Spatiotemporal Variability and Covariability of Temperature, Precipitation, Soil Moisture, and Vegetation in North America for Regional Climate Model Applications

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Presentation Outline

Motivation for analyzing long-term variability in land surface parameters and their relationships with precipitation and temperature

Hypothesized role of land surface and methodology to test in a RCM framework

Description of land surface and atmospheric forcing datasets

Statistical analysis methods

Analysis results

- **Variability in precipitation and temperature**
- **Variability in soil moisture and vegetation**
- **Covariability between land surface variables and precipitation**

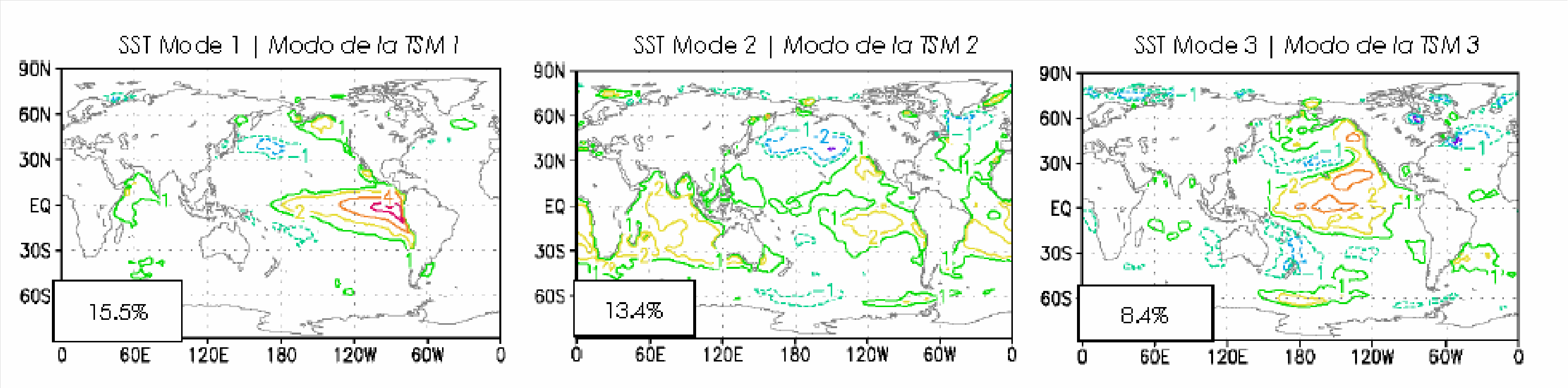
Conclusions and implications for ongoing regional climate model studies

Present work funded by NOAA through the Climate Prediction Program for the Americas

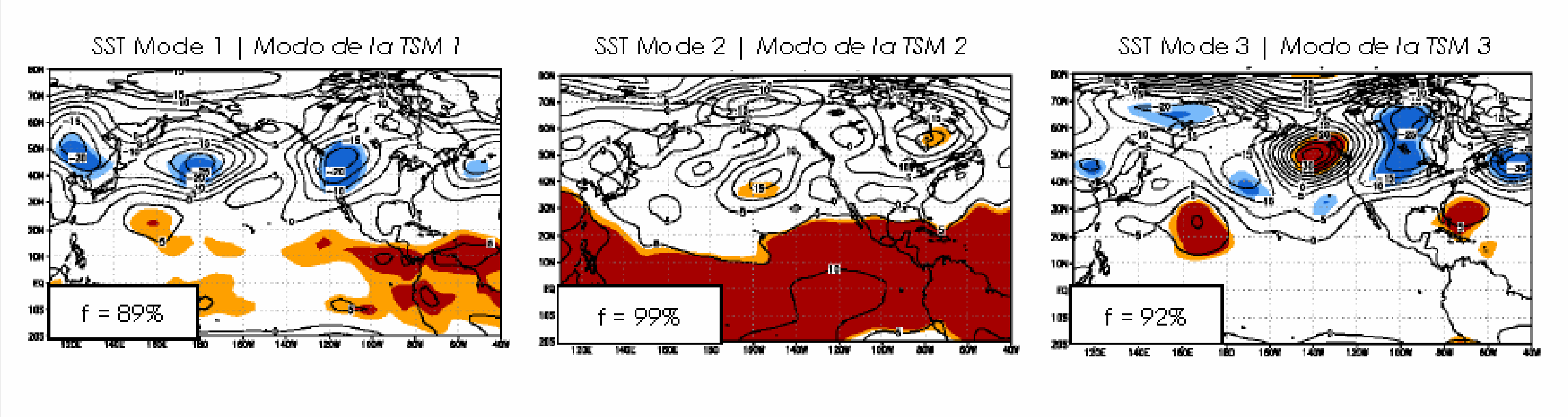
Large-Scale Forcing of North American Summer Climate Variability

Our previous work has established that the dominant modes of Pacific SSTs influence the summer climate of North America via remote forcing of the large-scale circulation. Teleconnections evolve in time and affect the onset of the North American monsoon.

Summer SST REOFs



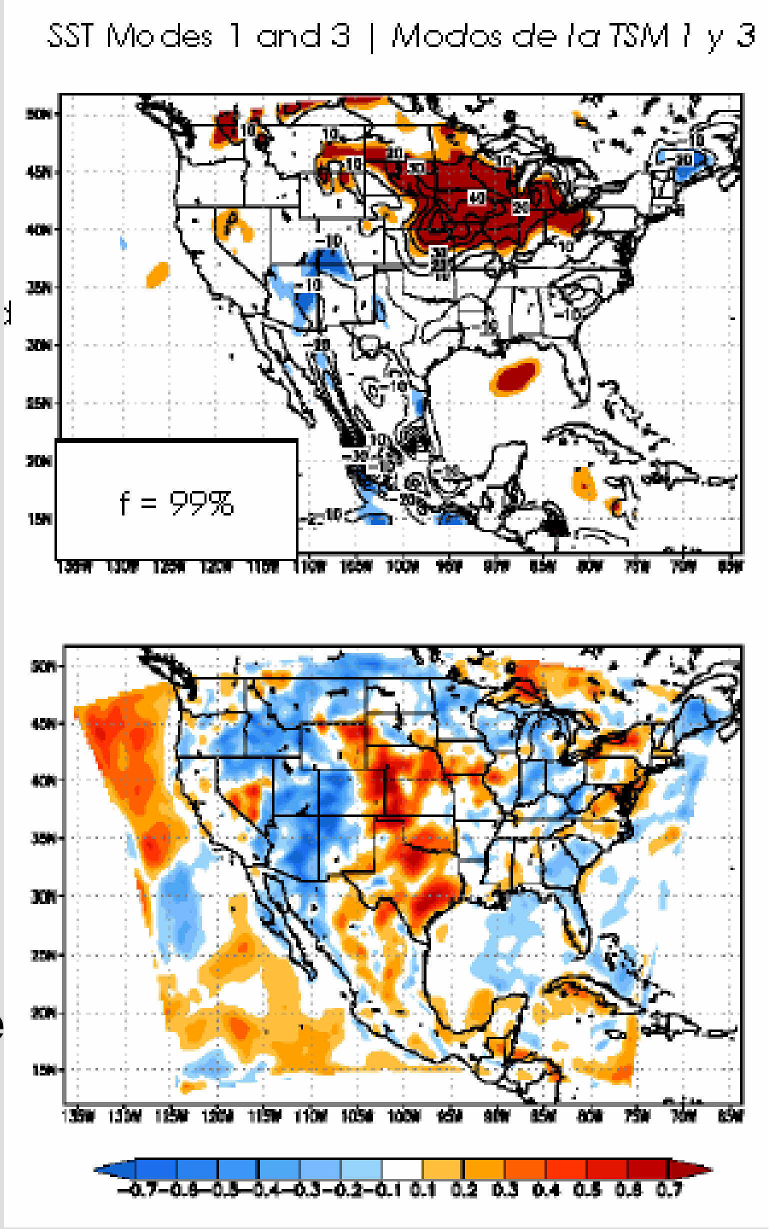
500-mb Height Anomalies at monsoon onset



(Castro et al. 2007, *J. Climate*, in press)

Utility of a regional model (RCM) to represent summer climate anomalies

RCM Precip. Anomaly (mm)



Change in diurnal moisture flux convergence

A regional climate model adds significant value in the representation of summer climate variability in North America over a coarser global model or reanalysis.

Added value by a RCM in the warm season is largely a due to better representation of the diurnal cycle of convection.

(Castro et al. 2007, *J. Climate*, in press)

What about the role of the land surface?

Sonoran Desert in Arizona during the monsoon

Sonoran Desert example

Though a desert, it is actually quite vegetated compared to others.

There is a rapid change in the vegetation which occurs during the North American Monsoon.

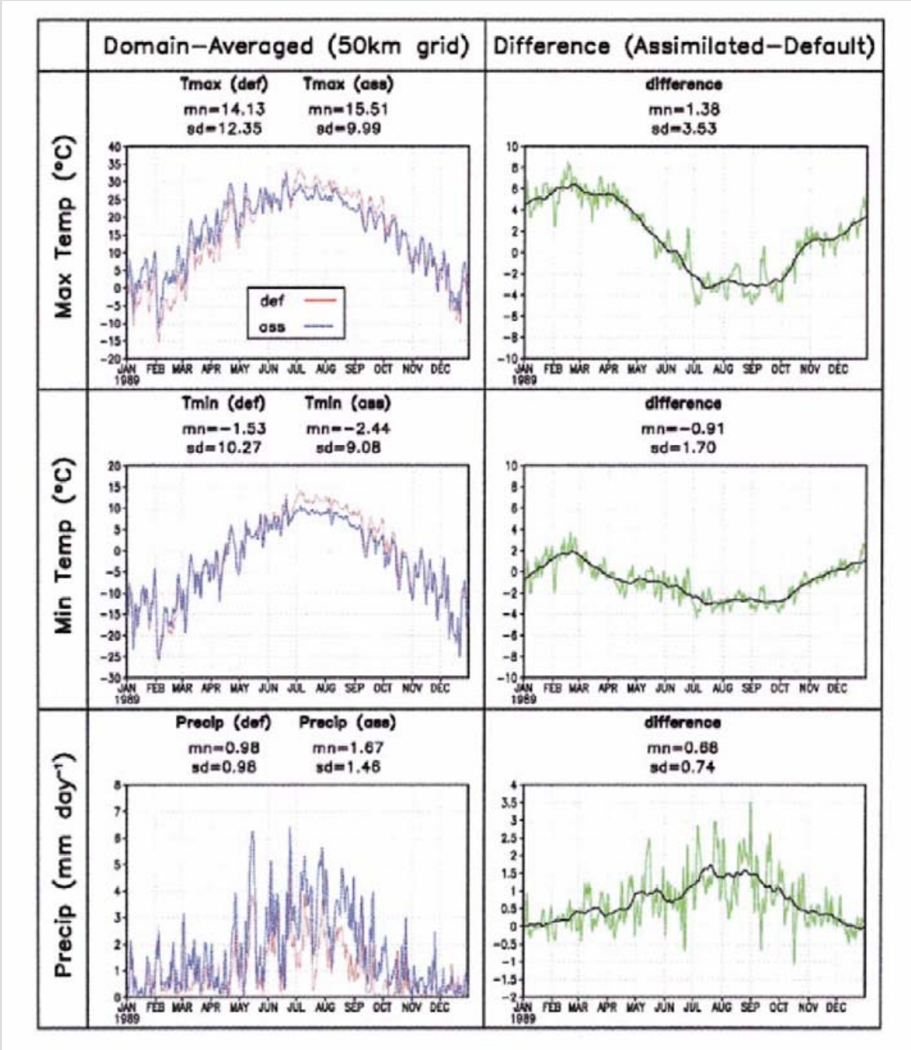
How might such land surface changes interact with the large-scale climate forcing? Is there a possible synergistic relationship?

