Water Cycle Variability over the Oceans Estimated Using Homogenized Reanalysis Fluxes

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- Model physics biases (moisture, clouds, radiation), coupled assimilation strategies are still maturing; error & bias treatments less than optimum.
- The observational record for water and energy fluxes varies dramatically over the satellite era, has flow or regime dependent biases, but is becoming more accurate and data-dense with time.

….Can we "homogenize" some aspects of reanalysis products?

Fall AGU Session A24E-02, Progress in Reanalysis: Development, Evaluation and Application

Assimilating Diverse Observations Into Comprehensive Global Physical Models Remains a Challenge

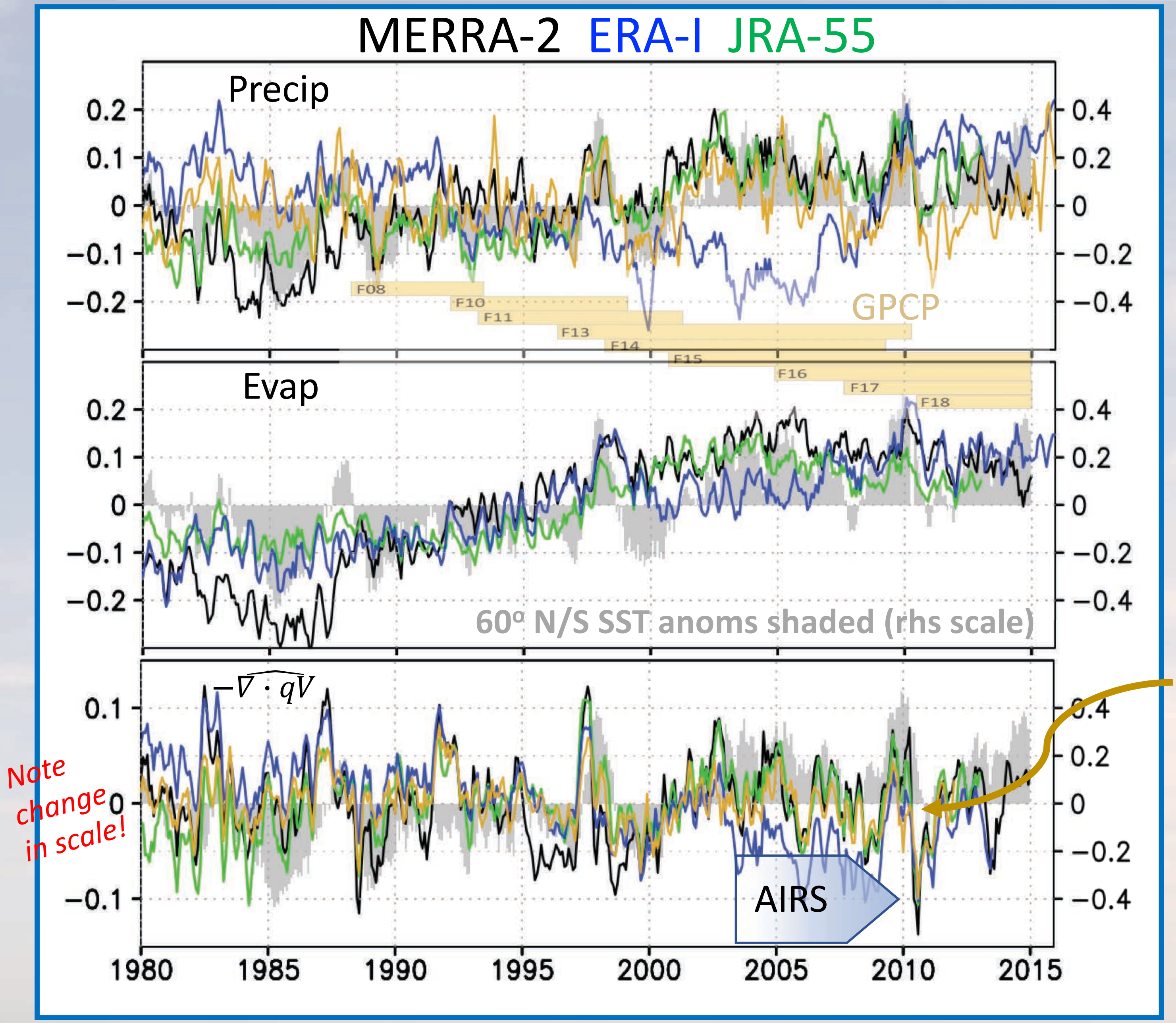
- How well are variations in Clausius-Clapeyron(C-C) and Hydrologic Cycle Scaling captured? Column water vapor sensitivity to SST, TLT still vary substantially from expected 6-7 % deg^{-1} δSST. P, E changes should be smaller (2% deg^{-1} δSST) but how do events like ENSO, PDV, AMO affect this?

