The Physics of Great Plains Drought:

It's Predictability and It's Changed Risk in a Warmer World

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Agenda

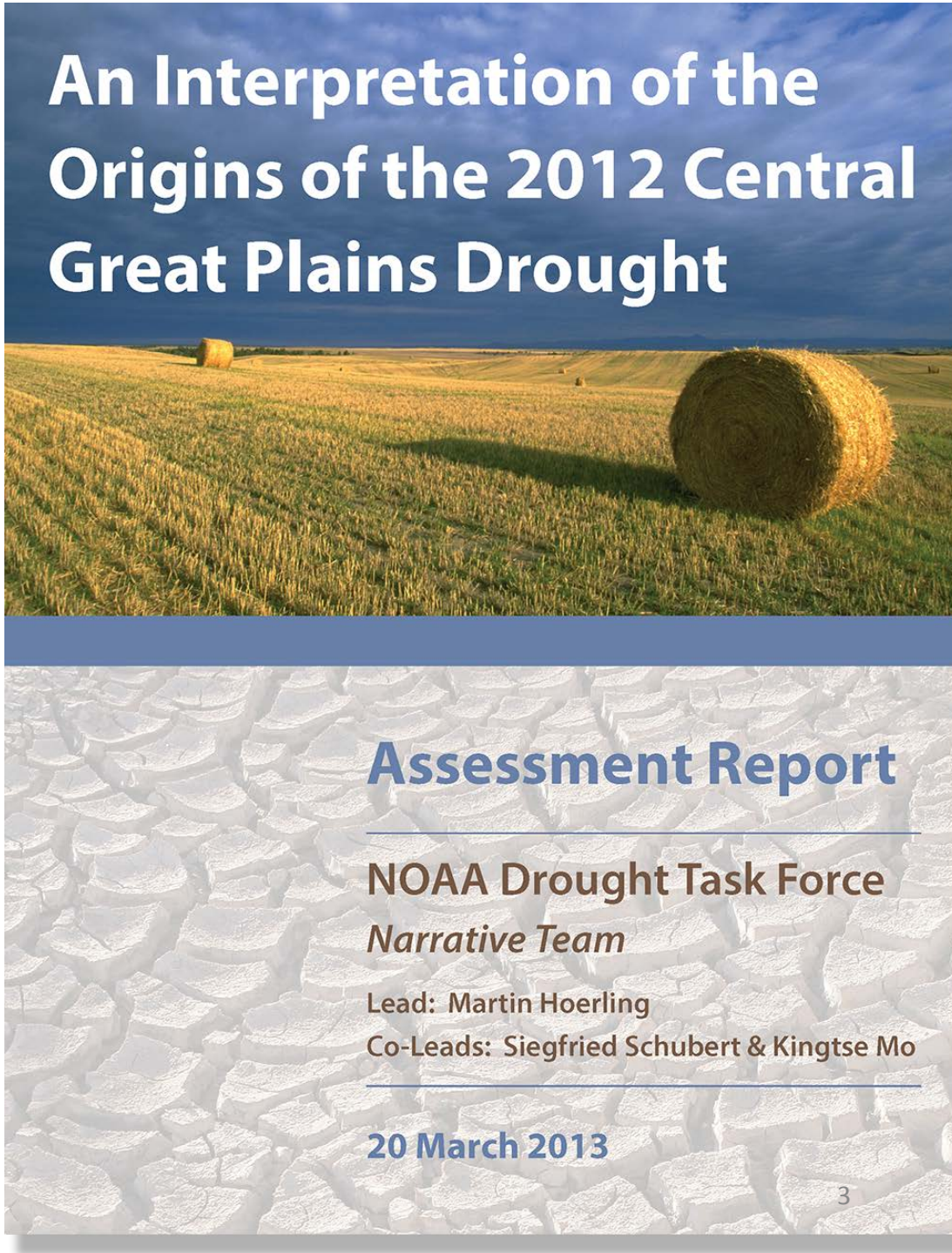
- Motivation—a land-surface oriented understanding of proximal causes of drought.
- Land surface model experiments—2012 Great Plains Drought—isolate precipitation and temperature effects on soil drying
- Predictability
- Exploring future drought severity

Overview

- Previous work has focused on meteorological conditions and their drivers for the 2012 event

<u>Distinction</u>:

- Focus on hydrologic sensitivities and potential sources of predictability from the land-surface



Meteorological conditions in MJJA 2012

- May-August Standardized Anomaly, 1981-2010 reference period:

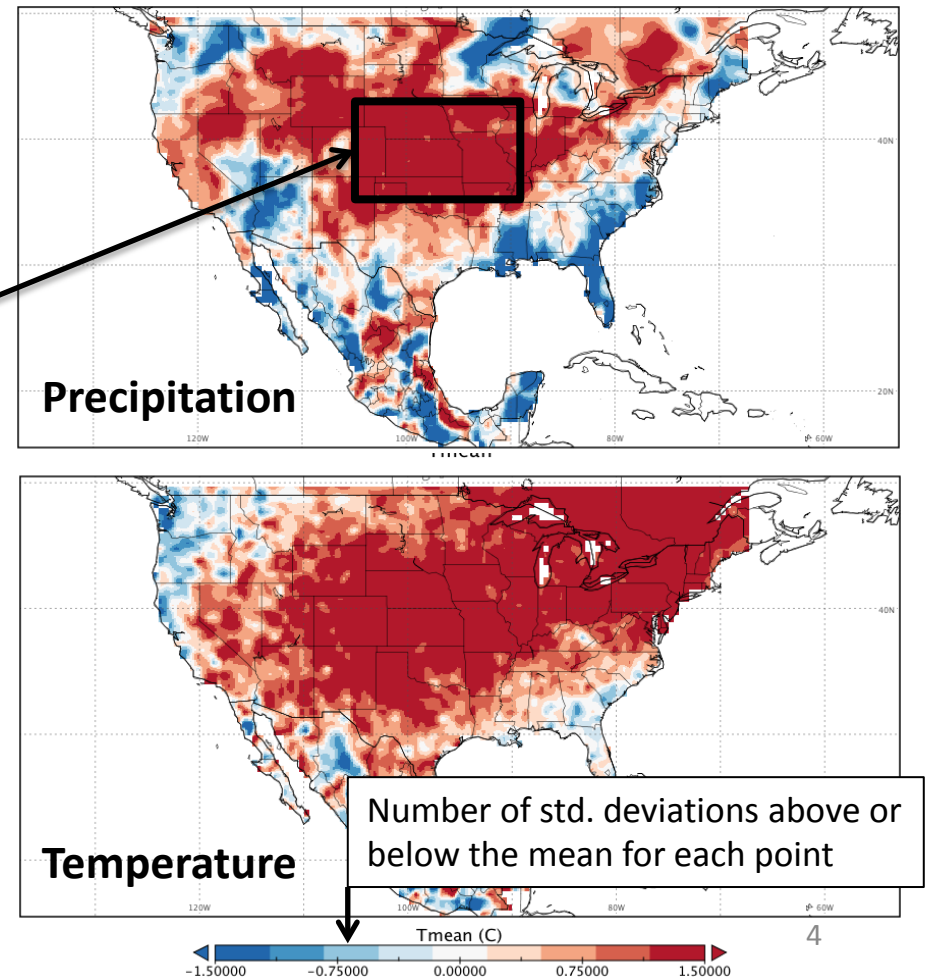
$$\frac{x - \bar{x}}{S}$$

mean

Std. dev.

"Central Great Plains"

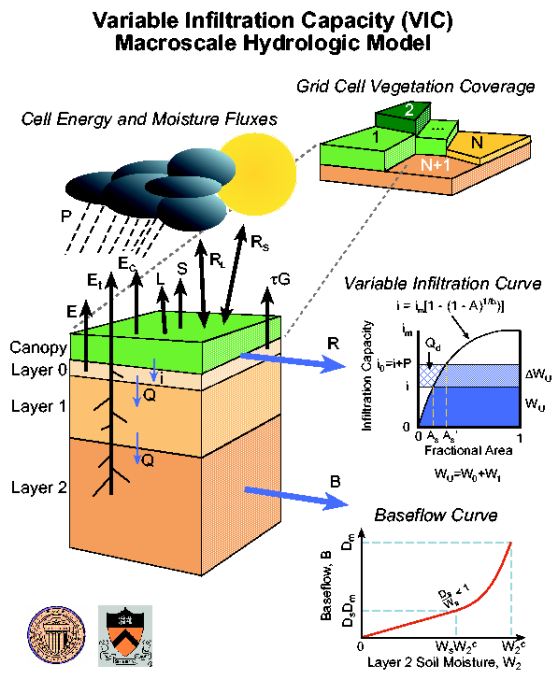
Livneh et al. (2015) Gridded Station Data[1]



Number of std. deviations above or below the mean for each point

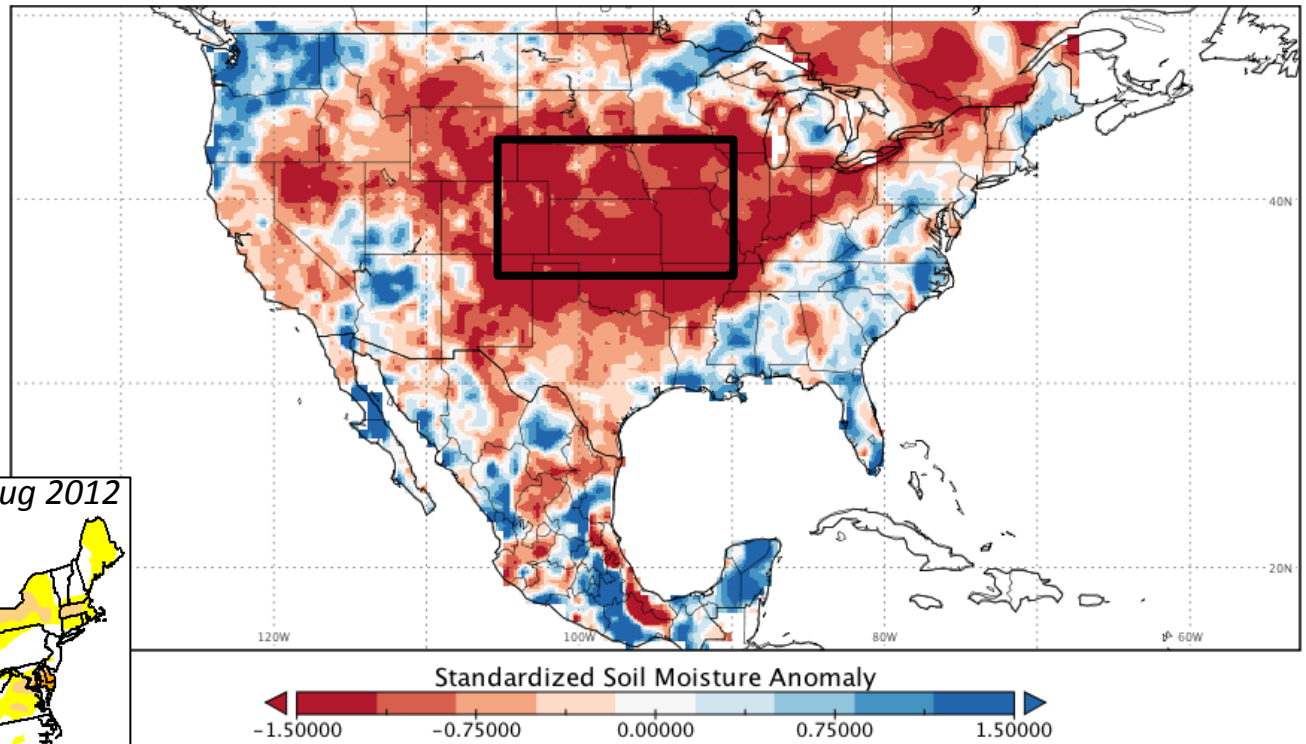
[1]B. Livneh, D.S. Pierce, T.J. Bohn, F. Munoz-Ariola, B. Nijssen, D. Cayan, R. Vose, and L.D. Brekki, 2015: Development of a spatially comprehensive, continental-scale hydrometeorlogical data set: challenges and hydrologic impact assessment., *Nature Scientific Data* (in review).

