Diagnosing the Climatology and Interannual Variability of North American Summer Climate with the Regional Atmospheric Modeling System (RAMS)

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Why is a Regional Climate Model Appropriate to Investigate North American Summer Climate?

1. Adds value to a GCM or reanalysis

General circulation models and atmospheric reanalyses have long records (on the order of 50 years) and contain large scale climate variability. But because of their coarse resolution they poorly represent key details of summer climate such as the diurnal cycle of convection, low-level jets, and the seasonal maximum in precipitation associated with the North American monsoon.

2. Establish physical linkages

Statistically based approaches can be used to determine spatial and temporal trends in fine-scale surface data, like precipitation or temperature. But atmospheric data at a scale of 10s of km is necessary to establish physical linkages to large-scale climate variability. Focus of attention here is moisture flux and moisture flux convergence.

Questions Posed with the Regional Climate Model

1. *Does RAMS used as a regional climate model give a reasonable depiction of summer climate in North America and add value beyond that of a GCM?*

   Precipitation evolution through the summer season

   Variation of atmospheric moisture at various timescales

2. *If so, then how does it represent interannual variability associated with changes in Pacific SSTs? What implications does this have for predictability?*

   Define ENSO and PDO in terms of SST modes

   Show that these modes are associated with summer teleconnections

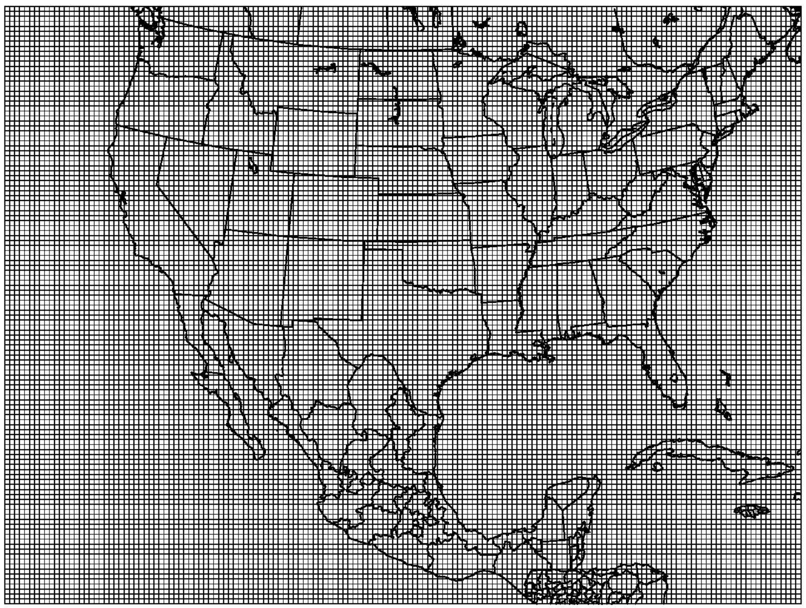
   Precipitation responses

   Atmospheric moisture response

   Long-term wet and dry cycles in the central U.S.

   Discussion of the summer of 2004

RAMS Dynamical Downscaling: Setup



Simulation length: 15 May-31 Aug

Grid spacing: 35 km

Surface boundary constraints:
- Variable soil type (FAO)
- Variable initial soil moisture according to VIC hydrologic model
- Reynolds and Smith SST

Parameterizations:
- Kain-Fritsch CPS with trigger adjustment and dumpbucket scheme for non-convective precipitation
- Standard radiation and PBL schemes for simulations of this type

RAMS Dynamical Downscaling: Ensemble Experiments

1. Observed NCEP Reanalysis

53 years (1950-2002)
Year-specific soil moisture from VIC model

Constitutes a RAMS-NAMS climatology from which to evaluate existence of interannual variability

2. NSIPP GCM data (Schubert et al. 2002)

20 years of climatological SST
40 years of EOF-forced runs (10 per sign of anomaly)
Climatological VIC soil moisture

Explicitly test hypothesis that NAMS evolution is significantly modulated by ENSO and PDO independent of local surface influences.

PART I

Climatology of Precipitation and Atmospheric Moisture

Where and when should we expect a RCM to add value to a GCM or reanalysis?

1. Later in the summer season

Rainfall has less of a dependence on large-scale synoptic weather systems. The majority of continental rainfall from diurnally forced convection or propagating mesoscale convective systems.

2. Locations in which diurnal cycle of convection is dominant

Areas of complex topography and/or land-sea contrast, such as the Rocky Mountains and the Sierra Madre Occidental. Accounts for majority of North American monsoon rainfall.

3. Areas where transport of moisture from low-level jets is important

Core NAMS region of Southwest U.S. and northwest Mexico: periodic surges of moisture from the Gulf of California often associated with passage of tropical easterly waves

Great Plains: low-level jet strongest at night (inertial oscillation)

4. Areas where land surface feedback (soil moisture, vegetation) may be important

We know, for example, many studies suggest that the central U.S. is probably quite sensitive. Recent work also suggest a strong sensitivity in the core NAMS region.

Guide for Figures

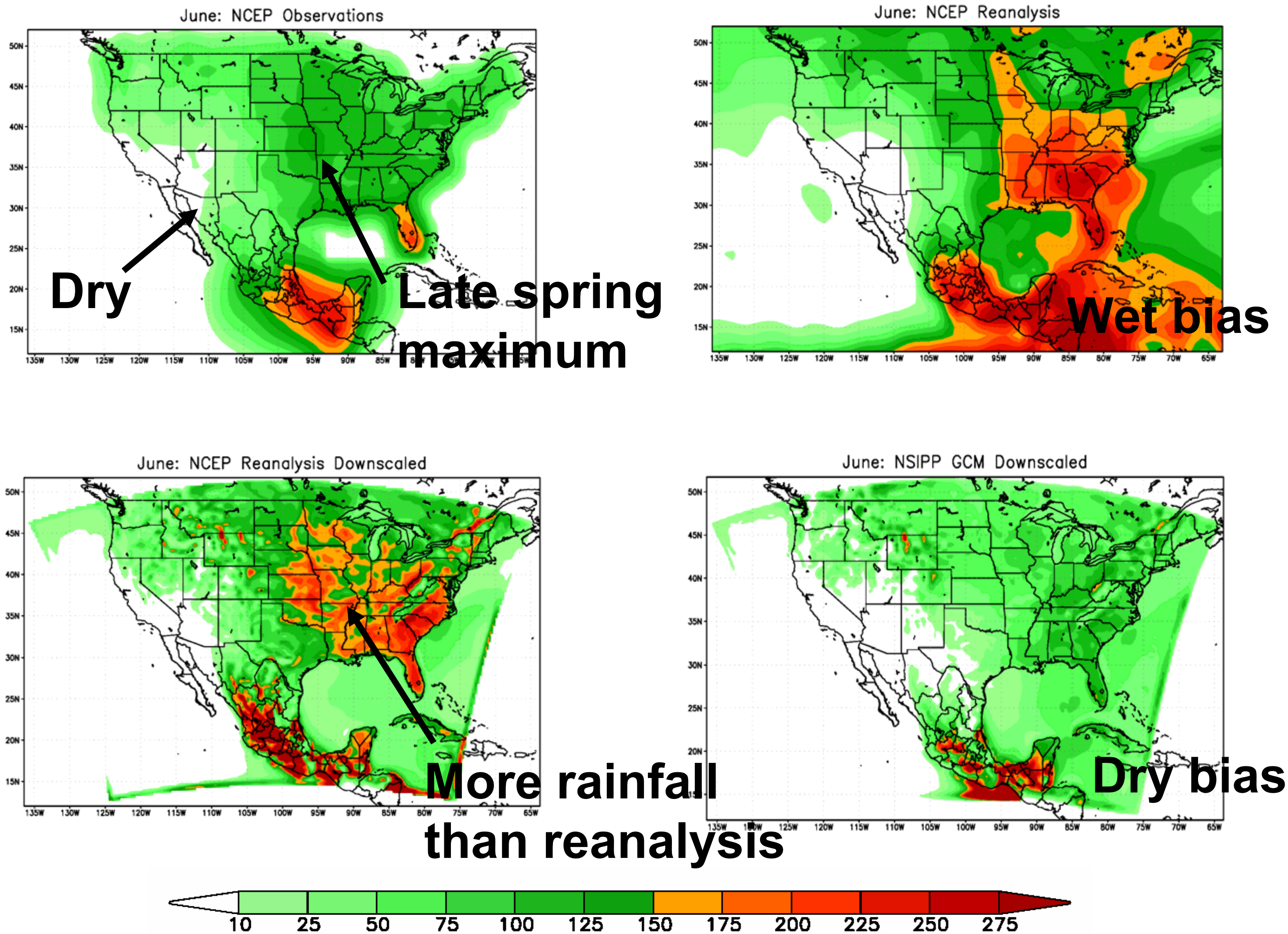
NCEP Observations: 1 x 1 degree U.S.-Mexico precipitation dataset. Obtained on-line through CPC**.**

NCEP Reanalysis: Daily reanalysis precipitation obtained through CDC**.**

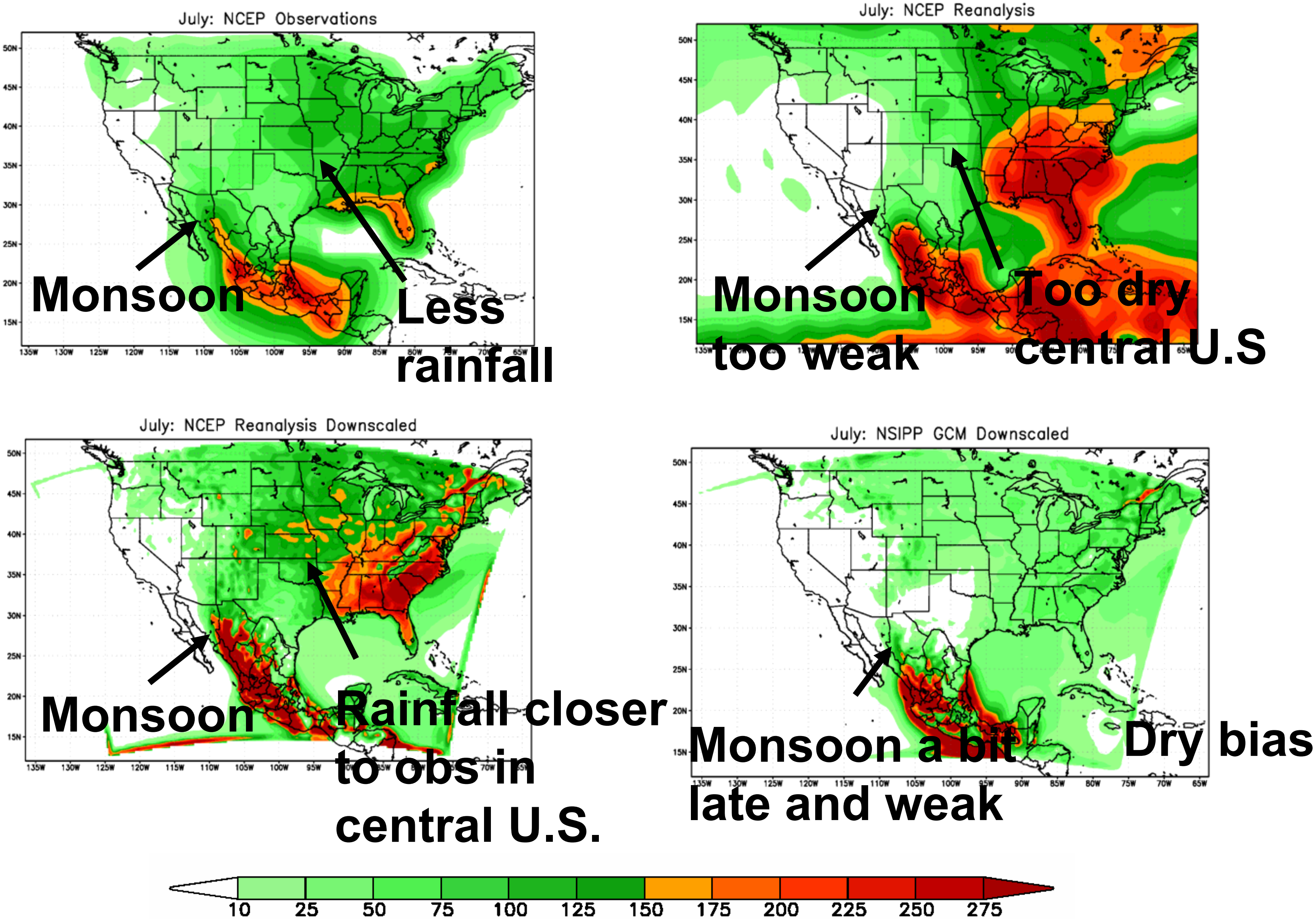
NCEP Reanalysis Downscaled: Precipitation or atmospheric fields from RAMS model using NCEP Reanalysis as lateral boundary forcing.