- Is pattern amplification in P, E response to SST forcing (Wet-get-Wetter, Dry-get-Drier) realistic? Extreme hydrologic events captured?

- Do strong interannual signals (e.g. ENSO) currently preclude accurately identifying water cycle trends?

So we ask: are adjustments or "homogenizing" fluxes of utility?

Reanalysis Ocean Flux Anomalies (60ºN/S, mm d^{-1})



- Significant uncertainty in decadal variations and trends.
- More coherence in interannual variations
- Influence of SSMI passive microwave data availability evident (MERRA-2, ERA-I)
- Scaled P-ET from an ensemble Land Sfc Models forced with obs precip & near Sfc meteorology (Robertson et al. (2016)

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.

MERRA-2 Adjustment Strategy:

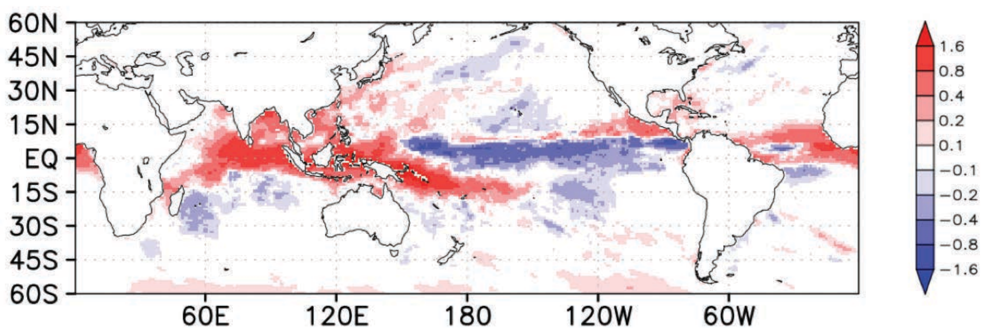
(1) Use EOF analysis of Q-inc to identify time-dependent components most likely associated with the changing satellite observations. (A 27-month smoother is applied to Q-inc beforehand to avoid affecting interannual variability since non-physical signals from satellite system changes, while discrete in nature, produce low-frequency variations on longer scales.)

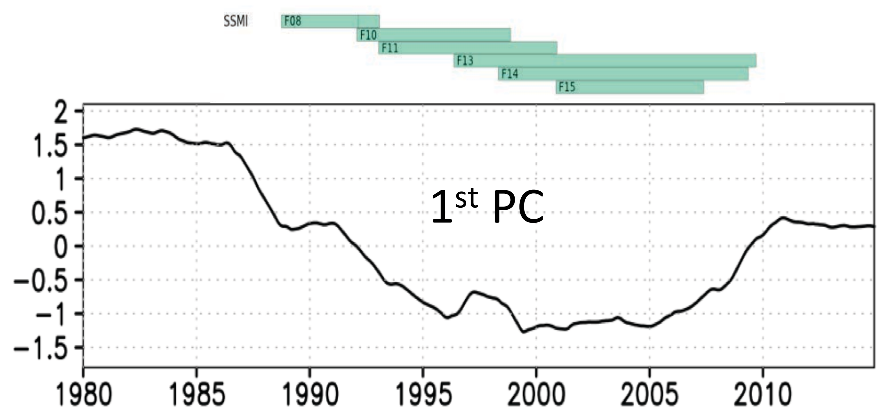
(2) Regress budget terms on these modes, and remove these spurious signals from the budget terms.

