Prediction skill of U.S. flash droughts in Subseasonal Experiment (SubX) model hindcasts

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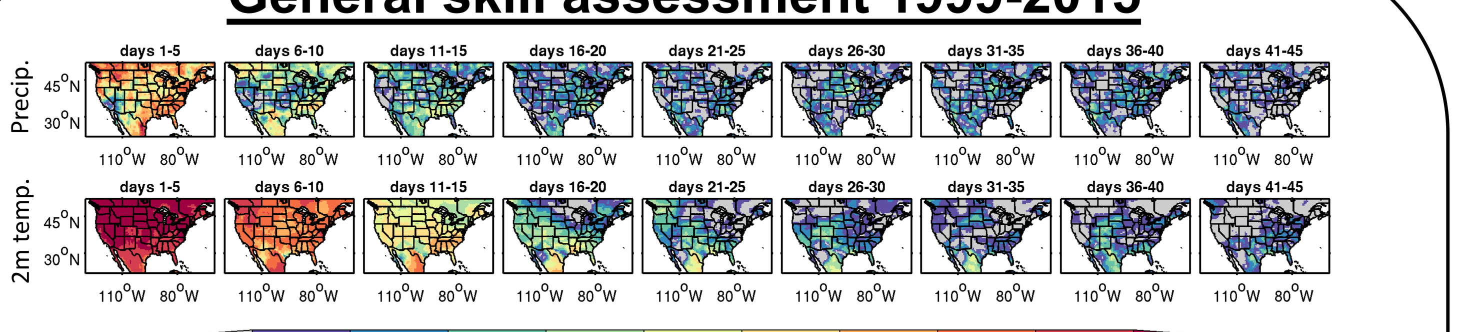
Abstract

Droughts that establish themselves over a short period of time (weeks to a few months), referred to as flash droughts, can have devastating impacts on agriculture, water resources, and ecosystems. The ability to predict such droughts in advance would greatly enhance our preparation for them and potentially reduce their impacts. The subseasonal time scale at which flash droughts occur emphasizes the importance of producing forecasts at weekly or finer intervals that extend beyond the numerical weather prediction time frame. Here we assess the ability of eight global forecast systems, each participating in the Subseasonal Experiment project (SubX), to predict key features associated with rapidly developing droughts over the United States during the last two decades. MERRA2 reanalysis is used as observations. Prediction skill for temperature and precipitation anomalies during these events is limited to the first 1-2 weeks after initialization for most hindcasts. However, there are some hindcasts in which large anomalies are well predicted 3-4 weeks or more in advance. The physical mechanisms that are key to the development of surface anomalies, including quasi-stationary atmospheric waves, were also evaluated. Most hindcasts were unable to capture the development or progression of such drought-inducing circulation features more than 1-2 weeks in advance.

