MERRA: Overview, Applications and Next Steps

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Climate Reanalysis Task Force Briefing
March 26, 2014

Overview

- MERRA
  - Project overview
  - Strengths and Weaknesses
- Reanalyses and Climate Applications
  - Regional Climate Variability
  - National Climate Assessment
  - Climate Monitoring
- MERRA2 and Beyond
  - Rationale for a sequel
  - Recent development

NASA and Reanalysis

NASA's strategic goal
"Advance Earth System Science to meet the challenges of climate and environmental change"

- Approach: characterize, understand, predict using NASA's observations and so acquire deeper scientific understanding of the components of the Earth system and their interactions.

- **Role of Reanalyses in NASA's mission:**
  - Long-term synthesis of data for a physically consistent climate research-quality data sets
  - Initial and boundary conditions for predictions
  - Validation and verification references, and internal and external constraints to models

MERRA

- **GEOS-5 ADAS, 2008 version** – GEOS-5.2.0
  - 1/2° × 2/3° × 72L
  - 1979-present; cont. as a ~2-week delayed NRT climate analysis
  - **MERRA-Land** as an update to the land-surface collection

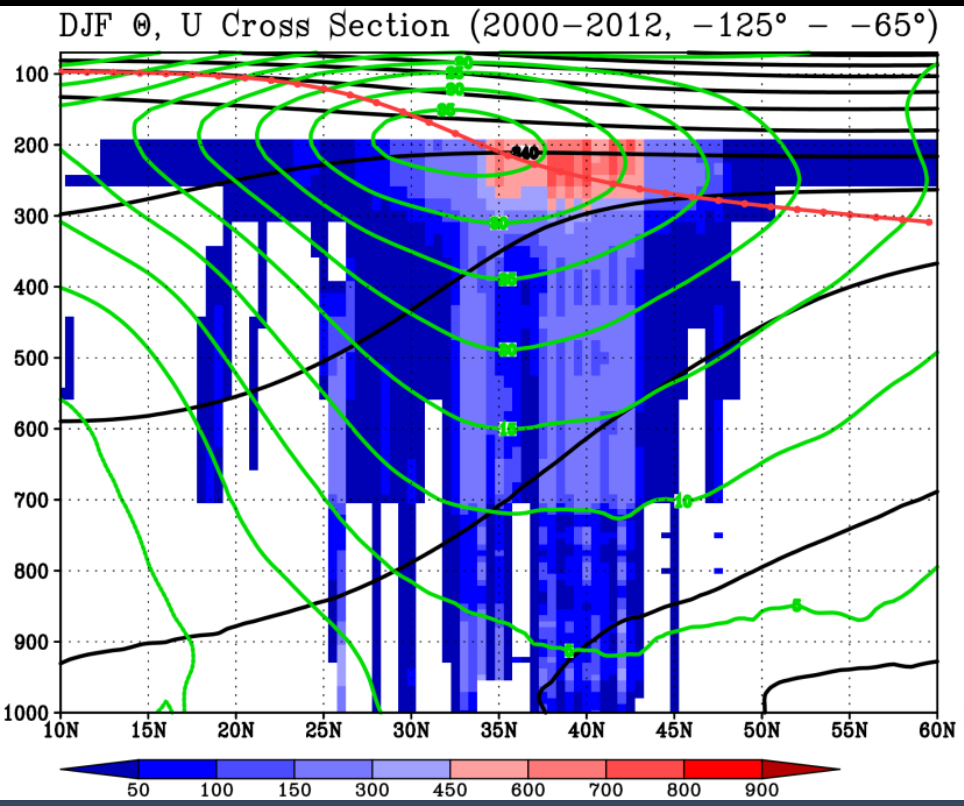
- Web site (FAQ, blog, issues found/resolved) **http://gmao.gsfc.nasa.gov/merra**
  - **MERRA Atlas** (**http://gmao.gsfc.nasa.gov/ref/merra/atlas/**)
  - Data online through the GES DISC (**http://disc.sci.gsfc.nasa.gov/mdisc/**)
    - > 2.2 PB distributed to date – Several access options
    - International by Volume: Canada, Japan, Germany, Spain, Taiwan, UK
  - MERRA is **online at PCMDI's ESG** for CMIP5 model evaluations (other reanalyses have been included lately)

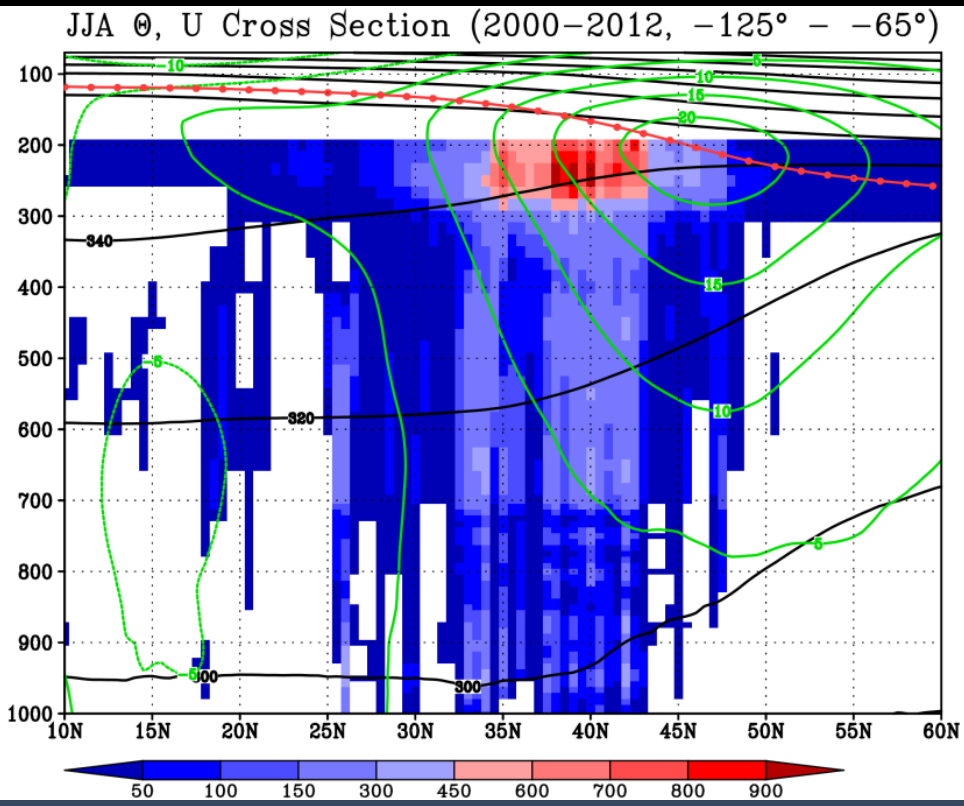
- **MERRA Special Collection in *J. Climate***
  - *GMAO's* Overview paper – Rienecker et al. (2011)
  - 20 papers

GIO

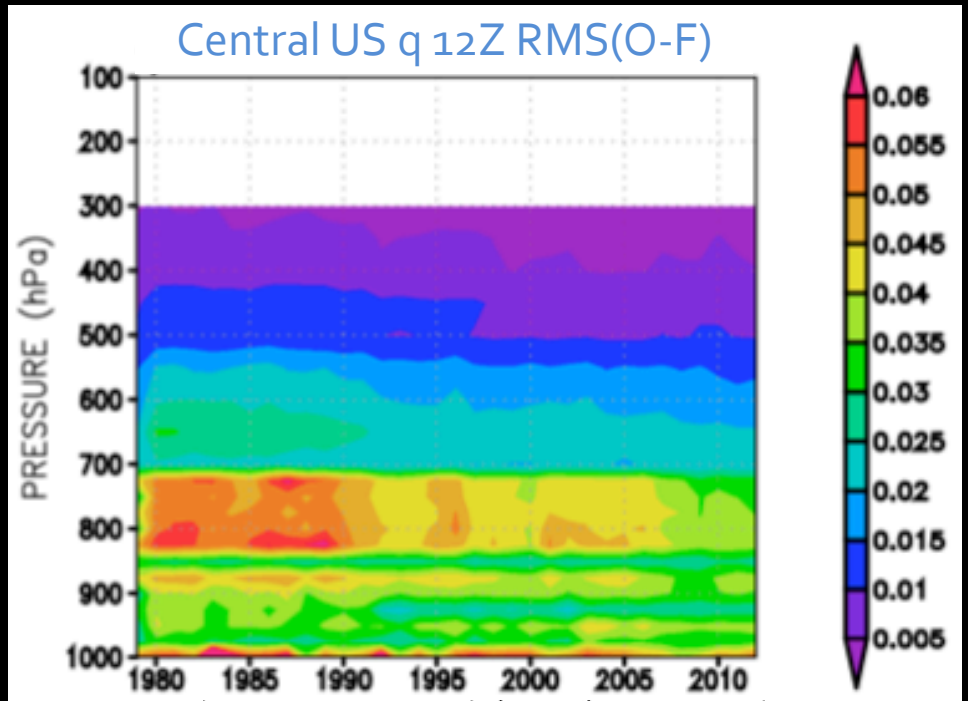
- Gridded Innovations and Observations (GIO)
  - Derived from GSI "diag" (feedback) files, and includes the observation, background forecast departure (OmF) and analysis departure (OmA)
  - Conventional obs (sonde, stn pressure, retrieved quantities) and also Radiance data
  - **Binned** to MERRA's native pressure coordinate – ½°×⅔°, 42 pressure levels for every 6 hour analysis time, 1979-current
- There are limitations, but: How deep can we dig into the analysis and observations with this kind of post processed observations?