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

Disadvantage: Ultimately a subjective methodology

1st Precip Adjustment EOF





Adjustment Strategy cont:

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

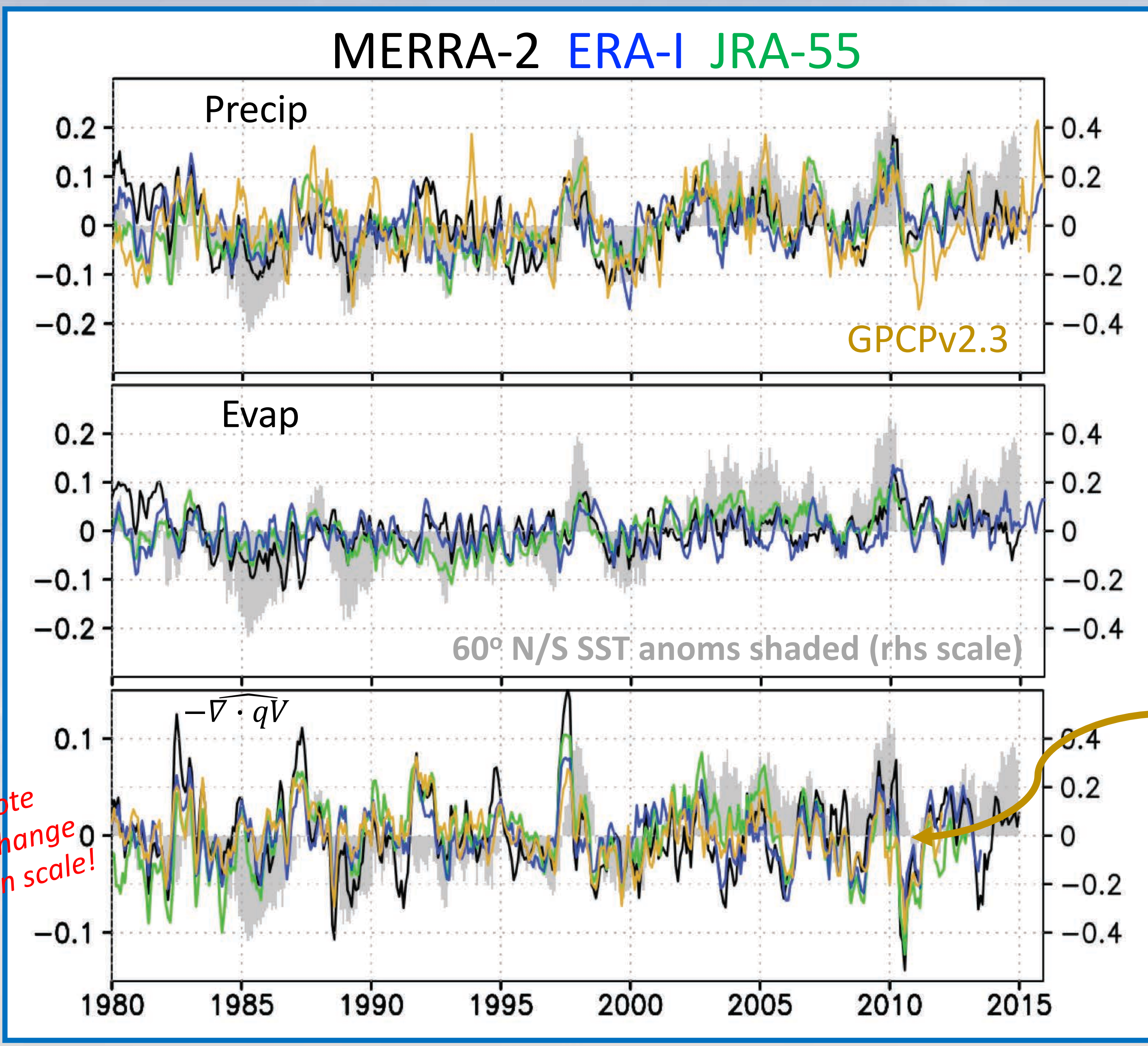
JRA-55

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) ERA-20C assimilation only of Sfc Pressure and Marine Winds provides an estimate of climate variations w/o overt changes in observing systems.
