

# NASA's Modern Era Retrospective-analysis for Research and Applications (MERRA): Global Energy and Water Budgets

Michael Bosilovich  
Franklin R. Robertson  
and Junye Chen

- ▶ With many acknowledgements to GMAO personnel and collaborators

GEWEX Science Conference, Melbourne Australia

August 2009

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

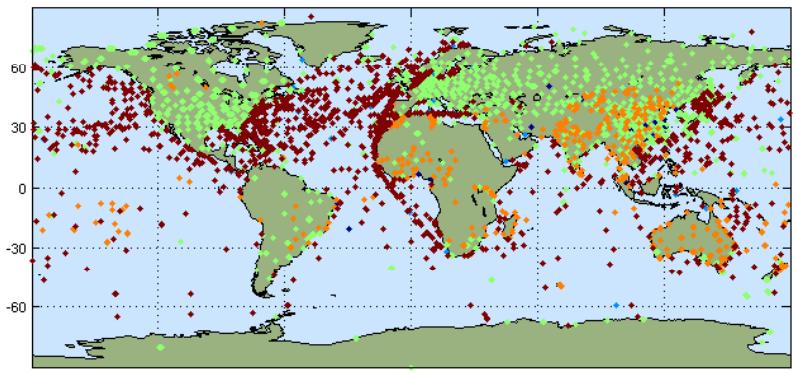
- ▶ 2002 Proposed Objective: Improving the water and energy cycle representation in a reanalysis
- ▶ GEOS5 system development including NASA global climate model with NCEP GSI data assimilation
- ▶ Nov 2007 – External User Review Group endorses the Validation Review of GEOS5 for MERRA
- ▶ Production began in Mar 2008
- ▶ ..... And again in May 2008
- ▶ Currently 1979 through 2005 are available online

# The Changing Observing System

07-Jan-1973 12UTC All data: 77098 observations

all lat; all lon; all lev; all kt; all kx; all qc<sub>x</sub>; all qc<sub>h</sub>  
/data/austin/b500\_swp\_73/all\_ods\_workdir/SAVE\_ODS/b500\_swp\_73.ana.obs.19730107\_12z.ods

Observation Locations

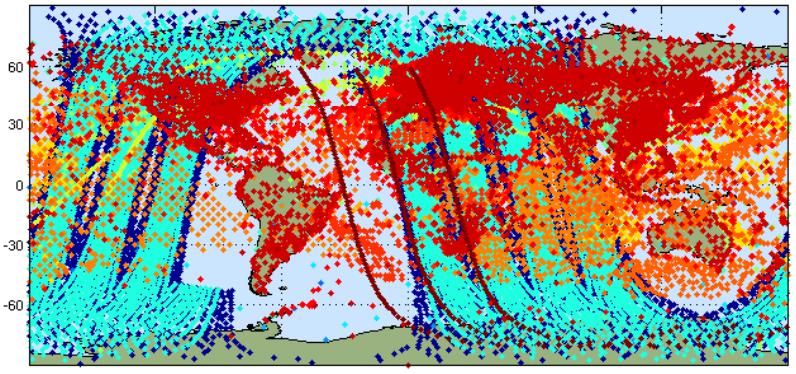


1973 – 77K Obs every 6hrs

07-Jan-1979 12UTC All data: 325765 observations

all lat; all lon; all lev; all kt; all kx; all qc<sub>x</sub>; all qc<sub>h</sub>  
/data/austin/b500\_swp\_73/all\_ods\_workdir/SAVE\_ODS/b500\_swp\_73.ana.obs.19790107\_12z.ods

Observation Locations

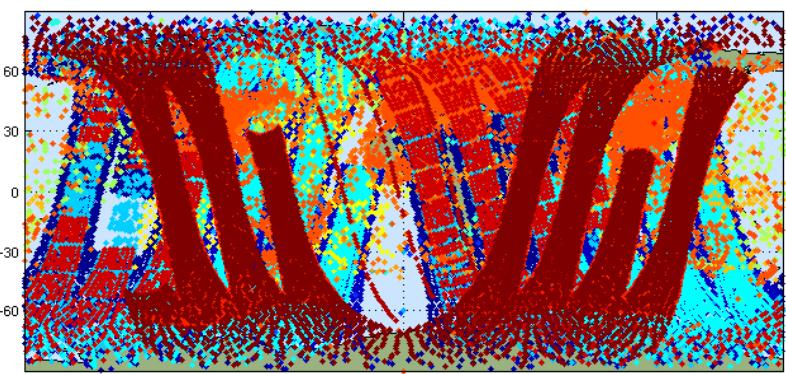


1979 – 325K Obs every 6hrs

02-Aug-1987 12UTC All data: 550602 observations

all lat; all lon; all lev; all kt; all kx; all qc<sub>x</sub>; all qc<sub>h</sub>  
/data/austin/b500\_b10p9\_84/all\_ods\_workdir/b500\_b10p9\_84.ana.obs.19870802\_12z.ods

Observation Locations

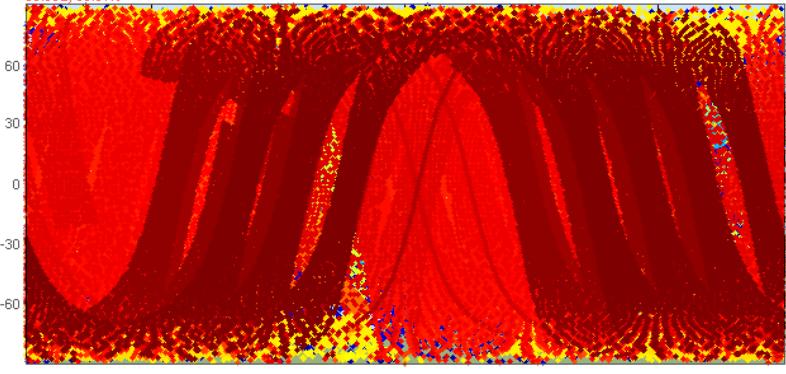


1987 – 550K Obs every 6hrs

07-Jan-2006 12UTC All data: 4217655 observations

all lat; all lon; all lev; all kt; all kx; all qc<sub>x</sub>; all qc<sub>h</sub>  
/data/austin/d5\_b10p9stab12\_jan06/all\_ods\_workdir/d5\_b10p9stab12\_jan06.ana.obs.20060107\_12z.ods