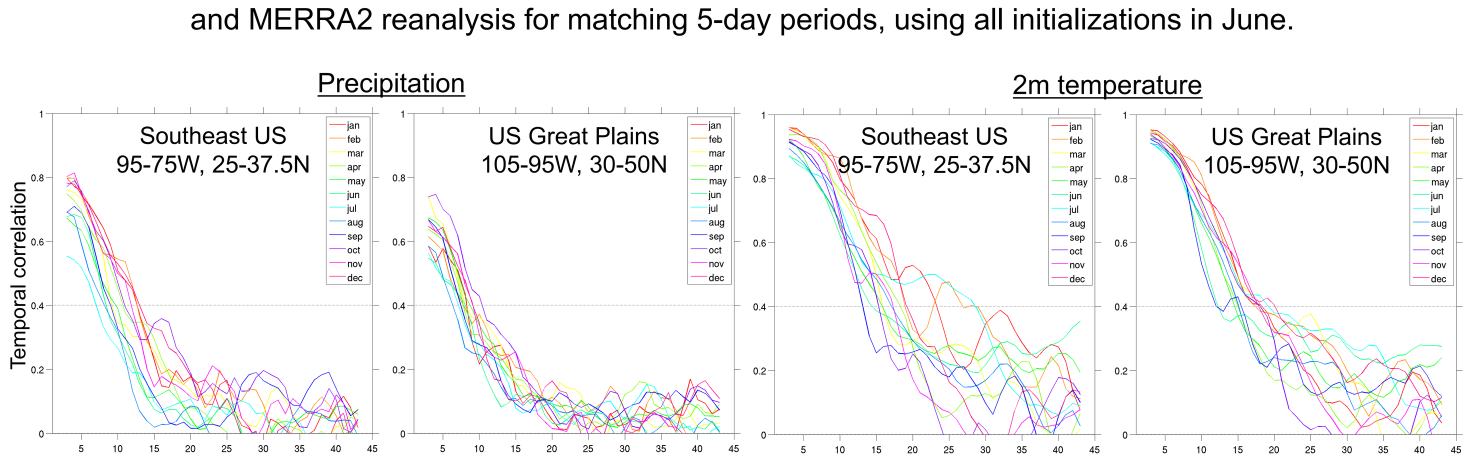
SubX model hindcasts

Model	# Members	Forecast Length	Initializations
CESM-46LCESM1	10	45 days	Every Wednesday 1999-2015
ECCC-GEM	4	32 days	Every 7 days 1995-2014
EMC-GEFS	11	35 days	Every Wednesday 1999-2016
ESRL-FIMr1p1	4	32 days	Every Wednesday 1999-2017
GMAO-GEOS-v2.1	4	45 days	Every 5 days 1999-2016
NCEP-CFSv2	1	44 days	Every 6 hours 1999-2017
NRL-NESM	1	45 days	4 consecutive days each week 1999-2016
RSMAS-CCSM4	3	45 days	Every 7 days 1999-2016

General skill assessment 1999-2015



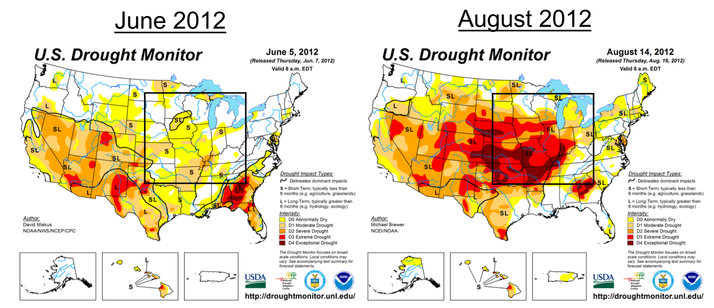
Multi-model mean (MMM) prediction skill as a function of forecast day for the month of June for precipitation (top) and 2m temperature (bottom). Shown at each location is the temporal correlation between forecasts and MERRA2 reanalysis for matching 5-day periods, using all initializations in June.

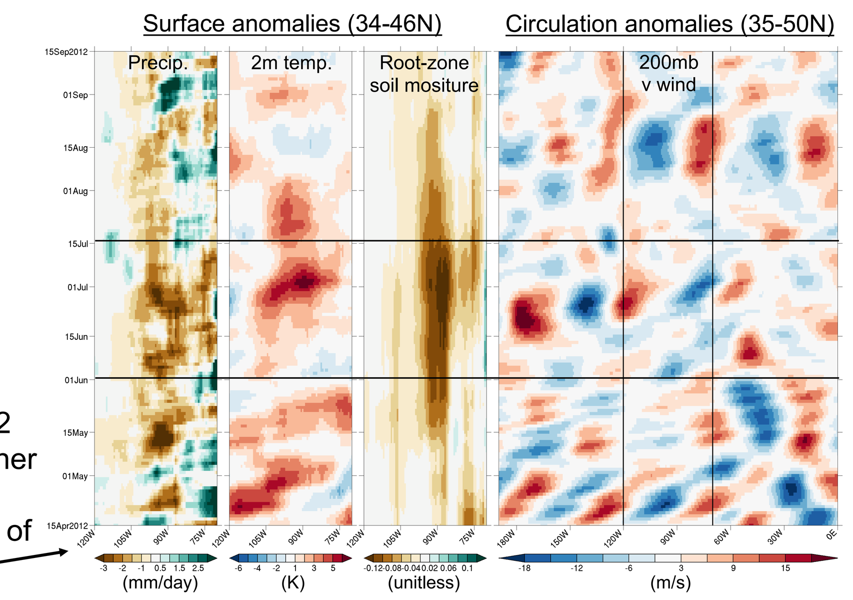


The MMM regional-mean temporal correlation for all months and forecast days. ***Prediction skill is limited to the first 1-2 weeks after initialization for precipitation and to the first 2-3 weeks for temperature. Prediction skill tends to be better in winter than summer, especially in the Southeast US.***

