Science and Technology Infusion Climate Bulletin
NOAA's National Weather Service
41st NOAA Annual Climate Diagnostics and Prediction Workshop
Orono, ME, 3-6 October 2016

Attribution and Prediction of China Droughts Across Scales

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1. Introduction

Droughts are driven by naturally occurring climate variations. However, climate change and human activities may have altered the characteristics of droughts, and increased society's vulnerability to them. Droughts have a variety of spatiotemporal scales from flash droughts at local scales that are usually concurrent with heat extremes, to seasonal/decadal droughts at regional to continental scales that are associated with large-scale climate anomalies and certain atmospheric circulation patterns. Droughts also have quite different implications across a number of sectors, depending on whether they manifests as a meteorological, agricultural or hydrological drought, where the latter type of droughts could be affected by human activities directly. This raises many challenges to attributing changes, understanding predictability and to investigating the impacts of droughts across spatial and temporal scales in a changing environment. This article will show a few progresses on the attribution and prediction of China droughts across scale, which also has implications for drought research over other regions of the world.

2. Increasing flash droughts over China during past 30 years

In recent years, the frequent occurrence of flash droughts across the world has raised much attention. Flash drought is triggered by heatwave accompanied with low soil moisture (SM) and high evapotranspiration (ET). Due to its rapid onset and unusual intensity, the impact of flash drought can be devastating in some cases. Here we assessed the long-term trend and variability of flash droughts over China during 1979-2010 based on pentad-mean temperature from over two thousand meteorological stations and SM and ET from three global reanalysis products (Wang *et al.* 2016). Overall, all three reanalysis data show that there is an increasing trend

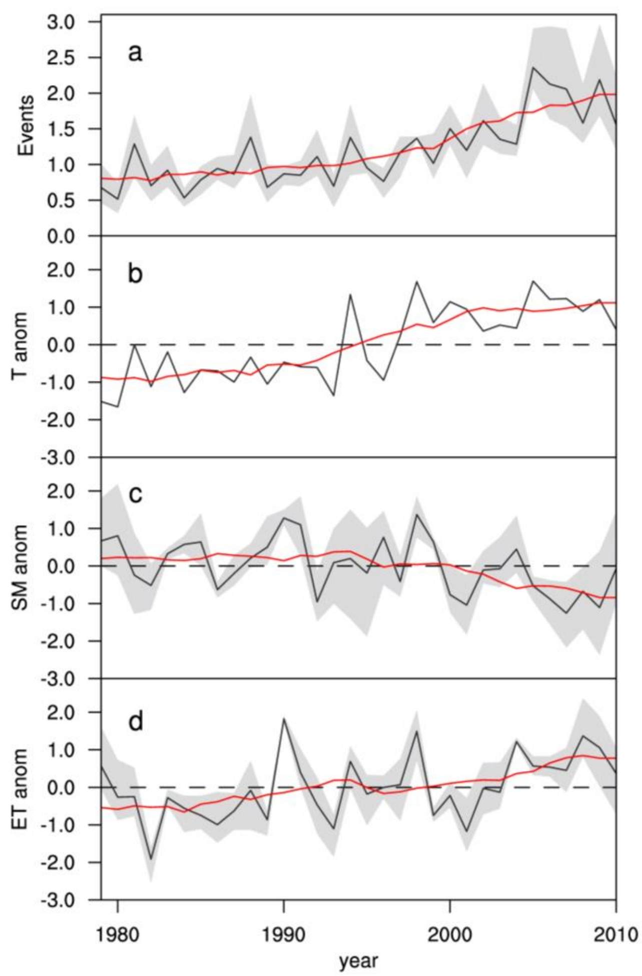

Fig. 1 Changes of ensemble mean flash drought event and its component variables averaged over China. (a) The number of flash drought events per year, (**b**) surface air temperature (T) anomaly, (**c**) soil moisture (SM) anomaly, (**d**) ET anomaly (black curves). The red curves are the 10-year running means and the grey shadows are the ranges of results from different reanalysis products. (Wang *et al.*, 2016)