Observation Locations

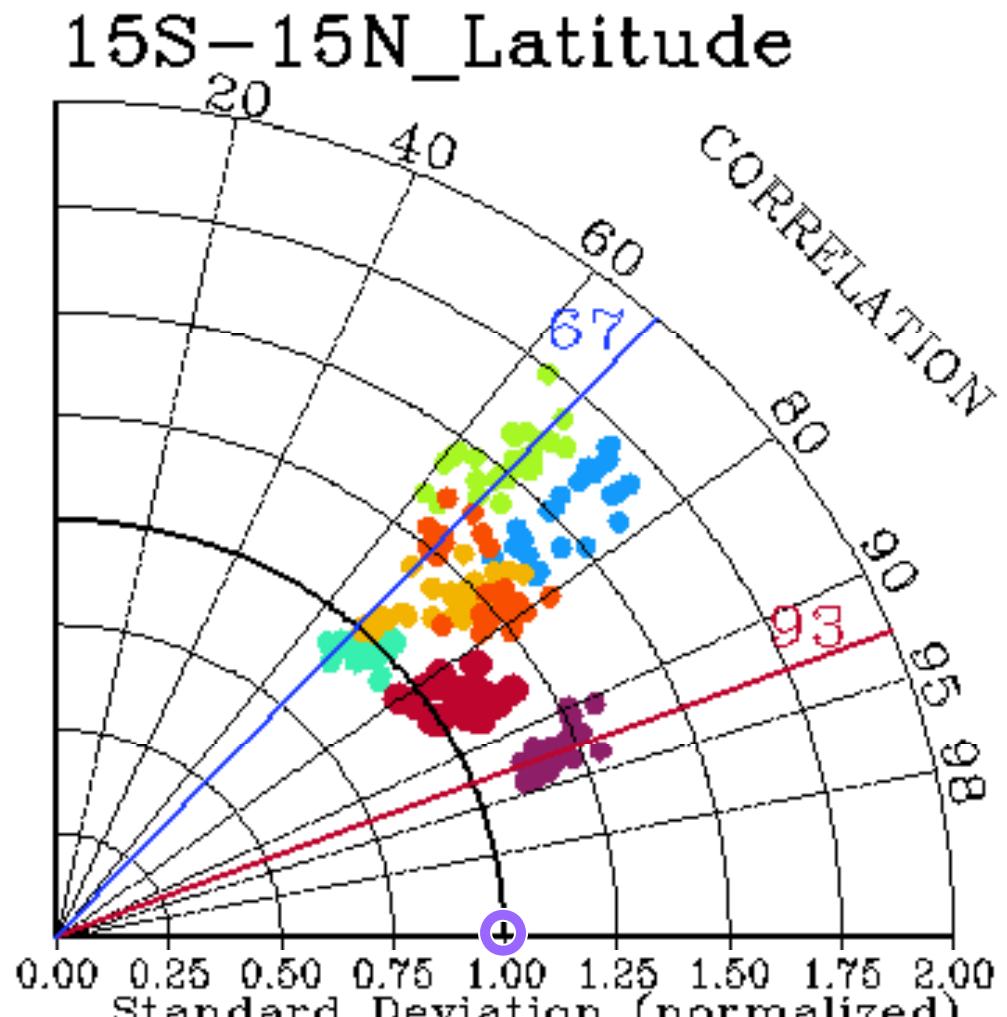


2006 – 4.2M Obs every 6hrs

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

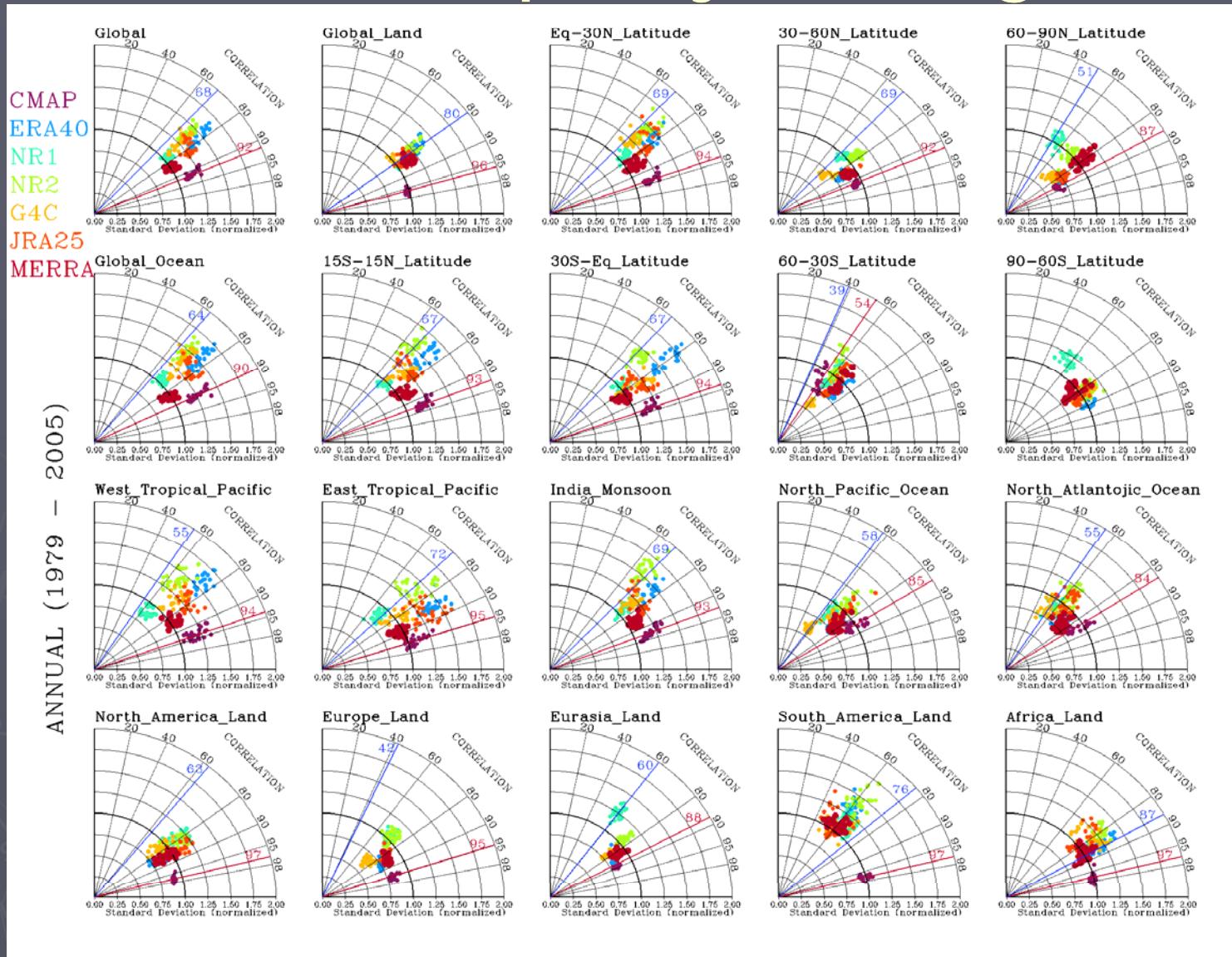
- ▶ 1979-present (continuing as it is feasible)
- ▶  $\frac{1}{2}^\circ$  horizontal resolution (72 model levels, sfc-strat)
- ▶ 1 hourly surface and 2D diagnostic data
  - Including complete budgets and extensive meteorology, lowest model level states
- ▶ 6 hourly 3-Dimensional atmospheric analysis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

CMAP  
ERA40  
NR1  
NR2  
G4C  
JRA25  
MERRA



Taylor diagrams for tropical precipitation. GPCP merged precipitation is the reference data set. The diagrams compare spatial correlation (to GPCP) of the analysis to standard deviation normalized by the reference data set. If a field exactly duplicated GPCP, it would be at the 1,1 point. Linear distance to the 1,1 point is a measure of skill in reproducing the reference data set (annual 1979-2005).

