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

Global Modeling and Assimilation Office

- Overview and Validation
- Global Water and Energy Budget
- Some Weather Features

Presented by Michael Bosilovich, Purdue University, West Lafayette IN

September 24, 2009

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

- When satellite profiles became useful for initializing weather forecasts, the analyses also provided global maps of the circulation
- After some time passed and there were years of analyses, the data were analyzed for climate studies
- Changes in the modeling systems, lead to changes in the resulting climate so that these data were unreliable for climate studies
- Static modeling and data assimilation systems were used to re-analyze the long time series (NCEP, ERA15)
- Currently, many new observations are being made and assimilated into the Earth system

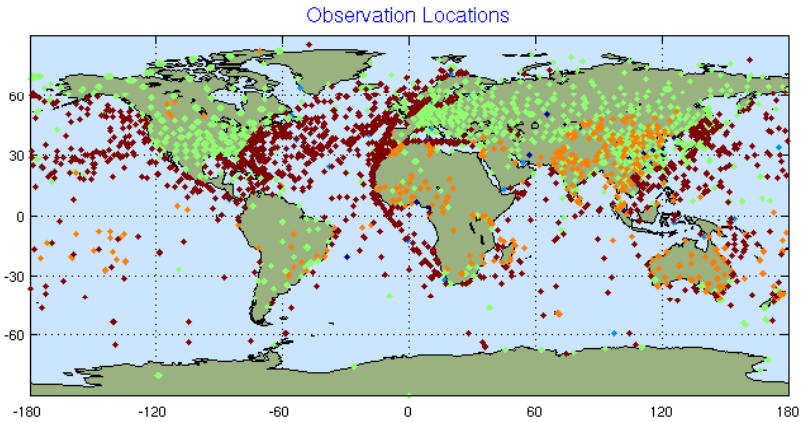
NASA's Modern Era Retrospective-analysis for Research and Applications (MERRA)

- 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 qcx; all qch
/data/austin/b500_swp_73/all_ods_workdir/SAVE_ODS/b500_swp_73.ana.obs.19730107_12z.ods



1973 – 77K Obs every 6hrs

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

all lat; all lon; all lev; all kt; all kx; all qcx; all qch
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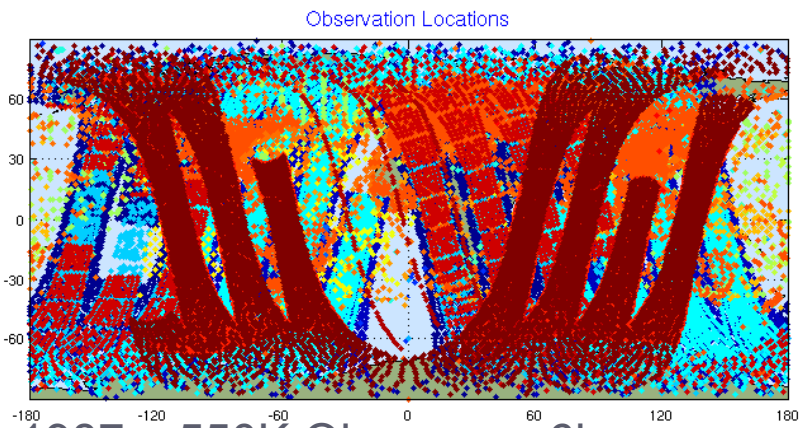

1987 – 550K Obs every 6hrs

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

all lat; all lon; all lev; all kt; all kx; all qcx; all qch
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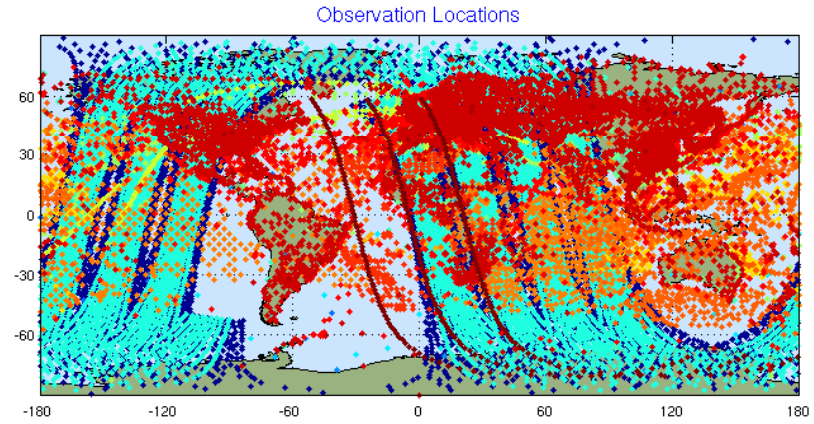

1979 – 325K Obs every 6hrs

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

all lat; all lon; all lev; all kt; all kx; all qcx; all qch
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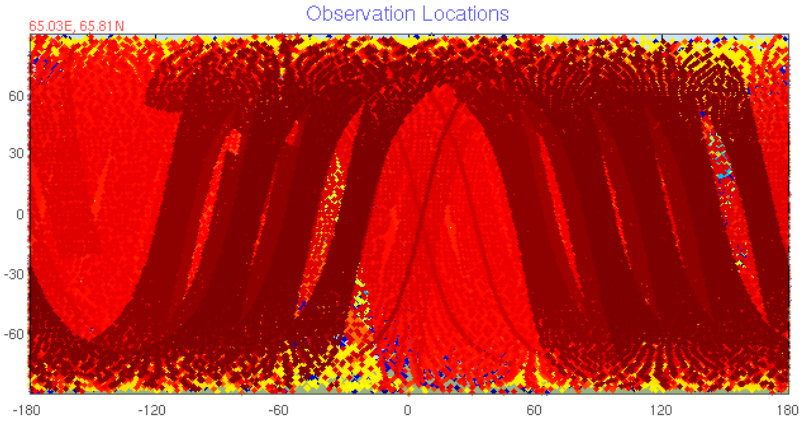


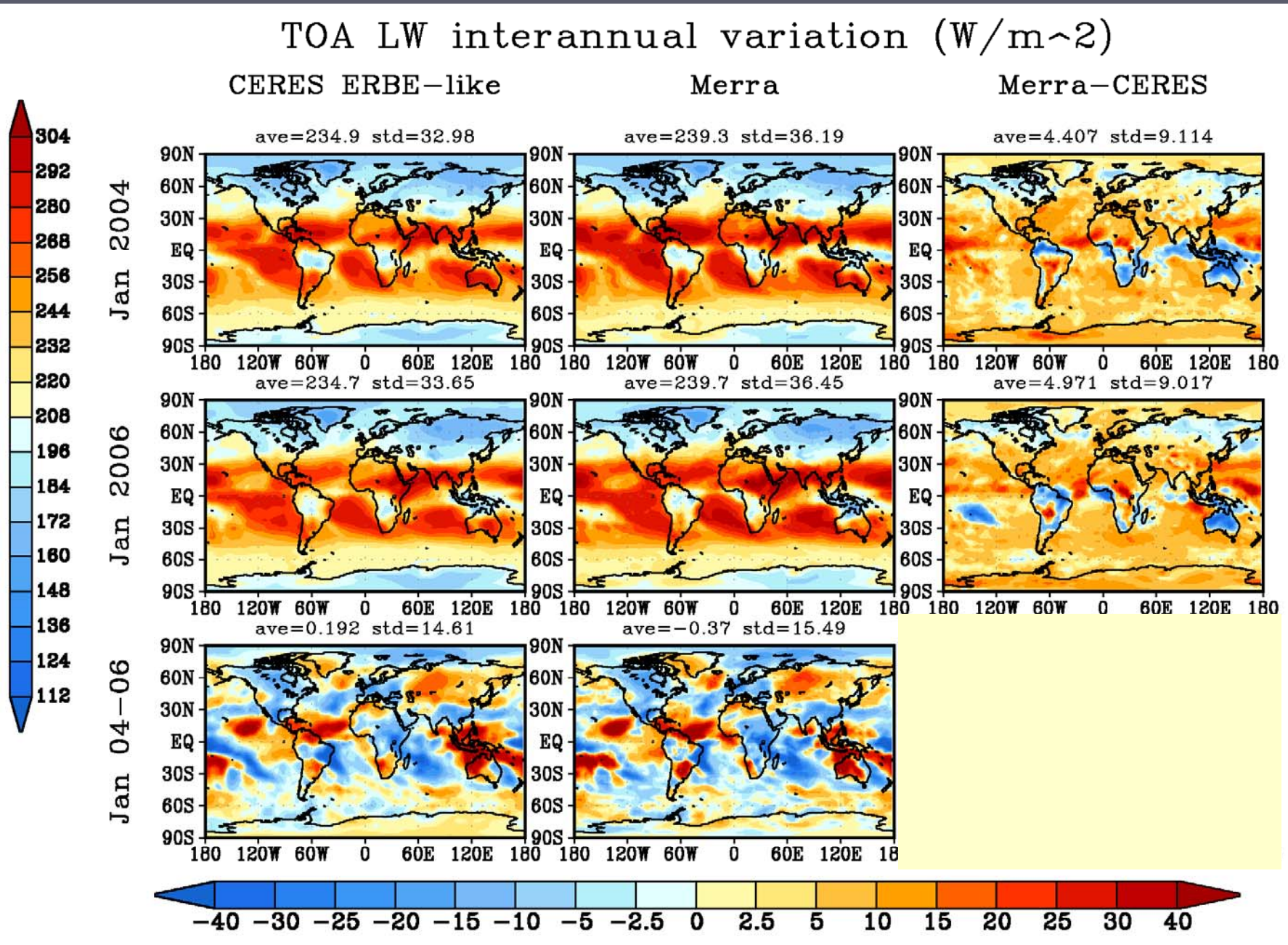
2006 – 4.2M Obs every 6hrs

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

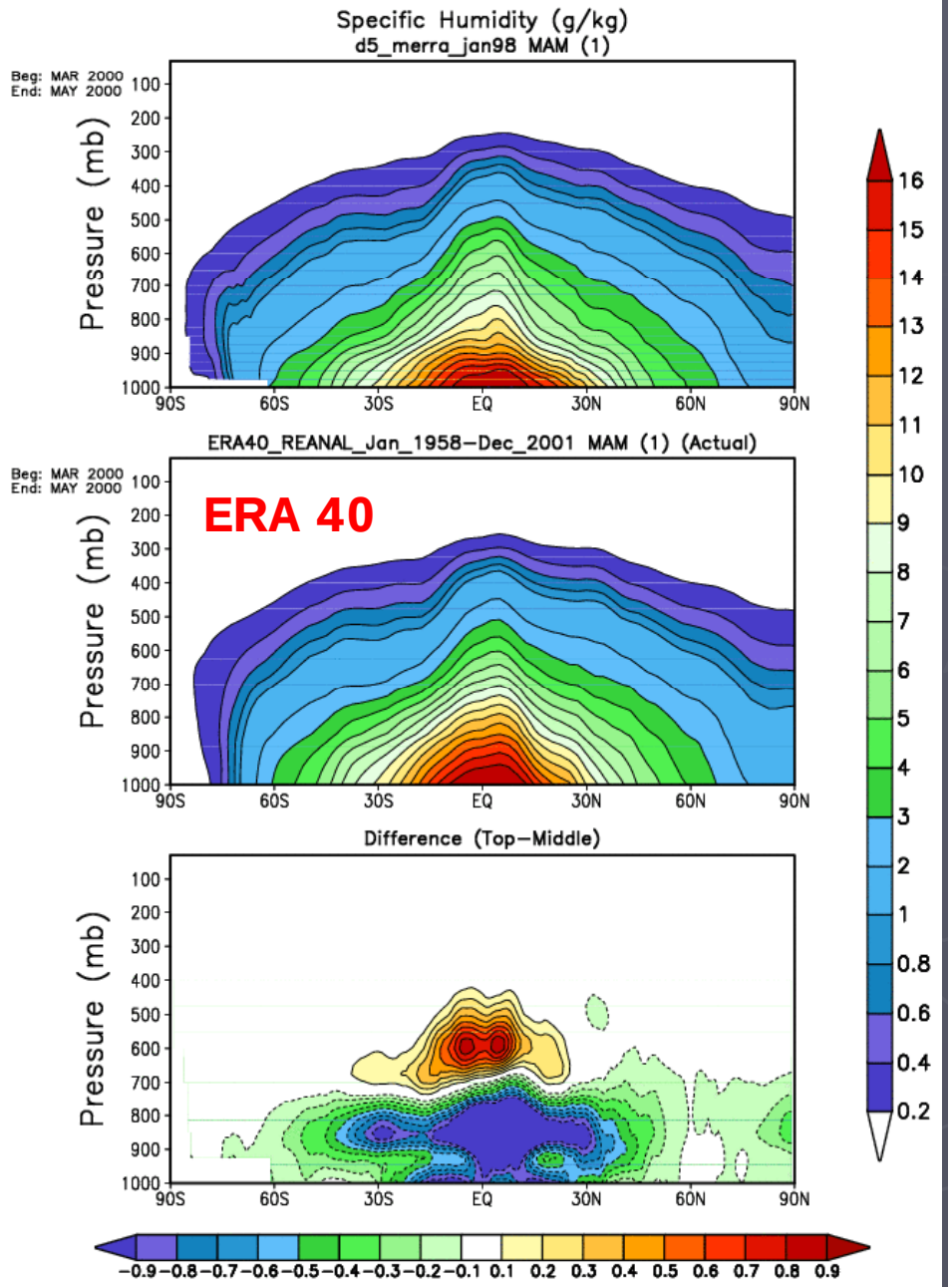
MERRA Validation

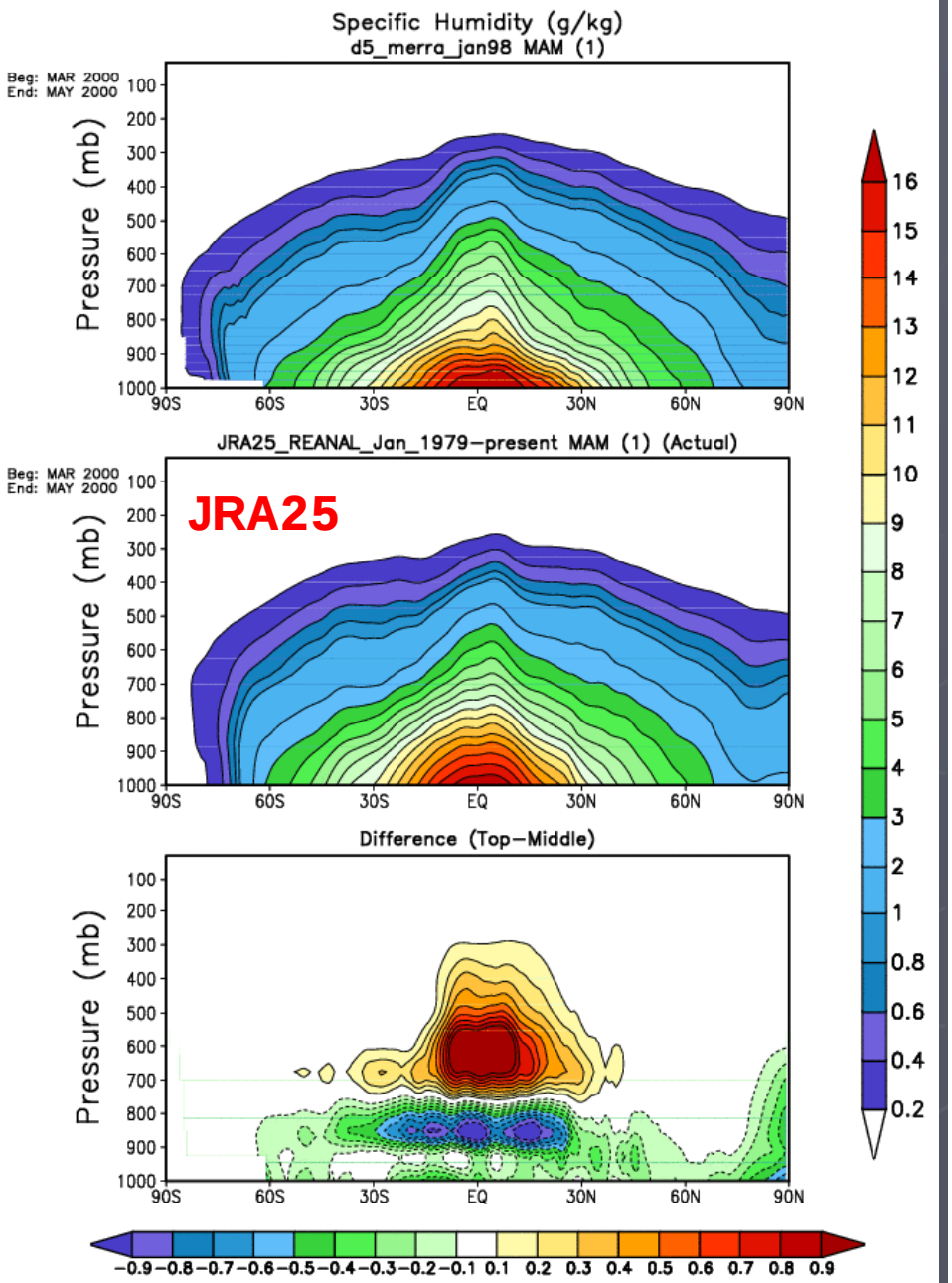
- Experiment Review, Nov 2007
- Included Short Experiments at native resolution (9 months was the longest)
  - Long experiment with coarse resolution (Scout)
- Radiation, clouds, precipitation, surface temperature, UTH, general circulation
- Data sources: SRB, CERES, MODIS, GPCP, enhanced station obs, existing reanalyses
- Increments (e.g. P-E), Indian Monsoon


