# MERRA: A Preview of Climate and its Variability During the Satellite Era

**F. Robertson, M. Bosilovich, J. Chen**

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# NASA's Modern Era Retrospective-analysis for Research and Applications (MERRA)

- 1979-present (continuing as it is feasible)
- ½° horizontal resolution (72 model levels, sfc-strat)
- 1 hourly surface and 2D diagnostic data
  - Including complete budgets and extensive meteorology, lowest model level states
- 6 hourly 3-Dimensional atmospheric analysis
- 3 hourly 3-D model background including diagnostics, coarse resolution
- >70 Tbs online storage, many portals

# *GEOS-5 Atmospheric Data Assimilation System*

## AGCM

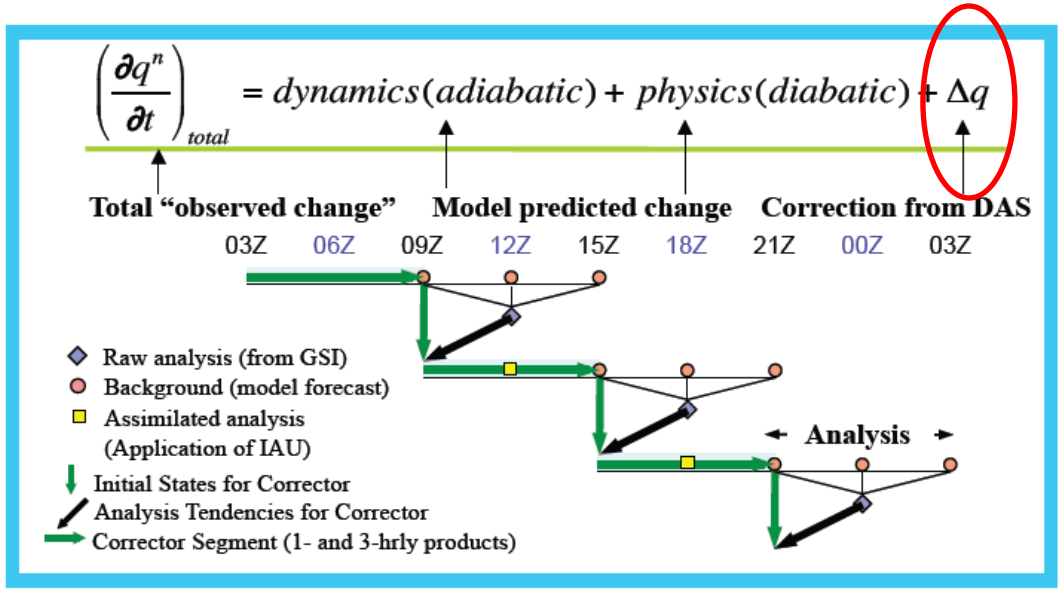
- Finite-volume dynamical core
- Integrated set of physics packages
- Physics integrated under the Earth System Modeling Framework (ESMF)
- Generalized vertical coord to 0.01 hPa
- Catchment land surface model
- Prescribed aerosols
- Interactive ozone
- Prescribed SST, sea-ice

## Analysis

- Grid Point Statistical Interpolation - GSI (co-dev. with NCEP)
- Direct assimilation of satellite radiance data using JCSDA Community Radiative Transfer Model (CRTM)
- Variational bias correction for radiances

## Assimilation

- Apply Incremental Analysis Increments (IAU) to reduce shock of data insertion
- IAU gradually forces the model integration throughout the 6 hour analysis period
- Provides a "replay" capability