NSIPP GCM Downscaled: Precipitation or atmospheric fields from RAMS model using NSIPP GCM data as lateral boundary forcing.

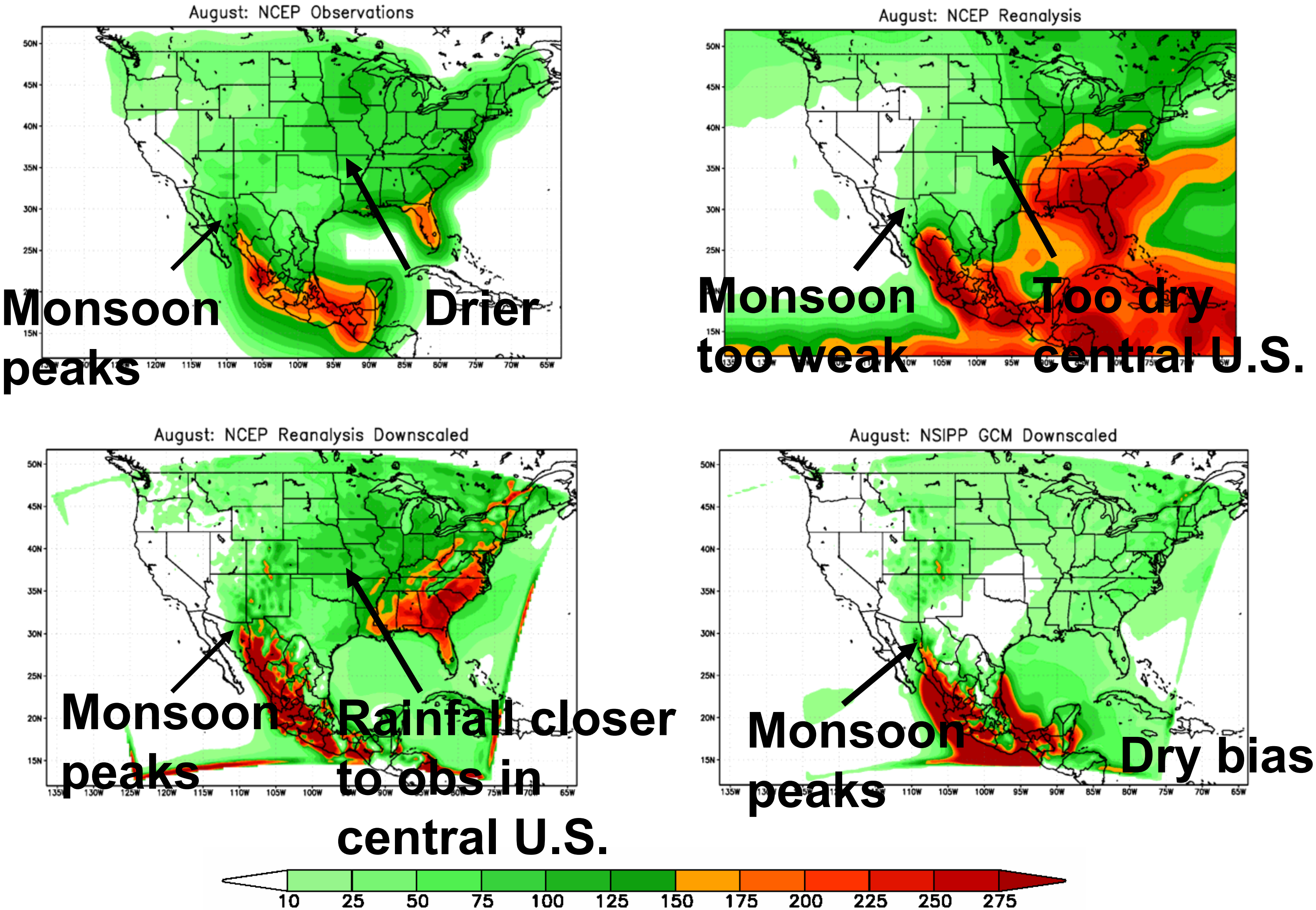
Average June Precipitation (mm)



Average July Precipitation (mm)



Average August Precipitation (mm)



RAMS Climatology of Moisture Flux and Moisture Flux Convergence

Why these variables?

Related to rainfall via the water balance equation.

Reflect features for which the RCM should add value

Analysis Methodology

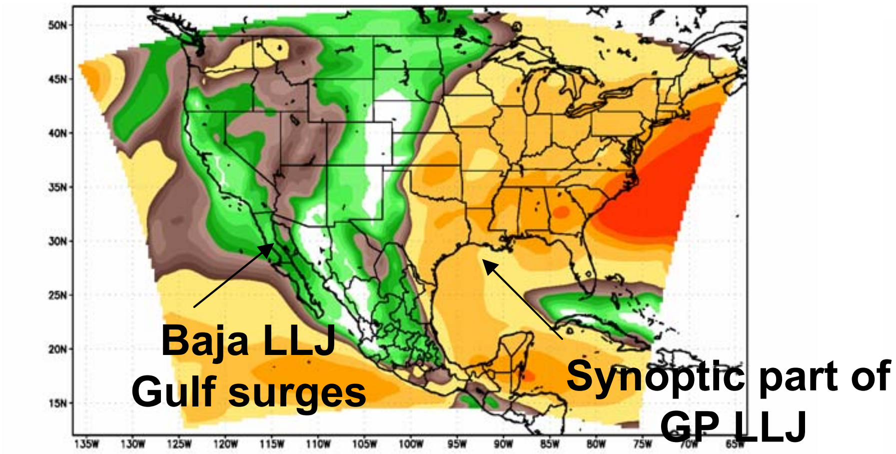
Conventional Fourier analysis techniques are used to spectrally decompose both variables for the 30-day period about the date. Spectra are then averaged for all the years in a given set of downscaling experiments.

Four distinct frequency bands were determined: a **synoptic** mode (4-10 days), a **sub-synoptic** mode (2-3 days), a **semidiurnal** mode (1.5 days) and a **diurnal** mode (1 day). The spectral power was computed as the average of the power spectrum in the given frequency band.

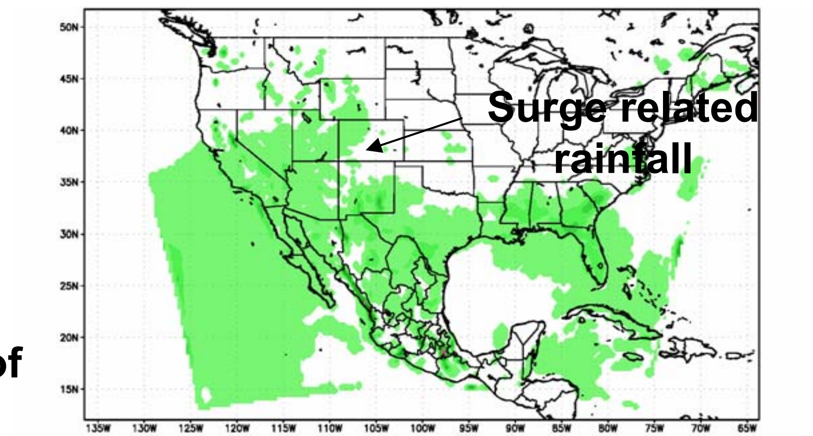
This quantity is then multiplied by the fraction of spectral power above the 95% confidence level in the band, with a value of zero meaning there is no statistically significant spectral power in the band and a value of one meaning all the spectral power in the band is significant. This weighting ensures that the most statistically significant features are emphasized.

Significant Spectral Power: July
Synoptic Mode (4 -10 days)