TOA LW interannual variation (W/m~2)
CERES ERBE−like
Merra
Merra−CERES
ave=234.9 std=32.98
ave=239.3 std=36.19
ave=4.407 std=9.114
ave=234.7 std=33.65
ave=239.7 std=36.45
ave=4.971 std=9.017
ave=0.192 std=14.61
ave=−0.37 std=15.49
Jan 2004
Jan 2006
Jan 04−06
304
292
280
268
256
244
232
220
208
196
184
172
160
148
136
124
112
−40 −30 −25 −20 −15 −10 −5 −2.5 0 2.5 5 10 15 20 25 30 40
90N
60N
30N
EQ
30S
60S
90S
180 120W 60W 0 60E 120E 180

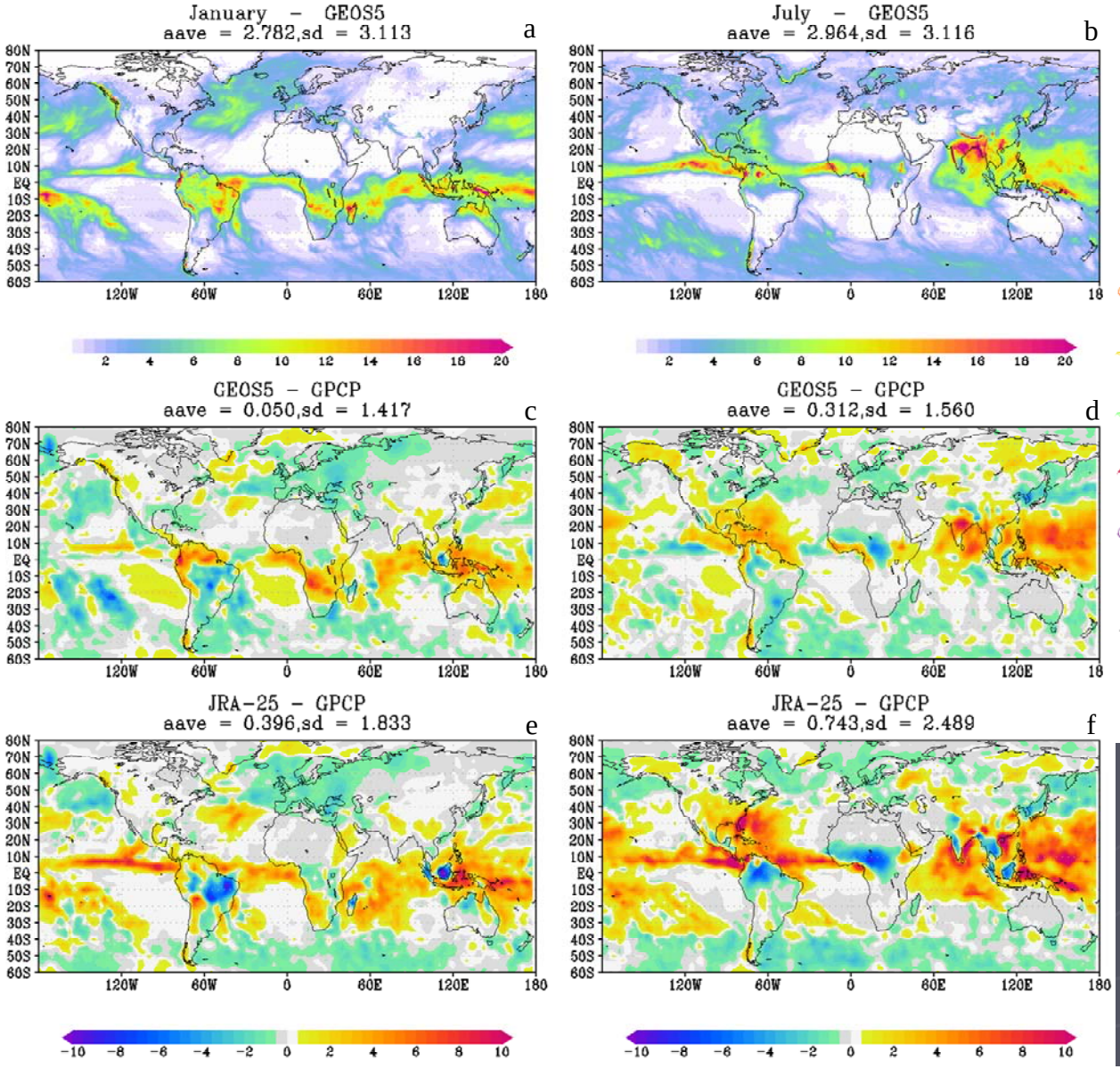
S. Schubert

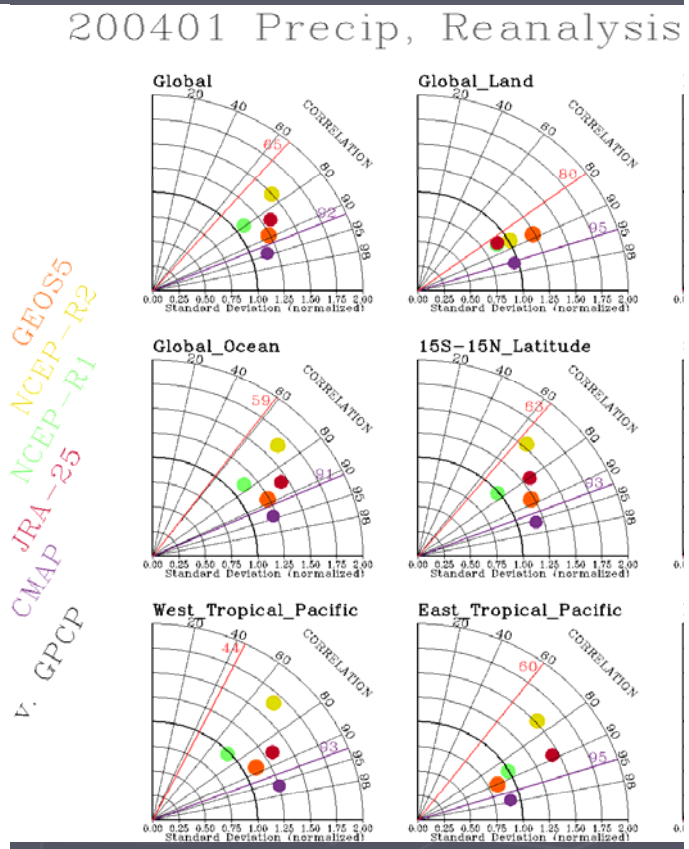
General Circulation: Tropical Moisture





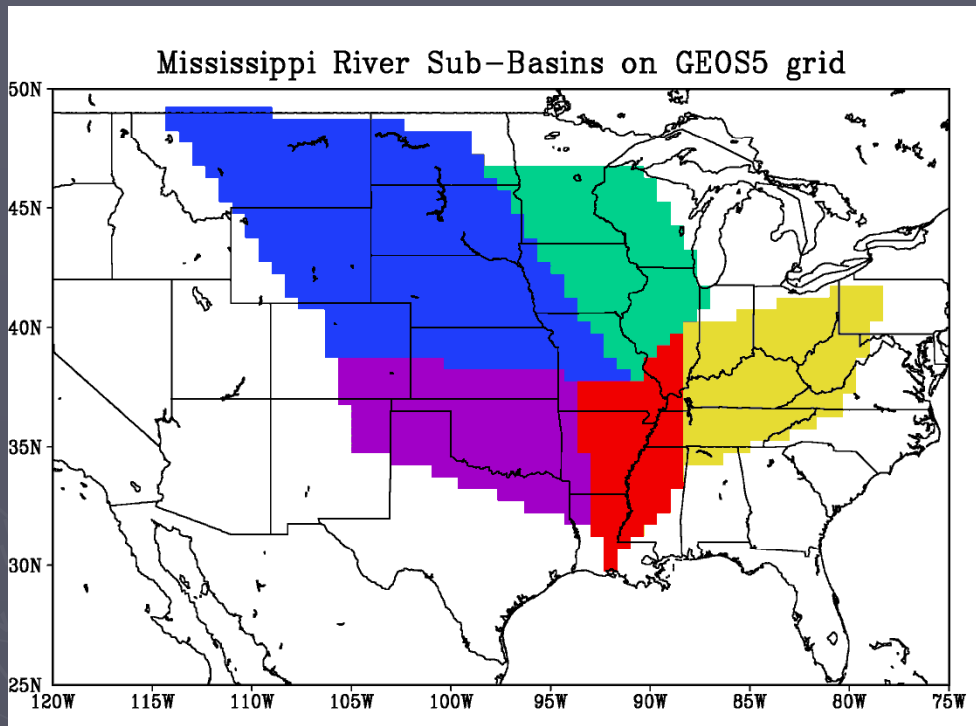
Jan/Jul 2004 Precipitation

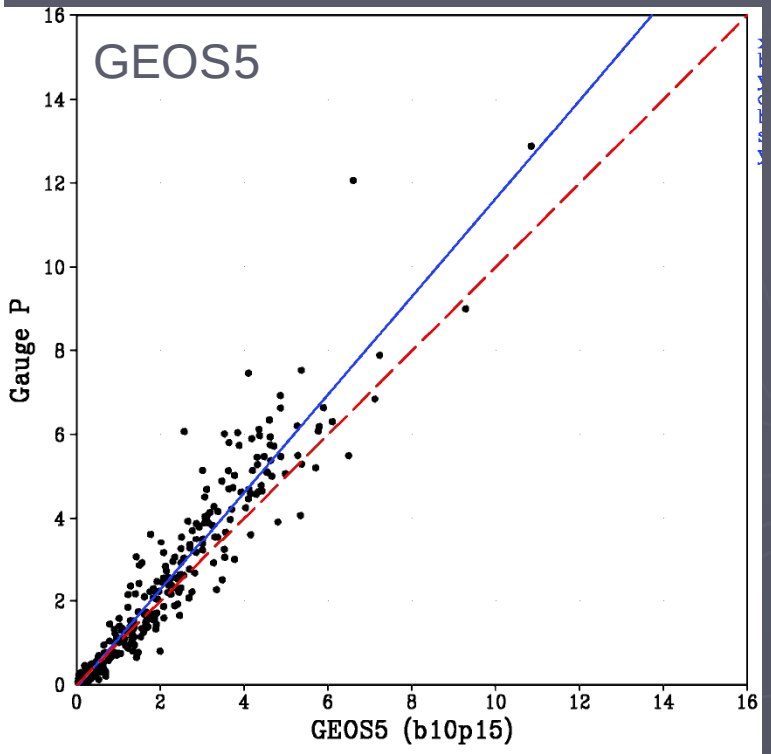




- Bosilovich et al. (2008 JHM)

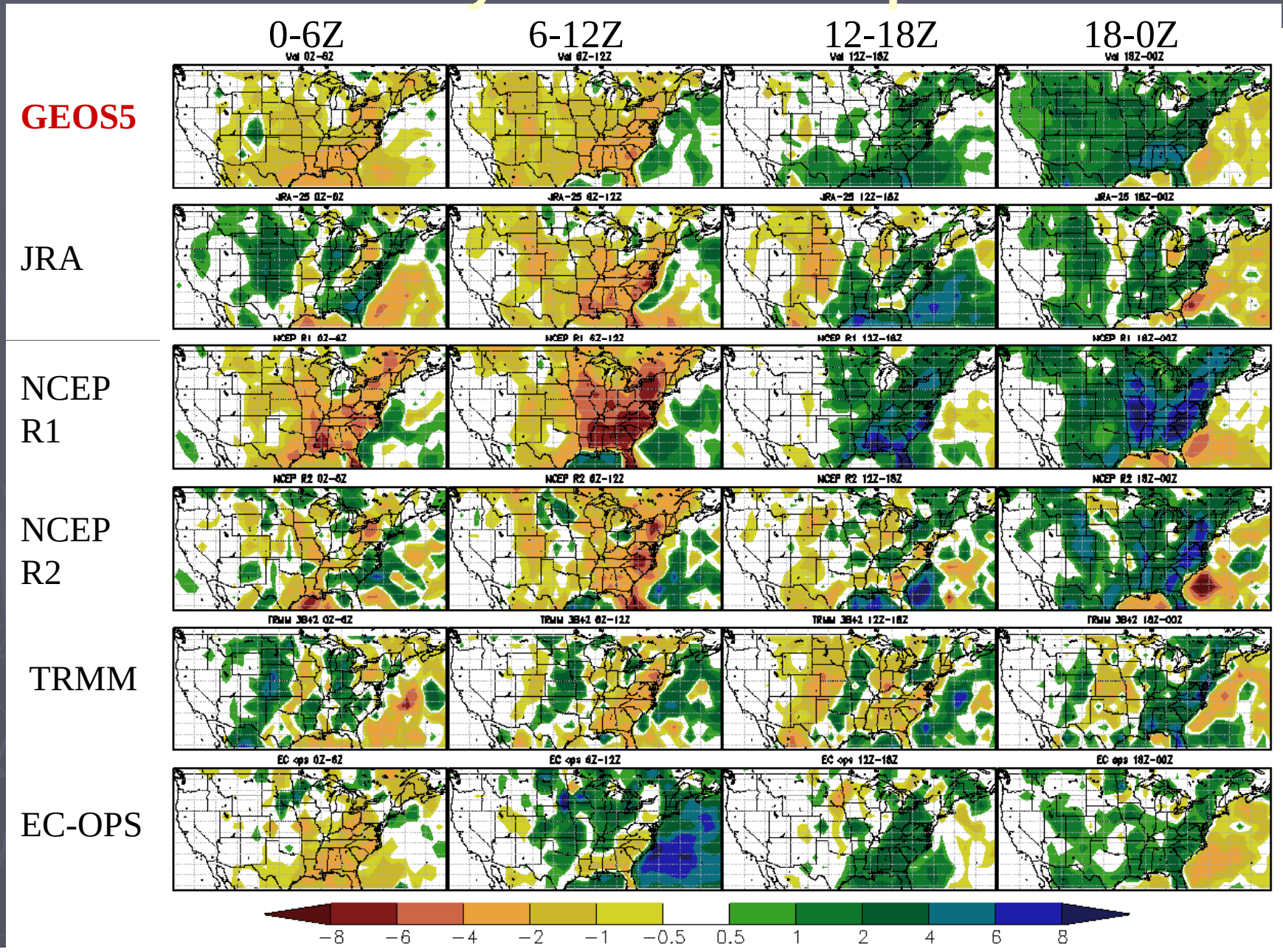
Basin-scale Precipitation





- CPC US ¼ gridded gauge data
- Daily, Jan 1 – Sep 30 2004
- Consider all of the Mississippi River Basin domain
- Comparable to NCEP, UKMO operational analyses