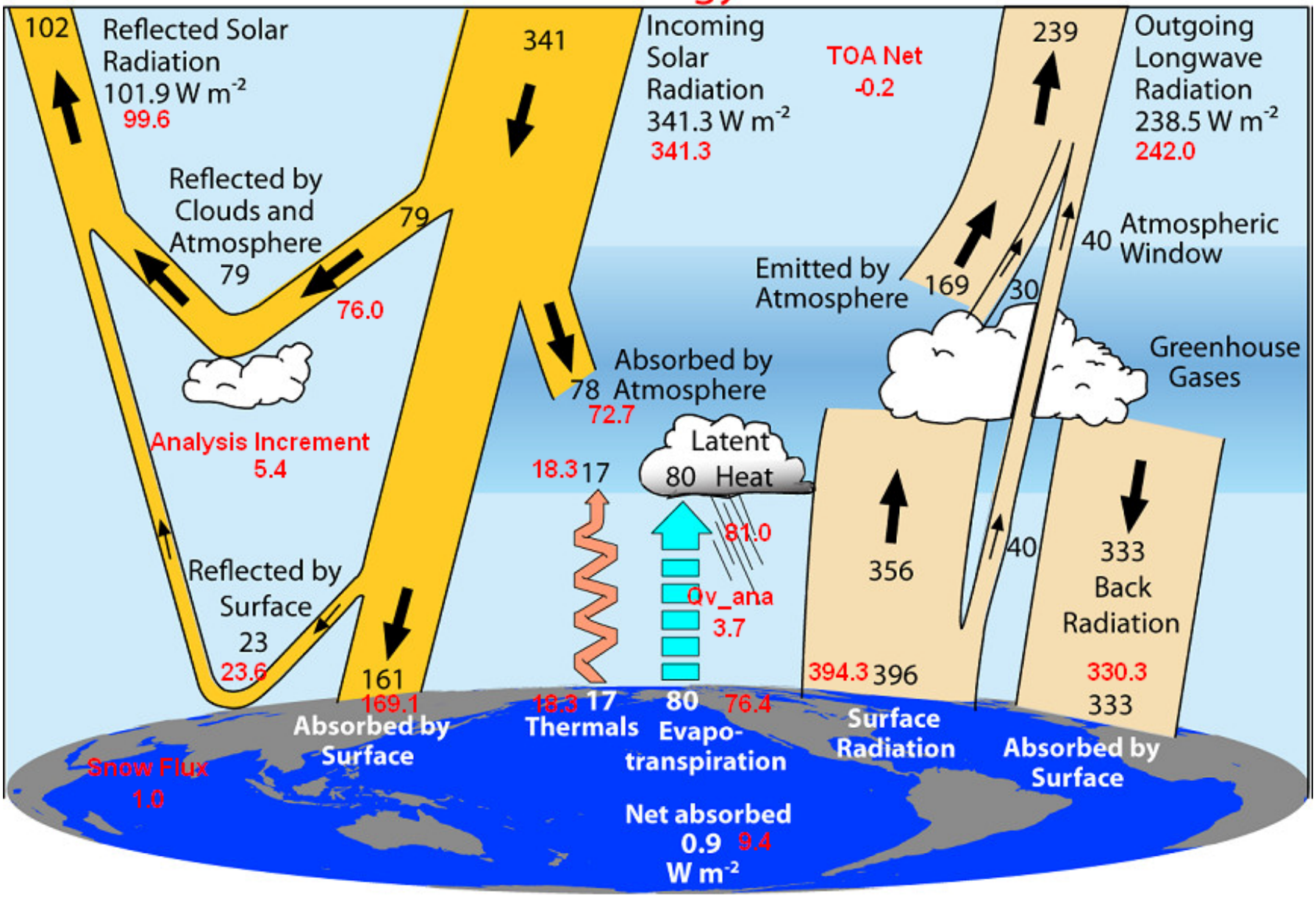



MERRA heat, moisture, and momentum budgets are always balanced…

…but at the expense of the increment forcing the first guess to the analysis

MERRA(RED) Mar 00 - May 04

# Global Energy Flows W m$^{-2}$

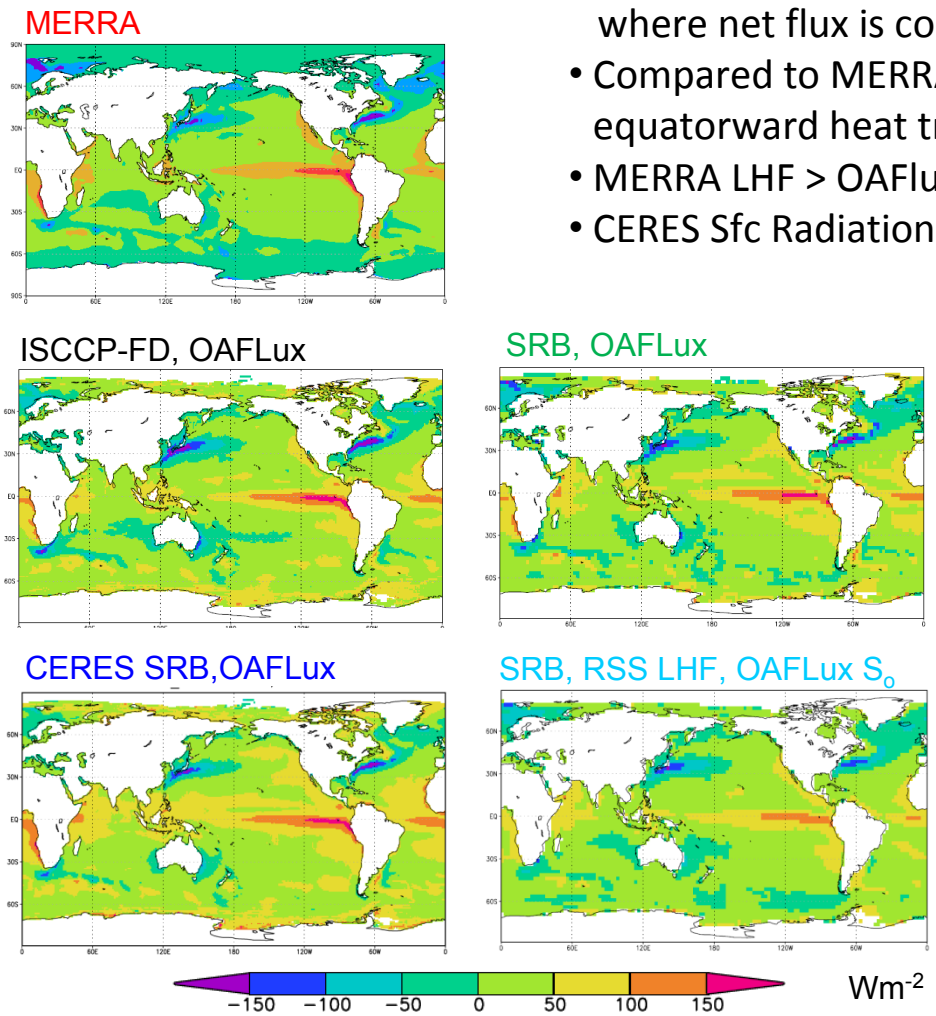


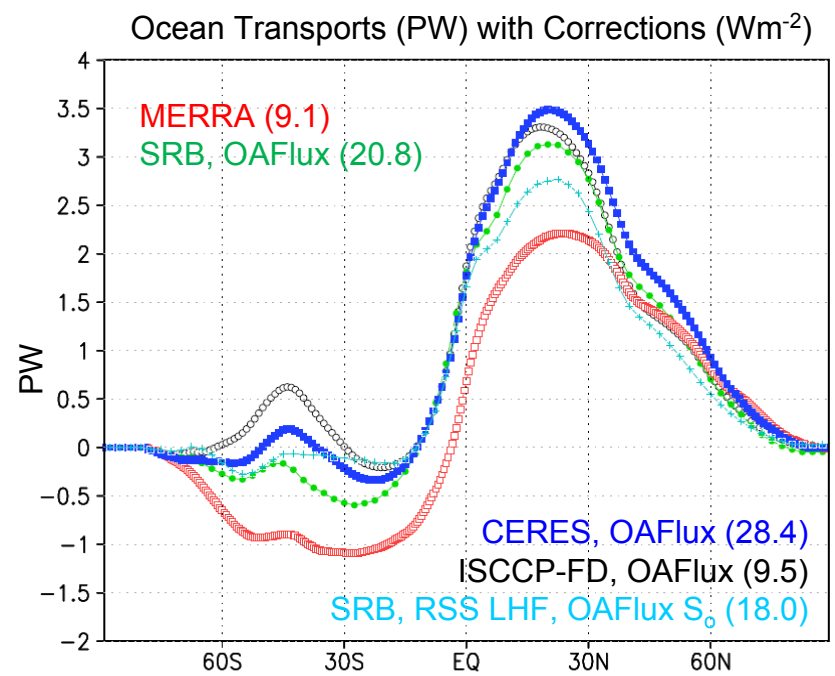

Background from Trenberth, Kiehl and Fasullo (2009, BAMS)

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

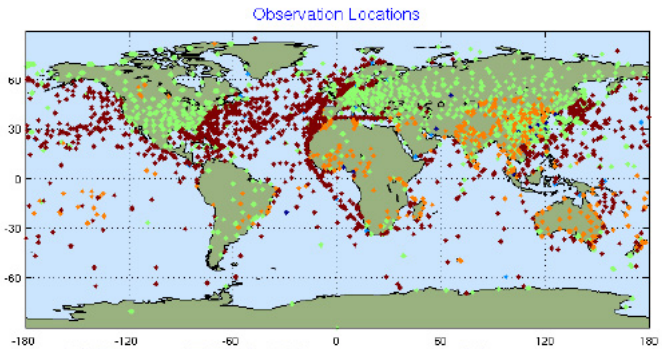
*Flux uncertainties yield transport uncertainties of order 1 PW*

- 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 , $\alpha$
- 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

