Mechanism behind the spring to summer drought memory and its impact on predictability of the summer drought over US Great Plains

Rong Fu,
Bing Pu, Robert Dickinson, Nelun Fernando

Jackson School of Geosciences, The University of Texas at Austin

The 39th Annual Climate Diagnostics and Prediction Workshop

St. Louis, Missouri, October 20-23, 2014

Predicting/projecting drought over US Great Plains is important for US economy and global food security

The New York Times

Business Day

WORLD | U.S. | N.Y. / REGION | BUSINESS | TECHNOLOGY | SCIENCE | HEALTH

Search | Global | DealBook | Markets | Economy

Severe Drought Seen as Driving Cost of Food Up

Neil Hamm/Associated Press

Rows of corn stalks in a field south of Blair, Neb., this week. The drought-damaged field was cut down for silage.

By ANNIE LOWREY and RON NIXON

Published: July 25, 2012 | 407 Comments

WASHINGTON — Scorching heat and the worst drought in nearly a half-century are threatening to send food prices up, spooking consumers and leading to worries about global food costs.

FACEBOOK

TWITTER

GOOGLE+

EMAIL

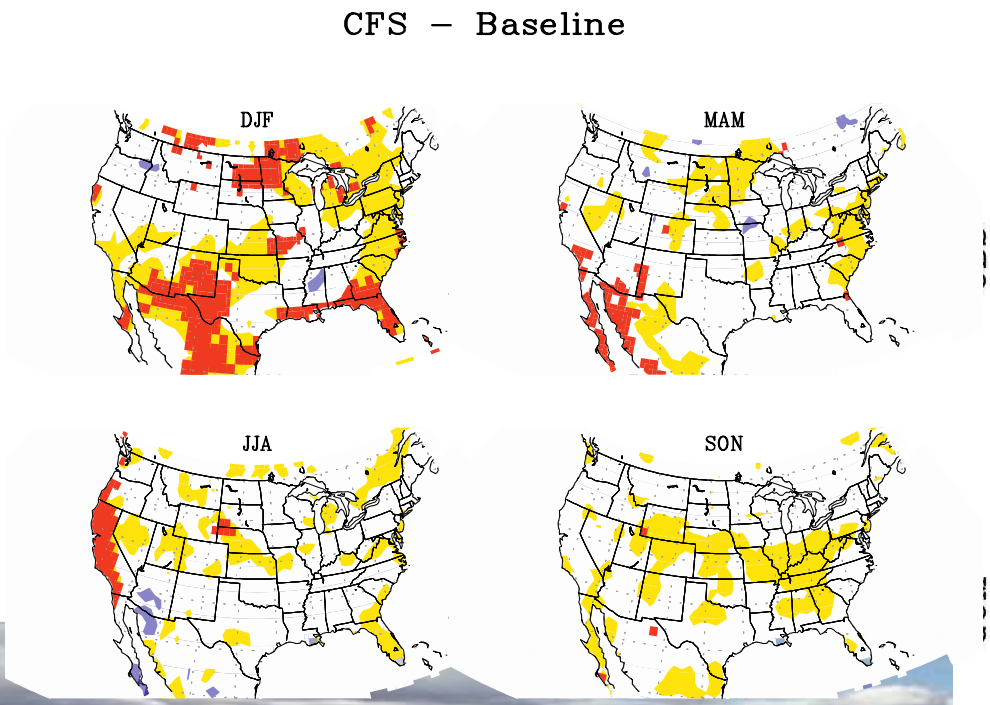
- Drought is among the most damaging and least understood of all natural hazards (http://www.drought.gov/drought;

- During 1980-2011: droughts with economic lost of >$1B occurred in 16 out of 21 years in US, with estimated annual averaged direct drought losess of $9.6B (adjusted to 2011 dollars, Smith and Katz 2013).

- 2012 US drought lead to 6% of price increase in food, and 23% increase in corn in global market in July 2012 (CNN Money, UN report)

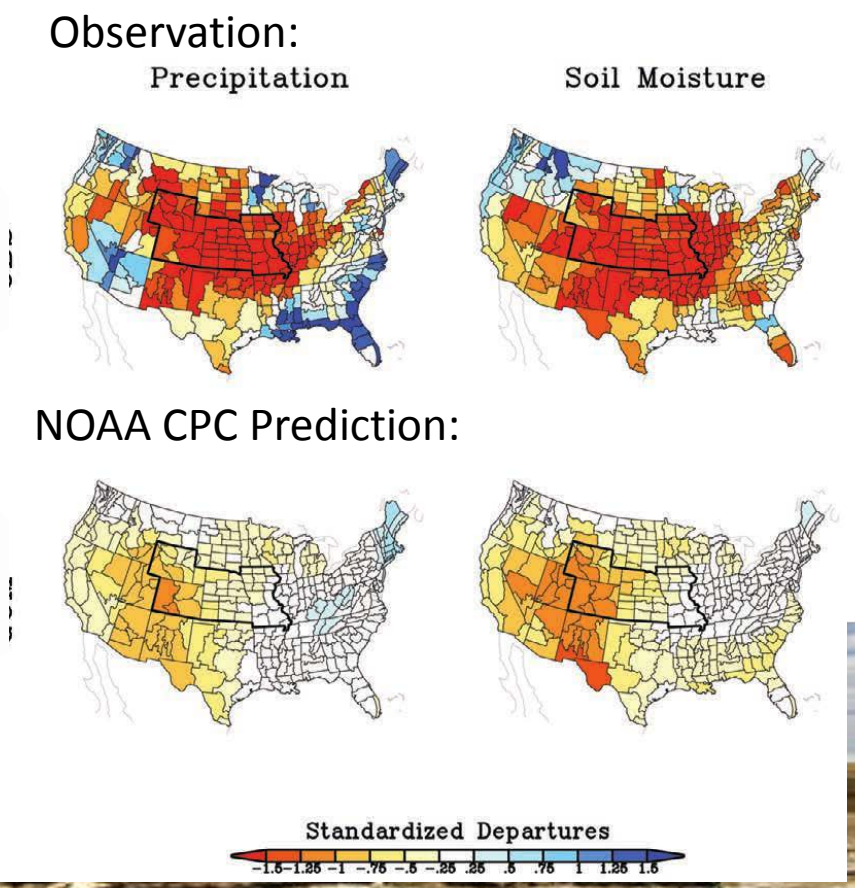
- **Seasonal forecast unable to predict major summer droughts in recent years, and does not show more skill than autocorrelation (Guan et al. 2012; Hoerling et al. 2013).**

Guan et al. 2012:

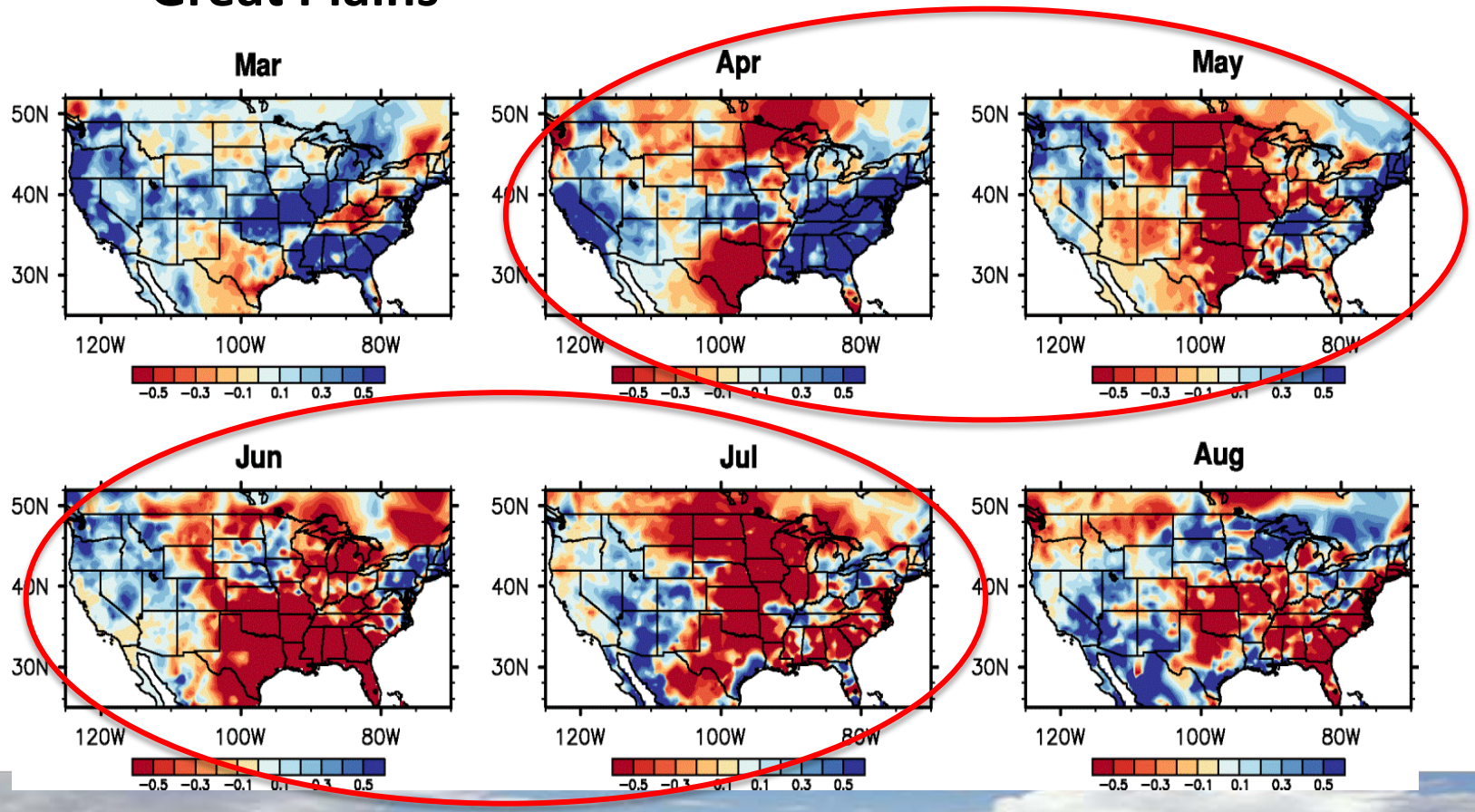


recast SPI6 skill and the baseline SPI6 skill.