# MERRA Precip Taylor Diagrams

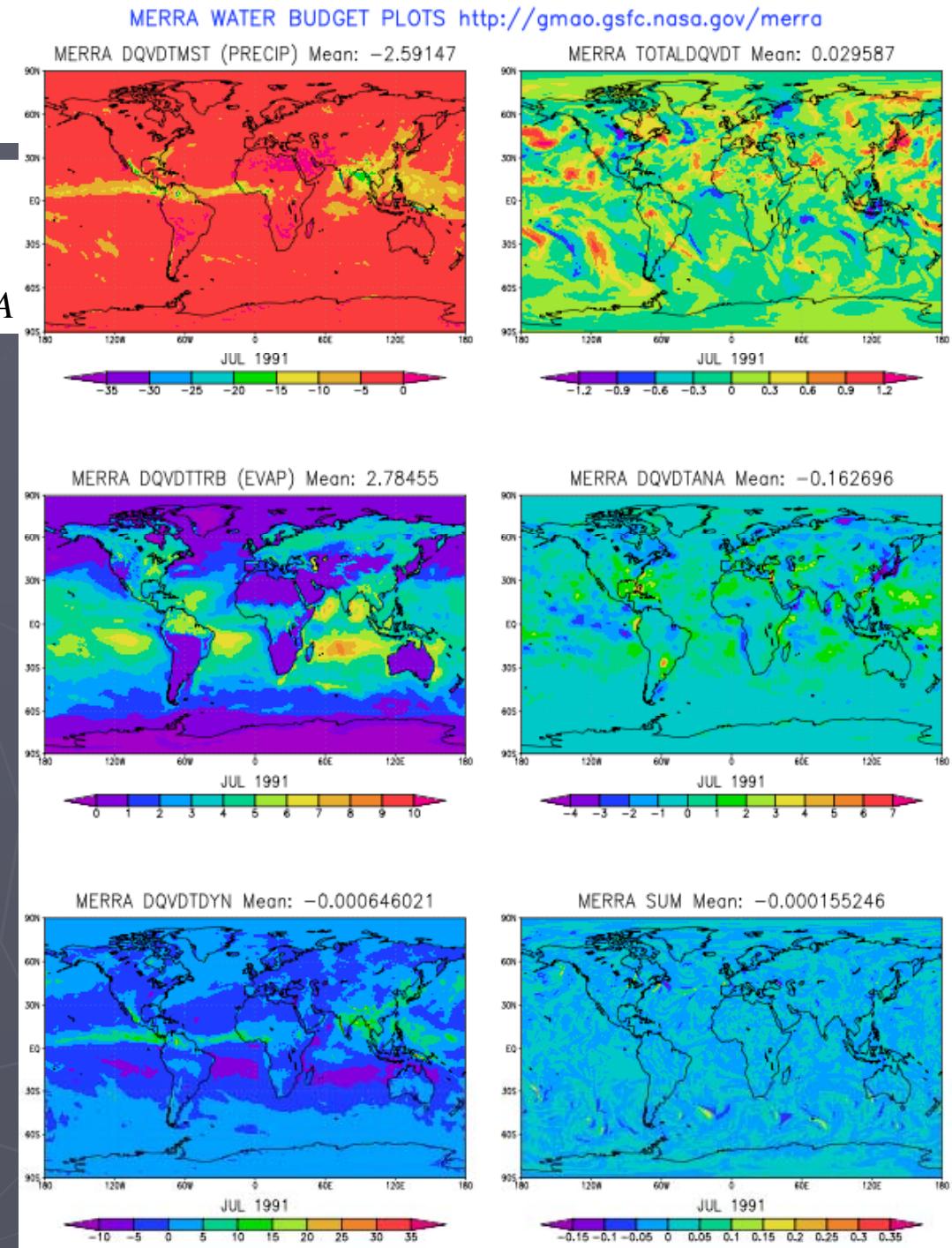


► Updated from: Bosilovich et al (2008, JAMC)