2) We similarly combine 27-mon smoothed ERA-20C data with corresponding hi-passed ERA-I fields as corrected flux estimates.

Adjusted Reanalysis Ocean Flux Anomalies (60ºN/S, mm d^{-1})



- Improved agreement among the reanalyses and between each reanalysis and independent GPCP and LSM P-ET data
- Scaled P-ET from an ensemble Land Sfc Models forced with obs precip & near Sfc meteorology (Robertson et al. (2016)

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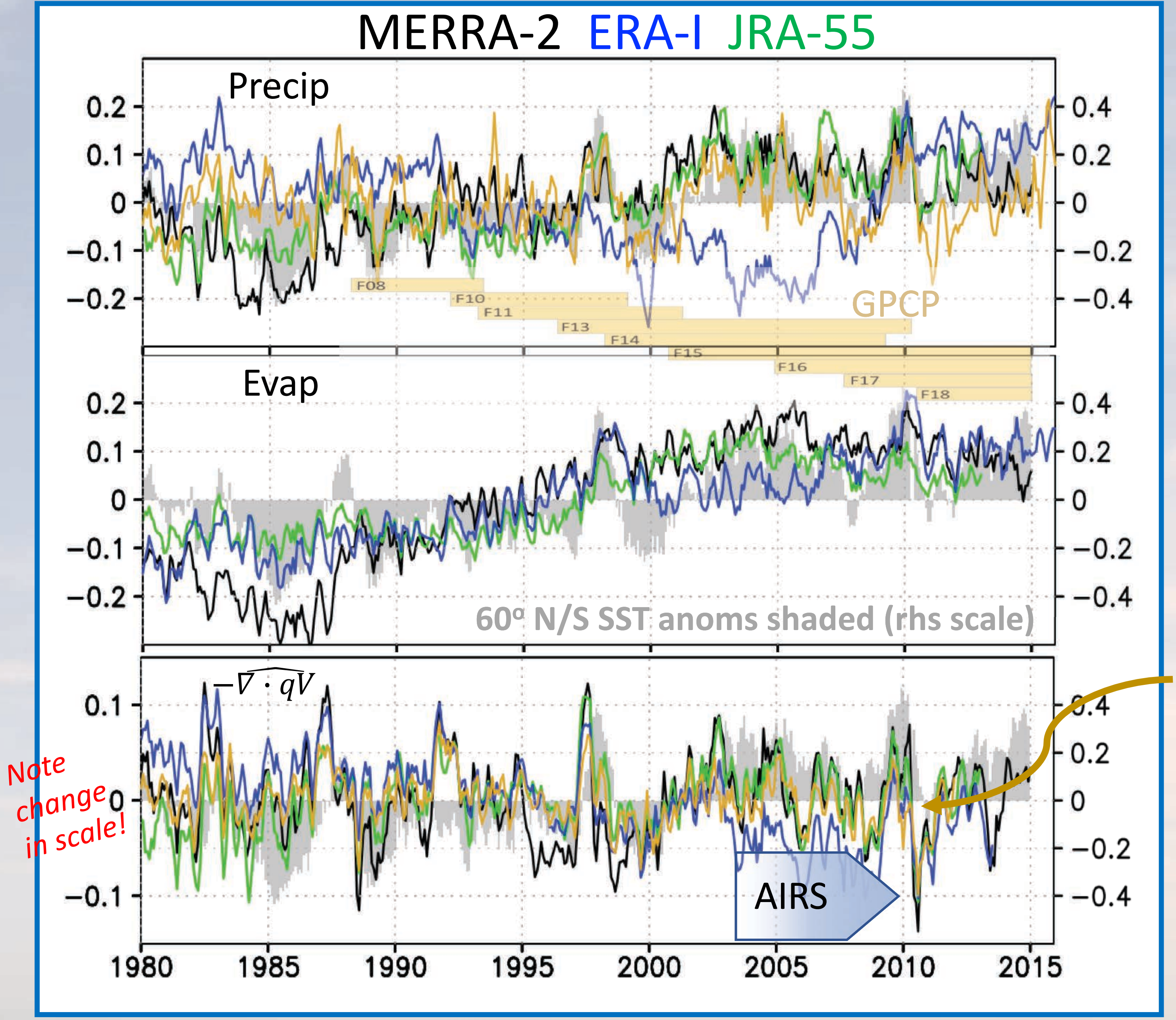