Established conclusions regarding the role of the land surface: RCM investigations

Land surface influences may significantly impact North American summer climate. RCM sensitivity-type studies have typically focused on the role of soil moisture in years with extreme climate conditions, like 1988 and 1993.

Fewer studies have investigated the role of vegetation, but it is likely important for summer climate as well.

Differences with incorporation of satellite-derived LAI: 1989 RAMS simulation in central U.S.



(Lu and Shuttleworth 2002, *J. Hydrometeor.*)

Established conclusions regarding the role of the land surface: relationship to large scale forcing

Soil moisture and vegetation variability is related to large scale climate forcing, in North America and other parts of the world.

The most recent drought in the central U.S. during the late 1990s to early 2000s is a good example.

GCM studies have concluded this drought was caused by SST anomalies in the Pacific and Indian Oceans (e.g. Hoerling and Kumar 2003)

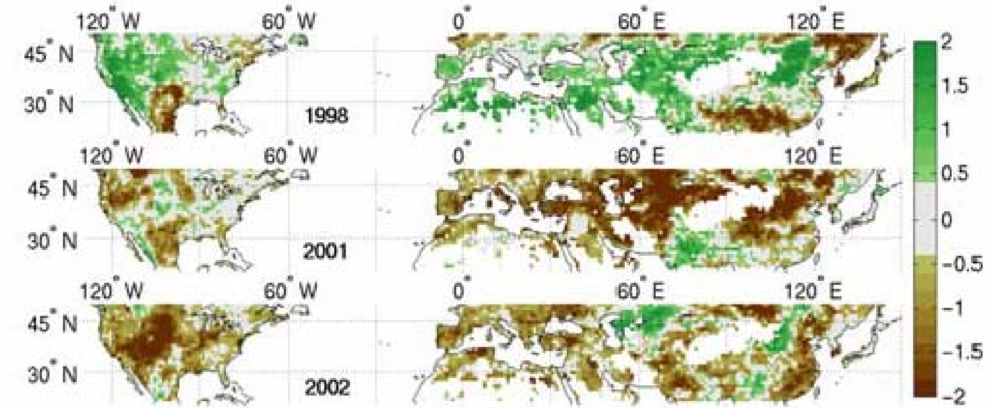


Figure 2. Summer NDVI anomalies for 1998, 2001 and 2002. Northern Hemisphere mid-latitude summer (July August) anomalies of NDVI are indicative of ecosystem photosynthetic activity. Brown colours indicate negative standard deviations from 1981 2002 July August means, and positive deviations are shown in green.

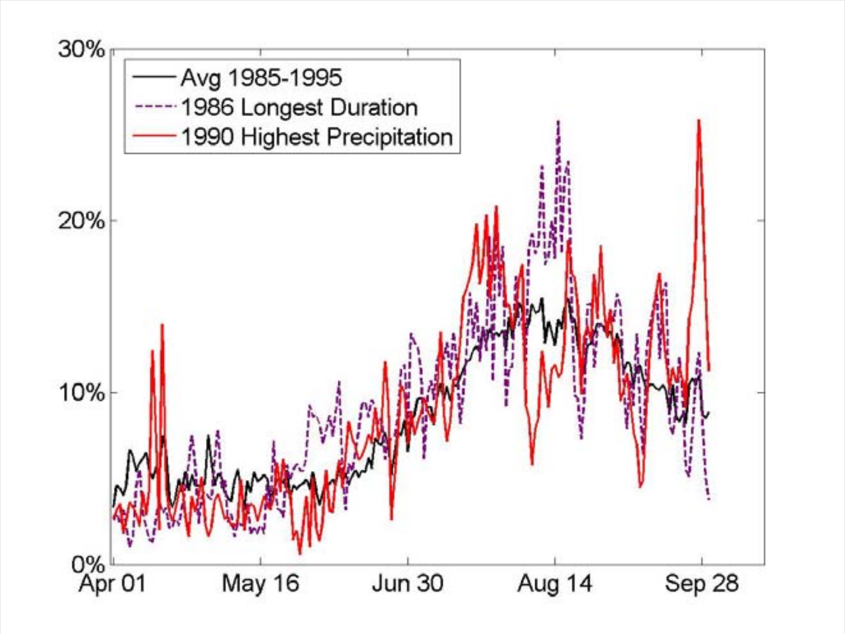
(Lotsch et al. 2005, *Geophys. Res. Lett.*)

Established conclusions regarding the role of the land surface: its importance may actually vary through the warm season!

With the use of a dynamic precipitation recycling model, it has been possible to diagnose that precipitation in the monsoon region due to moisture recycling appears to become more important in the latter part of the monsoon.

These very recent results are based on NARR. Methodology hasn't been applied to RCMs yet!

Percentage of precipitation due to recycled moisture in the NAMS region: 1986 and 1990



(Dominguez et al. 2007, *J. Climate*, in press)

Hypothesized role of land surface and methodology to test in a RCM framework

HYPOTHESIZED ROLE OF LAND SURFACE

The role of the land surface becomes more important during the latter part of the summer as the influence of remote SST forcing diminishes.

Soil moisture and vegetation act as “integrators” of the longer term atmospheric variability and may act synergistically with the remote forcing to create extreme summer climate conditions.

METHODOLOGY TO TEST IN RCM FRAMEWORK

FIRST STEP: Statistically characterize the spatiotemporal variability and covariability of the forcing (i.e. precipitation) and the land surface variables, isolating the interannual time scales.

SECOND STEP: Use these patterns to identify periods of interest in the climate record and conduct RCM sensitivity experiments varying soil moisture and vegetation according to the statistically significant patterns.

LAND SURFACE DATASETS

SOIL MOISTURE

Long-term integration of the Variable Infiltration Capacity (VIC) Model at one-eighth degree footprint (Maurer et al. 2002) from 1950-2000 over NLDAS region. Will use similar NOAH model data in the future.

VEGETATION GREENNESS

Normalized vegetation difference index (NDVI) from GIMMS-NDVI data available from 1981-present at 8km footprint (Tucker et al. 2005). Gives measure of photosynthetic activity.

ATMOSPHERIC FORCING DATASETS

PRECIPITATION

U.S.-Mexico CPC product at half-degree footprint (1950-present).

TEMPERATURE

Temperature forcing data taken from VIC model and MOSAIC model.

Multi-taper singular value decomposition (MTM-SVD)

Allows for the detection and reconstruction of quasi-oscillatory spatiotemporal climate signals that exhibit episodes of spatially correlated behavior.

Products of MTM-SVD analysis:

1. Local fractional variance (LFV) spectrum of principal eigenmode
2. Statistical confidence intervals for the LFV spectrum
3. Reconstructed anomaly patterns and time series corresponding to the significant time-varying modes.

Use code described in Rajagopalan et al. (1998)

All the following plots reference the spatiotemporal variability patterns to a grid point in the central U.S.

Standardized Precipitation Index (SPI)

Normalizes a given precipitation total at each point to a gamma distribution computed for the given period of record. The precipitation total can be for any timescale, typically it ranges from 1 to 24 months (McKee et al. 1993).

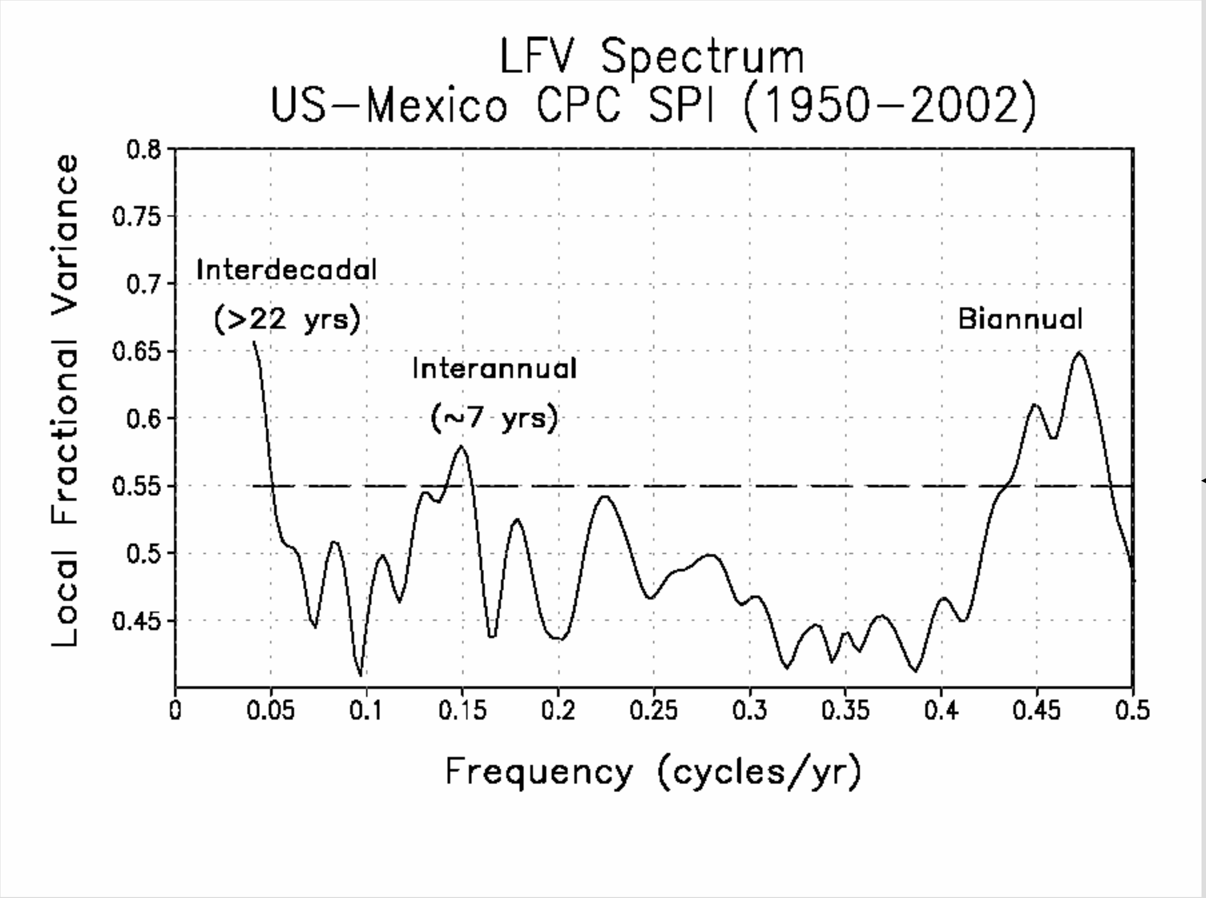
<u>Advantages of SPI over raw precipitation</u>