# Vertically-Integrated Water Vapor Budget for July 1991

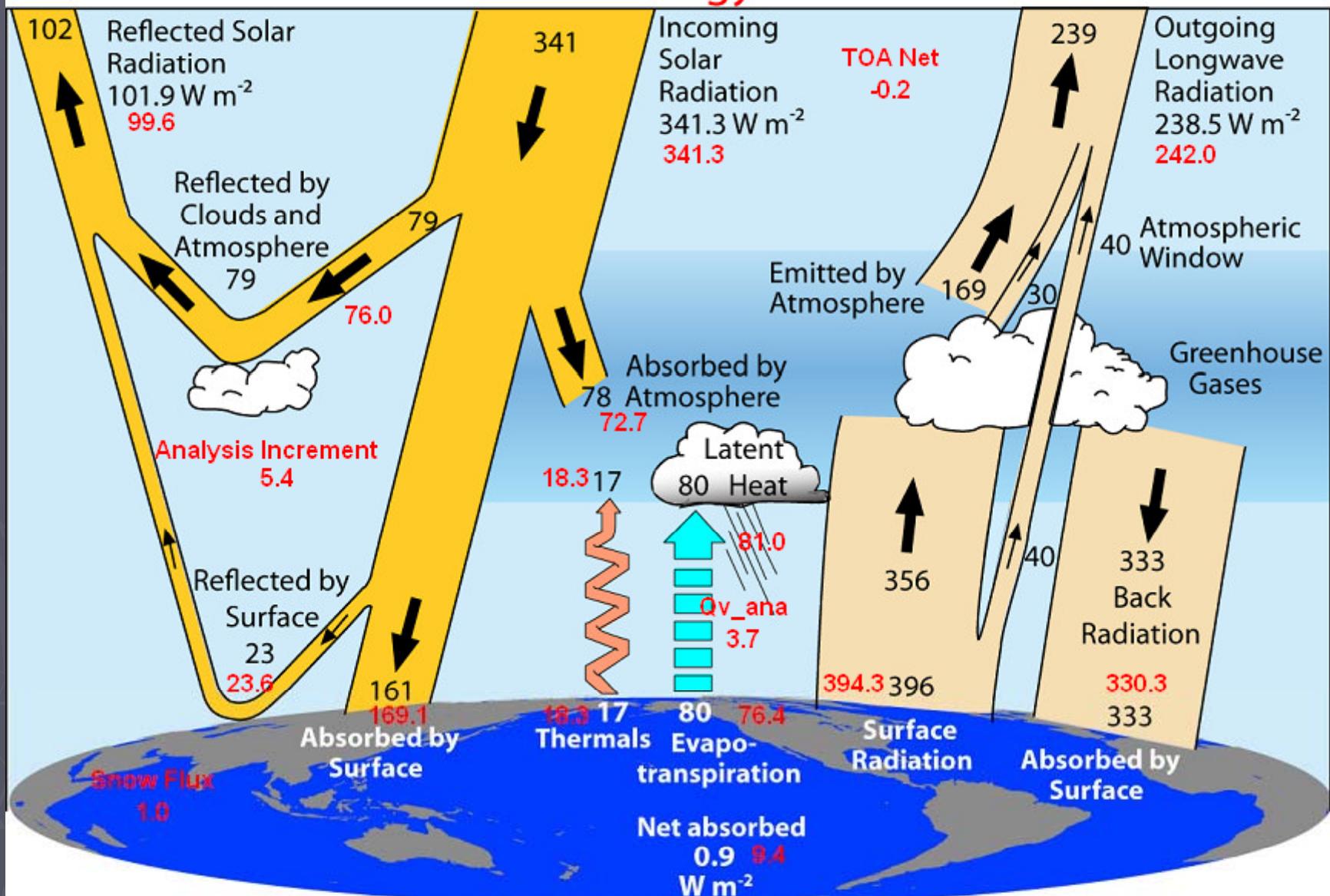
$$\frac{\partial qv}{\partial t} = E - P - \nabla \cdot qv + \frac{\partial qv}{\partial t} \text{ ANA}$$

- ▶ Complete budgets are available including all tendencies and analysis increments
- ▶ Water (all phases), Ozone, KE, Enthalpy, Included
- ▶ Also, land-only budgets
- ▶ Tremendous effort by Max Suarez, Larry Takacs and Randy Koster



