A Reanalysis Synthesis of EOS Observations at Regional Scales to support the National Climate Assessment

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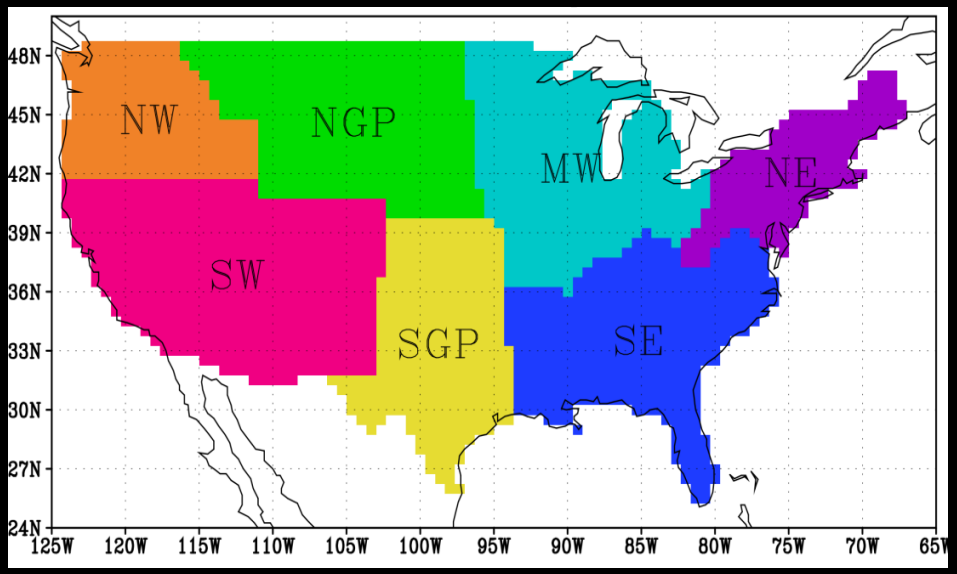
GMAO NCA Enabling Tools Project update
June 22, 2015

Overview

- Initial NCA Project
  - Proof of Concept: MERRA
  - Reanalysis Assessment
  - New Products
- Reanalyses and Climate Applications
  - Regional Climate Variability
  - Climate Monitoring
  - Extreme Events
- MERRA-2 and Beyond
  - Rationale for a sequel
  - Recent development

NCA Regions (plus AK and HI)



Project Page:
http://gmao.gsfc.nasa.gov/projects/NCA/

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, development of integrated Earth system models and analyses
  - Validation and verification references, and internal and external constraints to models

MERRA-2 Motivation and Objectives

Produce an ongoing, intermediate reanalysis for the satellite era using a recent version of GEOS-5 to

(1) address known limitations of MERRA (c. 2008), and

(2) provide a stepping stone to a *future coupled Earth system reanalysis.*

Specifics:

- Incorporate modern satellite observation types not available to MERRA
- Reduce spurious trends and jumps related to changes in the observing system
- Reduce biases and imbalances in the water and energy cycles
- Test coupling GOES-5 meteorology with other Earth system components

The MERRA-2 data assimilation system

GEOS-5.12.4 AGCM/GSI 3D-Var
0.5° x 0.625° x 72 hybrid-eta levels to 0.01 hPa

MERRA ⇒ MERRA-2 Evolution

- ❑ **Updat**
  - AGC
    - *Cu*
    - *Up*
    - *In*
  - GSI
    - *M*
    - *O*
    - *Up*
    - *Bias correction for aircraft temperature observations*
    - *Balance constraint for noise*
    - *TC Relocation*

blimation

IRI, Aura

MERRA-2
Processing Complete
Ready: Mid-July

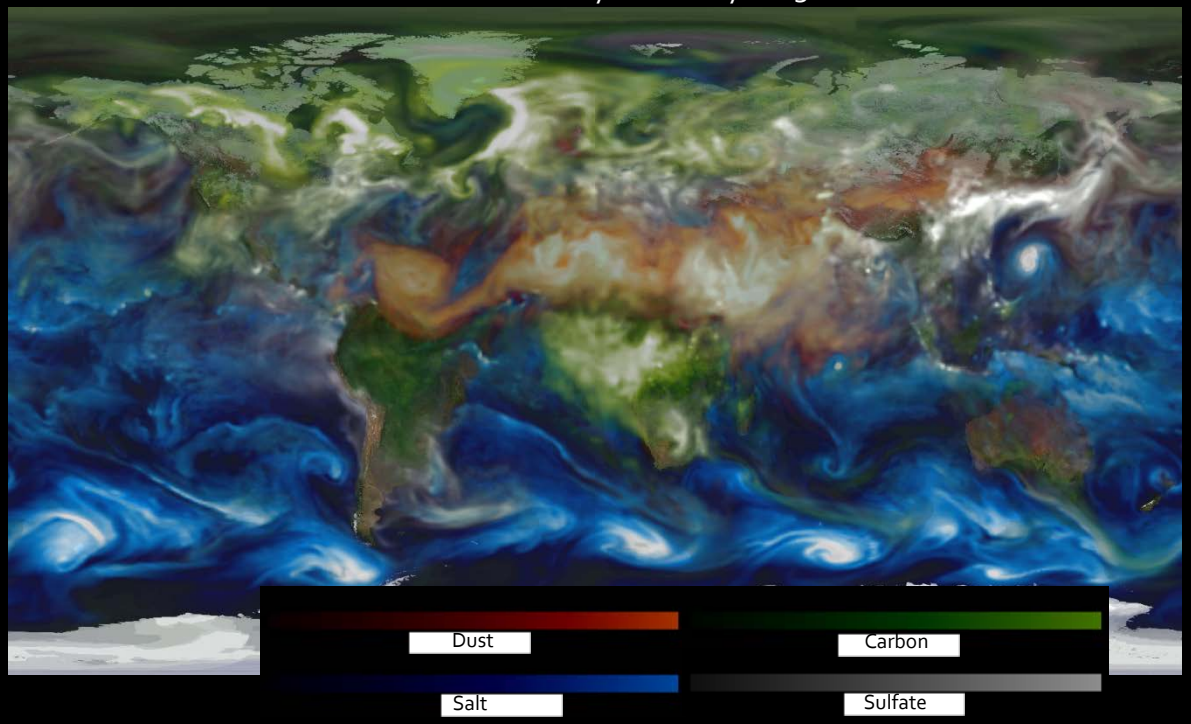
- ❑ **Aerosol assimilation with radiative coupling to AGCM (direct effects)**
- ❑ **Constraints on dry mass and globally integrated water**
- ❑ **Corrected precipitation for land surface forcing and aerosol deposition**

Reanalysis-based NCA Enabling Tool

- Advantages for MERRA-2 data in the National Climate Assessment
  - Observation-based precipitation for continental hydrology applications and diagnostics
  - Aerosol assimilation for dust and pollution connections with weather and extremes
  - 1 hourly diagnostics consistent across the globe to link local extreme events to large-scale weather
  - Will assimilate more than 62 Billion observations, mainly from satellite, over 35 years (1980-present)
- Main Goal: Connect the analyzed large-scale weather associated with historical extreme events to better forecast and prepare for future extremes
- Previous examples based on MERRA proof-of-concept

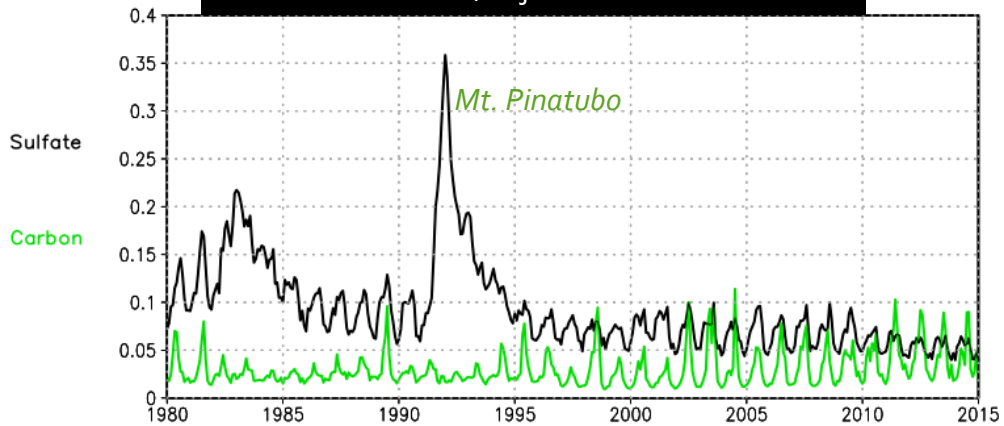
Aerosols and Trace Gases in MERRA-2

MERRA-2 Aerosol Analysis 10 July 2013 1200UTC

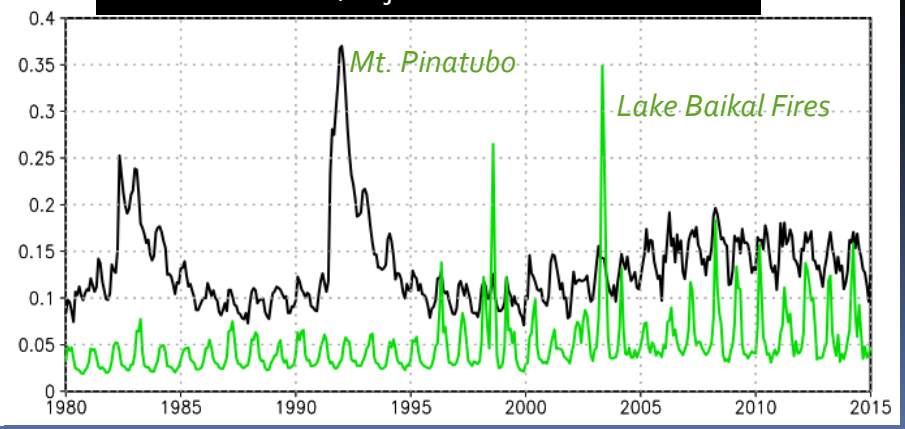


- **Black and organic carbon, dust, sea salt, sulfates**
- GOCART – mixing, chemistry and deposition
- Radiatively coupled with the dynamics
- Global 2-D AOD analysis with 3-D increments via local displacement ensembles
- Data: AVHRR 1979–2002; MODIS 2000–present; MISR; AERONET