Diurnal Cycle of Precipitation

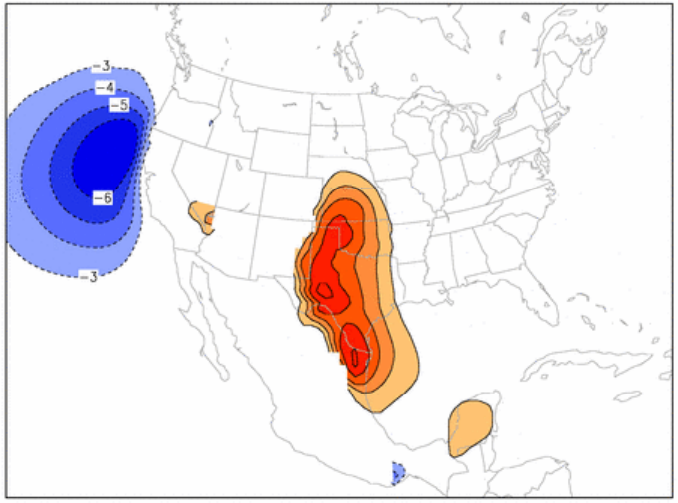


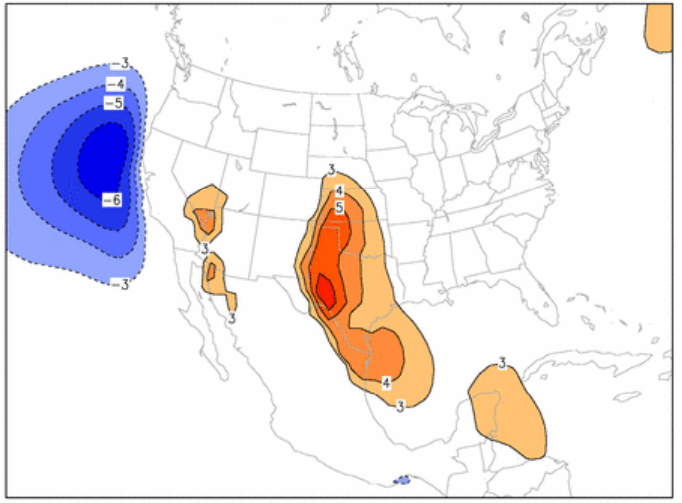
JJA v-wind at 850mb (9-yrs)

MERRA

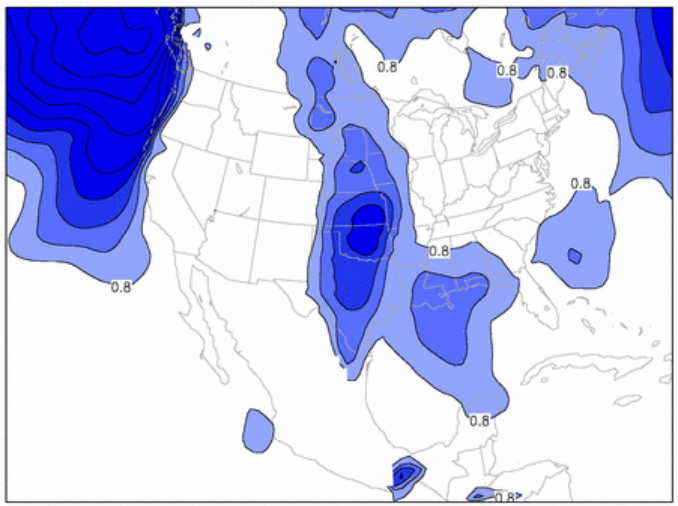
NARR

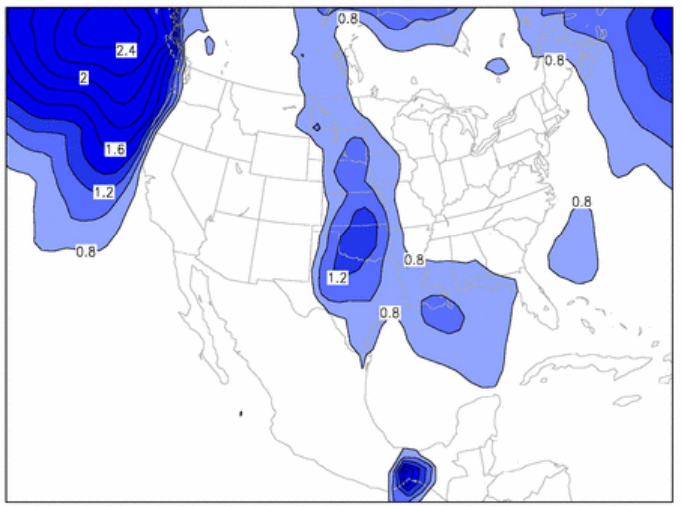
Mean





Std



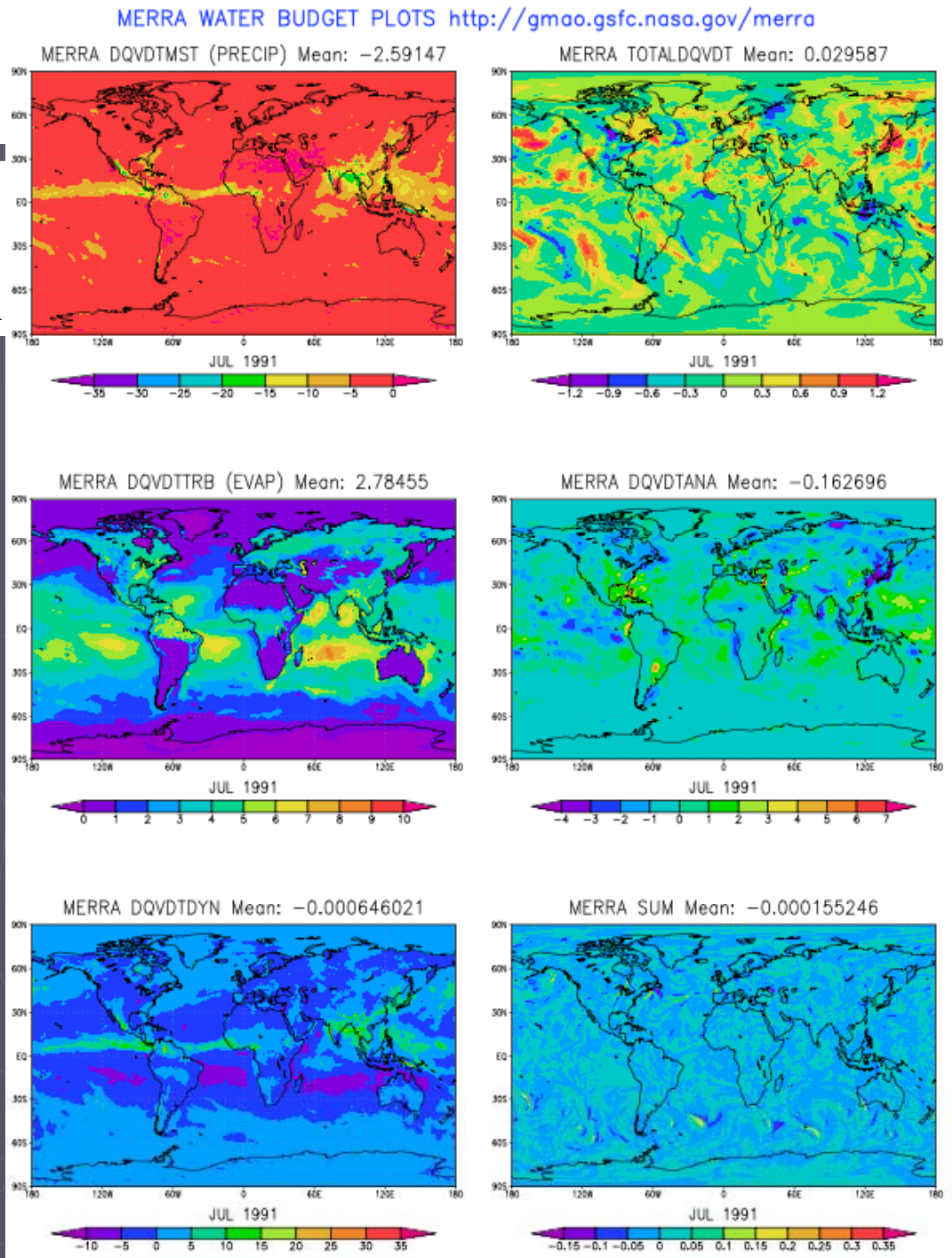


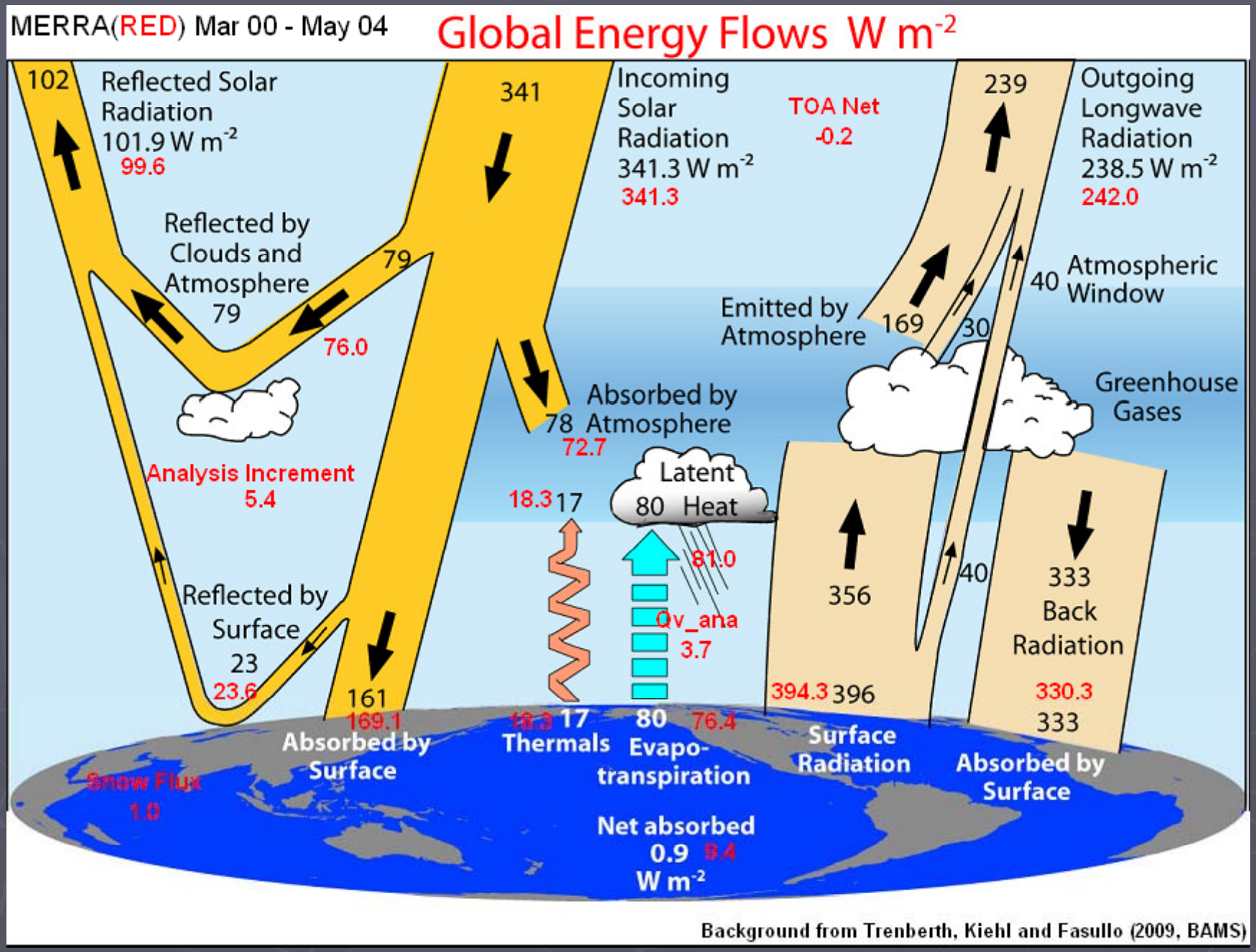
MERRA Water and Energy Budgets

Vertically-Integrated Water Vapor Budget for July 1991

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

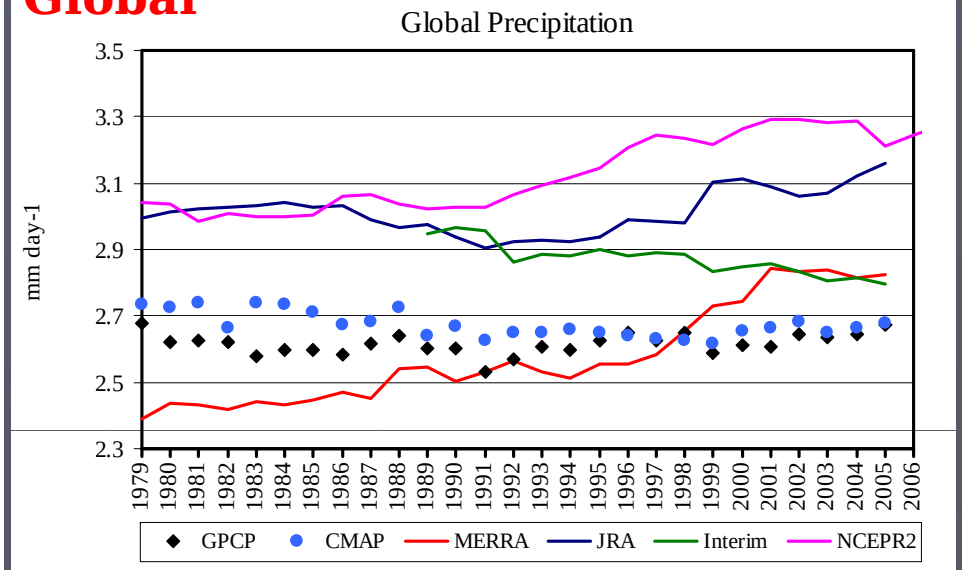
- Complete budgets are available including all tendencies and analysis increments
- Water (all phases), Ozone, KE, Enthalpy, Included
- Also, land-only budgets
- Tremendous effort by Max Suarez, Larry Takacs and Randy Koster