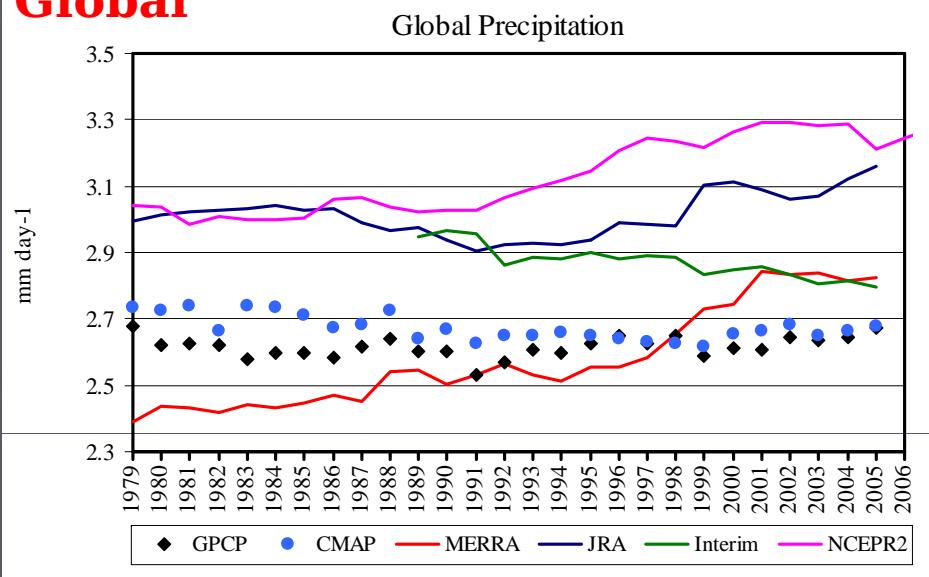
MERRA(RED) Mar 00 - May 04

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

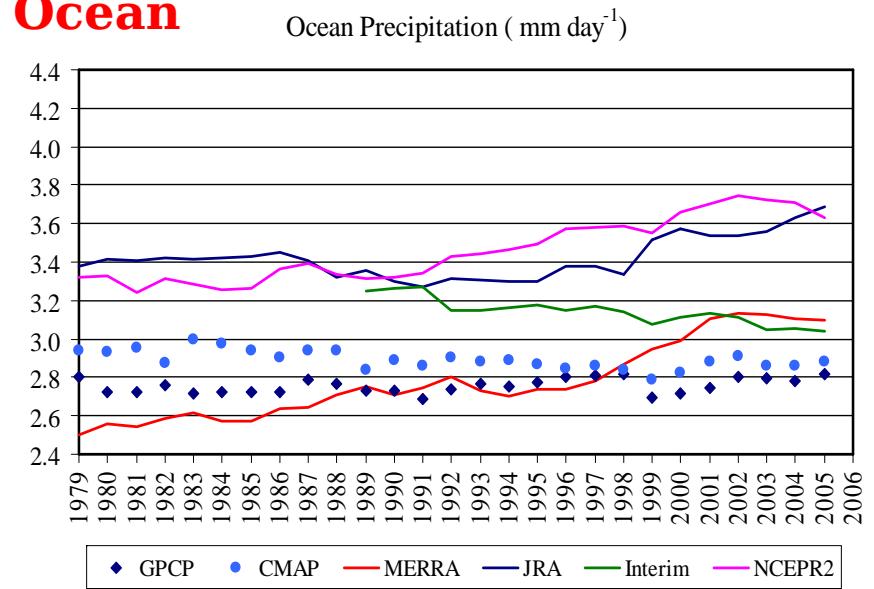


# Trends in the Water and Energy Cycles

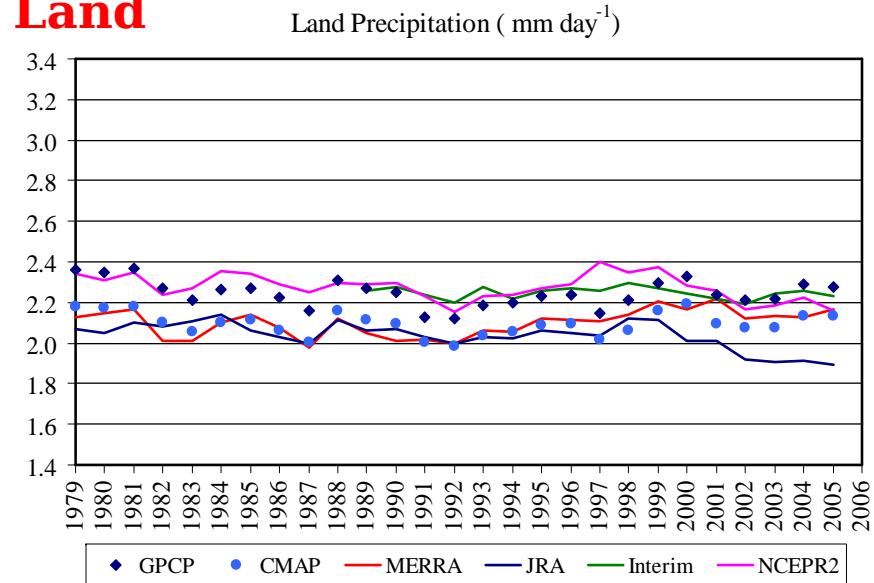
## Global



## Ocean

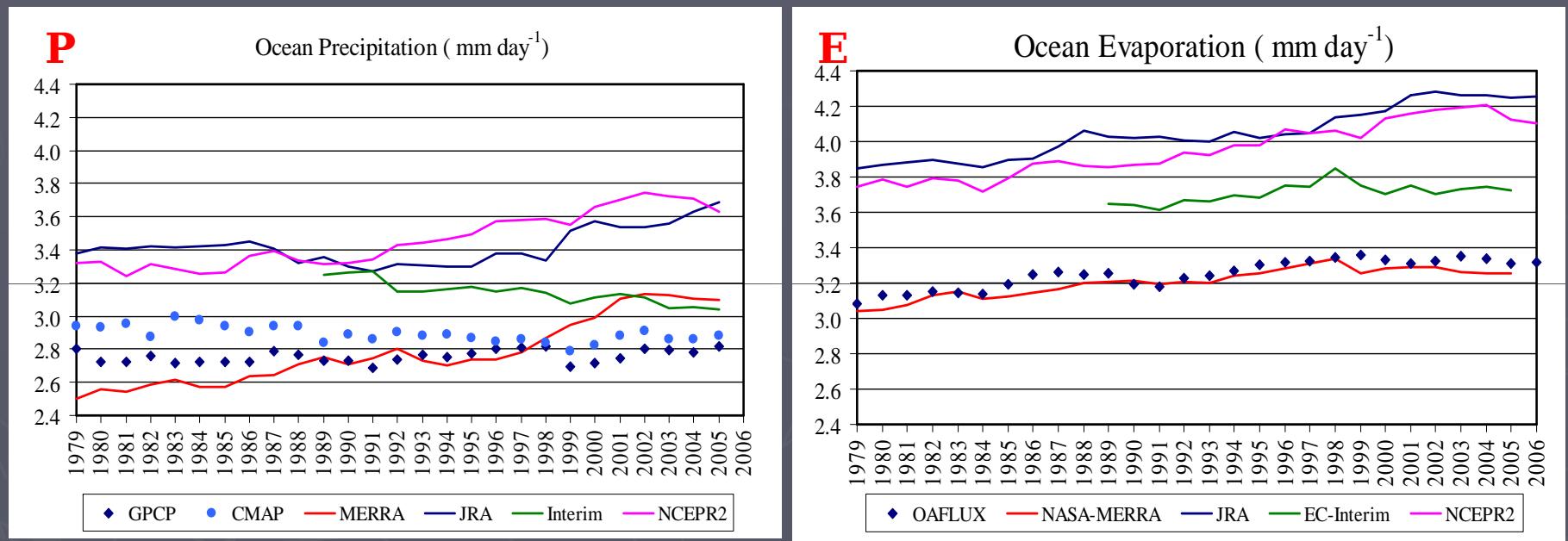


## Land



- ▶ Global P trend mostly over Ocean
- ▶ Land, taken together, are comparable with little apparent trend

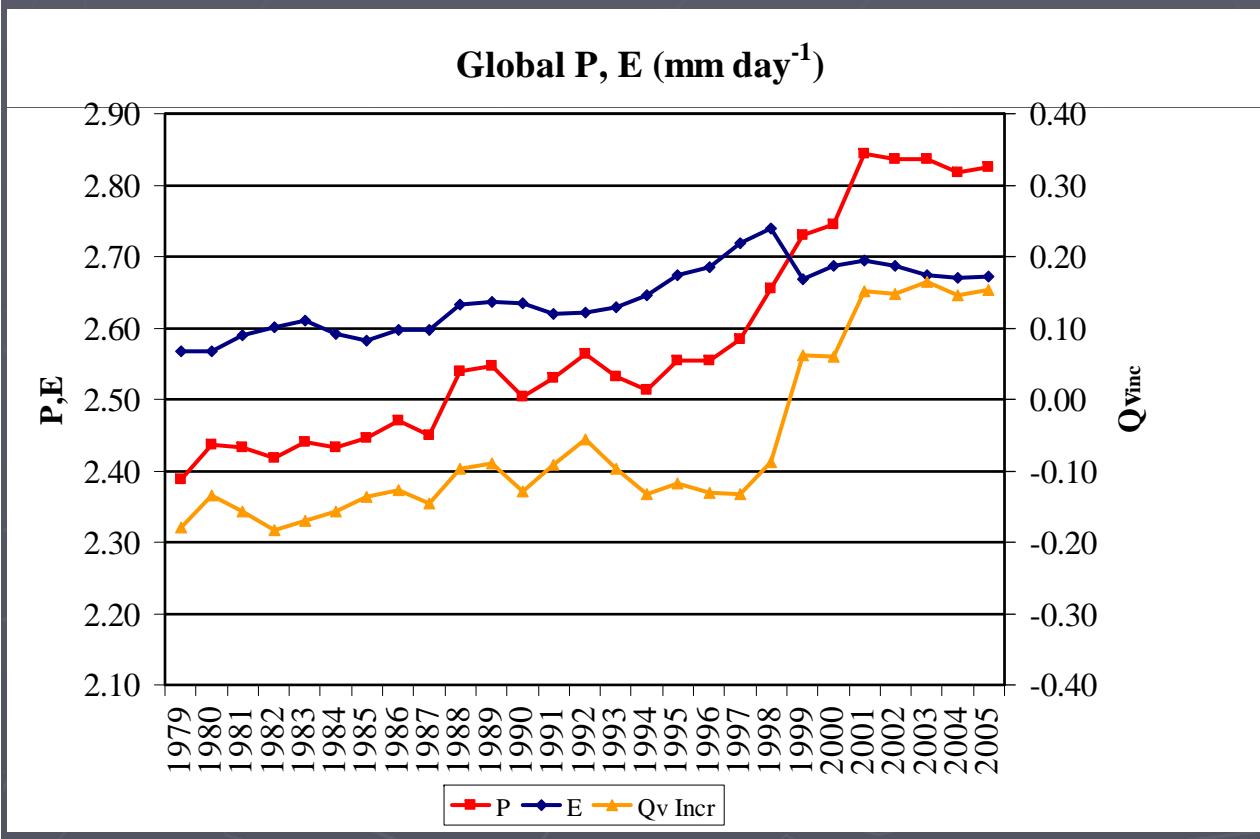
# Ocean only P and E



- The Upward trend in P exceeds E
- All reanalyses show upward trend in ocean evaporation (most also show increasing P)

