Potential re-emergence of seasonal soil moisture anomalies in North America

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Overview

- The Big Picture
- The long memory process in the oceans
- Re-occurrence versus Re-emergence
- The Soil moisture re-emergence
- Climate Processes driving the soil moisture re-emergence
- Uncertainty in model data
- Roles of precipitation variability and land-atmosphere interactions
- Concluding Remarks

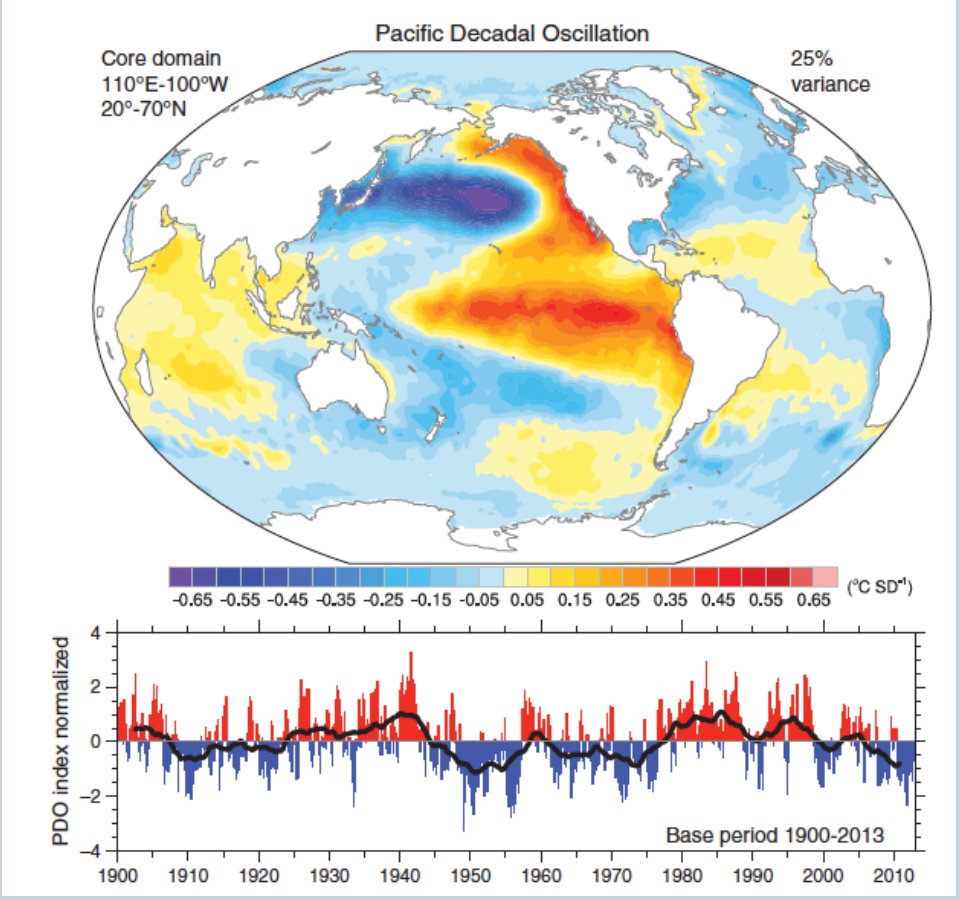
The Big Picture

1. Towards developing long-range (interseasoanl to decadal) soil moisture prediction system
2. To improve our understanding long-memory process over land, e.g. tree ring based re-construction of PDO.

The long-memory process in the ocean

The Pacific Decadal Oscillation

- Decadal persistence in SST anomaly over the extratropical North Pacific
- A combination of dynamical and local process drive the persistence (Newman et al., 2016)
- Have implications for global and regional climate, e.g. recent hiatus and a warmer southeastern US.



Trenberth and Fasullo (2013)