Aircraft data distribution



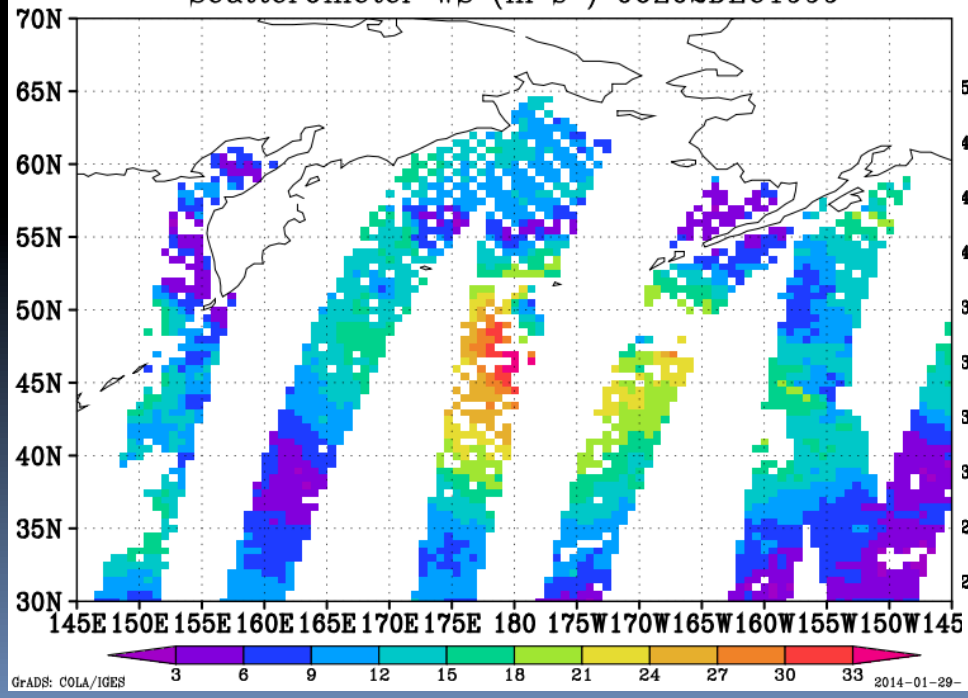


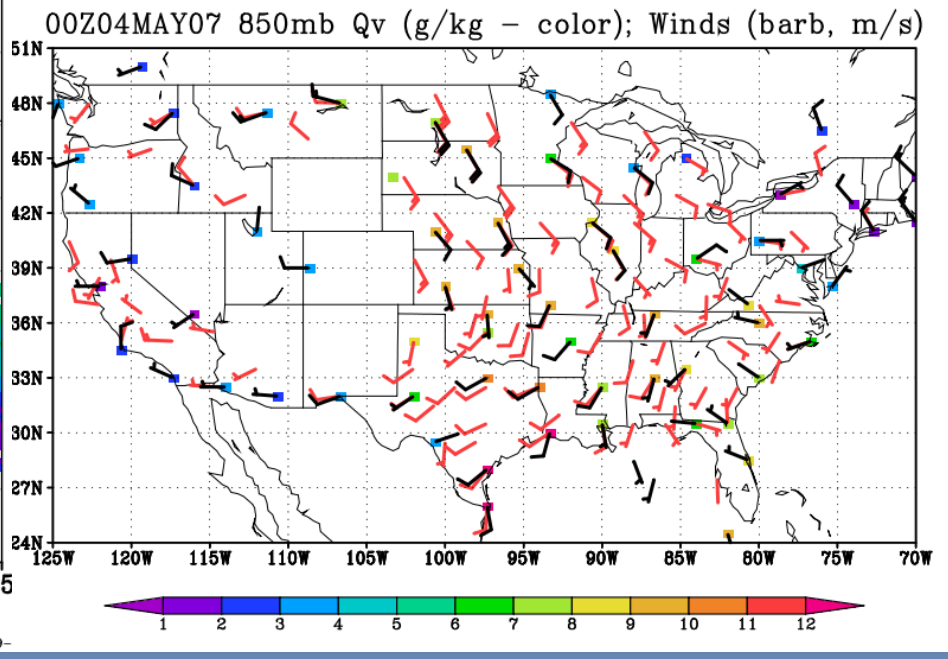
- Some grid points are screened due to low number of collocations
- Count is in thousands



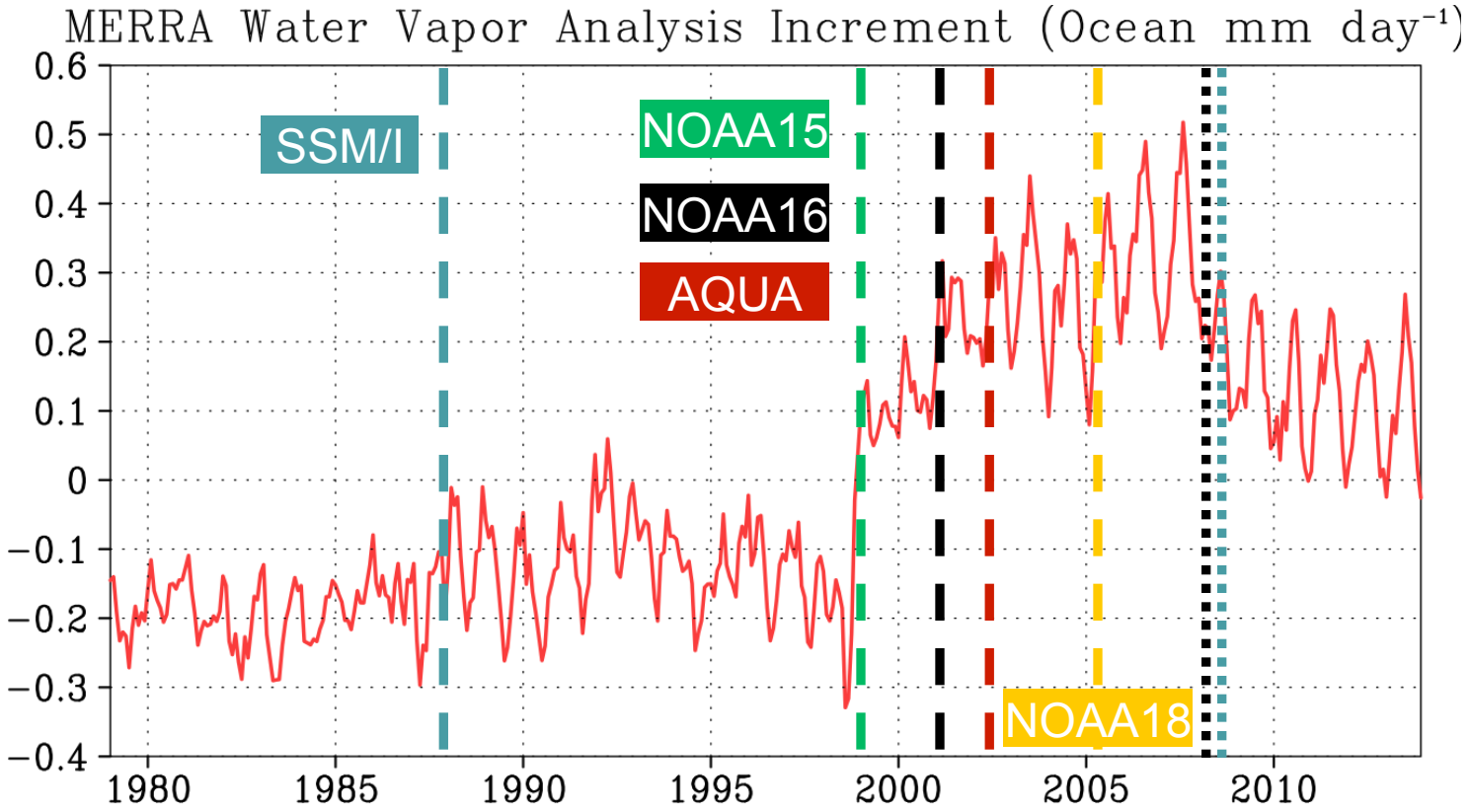
Examples of GIO

- Data can be easily accounted for across any observing system
- Some information is lost in the binning process





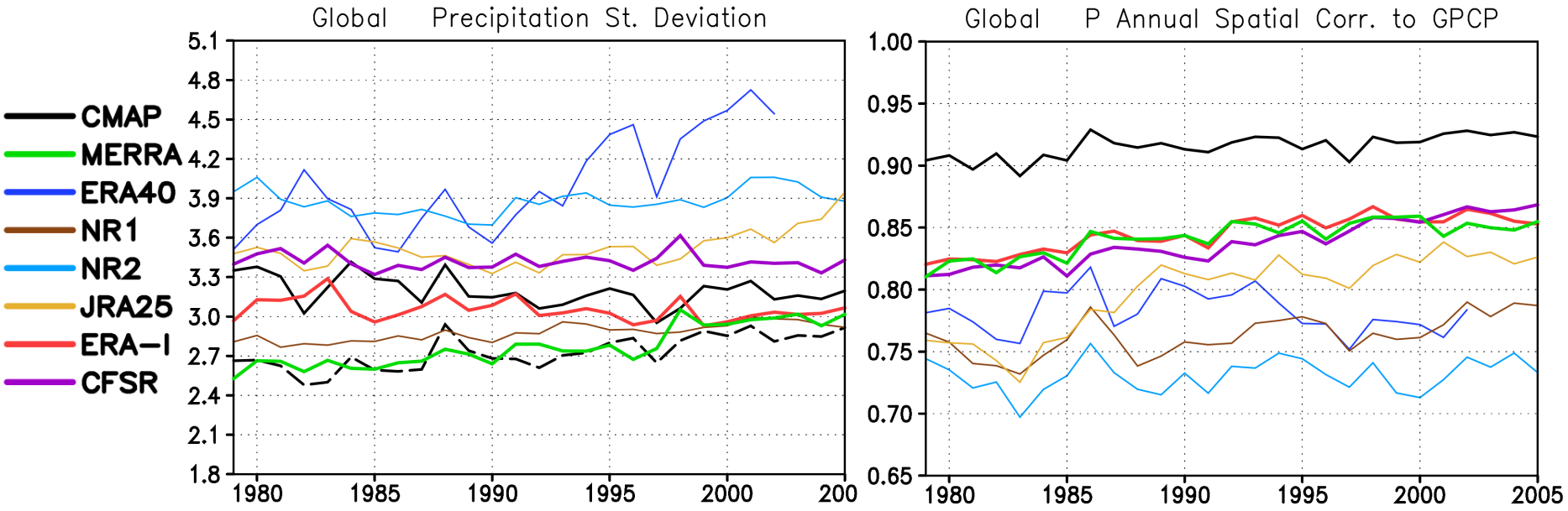
Satellite Observations and Water Vapor in Reanalyses



- 1987 SSMI Enters
- 1999 First AMSU on NOAA15
- 2002 AQUA includes AMSU and AIRS (Seasonal cycle changes)