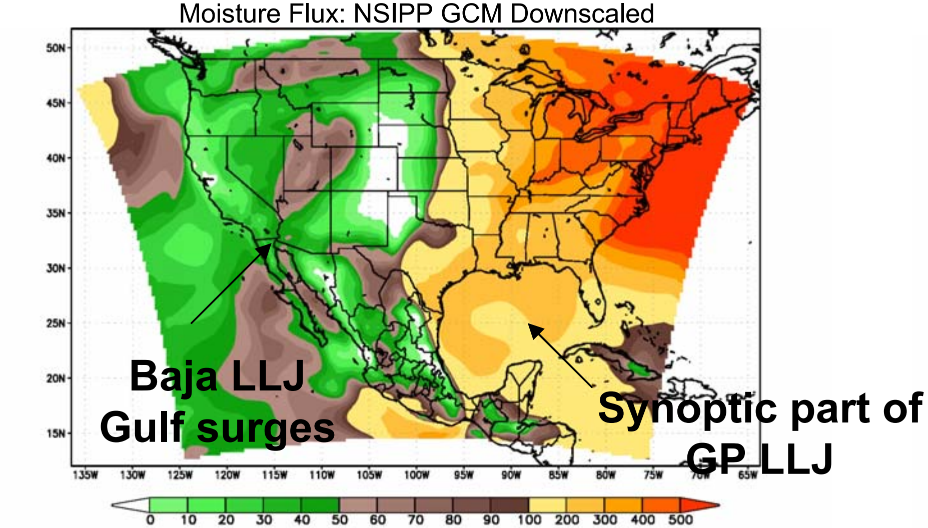
Moisture Flux: Reanalysis Downscaled



Moisture Flux Convergence: Reanalysis Downscaled

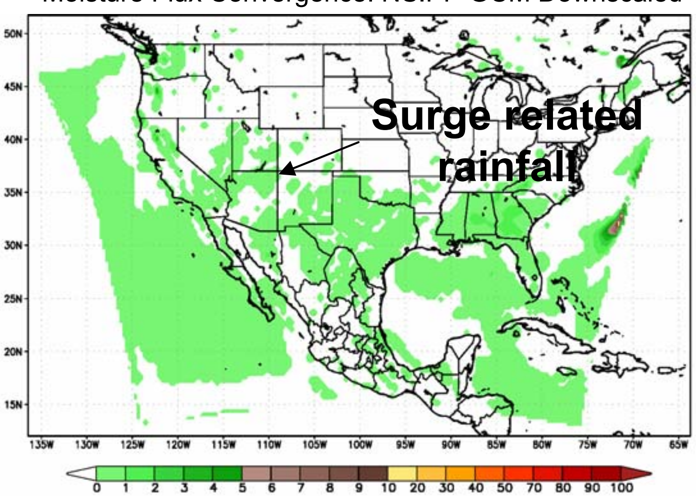


Moisture Flux: NSIPP GCM Downscaled



Units: kg^2 m^2 s^{-2}

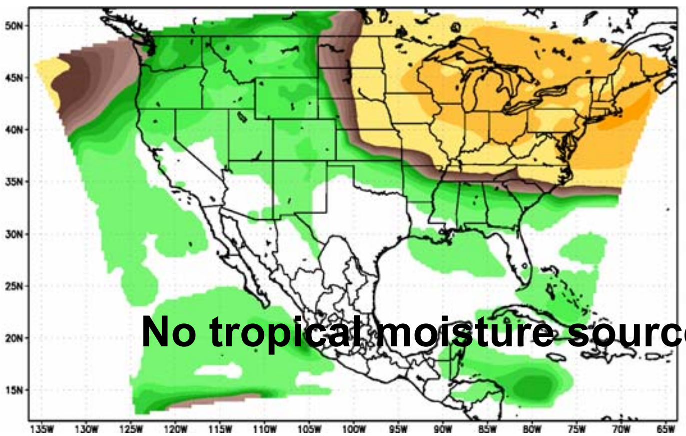
Moisture Flux Convergence: NSIPP GCM Downscaled



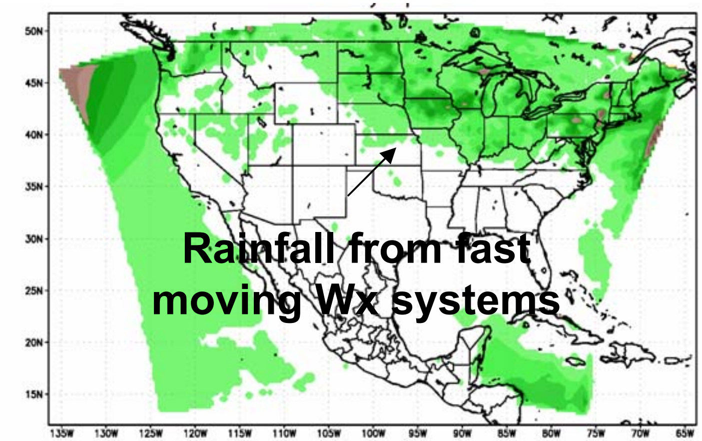
Units: mm^2 s^{-2}

Significant Spectral Power: July
Sub-Synoptic Mode (2 - 3 days)

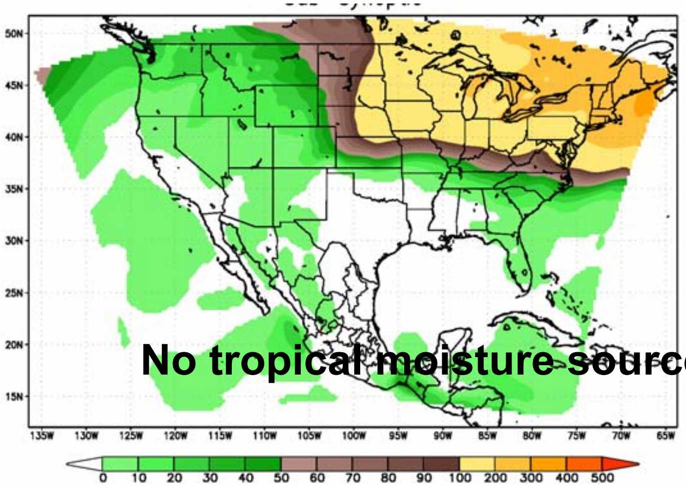
Moisture Flux: Reanalysis Downscaled



Moisture Flux Convergence: Reanalysis Downscaled

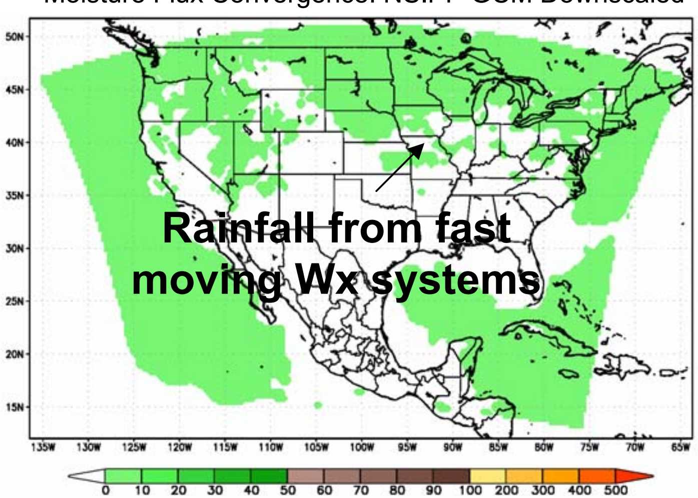


Moisture Flux: NSIPP GCM Downscaled



Units: kg^2 m^2 s^{-2}

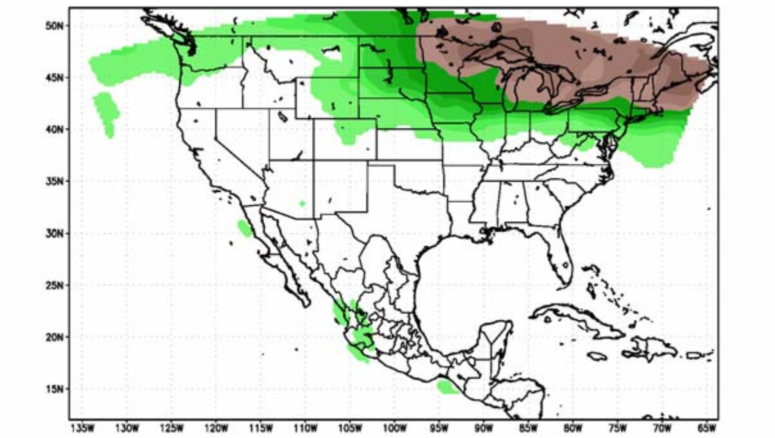
Moisture Flux Convergence: NSIPP GCM Downscaled



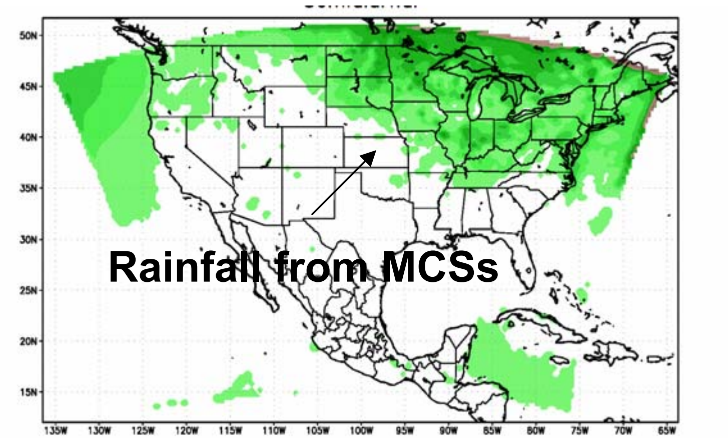
Units: mm^2 s^{-2}

Significant Spectral Power: July Semidiurnal Mode (1.5 days)

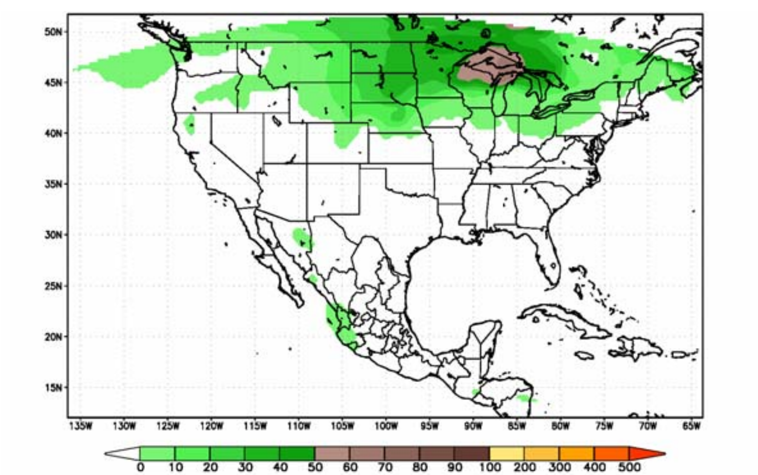
Moisture Flux: Reanalysis Downscaled



Moisture Flux Convergence: Reanalysis Downscaled

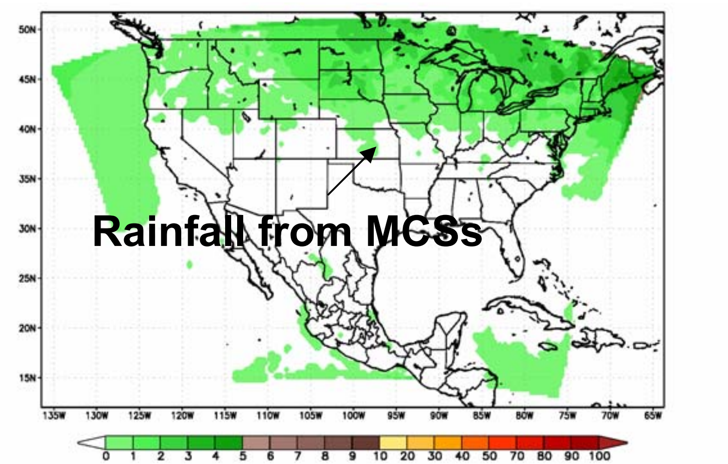


Moisture Flux: NSIPP GCM Downscaled



Units: $kg^2 m^2 s^{-2}$

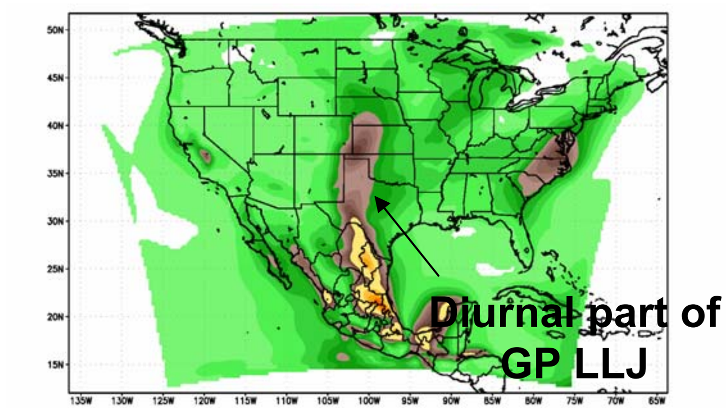
Moisture Flux Convergence: NSIPP GCM Downscaled