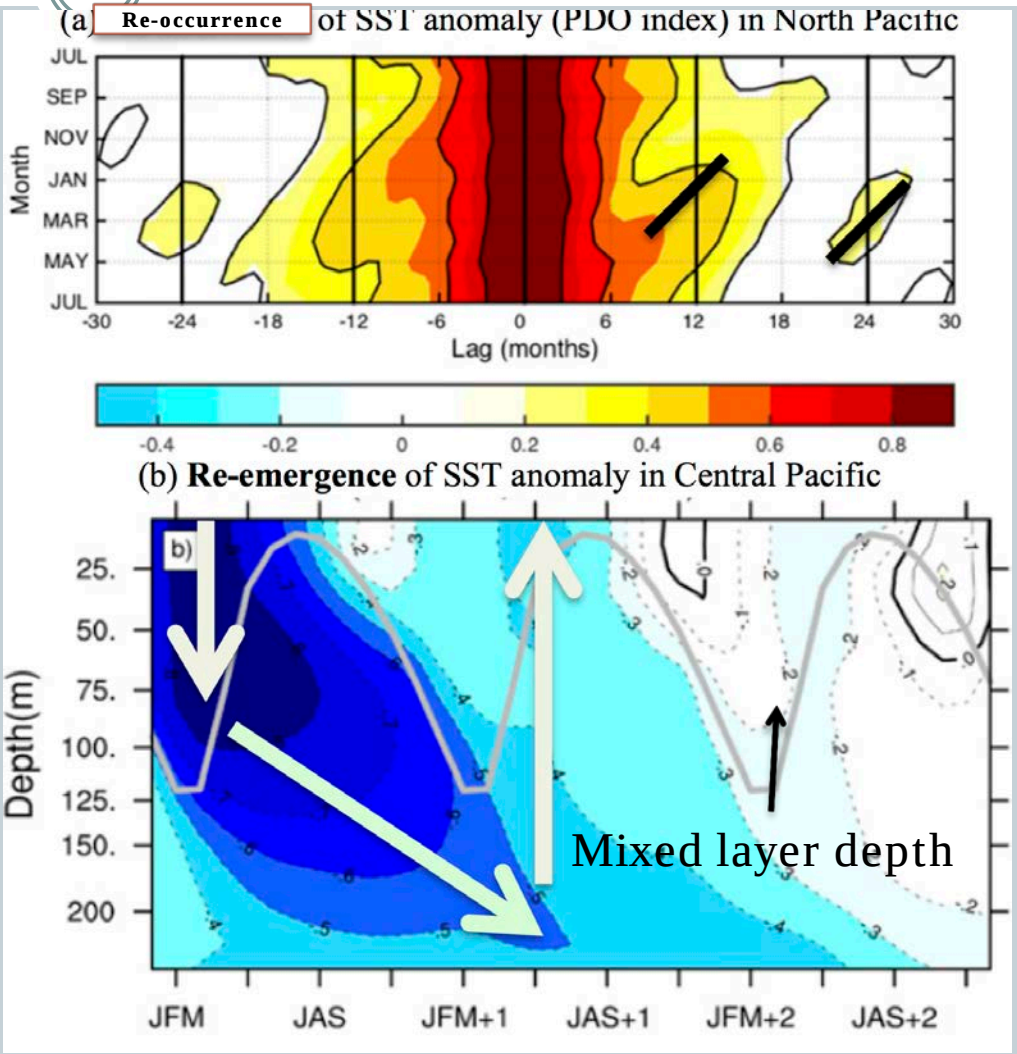
Re-occurrence versus Re-emergence

Re-occurrence of SST anomaly (PDO index)

- ✓ Lead-lag correlation of PDO index (1901 to 2014); only statistically significant correlations are shown
- ✓ Seasonal re-occurrence of SST anomaly during winter

Re-emergence of SST anomaly in the Central Pacific

- ✓ Evolution of SST anomaly along the ocean depth (y-axis) and time (x-axis)
- ✓ Mixed layer (ML) process: deeper mixed layer in the winter and shallower ML in summer
- ✓ Storage of memory in sub-surface layers and its re-emergence from one winter to the next



Newman et al. (2016)

Outstanding questions over LAND

1. Does similar re-emergence process also exist over land?
   - ✓ Most land related climate/hydrological predictability experiments, e.g. GLACE1 and GLACE2 are limited to seasonal time scales
2. If so, what are different climate process that drive re-emergence over land?
3. What is the contribution of land processes in reddening the tree-ring signal versus ocean contribution?

Does re-emergence exist over land?

An analysis of Illinois Climate Network (ICN) soil moisture observations (1985 to 2004)

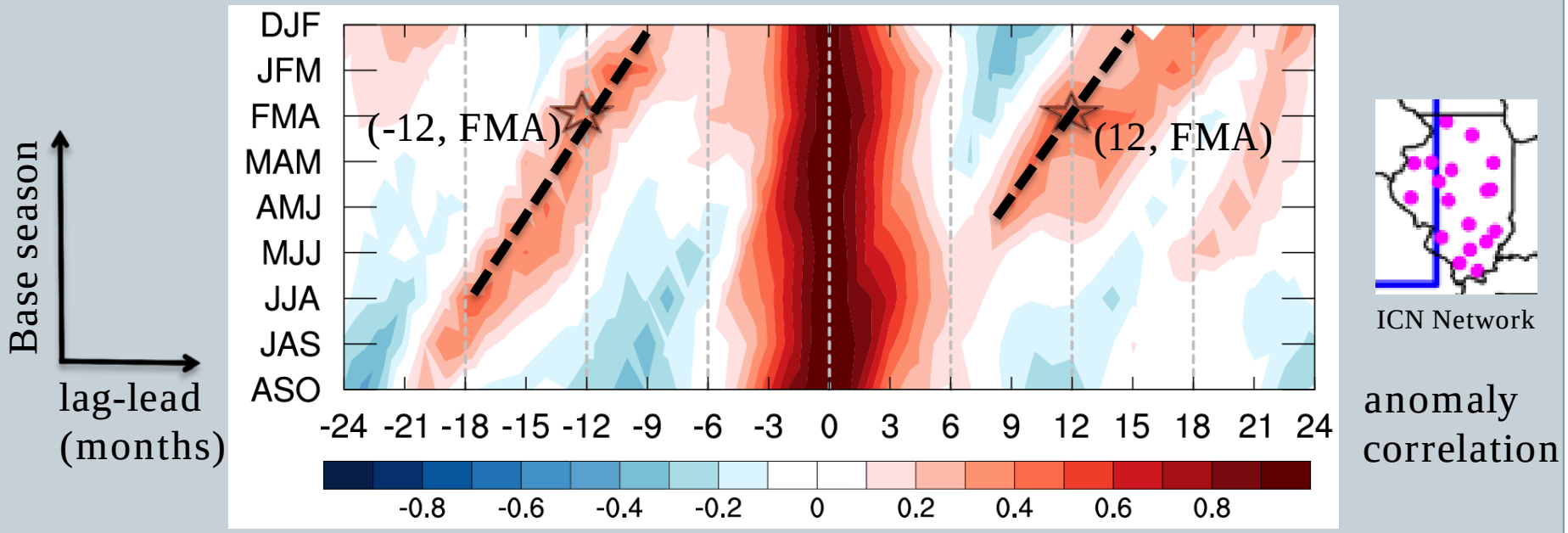


Fig. 3: The figure shows lead-lag correlations of 3-month running mean root zone (0 - 0.4 m depth) soil moisture anomaly, as a function of base season (fall season not shown). A point in Fig. 3, e.g. (-12, FMA) represents correlations between 12-month prior root zone soil moisture anomaly and the current month root zone soil moisture anomaly in FMA season. Similarly, (12, FMA) represents correlation between the current and 12 months later anomalies.

