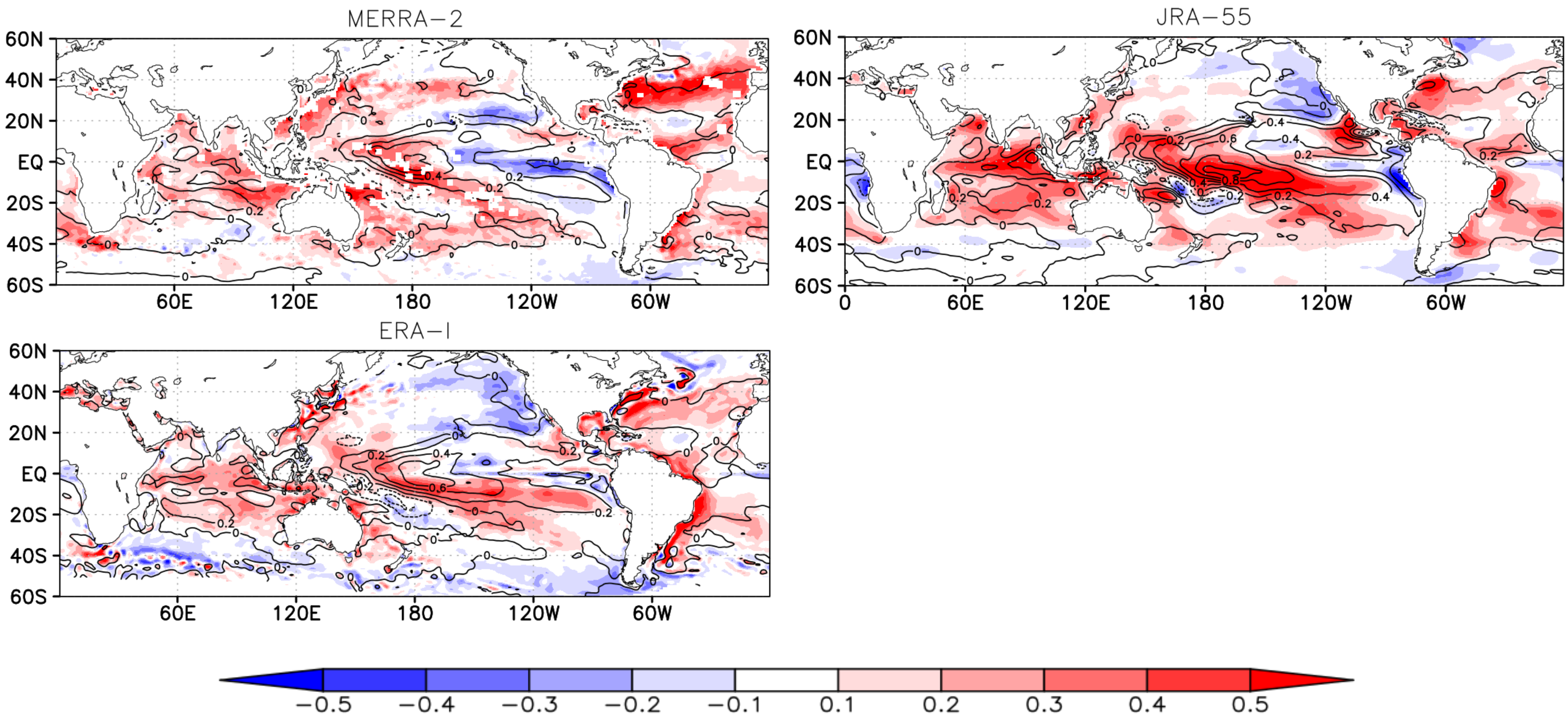
Evaporation (Shaded) Wind Component (contours)



- Evap trends are strongly influenced by wind speed changes. Wind speed increases in the west central Pacific are prominent signals.
- Evap decreases in subtropical eastern Pacific are more related to SST decreases

Trend Maps 1990 / 2010 (mm/day)