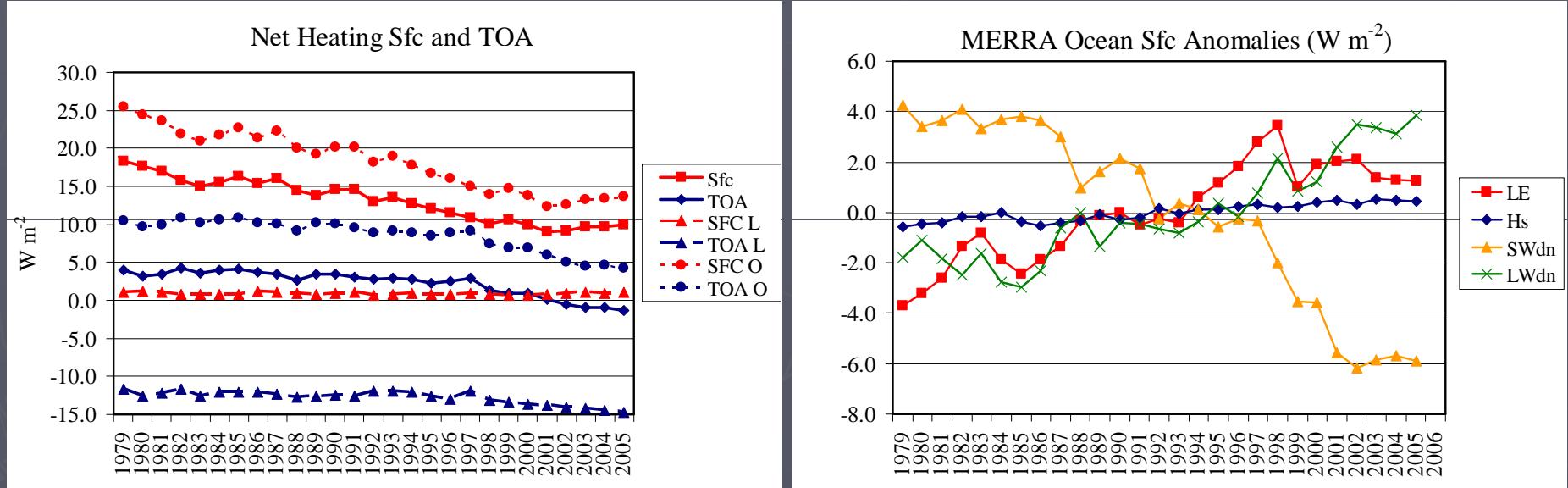
# Global water Balance

$$\frac{\partial \bar{w}}{\partial t} = -\nabla \cdot (\bar{v} \bar{w}) + E - P + \left[ \frac{\partial \bar{w}}{\partial t} \right]_{ANA} + F$$