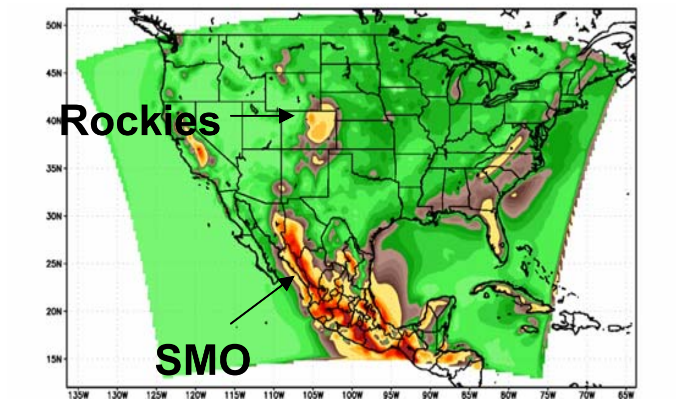
Units: $mm^2 s^{-2}$

Significant Spectral Power: July Diurnal Mode (1 day)

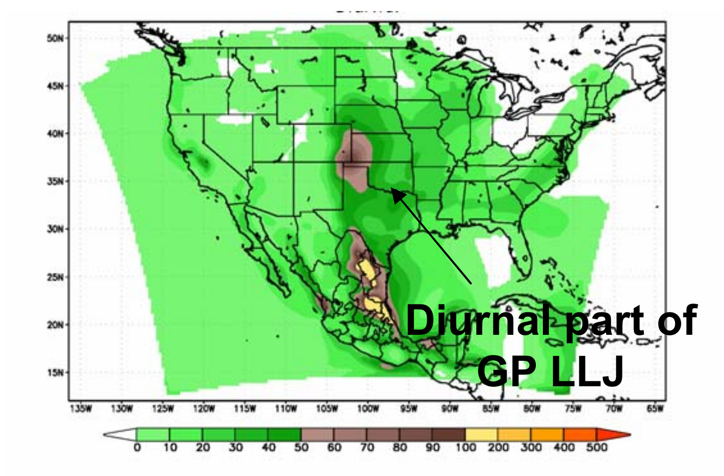
Moisture Flux: Reanalysis Downscaled



Moisture Flux Convergence: Reanalysis Downscaled

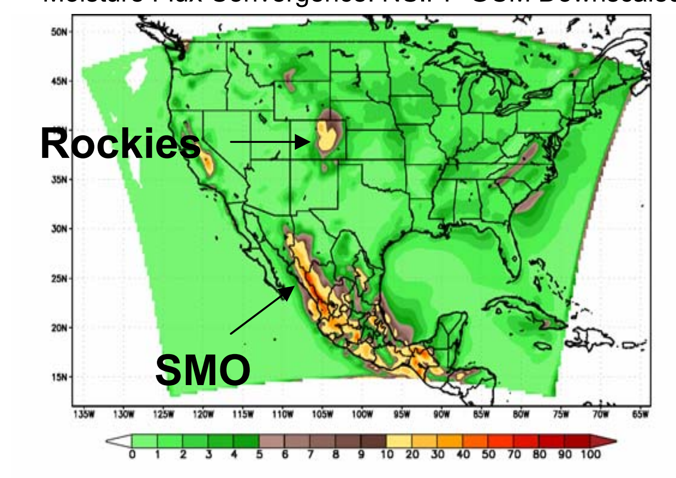


Moisture Flux: NSIPP GCM Downscaled



Units: kg^2 m^2 s^{-2}

Moisture Flux Convergence: NSIPP GCM Downscaled



Units: mm^2 s^{-2}

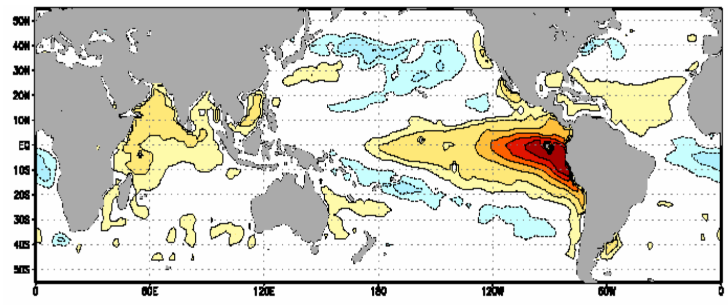
PART II

Interannual Variability Associated with the El Niño Southern Oscillation (ENSO) and the Pacific Decadal Oscillation (PDO)

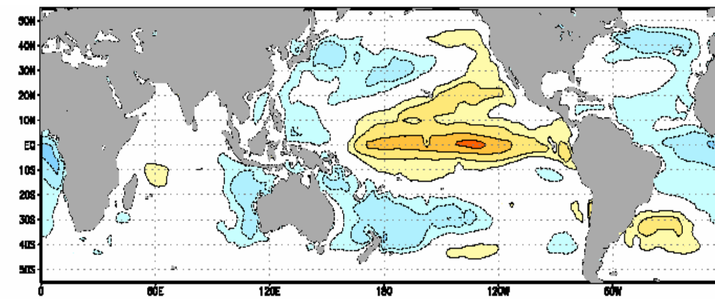
ENSO and PDO SST Modes Using EOF and Composite Analysis (SST Anomaly)

EOF Analysis
(Schubert et al. 2002)

Rotated EOF 1 (ENSO)

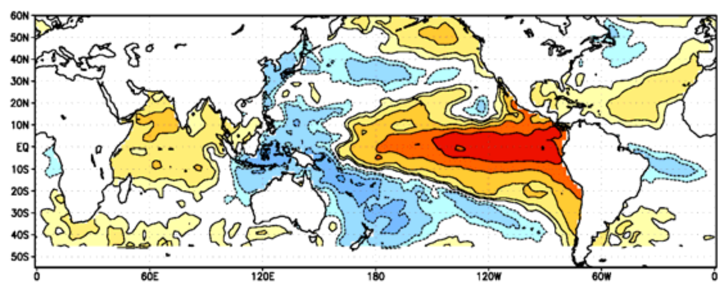


Rotated EOF 2 (PDO)

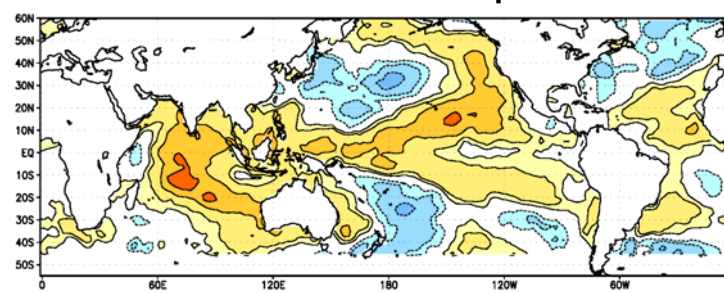


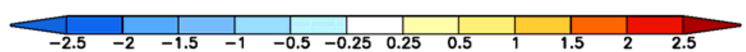
Composite Analysis
(Castro et al. 2001)

ENSO Composite



North Pacific Composite





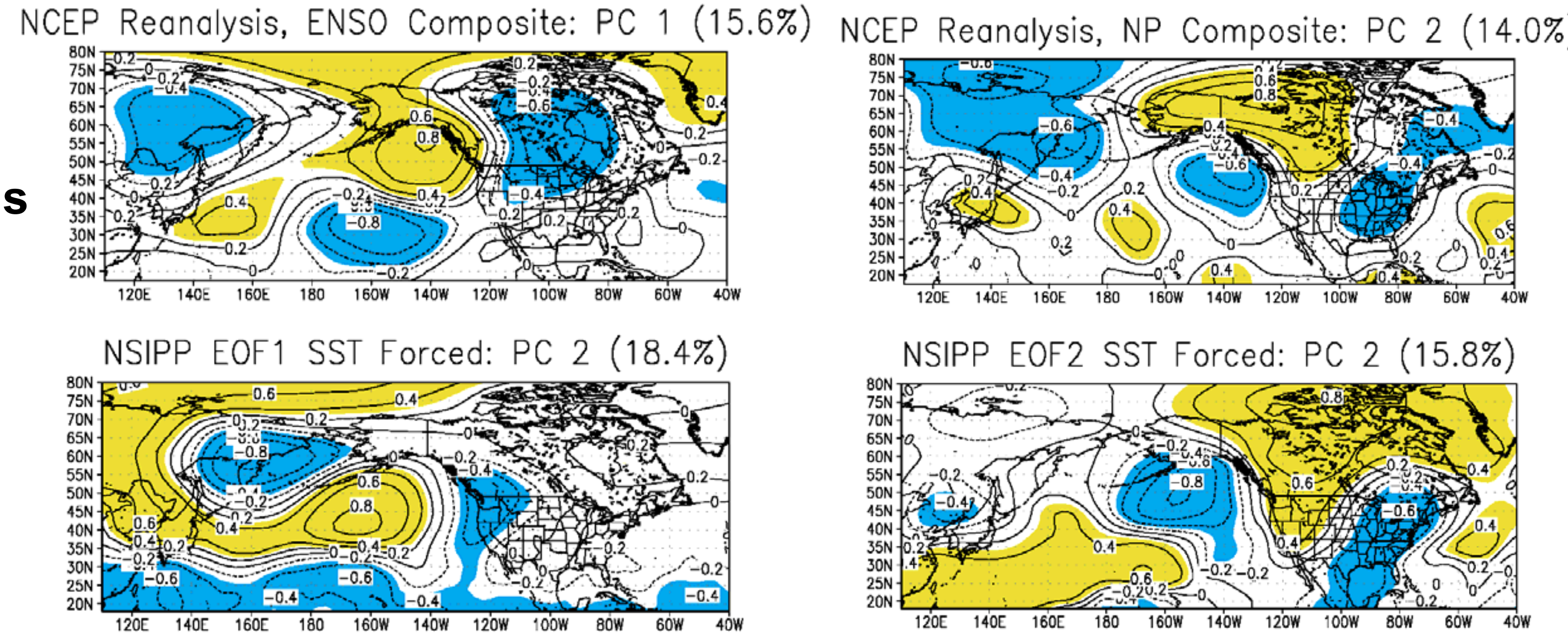
The dominant rotated EOF modes as they appear in the Pacific can also be roughly captured using the Castro et al. (2001) simple indices of Pacific SST.

Modes of Atmospheric Variability (500-mb) Associated with ENSO and PDO SST

ENSO mode at monsoon onset | **PDO mode at monsoon peak**

NCEP Reanalysis

NSIPP GCM



Nearly identical principal modes of atmospheric variability appear in the NCEP Reanalysis and a GCM forced with idealized SST reflecting ENSO and PDO modes. Teleconnections patterns have a time-evolving character.