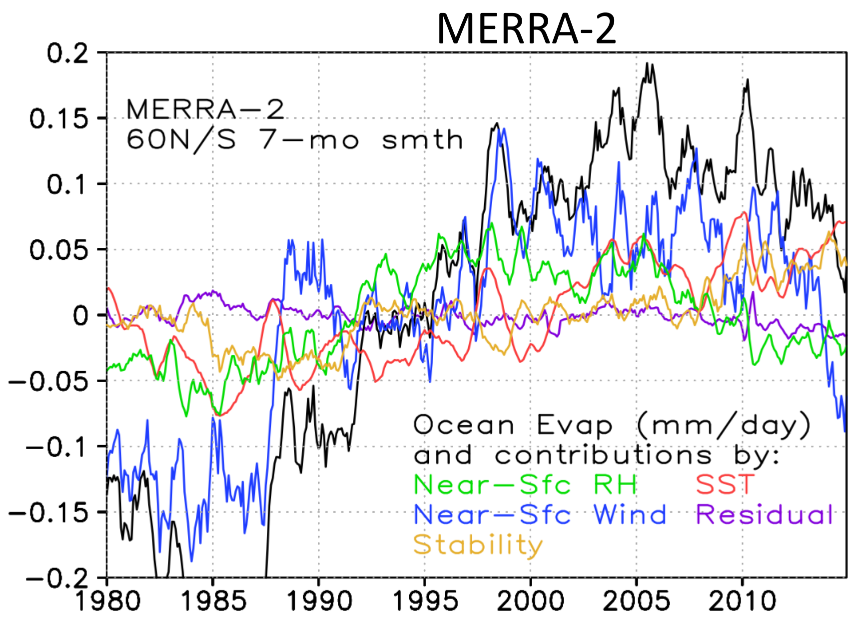
Evaporation (Shaded) Wind Component (contours)

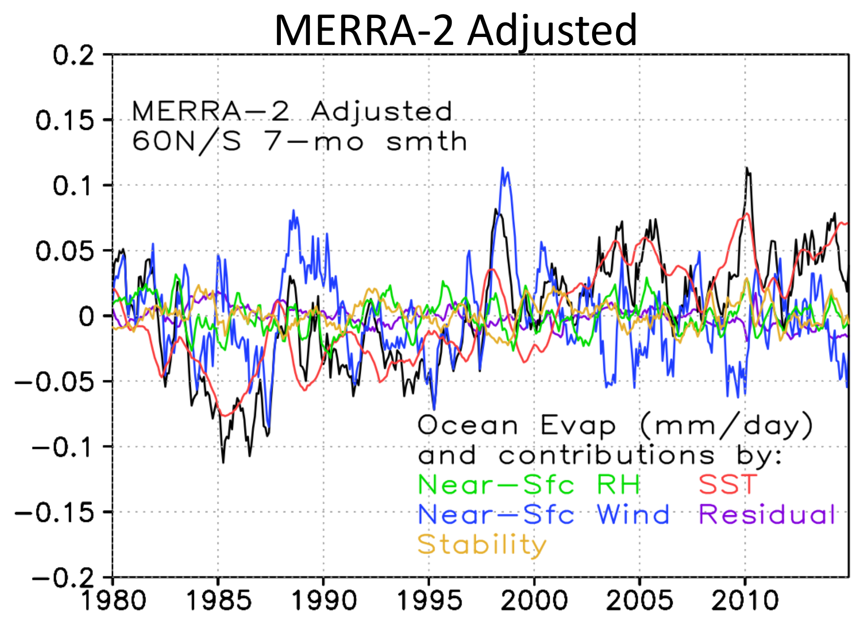


- Evaporation trends in unadjusted fields are uniformly higher.

B A C K U P S

MERRA-2 R-X Evaporation Decomposition (mmd^{-1})