North America/Adjacent Atlantic AOD

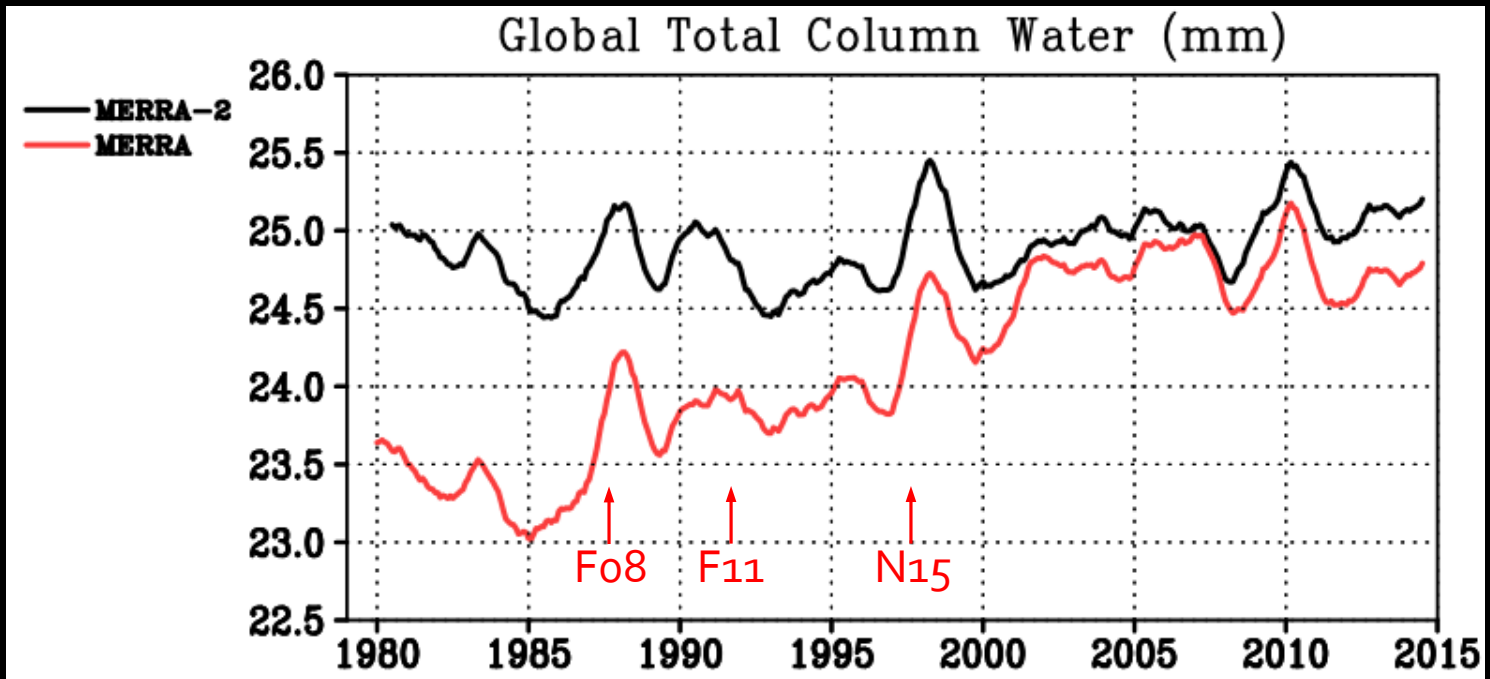


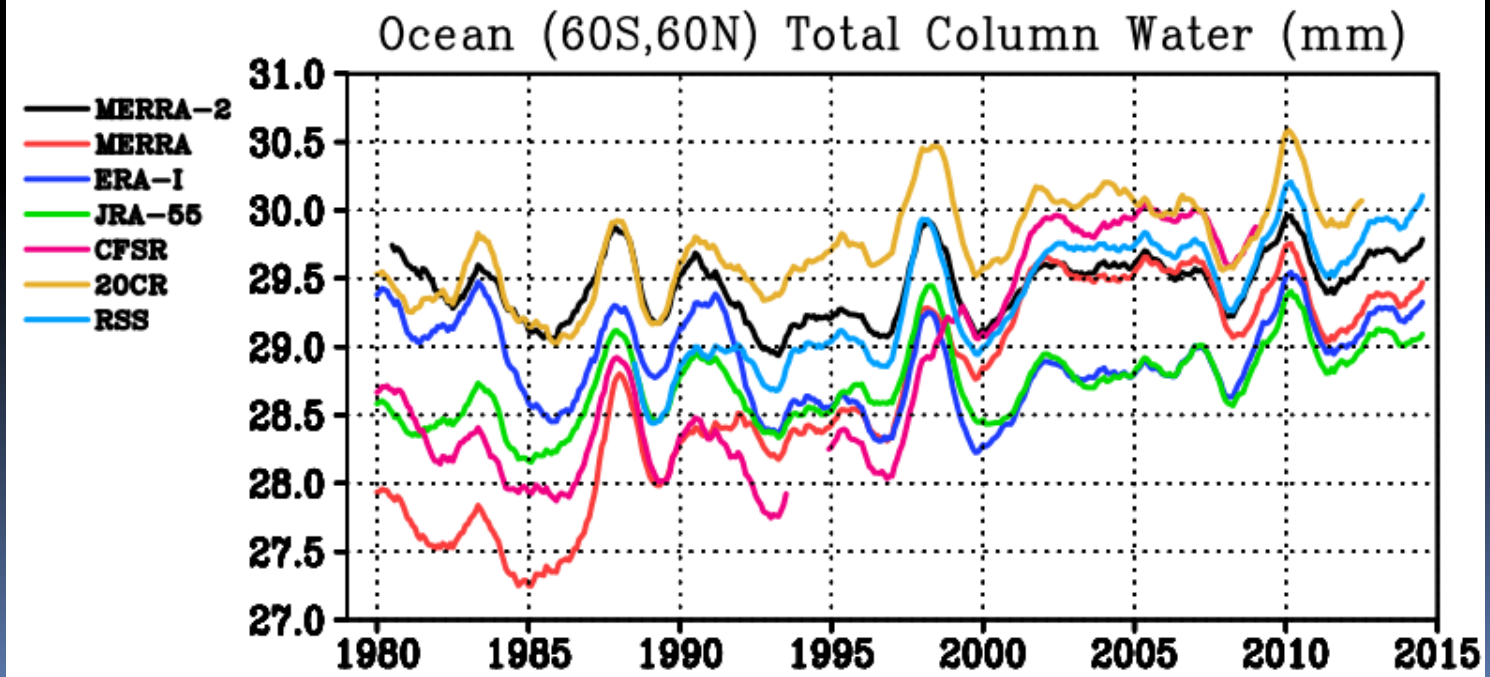
East Asia/Adjacent Pacific AOD



Time Series of Total Precipitable Water

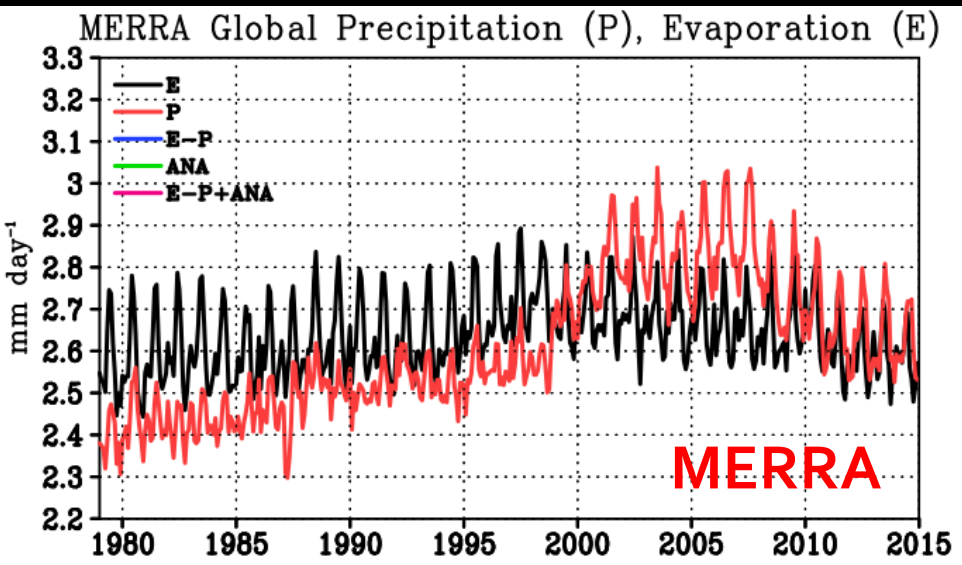
MW data sources with large impact on MERRA have much less impact on MERRA-2 Global TPW