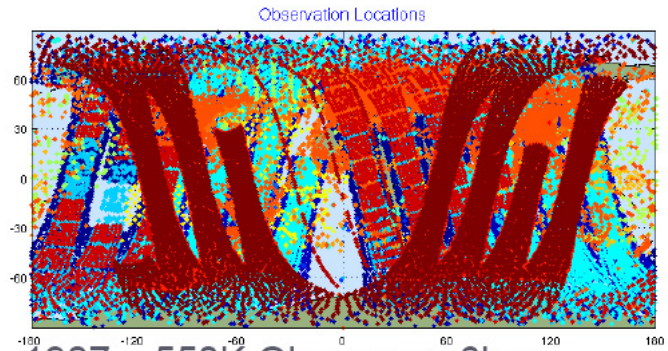


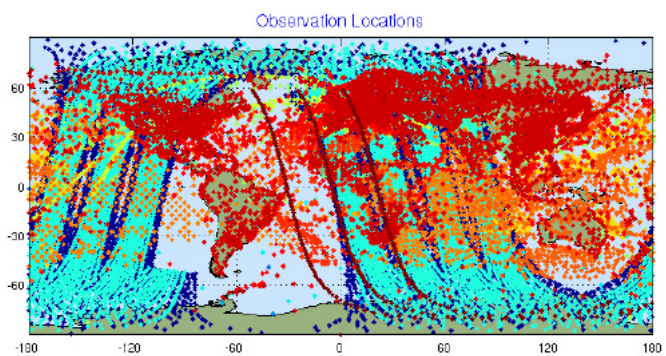
# The Changing Observing System



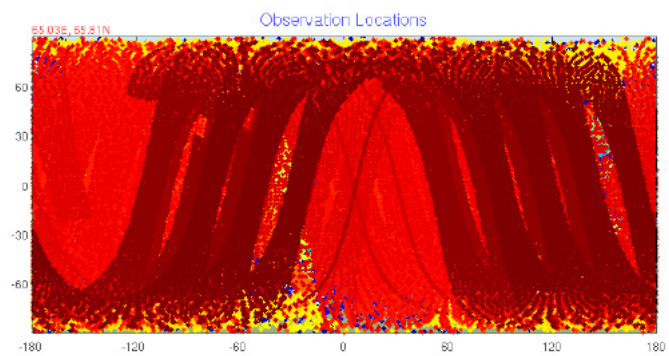

1973 – 77K Obs every 6hrs




1987 – 550K Obs every 6hrs



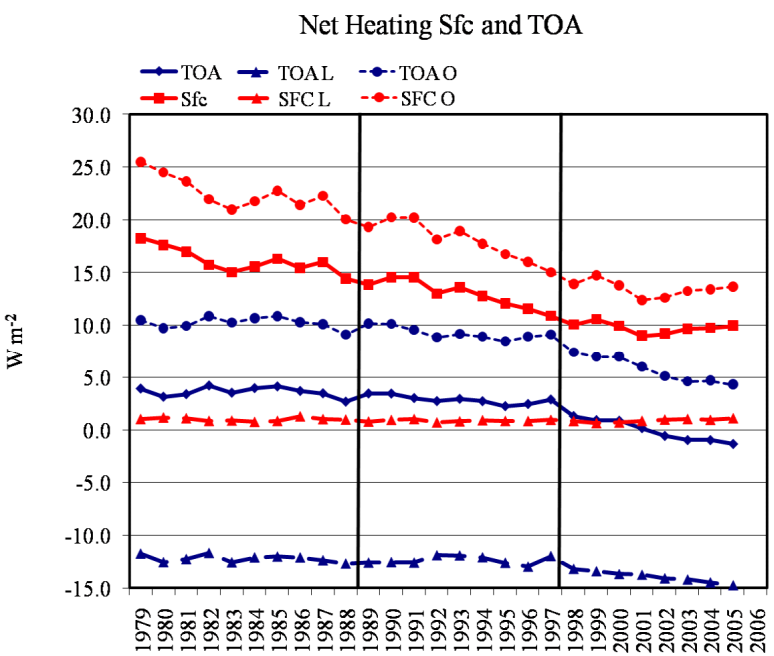

1979 – 325K Obs every 6hrs