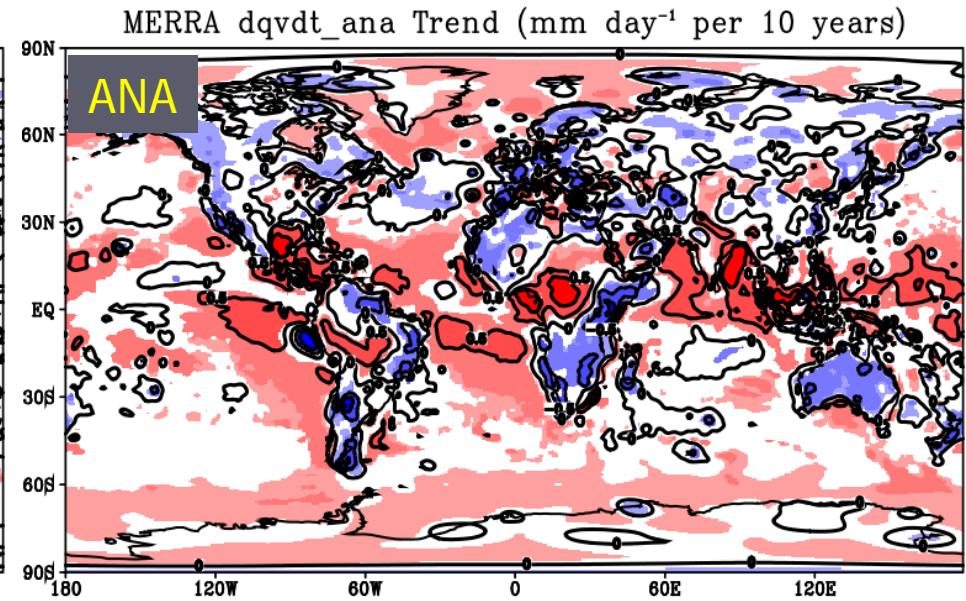
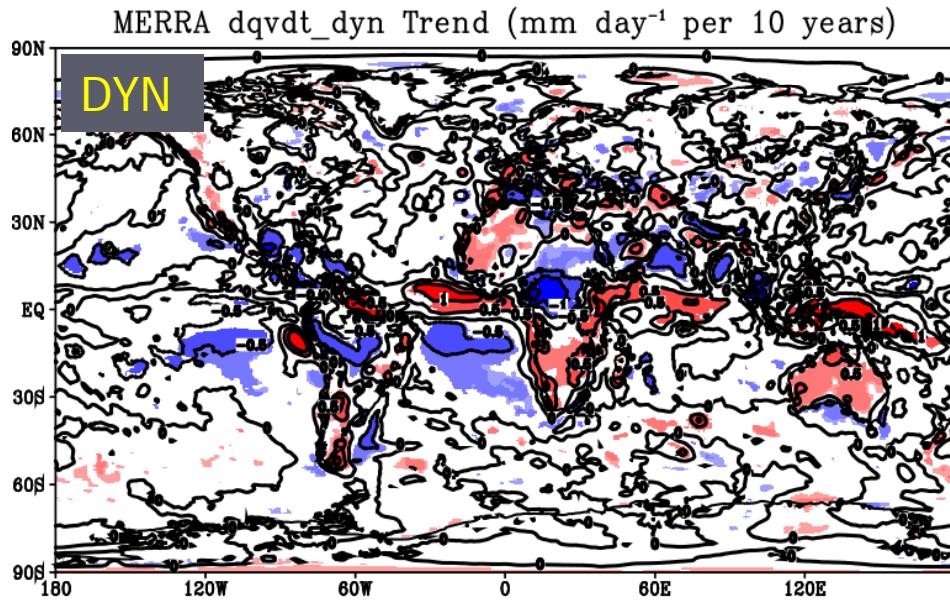
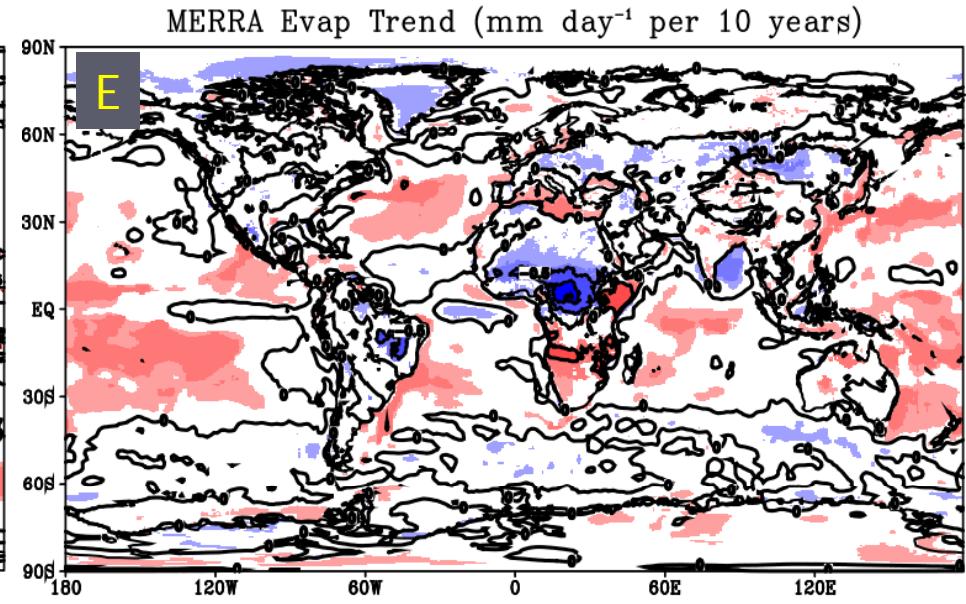
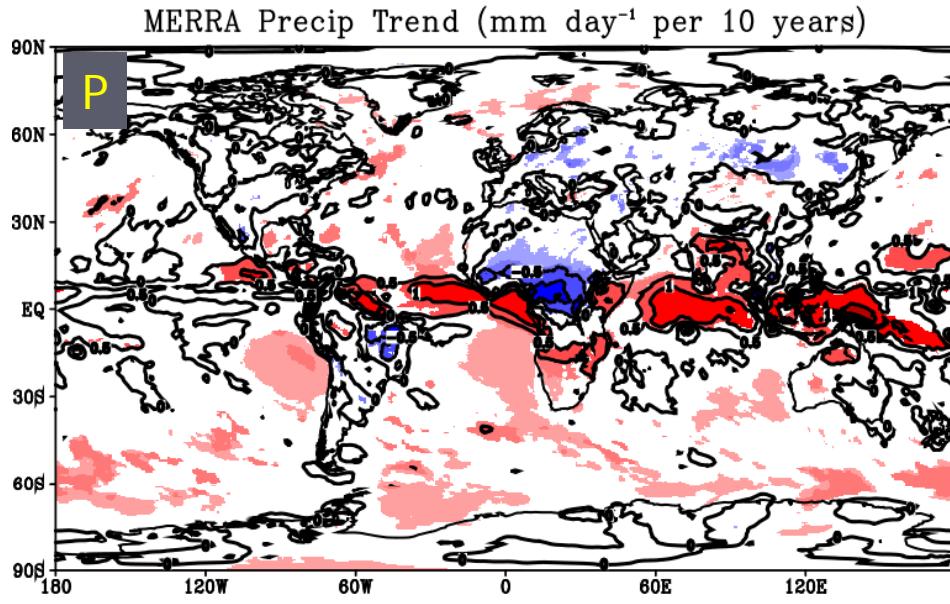
- ▶ Nov98 NOAA15
- ▶ Jul99 QSCAT
- ▶ Jan01 NOAA16
- ▶ Aug02 NOAA17
- ▶ Oct02 AIRS