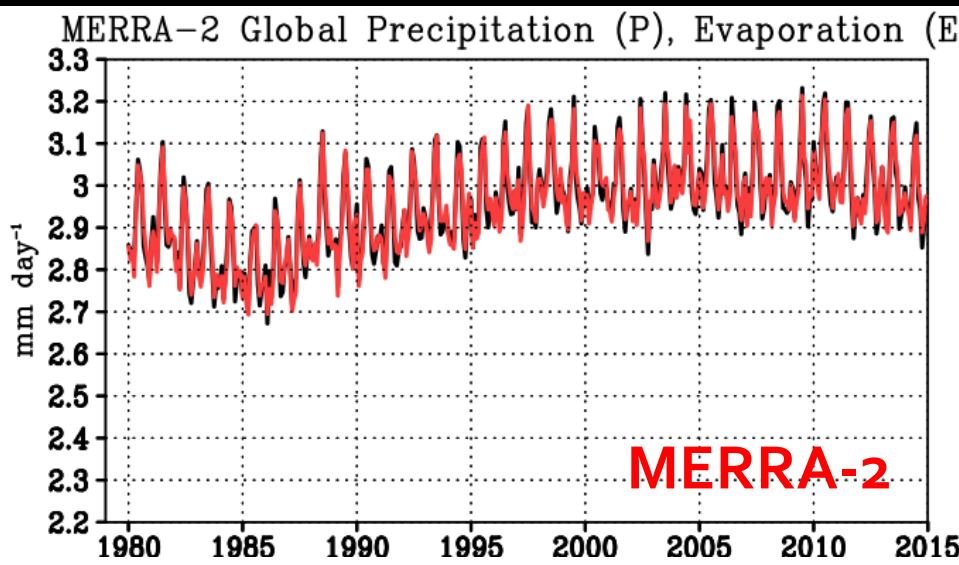


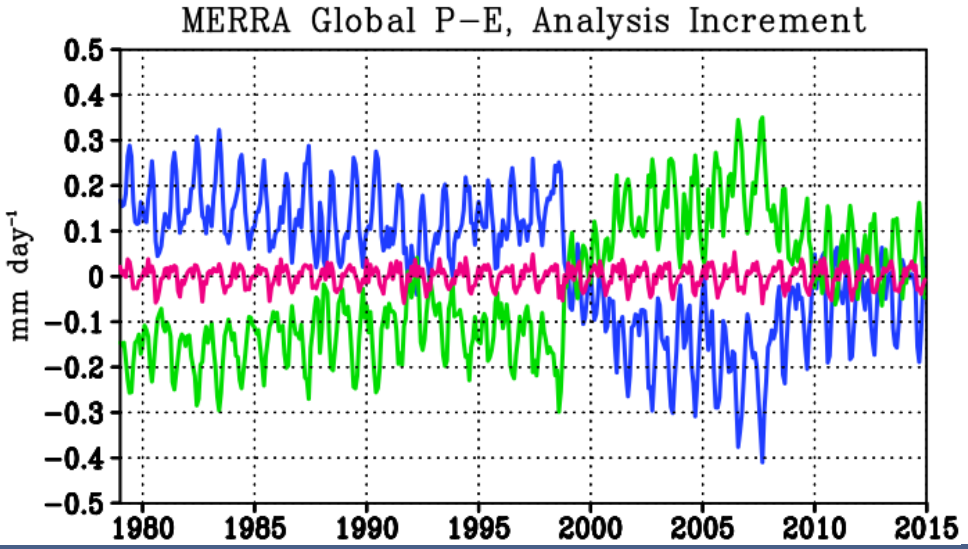


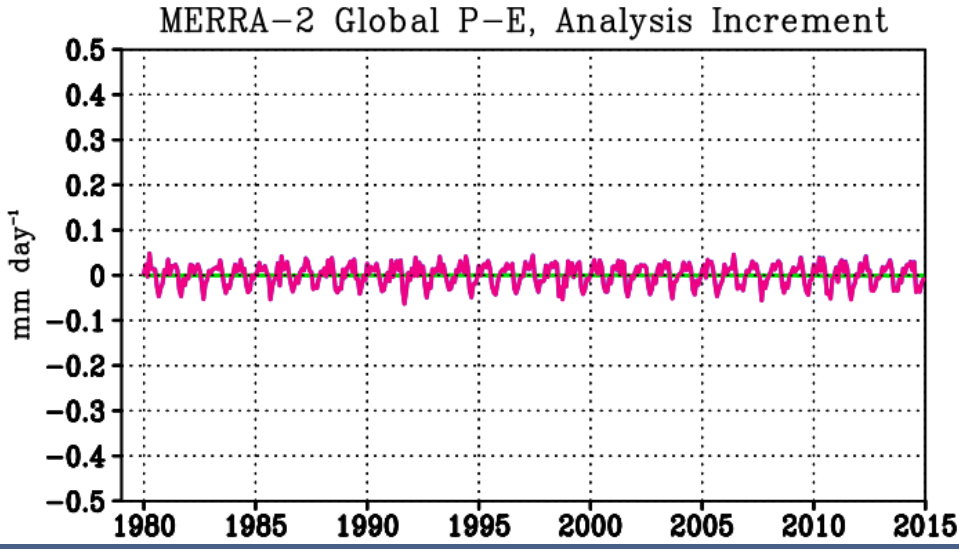
Globally precipitation, evaporation and analysis forcing

Surface pressure and water vapor analyses are penalized for global imbalances (Takacs et al., *NASA GMAO Tech Memo, 2015)*