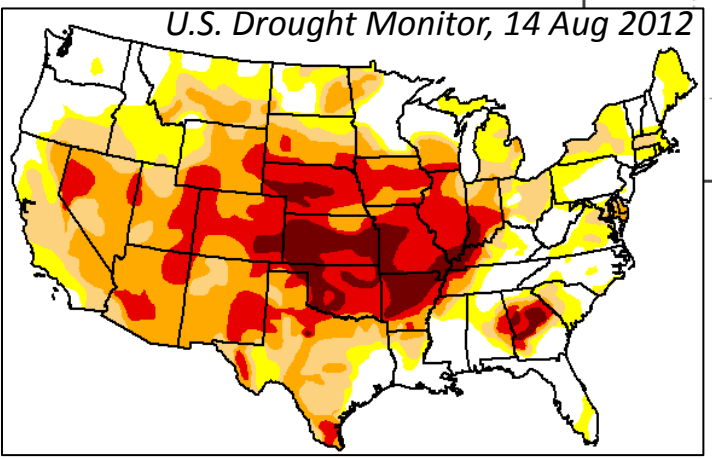
Soil Moisture Deficits in 2012



- **VIC soil moisture deficits** (top 1m of soil)
- **<u>August</u>** Standardized Anomaly, 1981-2010 reference period:

VIC Simulated Soil Moisture: August 2012

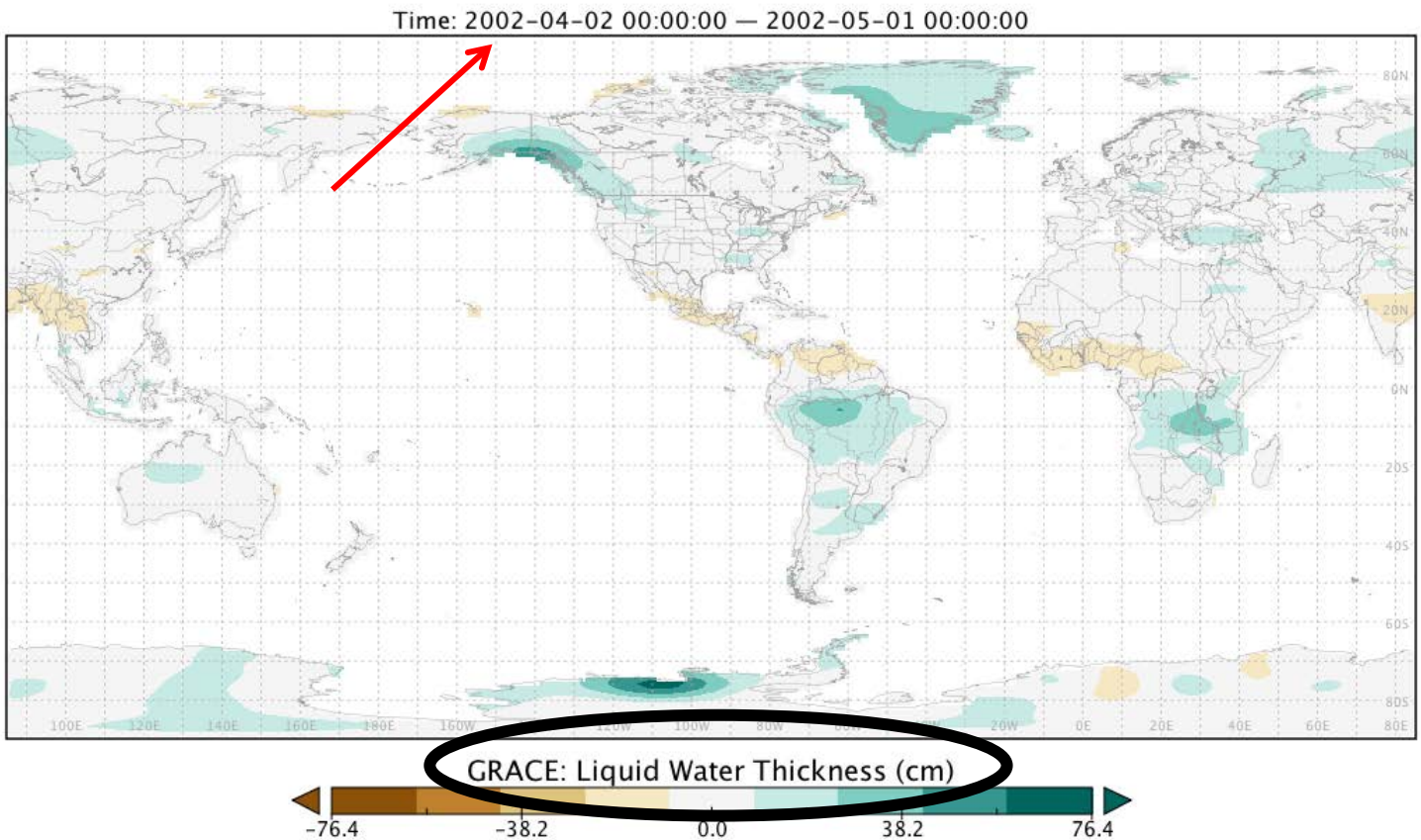




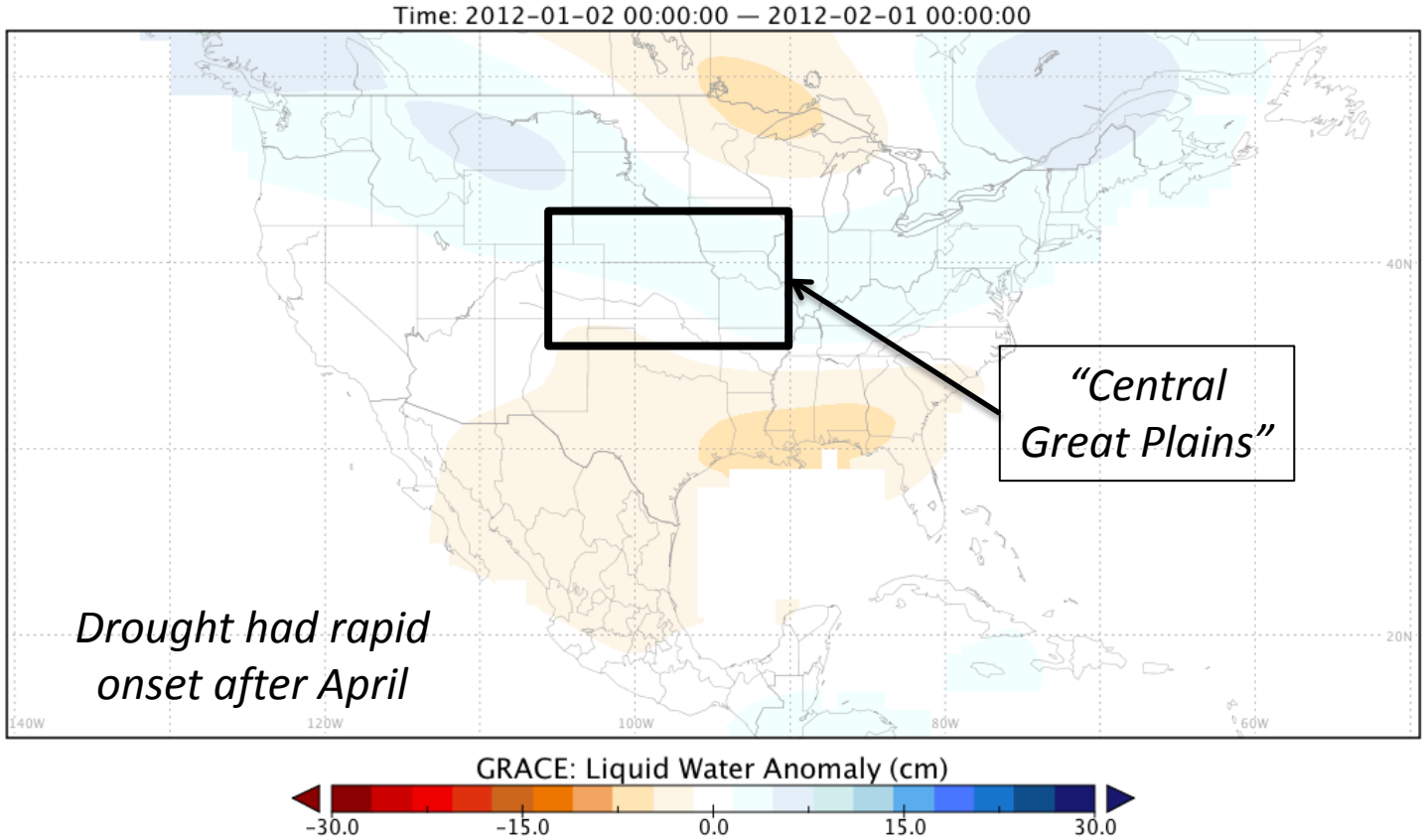
http://droughtmonitor.unl.edu/MapsAndData/MapArchive.aspx

Large-scale validation data

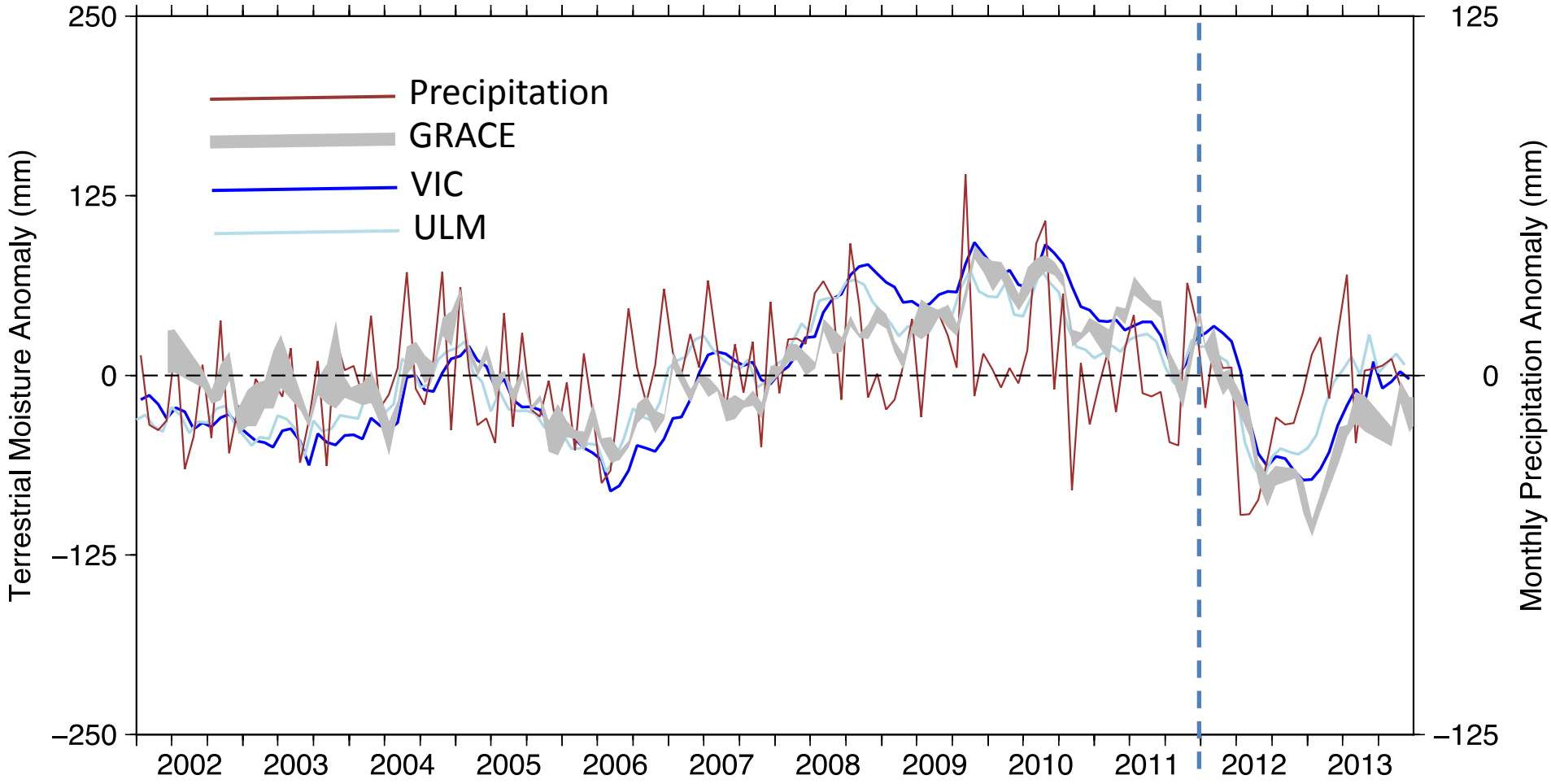
- Gravity Recovery and Climate Experiment (GRACE) twin satellites
- Coarse scale, commensurate with drought