Hoerling et al. 2013, BAMS:



- **Observations show persistent rainfall deficit from May-August during summer droughts over US Great Plains**

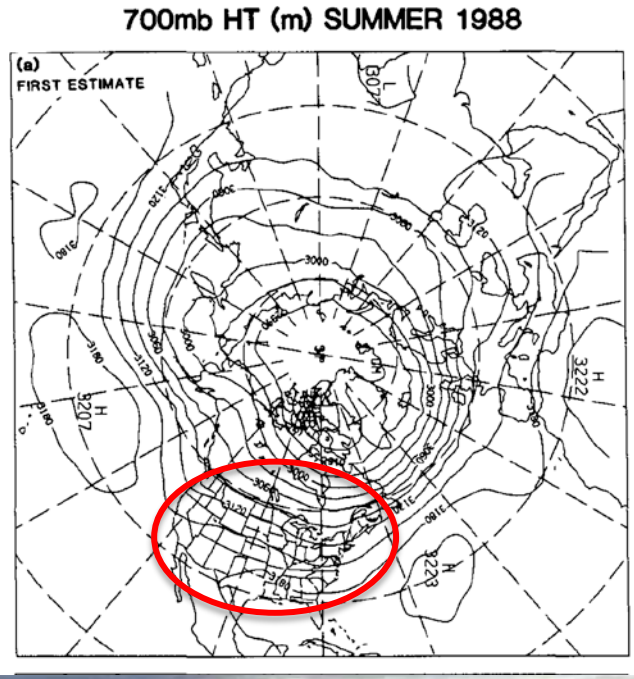


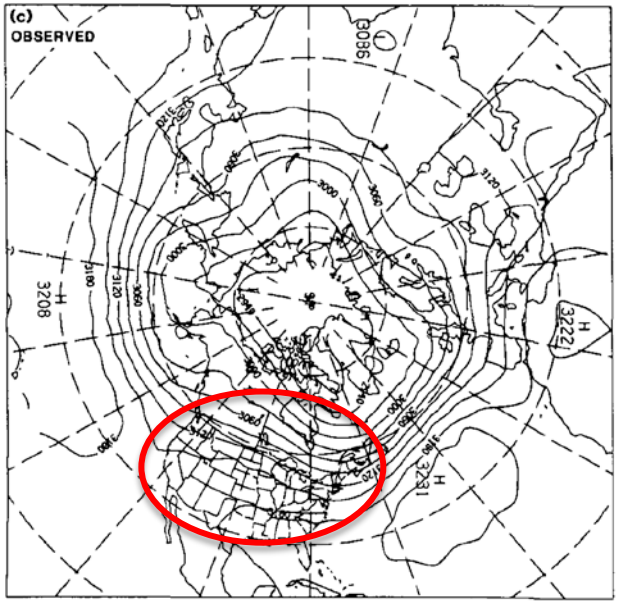
- *Composite of rainfall (mm/day) for SGP dry years (1949-2012)*

Observations: Drought persistence can potentially improve drought predictability

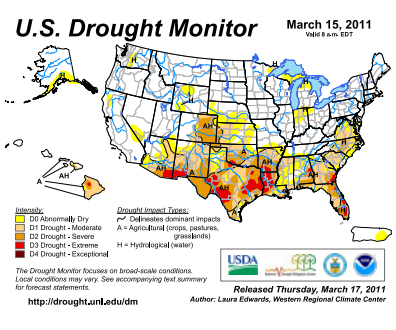
Namias 1982; 1991:

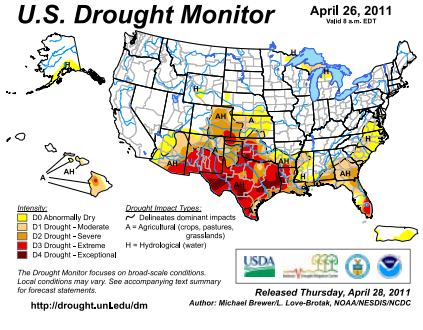
- ***Persistence of the drought circulation anomalies from March to June provides reasonable good predictability for 1980 and 1988 summer droughts.***

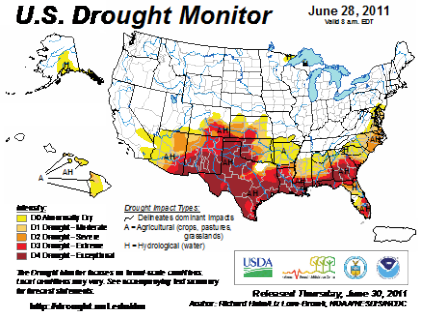


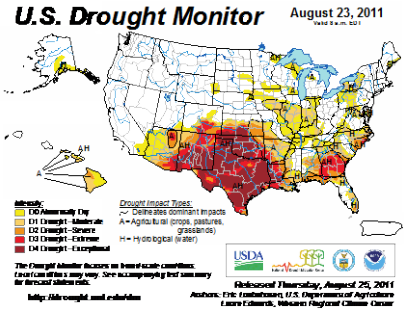


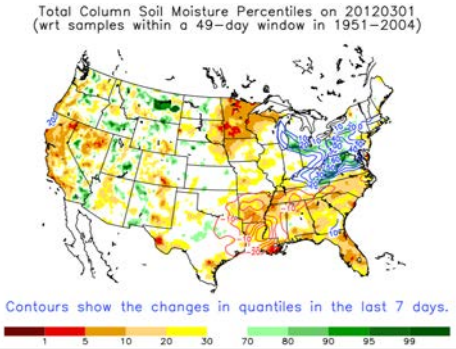
- ***However, soil moisture deficit does not persist for > 1 month in seasonal prediction.***

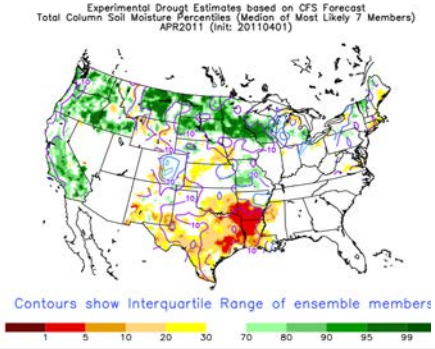


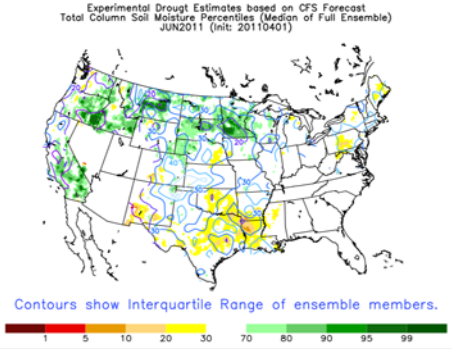


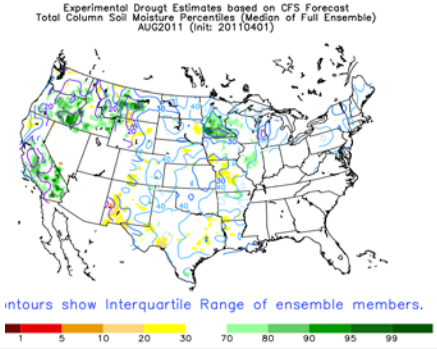












- ***What cause apparent drought memory from spring to summer in observations?***