Example Flash Drought: US Great Plains in Summer 2012

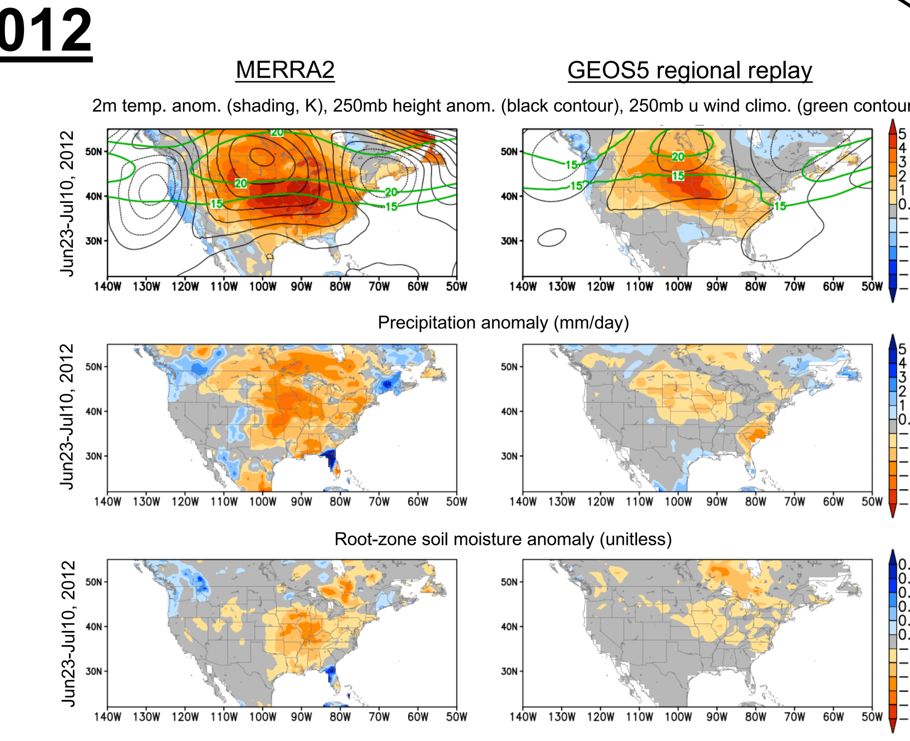
1. Overview





(Above) U.S. Drought Monitor maps showing the 2012 drought intensification. The boxed region is studied further for the evaluation of relevant surface anomalies. (Right) Hovmöller plots showing the temporal evolution of drought-related quantities in MERRA2.