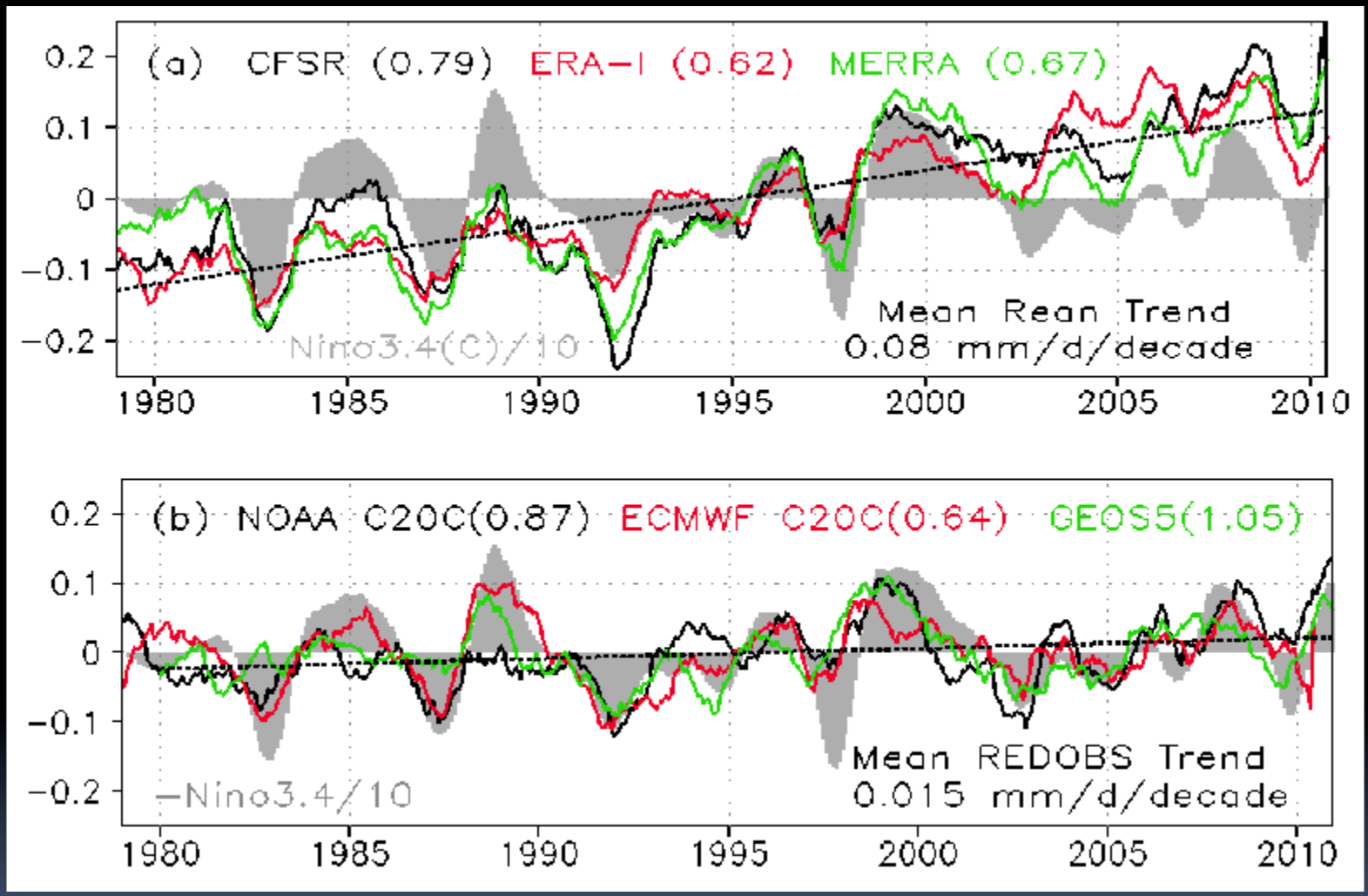
Annual Mean Precipitation

Spatial standard deviation and spatial correlation to GPCP



System improvements have aided the representation of spatial variations

Water Cycle Consistency

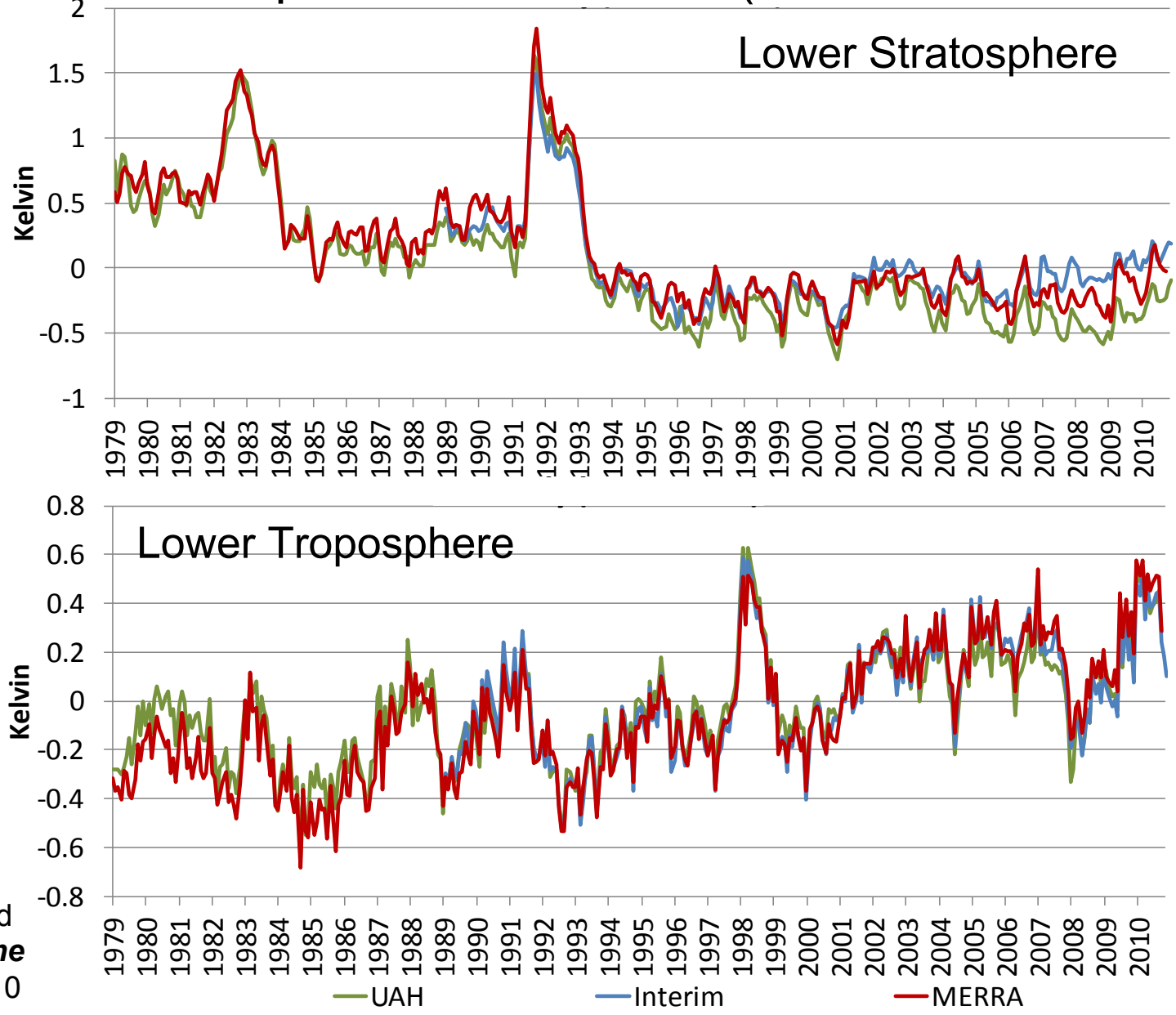


- Reanalyses Moisture Flux Convergence over Land
- REDOBS trend and variability closer to GLDAS P-E

Robertson et al (2014)

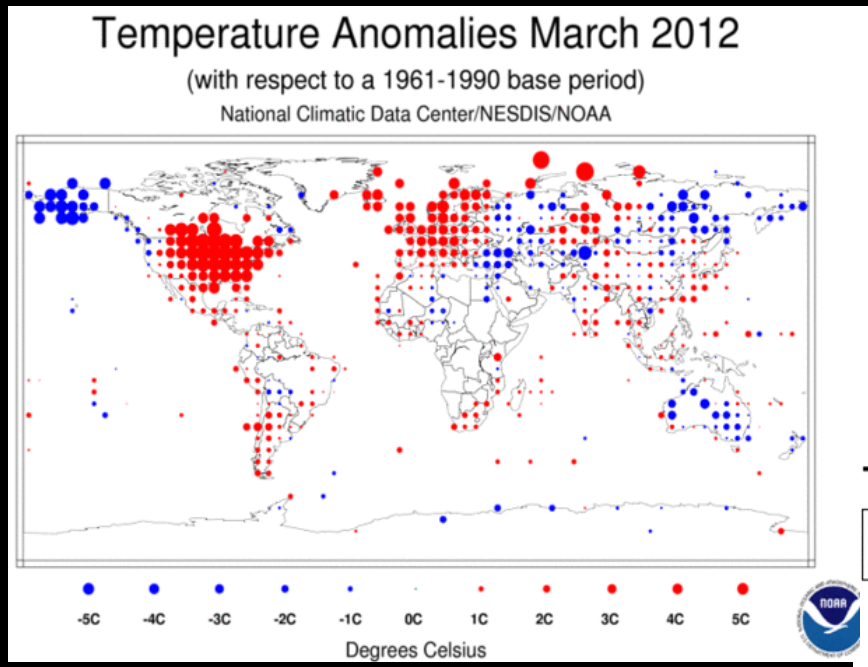
MERRA, ERA-Interim & MSU (UAH)

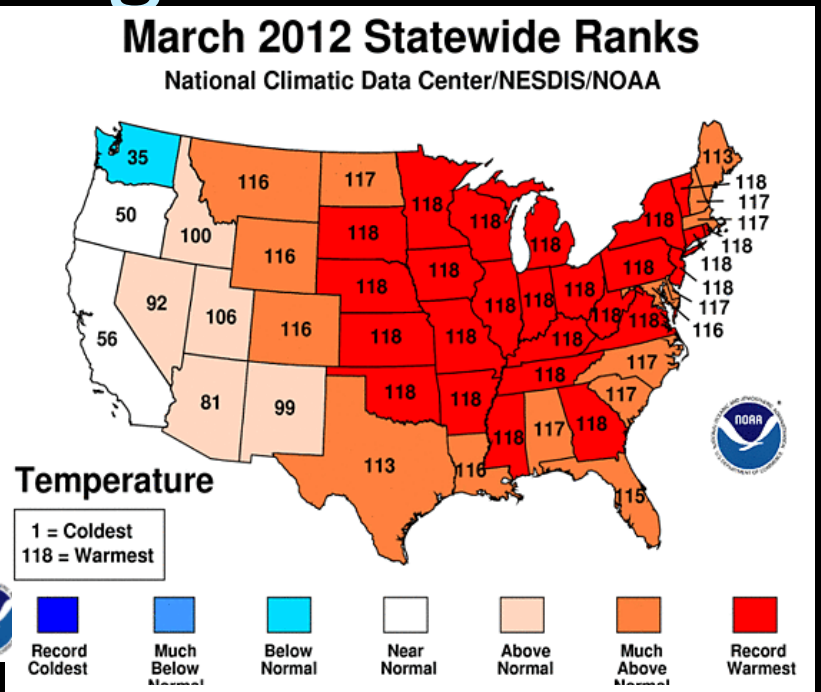
Global mean temperature anomalies (rel. to 1989-2008 mean)