Analysis of Interannual and Interdecadal Variability Via Thirty Day Precipitation About the Date

1. **NCEP Precipitation Observations and RAMS Reanalysis Downscaling**

   Categorize observed years according to thresholds in Pacific SST indices similar to Castro (et al. 2001). ENSO and PDO-type years are defined from the 53 year record.

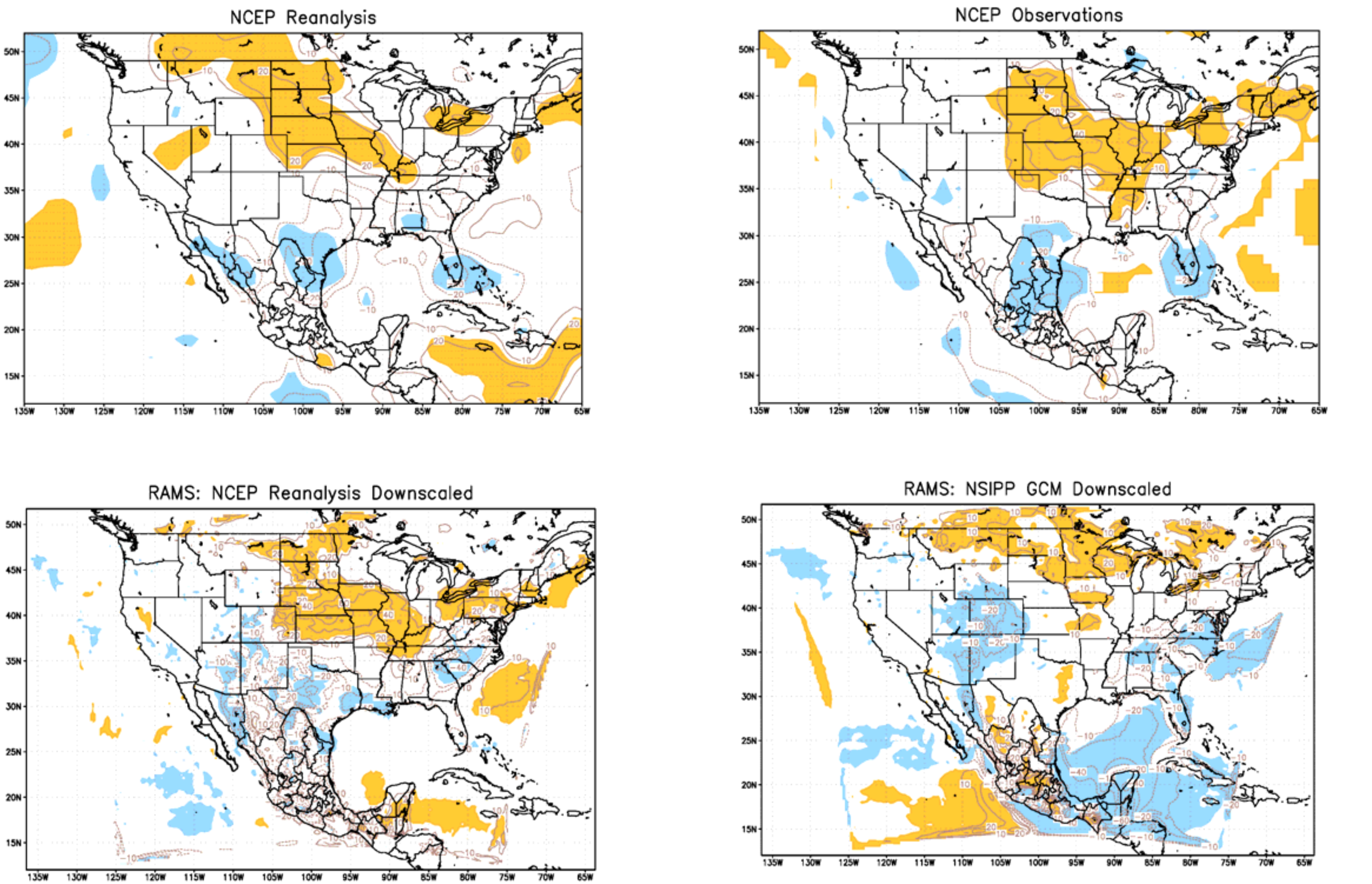
   Statistical significance determined by evaluating each selected set of composite years against all other years using a two-tailed t-test.

2. **NSIPP-RAMS Downscaling**

   Statistical significance of each ten year EOF-forced ensemble evaluated by a two tailed t-test against the 20-year climatology ensemble and the other thirty EOF-forced runs.

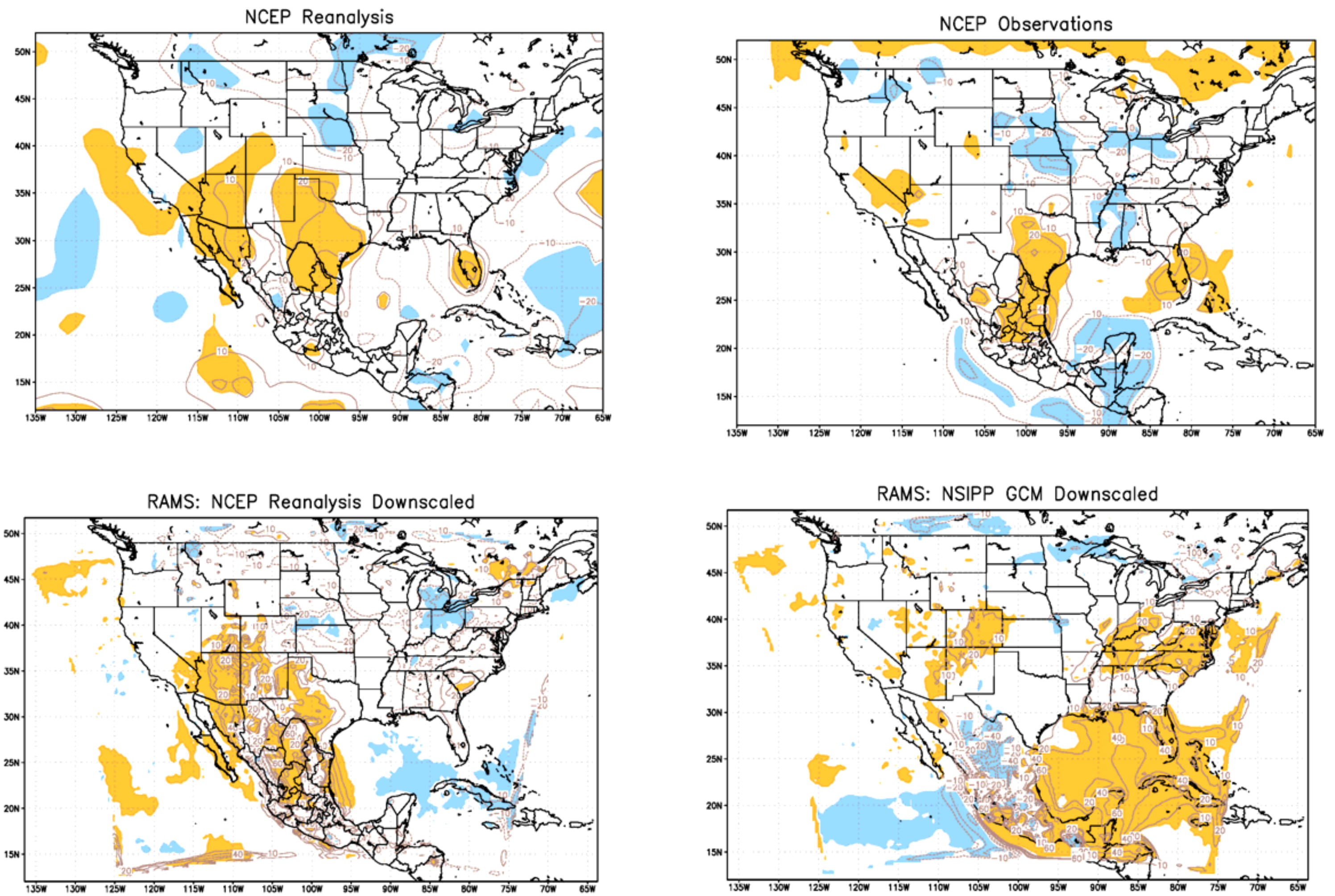
   Significance plotted at the 80% level and above to show the continental-scale precipitation anomaly pattern

July Precipitation Anomaly (mm): Positive PDO Years



Most statistically significant grouping of years. Extended late spring wet period in the central U.S.. Delayed monsoon onset and dry in the core NAMS region, which becomes statistically significant when RCM is used. RCM also increases the magnitude of the wet anomaly so it is closer to observations.

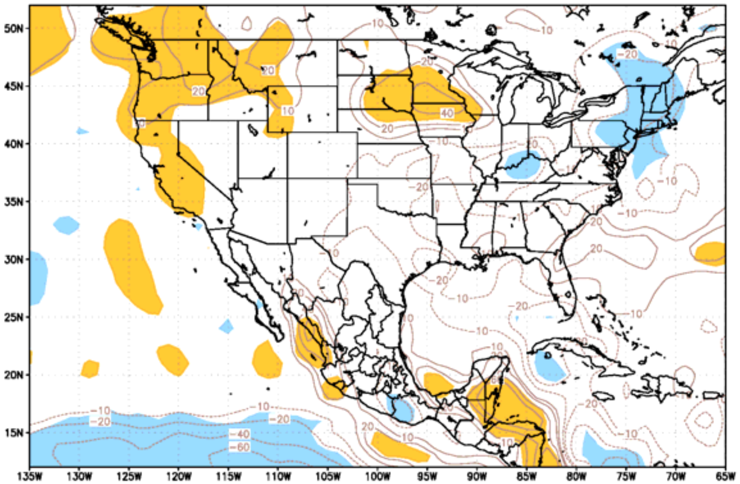
July Precipitation Anomaly (mm): Negative PDO Years



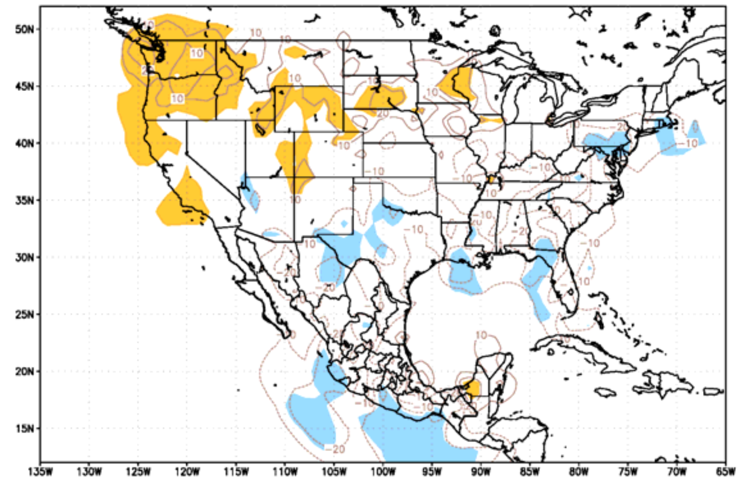
Approximately the reverse signal of positive PDO years, though the dry anomaly in the central U.S. is not as significant. Wet anomaly in the core NAMS region is stronger and more significant in RAMS simulations.