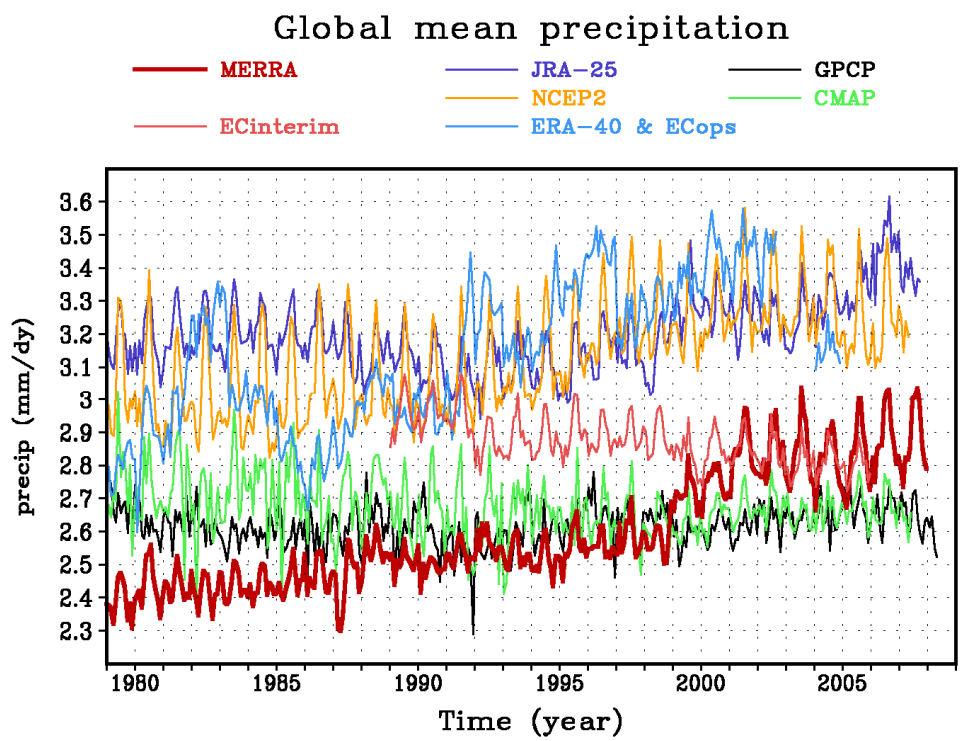



2006 – 4.2M Obs every 6hrs

# 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



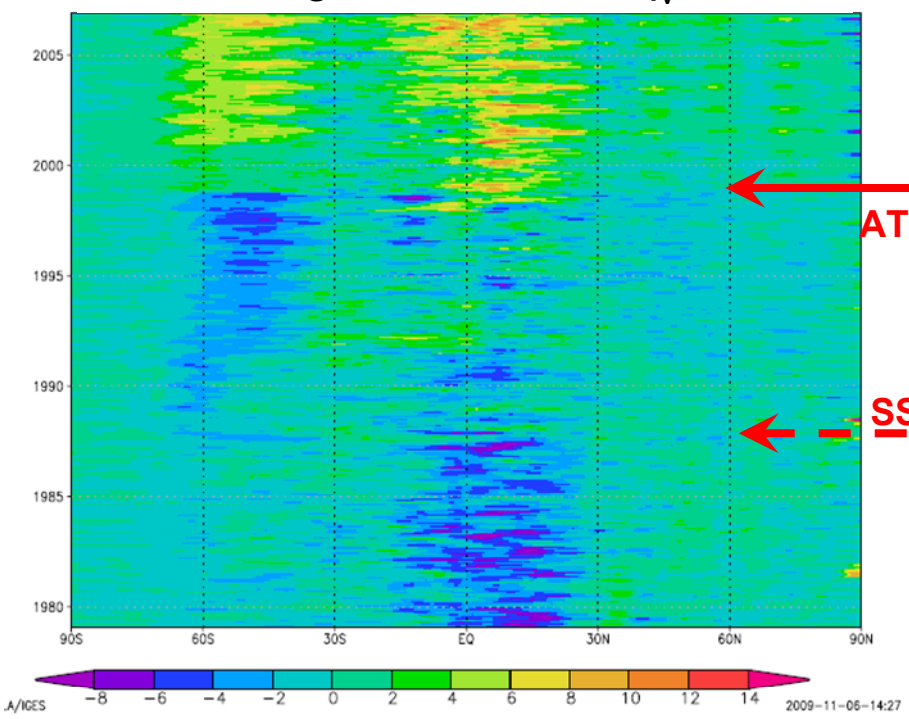



# Time Dependent $q_v$ Analysis Increments Affect Rainfall

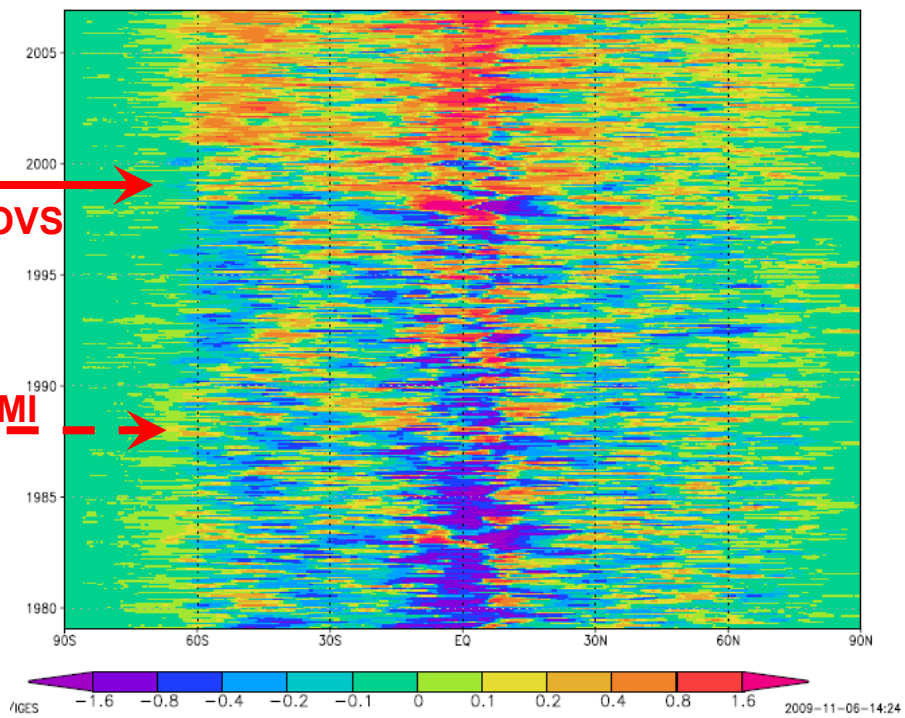