1. Since SPI can be computed for a variety of timescales, it is a pretty robust measure of long-term climate anomalies, such as drought.

2. Allows for a comparison of precipitation anomaly patterns for very large area, such as a continent, which may have many diverse climate types.

3. Previous work has shown that soil moisture and vegetation have fairly robust statistical relationships with SPI computed at a timescale of three months or more (e.g. Lotsch et al. 2003).

Also, soil moisture, vegetation, and temperature anomalies have been normalized as well for the proceeding analyses, the first two also assuming a gamma distribution.

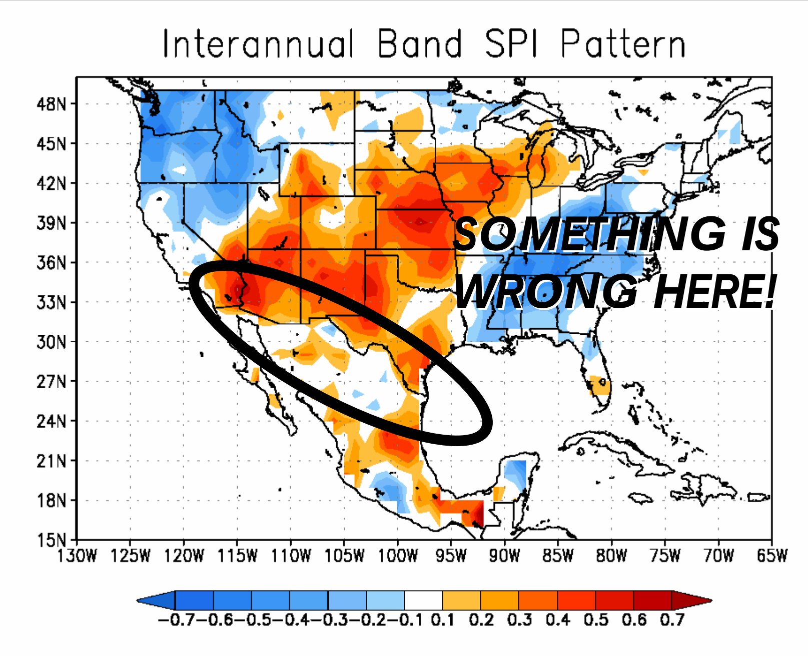


95 % confidence interval

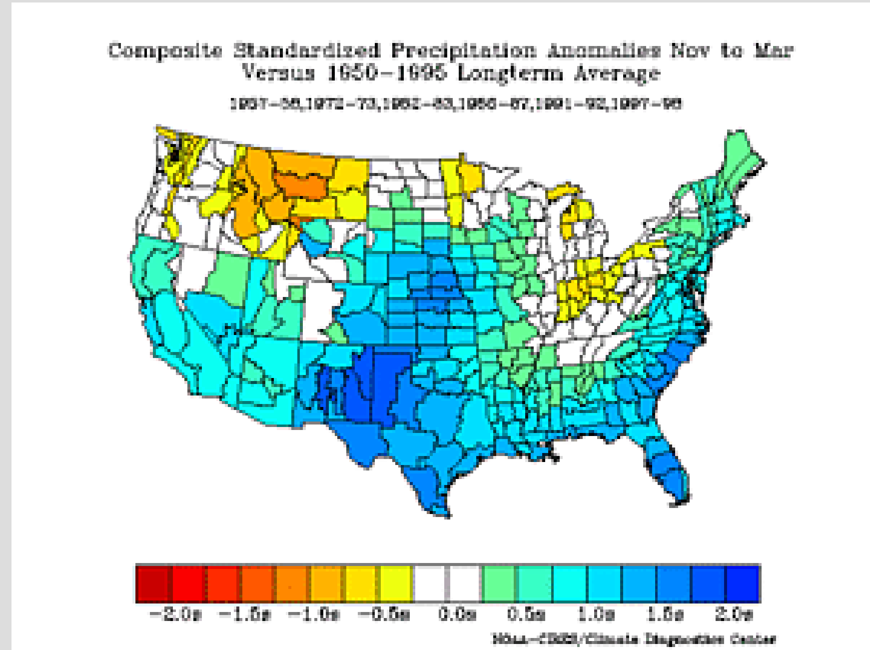
Local fractional variance spectrum for SPI considering the entire North American record shows significant interannual variability at a timescale of about 7 years.

Focus to this timescale because of the significant variability in soil moisture and vegetation at about the same timescale.

Using MTM-SVD



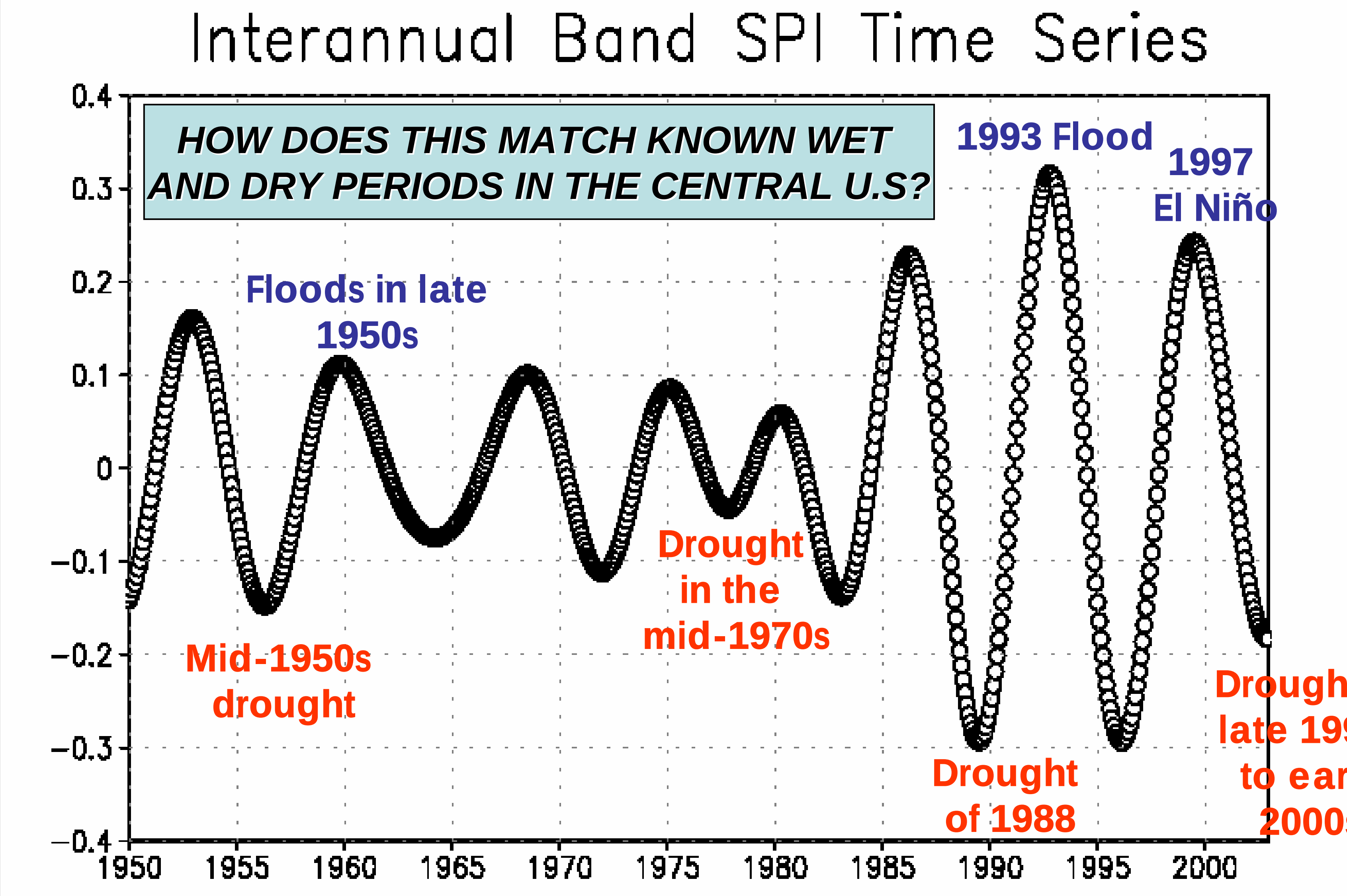
Composite El Niño years



The interannual variability in SPI reflects, for the most part, established relationships between North American winter precipitation and ENSO-PDO.