Great Plains Drought

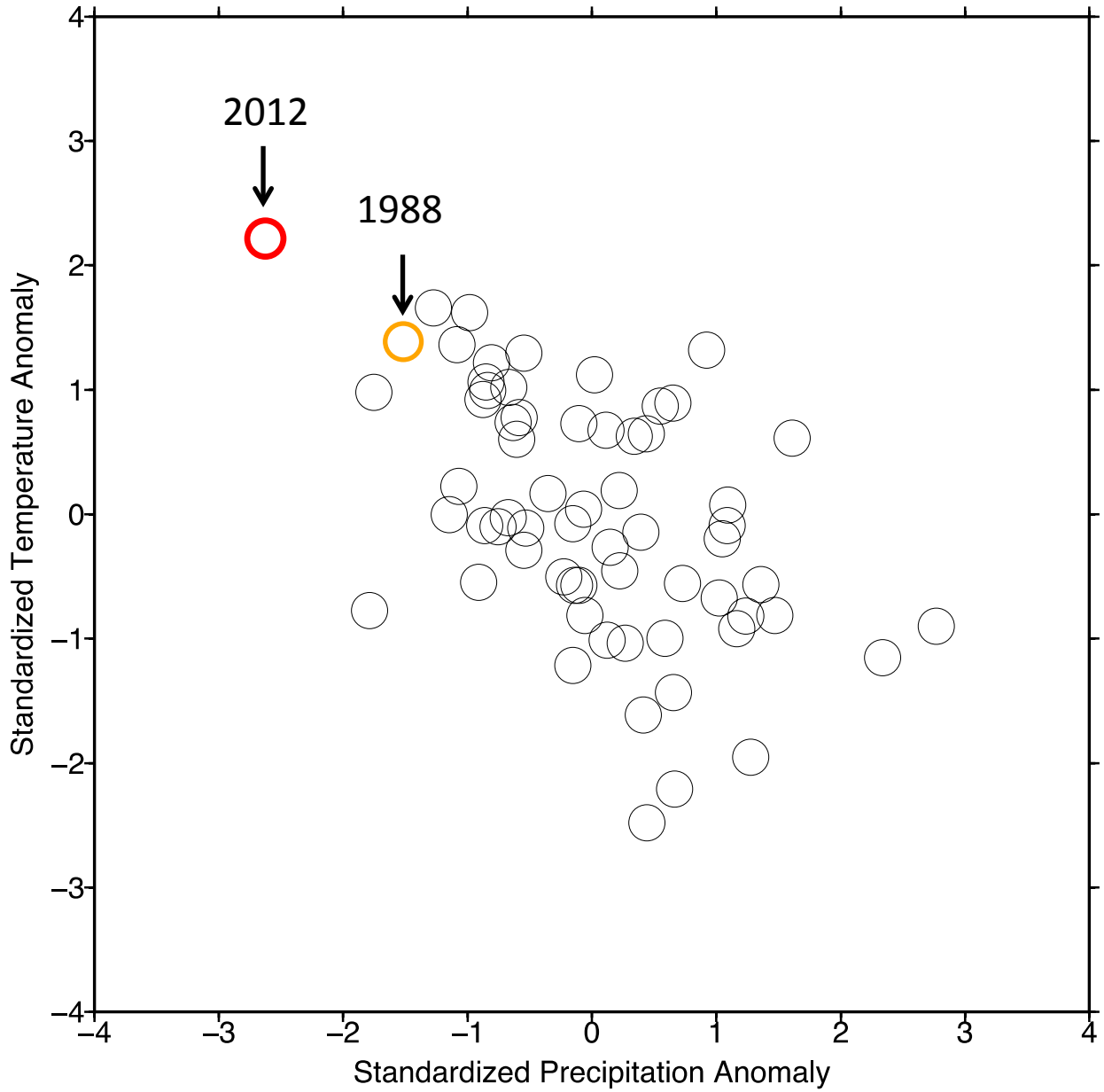


Central Great Plains Moisture Anomalies



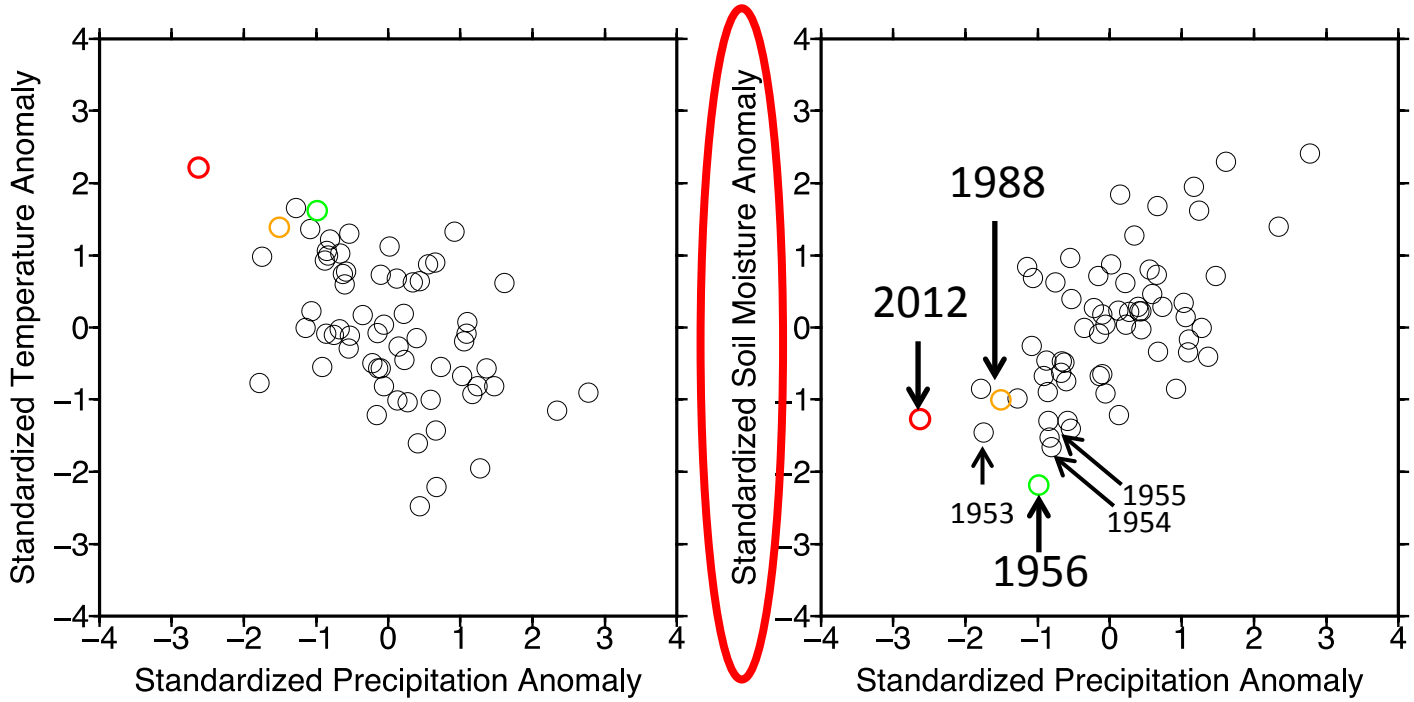
Monthly anomalies (2002-2013) for observed precipitation (right ordinate axis), GRACE, ULM, and VIC terrestrial water (left ordinate axis) averaged over the Great Plains domain.

Historical Context of meteorological anomalies



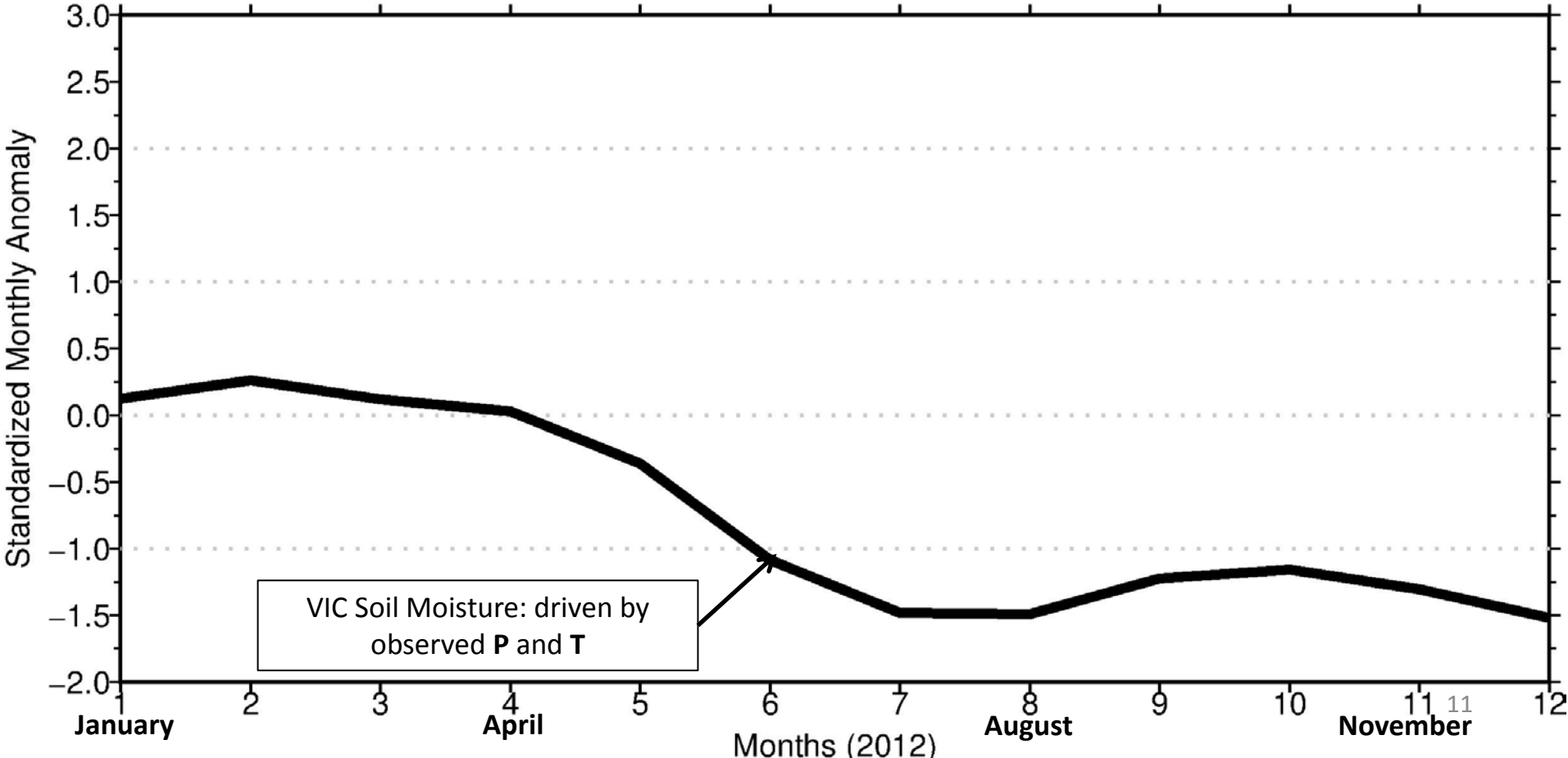
*Central Great Plains domain.