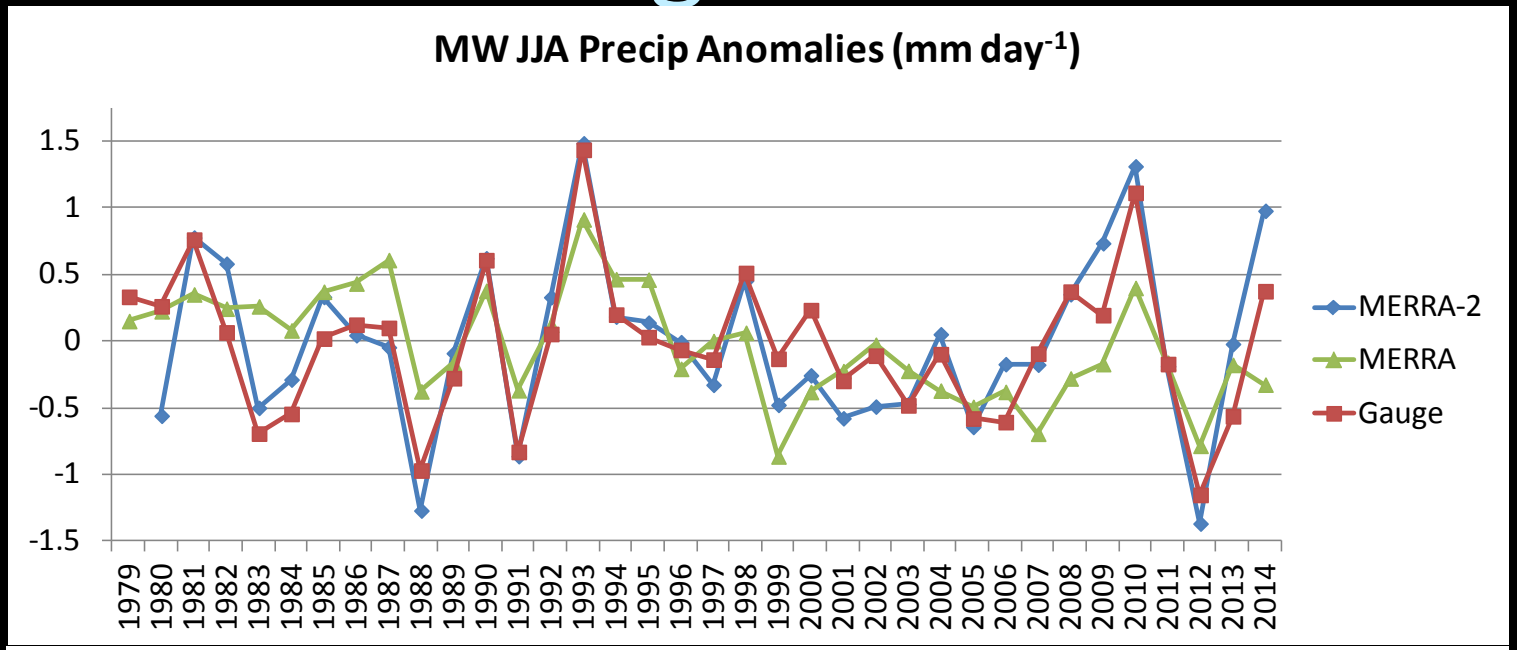


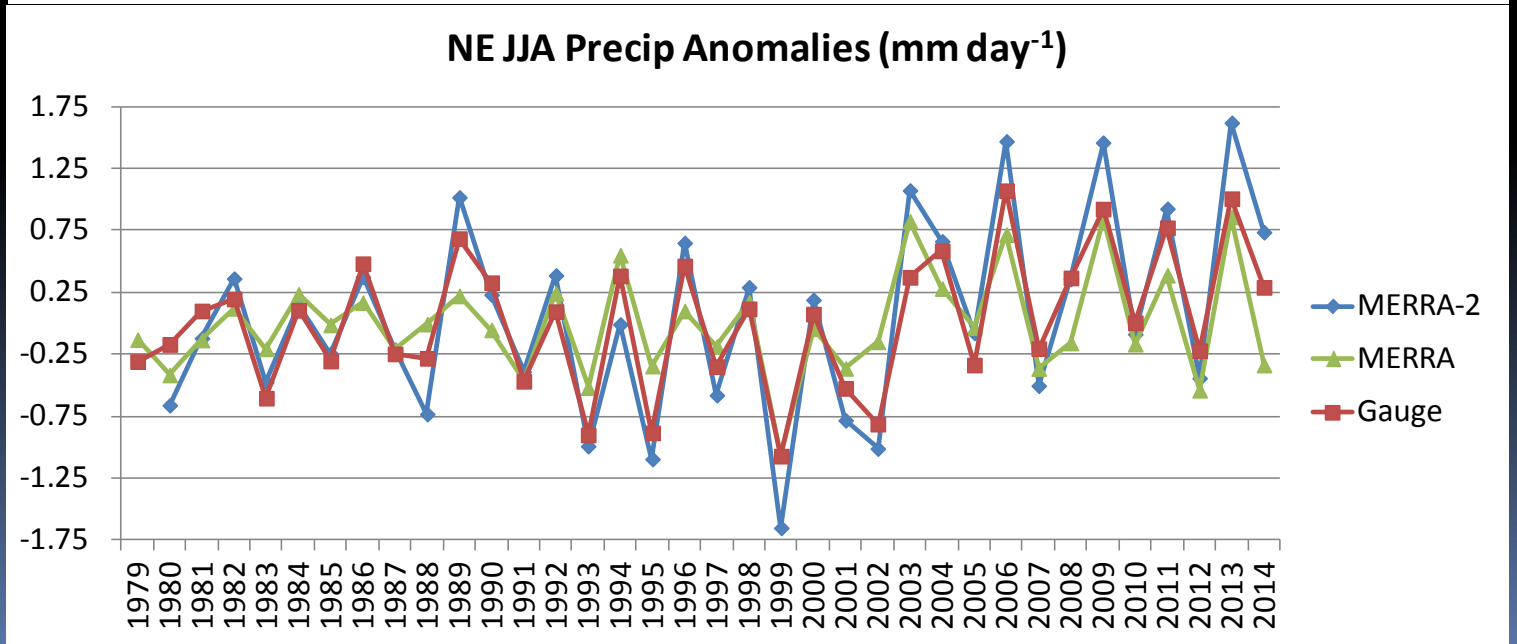


In MERRA, imbalances of P and E result from analysis adjustments, sensitive to changes in the observing system.

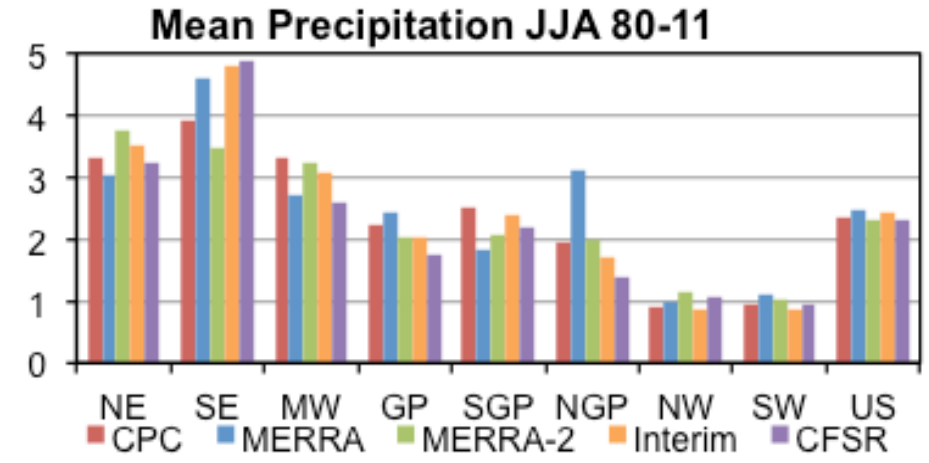
In MERRA-2, unphysical changes in total mass are ameliorated and global balance between P, E is maintained