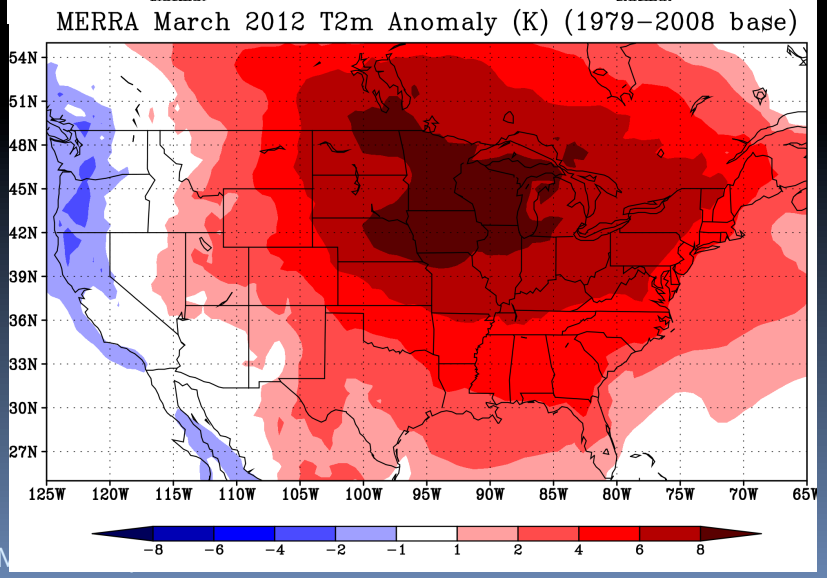
Data reported in ***State of the Climate***, 2010

Climate Monitoring

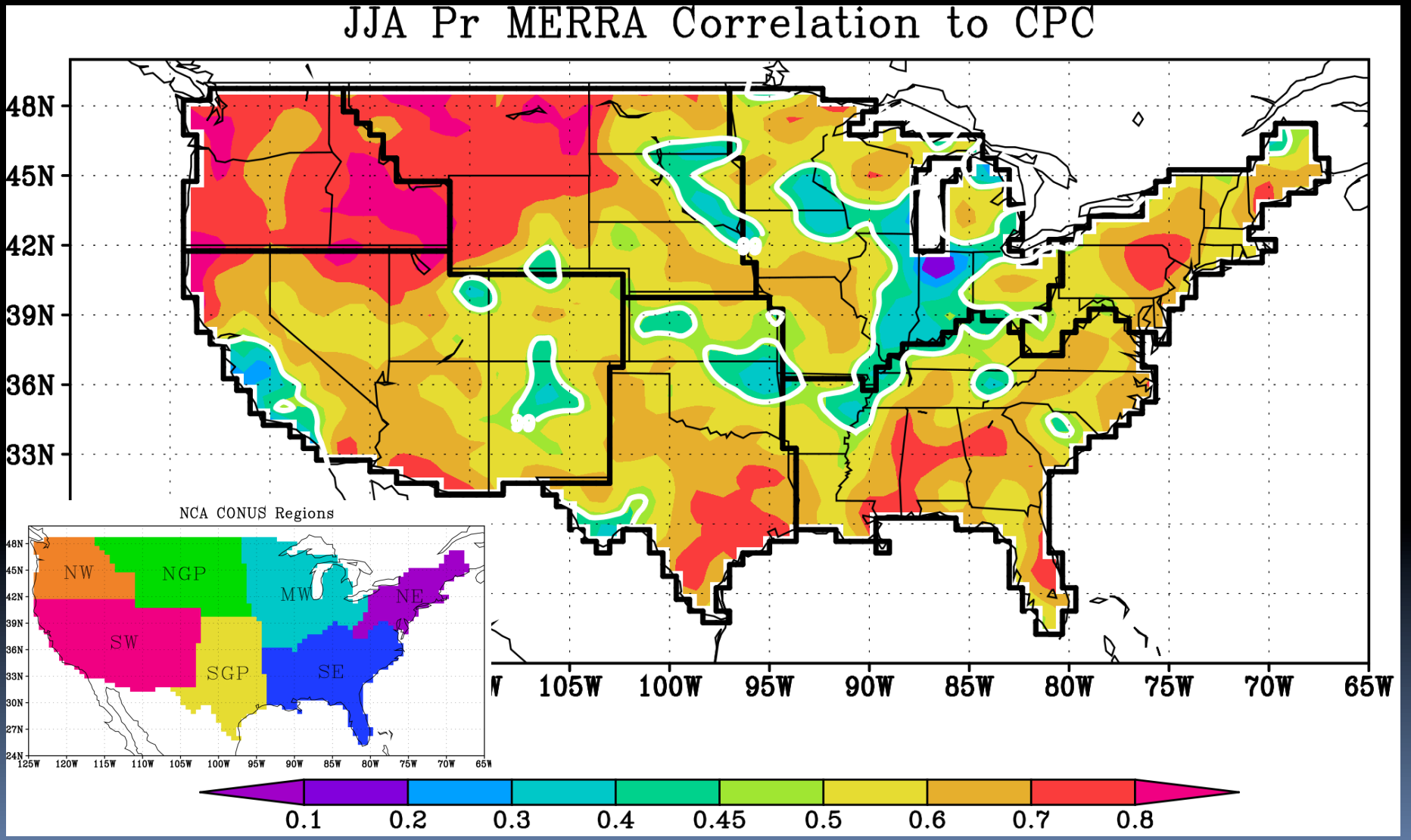




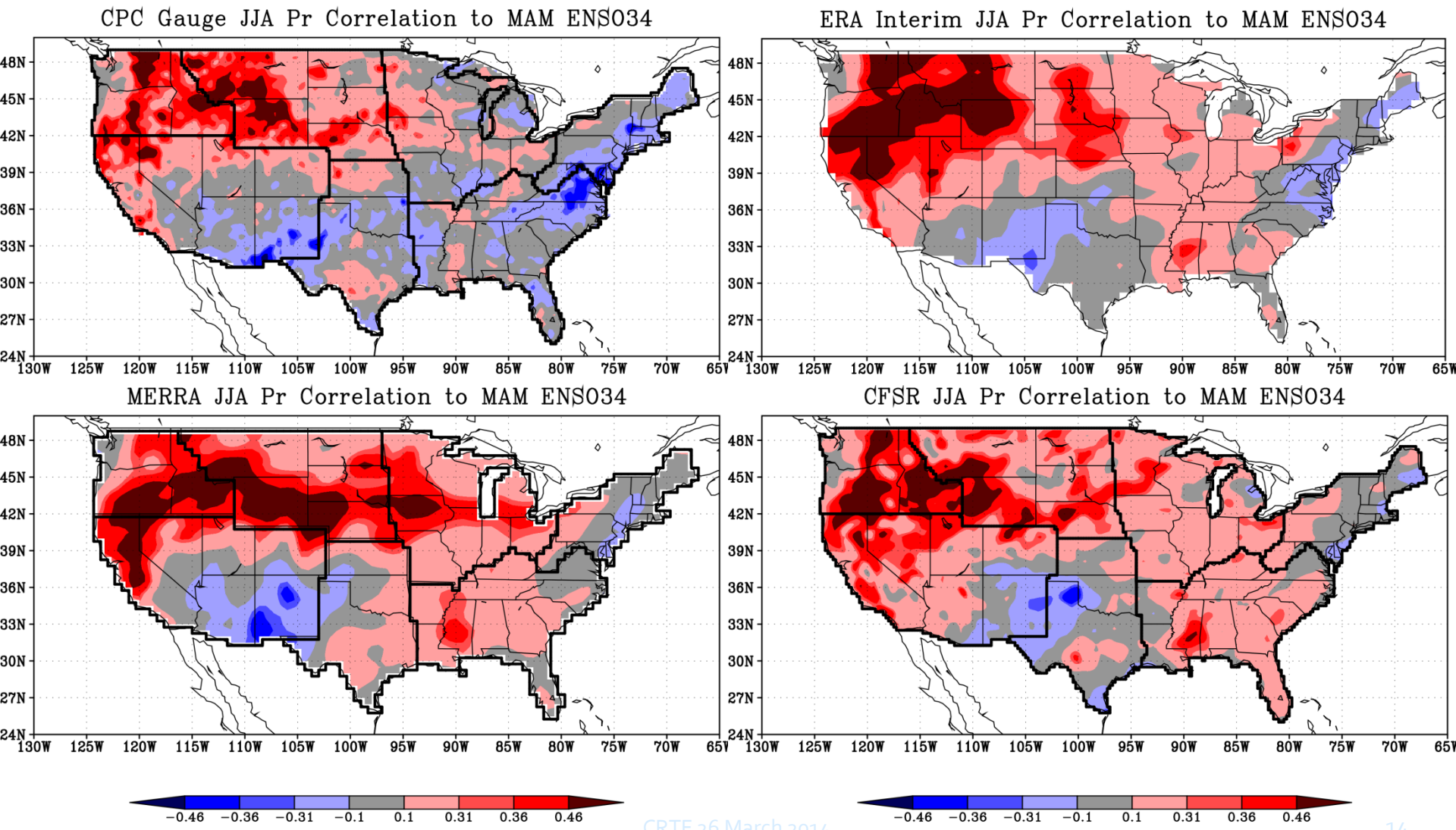
- Temperature can be robust
- Biases remain; no surface temperature analysis



