Impact of the Evolving Satellite Data Record on Reanalysis Water and Energy Fluxes During the Past 30 Years

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Research Supported by NASA Energy and Water Cycle Study (NEWS) and NASA Modeling and Analysis and Prediction (MAP) Programs

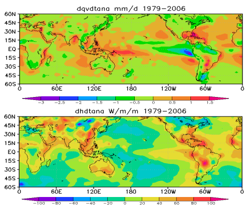
Problem / Objectives

Changes in satellite observing system technologies, particularly passive microwave sensing of moisture, have resulted in step-like discontinuities in reanalysis water and energy fluxes. The onset of data availability with SSMI and, in particular, AMSU-A have induced non-physical trends over the 30+ years of the Modern Era Retrospective Analysis for Research and Applications (MERRA). These artifacts are present as well as in other reanalyses to varying degrees. ***Can these artifacts in the vertically integrated water and energy budgets be isolated and removed?***

Summary / Takeaway Points

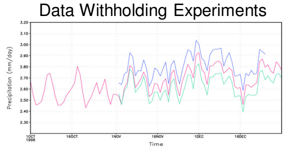
- Data withholding experiments confirm that uncertainties in the bias correction and / or forward modeling of moisture sensitive channels, in combination with MERRA moist physics biases, result in areal-mean trends that distort climate signals.
- Statistical regression (Redundancy Analysis) is effective in isolating and greatly reducing these artifacts. Time-dependent biases in budget increments are used to statistically "predict" and remove correlated structures in physical terms of the heat and moisture budgets. Remaining increments then are largely responding to model physics biases.
- Interannual and decadal signals in MERRA are clarified (e.g. much better agreement with GPCP), though any global mean trends in fluxes (but not state variables) are likely lost. Data withholding experiments currently in progress sequentially treating critical sensor changes (see paper J1.4) may offer a strategy to detect trends, to the extent they exist.
- While many reanalysis applications may not need these adjustments, they appear critical for climate variability studies.

Mean moisture and heat budget increments 1979-2007

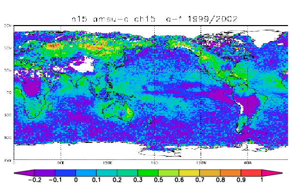


Vertically integrated moisture (mm^{-1} day^{-1}) and heating increments (Wm^{-2}) are budget terms needed to keep assimilated T_v and q_v near observations. The non-zero values of these fields indicate regions of *systematic* GEOS-5 model bias.

Data Withholding Experiments



Global mean precipitation for MERRA reanalysis; exp m98a (AMSU-A Ch 1,2,3,15 withheld from assimilation); exp m98b (no cloud liquid water bias correction applied to AMSU-A Ch 1,2,3,15).



AMSU-A Ch15 (89 GHz) analysis minus guess Tb indicates that increased emission (more moisture) is needed in the 6h forecast to match observations. Note correlation to mean moisture increment (above top).

MERRA vertically-integrated water and heat budget terms

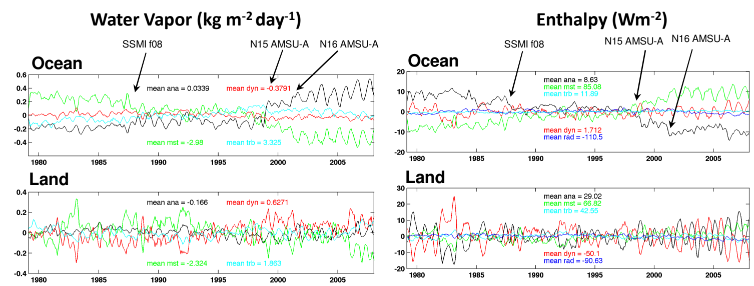
$$\frac{\partial q_v}{\partial t} = \overline{qfluxconv} + MST_q + EVAP + ANA_q + Res_q \quad (1)$$