- May-August conditions (1950-2013) standardized by the same reference period (1981-2010)
- P vs T relationship is of importance for drought

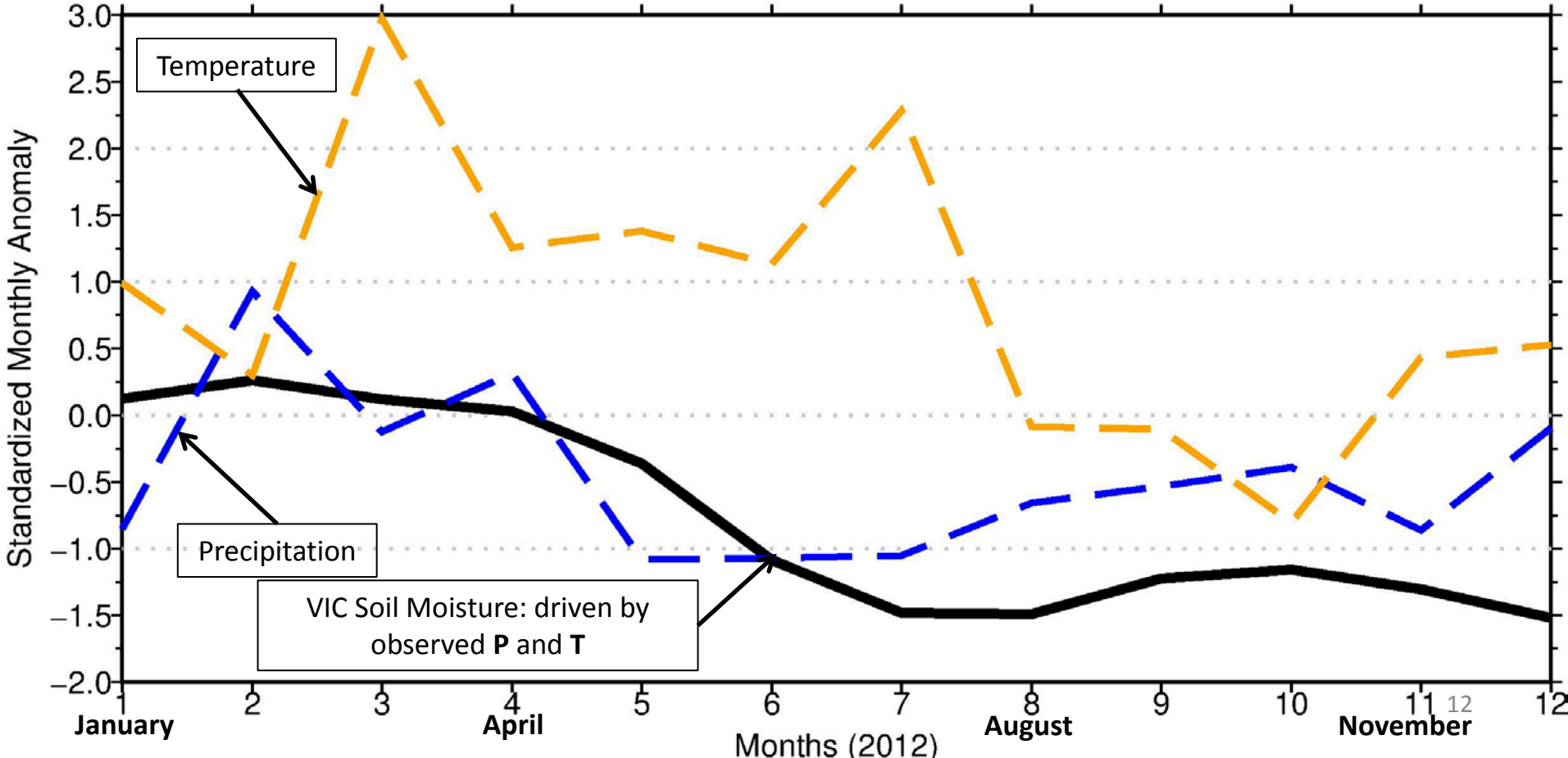


- Soil moisture integrates weather over long time periods
- 2012 had a relatively rapid onset.
- Observations alone cannot tell us whether precipitation or temperature is more important for soil drying, requires models…

Time evolution of soil drying and meteorology

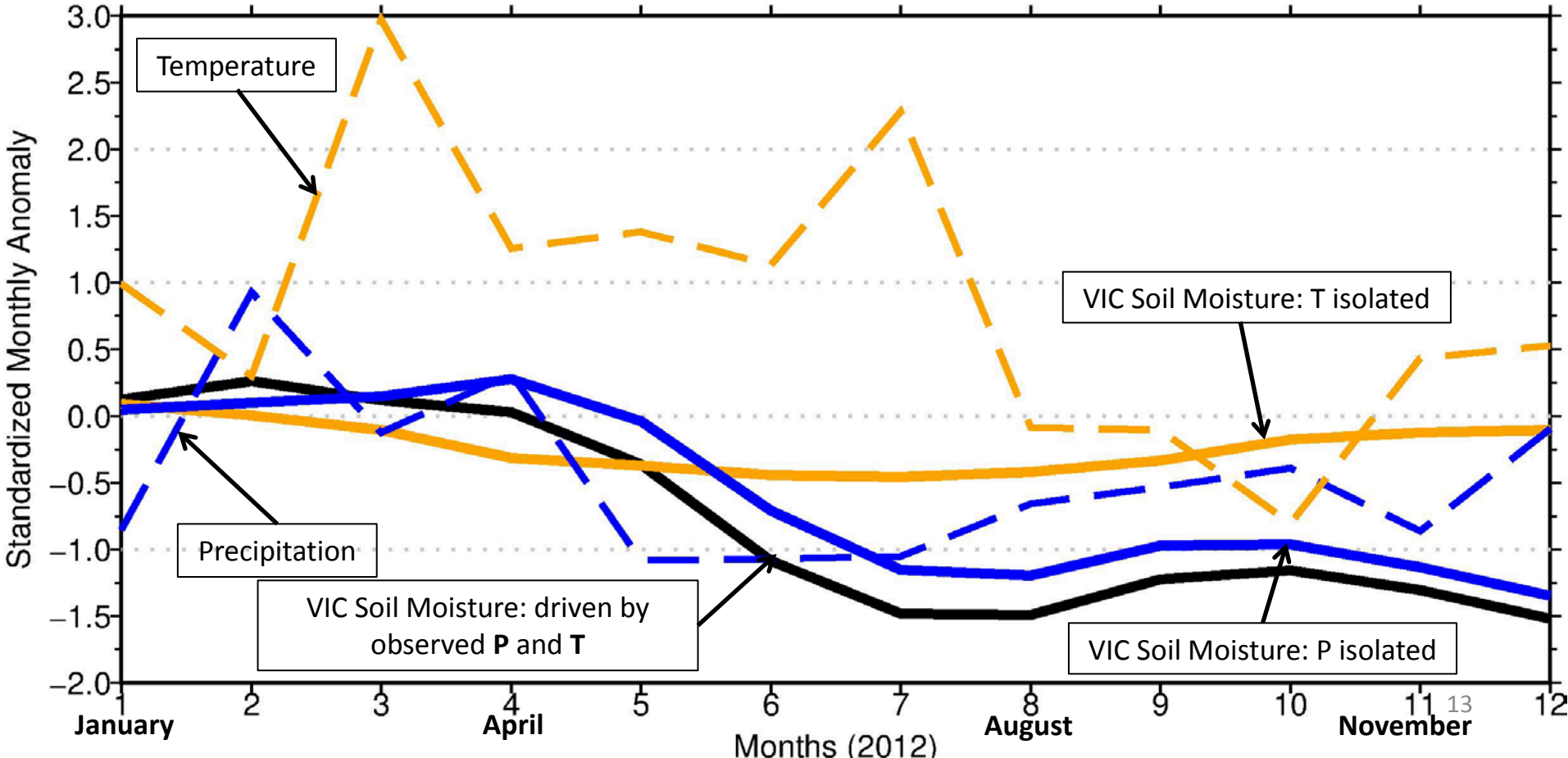


Time evolution of soil drying and meteorology



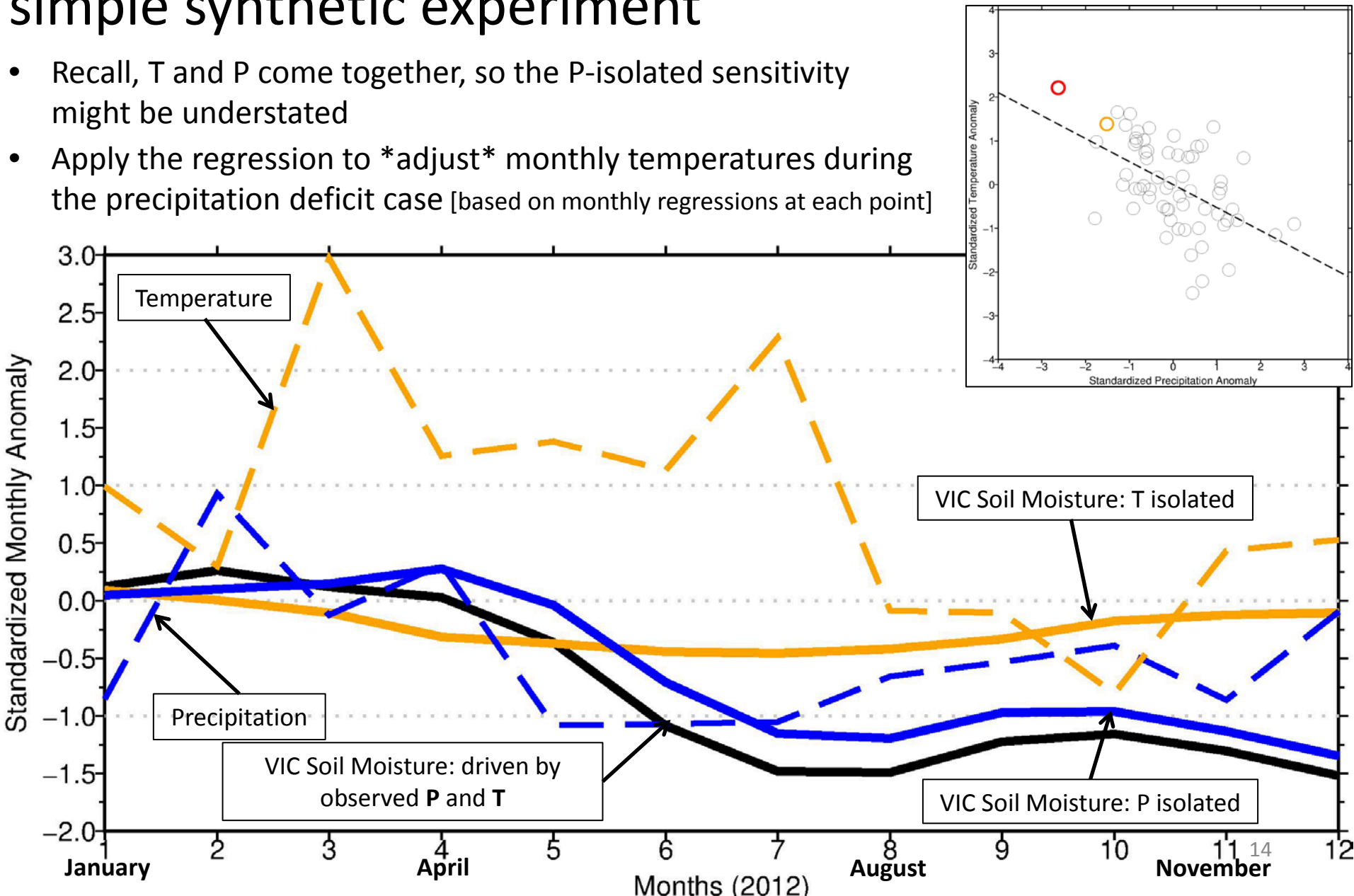
Isolate the roles of precipitation and temperature on soil drying.