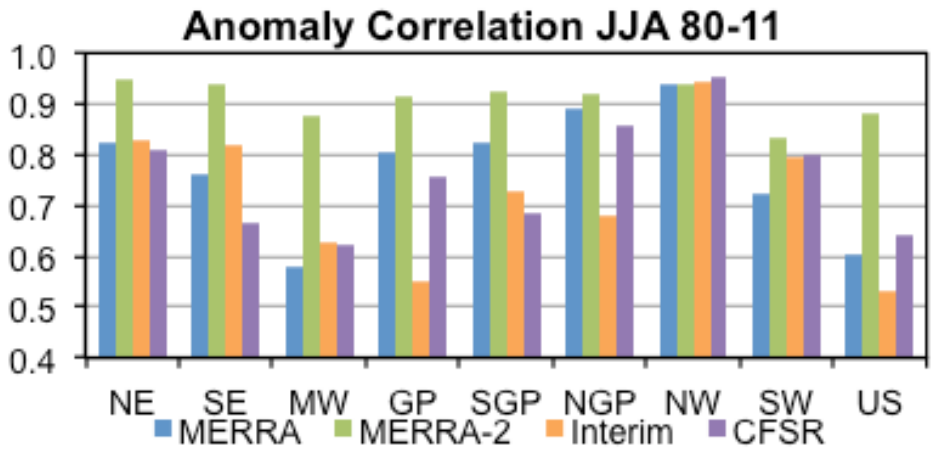
MERRA-2 JJA Regional Time Series

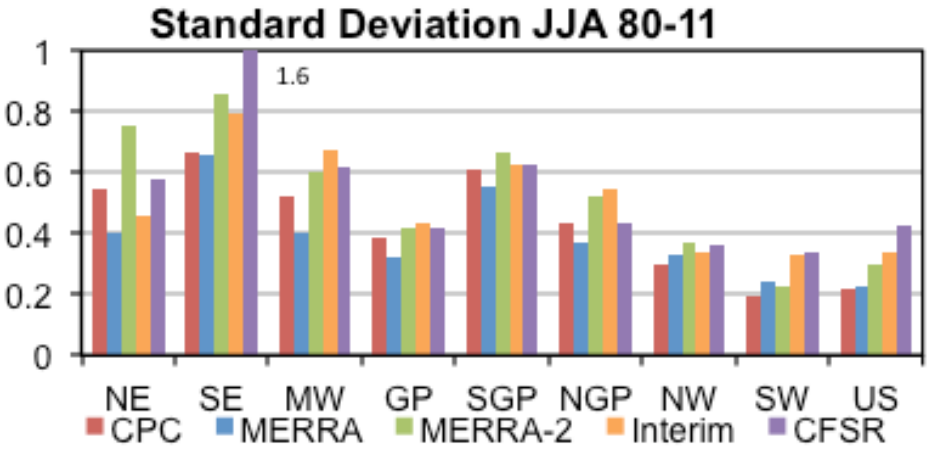


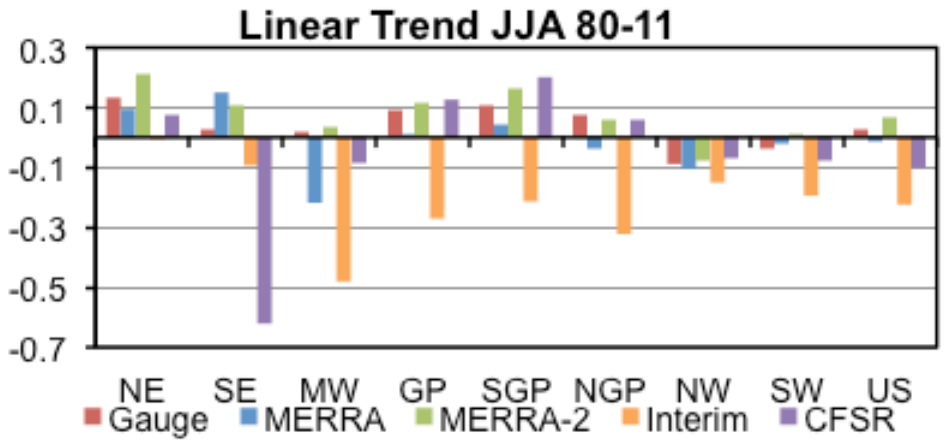


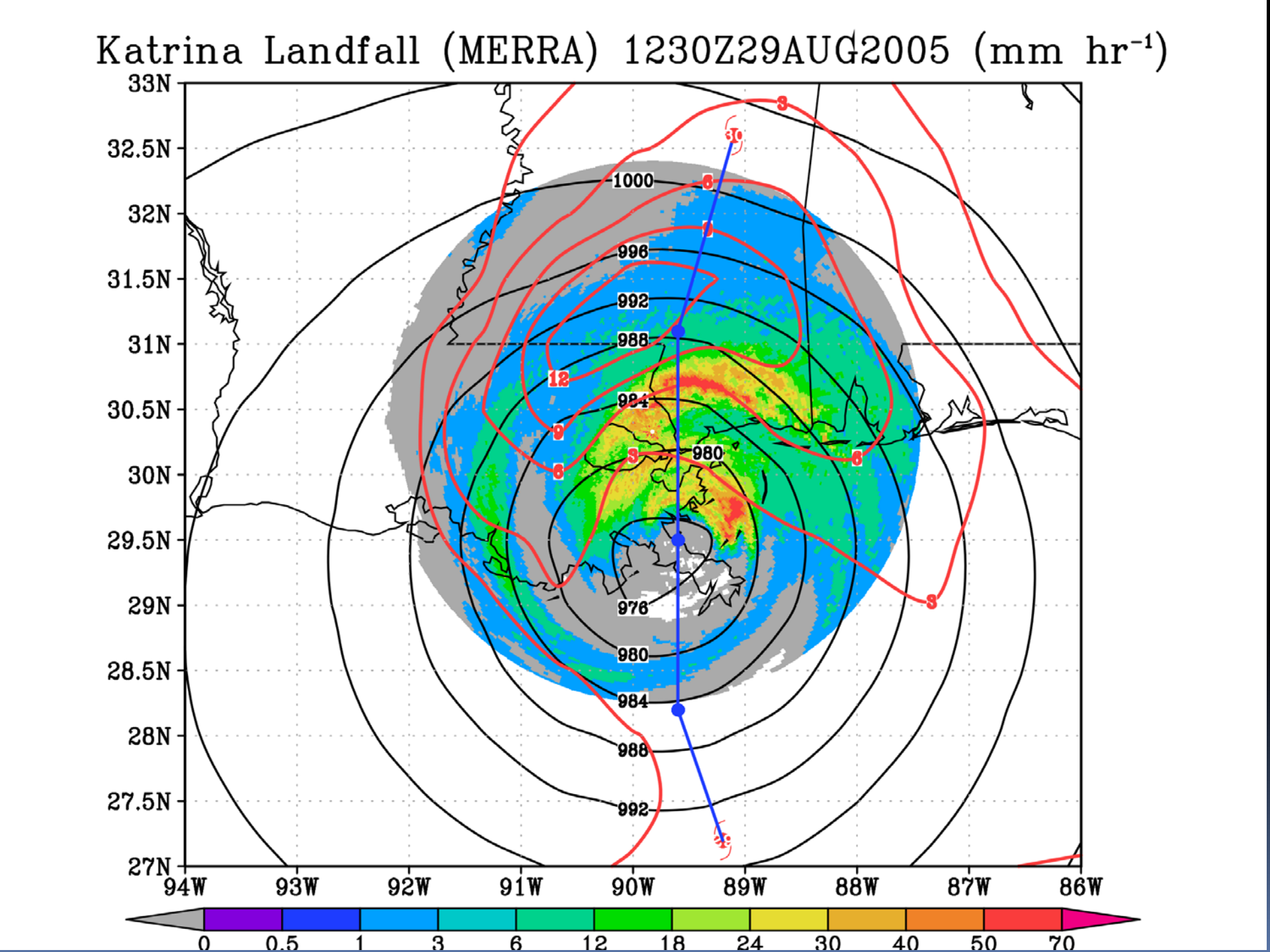
NCA Regional Time Series Stats










Katrina Landfall (MERRA) 1230Z29AUG2005 (mm hr⁻¹)
33N
32.5N
32N
31.5N
31N
30.5N
30N
29.5N
29N
28.5N
28N
27.5N
27N
94W
93W
92W
91W
90W
89W
88W
87W
86W
1000
996
992
988
984
980
976
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12
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1
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18
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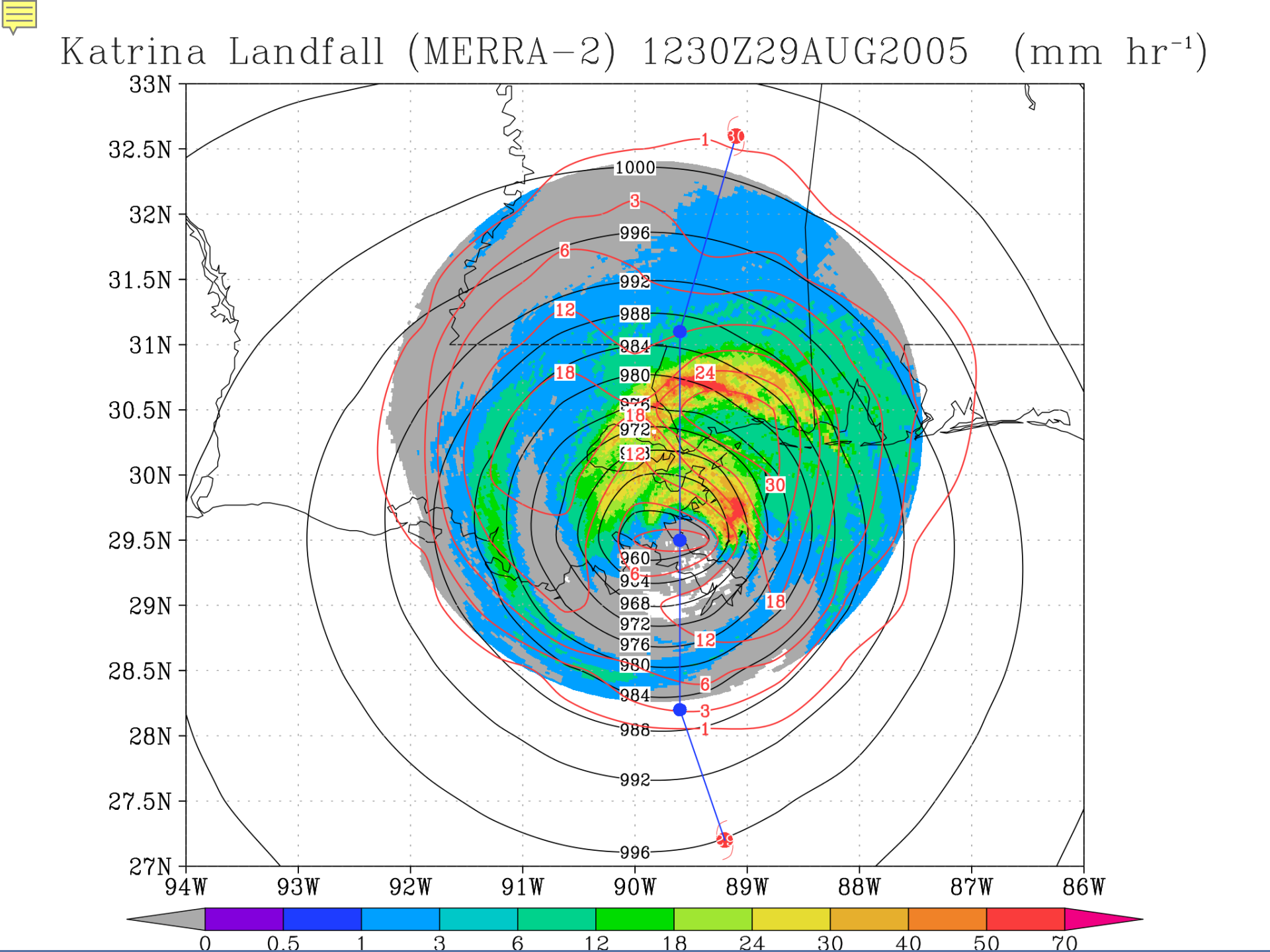
30
40
50
70


Katrina Landfall (MERRA-2) 1230Z29AUG2005 (mm hr-1)
33N
32.5N
32N
31.5N
31N
30.5N
30N
29.5N
29N
28.5N
28N
27.5N
27N
94W
93W
92W
91W
90W
89W
88W
87W
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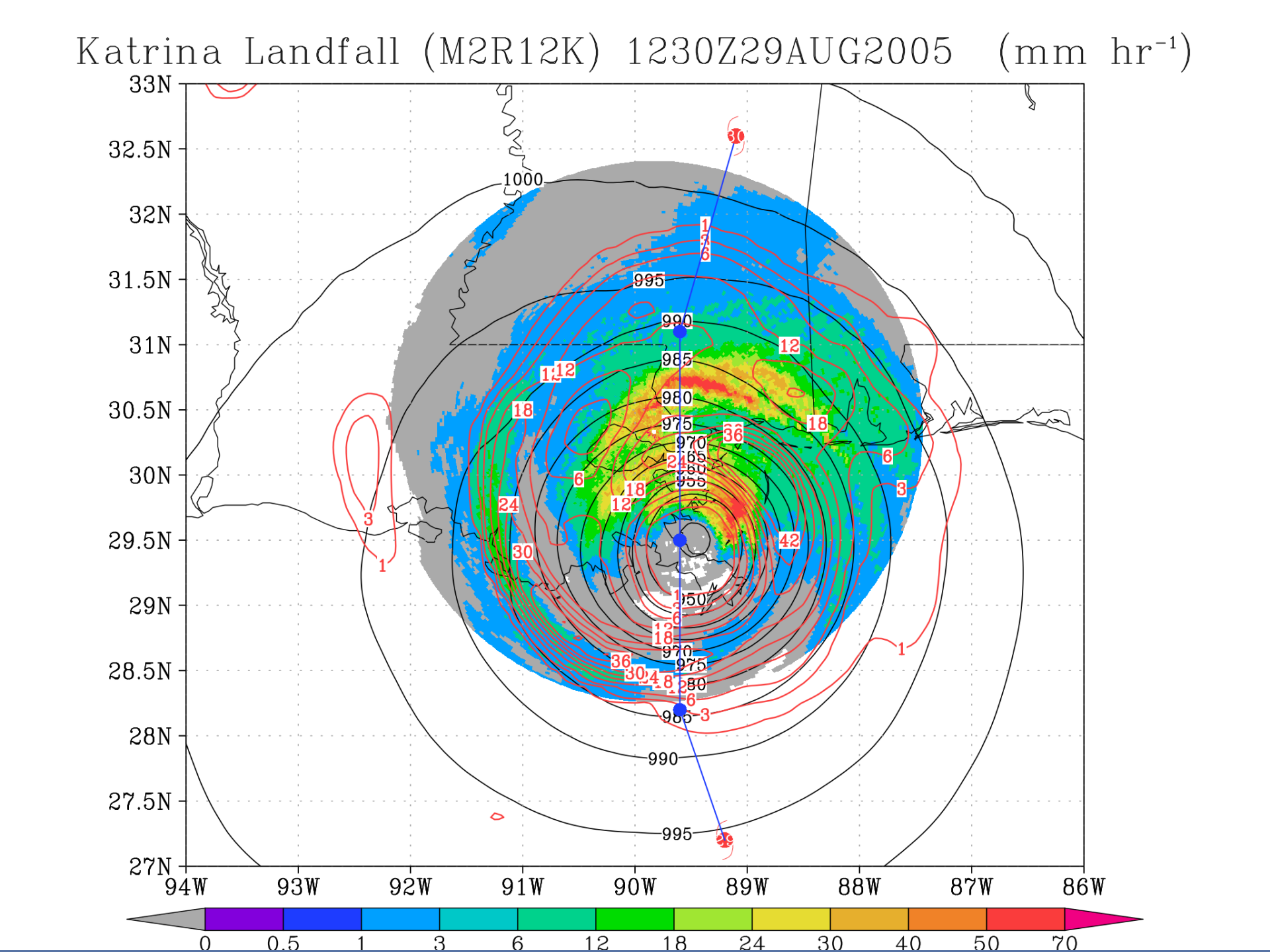
Katrina Landfall (M2R12K) 1230Z29AUG2005 (mm hr⁻¹)
33N
32.5N
32
31.5N
31N
30.5N
30N
29.5N
29N
28.5N
28N
27.5N
27N
94W
93W
92W
91W
90W
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88W
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86W
1000
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955
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Recent Major Activities