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Do Changes In Oceanic Ascending / Descending Regimes Adhere to Hypothesized "Wet-get Wetter" / "Dry-get Drier" Behavior ?

- As noted by Held & Soden, 2006; Chou et al, 2007; Allan et al, 2010), under the assumption of small changes in circulation relative to SST- induced humidity changes, the expectations for hydrologic cycle change,

  $\delta(E-P) = \nabla \cdot \widehat{\delta(qV)}$ can be approximated by

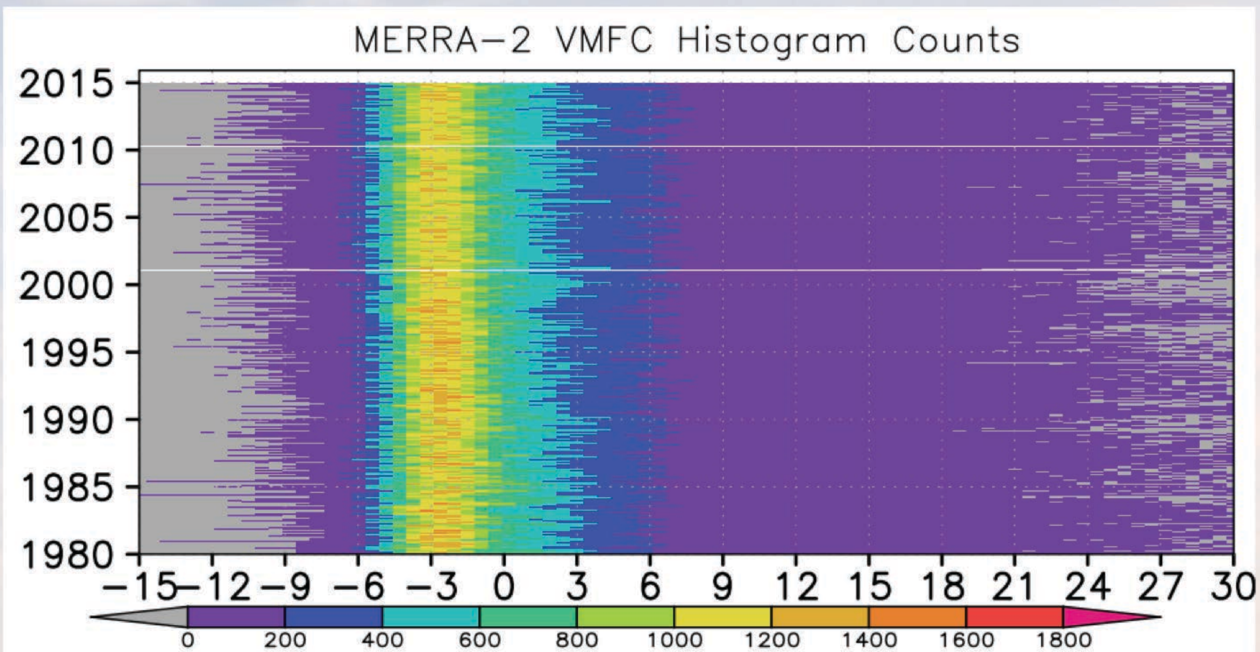
  $\delta(E-P)/(E-P) \approx \alpha\delta SST \approx 7\%\, deg^{-1}\delta SST.$