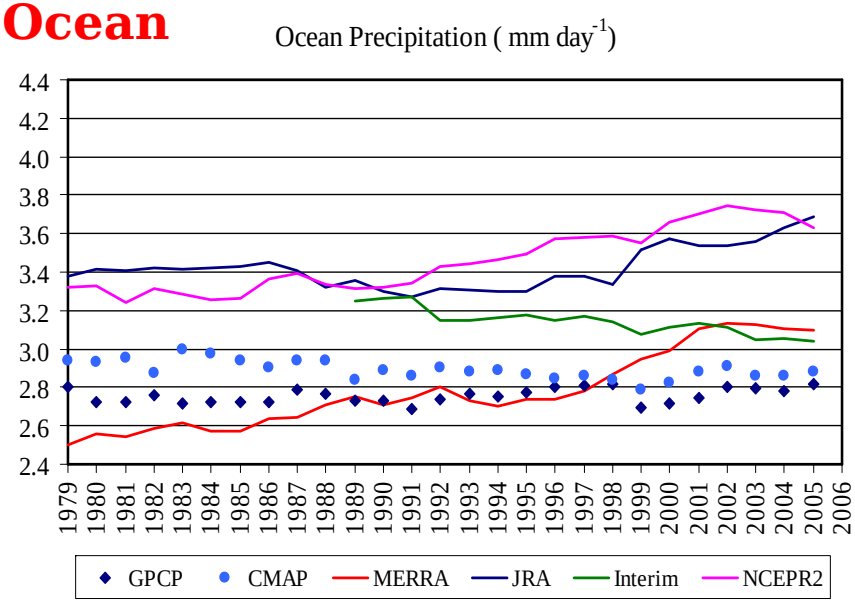

MERRA(RED) Mar 00 - May 04
Global Energy Flows W m-2
102
Reflected Solar Radiation
101.9 W m-2
99.6
341
Incoming Solar Radiation
341.3 W m-2
341.3
TOA Net
-0.2
239
Outgoing Longwave Radiation
238.5 W m-2
242.0
Reflected by Clouds and Atmosphere
79
79
76.0
Analysis Increment
5.4
Absorbed by Atmosphere
78
72.7
Emitted by Atmosphere
169
30
40 Atmospheric Window
Greenhouse Gases
Latent Heat
80
18.3 17
81.0
Qv_ana
3.7
Reflected by Surface
23
23.6
161
169.1
356
40
333 Back Radiation
330.3
333
394.3 396
Absorbed by Surface
18.3 17 Thermals
80 Evapo-transpiration
76.4
Surface Radiation
Absorbed by Surface
Snow Flux
1.0
Net absorbed
0.9 9.4
W m-2
Background from Trenberth, Kiehl and Fasullo (2009, BAMS)

Trends in the Water and Energy Cycles

Global

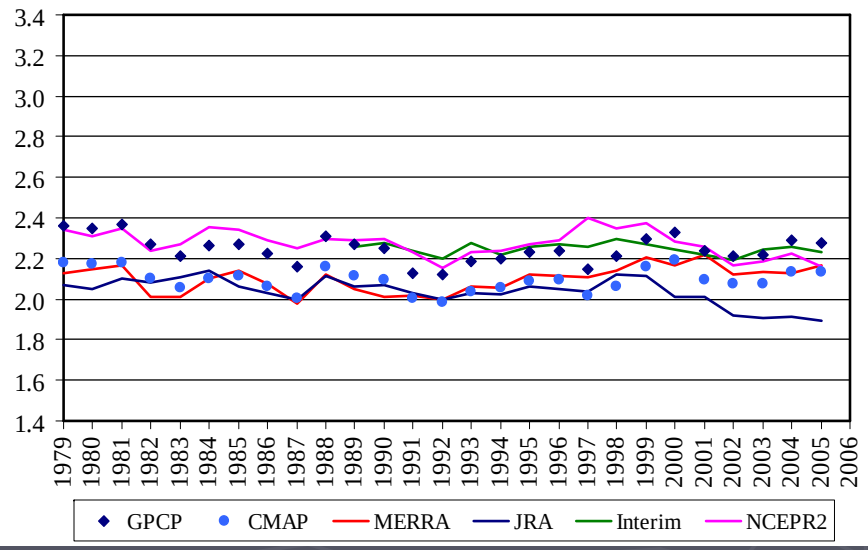


Ocean

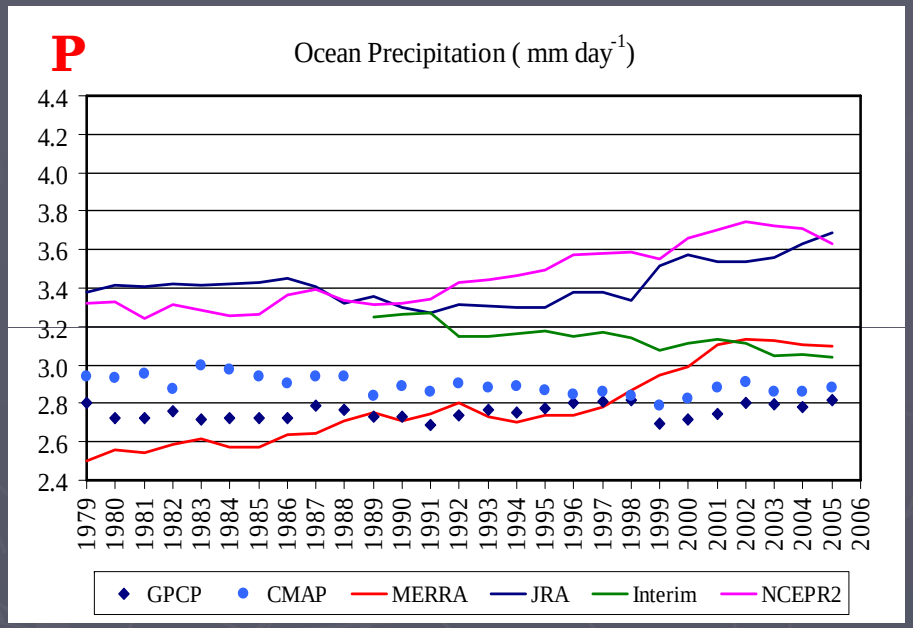


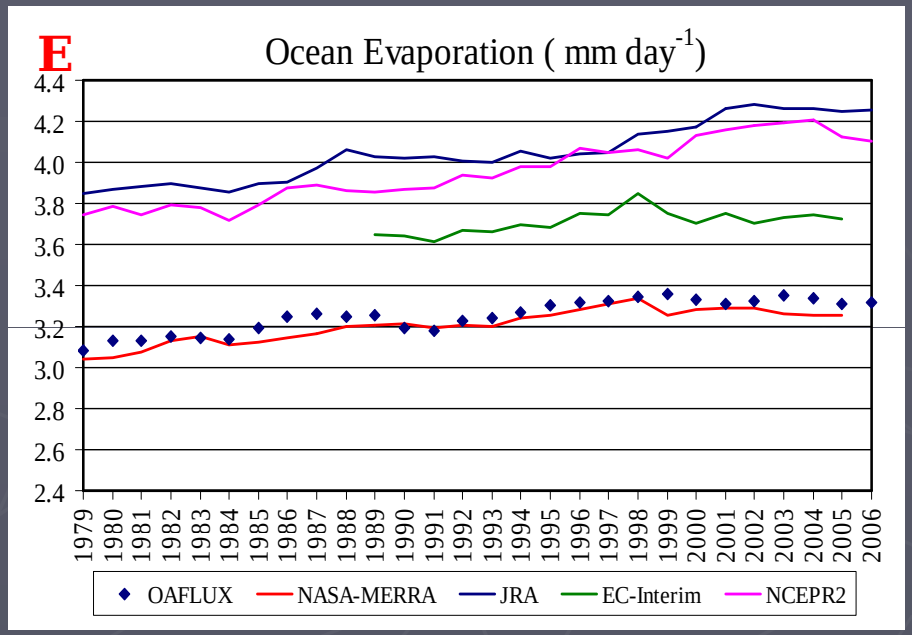
- Global P trend mostly over Ocean
- Land, taken together, are comparable with little apparent trend

Land



Ocean only P and E

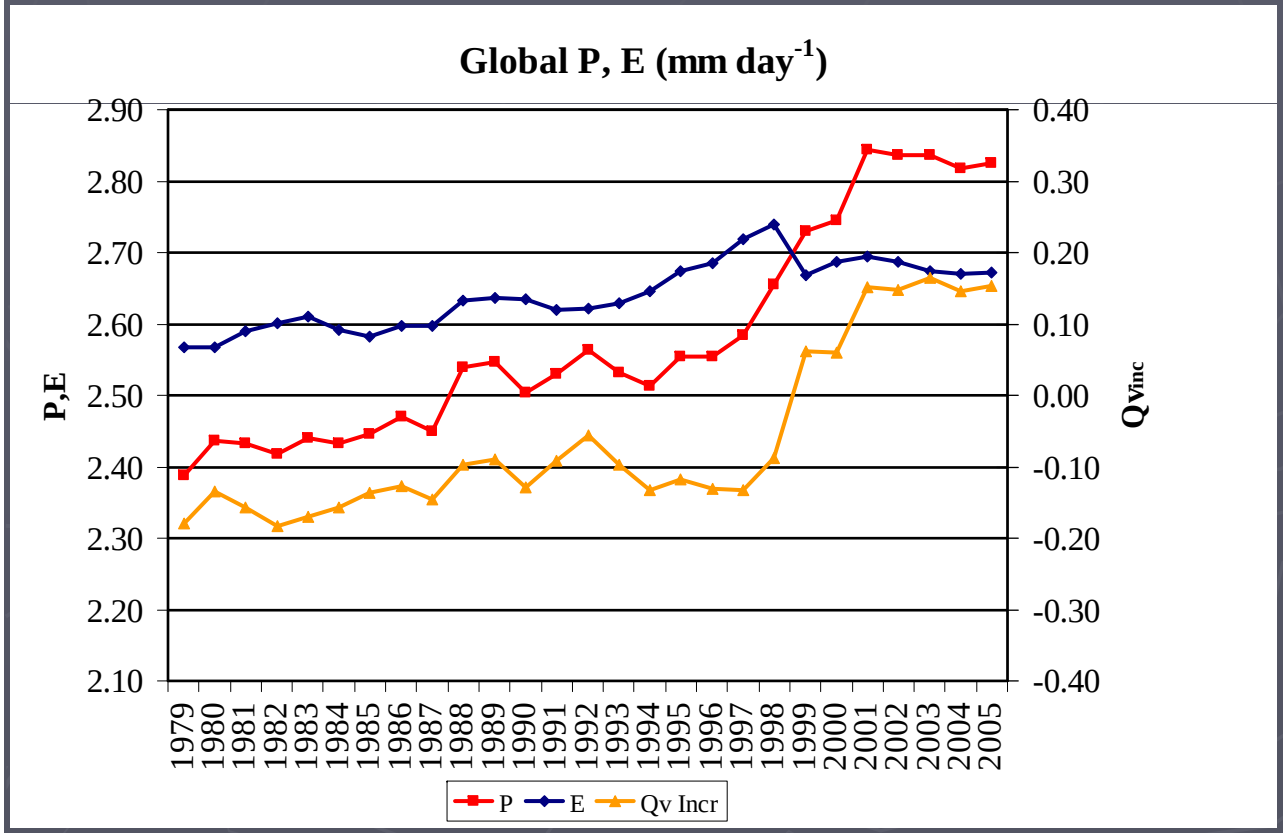




- The Upward trend in P exceeds E
- All reanalyses show upward trend in ocean evaporation (most also show increasing P)

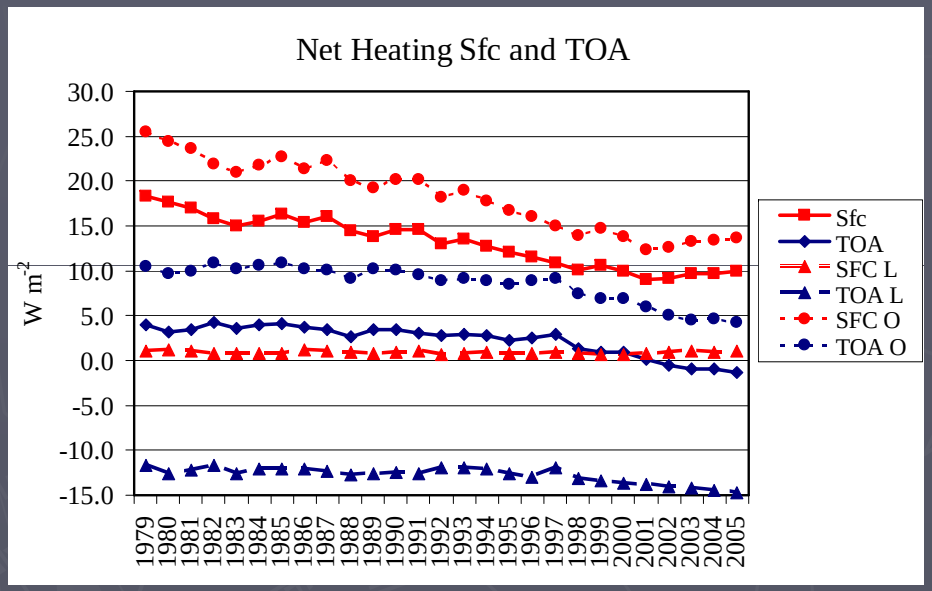
Global water Balance

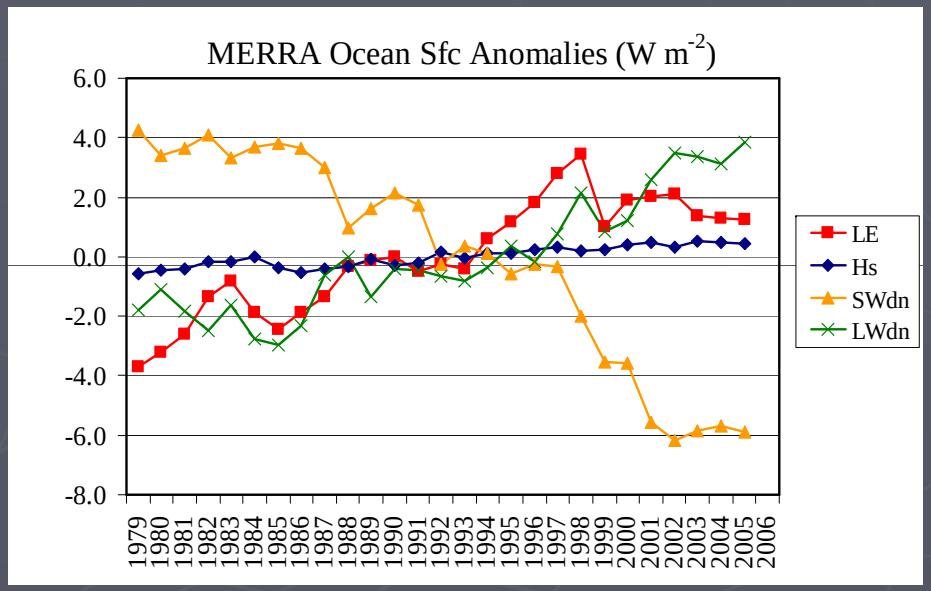
$$\frac{\partial \overline{w}}{\partial t} = -\nabla \cdot \left(\overline{\vec{v} w}\right) + E - P + \left[\frac{\partial \overline{w}}{\partial t}\right]_{ANA} + F$$