- Conduct synthetic experiments, where: e.g. VIC rerun with **T is set to climatology** to **isolate the role of P** during 2012 event
- Precipitation dominates the soil moisture response signal, approximately 2.5:1 ratio with temperature



Precipitation effect on soil drying understated by simple synthetic experiment

- Recall, T and P come together, so the P-isolated sensitivity might be understated
- Apply the regression to *adjust* monthly temperatures during the precipitation deficit case [based on monthly regressions at each point]



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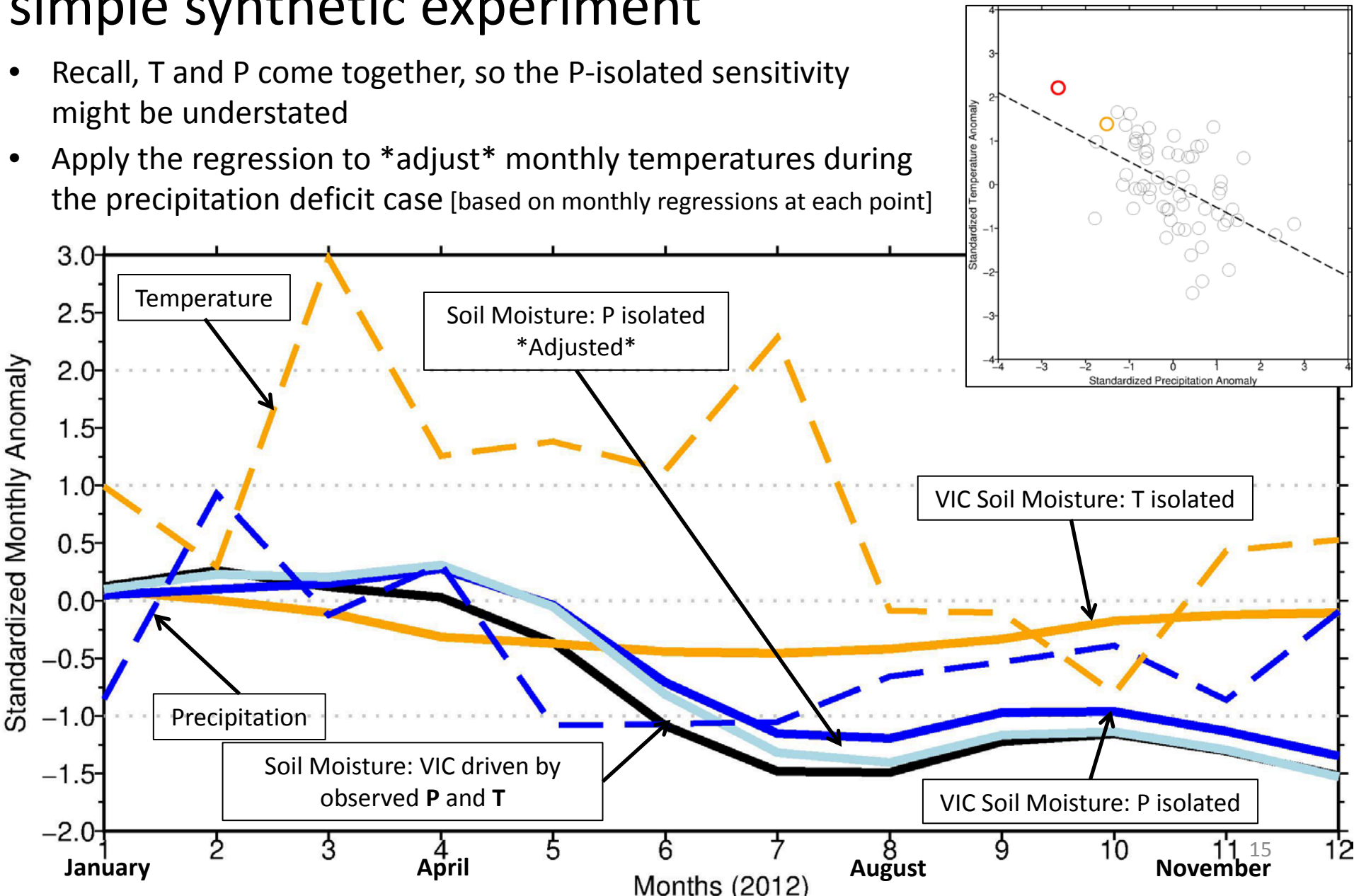
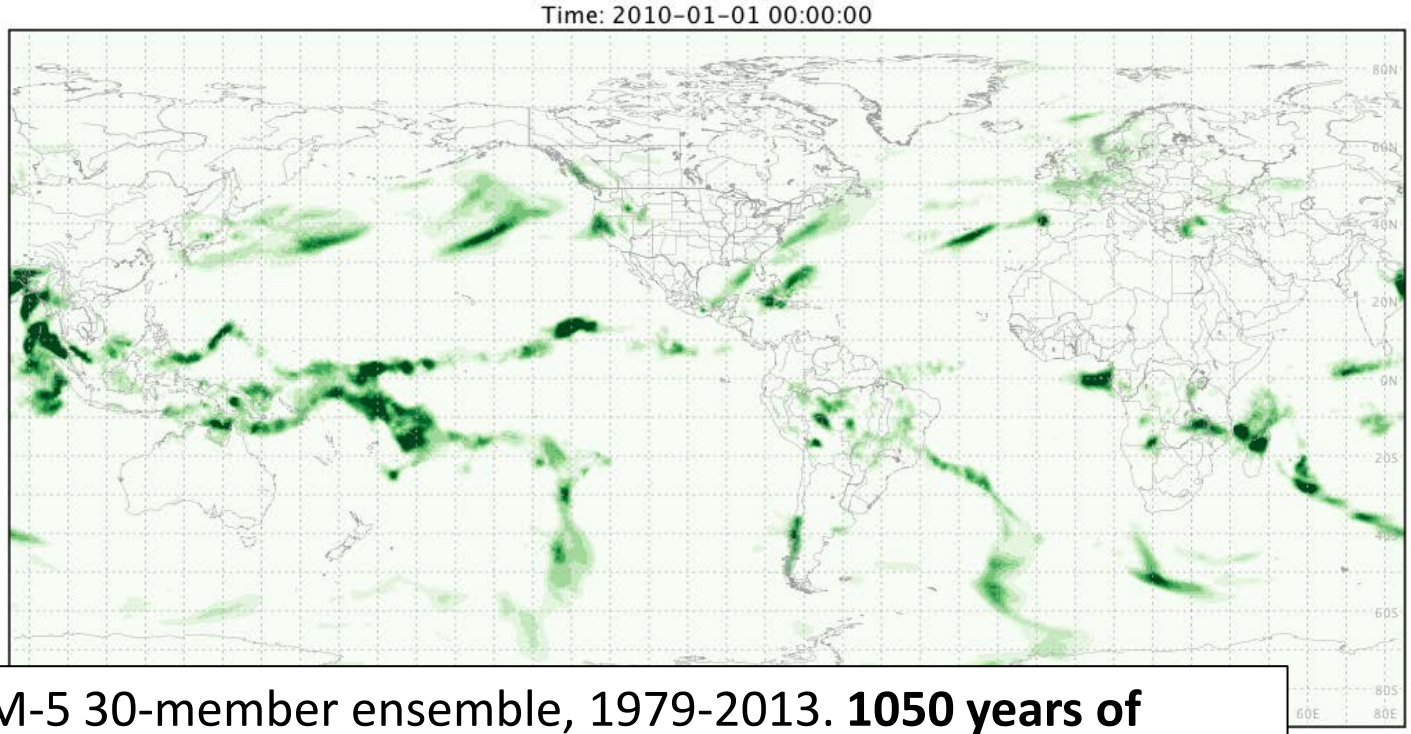


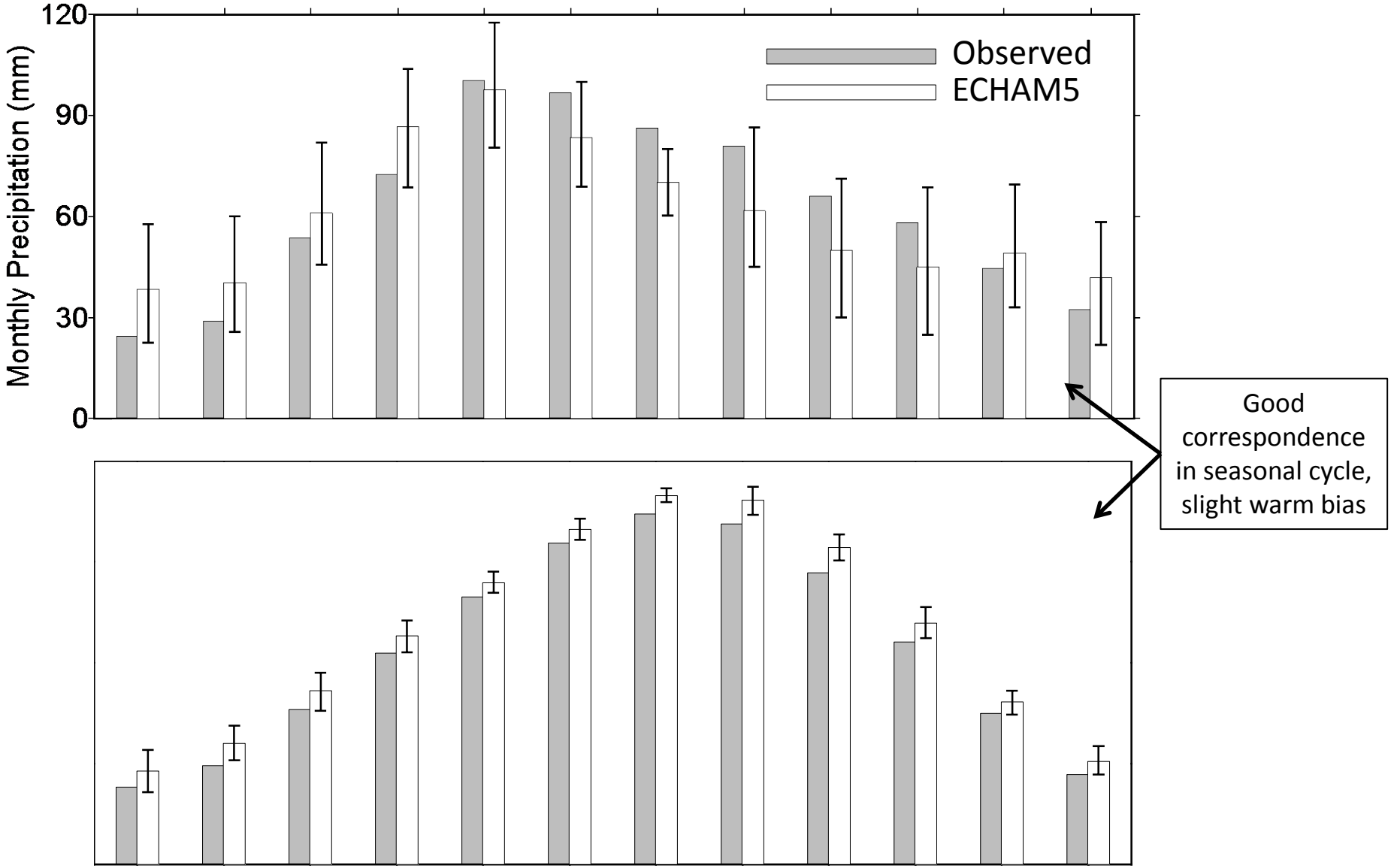
ECHAM5 ensemble used to explore general drought characteristics and predictability

Overcomes the limited observed sample size (e.g. 64 years)