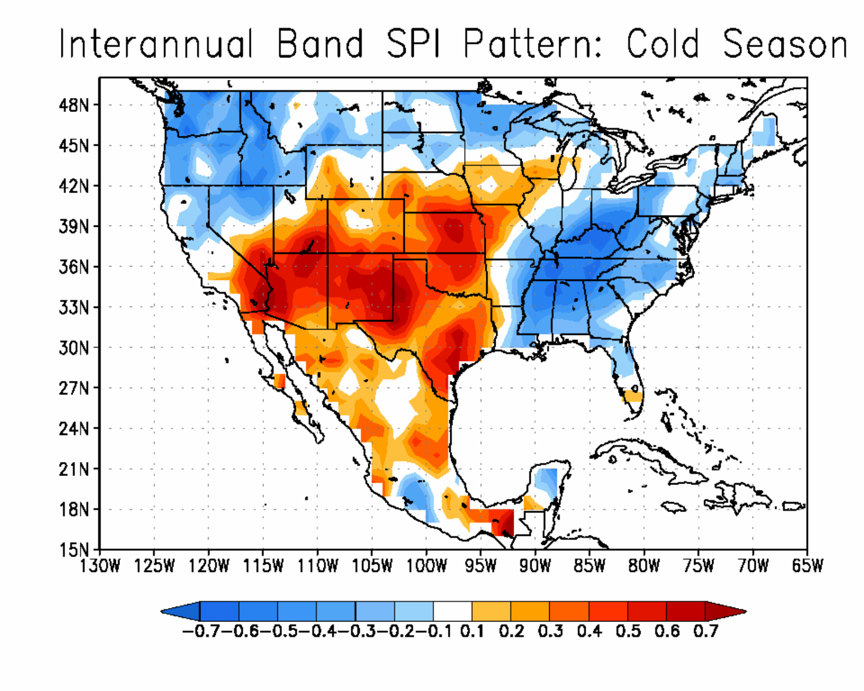
Particularly strong coherence in western U.S., but much less so in the southeast.

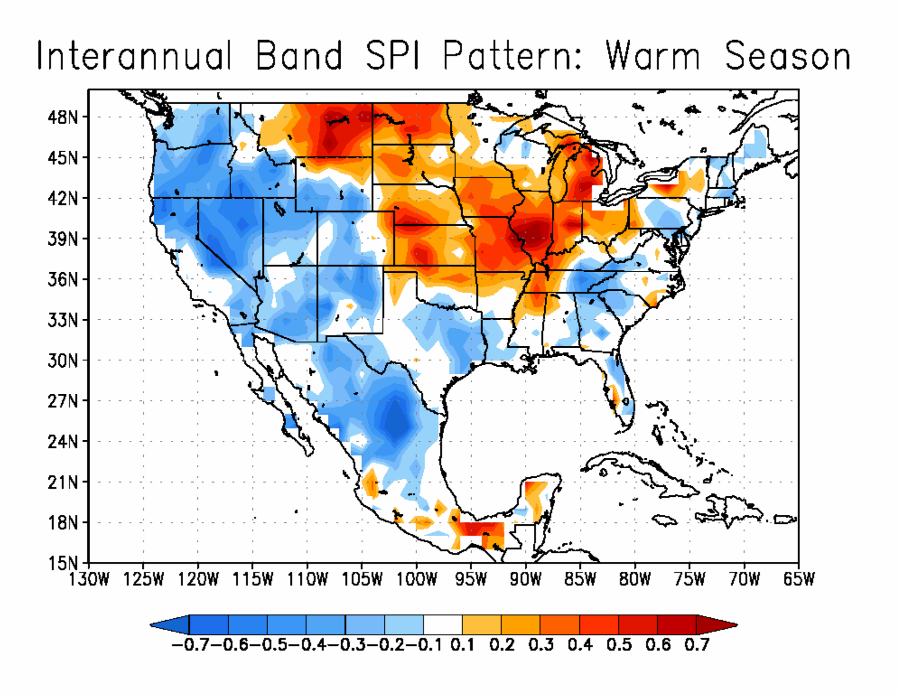
Strange things happen at the U.S.-Mexico border! Does the variability suddenly "disappear" there as the picture suggests? Probably not! *Suggests there may be some quality control issues with the CPC U.S.-Mexico precipitation data—or there's just not enough data for Mexico!*



From GCM experiments, we know these wet and dry periods are tied to tropical Pacific SST forcing. ***Though prior to this record, the most infamous drought in the twentieth century, the Dust Bowl, is a good example (e.g. Schubert et al. 2004).***

Cold and warm season interannual SPI variability is different!



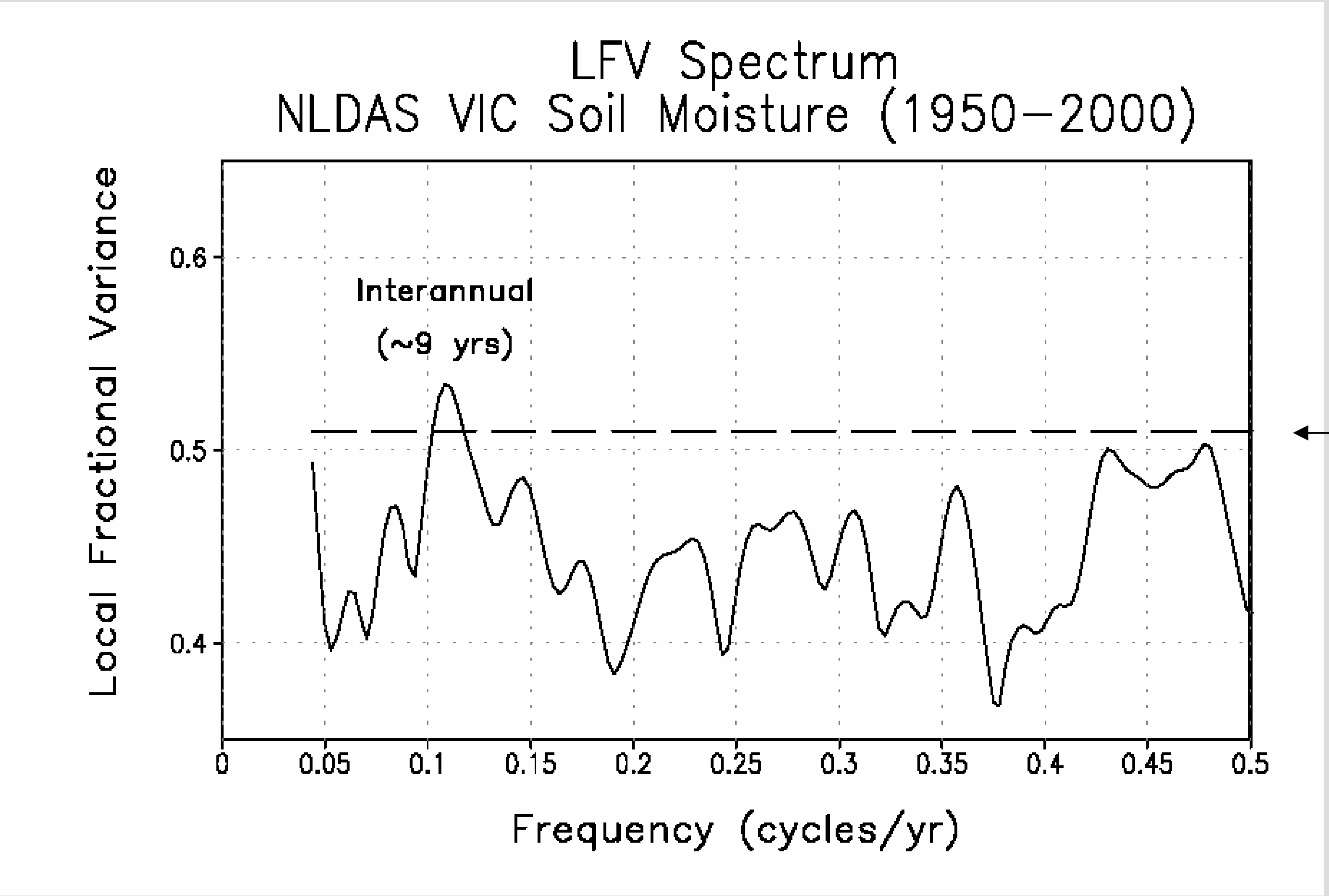


Central U.S. precipitation anomalies vary in the same way throughout the year.

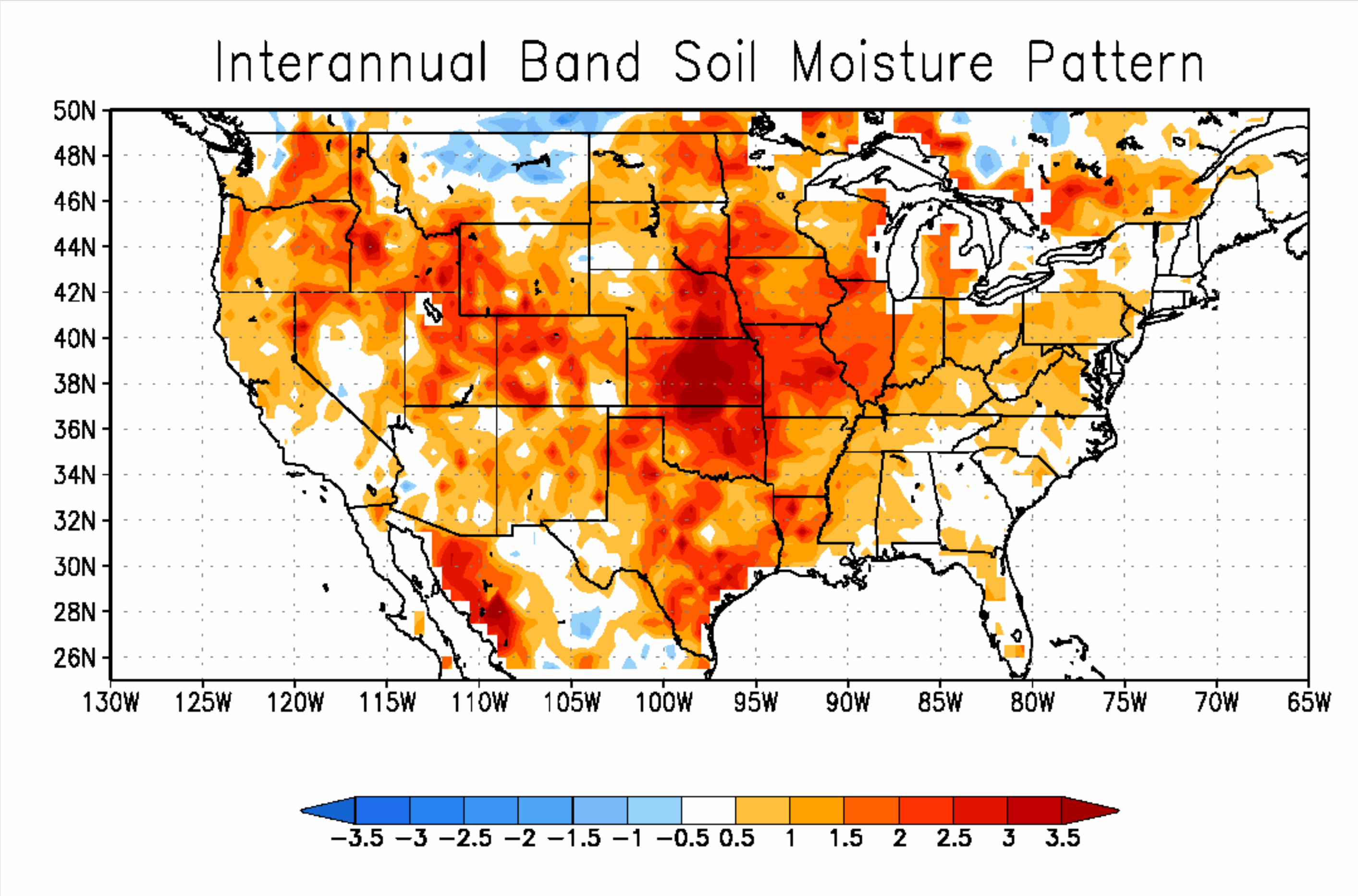
Most dramatic seasonal shift in the sign of precipitation anomalies occurs in the NAMS region. *Reflects a well documented observation*:

Wet winter in Southwest U.S.→ Dry monsoon in Southwest U.S.