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

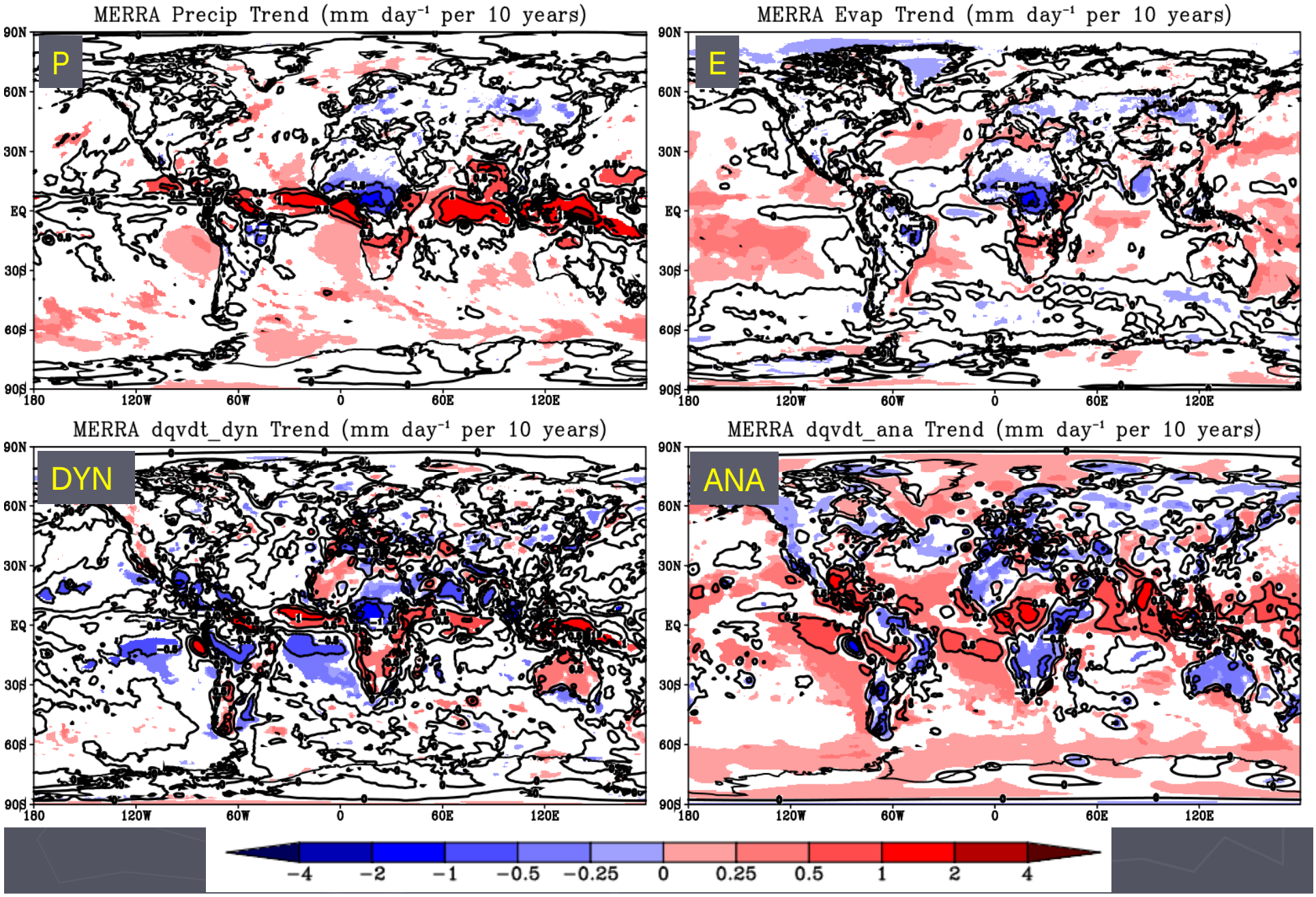
Net Surface and TOA Imbalance



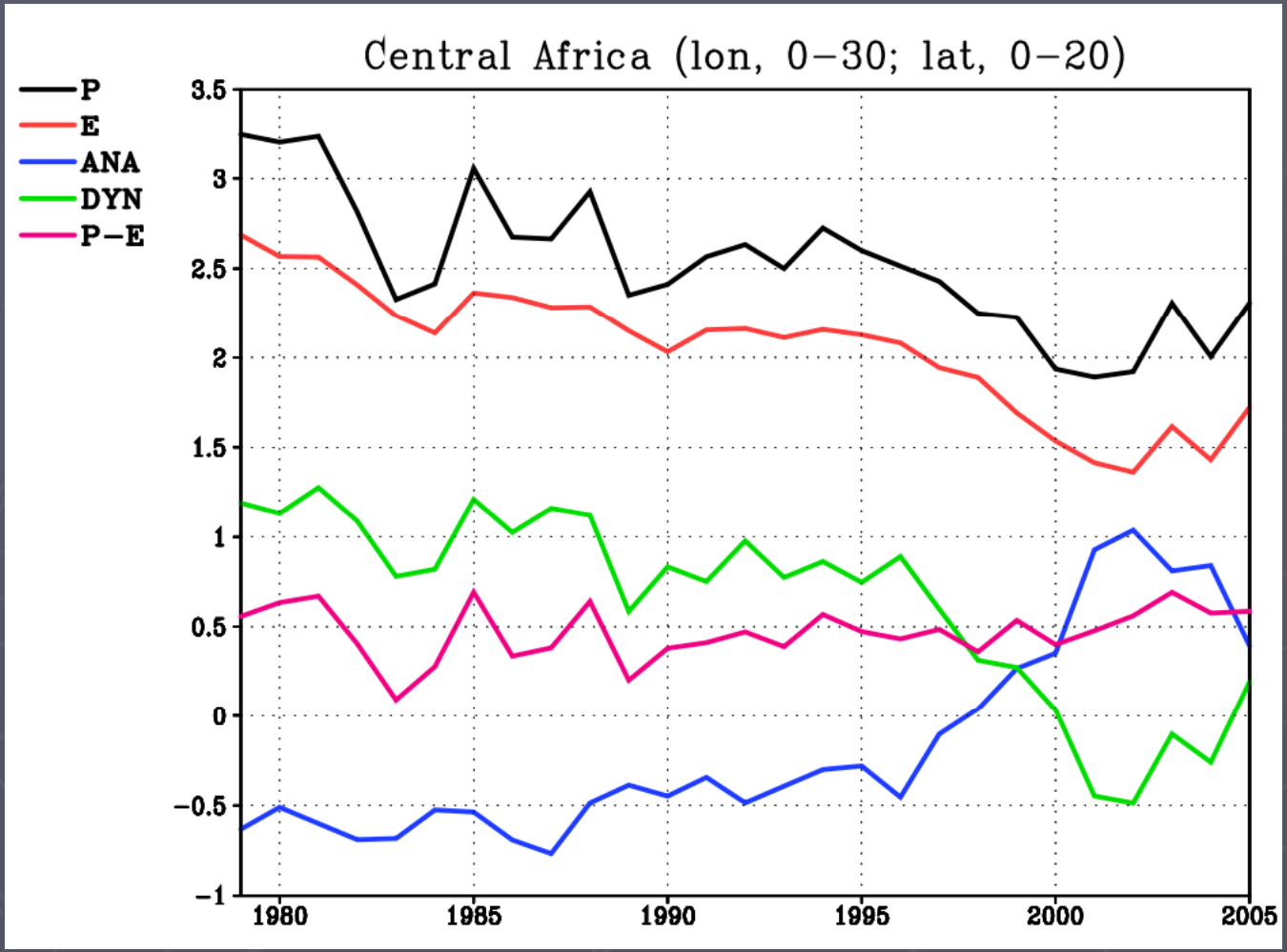


- Global surface net imbalance is improving in time, mostly changing over Ocean
- The Ocean net imbalance is decreasing in incoming SW radiation and increasing LE

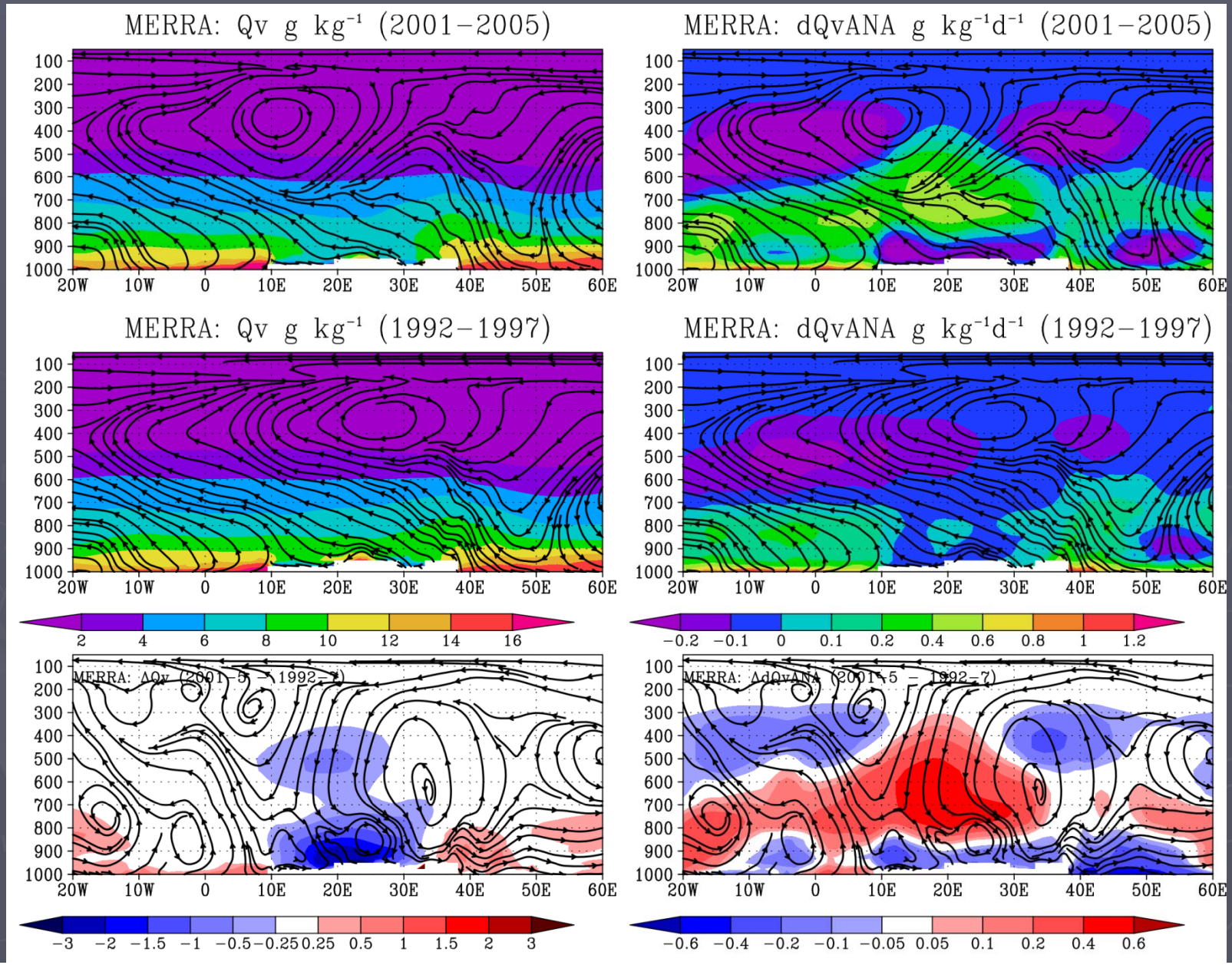
Spatial Distribution of Linear Trends



Central Africa Water Budget



Water Vapor Before and After



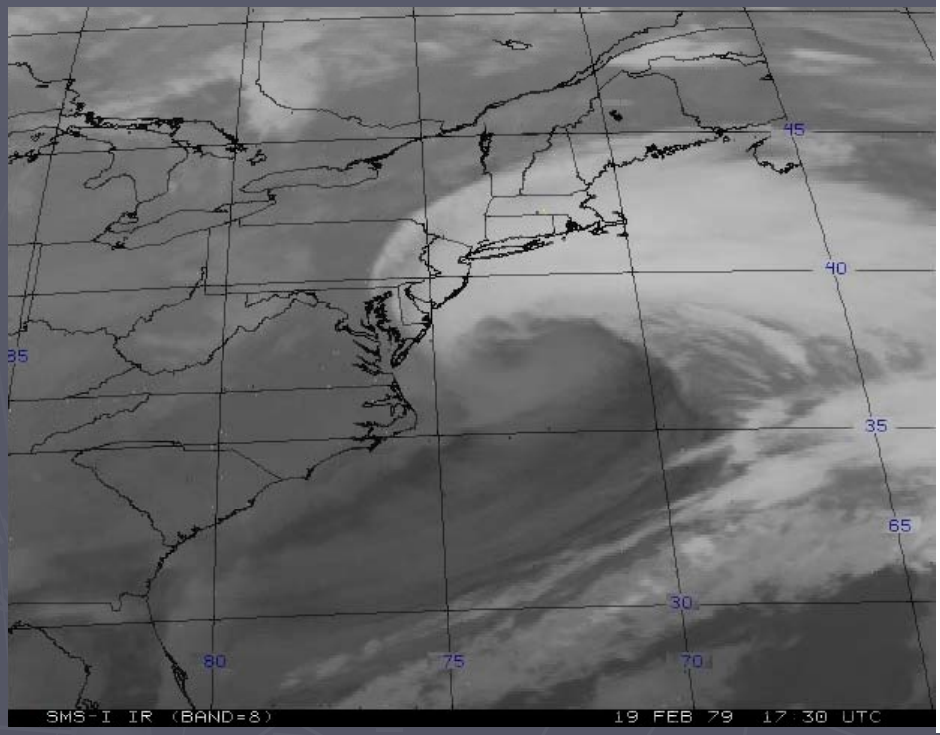
Summary

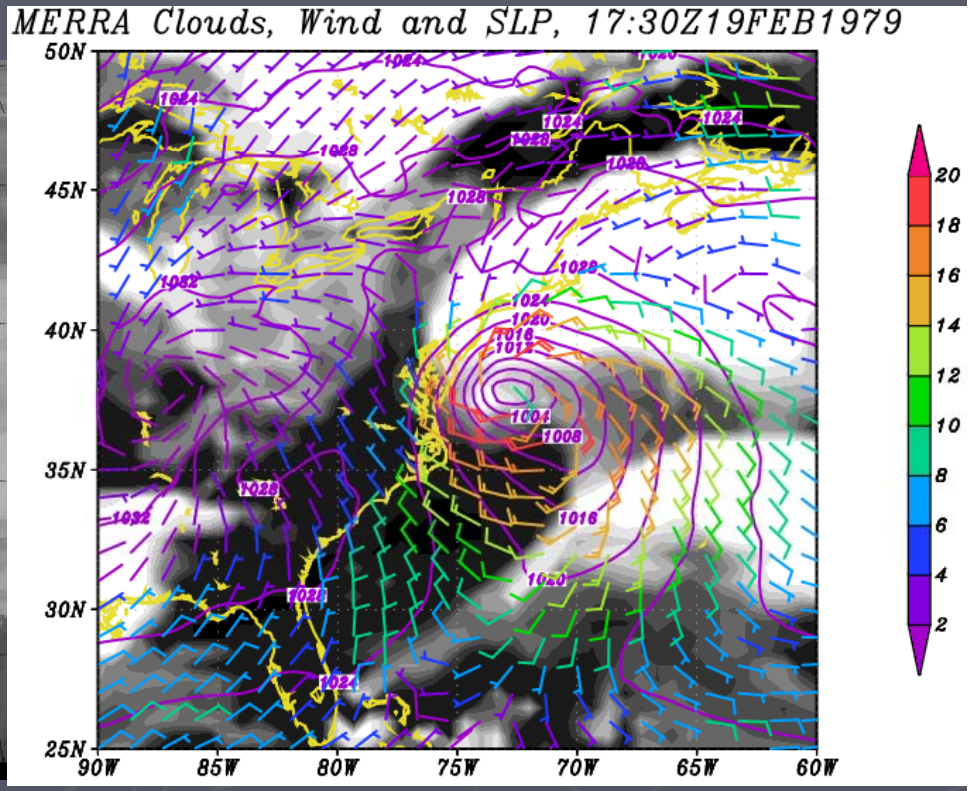
- MERRA Precipitation shows skill compared to GPCP, relative to other reanalyses, the trends are on the order of other reanalyses, but the bias is much improved
- Energy balance looks reasonable in recent period, ~8Wm^{-2} imbalance (recent period, mostly ocean)
- Remaining issues in reanalyses: trends 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