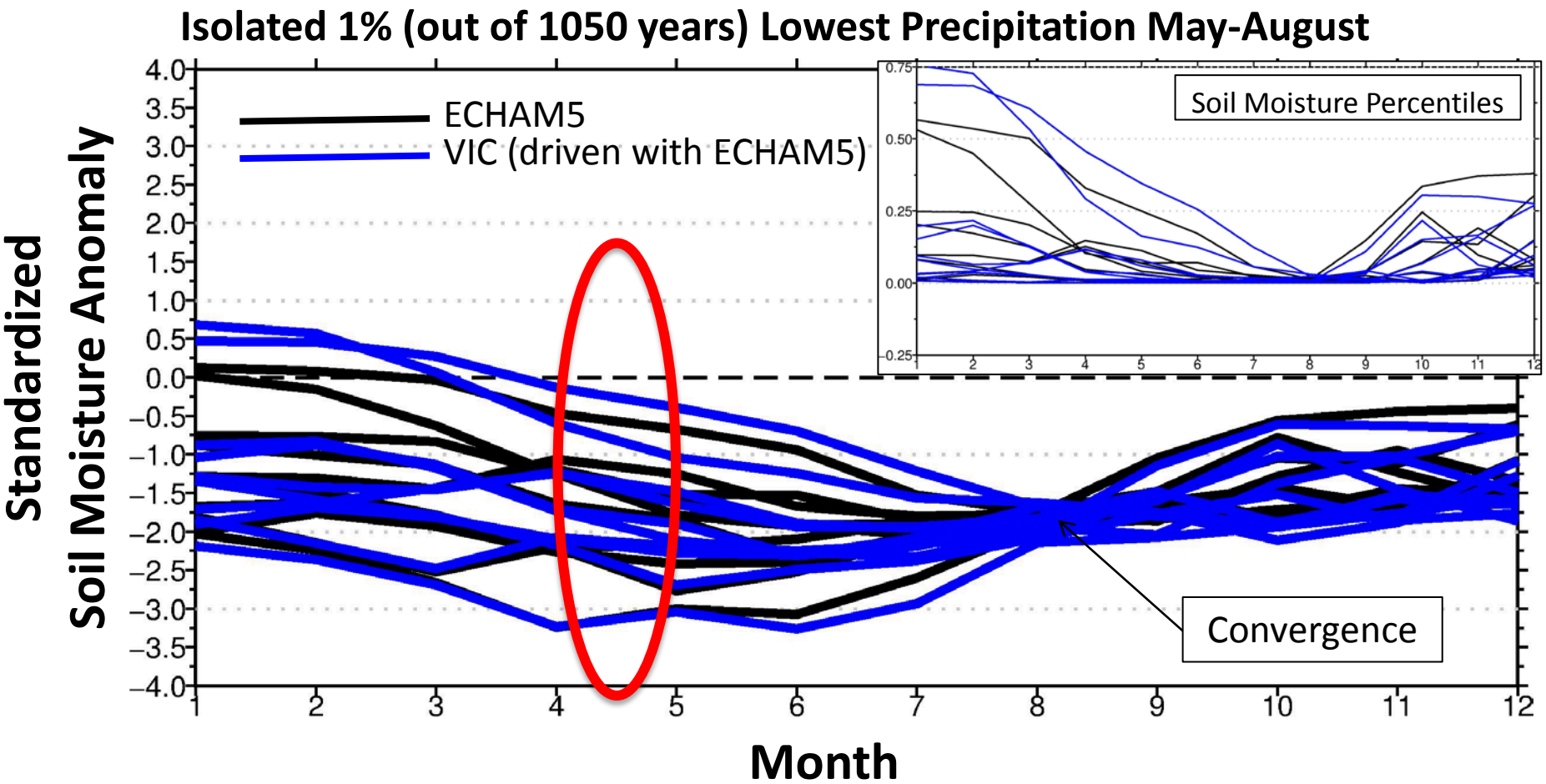
ECHAM-5 30-member ensemble, 1979-2013. **1050 years of '*recent climate*' simulations**. AMIP-style driven with observed Greenhouse Gases and Sea Surface Temperatures

Validating ECHAM5 meteorology (1979-2013) with observations over the Great Plains domain; captures the seasonal cycle



Importance of Initial Conditions

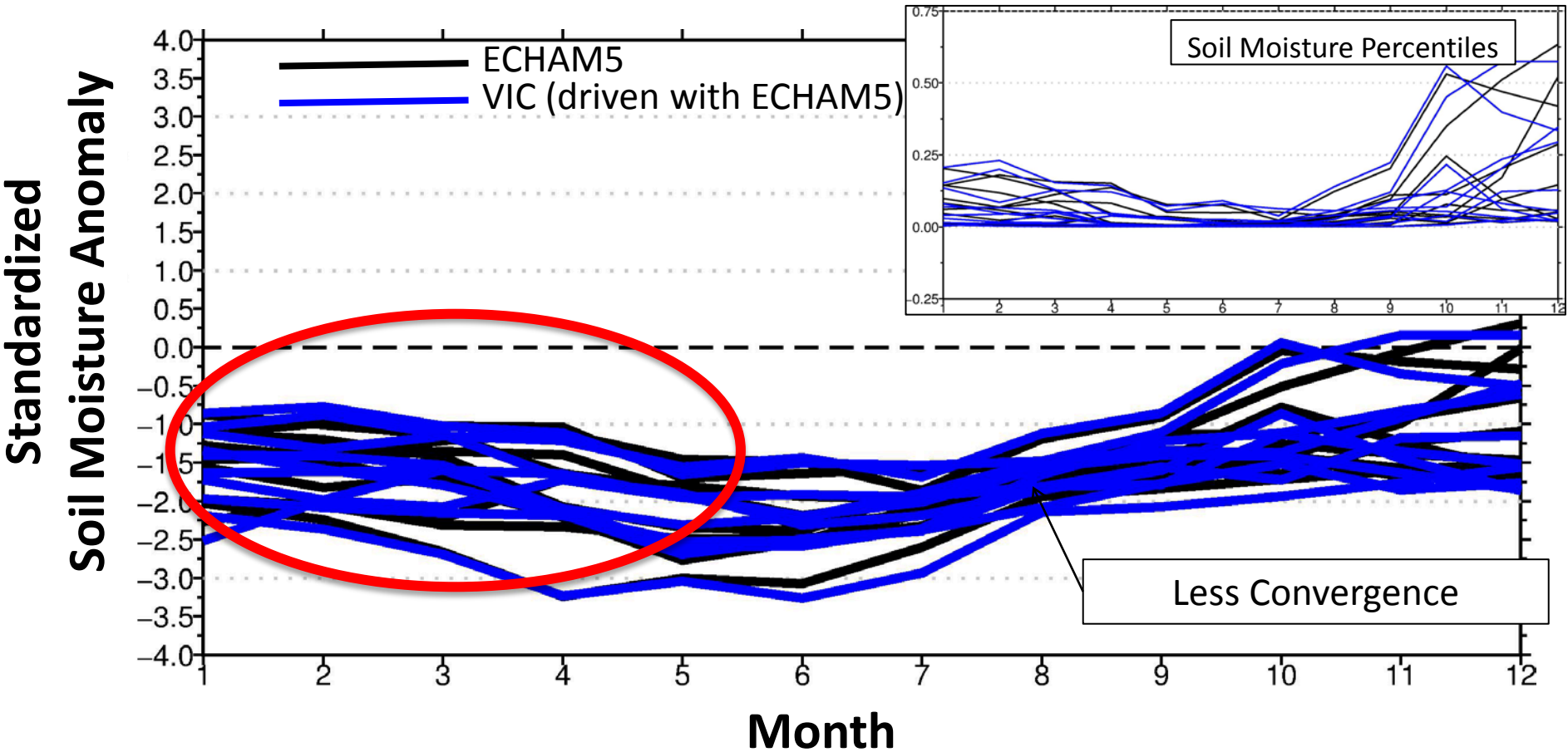
Prominence of Precipitation Control on Soil Moisture



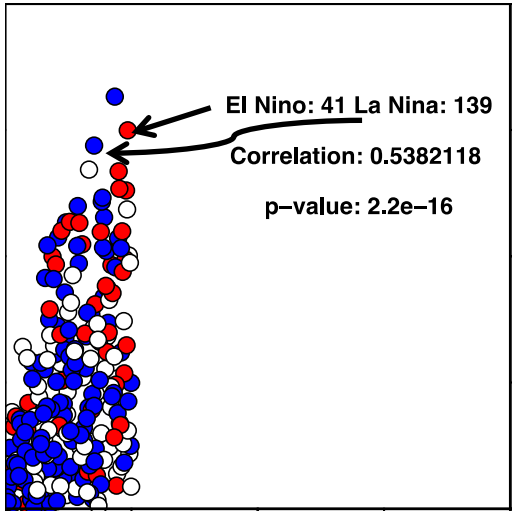
Importance of Initial Conditions

Lack of Prominence of Temperature Control on Soil Moisture

Isolated 1% (out of 1050 years) Highest Temperature May-August

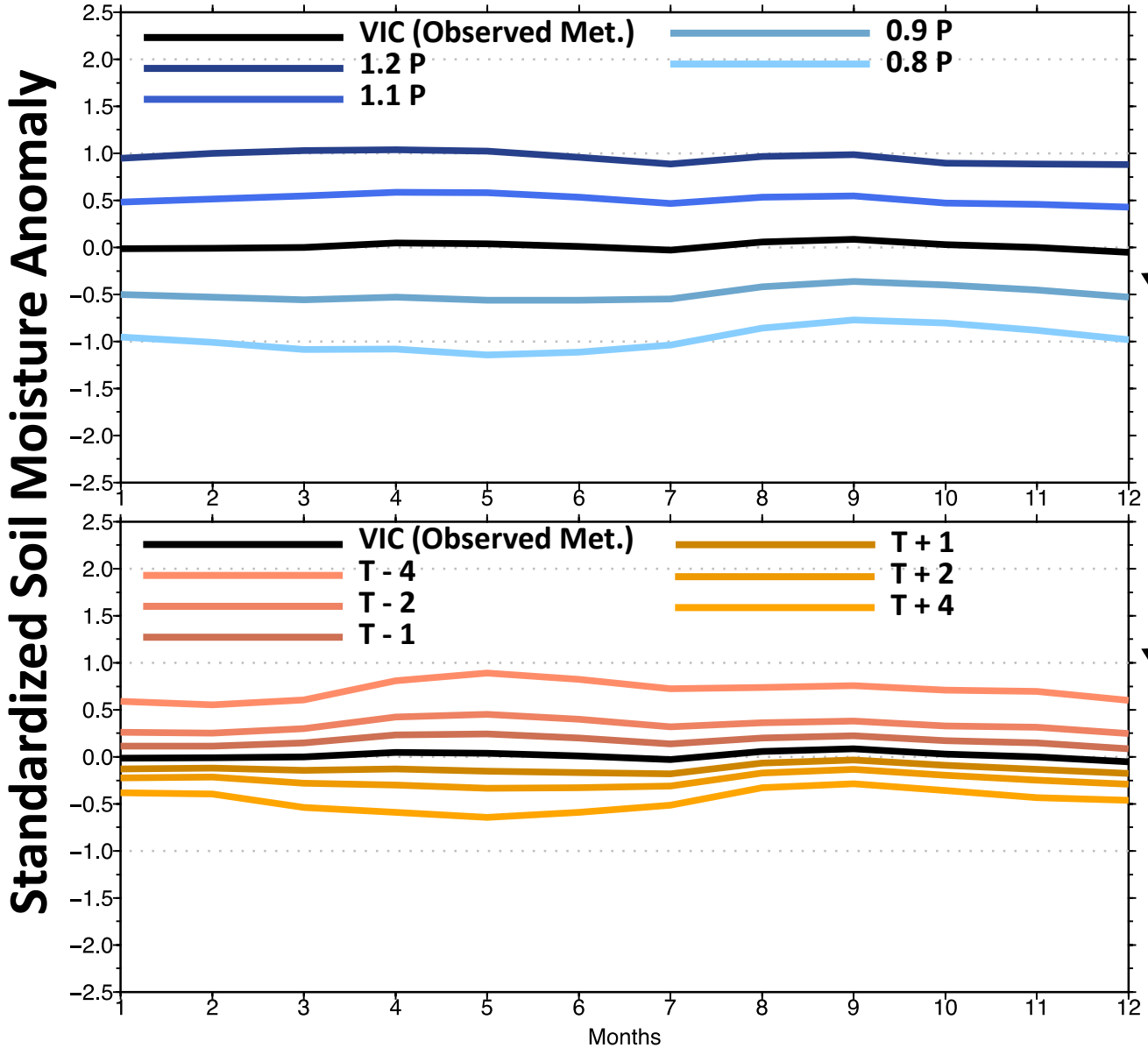


Inter-seasonal predictability, knowledge of antecedent conditions



- Seasonal percentiles of soil moisture, and temperature for the Great Plains **summer (MJJA) and preceding season (JFMA)**
- Isolating the driest 25% of years and highest temperature years with data points colored based on the Nino 3.4 index.
- **Antecedent moisture is the strongest predictor**, then precipitation (not shown) and temperature
- **La Nina years have a tendency towards dry Great Plains soils**

Monthly standardized anomalies for the **recent decade 2004-2013** (relative to 1981-2010) for VIC simulations using observed meteorology. **Sensitivities to unit wetting/drying or warming/cooling**



Precipitation sensitivities are very pronounced

Temperature sensitivities more modest, non-divergent

Summary

- Understanding drought requires a culmination of many information sources
- Land surface model experiments indicate that precipitation dominates drought response in the Great Plains
- Relatively modest temperature sensitivity suggest semi-permanent future drought conditions are unlikely to emerge.

Livneh B., and M.P. Hoerling, 2015: Fundamental Physics of Drought in the U.S. Central Great Plains. *Journal of Climate* (in review).