*Zonal Mean Time Series (Mean Annual Cycle Removed)*

- 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



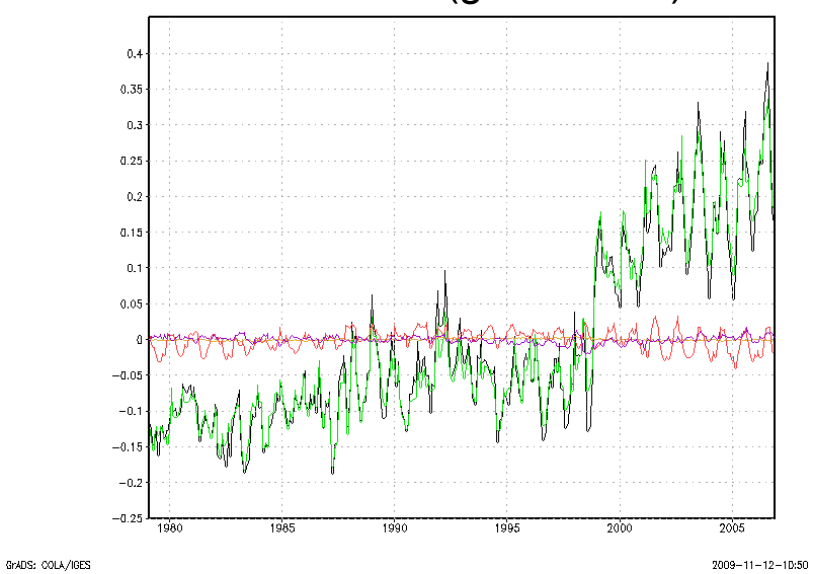

ATOVS

SSMI

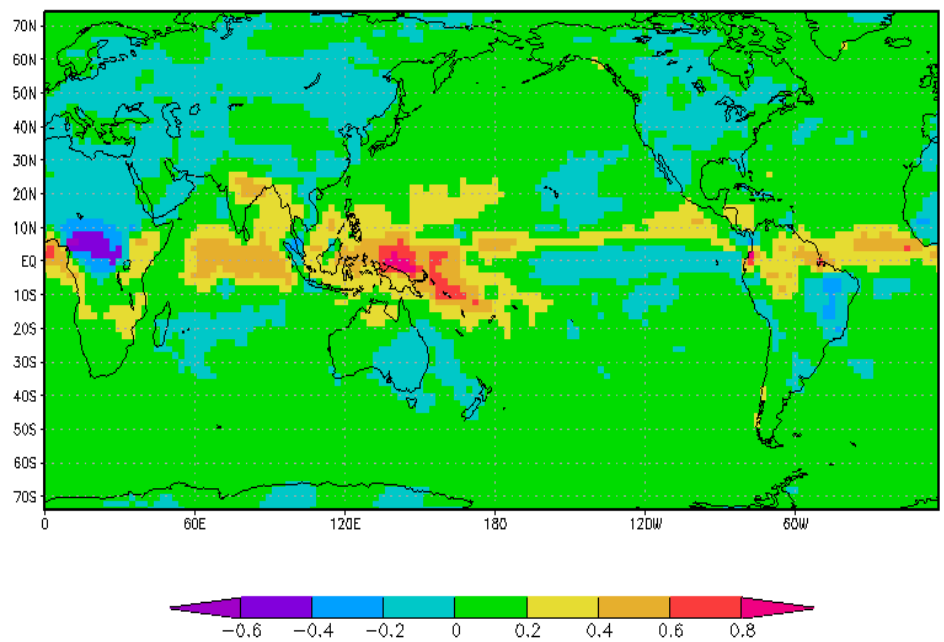
# SVD Analysis May Enable Removal of Spurious Precip Signal to First Order