# Net Surface and TOA Imbalance

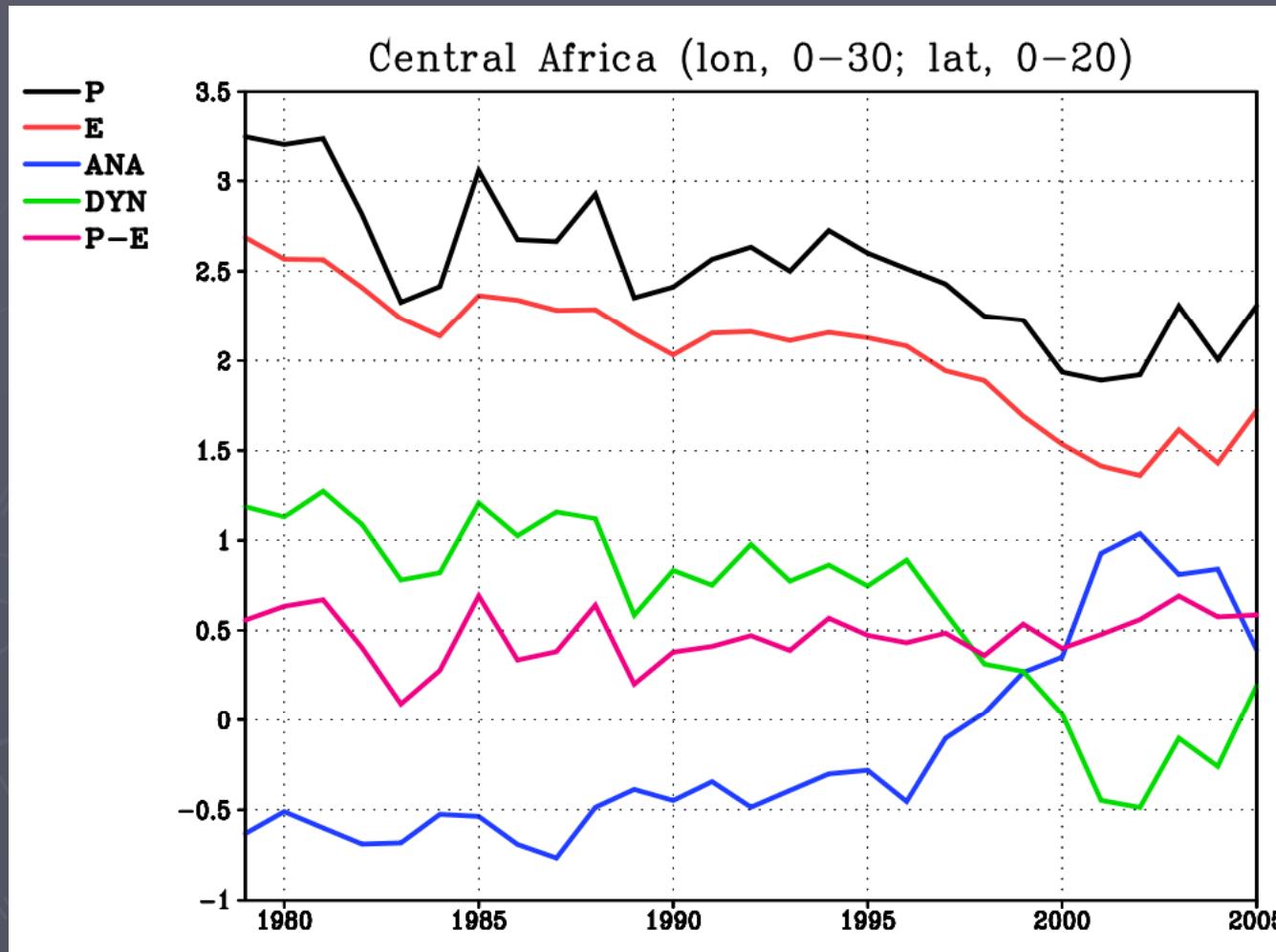


- ▶ Global surface net imbalance is improving in time, mostly changing over Ocean
- ▶ The Ocean net imbalance is decreasing in incoming SW radiation and increasing LE

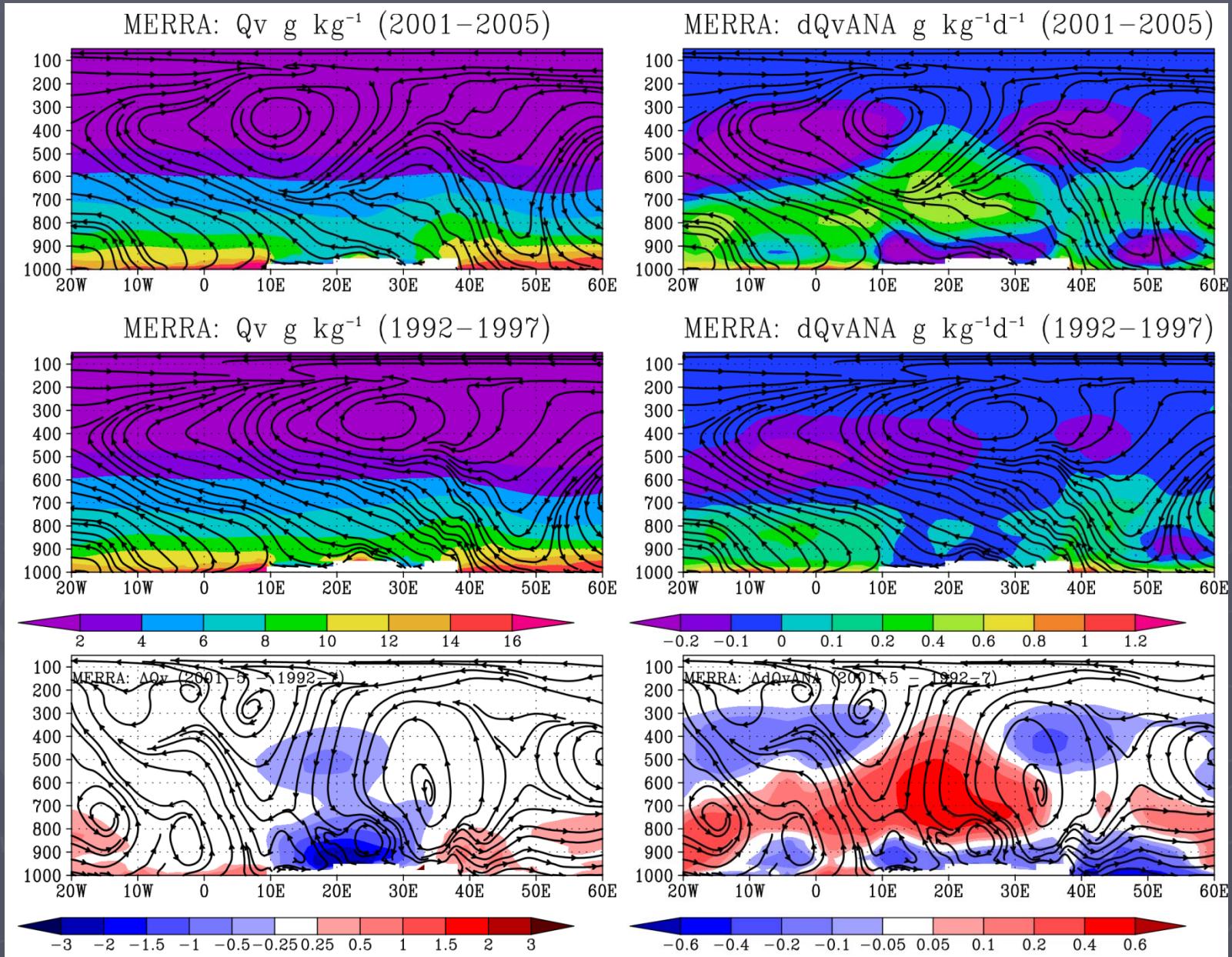
# Spatial Distribution of Linear Trends



# Central Africa Water Budget



# Water Vapor Before and After



# Summary

- ▶ MERRA Precipitation shows skill compared to GPCP, relative to other reanalyses, the trends are on the order of other reanalyses, but the bias is much improved
- ▶ Energy balance looks reasonable in recent period,  $\sim 8\text{Wm}^{-2}$  imbalance (mostly ocean)
- ▶ Remaining issues in reanalyses: trends apparently related to the changing observing system, affecting water and energy cycles, and ultimately regional dynamics
- ▶ Regionally, researchers must evaluate the processes important to their project

# Thank You

- ▶ Home - <http://gmao.gsfc.nasa.gov/merra/>
- ▶ Data - <http://disc.sci.gsfc.nasa.gov/MDISC/>
- ▶ Discussion –  
<http://merra-reanalysis.blogspot.com/>
- ▶ [merra-questions@listserv.gsfc.nasa.gov](mailto:merra-questions@listserv.gsfc.nasa.gov)
- ▶ [Michael.Bosilovich@nasa.gov](mailto:Michael.Bosilovich@nasa.gov)

# MERRA Documentation

- ▶ GEOS5 Model and Assimilation Document, Rienecker et al.
- ▶ MERRA File Specification, Suarez et al. (Outlines the output data format, and information on variables)
- ▶ MERRA Validation, (Results of the GEOS5 Validation Experiments, prior to beginning MERRA production)