Thank you

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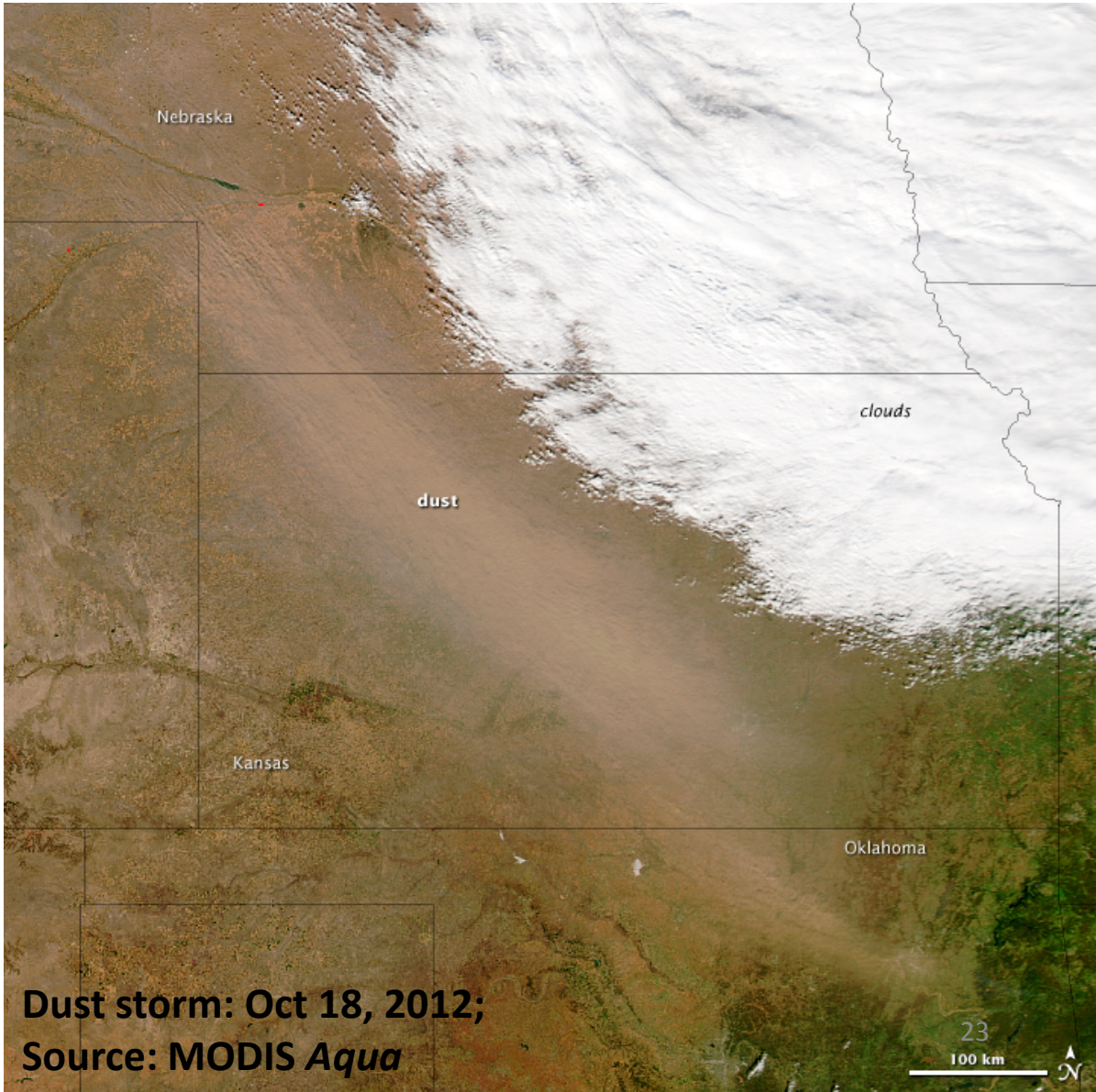
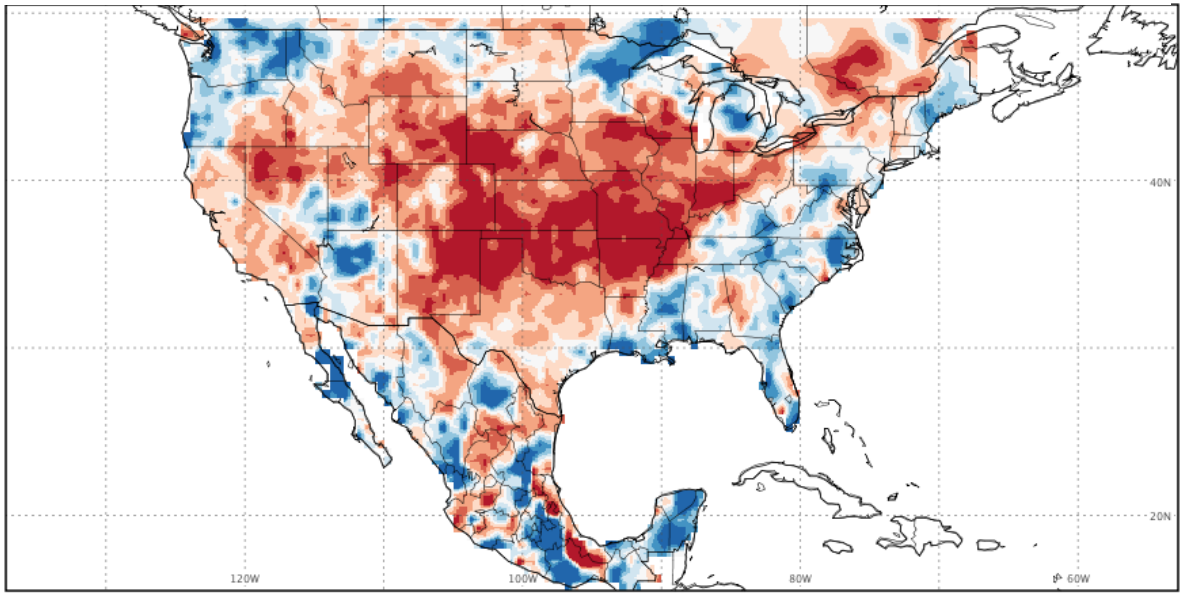


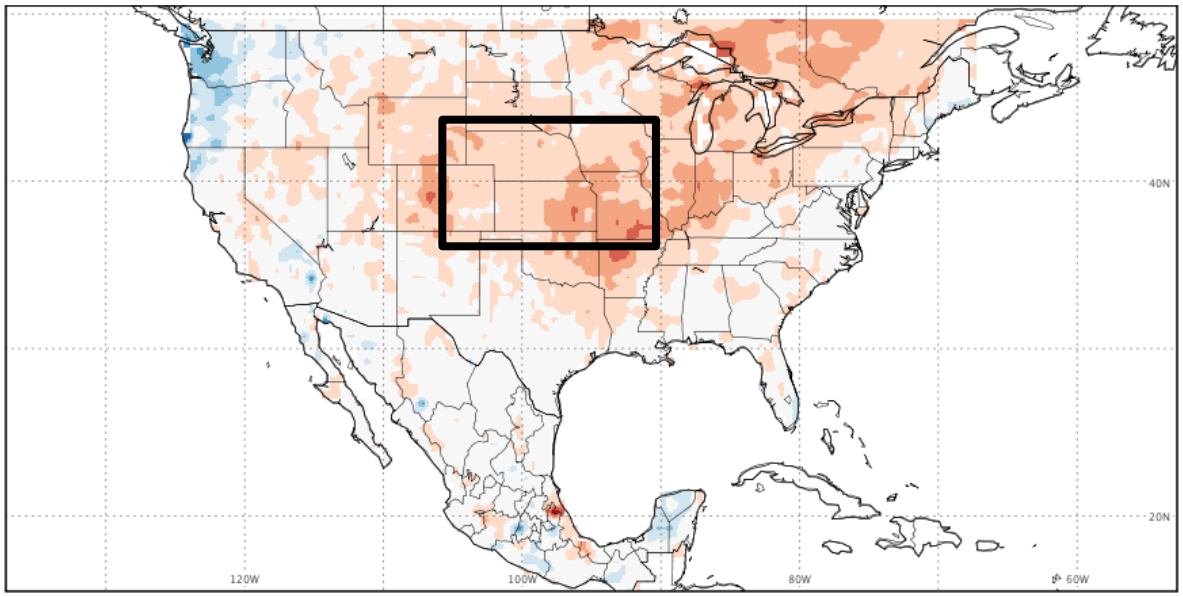
Dust storm: Oct 18, 2012;
Source: MODIS *Aqua*

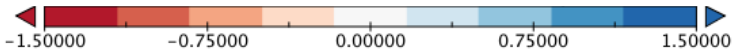
Isolated roles of temperature and precipitation on soil moisture

P-isolated (T set to climatology)

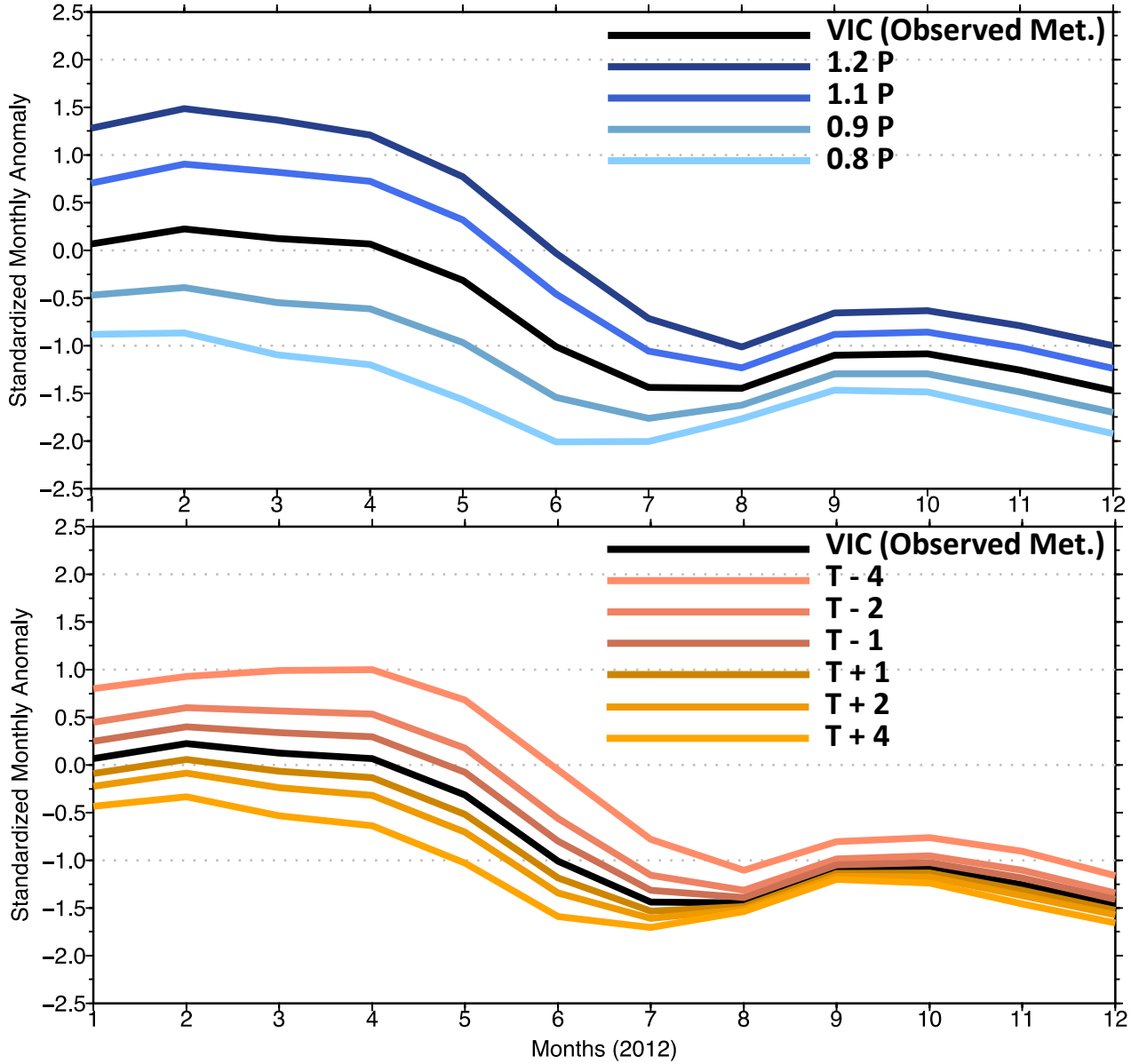


T-isolated (P set to climatology)