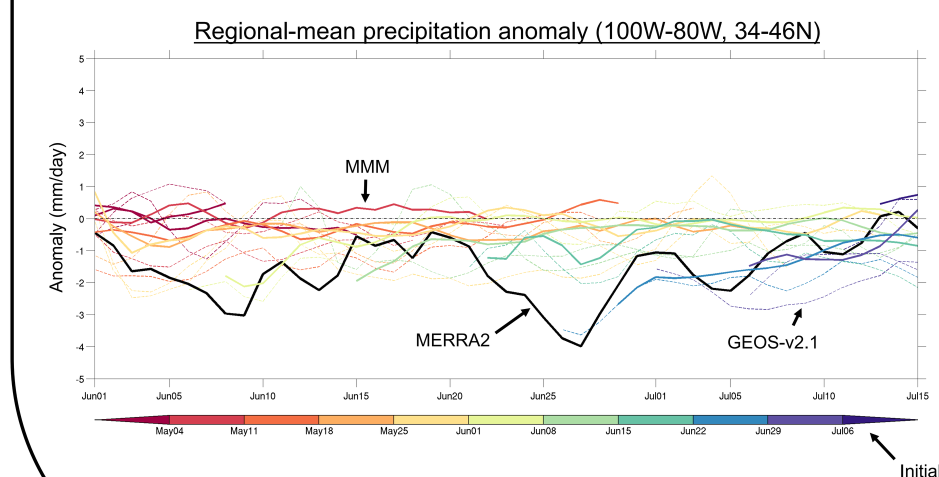
2. Physical mechanisms

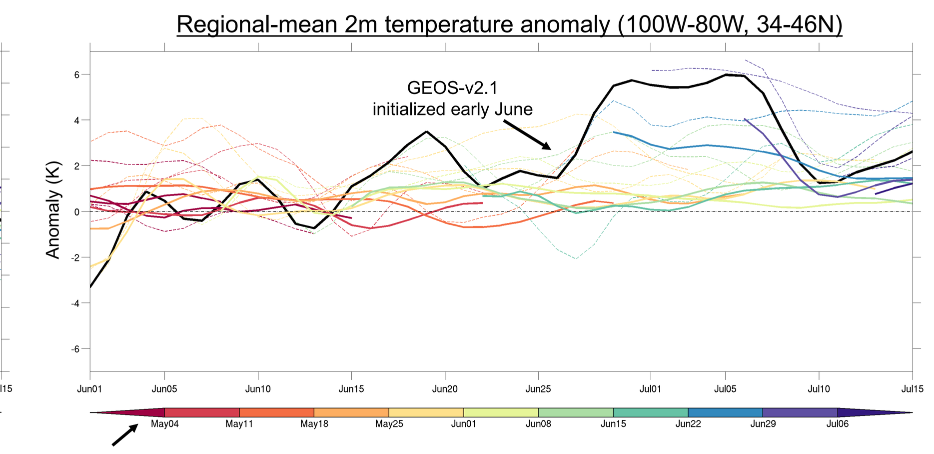


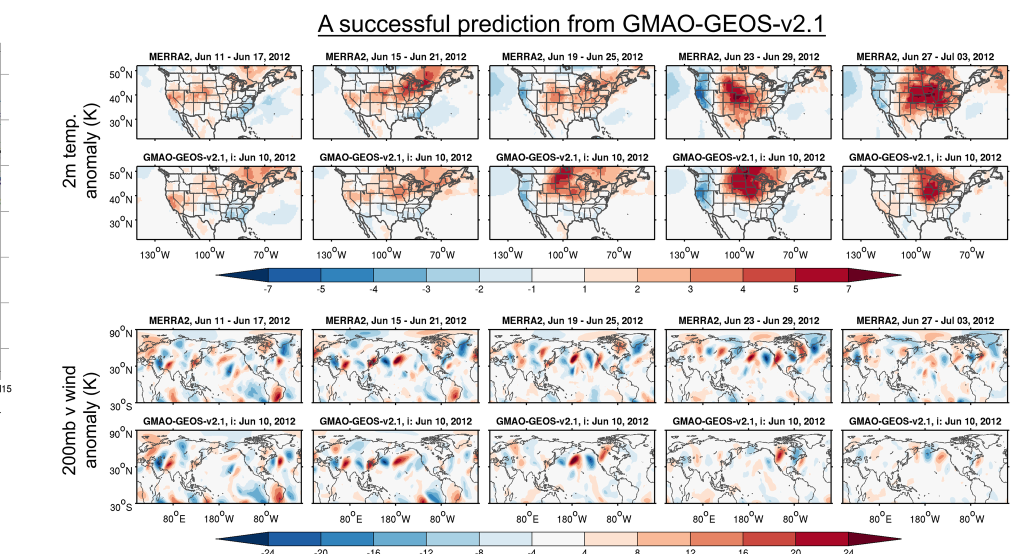
Regional replay: Simulations were conducted with the NASA-GEOS5 AGCM in which an atmospheric region encompassing southeast Asia (70-140E, 0-45N) is constrained to be close to observations, while in the rest of the world the model atmosphere evolves freely.

Good agreement between MERRA2 and the regional replay suggests convective processes in the western subtropical Pacific contribute to the 2012 flash drought development. However, the dry anomaly is considerably underestimated, possibly due to the model's warm and dry bias in the central US in the summer.

3. SubX skill assessment







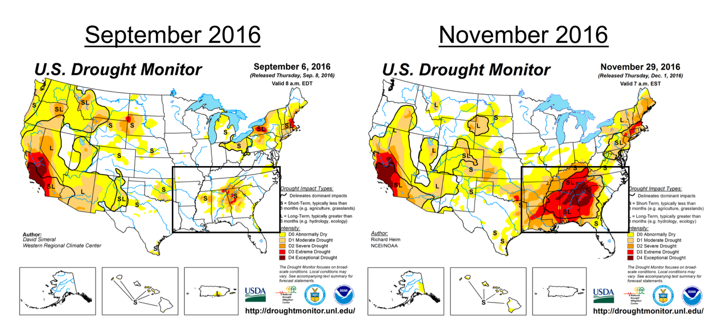
A prediction from the GMAO-GEOS-v2.1 model initialized Jun 10, 2012. The Great Plains heat wave is successfully predicted ~3 weeks in advance.