Newman et al., in prep.

Precipitation is not a proxy for soil moisture re-emergence

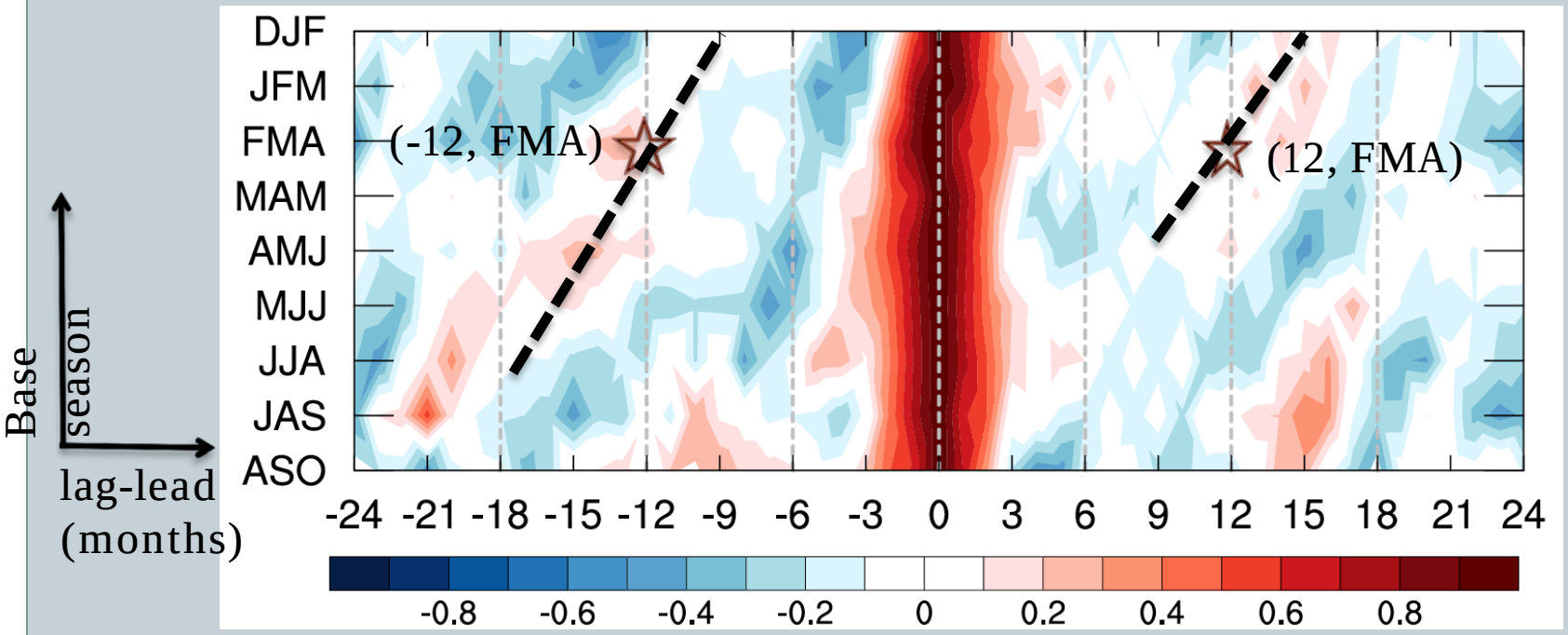


Fig. 4: Same as Fig. 3 using precipitation data nearest to ICN soil moisture stations

Newman et al., in prep.