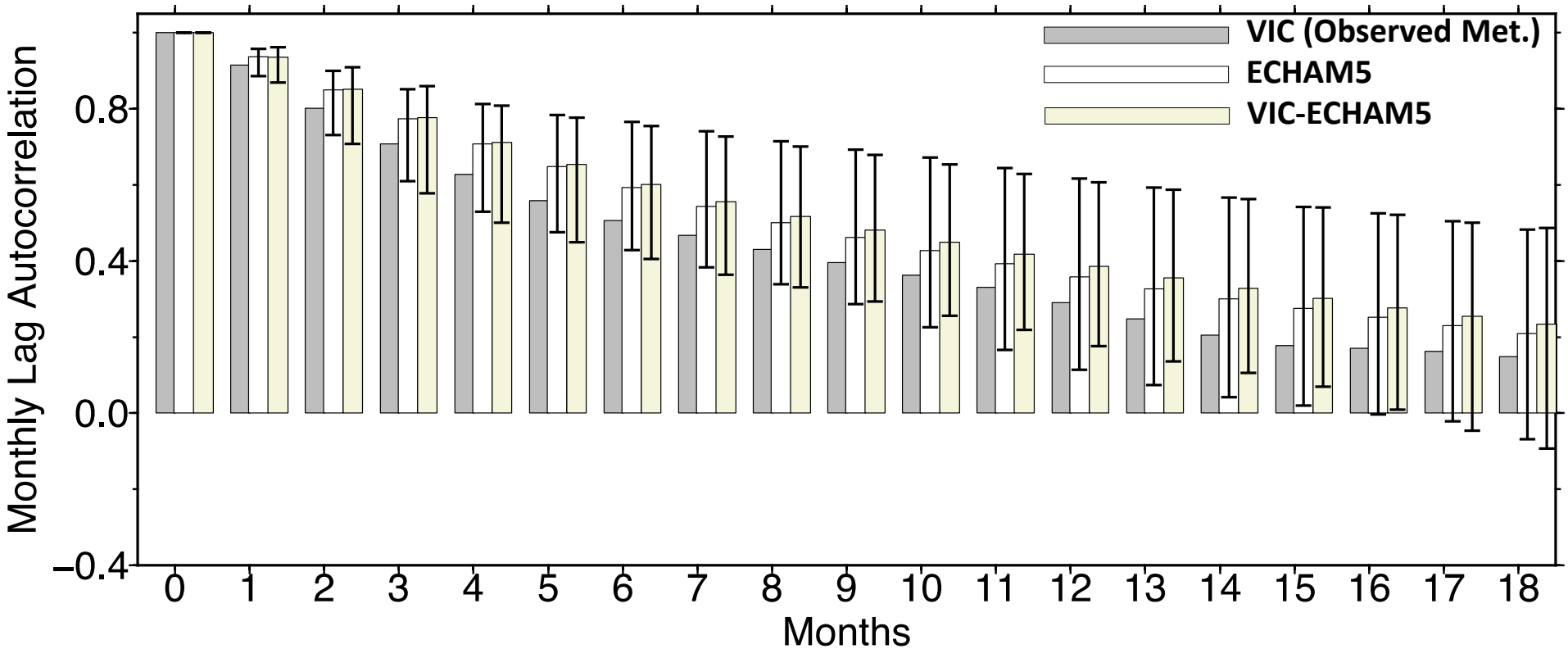




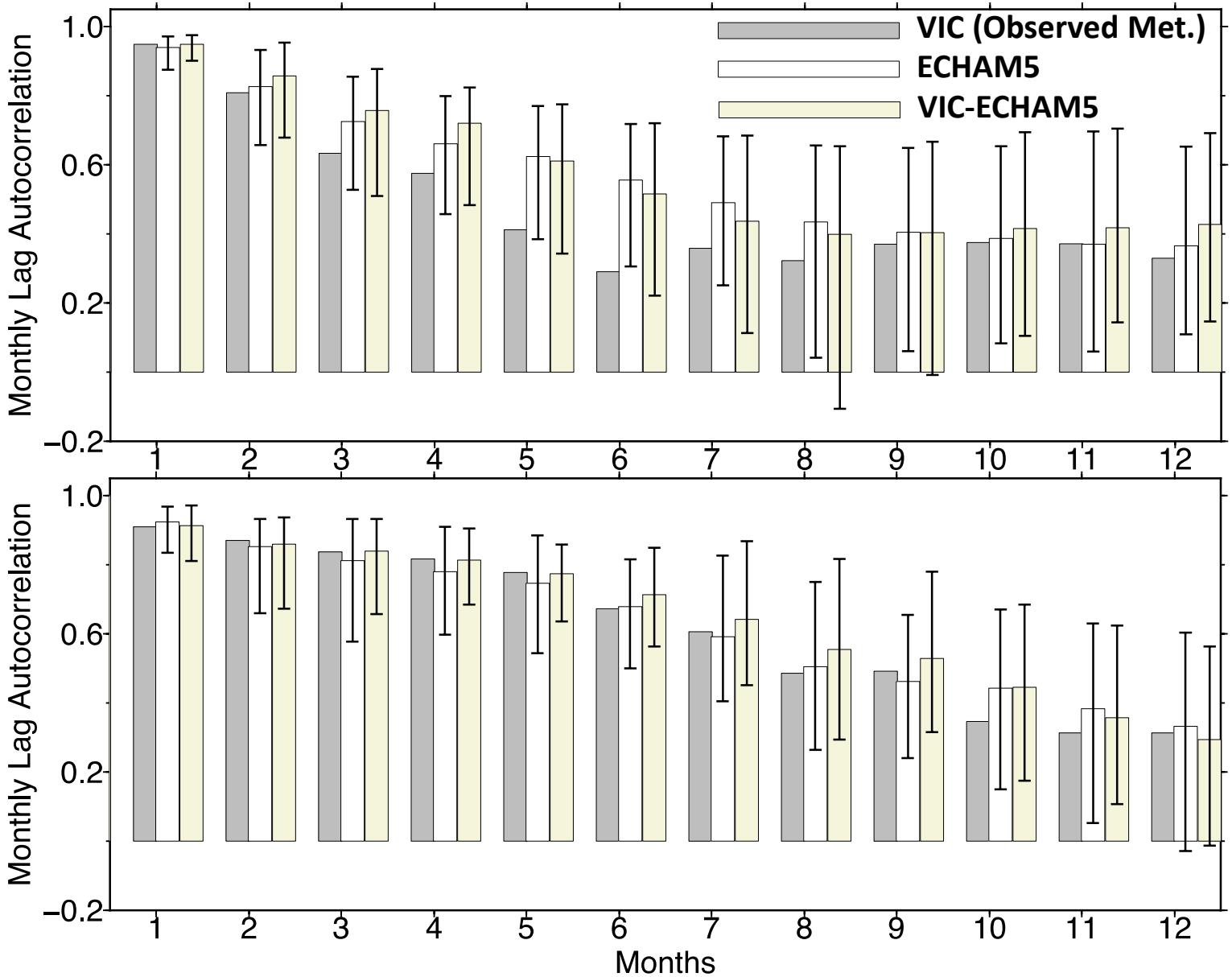
Standardized Soil Moisture Anomaly



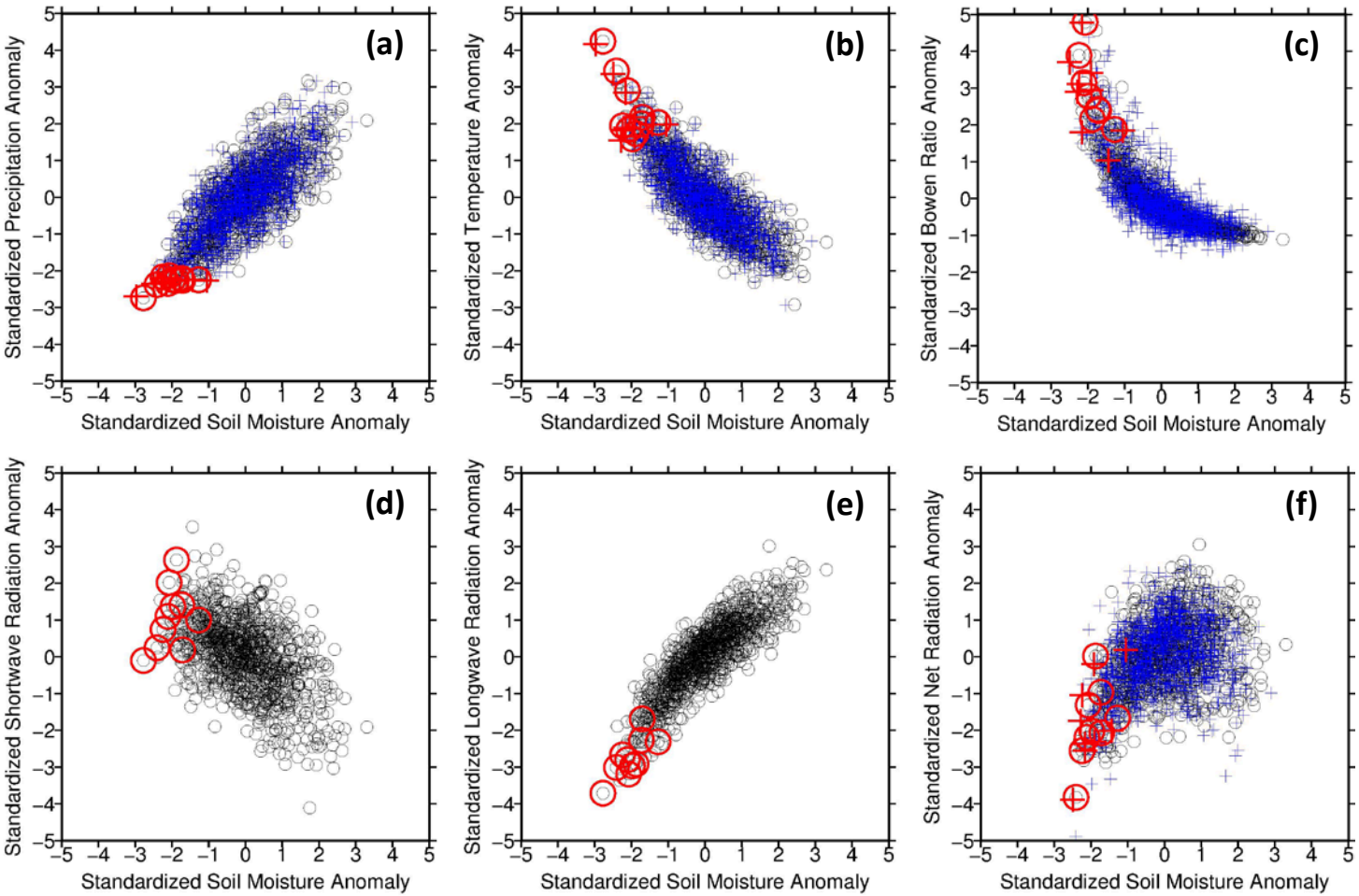
Monthly standardized anomalies for 2012 (relative to 1981-2010) for VIC simulations using observed meteorology in black, with (a) synthetic precipitation scaling shown in blue shading and (b) synthetic temperature deltas shown orange shading applied relative to observations for all months respectively.



Monthly lag-autocorrelation of soil moisture comparing monthly anomalies of VIC (top 1m of soil) driven by observed meteorology (1979-2013) with both the soil moisture from the 30-member ECHAM ensemble for the same period, as well as VIC driven by ECHAM meteorology (VIC-GCM) over the Great Plains domain; error bars denote minimum and maximum member values.



Monthly lag-autocorrelation of soil moisture (top) starting in March and (bottom) October comparing monthly anomalies of VIC (**top 1 m of soil**) driven by observed meteorology (1979-2013) with the 30-member ECHAM ensemble, as well as VIC driven by ECHAM meteorology (VIC-GCM) for the same period over the Great Plains domain; error bars denote minimum and maximum member values.



Comparison of MJJA standardized anomalies for various states and fluxes between ECHAM5 (circles) and VIC (crosses), where the 1% lowest MJJA precipitation simulations are highlighted in red.