- Large-scale Processes and Extremes
- The primary consideration of reanalyses in extremes is to characterize the large-scale circulation and climate dynamics associated with extreme events
- US CLIVAR Working Group on Extremes
  - Grotjahn et al. North American extreme temperature events and related large scale meteorological patterns: a review of statistical methods, dynamics, modeling, and trends, Climate Dynamics, DOI: 10.1007/s00382-015-2638-6
  - http://www.usclivar.org/working-groups/extremes

Recent Major Activities

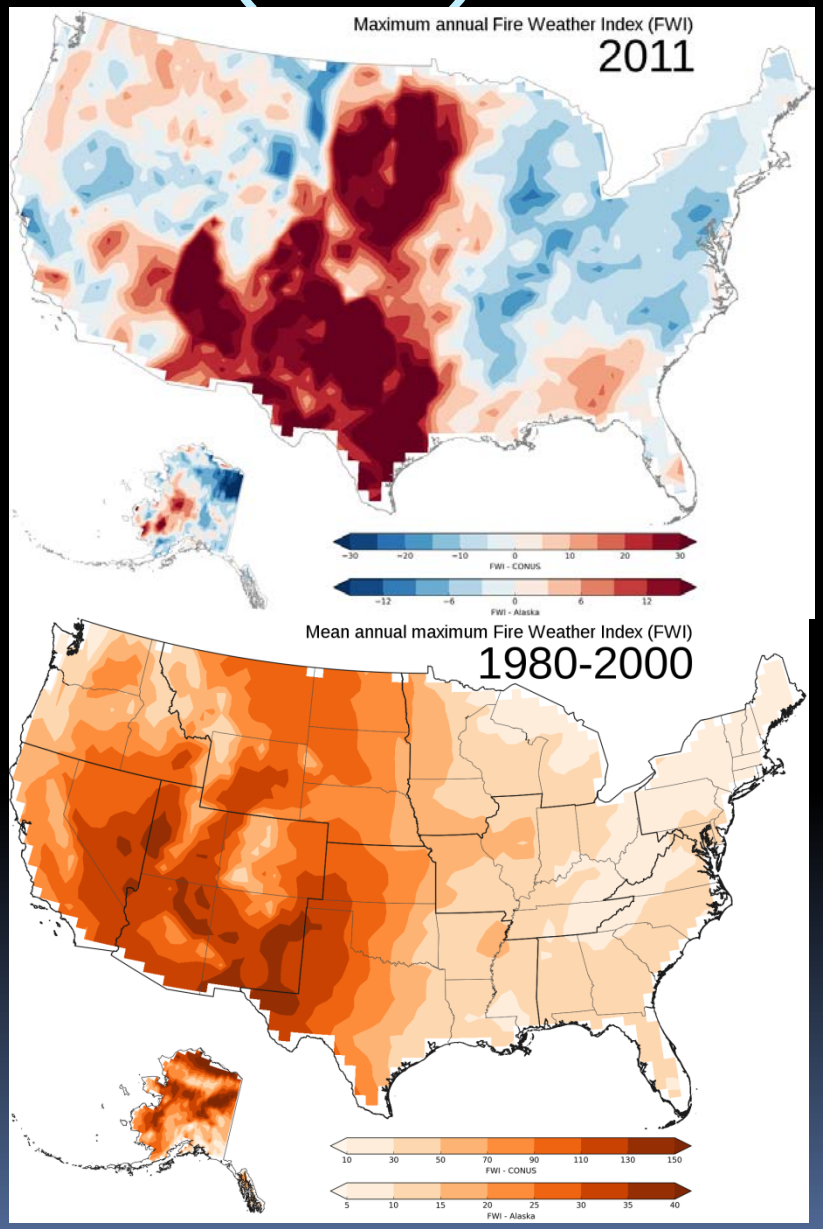
- Moved indices code to look at MERRA-2
  - E.g. Max Daily Rainfall, warm/cold spell indices
- Evaluating unique MERRA-2 features in NCA usefulness (Just Starting)
  - Observation-based precipitation forcing for land
  - Daily surface air temperature Min/Max/Mean from instantaneous data
- Evaluation of Arctic Amplification in MERRA-2
  - Reanalysis intercomparison/Uncertainty
  - Links to extremes through the indices

Indices Computed

- Current MERRA-2 Based Indices
  - Processed using Climate Data Operators (CDO)
  - RX5day – Max 5 day precipitation in a month or season
  - 95^{th}, 90^{th} and 75^{th} Percentile Precipitation
  - Heat (Cold) Wave Duration Index
  - Warm (Cold) Spell Duration Index
  - Consecutive Dry Days (CDD)
  - Growing Season Length
  - Fire Weather Index (Co-I Darmenov)
  - Some assorted data processed for input

Fire Weather Index (FWI)

- Basic Meteorology joint input: T, RH, 24hr Precip and wind
- Intended to be more of a predictive/warning tool
  - In low population areas, starter is limited to passing storms
- Investigating the relationships to the biomass burning (AOD and radiative effect)

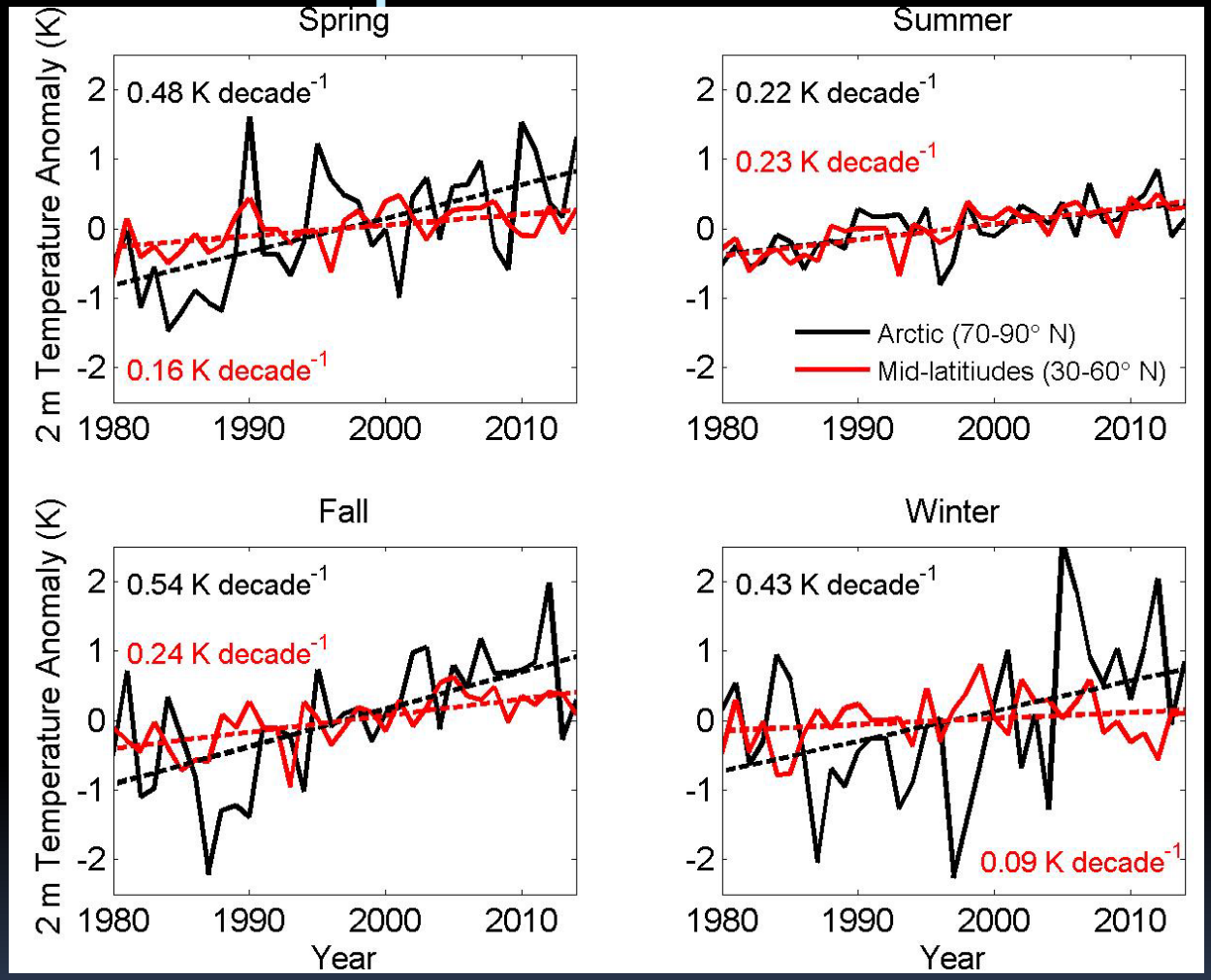


Arctic Amplification

- Francis and Vavrus (2015) argue AA reduces propagation speed of baroclinic systems and propose the Meridional Circulation Index (MCI) as a metric of the seasonal circulation that shows the intensity of stable waves (weaker zonal jets)
- Persistent stationary waves, such as blocking high pressure should be reflected as large MCI