Land processes drive the re-emergence

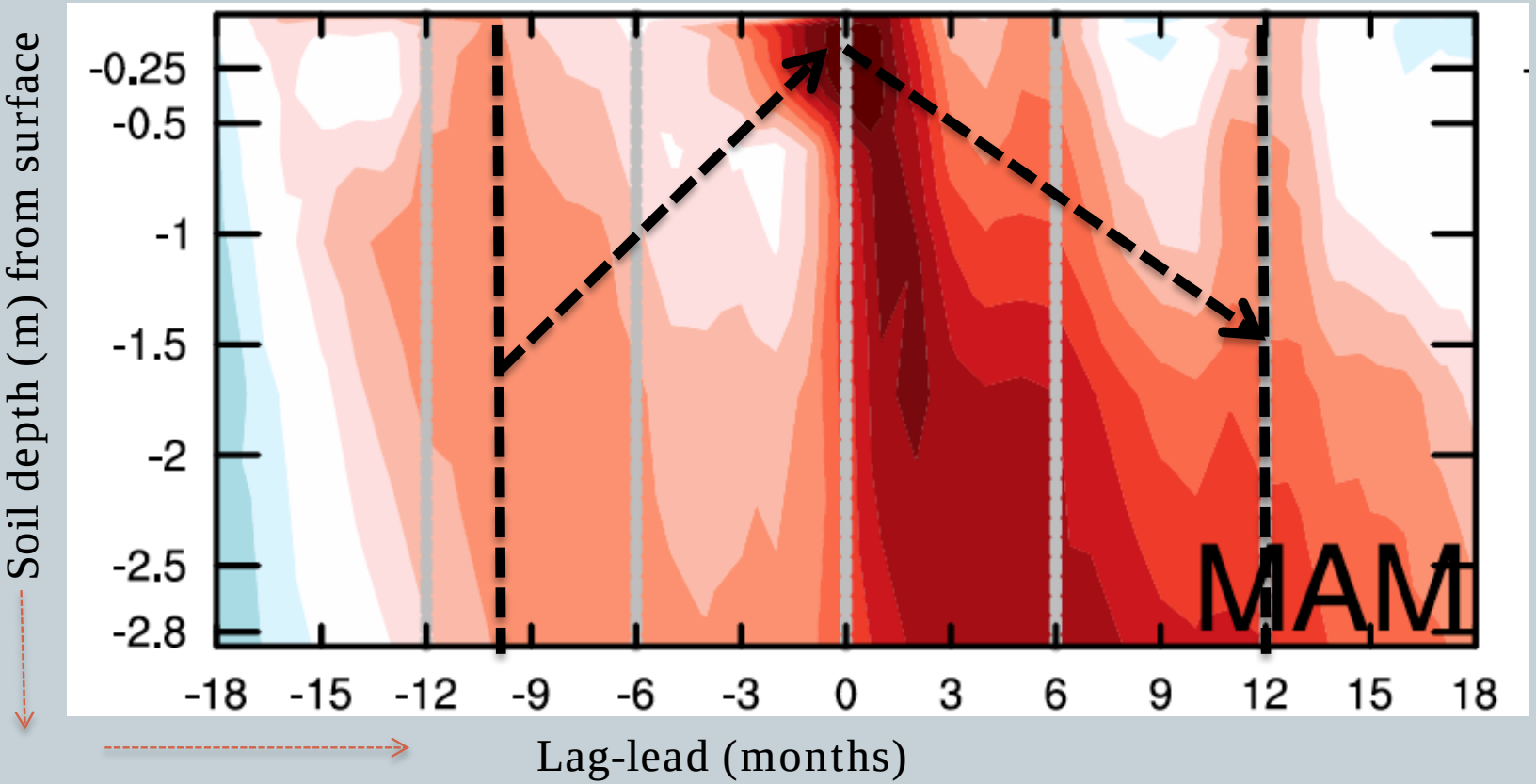


Fig. 5: Lead-lag cross-correlation of the root zone (0 to 0.5m) soil moisture anomaly in the given season with the individual layer's soil moisture anomaly at given lags and leads (in months) in in **CLM4.5 data** corresponding to ICN network

Newman et al., in prep.