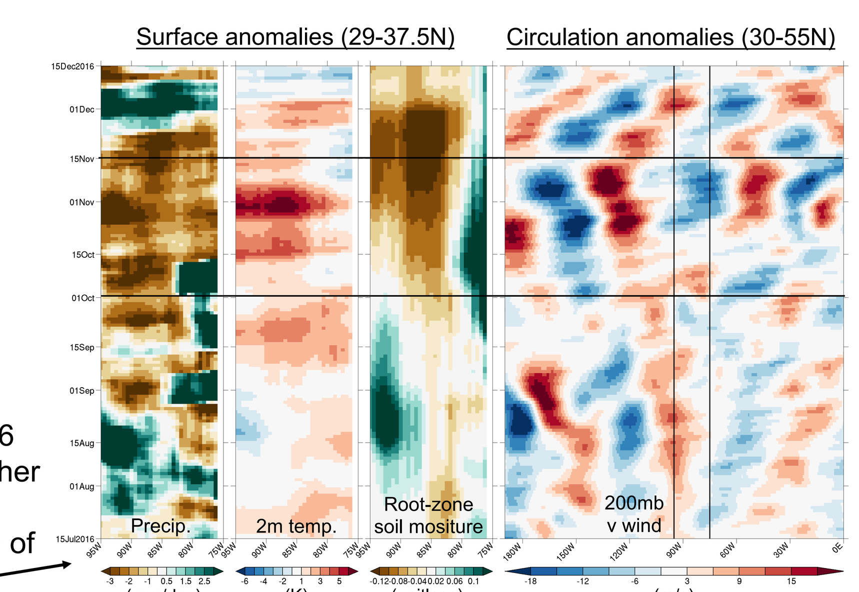
In this hindcast, the quasi-stationary wave train originating from East Asia develops and progresses east to North America.

Collectively, SubX hindcasts cannot reproduce observed large anomalies when initialized more than 1-2 weeks prior. However, a few successful GEOS-v2.1 hindcasts (with predictability >3 weeks in advance) are evident.

Example Flash Drought: Southeast US in Fall 2016

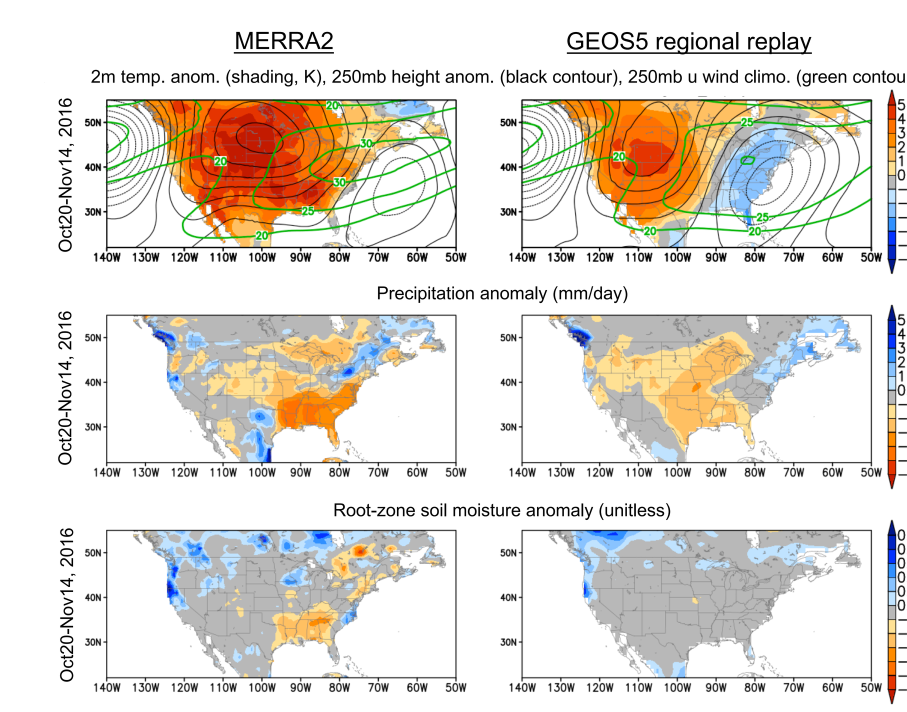
1. Overview





(Above) U.S. Drought Monitor maps showing the 2016 drought intensification. The boxed region is studied further for the evaluation of relevant surface anomalies. (Right) Hovmöller plots showing the temporal evolution of drought-related quantities in MERRA2.