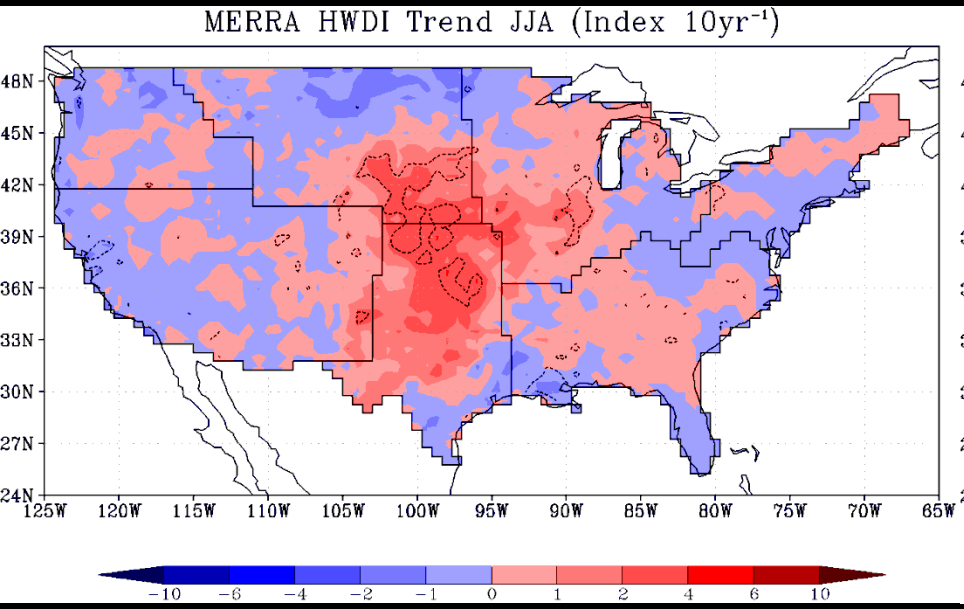
Summer MERRA – Gauge Correlation

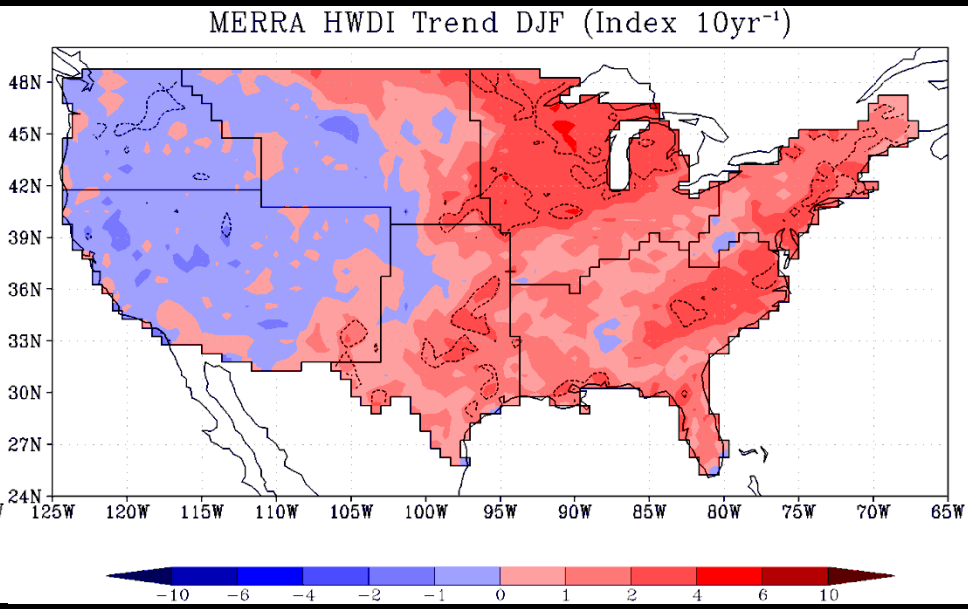


ENSO Connection



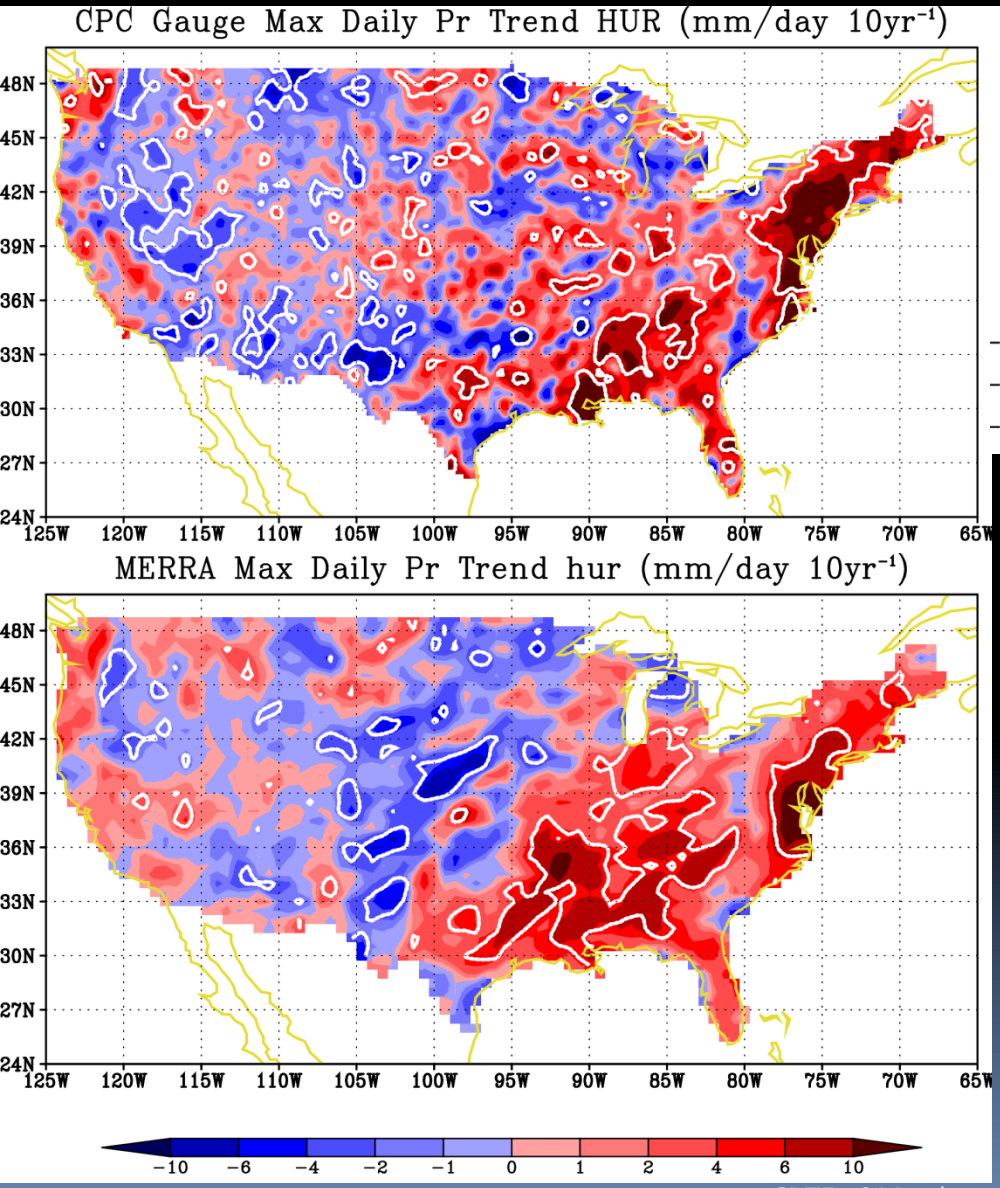
Heat Wave Duration Index

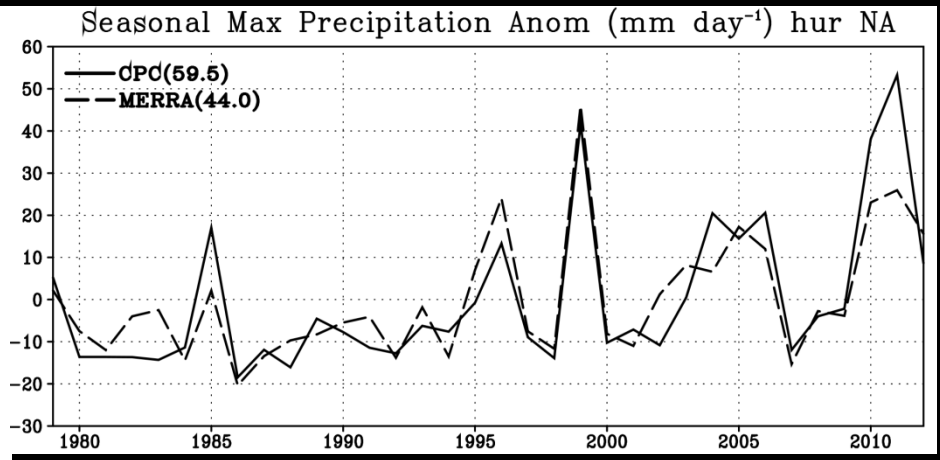




- 5K above climatology for 5 day stretches
- Not exactly warming, but affected by warming
- Identifying an appropriate daily temperature data set for comparisons