So regional changes in E, P and moisture transport would scale at the C-C rate.
But we know that dynamical changes are a significant hallmark of interannual to decadal variability.

- To isolate tropical wet & dry (~ ascending & descending) regimes, monthly $-\widehat{\nabla \cdot qV}$ values at each gridpoint (30^o N/S) were sorted into 0.5 mmd^{-1} resolution bins forming histograms.
- P and E were also stratified according to the $-\widehat{\nabla \cdot qV}$ bins into which they fell.
- Climatological values were removed to examine temporal variability.

MERRA-2 Adjusted Vertically Integrated Moisture Flux Convergence Histograms

- X-axis denotes bin values of $-\widehat{\nabla \cdot qV}$ (mm d^{-1}). Moist Div is left, Moist Conv (right)
- Histogram counts (color bar) reveal interannual signals associated with ENSO (e.g. 1982/3; 1997/8, 2009/10 as well as low frequency behavior.
- Most frequent variations occur in the descent regions because of the larger size of descending compared to ascending regions…. But the extreme moist convergence tails get weighted heavily.

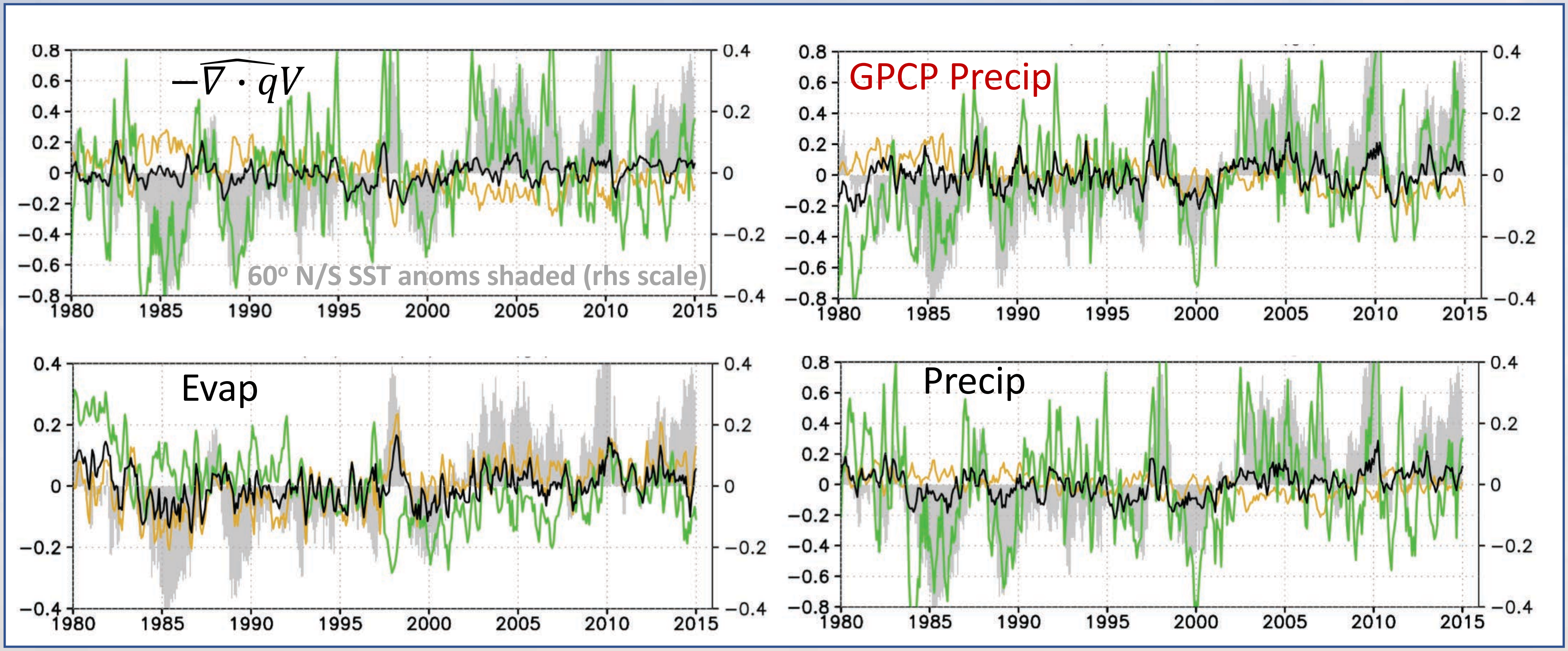


<0 $-\widehat{\nabla \cdot qV}$ >0

MERRA-2 Adjusted Moisture Budget Anomalies Stratified By Moisture Convergence / Divergence Regions

$-\widehat{\nabla \cdot qV}$, P and E time series anomalies (mm d^{-1}) are area-averages over the ***Convergent***, ***Divergent*** and ***Entire*** extent of 30°N/S ocean domain.

ENSO warm events and their frequency are major drivers: Increased moisture convergence & precip in wet regions and moisture divergence and evap in dry regions. The opposite holds for ENSO cold events.



Sensitivities of Tropical (30°N/S) Water Cycle Fluxes to Sea-Surface Temperature Change (% K^{-1})