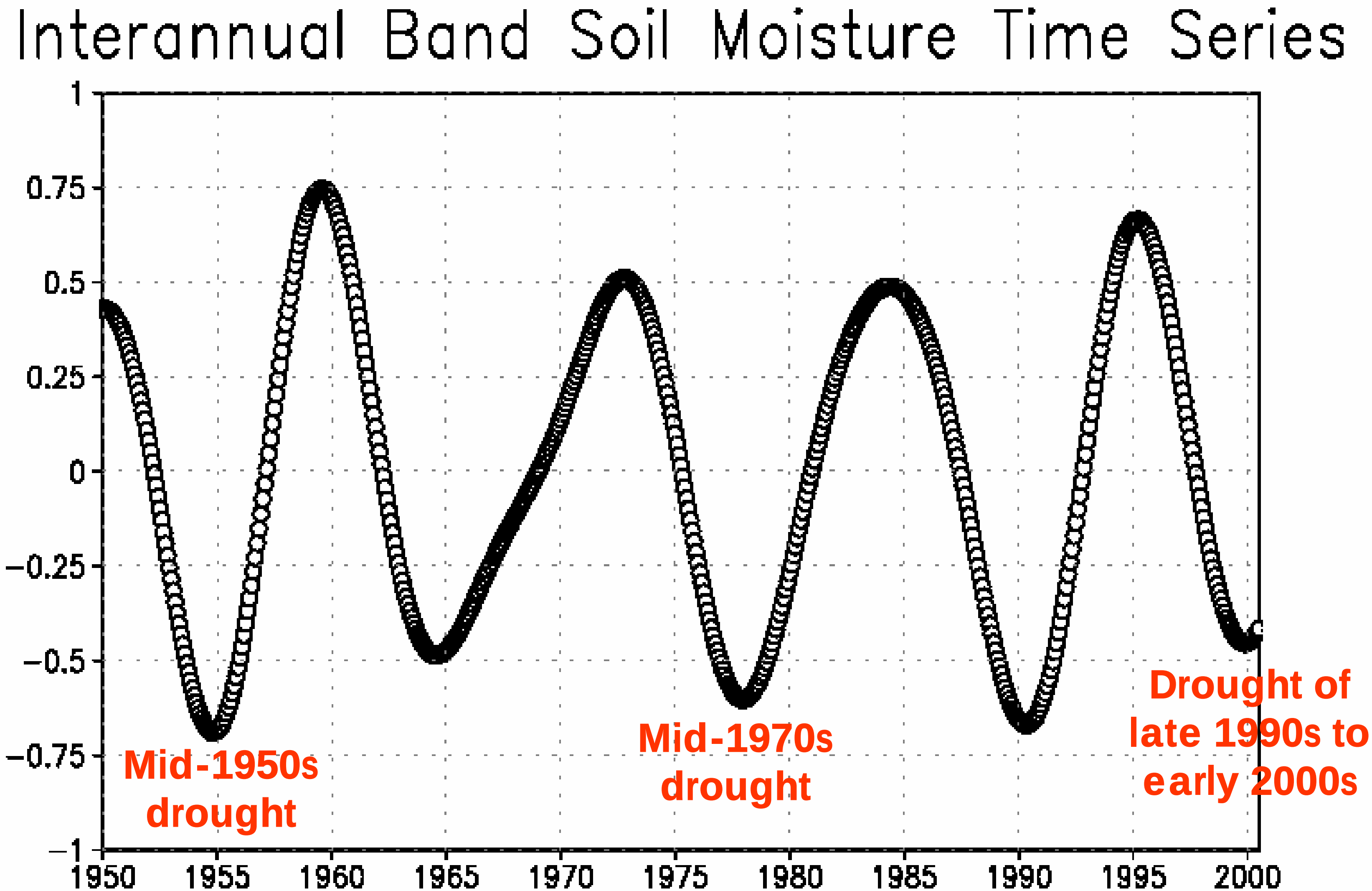
Dry winter in Southwest U.S. → Wet monsoon in Southwest U.S.



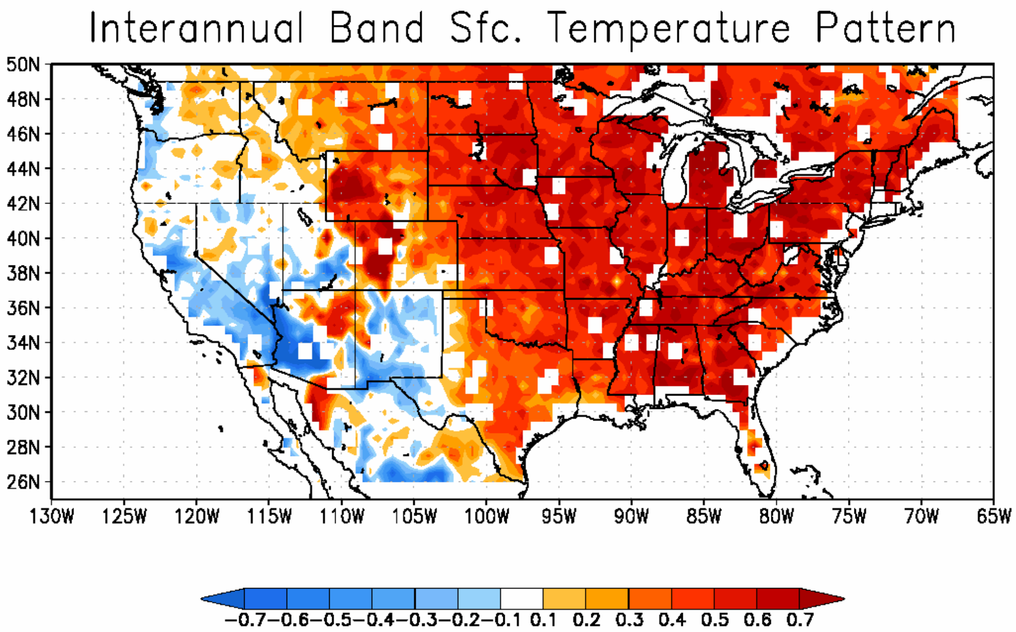
**95 %
confidence
interval**

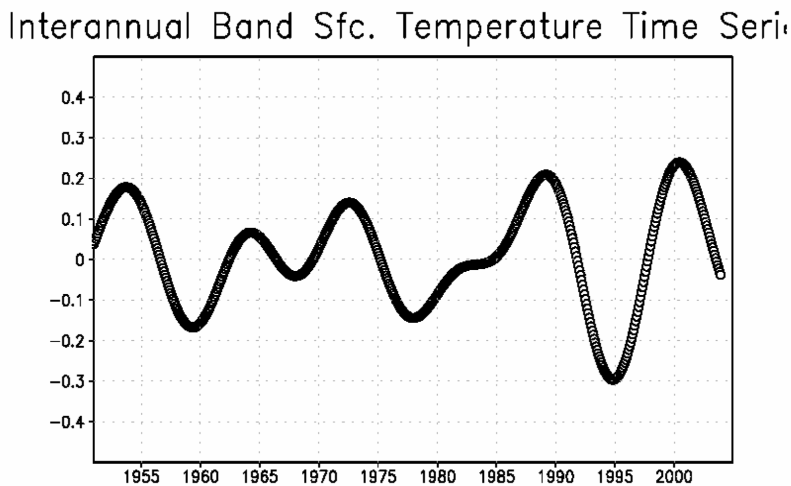


The strongest signal in interannual variability of soil moisture is centered in the central U.S. because precipitation anomalies associated with Pacific SST variability are consistent through an annual cycle there.