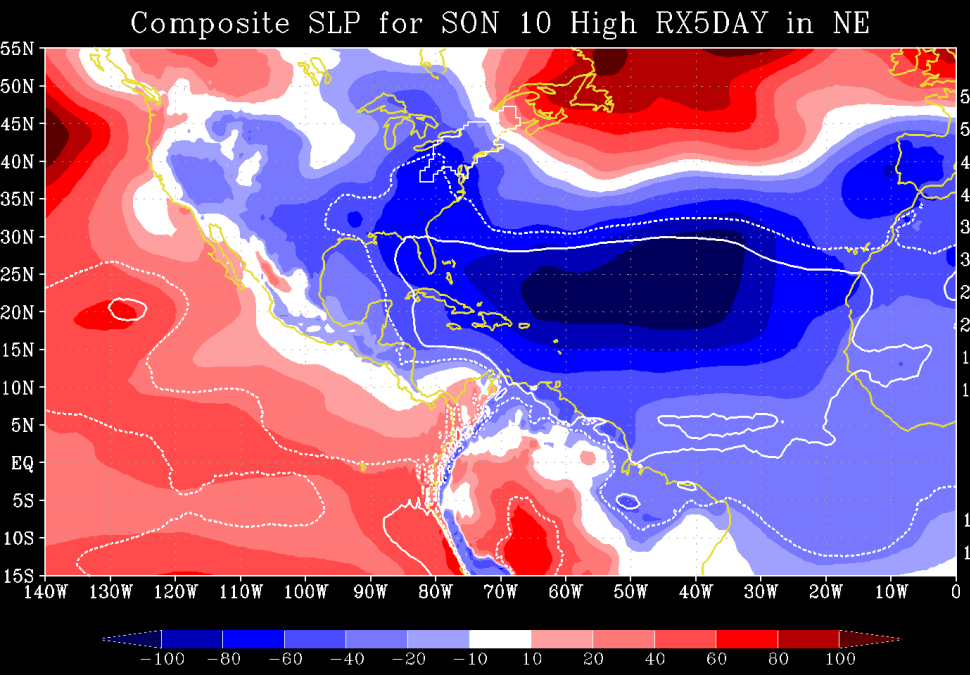
Max Precip in a Season

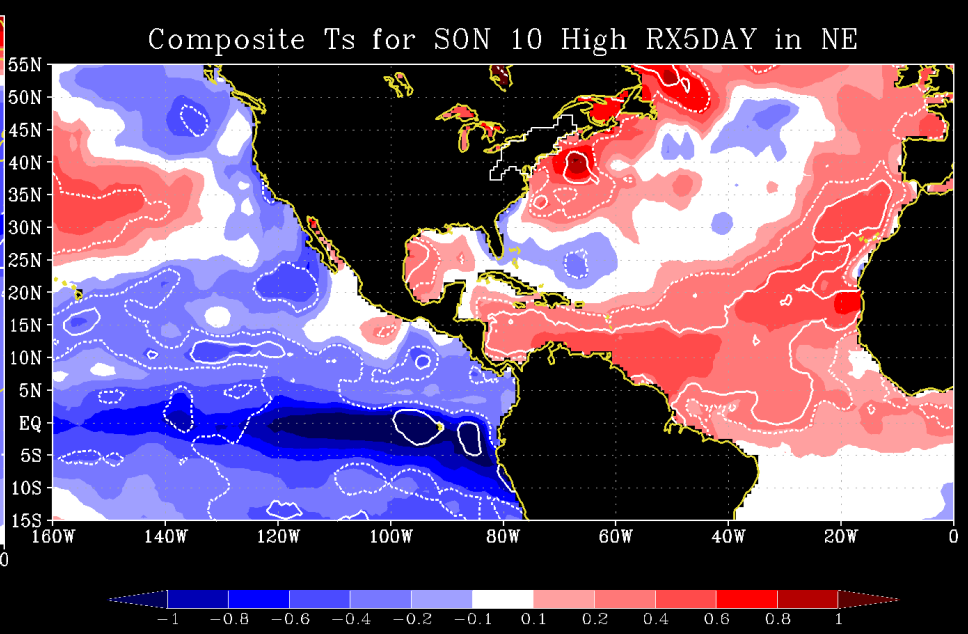




- Largest precip occurrence each season at each grid point
- Hurricane Season (Jun-Nov) shows increases along East Coast and SE US
- MERRA represents the variability of the extreme precipitation well

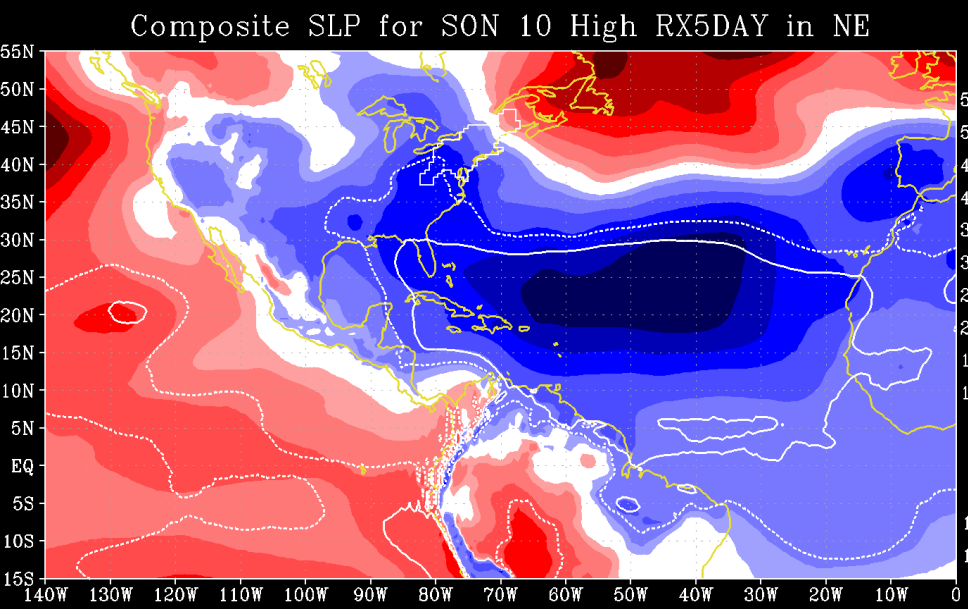
Max Precip SLP/Ts Composite

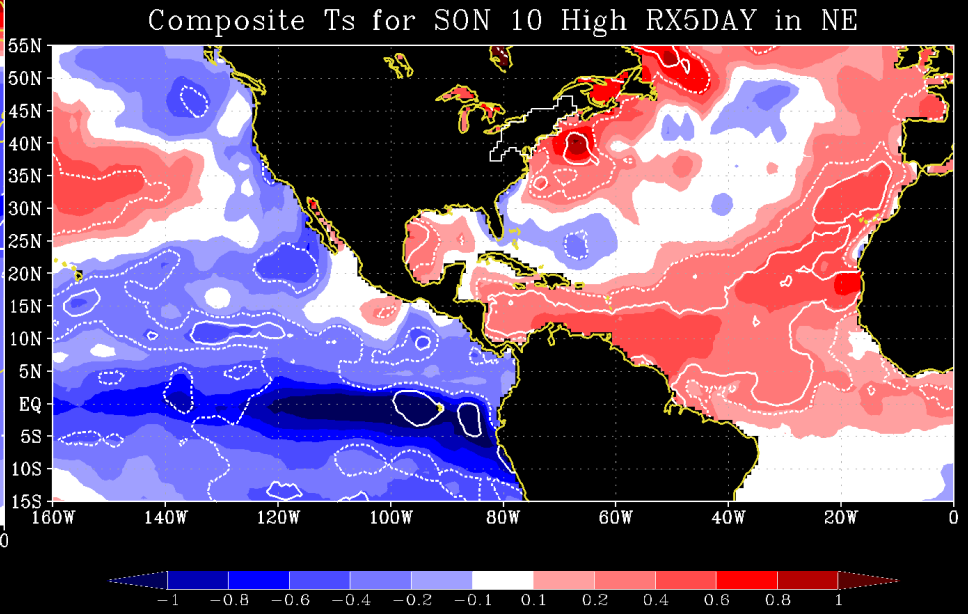


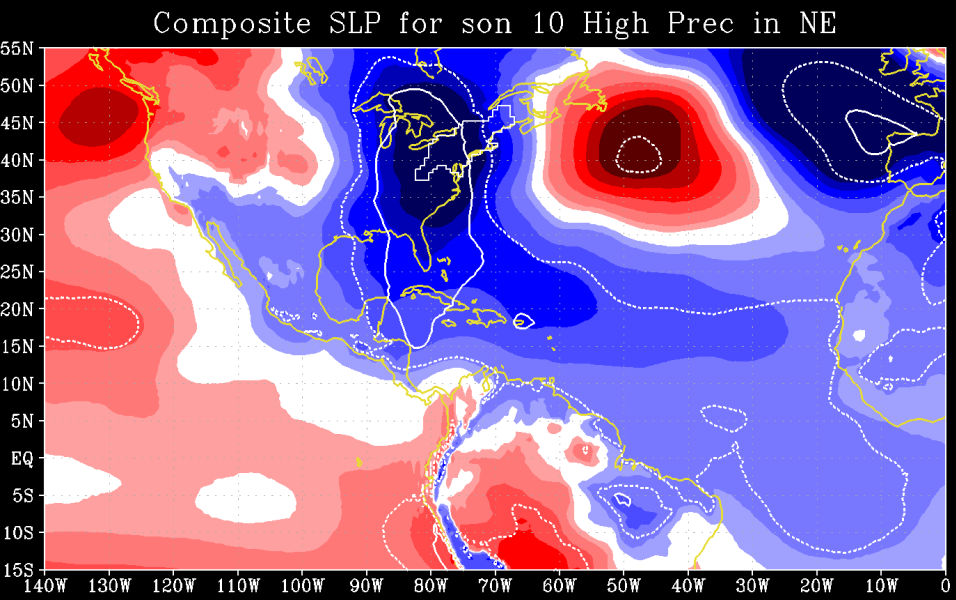


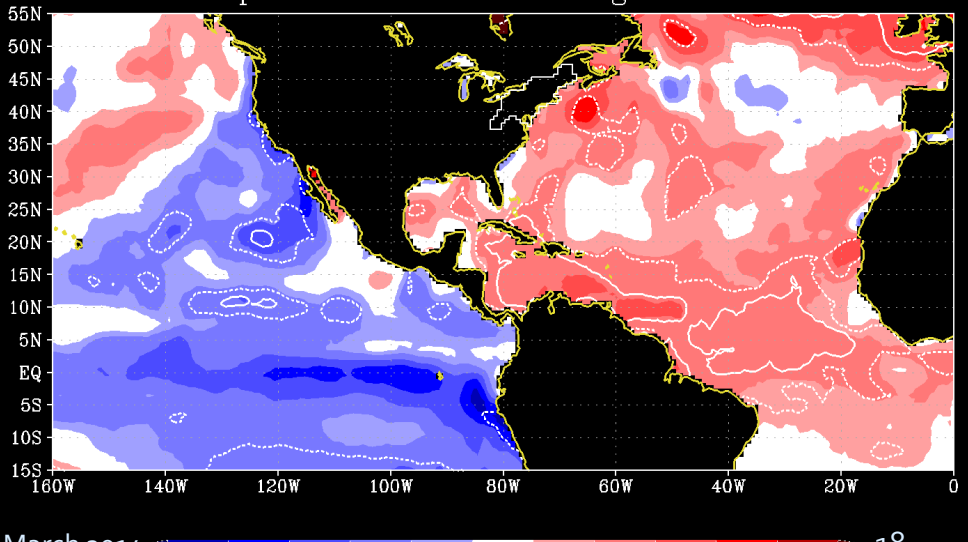
- Compositing the most extreme years to show the supporting large scale environment
- Low pressure in tropical Atlantic, with weaker westerly flow
- SST Shows warm Atlantic, including off the east coast and La Niña Pacific pattern