- MERRA-2 adjustments yield a consistent response to SST of increasing moisture cycling over the tropical oceans.
- Adjusted MERRA-2 precip response to SST in precipitating regions and over the total tropical band matches GPCP better.

	Dynamical Region	$-\widehat{\nabla \cdot qV}$	Precip (GPCPv2.3)	Evap	Fractional Area Change
MERRA-2	Moist Conv	3.7	7.0	22	-3.67
	Moist Div	-15.7	15.9	21.3	3.67
	30°N/S Oceans	5.5	20.5	21.4	---
MERRA-2 Adjusted	Moist Conv	16.8	3.3 (6.1)	-11.4	0.4
	Moist Div	-15.2	-3.4 (-31.6)	6.5	-0.4
	30°N/S Oceans	-1.8	4.5 (4.1)	1.5	---

Moist conv increases in conv regions, moist div increases in div regions

Precip increases in conv regions, decreases in div regions

Evap increases in div regions, decreases in conv regions

Summary / Major Points:

- Increase in satellite data since 1980 (SSMI, SSMIS, AMSU) has had a huge impact of climate variability in reanalyses. Not always uniform influence among reans … → unique model physics biases & assimilation strategies.

- Basic adjustments attempted here increase agreement of reanalyses with GPCP precipitation and consistency with inferred water vapor exchange with continents derived independently from P-ET from LSMs. Budget imbalance remains to be addressed.

- Amplification of E and P changes with SST change is consistent with expected (Wet-get-Wetter / Dry-get-Drier), for E and P. This is consistent with an increased rate of moisture flux between descending / ascending regions.

- ENSO events and their decadal variability are major signal drivers.

- The results help us understand / quantify reanalysis shortcomings and can be of use to initiatives such as NASA NEWS, GEWEX GDAP, and Ana4MIPS.

THANKS!