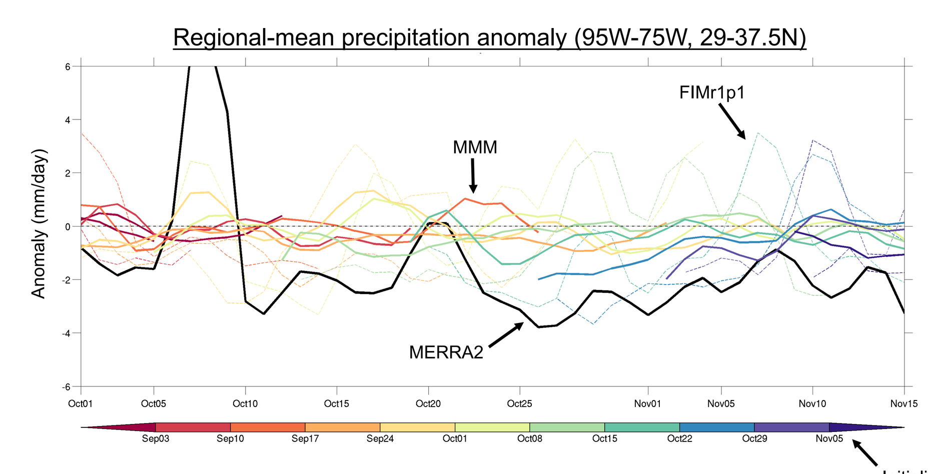
2. Physical mechanisms

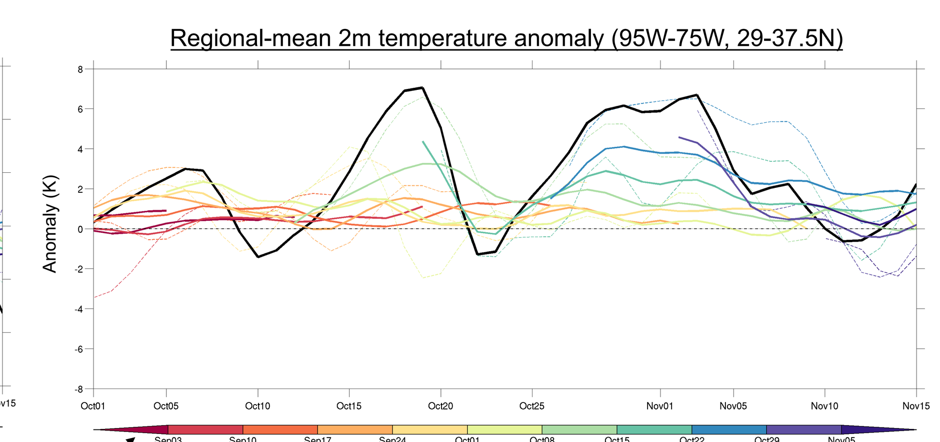


Regional replay: Similar to the 2012 case, regional replay experiments were conducted for 2016 but with a much broader upstream region being constrained to observations (60-230E, 30S-75N).

The regional replay is able to produce an upper-level high anomaly over the US, indicating the importance of upstream processes for generating the high. However, the high anomaly does not extend to the southeast US as in MERRA-2, possibly due to the model's weaker-than-observed jet over the eastern US.

3. SubX skill assessment





Like in the case of the 2012 Great Plains drought, SubX hindcasts are generally unable to capture the large anomalies associated with the 2016 Southeast drought more than 1-2 weeks in advance.

However, hindcasts initialized around the time of the development of a quasi-stationary wave train (mid October 2016) can adequately capture the development of a heat wave over the US in late October-early November. This indicates the potential for 2-3 week predictability of drought-related warm anomalies when forecasts are initialized with upstream circulation features that are relevant to the drought development.

Discussion and Conclusions

- SubX models are generally more skillful at predicting temperature anomalies than precipitation anomalies, but usually not more than 2 weeks after model initialization. Given the importance of precipitation deficits for flash drought development, this is problematic for the adequate prediction of destructive flash drought events.
- Quasi-stationary wave trains are critical features that encourage flash drought development. Thus, improvement in flash drought prediction may be gained through model development targeted at deficiencies in the upper-level jet stream, which is relevant for the accurate prediction of wave train development and progression.

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