Some Weather

President's Day Snow Feb 19, 1979

GOES IR 17:30Z19FEB1979

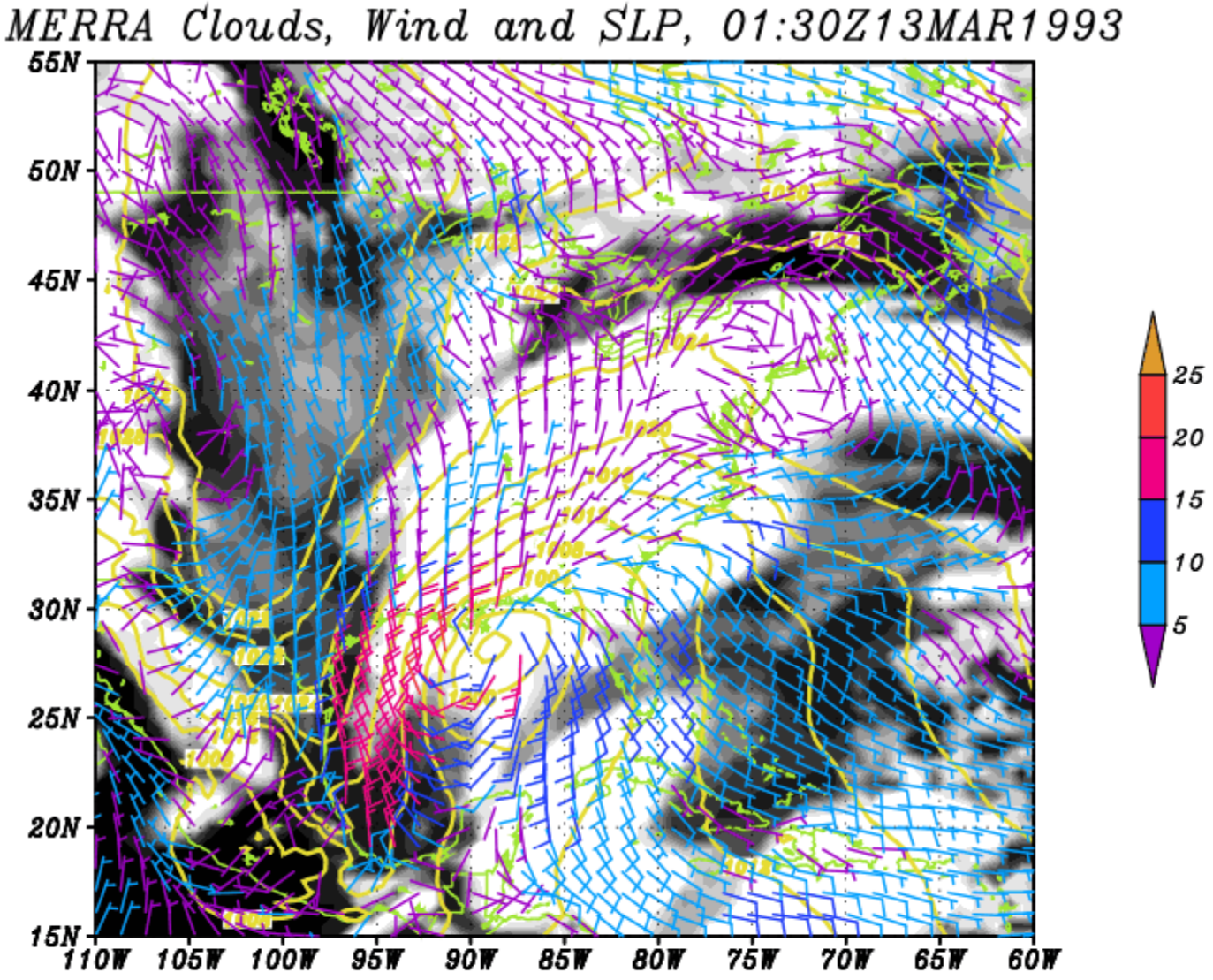




(Barbs every other grid space)

- Break in MERRA cloud fraction seems apparent in GOES IR

“Storm of the Century”



TROPOPAUSE FOLD

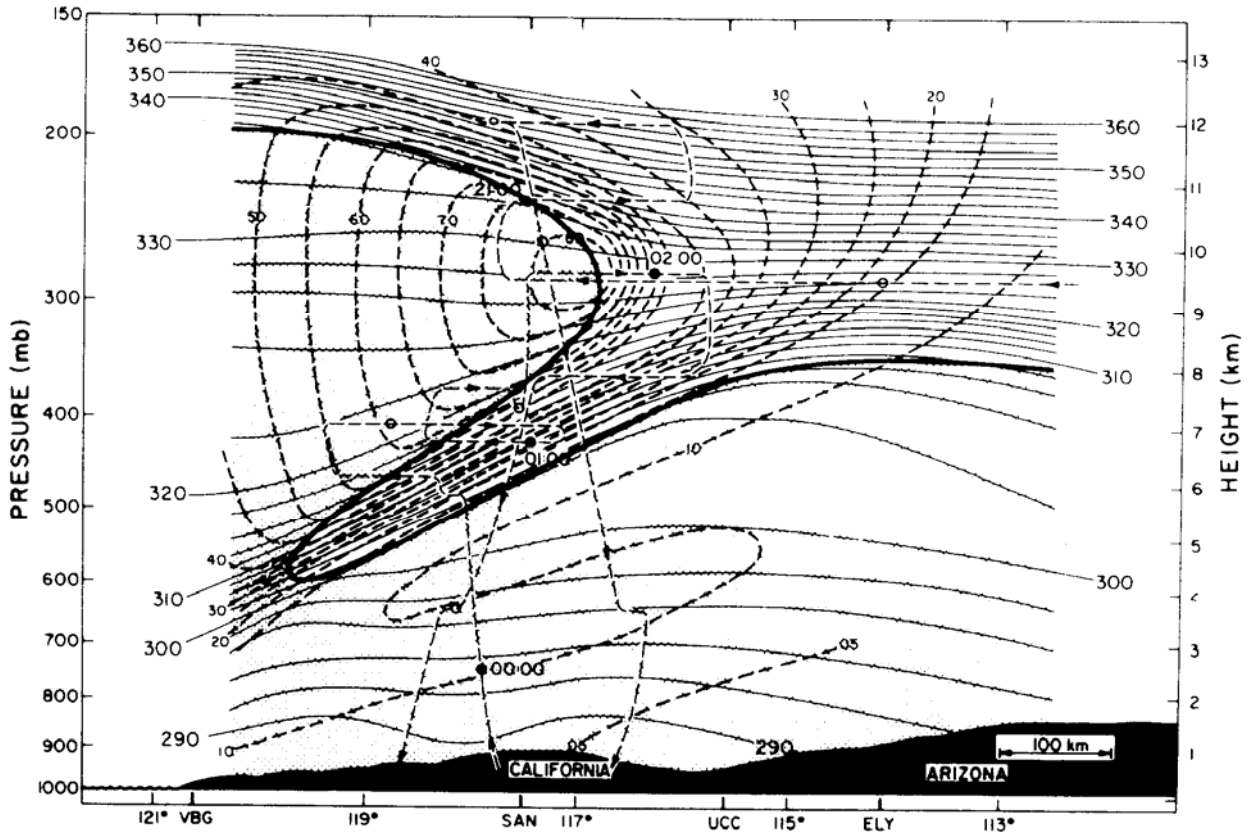
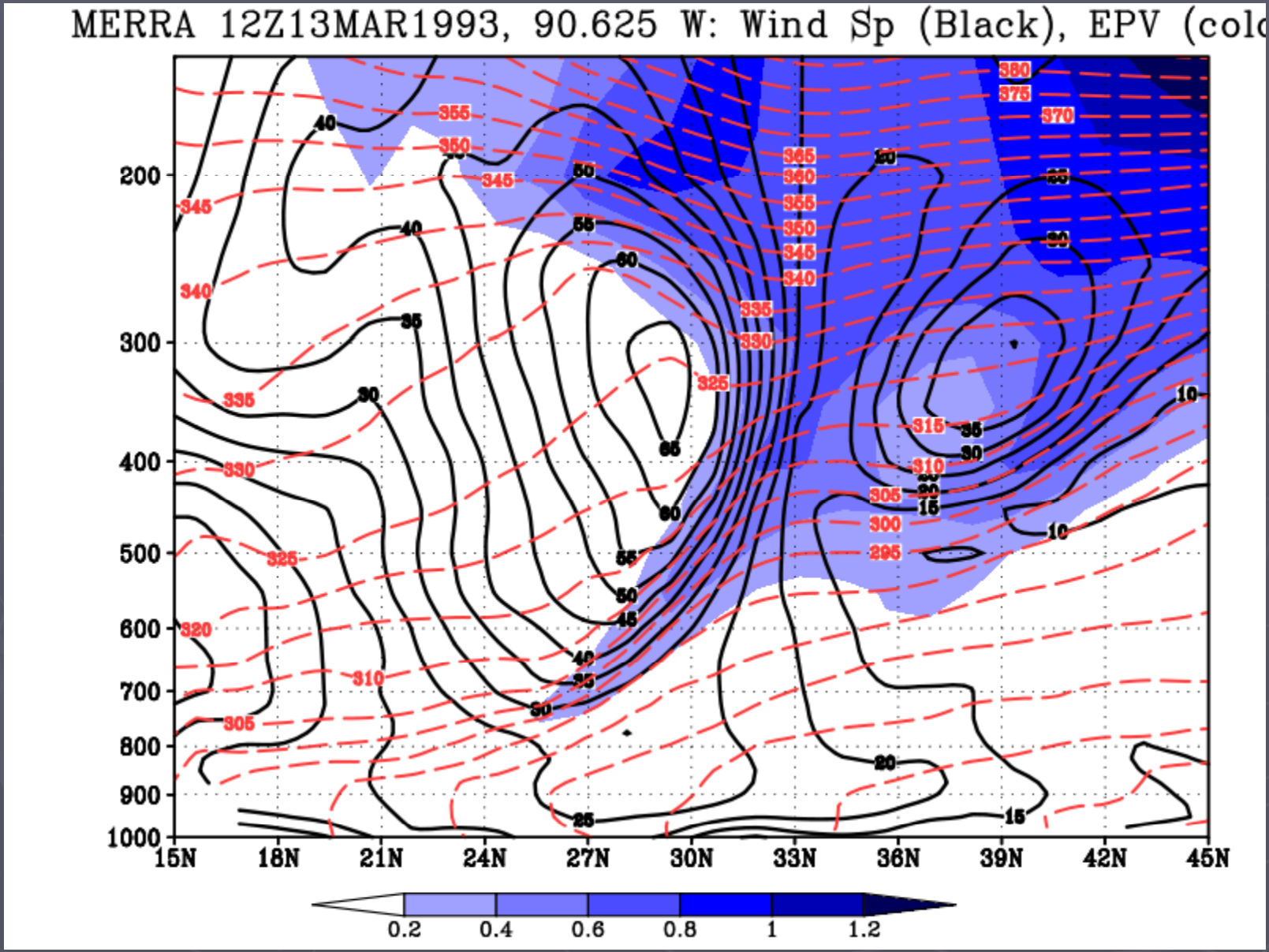
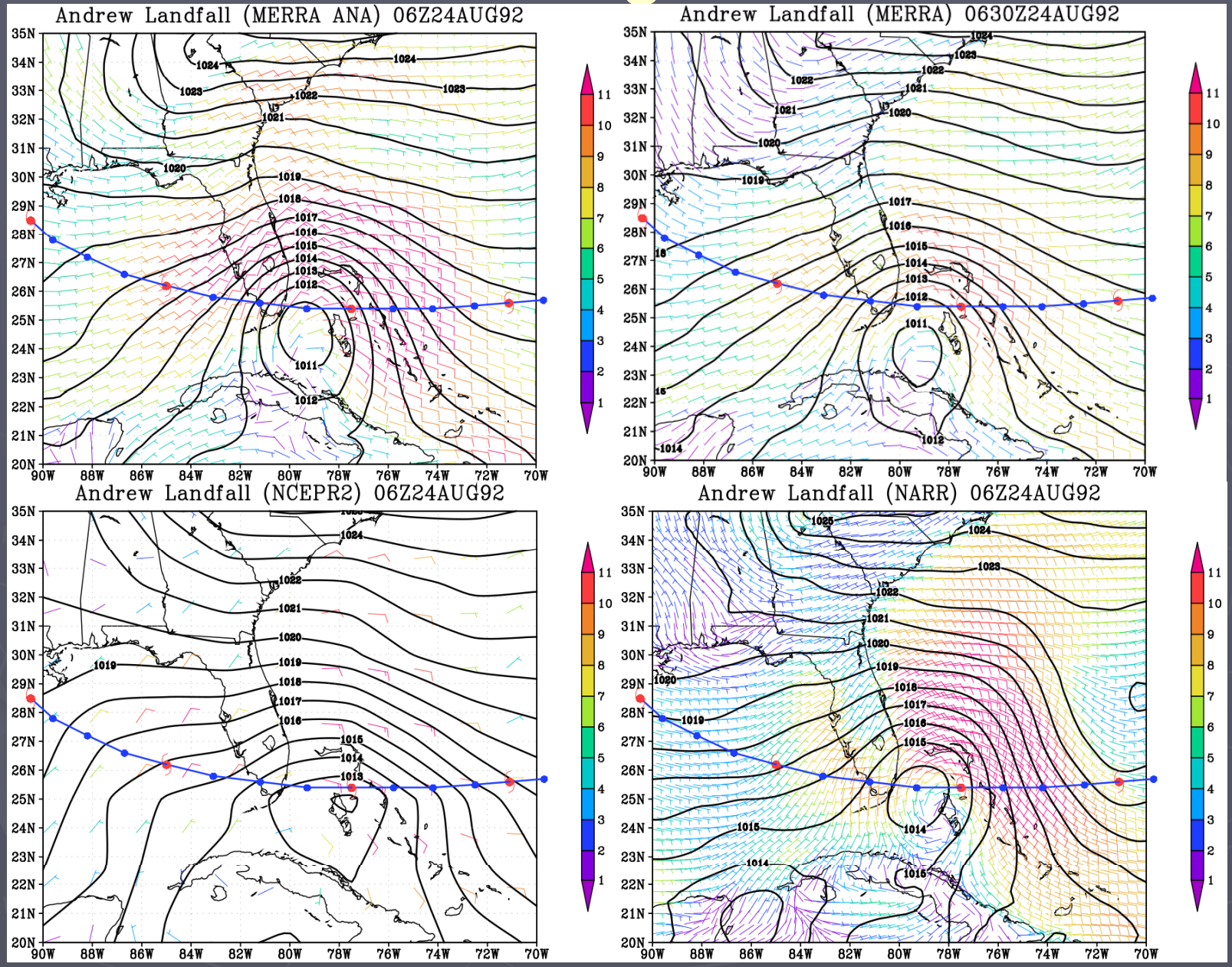


Figure 10.30. Cross section through a tropopause fold for 0000 GMT, 13 March 1978. Potential temperature (K) is indicated by thin solid lines; wind speed (m s^{-1}) by thick dashed lines; Sabreliner flight track by thin dashed lines; tropopause defined in terms of potential vorticity (100×10^{-7} K mb^{-1} s^{-1}) by thick solid line. The troposphere is stippled. (From Shapiro, 1980.)