July Precipitation Anomaly (mm): Positive ENSO Years

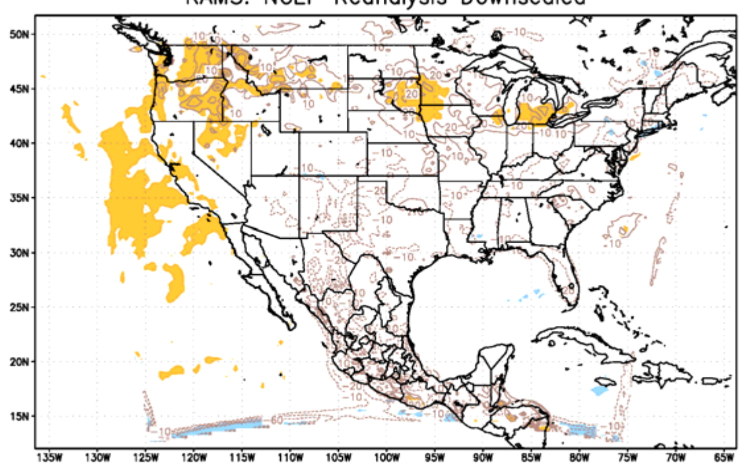
NCEP Reanalysis



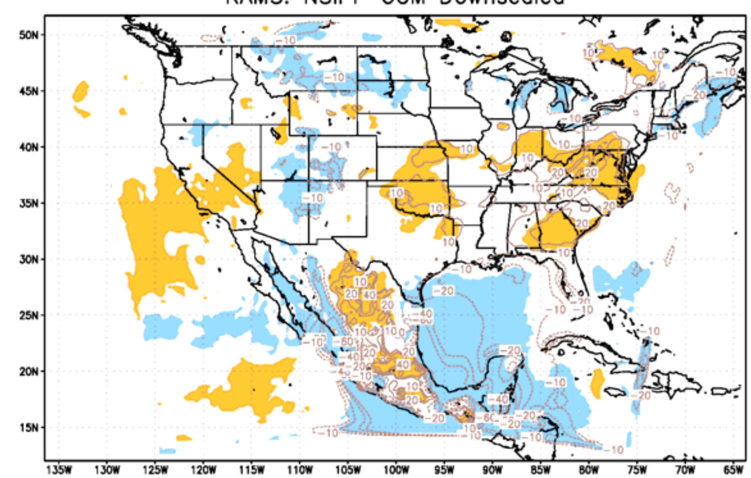
NCEP Observations



RAMS: NCEP Reanalysis Downscaled



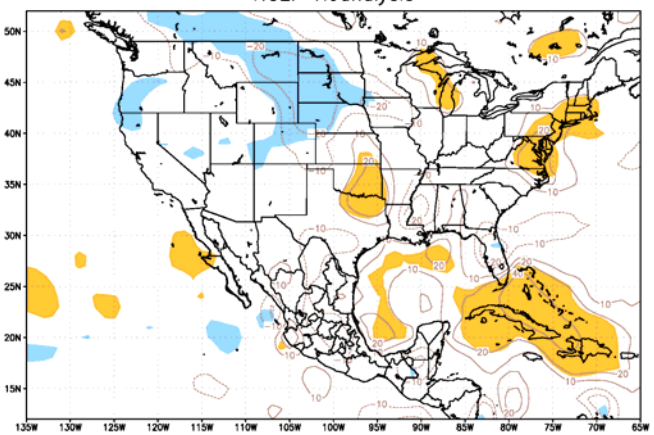
RAMS: NSIPP GCM Downscaled



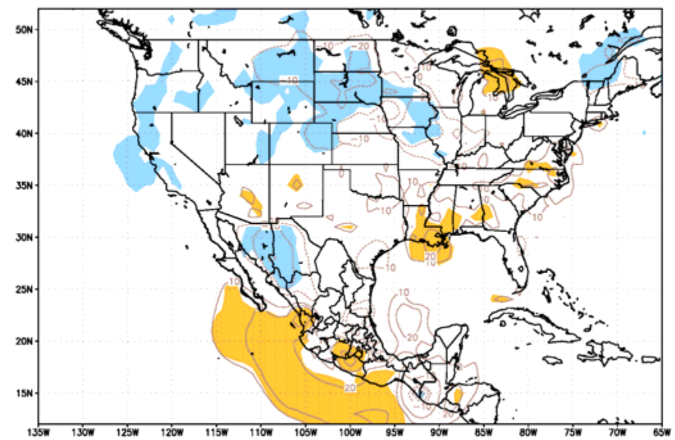
Similar to the positive PDO years, particularly in the NSIPP downscaling case, but not as statistically significant.

July Precipitation Anomaly (mm): Negative ENSO Years

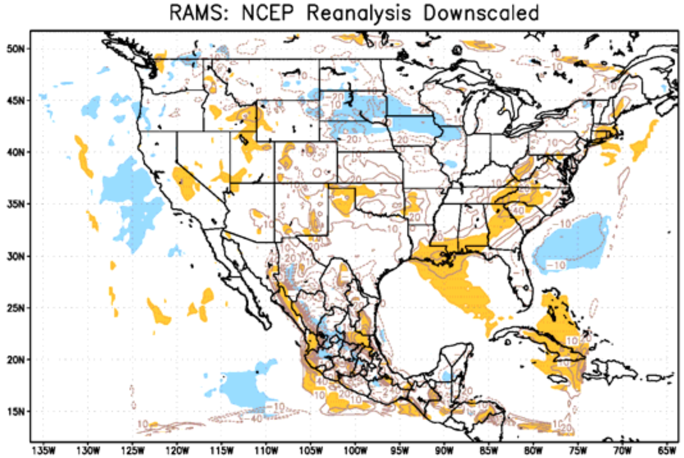
NCEP Reanalysis



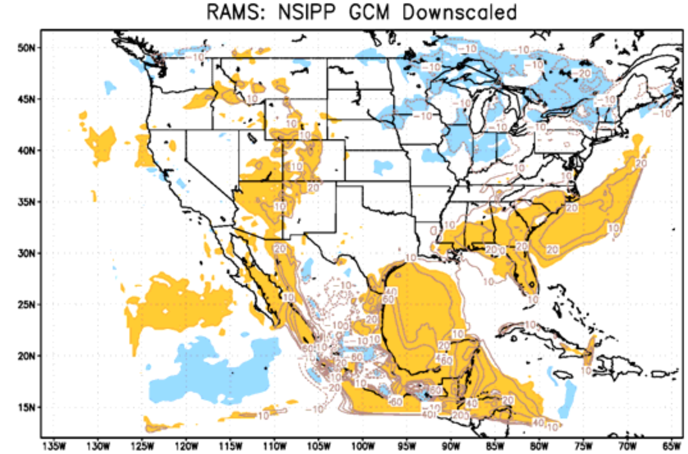
NCEP Observations



RAMS: NCEP Reanalysis Downscaled



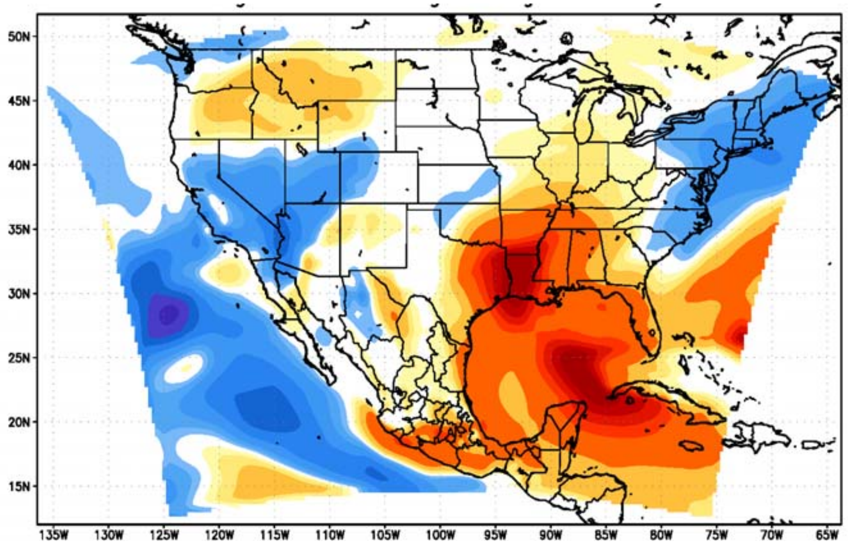
RAMS: NSIPP GCM Downscaled



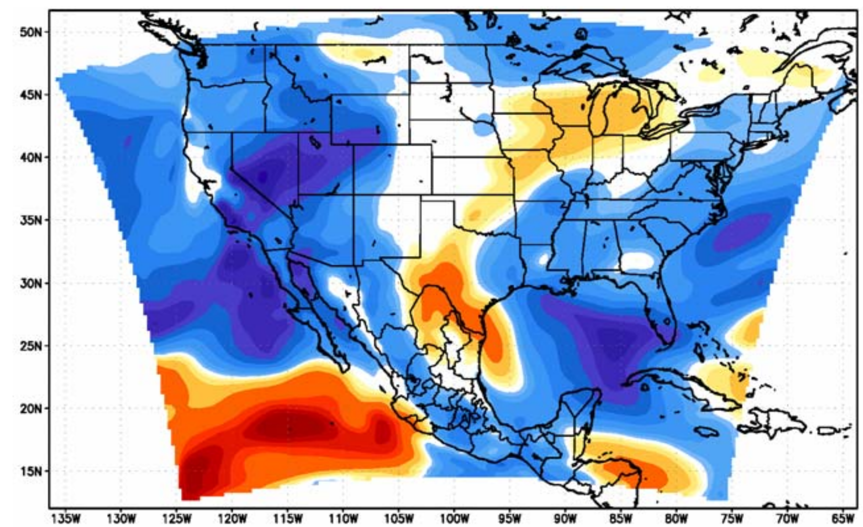
Similar to the negative PDO case. The dry anomaly in the central U.S. is more significant.