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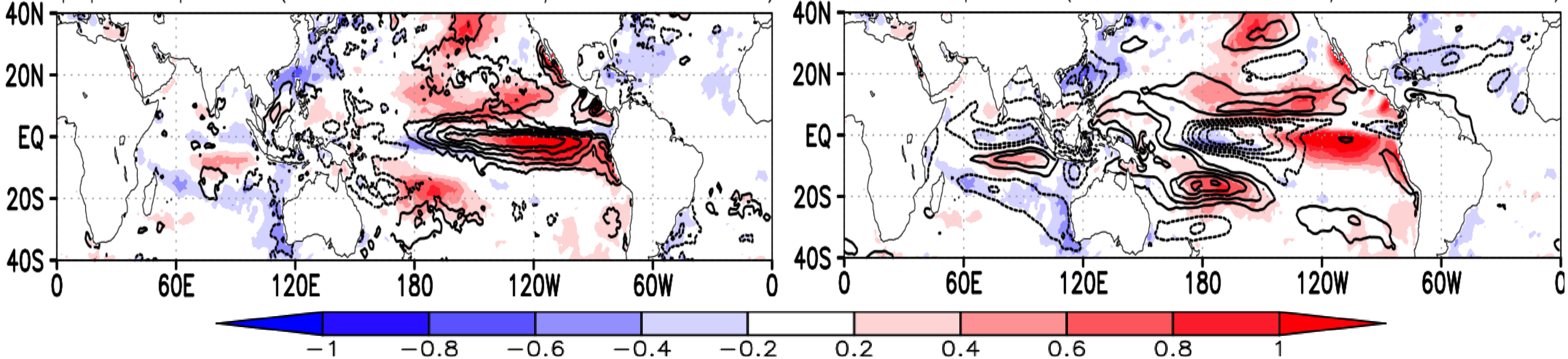
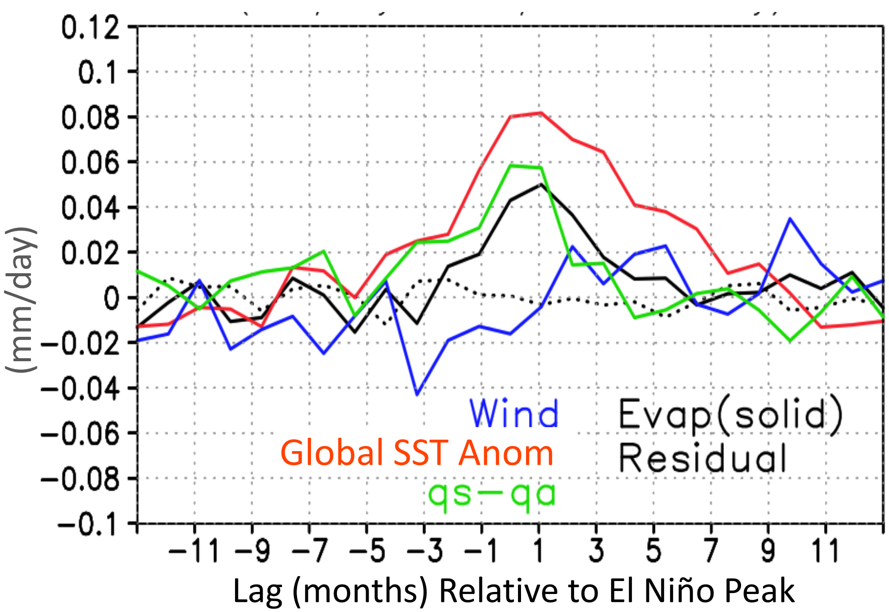
ERA-20C Composite
El Niño Evaporation Anomalies (shaded, mm/d)

qs-qa contrib *(contour int 0.2 mm/d)* wind speed contrib *(contour int 0.2 mm/d)*





EVAP Contributions: WSPD, QS-QA

1.0σ event composites 1950/2010

Global Ocean (60 N/S)

Vertically-Integrated Atmospheric Water Budget Within the Reanalysis Framework

For any gridpoint value,

$$E - P - \widehat{\nabla \cdot qV} = \frac{\partial W}{\partial t} - Qinc$$

where W is vertically-integrated water vapor and Q-inc is the vertically-integrated moisture increment.

For the MERRA-2 system, *Q-inc* embodies the miss-match between the 6-h forecast 1st guess and the ensuing analysis and is used as a budget term in a "re-forecast step" to drive the reanalysis moisture as close as possible to the analysis.

But since the model has imperfect physics and the accuracy and availability of assimilated observations varies in time, biases in the budget terms and in Q-inc arise. Q-inc is sensitive both.

Previous efforts (Schubert and Chang, 1995; Bosilovich and Schubert; Robertson et al, 2014, 2016) have had success using linear regression to explain error in budget equations in terms of their relationship to Q-inc.