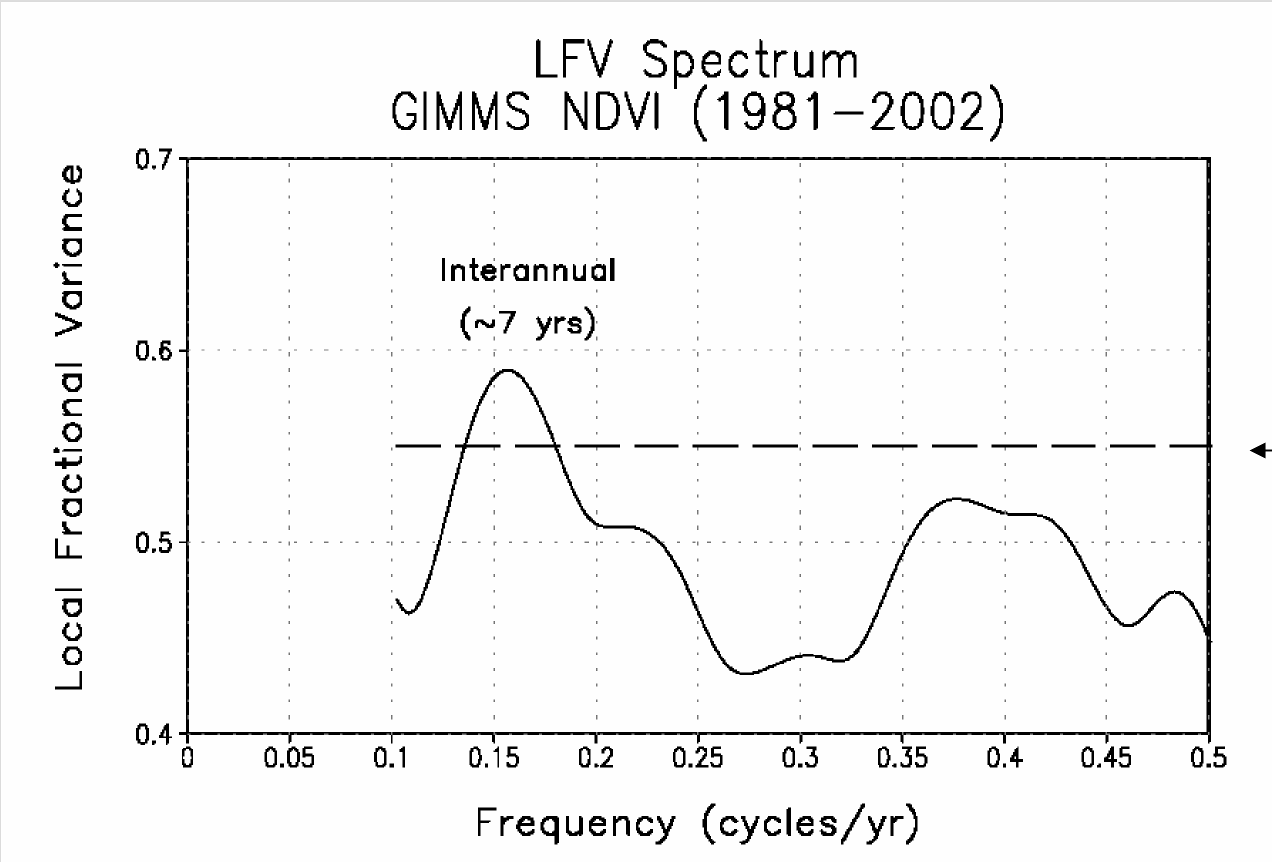
LONG TERM DROUGHTS IN CENTRAL U.S. OCCUR WITH A REGULAR MULTIDECADAL FREQUENCY RELATED TO PACIFIC SST FORCING





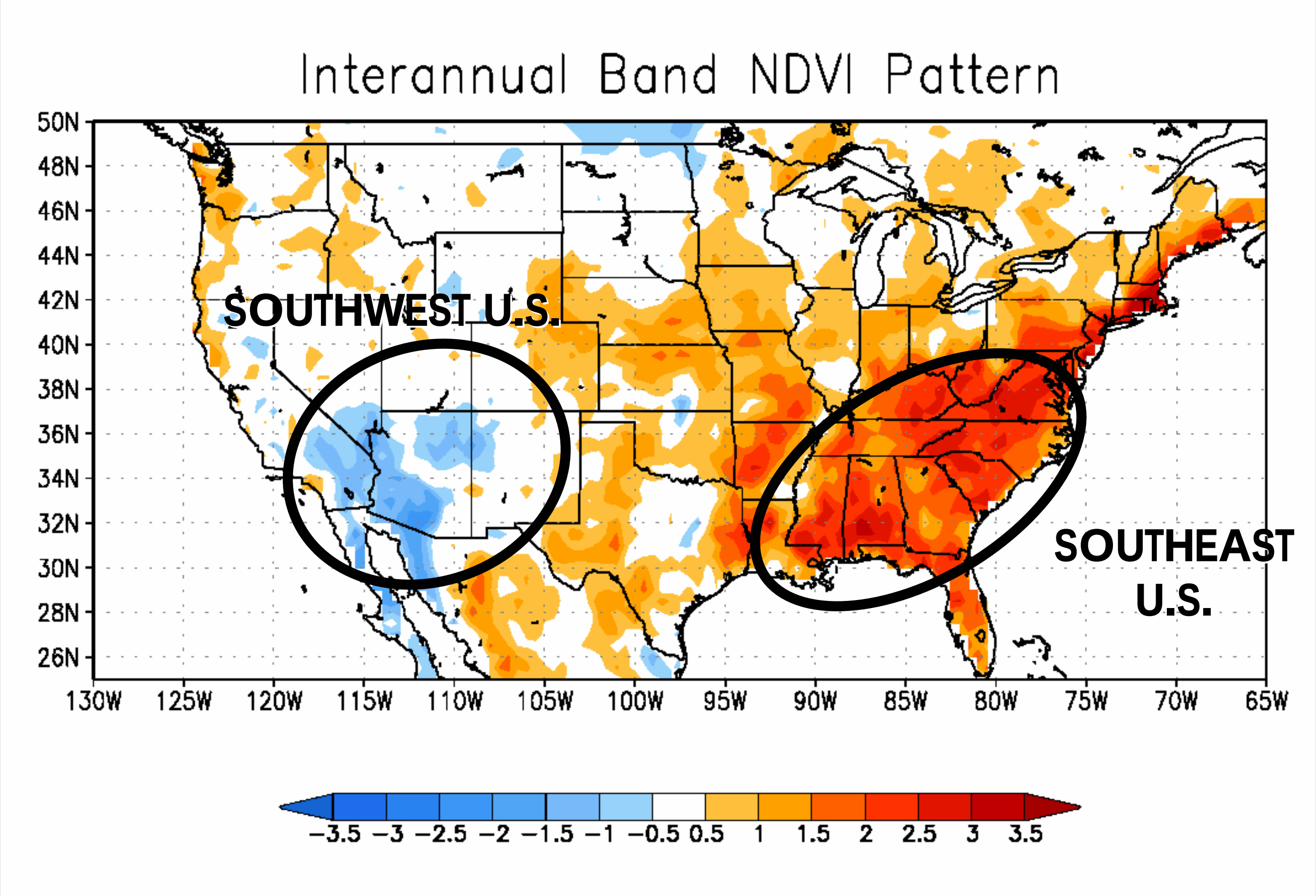
The spatiotemporal pattern of surface temperature variability shows higher temperatures occurring the central U.S. during the most severe drought periods in the past 50 years.

The reverse relationship with the Southwest U.S., suggests this pattern is likely driven by what happens in the warm season.



95 % confidence interval

Keep in mind this is based on a record of only 23 years…so we are probably stretching the limits a bit on trying to tease out the interannual variability.



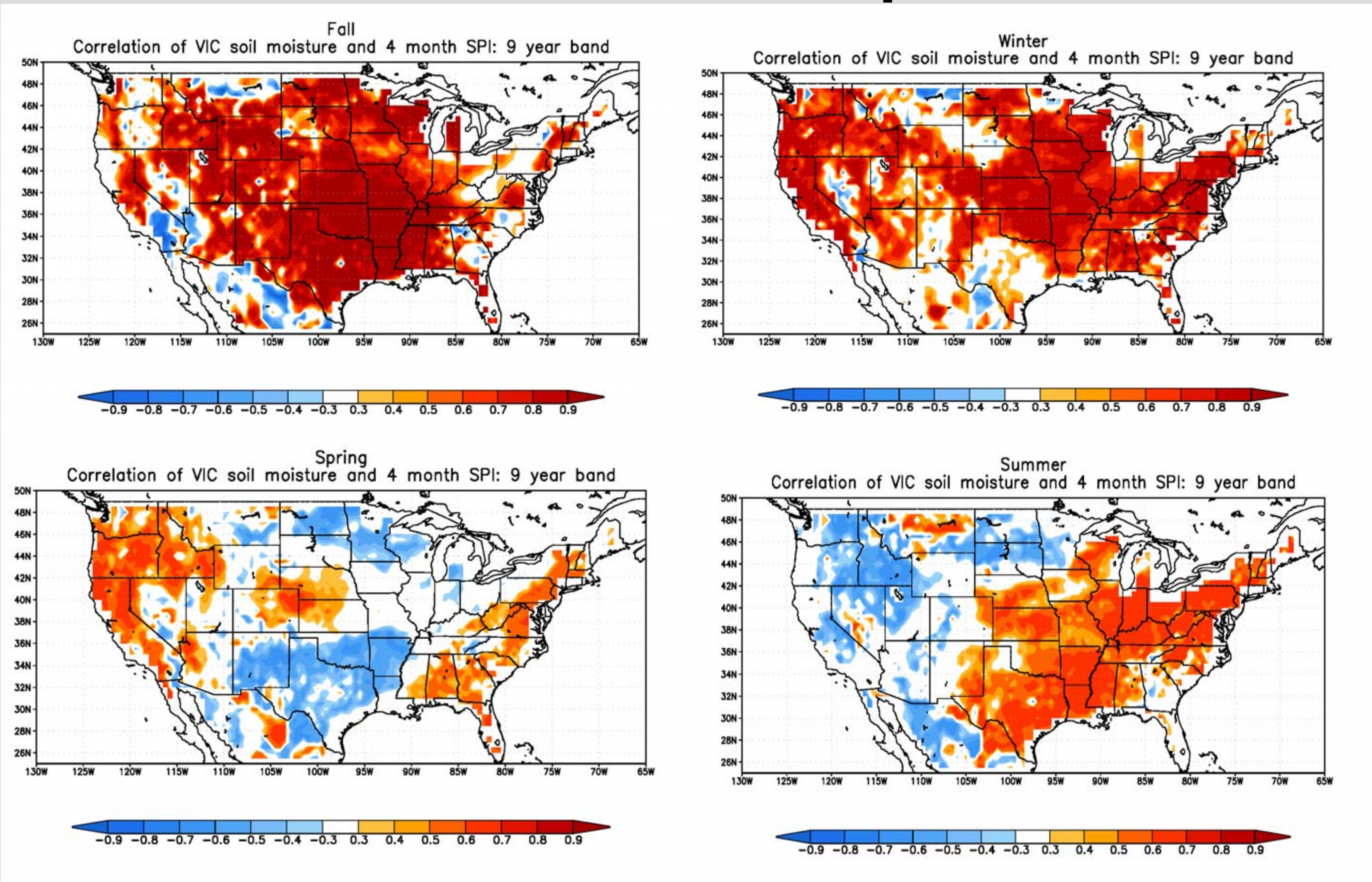
Strongest signal in interannual variability in vegetation greenness occurs in the southeast U.S.

A distinct signal in the NDVI in the Southwest U.S. Could it be tied to monsoon precipitation?