The re-emergence signal is weaker in the observations

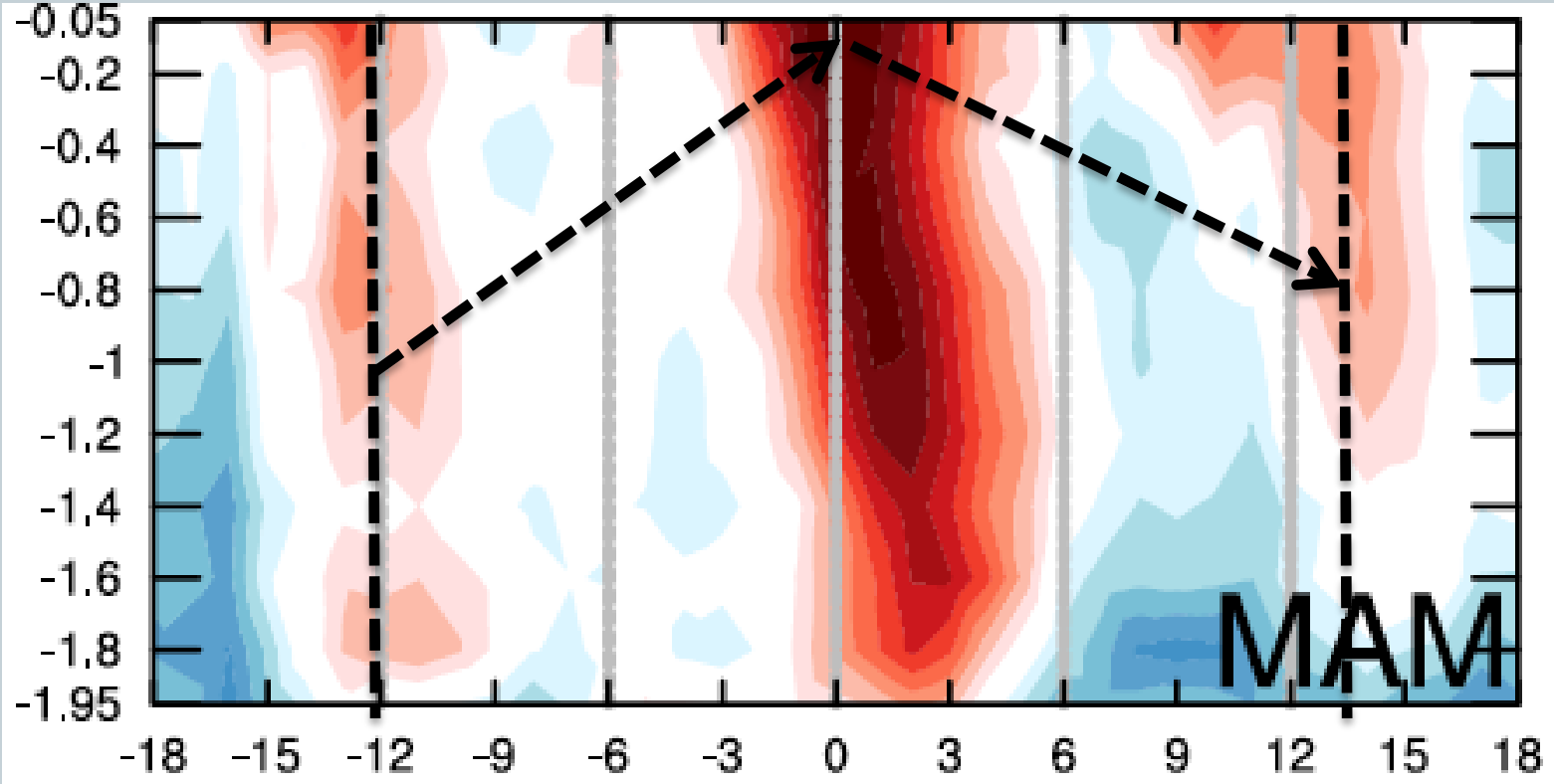


Fig. 6: Same as Fig. 5 using ICN soil moisture observations

Newman et al., in prep.

The soil moisture re-emergence mechanism

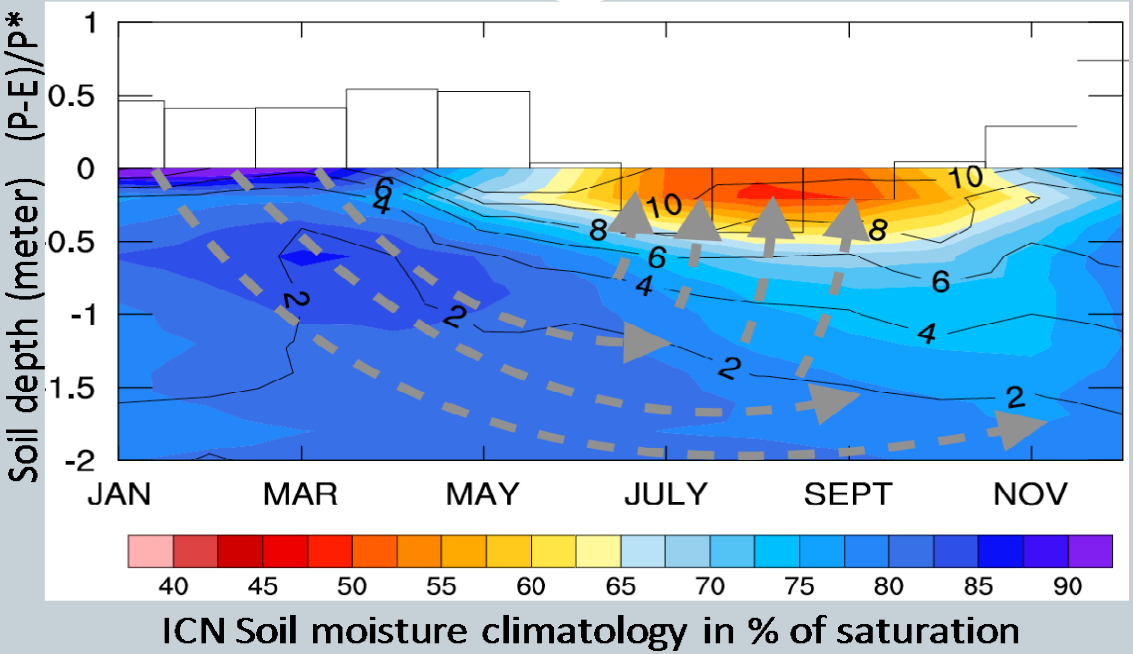


Fig. 7: Observed soil moisture climatology (1985 to 2004) from ICN observations are shown in colored contours, line contours show 1 standard deviation of inter-annual variability. P-E climatology are scaled with annual average precipitation (P*) from CLM4.5 offline simulations are shown using bars. The hypothesized "re-emergence" mechanism are shown using dotted arrows.

Newman et al., in prep.