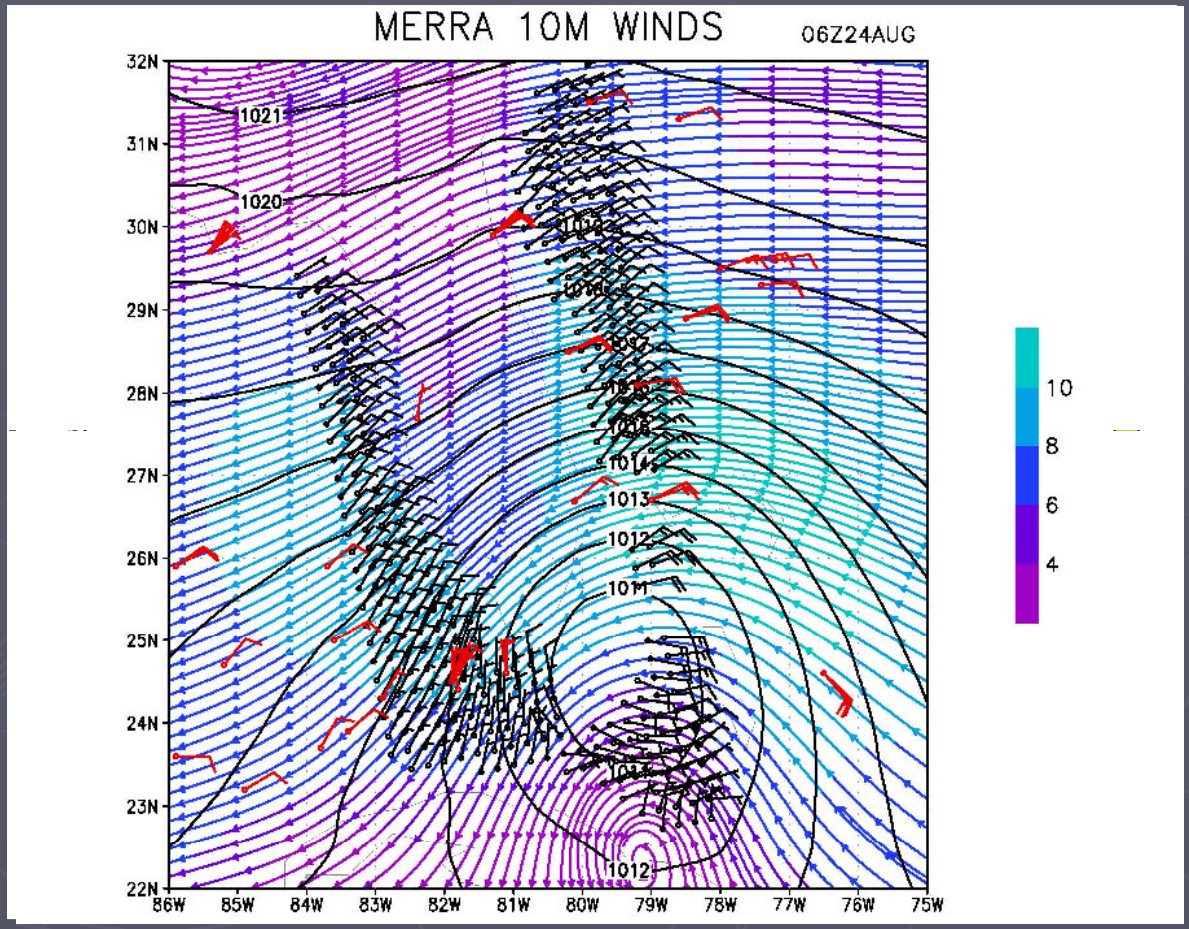
TROPOPAUSE FOLD



Andrew Aug 24, 1992

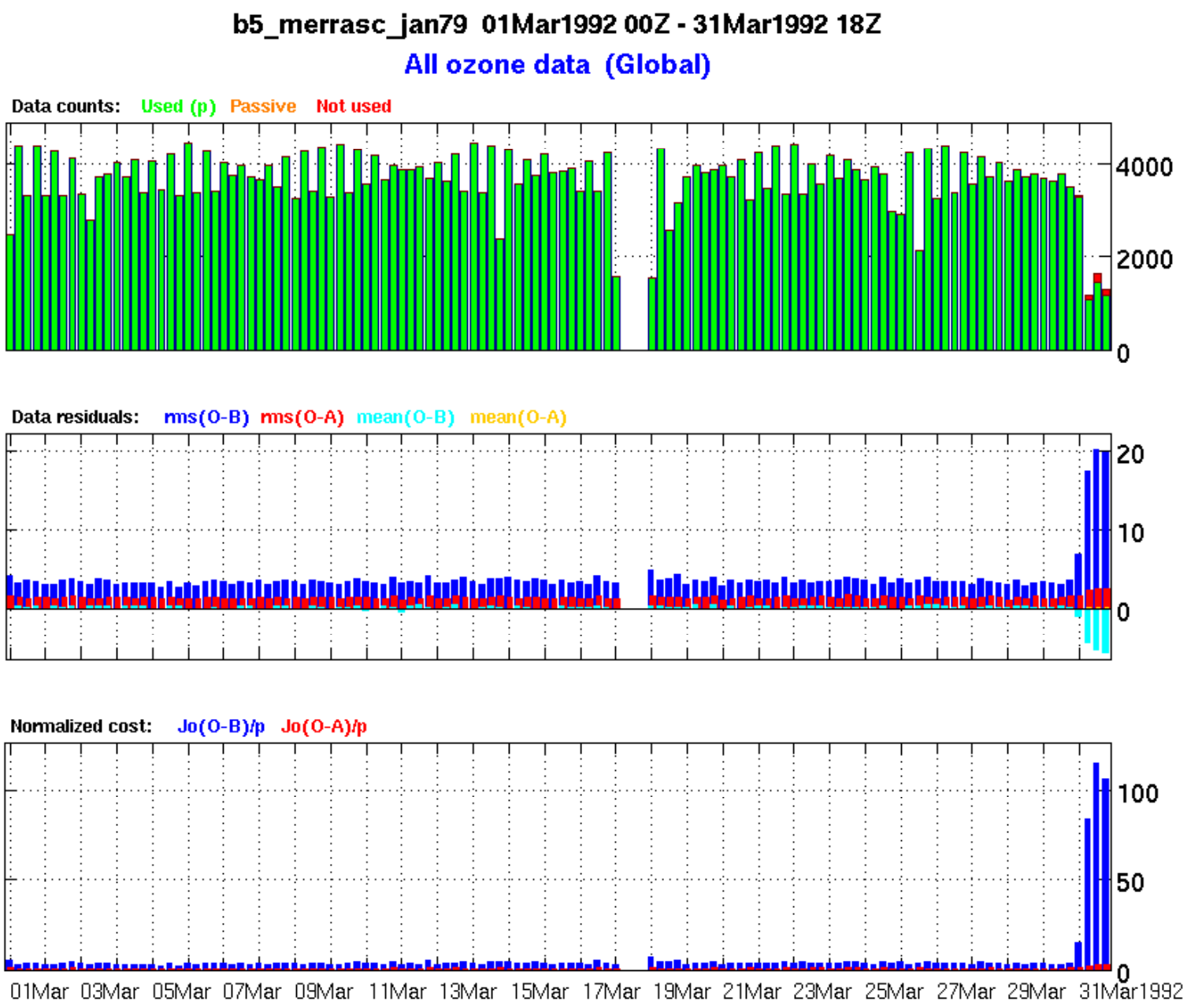


Andrew Aug 24, 1992



- Contaminated ERS1 data is used
- Resolution still too coarse for small TCs

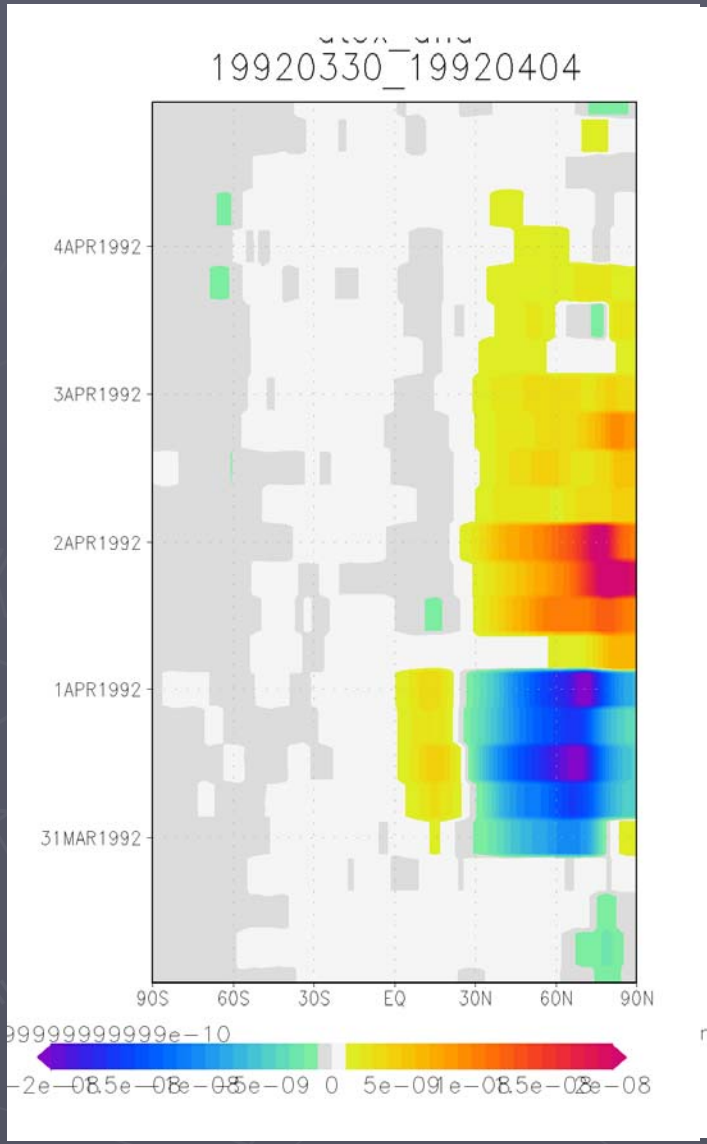
Production Monitoring



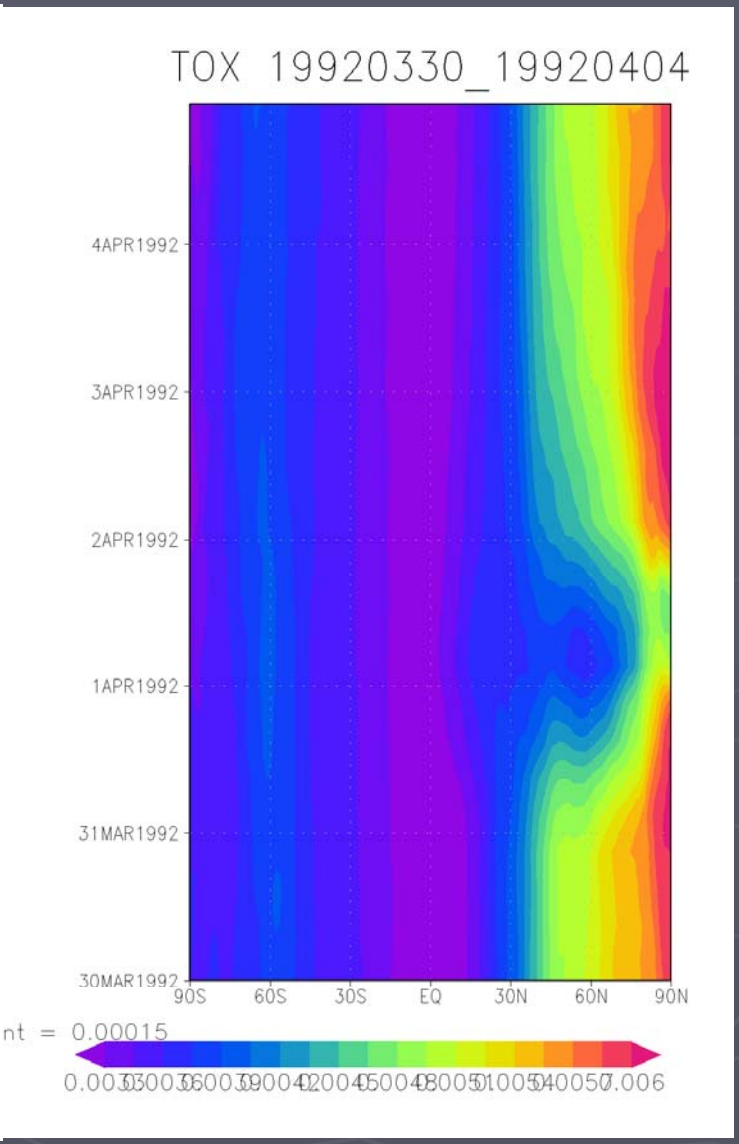
Scout SBUV Assimilation Statistics, Mar 1992