Max vs Mean Precip Composite

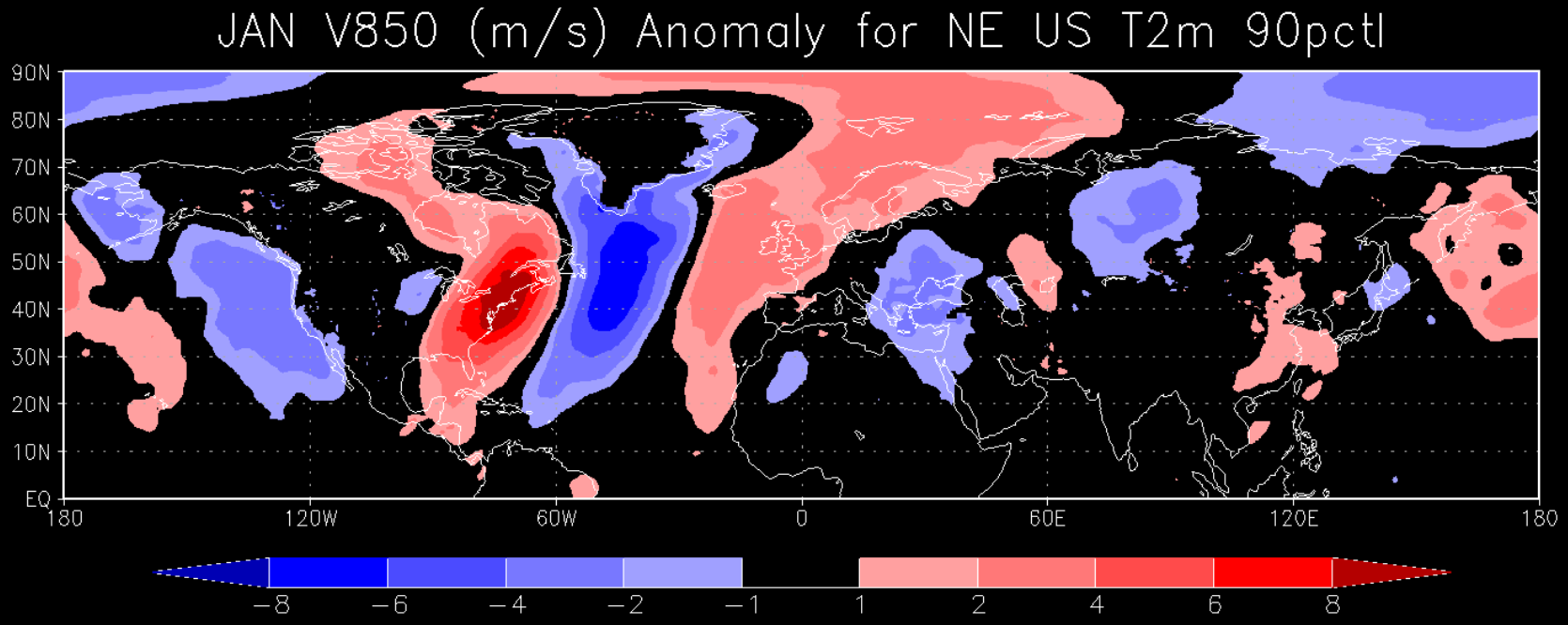








Daily Composites of Extremes



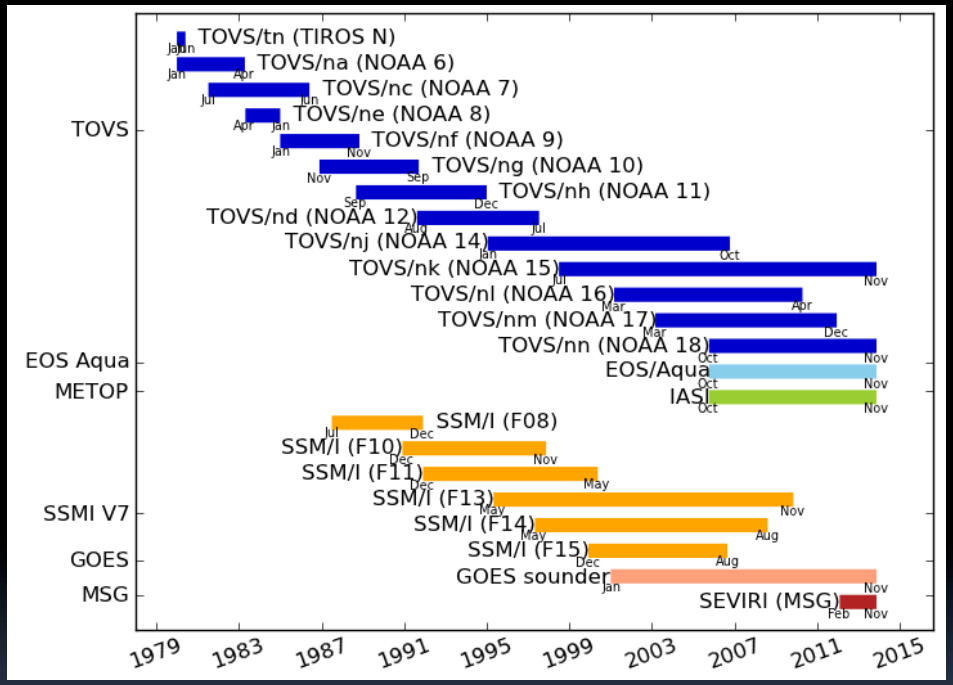
- Choose days when mean T2m exceeds 90th%
- JAN days in the Northeastern US
- Strong southerly flow ahead of low pressure to the west

Beginning of The End

- MERRA will eventually cease production
  - Termination is presently not planned, but will be determined as to the assimilated observations
  - New observations cannot go into MERRA without updating GSI (and the requisite fte) – Office philosophy is more looking forward to a new system
- MERRA2 originally planned to use the latest system, starting in 2010, and pick up where MERRA left off
  - Several overlapping years would permit corrections to the time series, if discontinuities would be large
  - But…. Upon further review-

MERRA2 – New Data in the Modern Climate Record From 1979 – Present

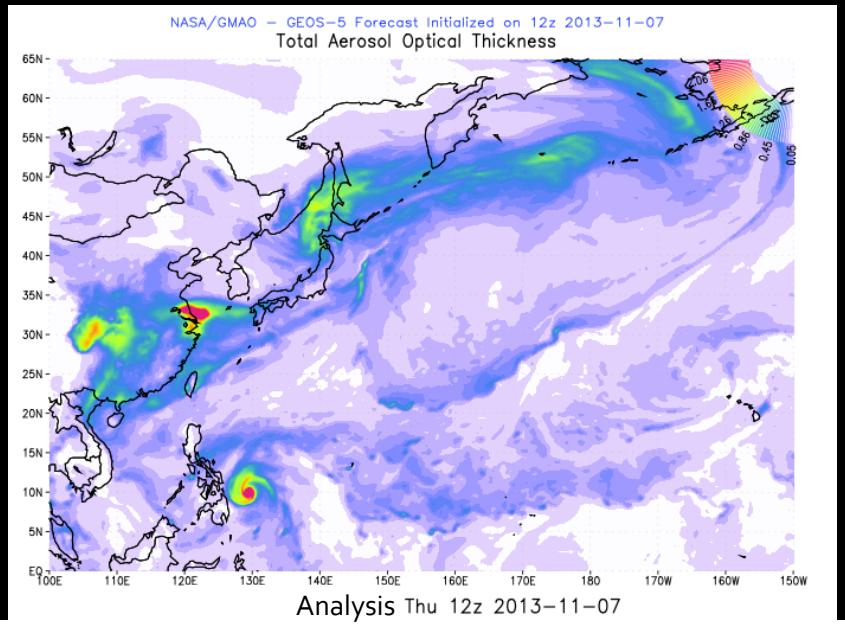
Satellite Radiances to be Assimilated

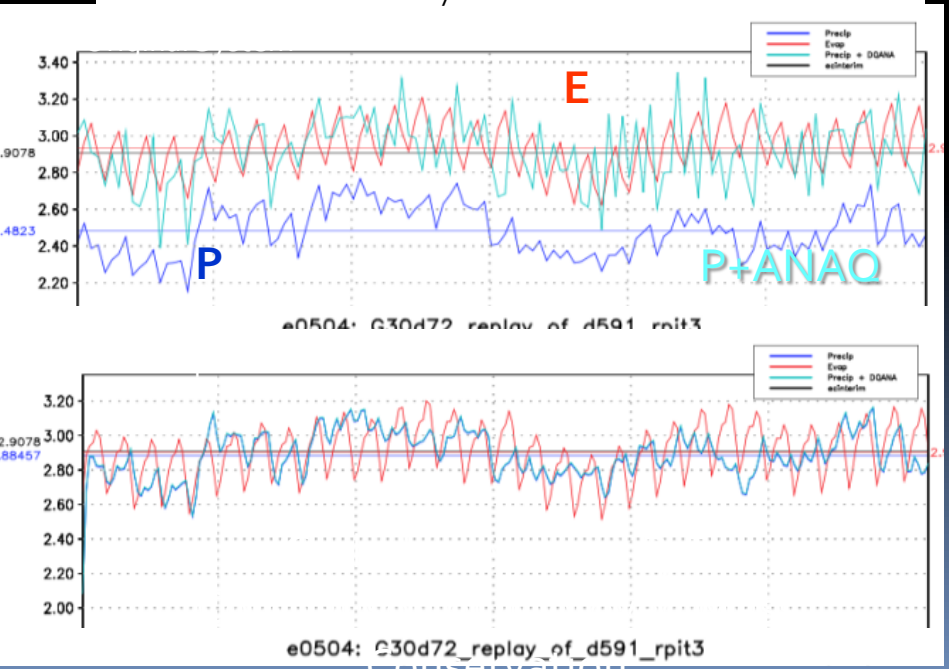


MERRA2 will begin from 1979 and carry on for several years to come, adding some of the latest observations and significant updates to the data assimilation and global model.