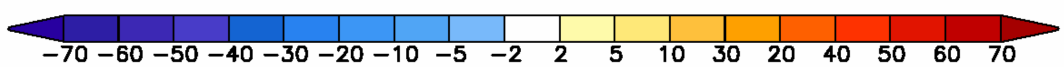
Percentage Change in Variance of Synoptic MF: High PDO Years, July

Reanalysis Downscaled



NSIPP GCM Downscaled

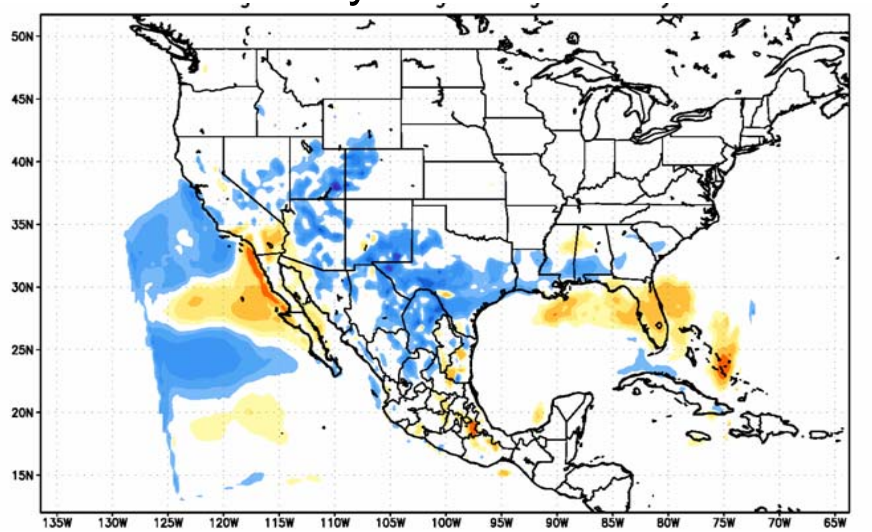




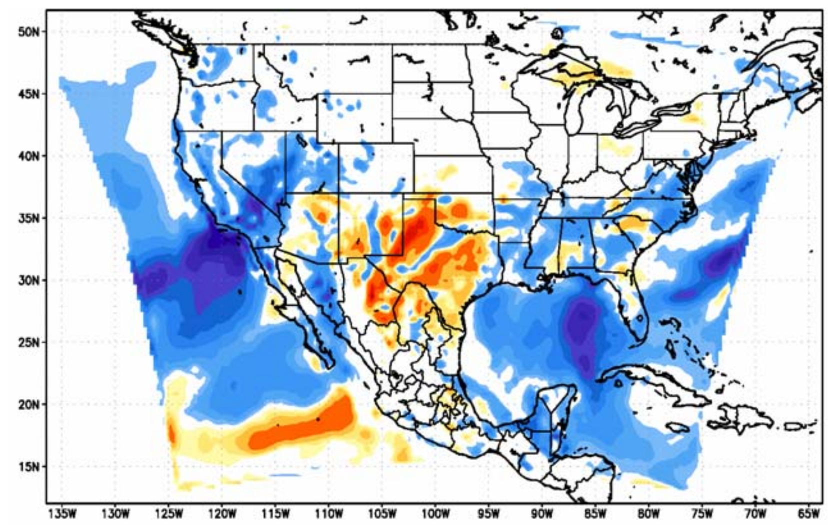
Increased moisture flux from the Gulf of Mexico in the central U.S., though this is apparent only in the reanalysis downscaling. Weaker and less frequent Gulf of California surge events.

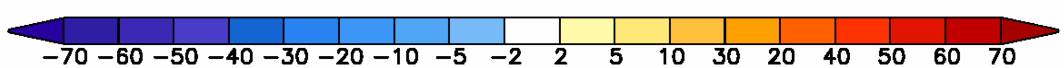
Percentage Change in Variance of Synoptic MFC: High PDO Years, July

Reanalysis Downscaled



NSIPP GCM Downscaled



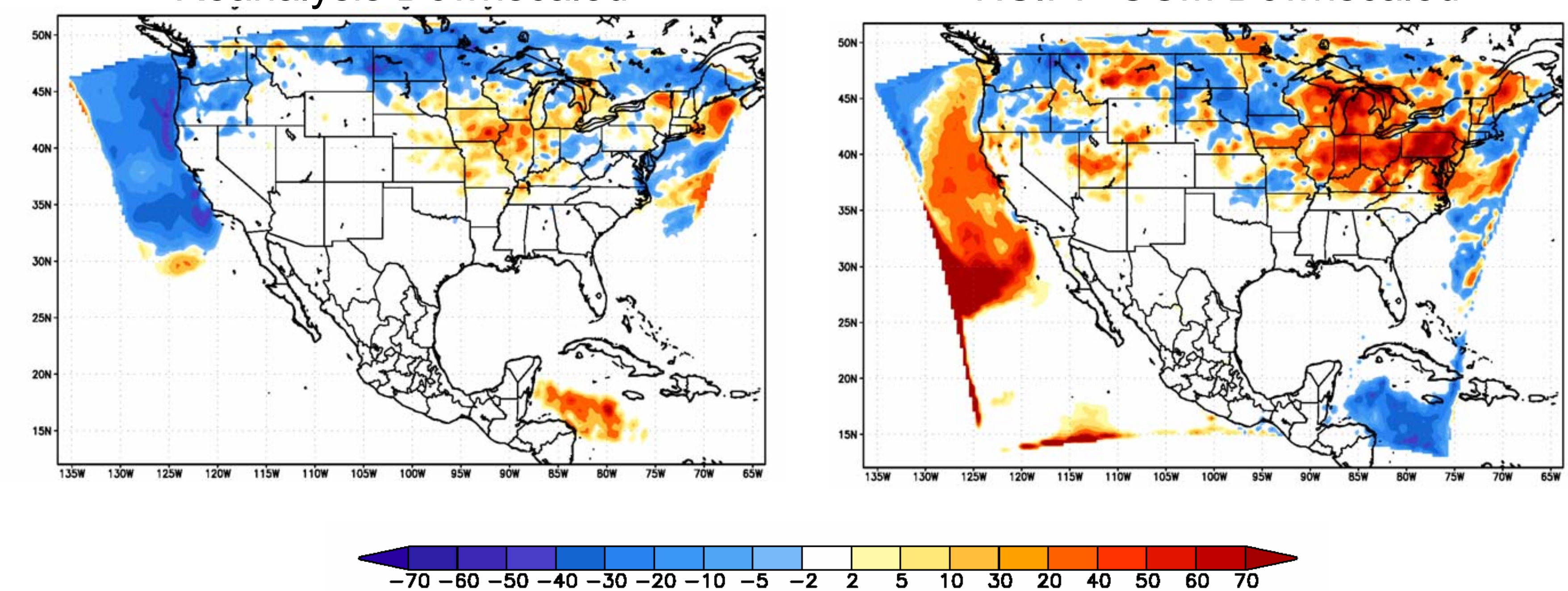


Decreased Gulf surge events leads to decreases in rainfall in the core NAMS region, particularly at lower elevations which receive their rainfall from westward propagating MCSs which form on the Mogollon Rim or Sierra Madre Occidental.

Percentage Change in Variance of Semidiurnal MFC: High PDO Years, July

Reanalysis Downscaled

NSIPP GCM Downscaled

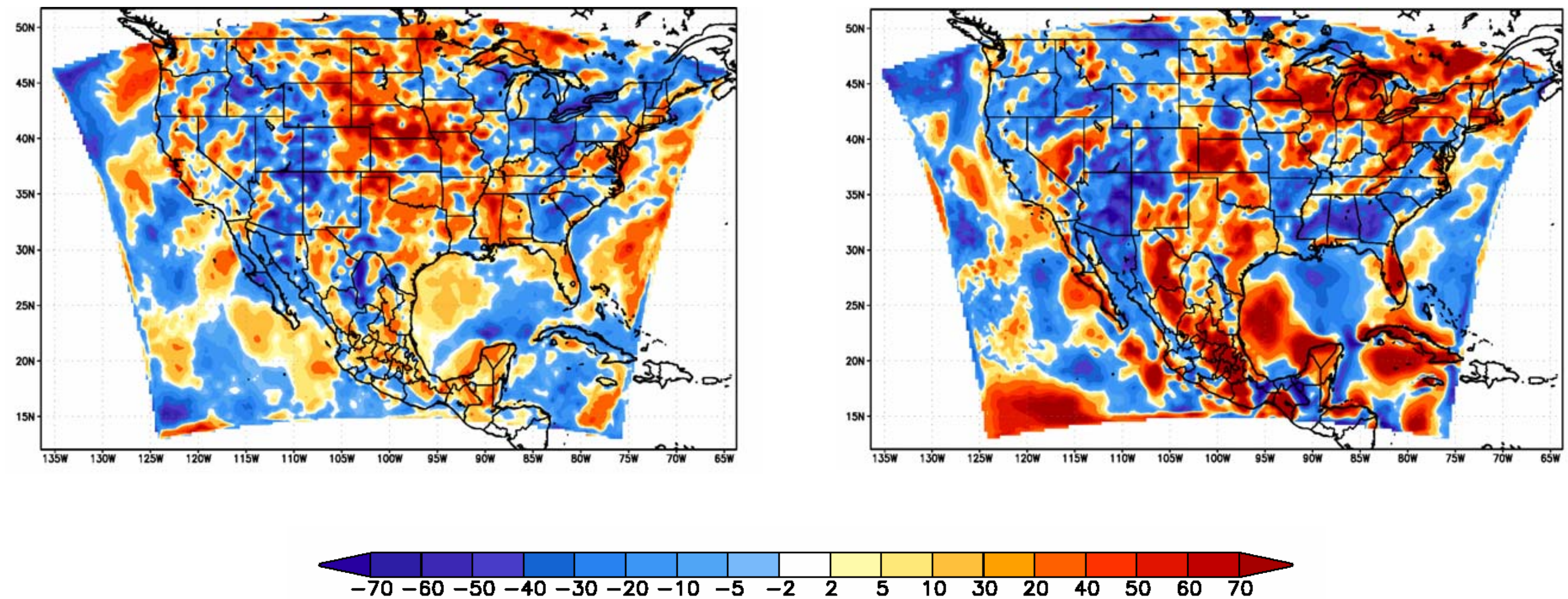


Propagating MCSs that affect rainfall in the Midwest are stronger and more frequent. The particular area with the strongest signal in the observed years corresponds with the location of maximum rainfall in the 1993 Flood.