- ***Why climate models cannot capture such apparent drought memory?***

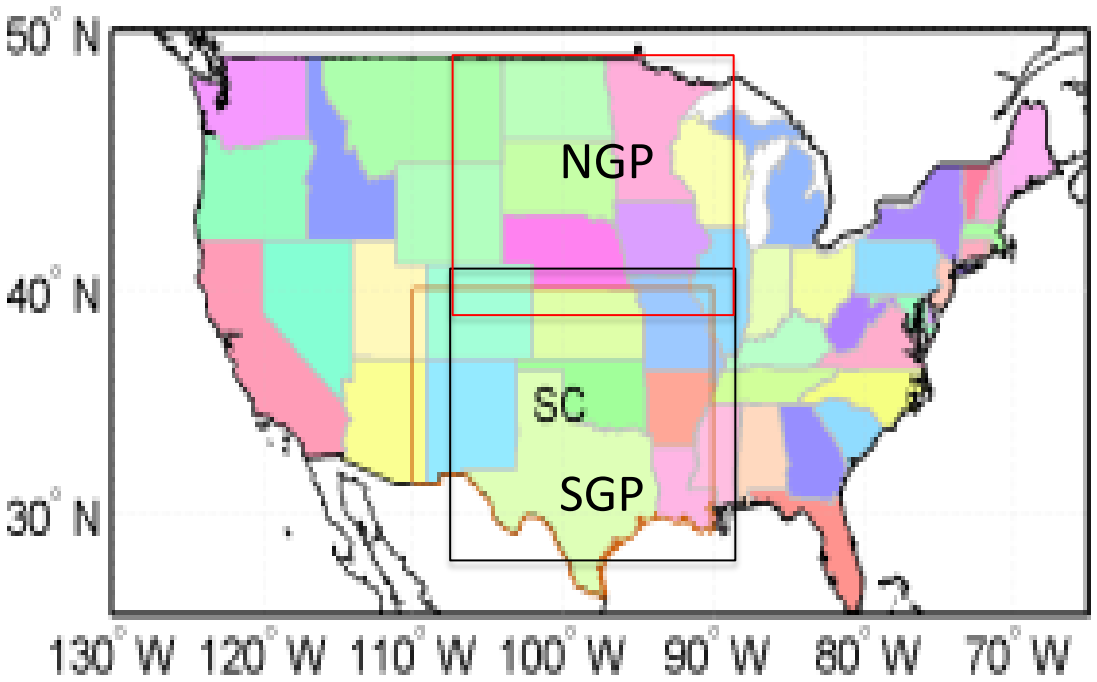
Main hypothesis

- ***Land-atmospheric coupling, through cloud radiative and precipitation feedbacks, play an important role in maintaining and re-enforcing large-scale subsidence and surface dryness, leading to persist drought memory over the US Great Plains.***

- ***Error in representing such cloud feedbacks and mean summer circulation in climate models could be important, but overlooked, contributors to the low skill and large uncertainty in predicting and projecting summer drought over this region.***

Southern and Northern Great Plains Domains:

- SGP: 92-110W, 25-40
- NGP: 92-110W, 38-50N



Datasets:

- ***North American Regional Reanalysis (NARR), soil moisture, 0.25 by 0.25 degree, daily, from, 3hourly from Jan. 1979-Dec. 2013, about 32 km resolution.***
- ***NCEP/NCAR reanalysis-1: 2.5 by 2.5 degree, monthly from Jan.1948-Dec. 2013***
- ***CRU TS3.21 precipitation, 0.5 by 0.5 degree, monthly from Jan. 1901- Dec. 2012***
- ***Essential Climate Variable (ECV) soil moisture data***

- ***Merged product from blending active and passive soil moisture products, derived from SMMR, SSM/I, TMI and ASMR-E , AMI-WS and ASCAT***

- ***IRI Analyses SPI SPI-CAMSOPI_6-Month***

- ***MERRA reanalysis-IAU 3d radiation diagnostics***
- ***CERES surface and atmospheric radiative fluxes: 2002-2011***
- ***ISCCP C2 data: 1983-2009***
- ***CloudSat-Calipso-MODIS merged cloud profile data: 2006-2011***
- ***TRMM latent heating profiles: 1998-2010***

Analysis periods: 1979-2012 for most of the analyses
CERES (2000-), TRMM (1999-)

What are the relative roles among these factors?

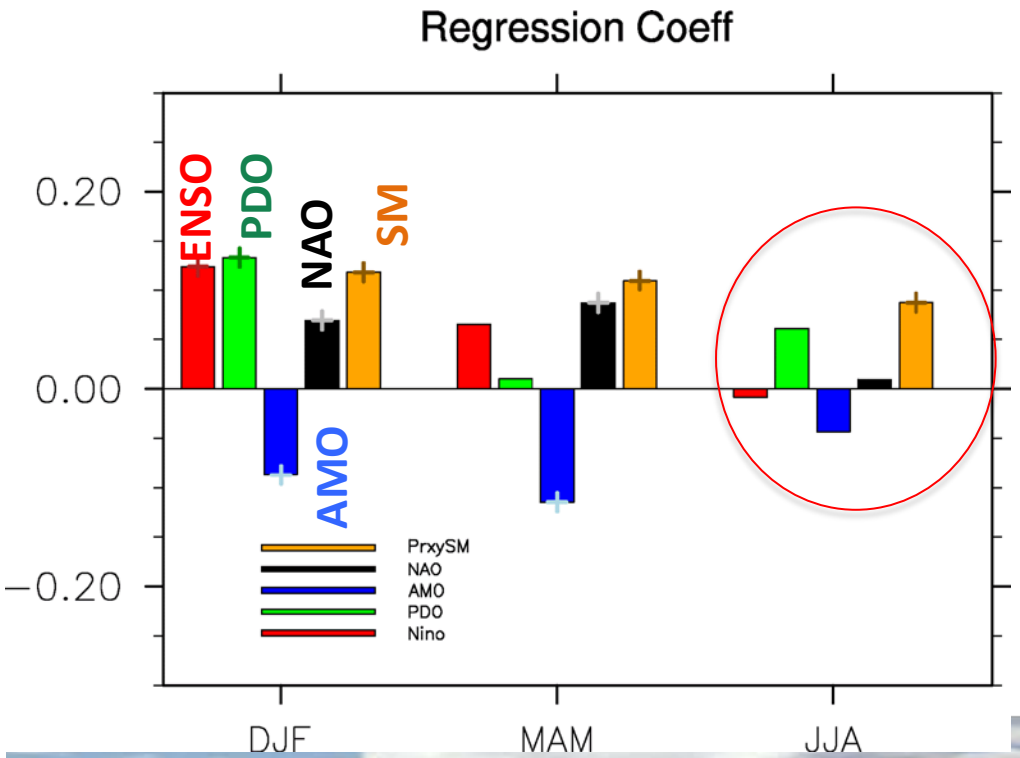
Causes of the droughts over US Great Plain reported in the literature:

- ***ENSO**: e.g., Trenberth et al 1988; Lau and Peng 1990; Cayan et al. 1999; Hoerling and Kumar 2003, and many more.*
- ***Combined tropical Atlantic and Pacific:** e.g., McCabe et al 2004; Hu and Feng 2008; Mo et al. 2009; Kushnir et al. 2010; Nigam et al. 2012.*
- ***North Pacific and Atlantic:** Namias 1982: Sutton and Hodson 2005;*
- ***Atmospheric internal variability**: Seager et al. 2013; Hoerling et al. 2013, Wang et al. 2014.*
- ***Soil moisture/vegetation feedback**: Namias 1959, 62, 82; 1991, Karl 1983; Carson and Sangster 1981, Rind 1982; Mintz 1984; Ogelsby and Erickson 1989; Oglesby 1991, Dirmeyer 1994; Hong and Kalnay 2000; Schubert et al. 2004; Myoung and Nelisen-Gammon 2010)*

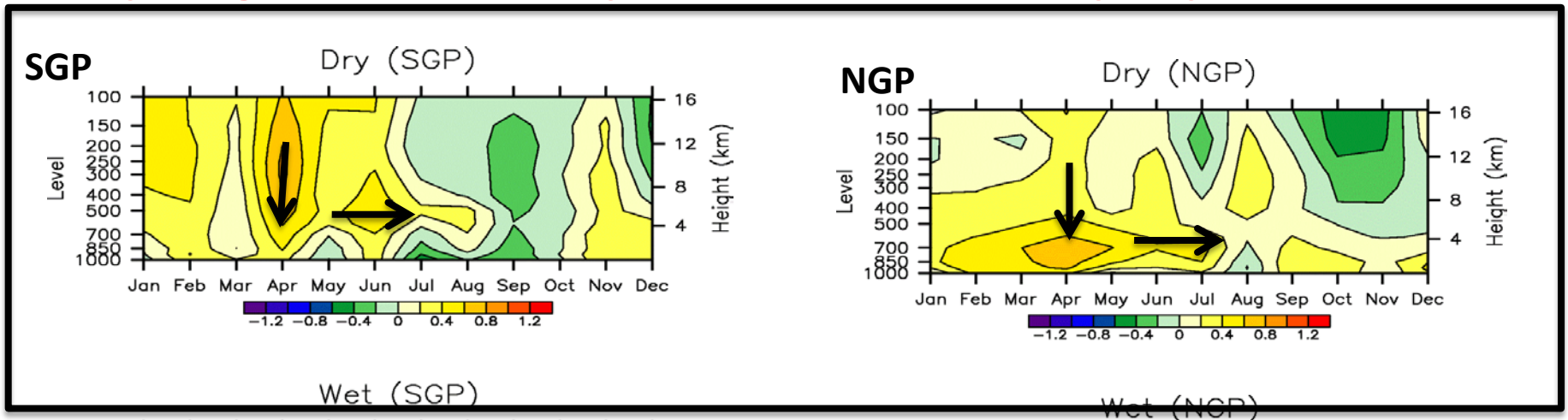
Relative importance among various factors:

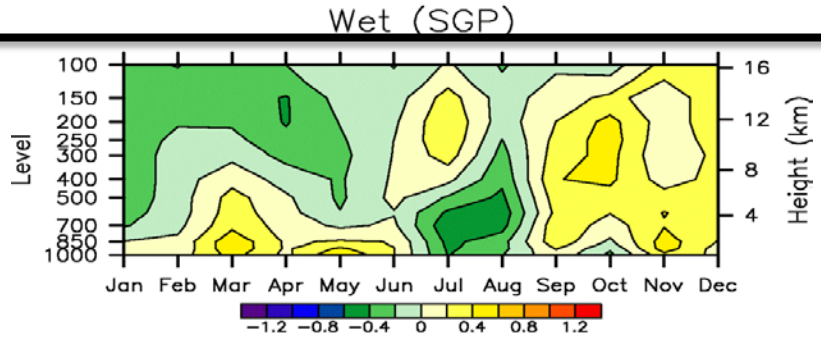
- ***Droughts in winter and spring are as much correlated with SSTA as with soil moisture of the previous seasons.***
- ***Summer drought is more correlated with soil moisture than with SSTA (negative PDO) in spring.***
- ***Drought is positively correlated with soil moisture anomalies in previous season in all seasons.***

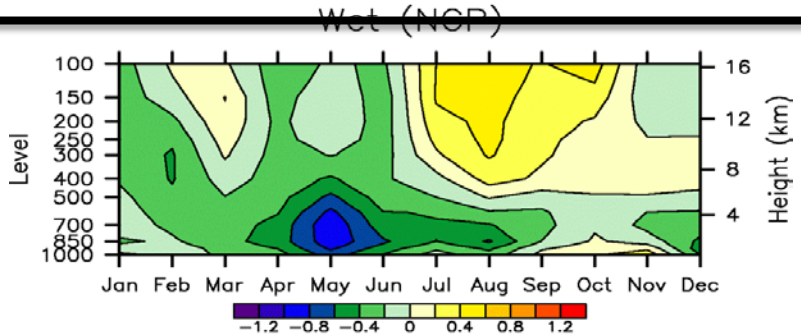
One-season lag regression of seasonal mean rainfall over SGP

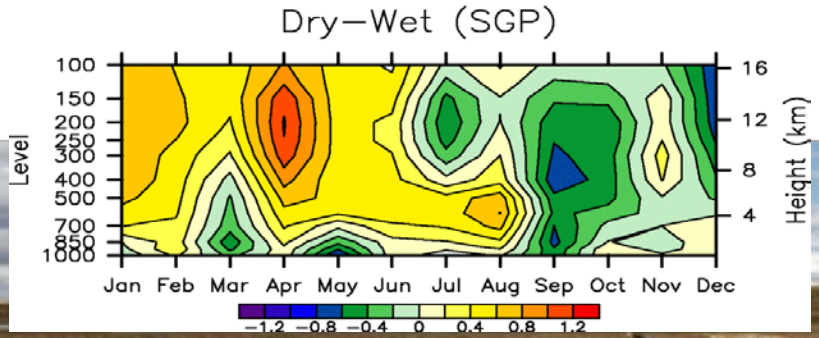


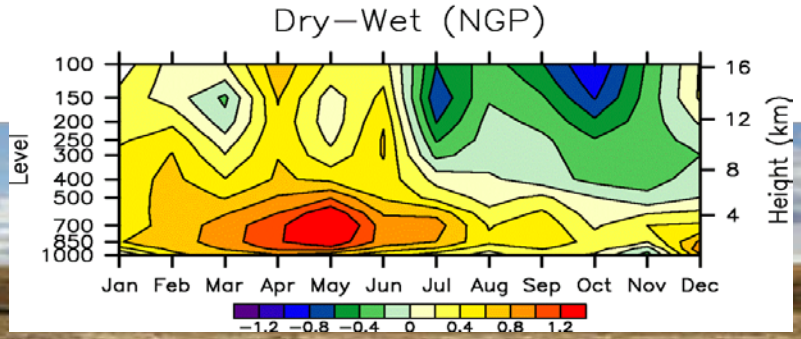
Drought signal originate from upper troposphere in spring, then developed in low-mid troposphere:



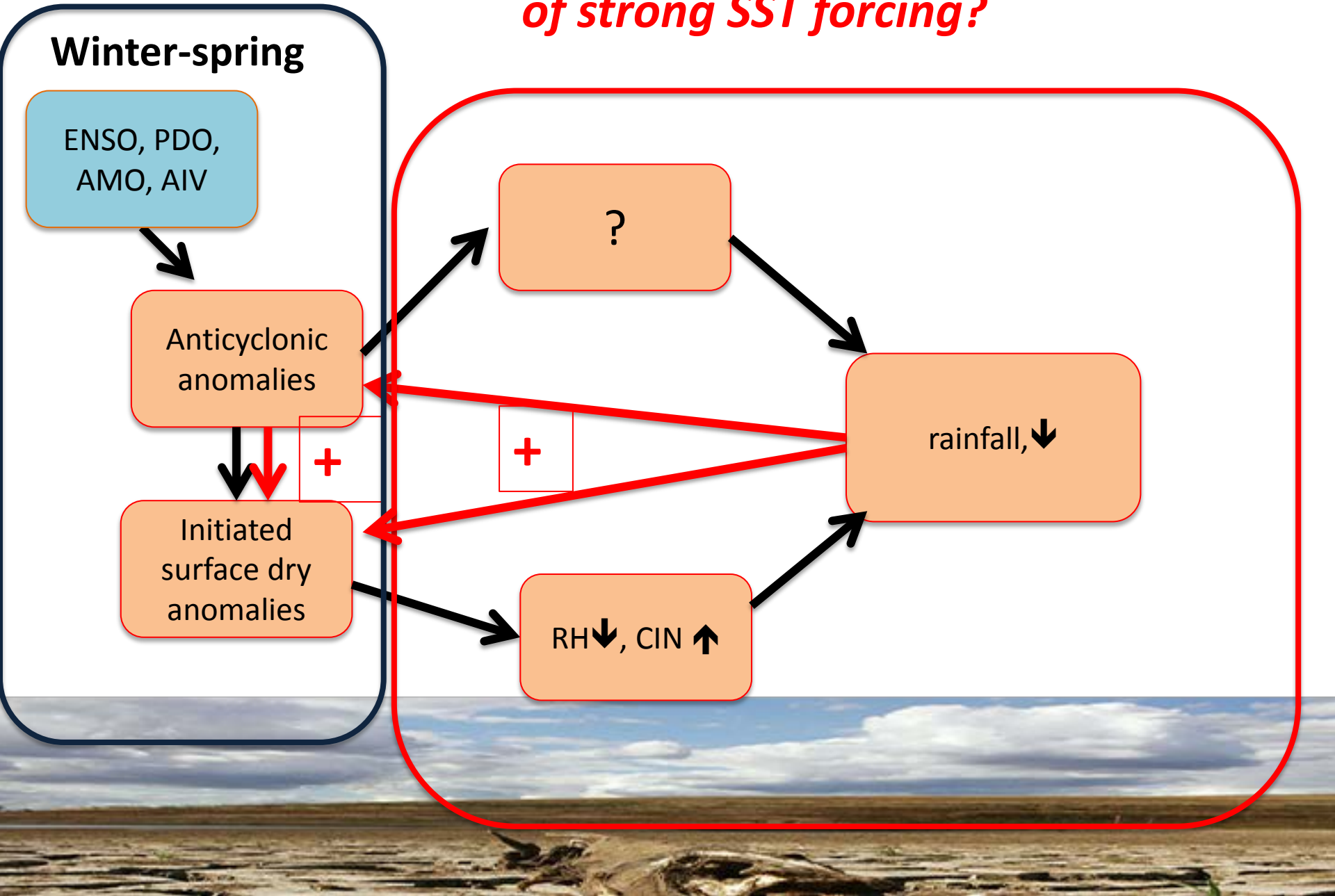




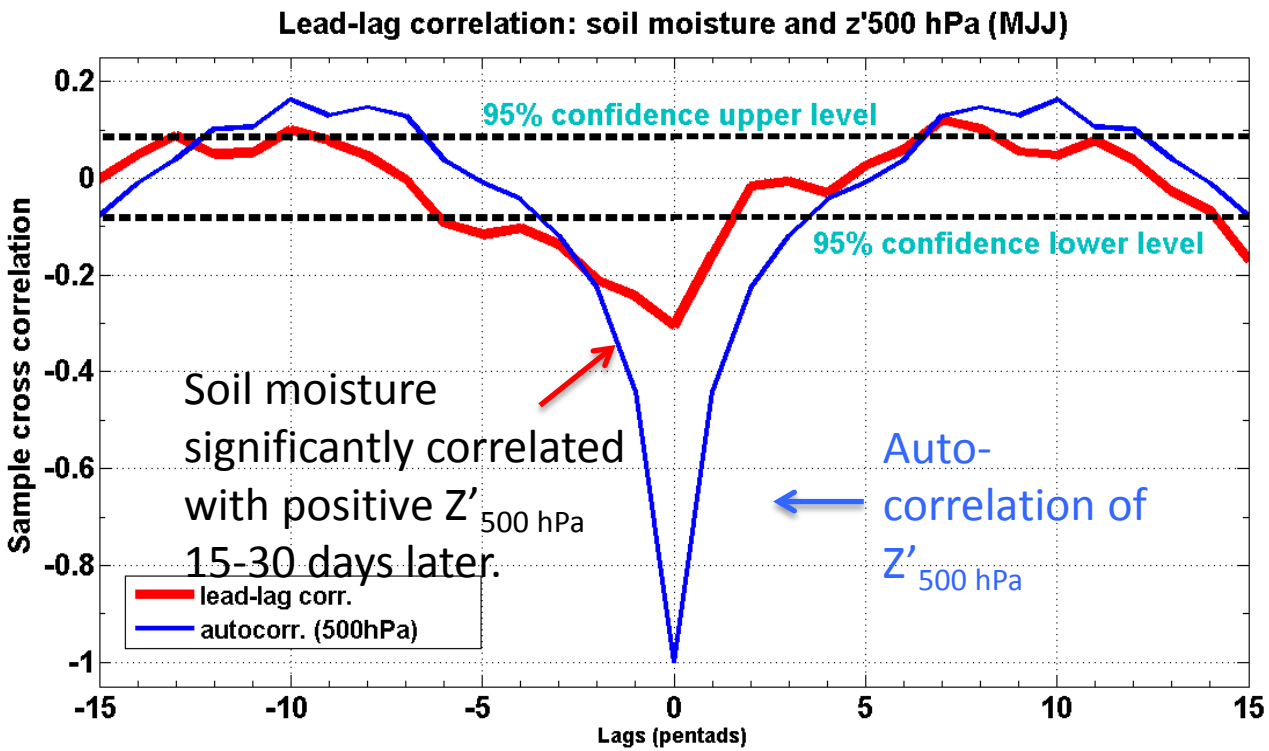




What cause persistent drought in absence of strong SST forcing?



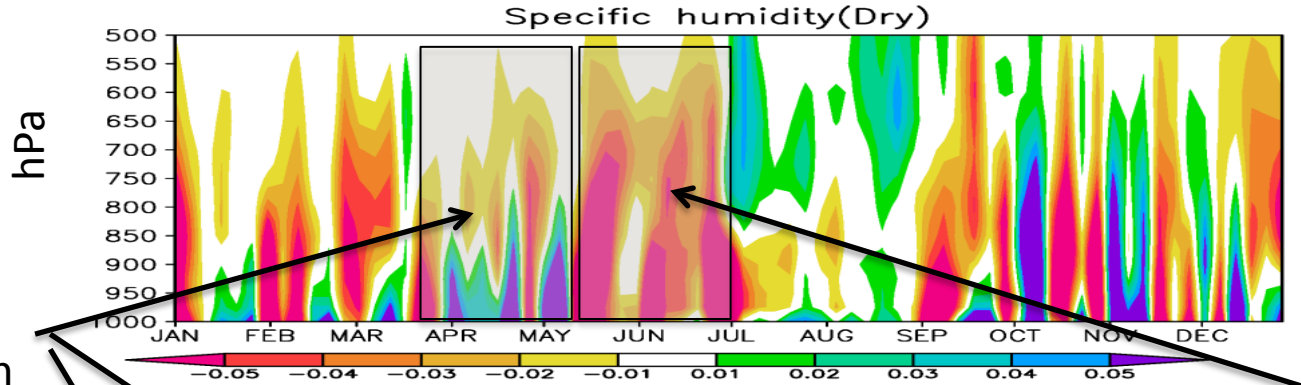
Dry soil moisture anomalies may re-enforce anomalous mid-tropospheric high during spring-summer.



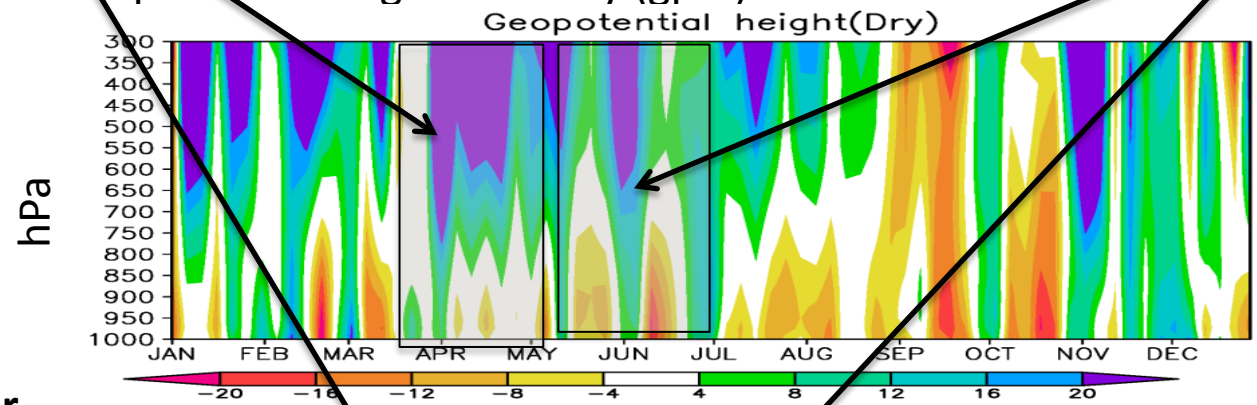
Soil moisture feedback may significantly influence circulation at 2-4 weeks time scale.

SGP:

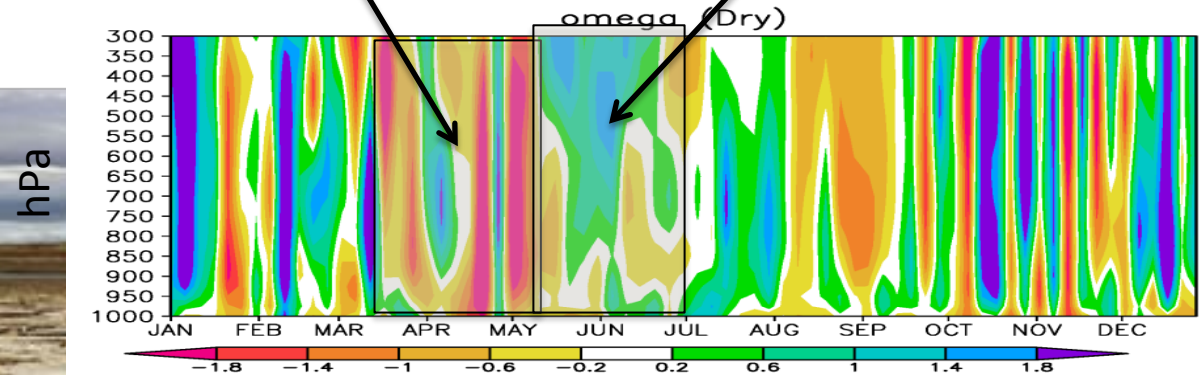
Specific humidify anomaly (10^{-2}kg/kg)



Geopotential height anomaly (gpm)



Vertical wind anomaly (10^{-2} Pa/s)



Anticyclonic anomalies in spring leads to drier mid-troposphere

Intensified drying and subsidence despite of weaker high anomalies

Composite anomalies for summer drought years

What maintain persistent subsidence in summer?

Anomalous diabatic cooling is needed to balance adiabatic warming to maintain persistent subsidence.

$$\frac{\partial \bar{T}}{\partial t} = \frac{\bar{Q}}{C_p} - \left(\frac{p}{p_0}\right)^{\kappa} \bar{\omega} \frac{\partial \bar{\theta}}{\partial p} - \bar{v} \cdot \cancel{\nabla_p} \bar{T} - \left(\frac{p}{p_0}\right)^{\kappa} \frac{\partial}{\partial p}\left(\overline{\omega' \theta'}\right) - \nabla_p \cdot \left(\cancel{\overline{v' T'}}\right)$$

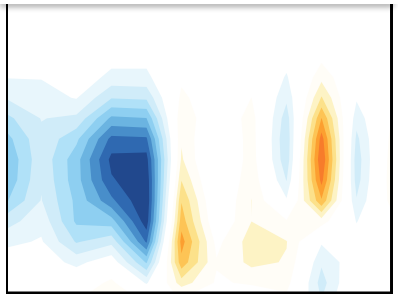
In subtropics or mid-latitudes summer:

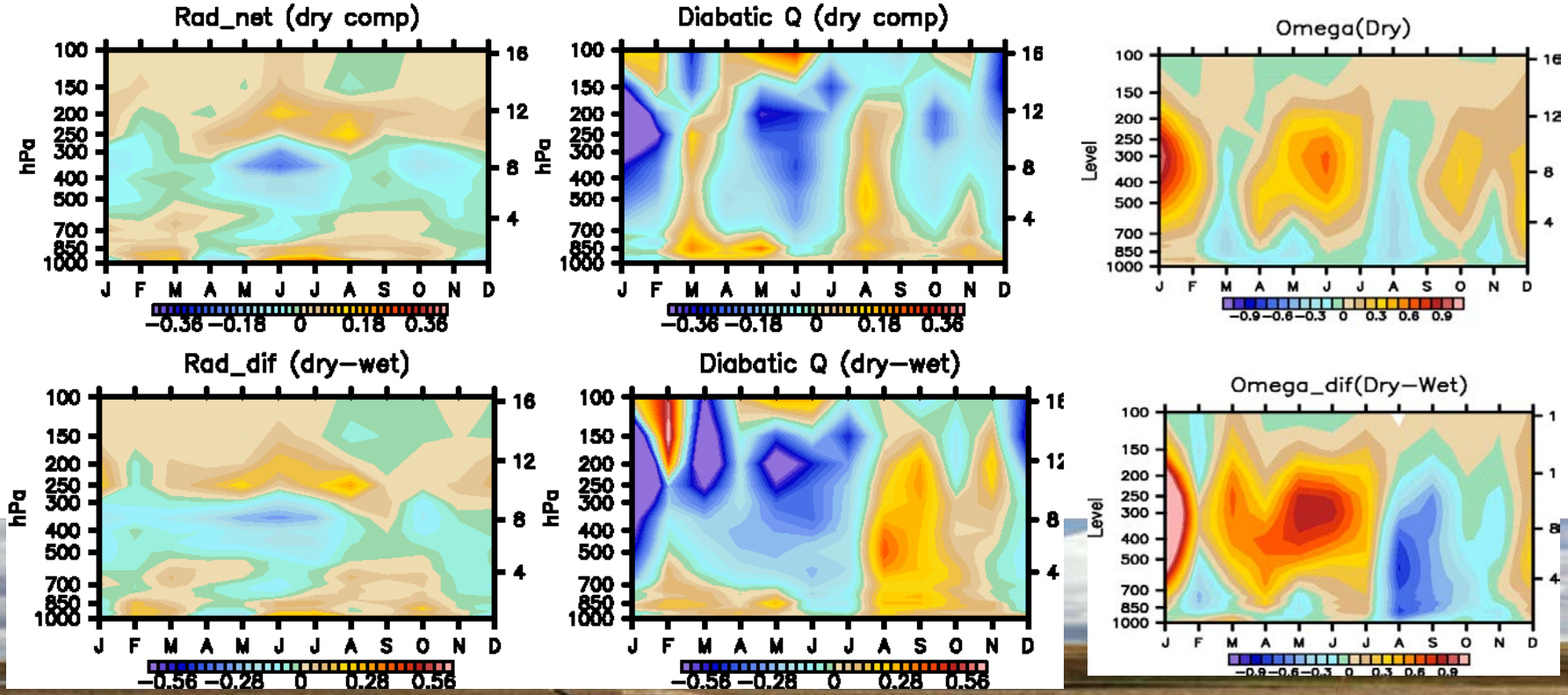
$$\boxed{\frac{\partial \bar{T}}{\partial t} \approx -\left(\frac{p}{p_o}\right)^{\kappa} \bar{\omega} \frac{\partial \bar{\theta}}{\partial p} + \frac{\bar{Q}}{C_p} \quad \text{or } \bar{\omega} \approx \left(\frac{p_o}{p}\right)^{\kappa} \frac{\bar{Q}}{C_p \frac{\partial \bar{\theta}}{\partial p}} \quad \text{if } \frac{\partial \bar{T}}{\partial t} \approx 0 \quad \text{in free troposphere}}$$

$$\frac{\partial \bar{T}}{\partial t} \approx -\left(\frac{p}{p_o}\right)^{\kappa} \bar{\omega} \frac{\partial \bar{\theta}}{\partial p} + \frac{\bar{Q}}{C_p} - \frac{\partial}{\partial p}\left(\overline{\omega' \theta'}\right), \text{ or } \bar{\omega} \approx \left(\frac{p_o}{p}\right)^{\kappa} \frac{\bar{Q}}{C_p \frac{\partial \bar{\theta}}{\partial p}} - \frac{\partial}{\partial p}\left(\overline{\omega' \theta'}\right) \text{ in ABL}$$

- **Diabatic cooling anomalies largely balances adiabatic warming**
- **Net radiative cooling, due to increased longwave cooling, is comparable to reduced latent heating in the middle troposphere.**

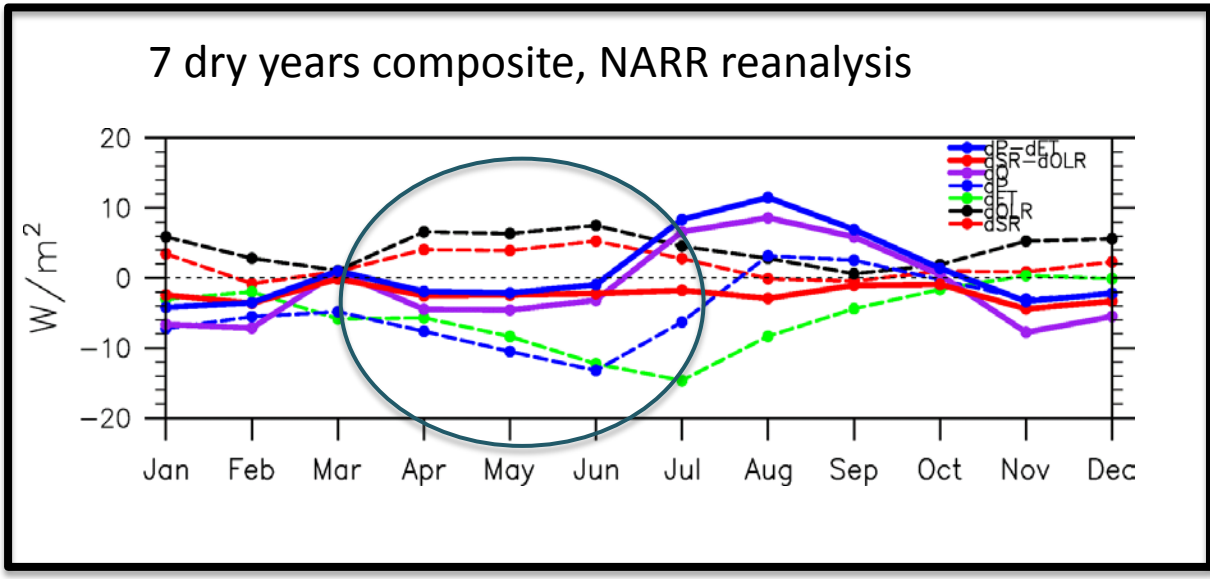
Latent heating difference(dry-wet, TRMM)