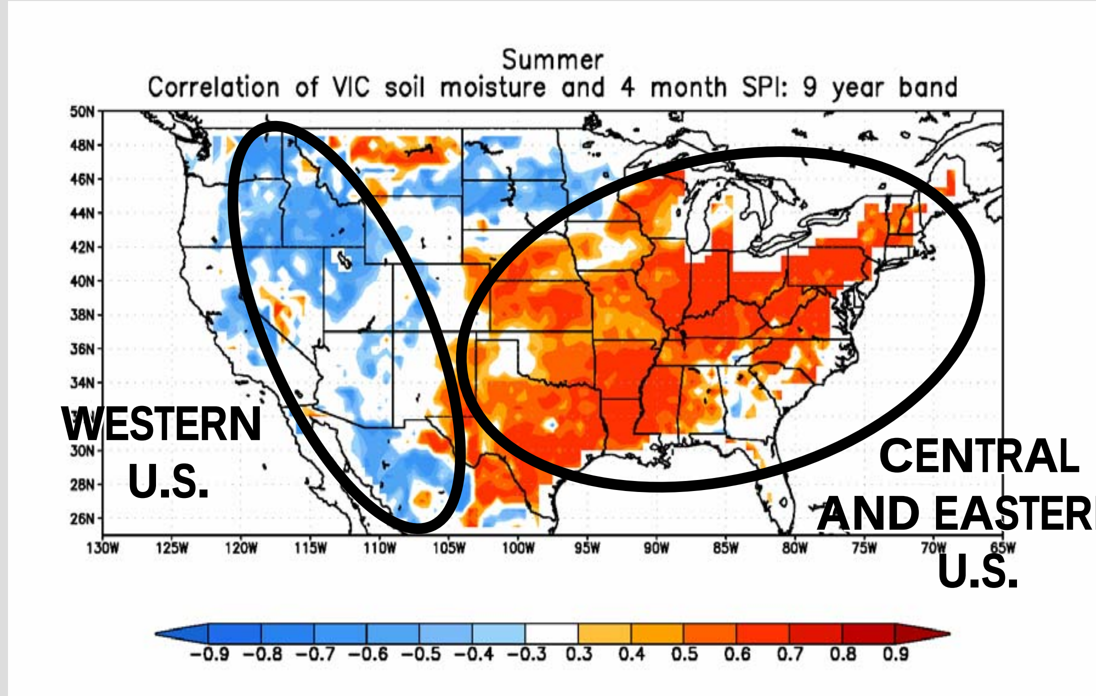
To get some more physical insights, correlation analyses were done for the SPI and land surface variables for the significant time-varying modes.

In this case, we use SPI at a longer timescale (3-4 months) because it correlates better with the raw unfiltered land surface data.

Soil Moisture and SPI correlation on interannual timescale: Cold season more important



Soil Moisture, SPI relationship on interannual timescale: warm season



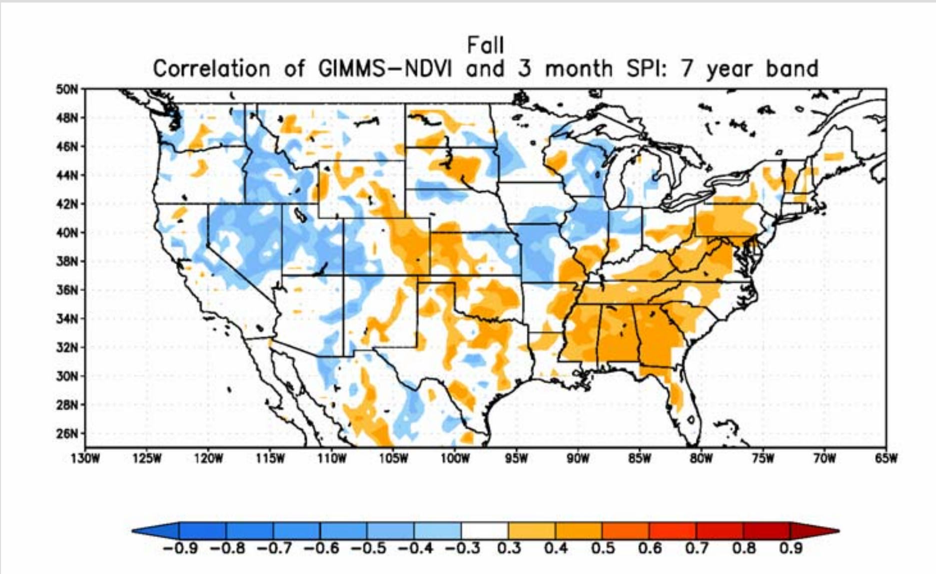
<u>CENTRAL AND EASTERN U.S</u>: Interannual variability in soil moisture positively correlated with interannual variability is warm season rainfall.

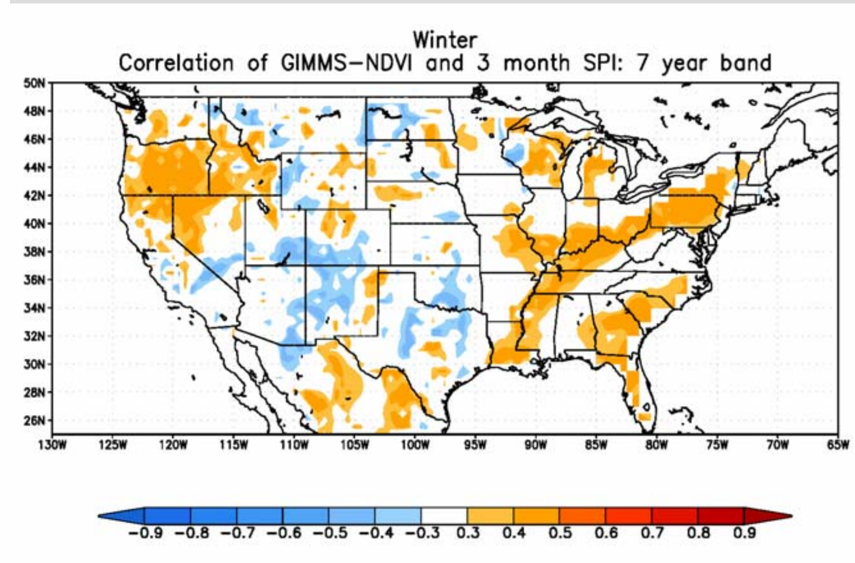
Long-term wetter soil moisture occurs with wet winters, wet summers.

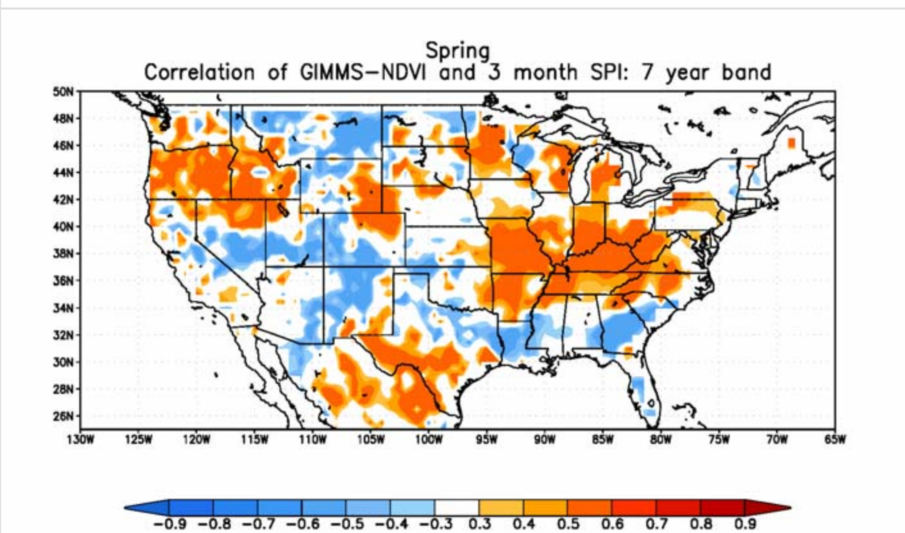
<u>WESTERN U.S (AND NORTHWEST MEXICO)</u>: Interannual variability in soil moisture negatively correlated with interannual variability in warm season rainfall.

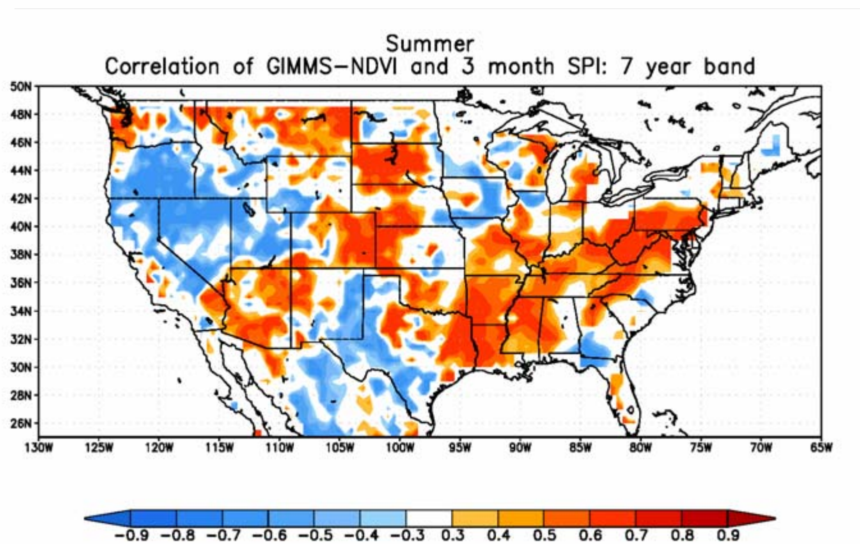
Long-term wetter soil moisture occurs with wet winters, dry summers.