Percentage Change in Variance of Diurnal MFC: High PDO Years, July

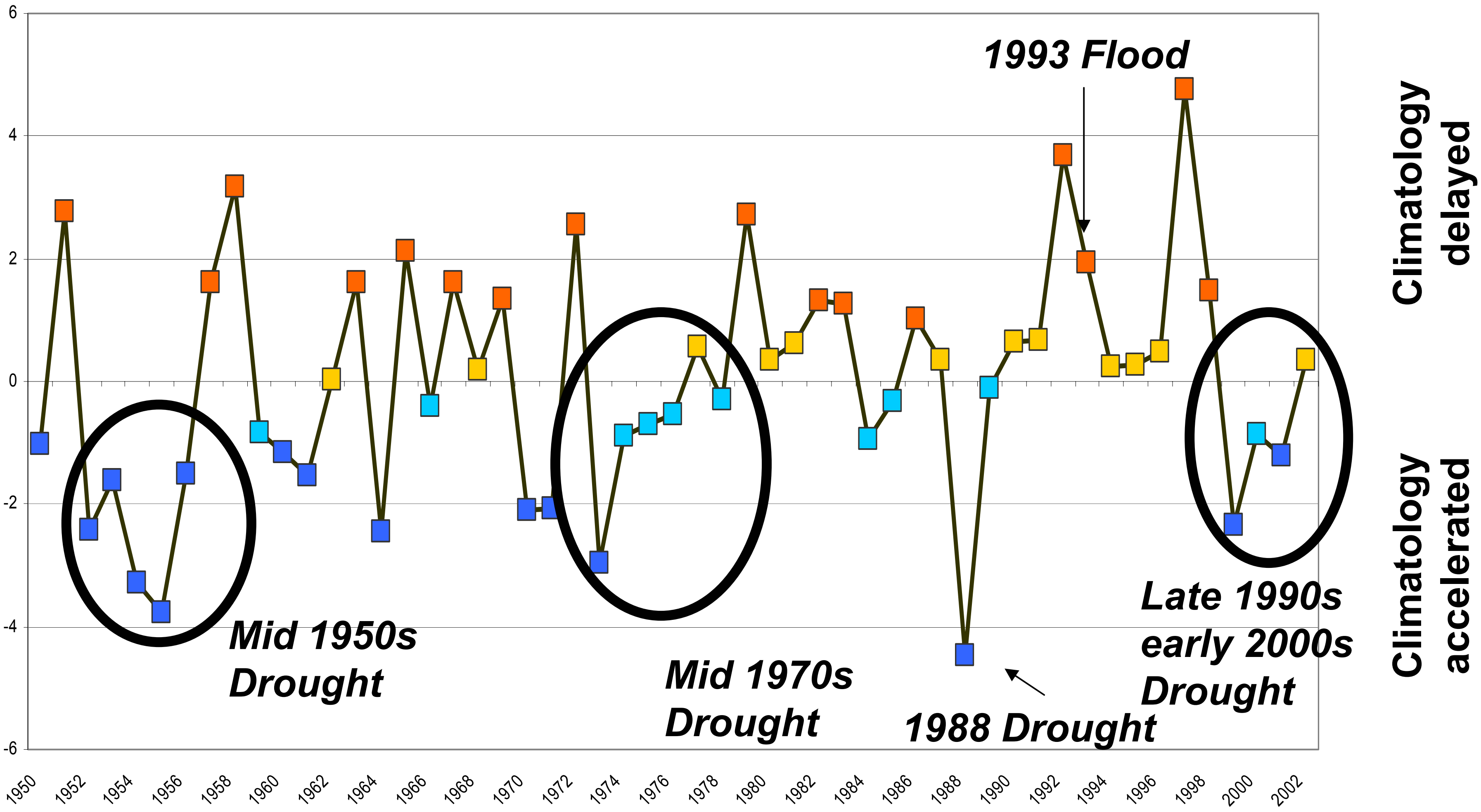
Reanalysis Downscaled

NSIPP GCM Downscaled

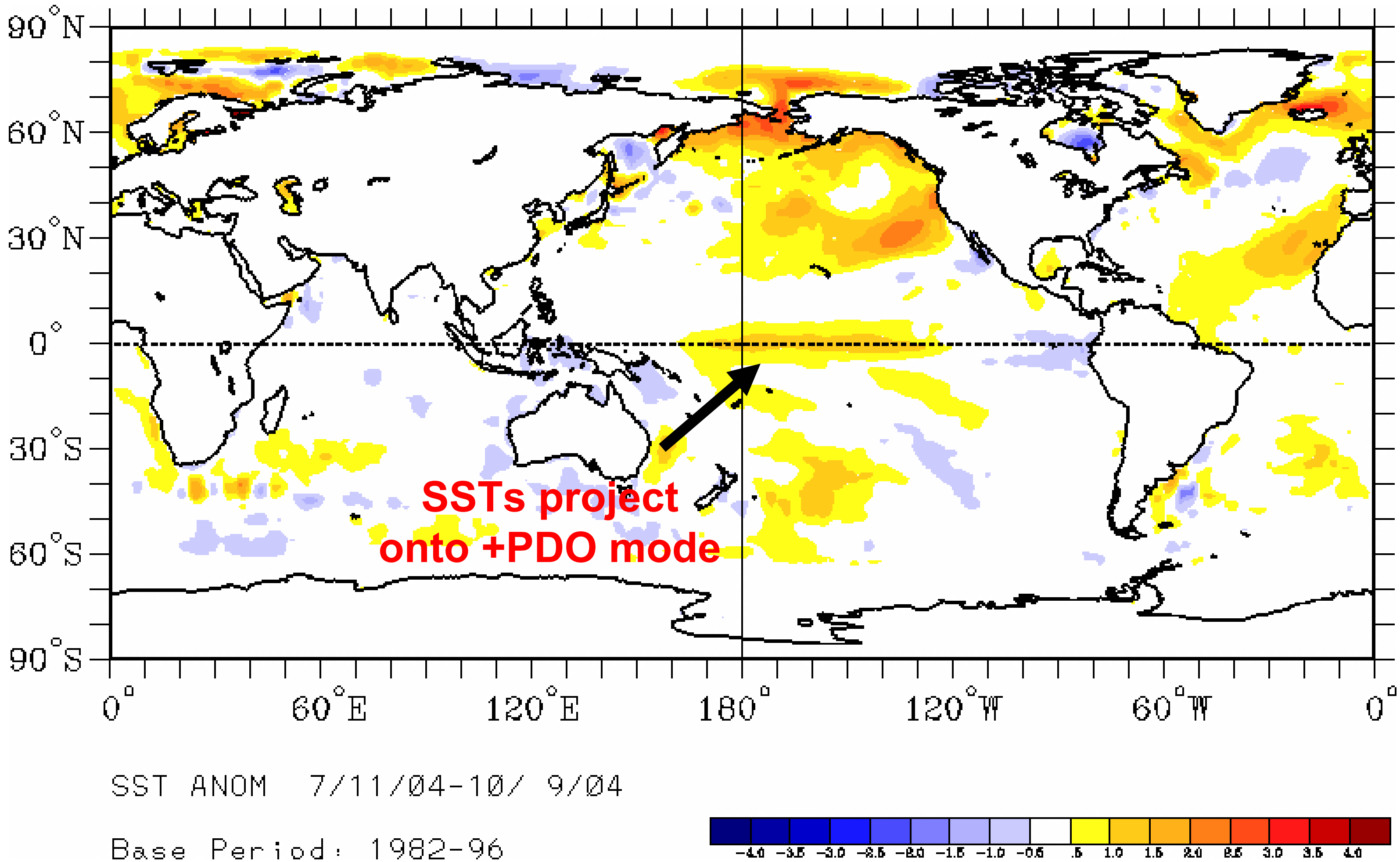


A stronger diurnal cycle in the Great Plains and weaker diurnal cycle in the core NAMS region. The demarcation between wet and dry signals associated with Pacific SST variability is roughly the continental divide. This creates a mixed signal in interannual variability in some locations, for example, Colorado.

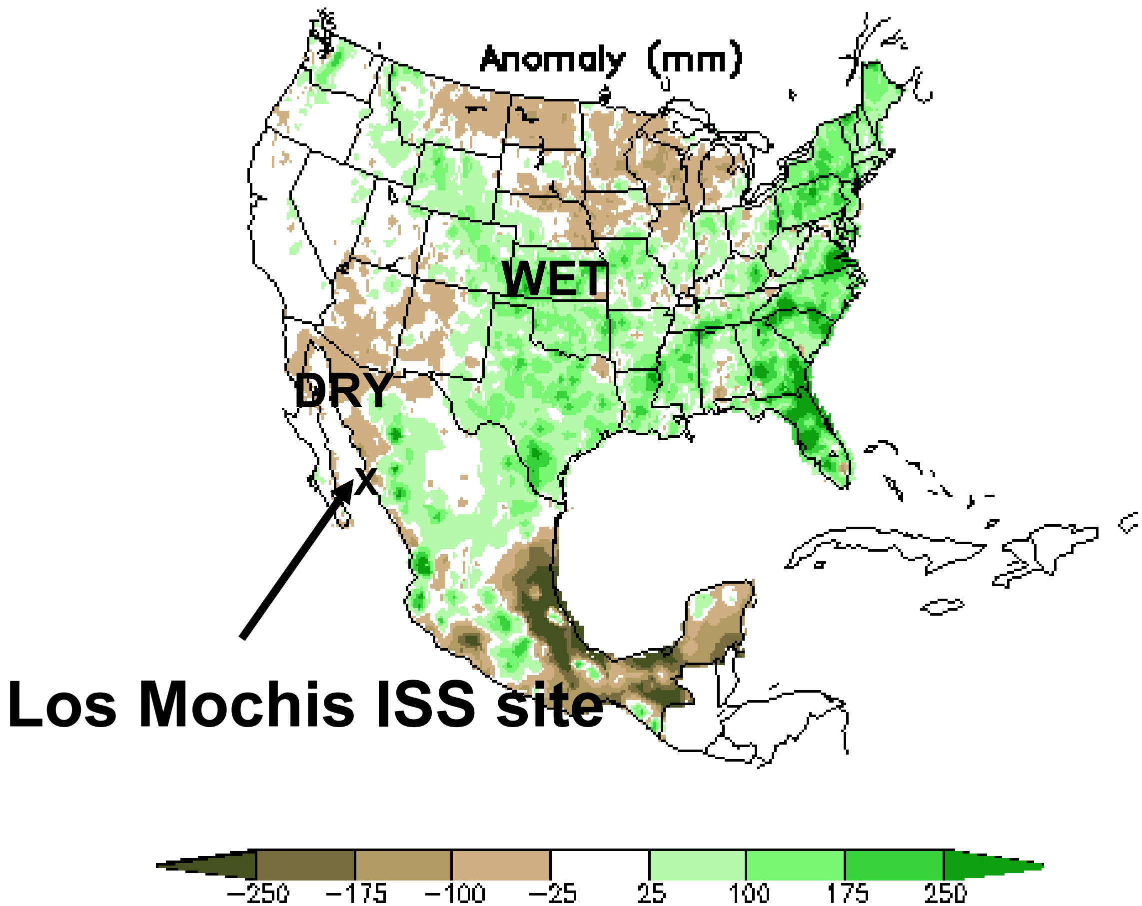
The Pacific (P) Index (ENSO+PDO) and Significant Climate Events in the Central and Western US



SST Anomaly for Summer 2004 (from CDC)



Past 90 day Precipitation Anomaly from Early September (CPC)



In retrospect, it may not have been the most ideal year to conduct NAME…

Monsoon onset in the core NAMS region was delayed. In Los Mochis, for example, little or no rainfall in late June and early July.

While I was waiting for it to rain in Mexico, back home in Fort Collins it rained about every day!

Summary

A regional climate model (RAMS) has been used to dynamically downscale the NCEP Reanalysis and NSIPP GCM data for the summer season. More than 100 summer seasons were simulated, which allows us to statistically analyze the RCM data.

A RCM adds value by capturing key hydrometeorological features a GCM cannot resolve, namely the diurnal cycle of convection and low-level jets which transport moisture into the continental interior. The largest precipitation differences from the reanalysis occur in central and western North America where these factors largely govern summer rainfall.

RAMS can successfully capture the observed coherent and continental scale pattern of precipitation anomalies associated with ENSO and PDO. The teleconnection patterns either delay or accelerate the evolution of the summer synoptic climatology in North America. Downscaling from the NSIPP GCM shows these anomalies occur even in the absence of local surface forcing.

The PDO yields the most statistically significant pattern of summer precipitation anomalies in North America, and its variability likely affects the occurrence of long-term wet or dry periods in the western and central U.S.

Further work is necessary to quantify how local surface influences may modulate the effect of remote SST forcing, but it is clear from this work that the latter is a first order influence on NAMS evolution and summer climate.