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.

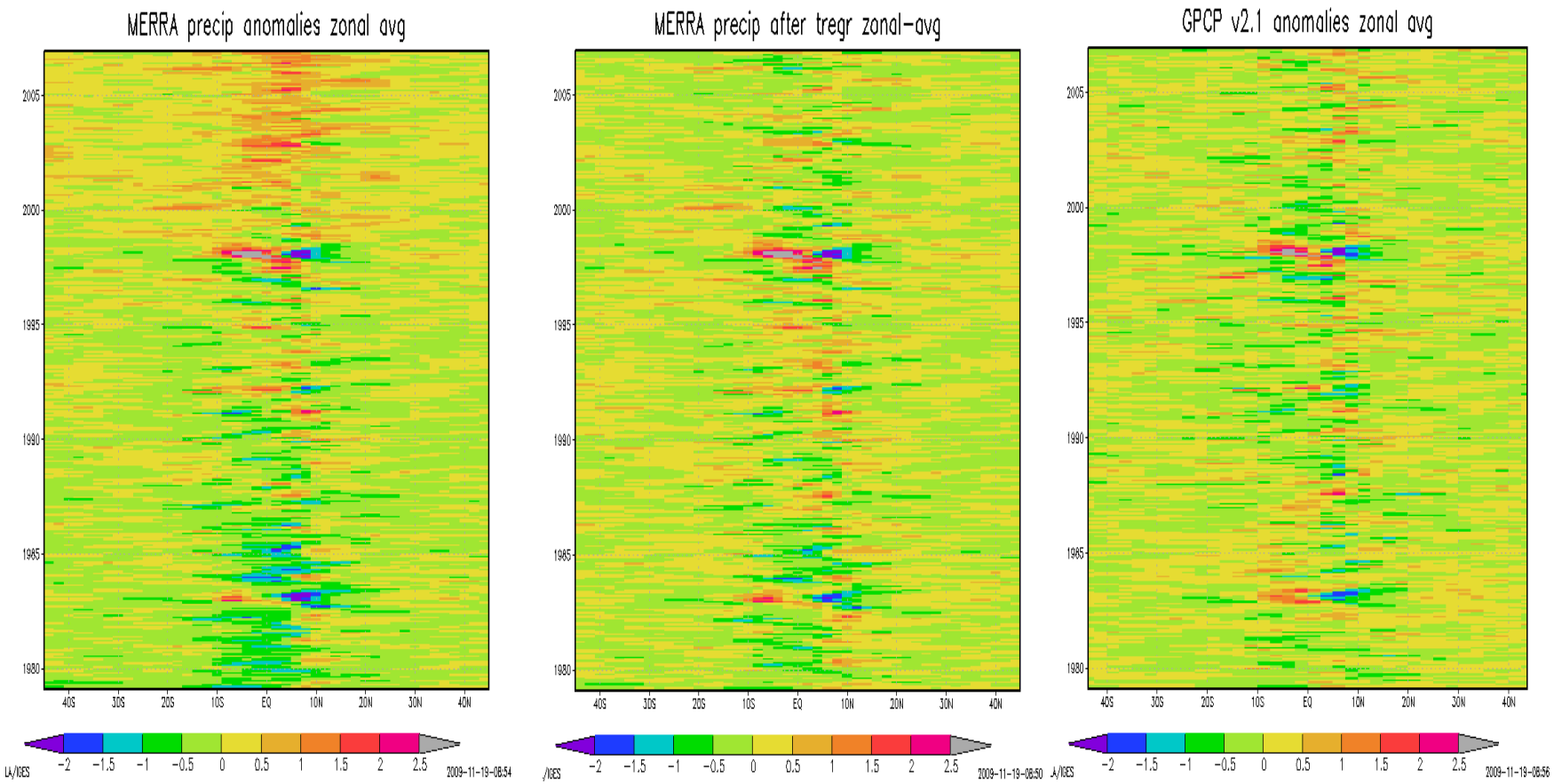
Zonal mean $dq_v dt$ (black) and SVD modes (green is 1st)