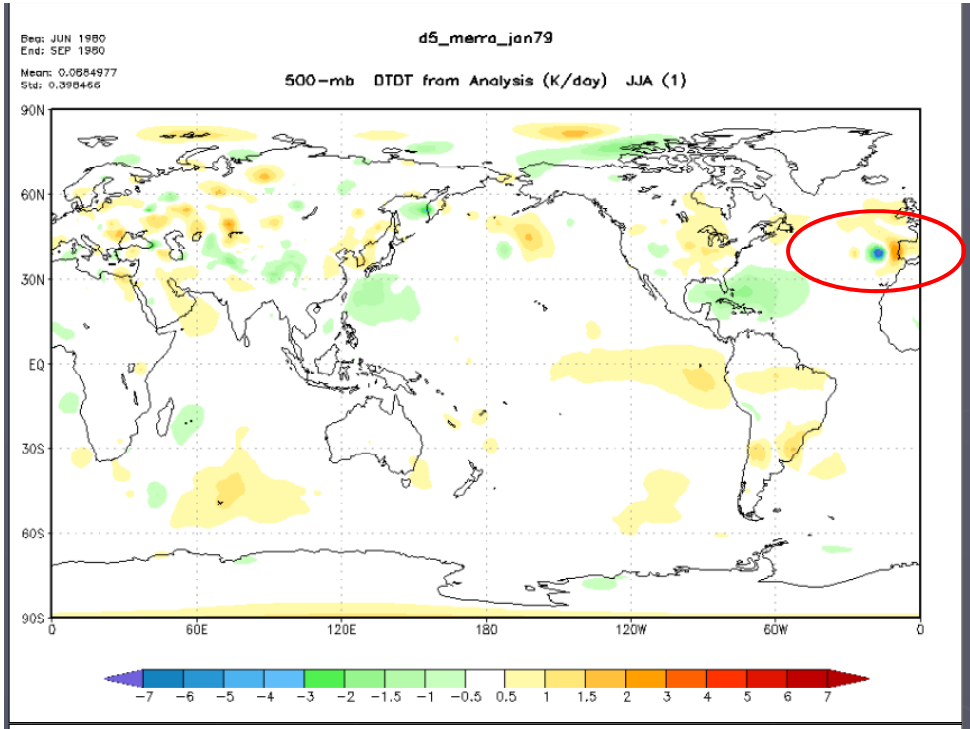
Ozone response to questionable data

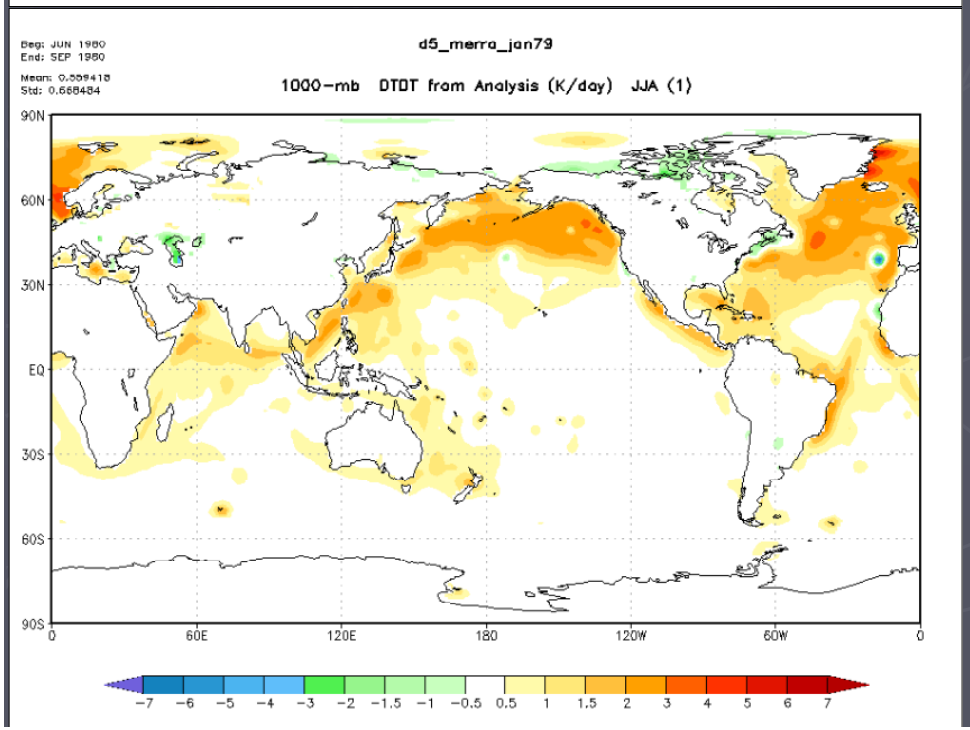
Increments



Ozone



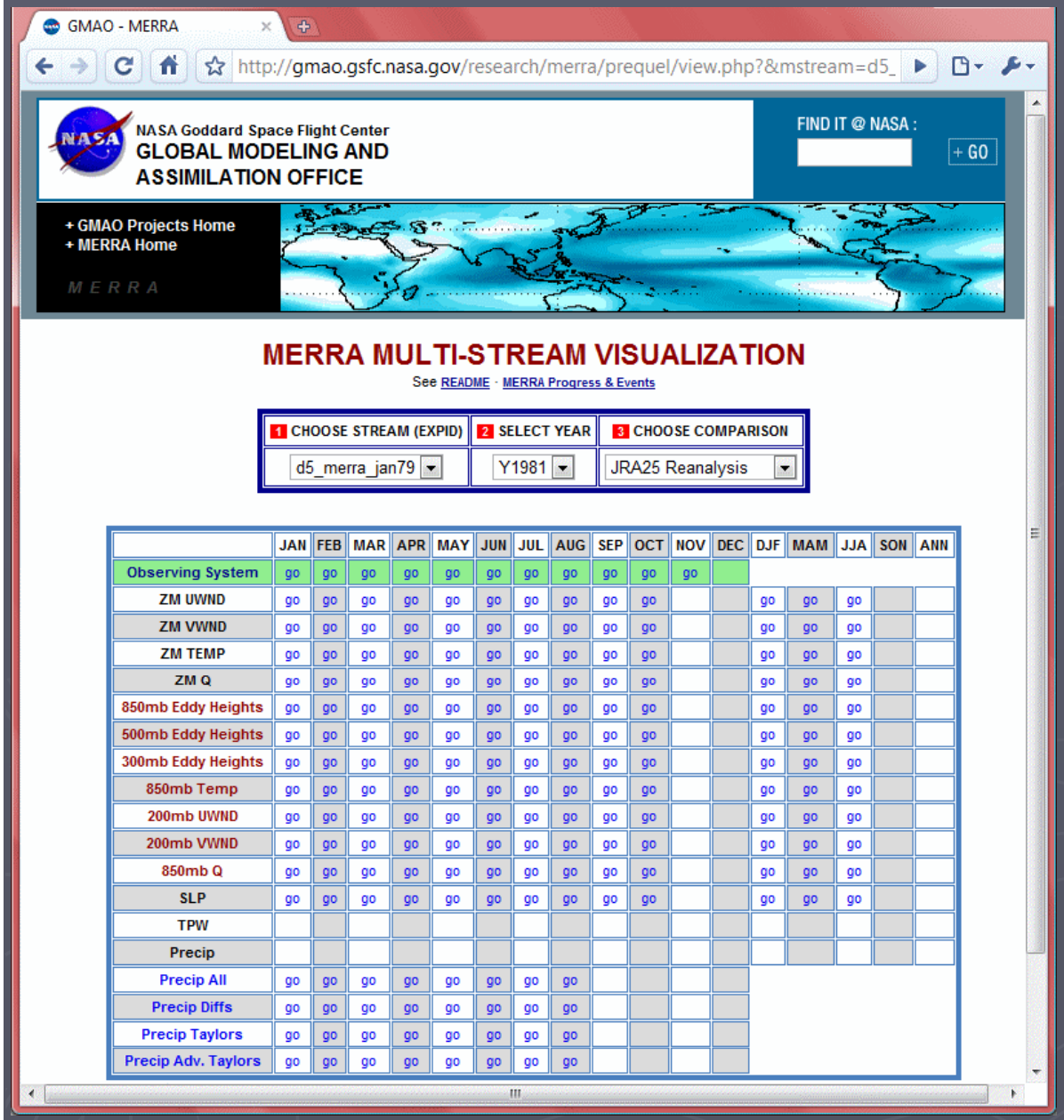




Flawed sounding: Azores

- 1979-1980: A persistent sounding west of Portugal is very different from others nearby
- The result is a persistent counter-increment that affects energetics and moisture budgets

MERRA On-Line Atlas



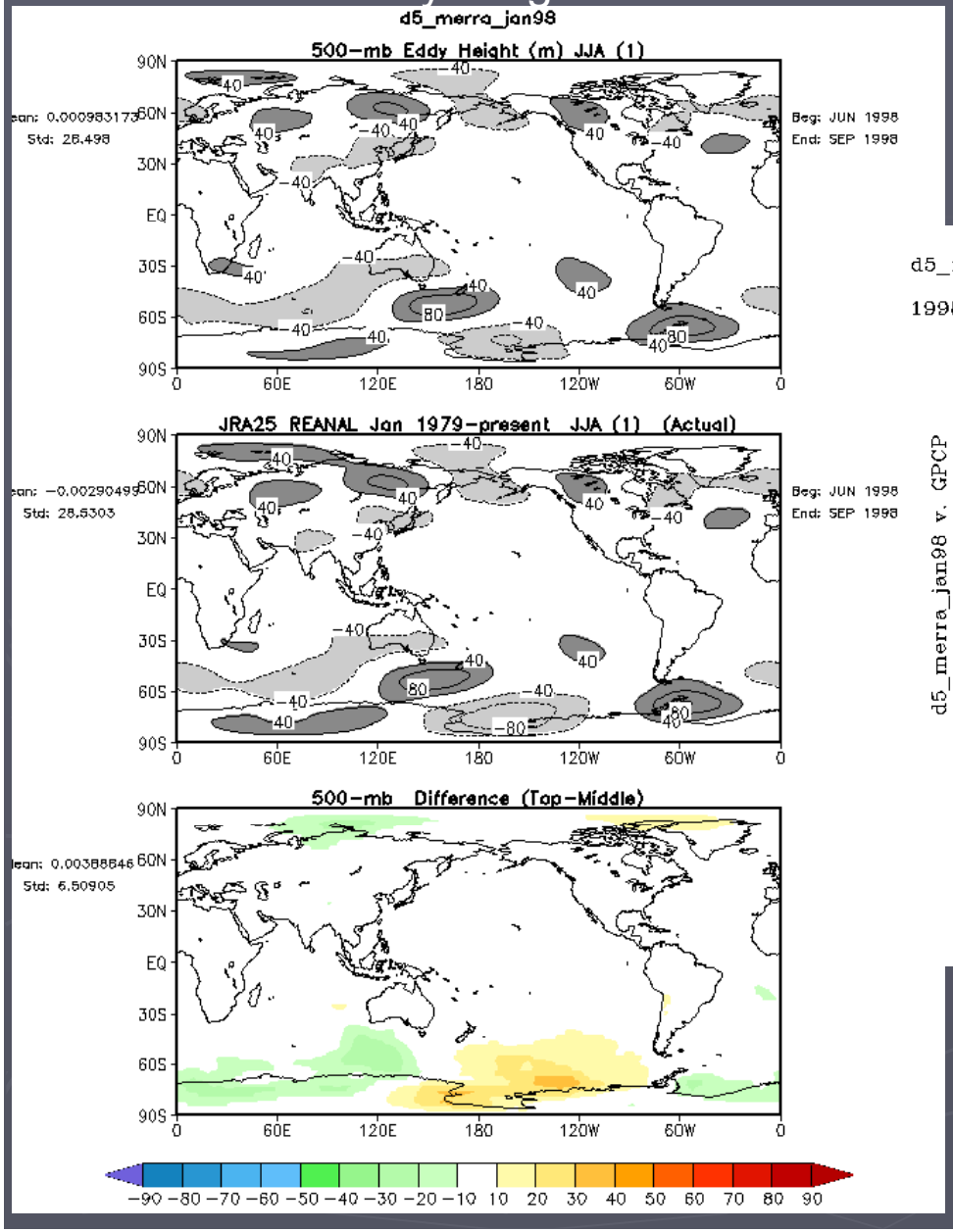
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	DJF	MAM	JJA	SON	ANN
Observing System	go	go	go	go	go	go	go	go	go	go	go						
ZM UWND	go	go	go	go	go	go	go	go	go	go			go	go	go		
ZM VWND	go	go	go	go	go	go	go	go	go	go			go	go	go		
ZM TEMP	go	go	go	go	go	go	go	go	go	go			go	go	go		
ZM Q	go	go	go	go	go	go	go	go	go	go			go	go	go		
850mb Eddy Heights	go	go	go	go	go	go	go	go	go	go			go	go	go		
500mb Eddy Heights	go	go	go	go	go	go	go	go	go	go			go	go	go		
300mb Eddy Heights	go	go	go	go	go	go	go	go	go	go			go	go	go		
850mb Temp	go	go	go	go	go	go	go	go	go	go			go	go	go		
200mb UWND	go	go	go	go	go	go	go	go	go	go			go	go	go		
200mb VWND	go	go	go	go	go	go	go	go	go	go			go	go	go		
850mb Q	go	go	go	go	go	go	go	go	go	go			go	go	go		
SLP	go	go	go	go	go	go	go	go	go	go			go	go	go		
TPW																	
Precip																	
Precip All	go	go	go	go	go	go	go	go									
Precip Diffs	go	go	go	go	go	go	go	go									
Precip Taylors	go	go	go	go	go	go	go	go									
Precip Adv. Taylors	go	go	go	go	go	go	go	go									

- Updated regularly with monthly comparisons versus existing reanalyses and some global observed data sets
- More comparisons being added and will be redone at the completion of MERRA
- Comments Welcome

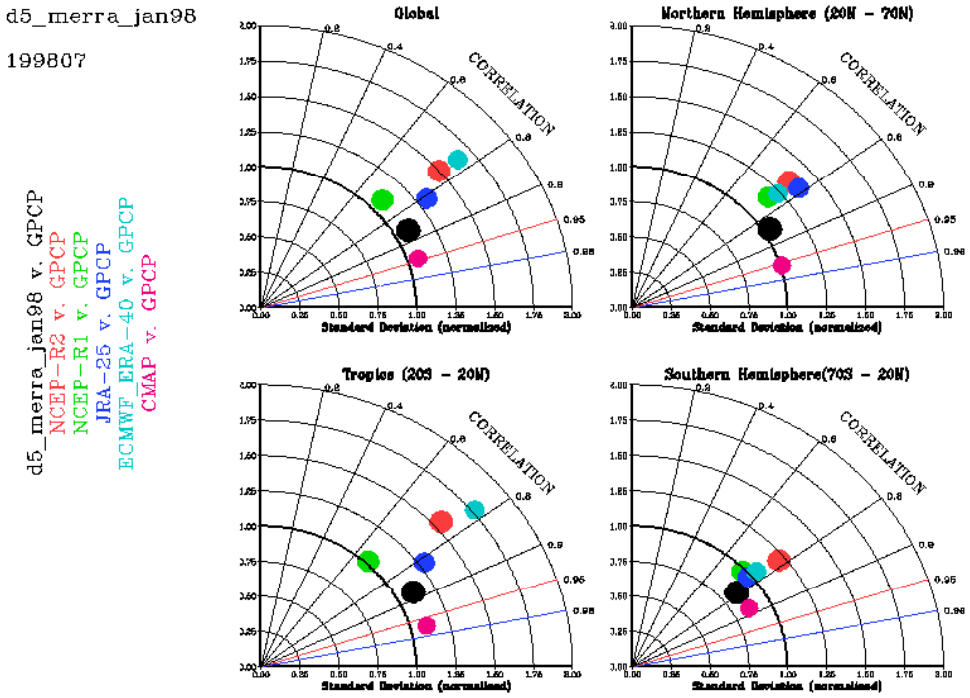
http://gmao.gsfc.nasa.gov/research/merra/prequel/view.php

Example figures from the Atlas

500mb Eddy Height vs JRA25



Precipitation Taylor Diagram, All Reanalyses using GPCP as the reference



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
- 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)