The soil moisture re-emergence and drought

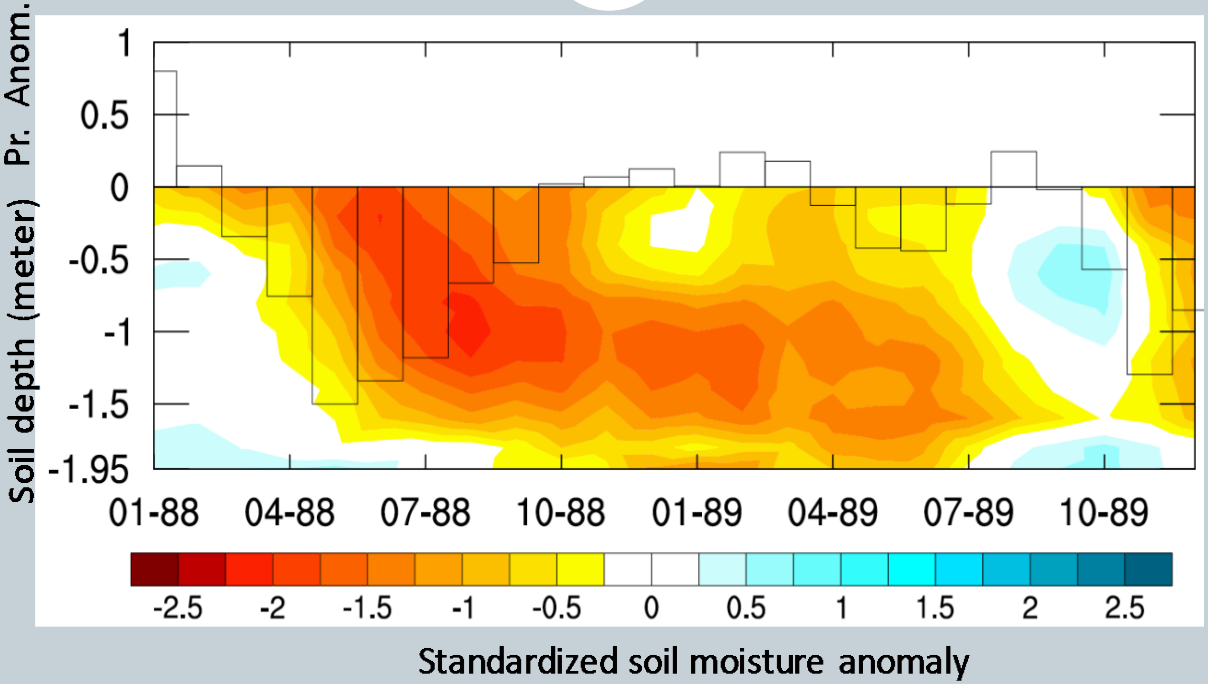


Fig. 8: Evolution of soil moisture anomaly during 1988 drought and the following year in ICN soil moisture observations. Standardized precipitation anomaly is shown using bars. Note the penetration of dry soil moisture anomaly in sub-surface layers, its disconnection from the surface layer in the winter and re-appearance following spring.

Newman et al., in prep.

Expanding the analysis

1. VIC (1/16th degree) [Livneh et al., 2015] – variable depth three layer soil moisture scheme; calibrated against stream flow observations.
2. VIC (1/2 degree) [Livneh, and Hoerling, 2016] – fixed depth three layers soil moisture scheme; not calibrated
3. CLM4.5 (1 degree) [Oleson et al., 2013] – fixed depth 10 layers soil moisture scheme; not calibrated
4. NLDAS2 (1/8th degree) [Xia et al., 2014] land surface models, e.g. NOAH and MOSIAC are used in operational forecasts
5. CPC (1/2 degree) [Huang et al., 1996; van den Dool et al., 2003] One layer 'leaky bucket' conceptual hydrological model

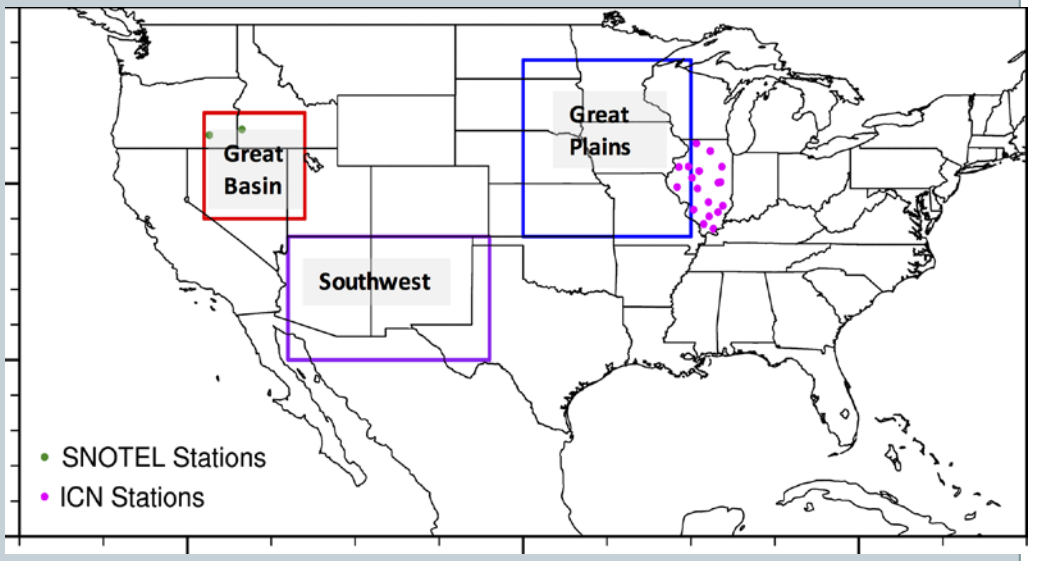


Fig. 9: Location of long-term soil moisture observations and regional boundaries.

Newman et al., in prep.