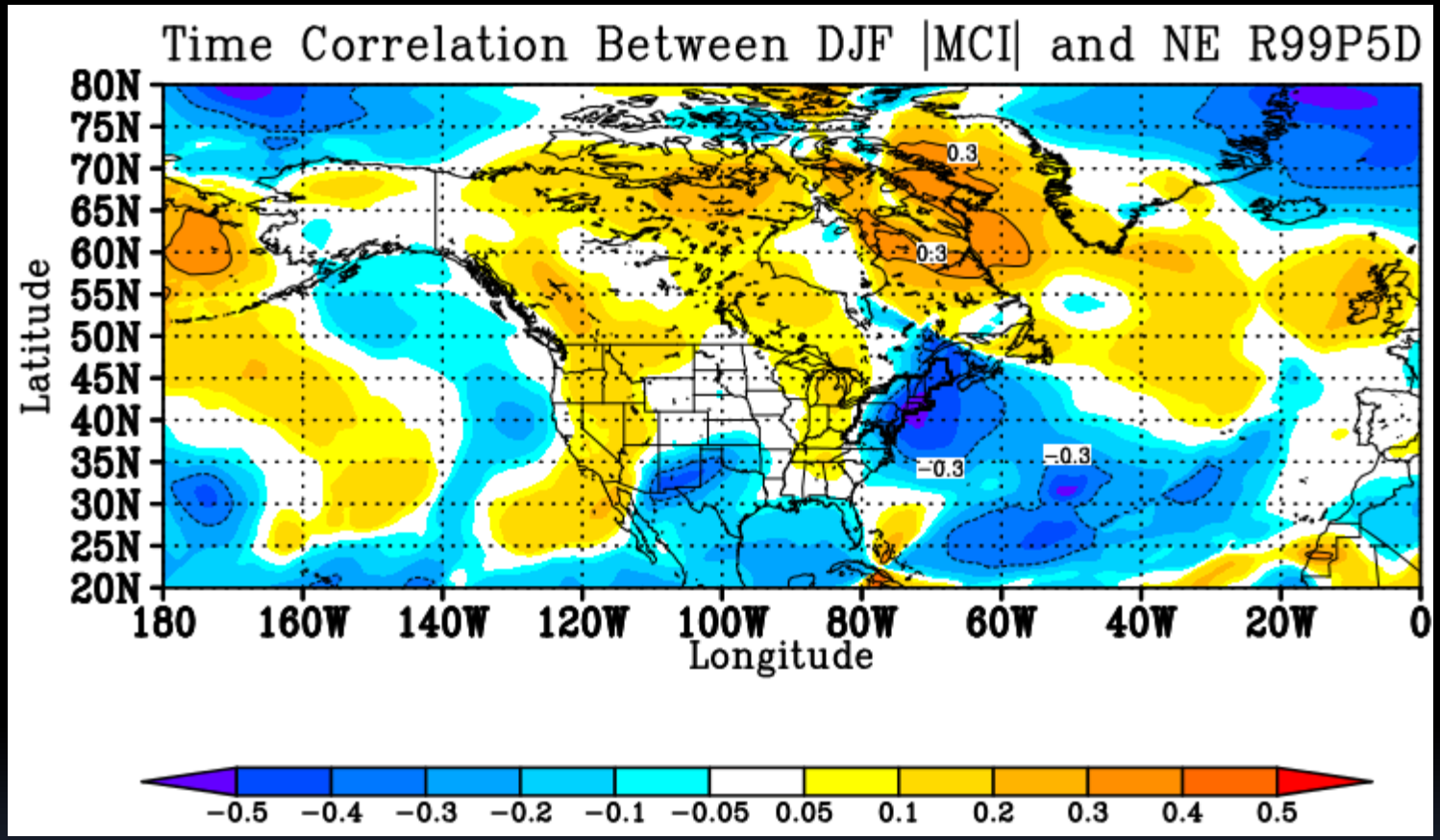
$$MCI = \frac{v \times |v|}{u^2 + v^2}$$

Arctic Amplification



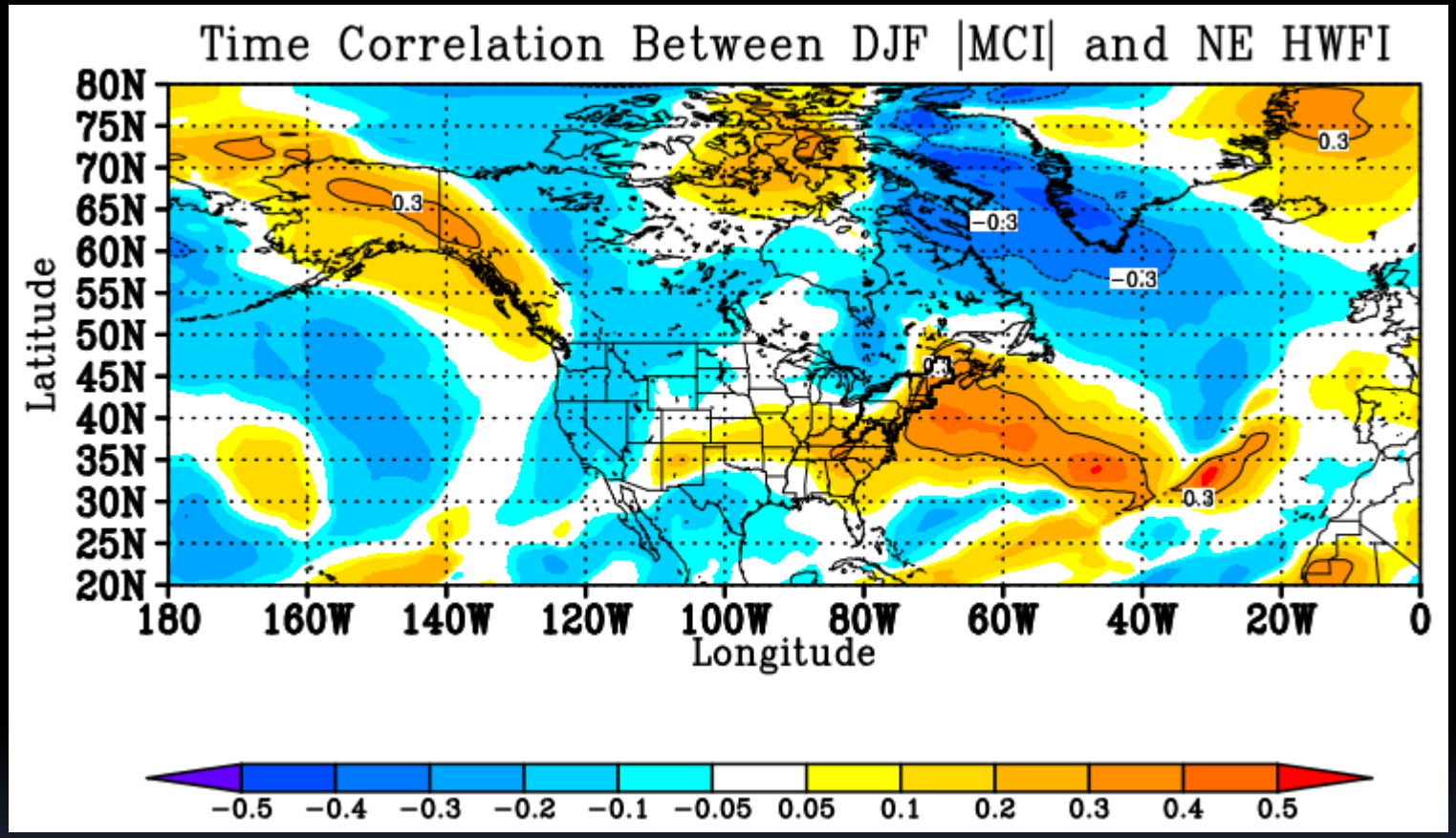
- MERRA-2 shows AA in Fall and Winter, some in Spring and none in summer.