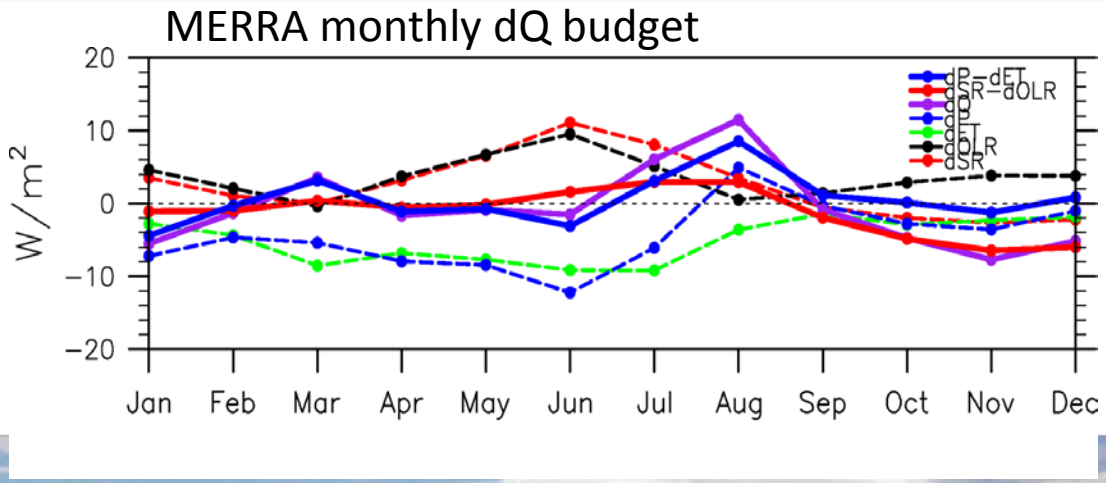




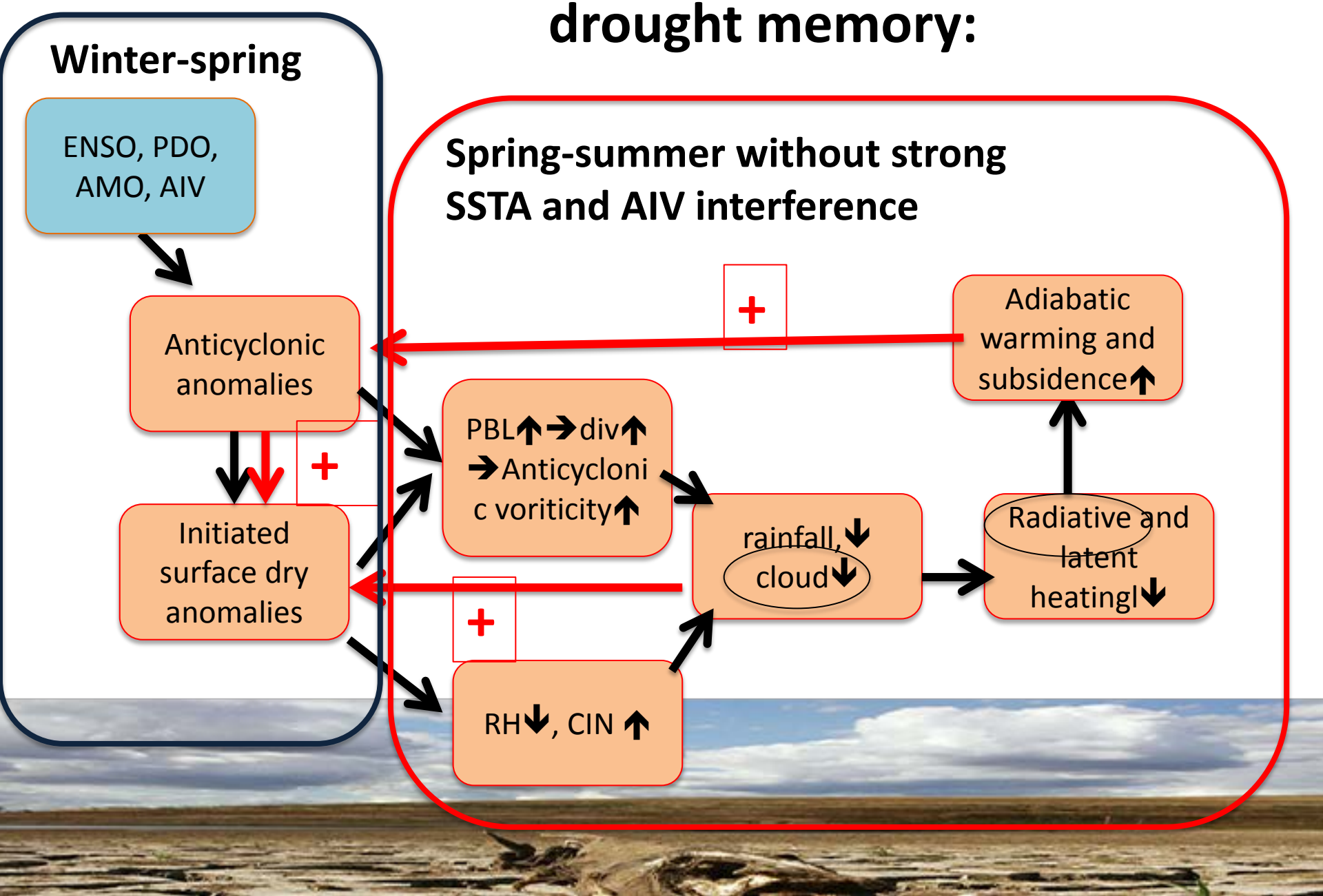
- **Anomalous net radiative cooling may play an as important role as that of latent cooling in enhancing mid-tropospheric subsidence during spring and summer.**

- **The actual diabatic cooling may be stronger than that shown by MERRA during the droughts**



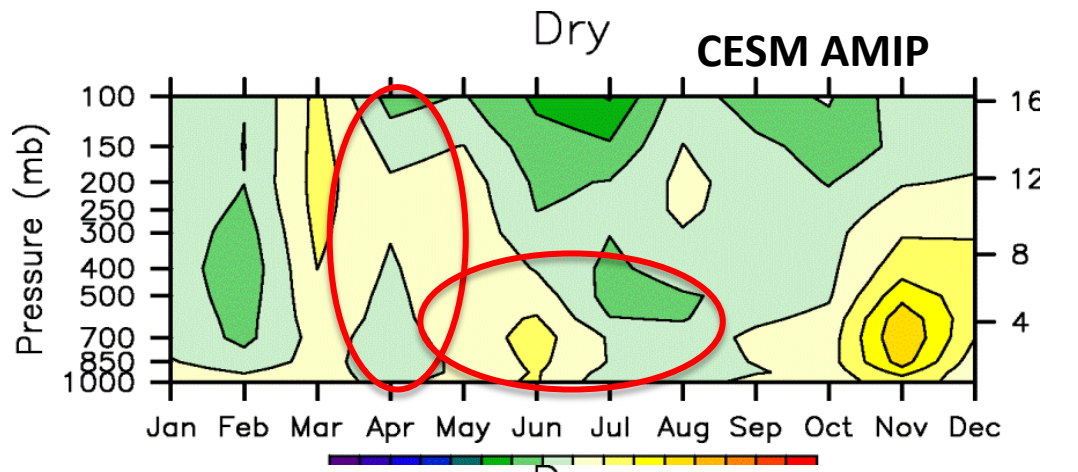


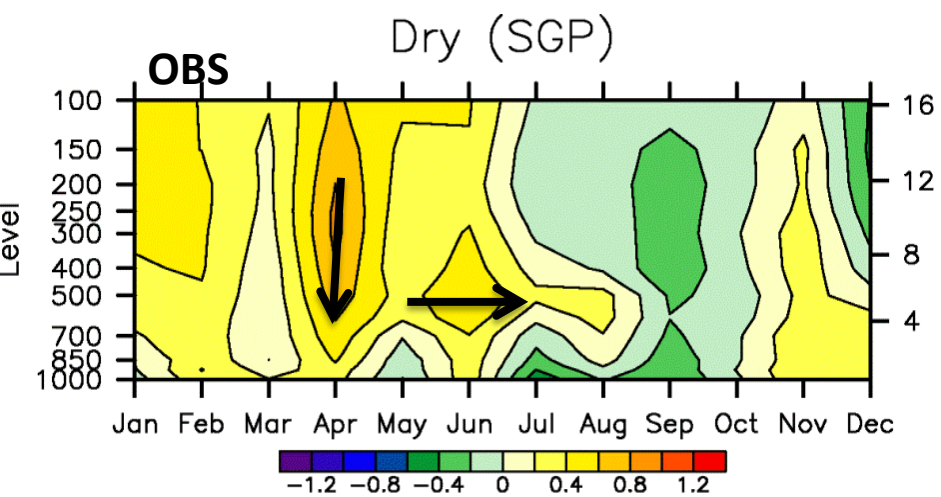
Feedbacks contribute to persist drought memory:

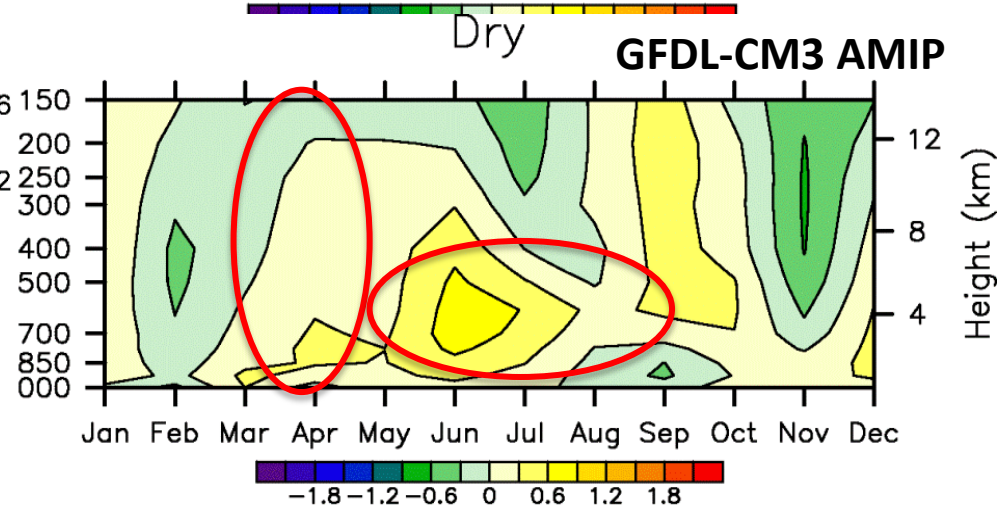


How well can climate models capture these processes?