- MERRA2 includes the latest satellite observing systems
  - NPP: ATMS, CrIS, OMPS
  - MetOp-A/B: IASI, ASCAT, GOME2, AMSU, MHS
  - OSCAT, GPS-RO, SSMI (v7)
  - Reprocessed AMV
  - SBUV-v8

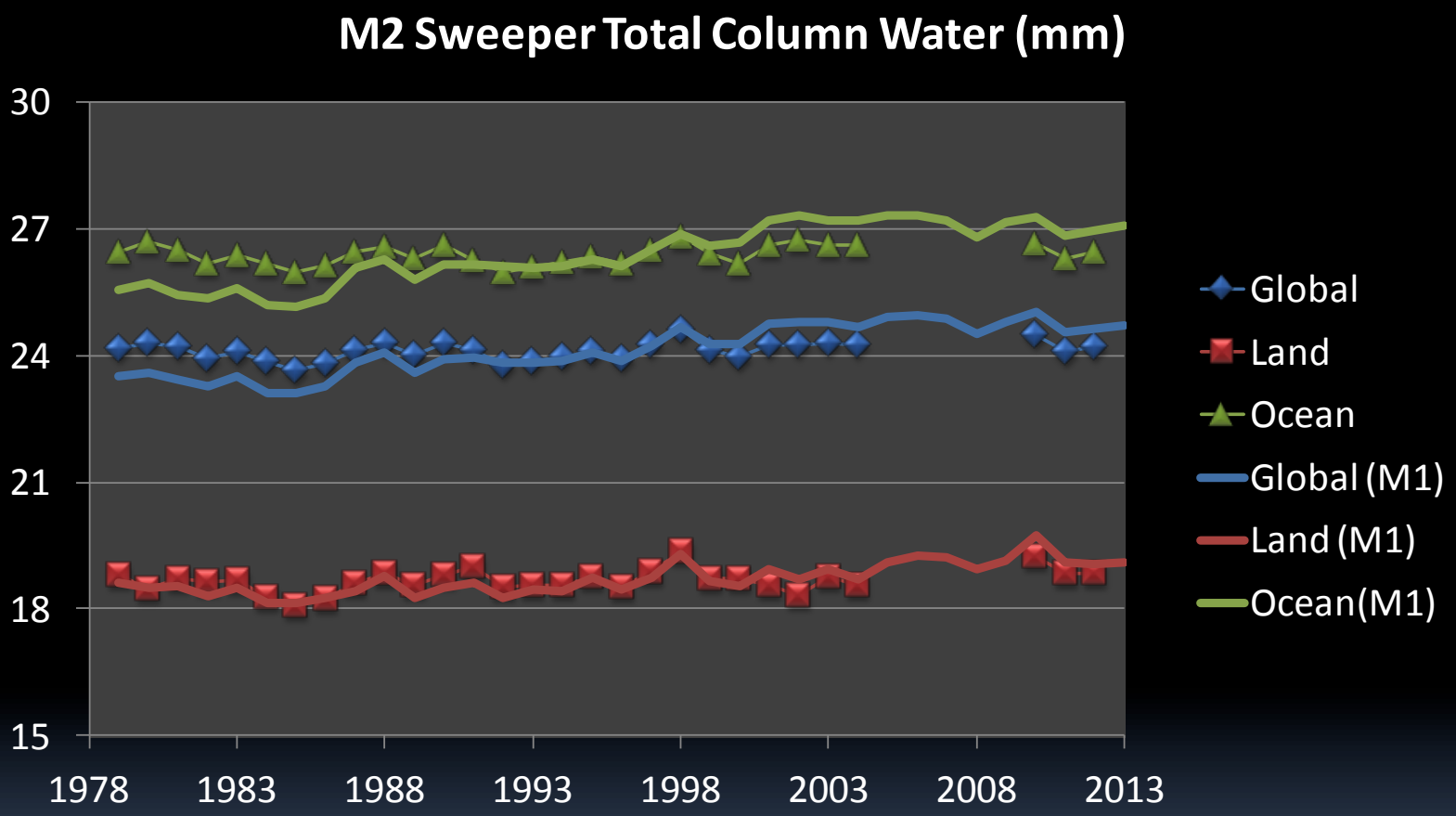
MERRA2 – Improved Analysis and Model





- **Aerosol Analysis**
  - Includes Black and Organic Carbon, Dust, Sea Salt
  - Interactive with modeled radiative fluxes
- **Water Vapor Conservation**
  - Surface pressure and water vapor (ANAQ) analyses are penalized for global imbalances
  - The result is that unphysical changes in total mass are ameliorated
  - Improved balance between global Precipitation (P) and Evaporation (E)

Sweeper (2 degree) Experiment



- Water Vapor Mass Conservation stabilizes TPW
- Global E/P balance – Increments are small
- Regional increments would still be locally influential

Building an Integrated Earth System Analysis

GMAO strategy for IESA is stepwise, building on the GEOS-5 ADAS and assimilation systems for other components.

1. **MERRA2**
   Coupled Aerosols, Trace gases
   Pr Bias corrected input for land surface
   Water vapor mass constrained increments

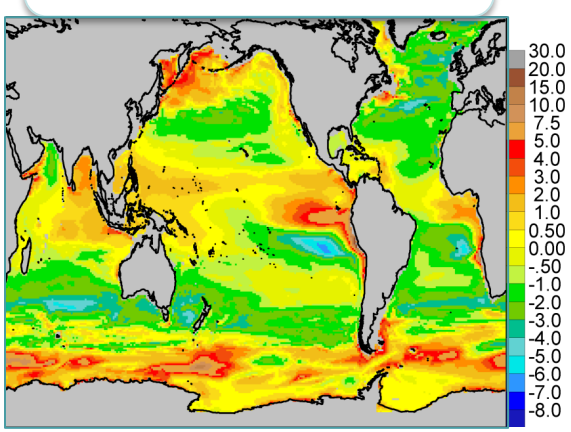
2. **Weakly coupled analysis**
   Atmosphere - Ocean analysis
   Atmosphere - Land analysis
   CO, CO_2 analysis
   Aerosol analysis

   First guess from coupled system
   Separate analyses

3. **GEOS IESA**
   More tightly coupled analyses
   Focused on the NASA EOS era

MERRA-driven component reanalyses

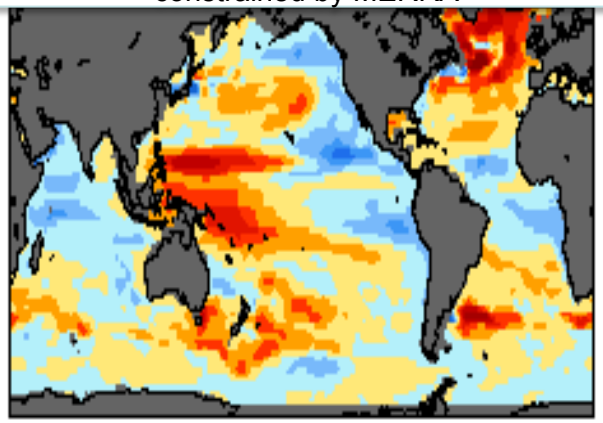
Annual Mean Air-sea CO_2 flux from ocean model (NOBM) forced with MERRA



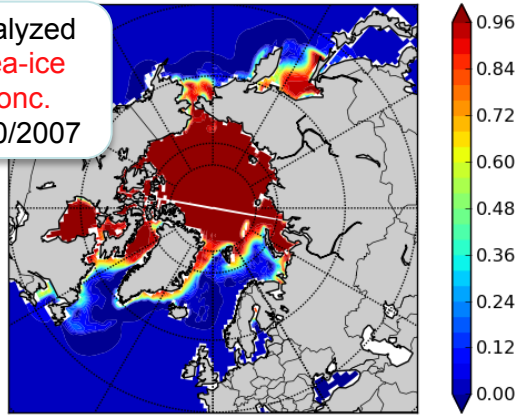
Underway:

- CO_2 (AIRS, AVHRR, MODIS)
- Aerosols (MODIS, MISR)
- Ocean (JASON, Argo, in situ)
- Sea-ice (ice concentration)
- Ocean biology (SeaWIFS, MODIS)
- Land surface (AMSR-E, ASCAT, SMOS, MODIS, GRACE)

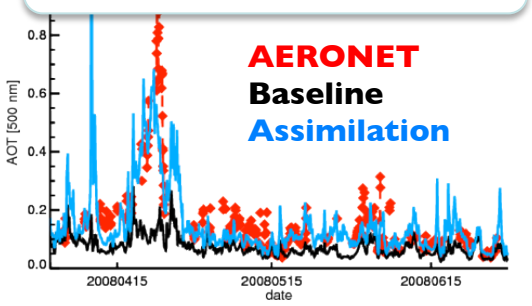
Linear trends of HC300, 1993–2009 from GMAO Ocean Reanalysis (°C/decade) constrained by MERRA



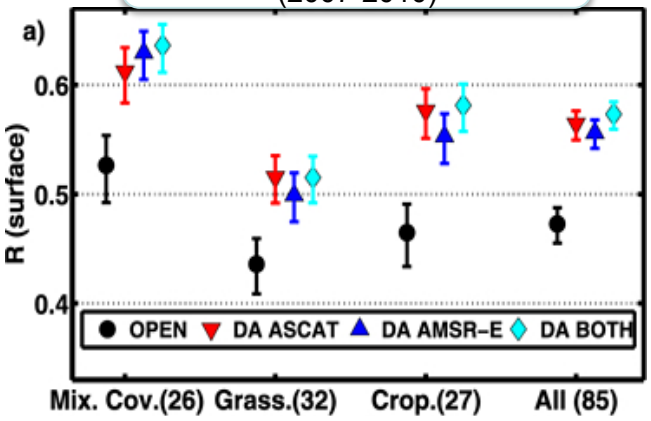
Analyzed Sea-ice conc. 2/20/2007



AOT (500 nm) at Bonanza Creek
Assimilation of MODIS data



Improvements in soil moisture skill (R) from data assimilation (2007-2010)



Summary

- MERRA and other current reanalyses represent an advance on the previous generation (ERA-40, NR1, NR2, …)
  - Interannual tropospheric variability is now almost indistinguishable in directly analyzed fields and getting closer in some aspects of the divergent flow, but still problematic in moisture-related fields.
  - Issues also remain in the stratosphere in the TOVS era
- Problems lie in model biases and in the treatment of observations
  - *Attention needed on how observations are used – an area that still remains to be mined; requires international coordination and collaboration*.
- MERRA products include increments and observation diag files
  - Analysis tendency terms are useful in diagnosing issues with how observations are used and model biases
  - Gridded observation files (O-F and O-A) that are available for further diagnostics
- Phased approach to IESA is being used to identify issues that need to be addressed in a truly integrated analysis.

MERRA Acknowledgements

System Development

GMAO: Ricardo Todling, Max Suarez, Julio Bacmeister, Emily Liu, Meta Sienkiewicz

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Non GMAO: Jack Woollen, Leo Haimberger, Joanna Joiner, Pete Robertson

Input data:

NCEP, NESDIS, NCAR, NCDC, RSS (SSMI radiances and wind speed), JPL (QuikSCAT), CERSAT (ERS winds); TRMM project; GSFC SBUV team

Production and Data Serving:

Rob Lucchesi, Tommy Owens, Doug Collins, Dana Ostrenga, Jerry Potter

External Advisory Group:

Phil Arkin, Alan Betts, Robert Black, David Bromwich, John Roads, Jose Rodriguez Steven Running, Paul Stackhouse, Kevin Trenberth, Glenn White

MERRA On-line Resources

- **http://gmao.gsfc.nasa.gov/merra**
  - **MERRA Atlas http://gmao.gsfc.nasa.gov/ref/merra/atlas/**
  - **MERRA-Land** as an update to land-surface collection **http://gmao.gsfc.nasa.gov/merra/merra-land.php**
  - Extremes **http://gmao.gsfc.nasa.gov/research/subseasonal/atlas/Extremes.html**
  - MERRA is online at PCMDI's ESG for CMIP5 model evaluations
- Data Access: GES DISC **http://disc.sci.gsfc.nasa.gov/mdisc/**