MCI Compared to R99P



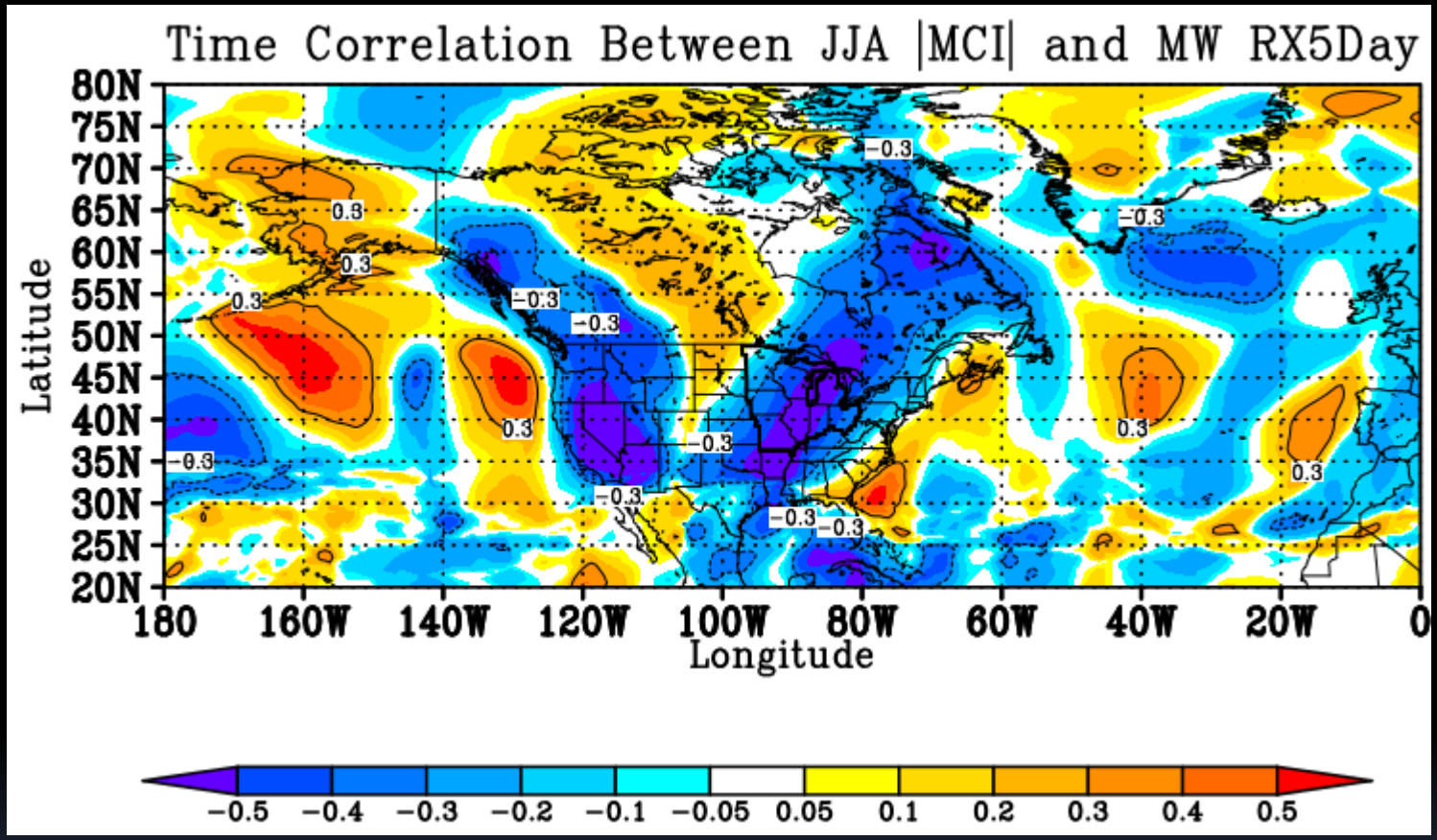
- East coast 99th pctl precip occurs with low local MCI
- Extreme precip more a local/synoptic effect than large scale influenced by Arctic amplification

MCI Compared to Warm Spell(HWFI)



- Little local effect, but reduction of MCI at higher latitudes may indicate a northward shift of the storm track

MCI compared to RX5DAY



- In MW heaviest precip occurs with low local MCI
- 1993 small values, while 1998 (drought) has high MCI

Future plans

- Investigate MERRA-2 US hydrology, considering the bias corrected precip forcing
- Characterizing the relationship between US extremes and large scale meteorology
  - What, if any, connection to the Arctic changes are apparent?
  - In this context, how much uncertainty exists in reanalyses?
- M2AMIP experiments underway, does the model include similar extreme/large scale connections?

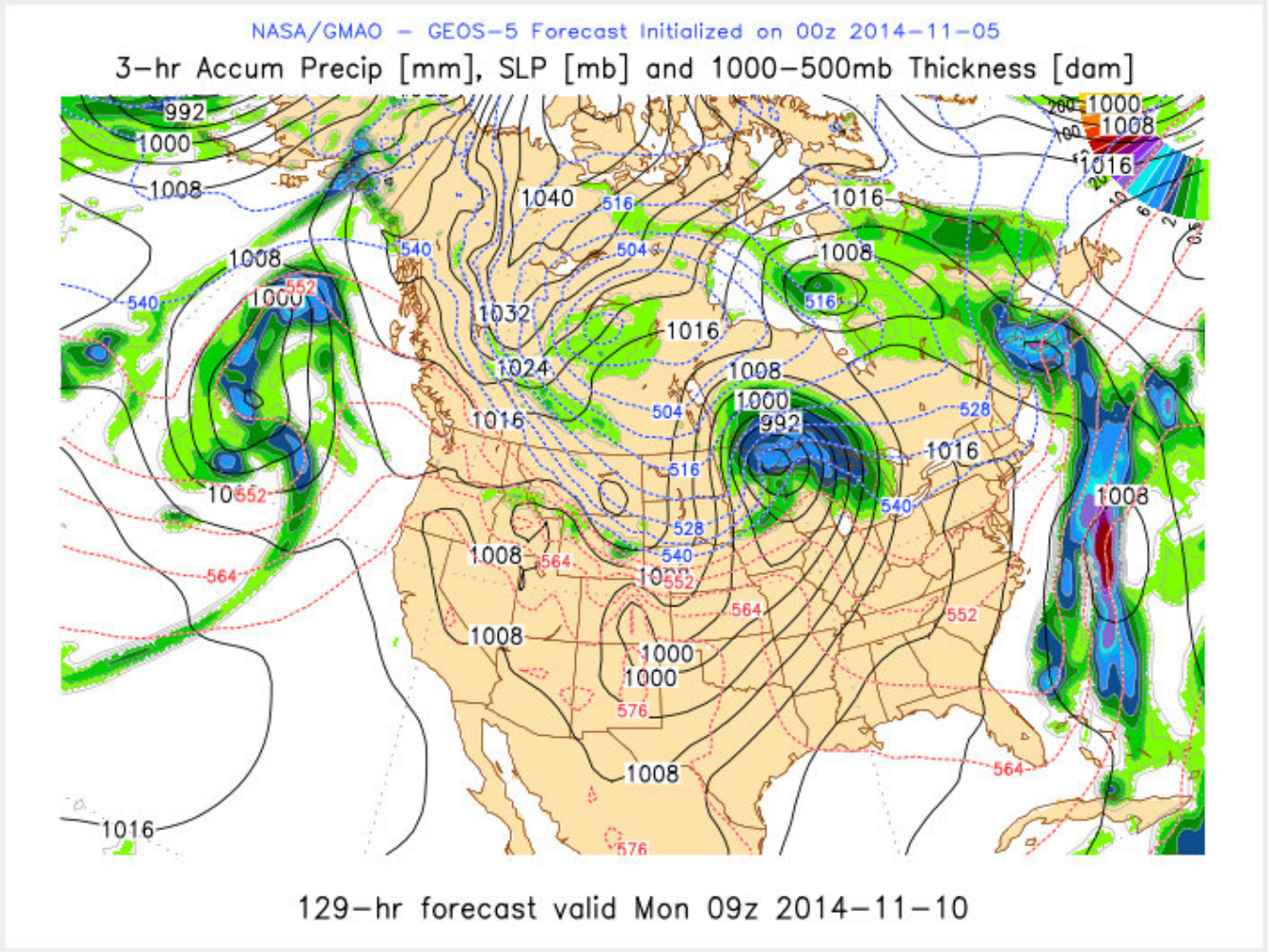
Thanks !

- Some additional or back up slides follow

Reanalysis-based NCA Enabling Tool

- Main Goal: Connect the analyzed large-scale weather associated with historical extreme events to better forecast and prepare for future extremes
- Considering ways to use river routing and aerosols in the climate assessment
- Interact with NCA – not the typical user of reanalysis data
- MERRA-2 based "Historical Weather Maps" leveraging the weather map plotting for the forecasts

Develop a Historical Wx Map Room based on MERRA-2



GMAO WxMaps

Forecast Initial Time

2014-Nov-05 00z

Forecast Lead Hour

000

Models	Levels	Variables
GEOS-5	200	Vorticity
GFS	300	Temperature
	500	Vert Velocity
	700	Humidity
	850	Wind Speed

Precip & SLP

Animate

Background

- Most figures below are MERRA based developed in the last year preparing for MERRA-2 production
  - MERRA-2 expected to be released in Spring 2015
  - Enabling tool will be based off MERRA-2 data
- MERRA basic information included below if needed
- Main Goal: Connect the analyzed large-scale weather associated with historical extreme events to better forecast and prepare for future extremes
- We are looking to have a web based visualization of extremes, and may be able to leverage some new cloud capability
- We also want to provide “use scenarios” to help explain the data to those working more closely wit resource management and decision making

Reanalysis Data

- In the era of satellite Earth observation, observing systems are diverse and many
  - Radiosonde, Ship, Buoy, Aircraft, LIDAR, Retrievals
  - Infrared, Microwave, Hyperspectral Radiances
  - Accounting for all in climate or climate variability studies would be formidable if not impossible
- Reanalyses use Models and a process called Data Assimilation to analyze these many observations into a single consistent global realization of the weather and climate
- The resulting data are easy to use, yet incorporate a vast array of Earth Observations (not without uncertainties, of course)

Motivation for the Follow-on using MERRA-2

- New data available for Reanalysis (MLS, OMI, GPSRO, IASI to name a few)
- Aerosol data assimilation incorporated
- 2013 NCA Report includes substantial discussions on extreme events and uncertainties
- Can reanalysis play a more significant role in regional climate assessment?
- Collaboration with the NASA Indicators team for advanced metrics in reanalysis evaluation