- **Too weak dynamic forcing in spring**
- **Too weak and short-lived drought memory**



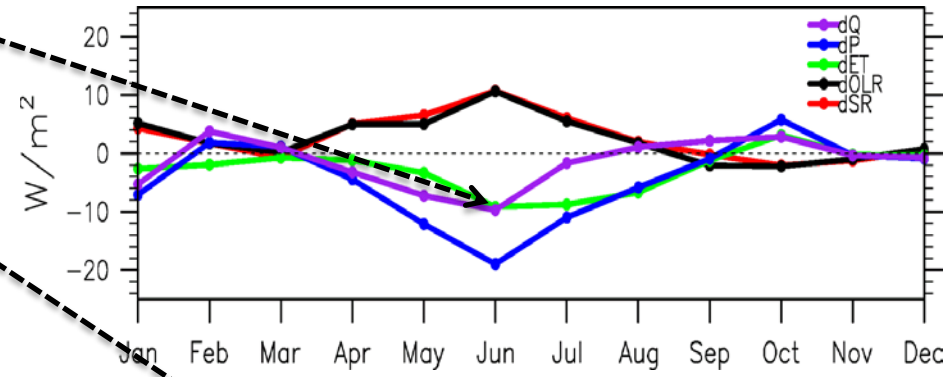




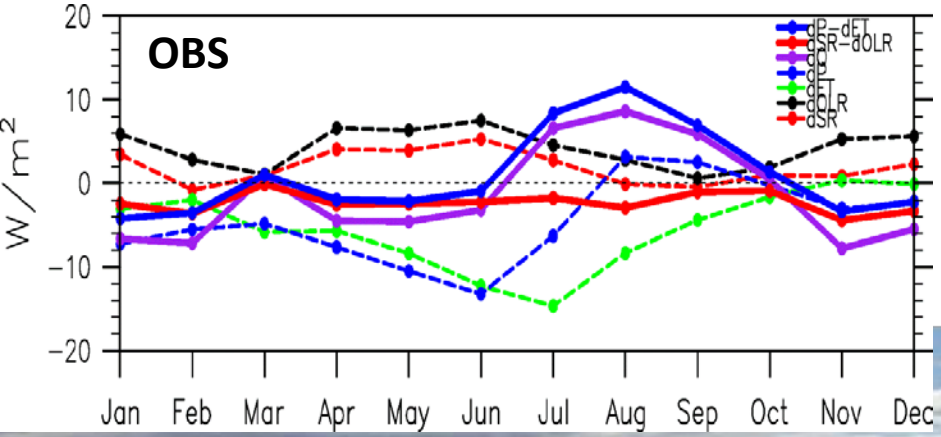
Biases in modeled diabatic heating anomalies:

- **Too late-peak in summer instead of in spring as observed**
- **Mainly due to lack of or opposite anomalous radiative cooling**

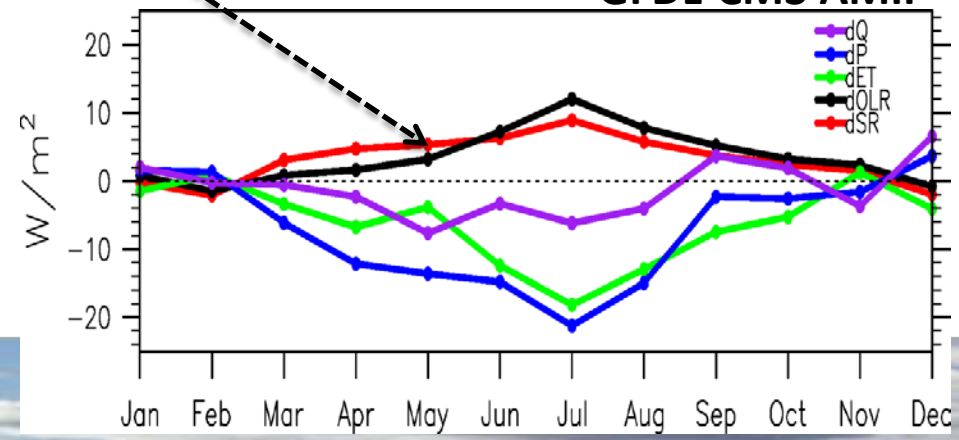
CESM AMIP



7 dry years composite, NARR reanalysis



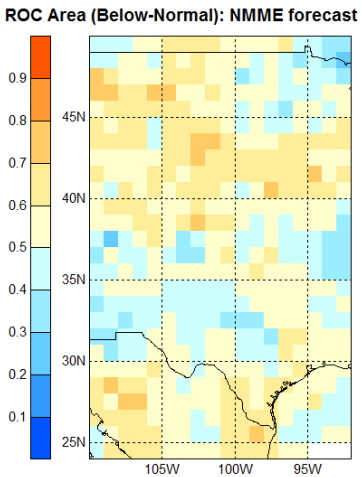
GFDL-CM3 AMIP



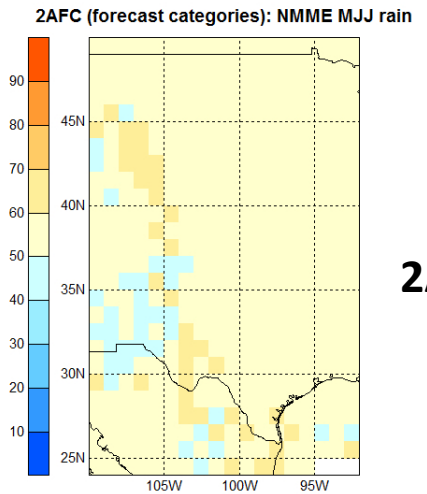
Can we improve the summer drought predictability using drought memory?

Seasonal prediction of May-July rainfall:

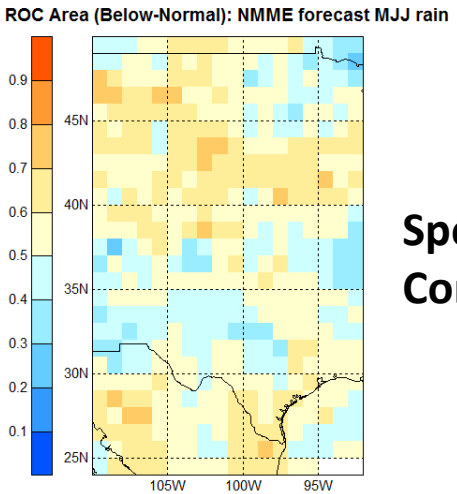
NMME forecast skill



ROC

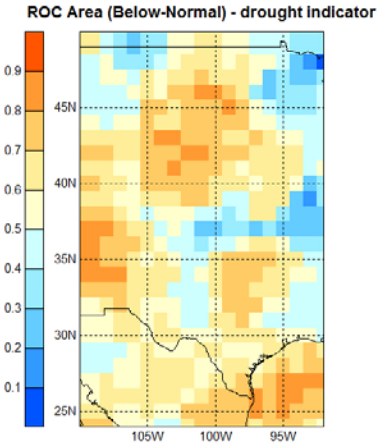


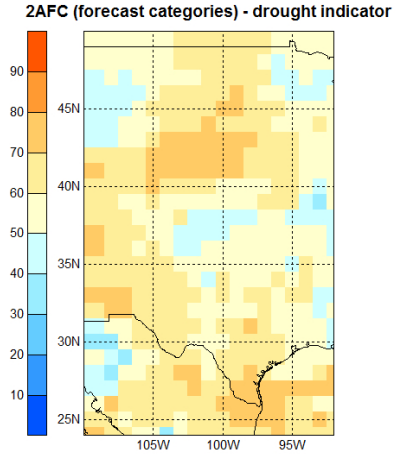
2AFC

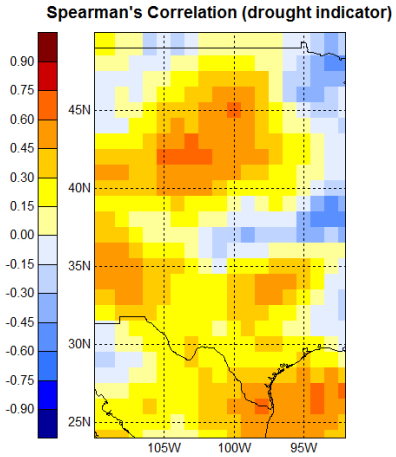


Spearman Correlation

Empirical forecast skill







A limiting factor for drought predictability:

Better understood and prediction skill

SSTA dominate

- Positive cloud, rainfall and dynamic feedbacks working in concert to maintain dry memory;

SM, AIV dominate

ENSO, PDO, SM

AMO, AIV(NAO), SM

SM,PDO

Summary and Implication:

- **Observations suggest that SSTA have limited impact on extreme summer droughts over US Great Plains. These droughts appear to be induced by anomalous anticyclonic circulation in spring, either due to warmer Atlantic SST or internal atmospheric variability, and re-enforced by clouds and precipitation feedbacks.**

- **Reduced cloudiness and (water vapor) lead to an increase of longwave cooling, comparable contribution to the diabatic cooling anomalies and subsidence to the anomalous latent cooling in late spring and early summer. Such radiative feedback work in concert with soil moisture-rainfall feedbacks to re-enforce the initial dry drought anomalies.**

- **Preliminary analysis of selected CMIP5 models underestimate both the dynamic forcing in spring and net cloud/radiative feedbacks and drought memory. The uncertainty of the clouds and their feedbacks in climate models can be an important, but overlooked, source of uncertainties in drought prediction/projection.**

Thank You!

- ***Analysis periods: 1979-2012 for most of the analyses***
- ***CERES (2000-), TRMM (1999-)***

Southern Great Plains (SGP):

Dry years (July SPI >-0.6)

- 1954, 1956, 1963, 1971, 1974, **1980, 1996, 2001, 2002, 2003, 2006 and 2011**

- Wet years (July SPI6<-0.6):
- 1949, 1957,1958,1968,1973, **1979,1981, 1990, 1992, 1999, 2004, 2007**

Northern Great Plains (NGP):

Dry years:

- **1980,1985,1988,1989,2002,2006,2012**

Wet years:

- **1982,1991,1993,1995,2005,2008,2010**

The limiting factor for drought prediction:

Better understood and prediction skill

Strong SSTA influence

Poorly understood
Predictability unclear

Seemingly random

ENSO, PDO,

AMO, AIV(NAO), ?

?