Uncertainty in soil moisture data

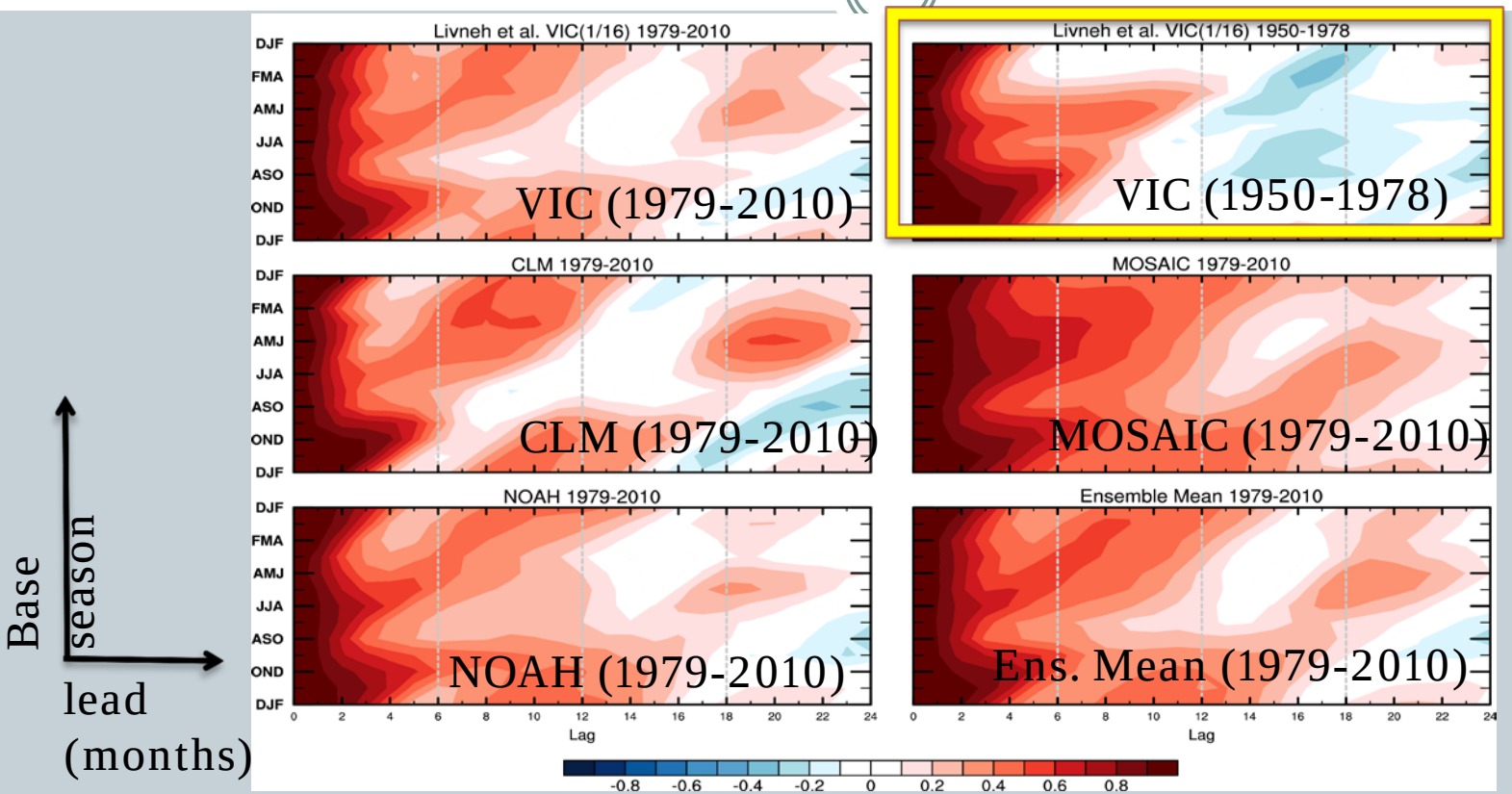


Fig. 10: Seasonal evolution of root zone anomalous soil moisture lag co-variability ("re-occurrence") averaged within the Great Plains region, in the (a, and b) VIC-L2015, (c) CLM, (d) MOSAIC, (e) NOAH, and (f) ensemble mean. All figures represent results from 1979-2010, except for panel (b), which is 1950-1978.

Newman et al., in prep.

Precipitation variability does not explain the re-emergence

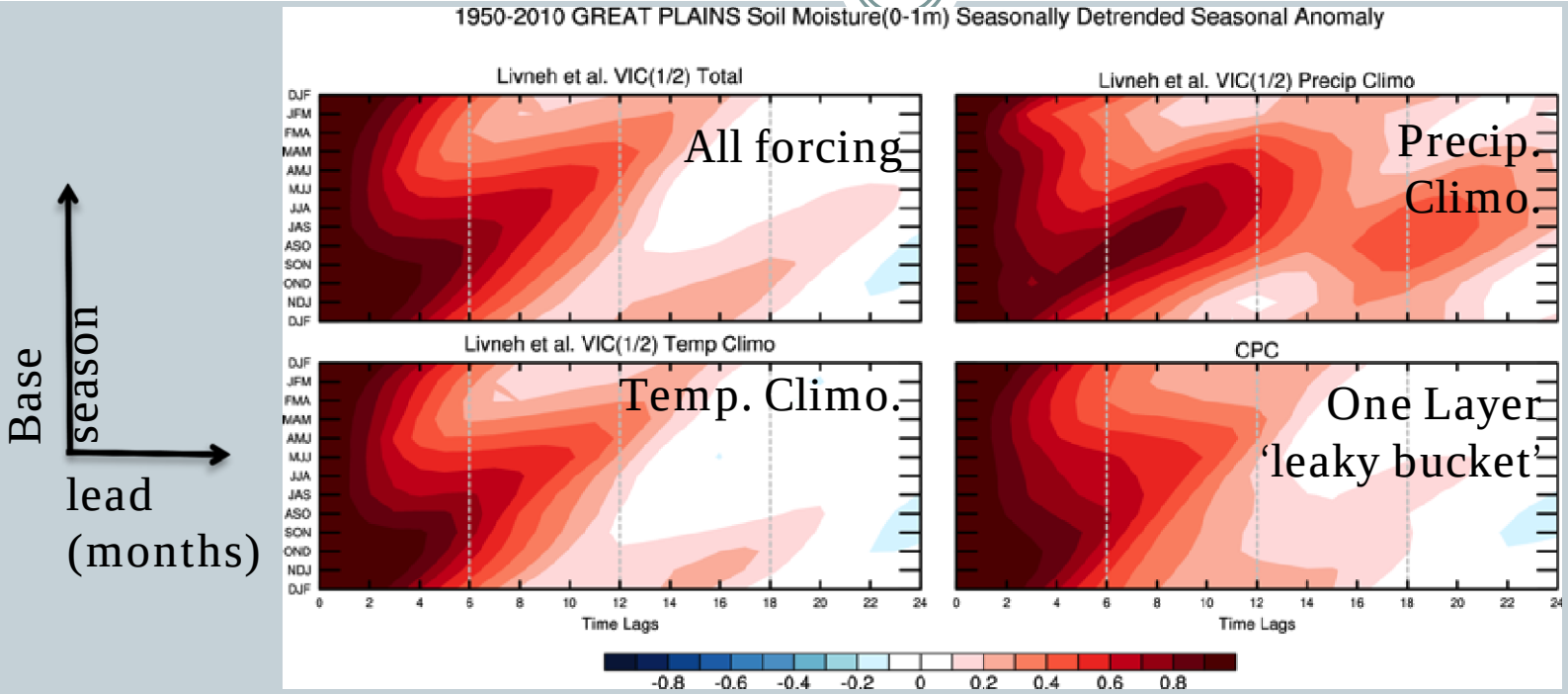
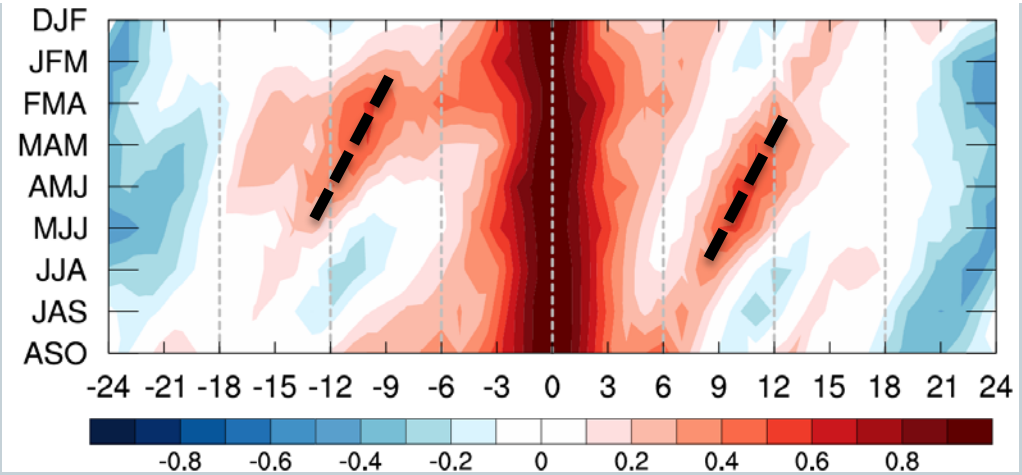