NDVI and SPI correlation on interannual timescale: warm season more important

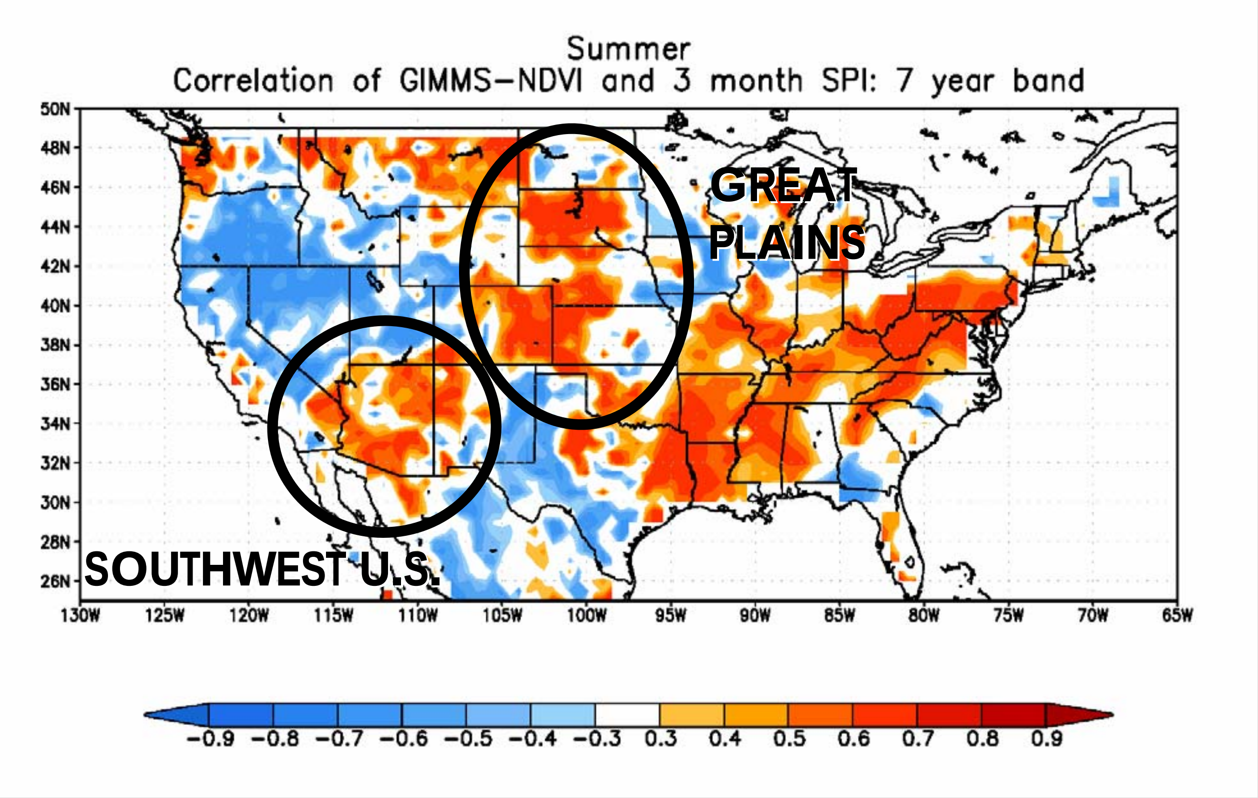








NDVI, SPI relationship on interannual timescale: warm season



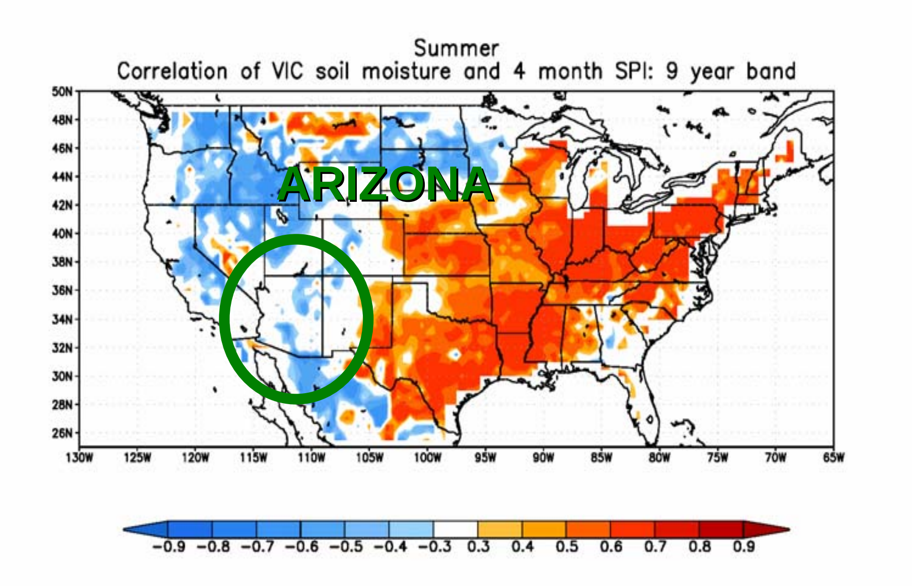
GREAT PLAINS: Interannual variability in vegetation greenness positively correlated with interannual variability in warm season rainfall.

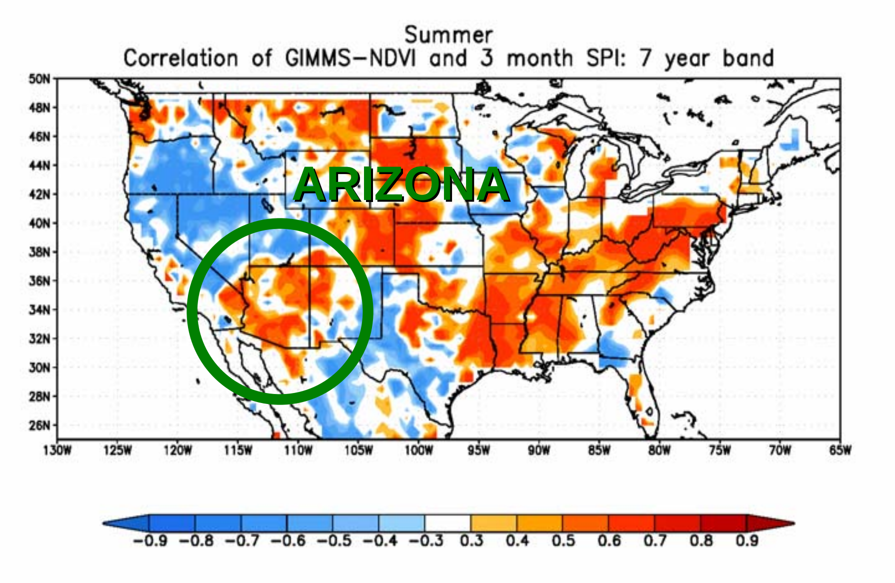
Long-term greener vegetation occurs with wet winters, wet summers.

SOUTHWEST U.S.: Interannual variability in vegetation greenness positively correlated with interannual variability in warm season rainfall.

Long-term greener vegetation occurs with dry winters, wet summers.

Implications for the monsoon in Arizona?



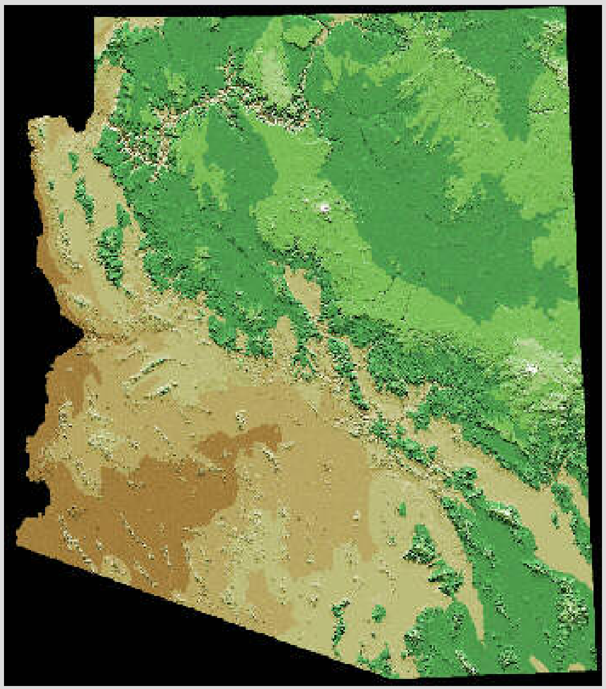


SOIL MOISTURE: Wet (dry) monsoons more likely to be associated with lower (higher) than average soil moisture on interannual time scales, *since the soil moisture signal is tied to winter precipitation.*

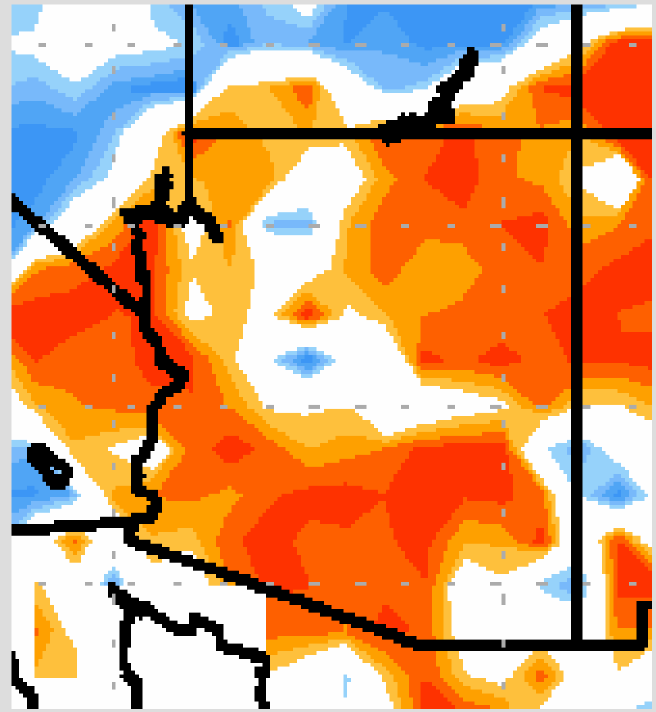
VEGETATION: Wet (dry) monsoons are more likely to be associated with higher (lower) than average vegetation on interannual time scales, *since the vegetation signal is tied to summer precipitation.*

There's elevation dependence too, especially for vegetation!

Topography of Arizona



NDVI covariability with precipitation on interannual timescale



The stronger signal with respect to interannual variability in NDVI in Arizona occurs at lower elevation, *where the precipitation is more intraseasonally variable and more related to large-scale forcing mechanisms, as opposed to the topographically forced diurnal convection. Makes physical sense!*

Conclusions and Future Work

The land surface likely interacts synergistically with remote forcing in the summer by acting as an integrator of longer-term atmospheric variability. As a first step toward testing this hypothesis in North America, the present study statistically characterized the spatiotemporal variability of the atmospheric forcing and land surface there.

The atmospheric and land surface datasets all have significant spatiotemporal variability at a timescale of 7-9 years.

Interannual variability in precipitation dramatically changes between winter and summer, consistent with known ENSO-PDO variability.

Soil moisture is driven primarily by cold season precipitation and is maximized in the central U.S. since the sign of precipitation anomalies there is consistent through an annual cycle. Vegetation is driven primarily by warm season precipitation. These relationships make physical sense given prior understanding of North American precipitation in the warm season, such as for the central U.S. and core monsoon regions.

Future work will test how interannual variability in soil moisture and vegetation affect climate in extreme summers in the 1950-2002 record with a RCM.

¡MUCHAS GRACIAS!