Dynamics | Precip | Evap / Sens Htg | Radiative Htg | Increment

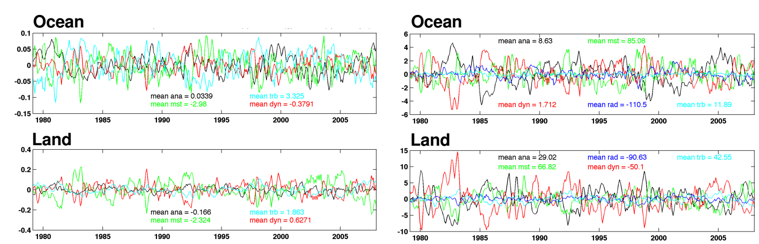
$$\frac{\partial H}{\partial t} = \overline{Hfluxconv} + \overline{\omega\alpha} + MST_H + RAD + SENS + ANA_H + Res_H \quad (2)$$

Original MERRA (*top four panels*) and Adjusted (*bottom four panels*)
Water Vapor and Heat Budget Anomaly Time Series

Quantities shown are departures from 1979-2007 monthly resolved climatological values averaged over near-global (60° N/S) ocean- and land-only areas



- Increments (ana) and precipitation (mst) are anti-correlated over the ocean implying strong interactions between satellite sensor forcing changes and MERRA physics.
- Ocean / land exchanges of moisture via dynamics control precipitation over land. Dynamical heating over land is strongly offset by heating increments.
- Note the prominence of non-stationary annual cycle.



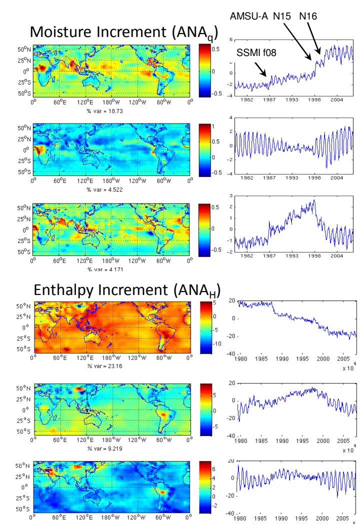
- We use Redundancy Analysis (see panel to right) to predict artifacts in physics terms based on leading PCA modes in the heat and moisture increments that carry the satellite artifact signals.
- After adjustment the increment terms are of the same order of magnitude as physical terms.
- Heat budget dynamics term and increment are now anti-correlated over both land and ocean, and non-stationarity in the annual cycle is substantially reduced.

Leading EOFs and PCs for the moisture and heat (enthalpy) increment anomalies (ANA_q, ANA_H) are dominated by satellite sensor change artifacts. Both step functions and non-stationary annual cycle effects are present. (Units of the EOF and PC products are kg m^{-2}d^{-1}and Wm^{-2}, respectively.)

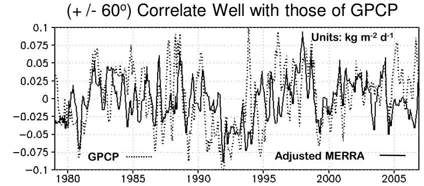
These modes, plus two others each for ANA_q and ANA_H, are used to extract the artifact signals via Redundancy Analysis (von Storch and Zwiers, 1999): If F is any one of the physical forcing terms in (1) or (2), then its predicted value, $\hat{F}$, can be obtained via regression onto $\hat{I}$

$$\hat{F} = C_{FI} C_{II}^{-1} \hat{I}$$

where $\hat{I}$ is the subset of modes defined as capturing the artifact structures, and C_{FI} and C_{II} are the cross-covariance and the covariance matrices of $\hat{F}$ and $\hat{I}$.

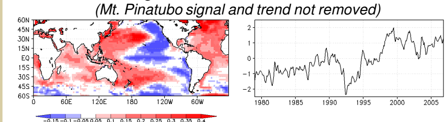


Adjusted Near-global Precipitation Variations (+ /- 60°) Correlate Well with those of GPCP



The quantity $P_q^* \equiv -1.0 * (MST_q + ANA_q)$ agrees most closely with GPCP precipitation suggesting that the remaining moisture increment, after removing the sensor change artifacts, largely represents modifications needed to the precipitation to yield global moisture balance E = P.

Leading non-ENSO SST EOF and PC
(Mt. Pinatubo signal and trend not removed)



MERRA flux anomalies regressed on the PC of the leading non-ENSO SST mode show coherent patterns strongly influenced by Pacific Decadal Variability. Unadjusted quantities are have non-physical trends and / or distorted patterns.