Fig. 11. Comparison of VIC-FD (fixed-depth) results for Great Plains for (a) observed forcing , (b) observed temperature and climatological precipitation forcing, and (c) climatological temperature and observed precipitation forcing, for the years 1950-2010. Panel (d) shows the results for the same region and period in the CPC ("leaky bucket") dataset.

Newman et al., in prep.

Role of land-atmosphere interactions

Land-Atmosphere interactions are active in the atmospheric forcing data generated using AMIP experiment (CAM5+CLM4.5)



Land-Atmosphere interactions are removed/tampered in the atmospheric forcing data generated using AMIP experiments and soil moisture climatology; then run CLM4.5 using the atmospheric forcing data

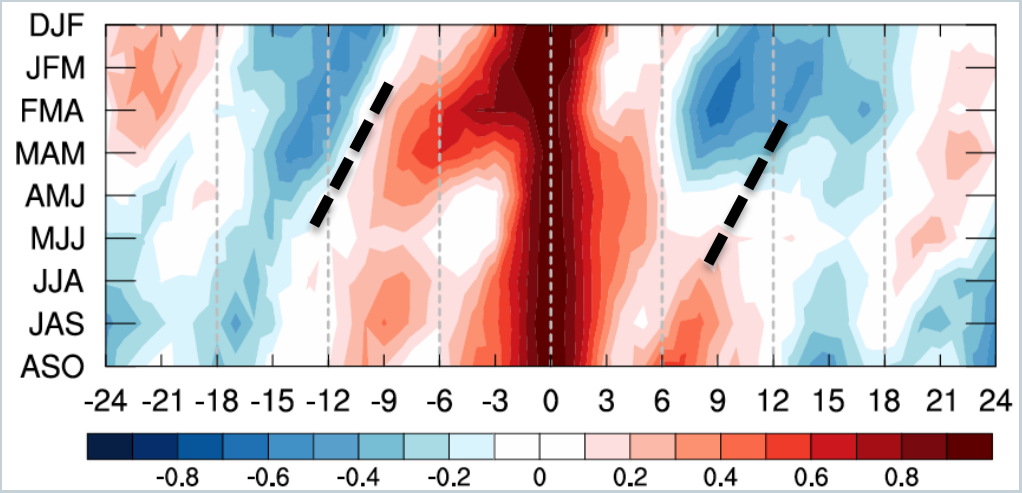


Fig. 12: Same as fig. 3 using soil moisture data from **The GLACE-Hydrology** experiment

Kumar et al., in prep.

Concluding Remarks

① There is pronounced seasonal and spatial (not shown) variations soil moisture anomaly autocorrelations

- ✓ Re-occurrence may lead to long-lead predictability in some seasons

② Comparison of surface and subsurface anomalies is suggestive of a "re-mergence" mechanism

- ✓ Our analysis suggests that atmospheric forcing (e.g. precipitation) variations does not explain the re-emergence.
- ✓ Additional experiment (The GLACE-Hydrology Experiment) suggests an important role of land-atmosphere interactions

③ Substantial uncertainty in "NLDAS" and other model based soil moisture data, vs. limited observations limits confidence in these results.