Precipitation regression map

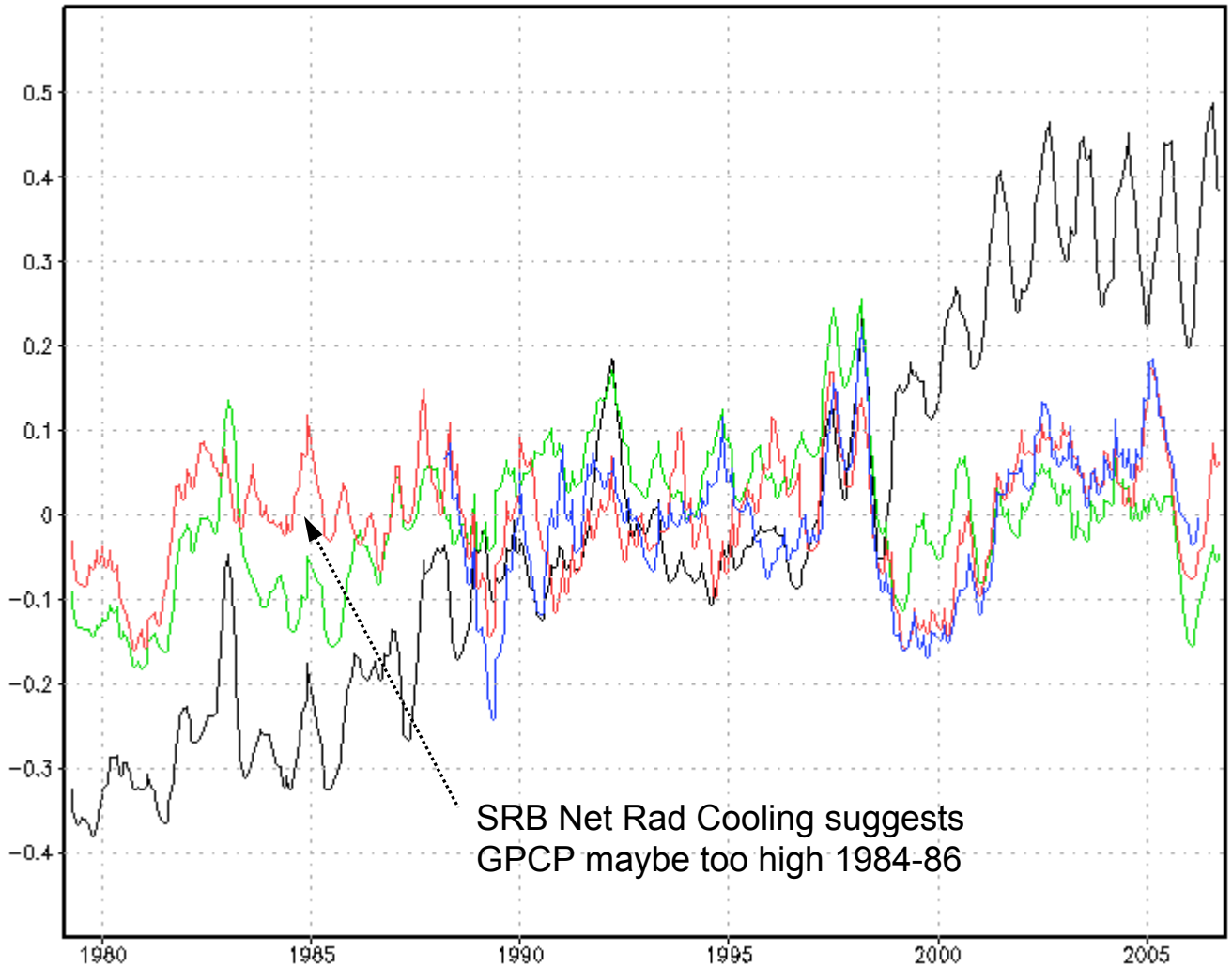


# Results of Correction by Linear Regression to Remove Artifact with Leading $dq_v dt$-ana Mode



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

MERRA Corrected MERRA, GPCP, RSS Hilburn/Wentz



# Summary Points:

- MERRA produces balanced budgets of water, heat, radiation within an assimilation framework that minimizes spinup / shock → MERRA fields smoothly varying on sub-daily time scale. WEC flux estimates in recent years (2000 & beyond) are likely as good or better than other recent reanalysis efforts.

- Because of evolving observing system 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 minimizing 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?**