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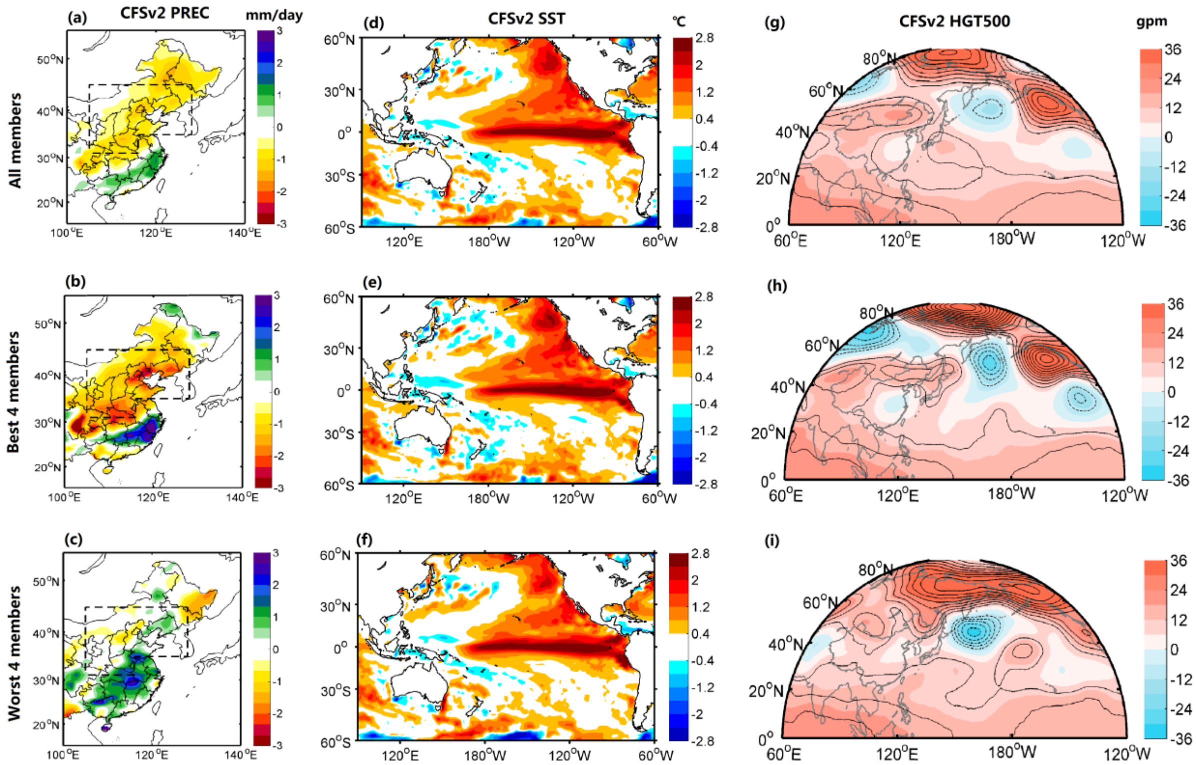

Fig. 2 Spatial distributions of CFSv2 predicted anomalies of precipitation, SST and 500-hPa geopotential height in the summer of 2015. The left panels are the composite of (a) all ensemble members, (b) four best and (c) four worst members for 0.5-month lead seasonal forecasts of precipitation anomaly(mm/day). The middle (d–f) and right panels (g–i) are the same as the left, but for the anomalies of SST (°C) and 500-hPa geopotential height (gpm). (Wang *et al.*, 2017)

for flash droughts in recent 30 years though there is some difference in amplitudes (Fig. 1). The increase in flash droughts is associated with changes of annual mean surface air temperature, SM and ET. The warming amplitude is 0.36°C per decade ($p < 0.01$) over China for the period 1979-2010. The long-term variability of SM and ET are less significant, despite a drying trend for SM ($p < 0.05$) and an increasing trend for ET ($p < 0.05$). Thus the ensemble mean of flash droughts increases by 109% over the whole period and the increase is mainly associated with the long-term warming trend. The increasing trends in flash droughts even tripled despite the warming hiatus since 1998. Further analyses indicate that the interannual variability of flash droughts is influenced by variation in SM and ET and the effect of the decreased temperature is compensated by decreased SM and increased ET (Wang *et al.* 2016).

3. Seasonal forecasting of the 2015 severe summer drought over North China

With a good prediction of the 2015/16 big El Niño, NCEP's Climate Forecast System version 2 (CFSv2) roughly captured the 2015 extreme summer drought over North China (Fig. 2, top panels). This raises a question of whether the 2015/16 monster El Niño help the forecasting of the 2015 extreme summer drought. Here, we show that a strong El Niño does not necessarily result in an extreme drought, but it depends on whether the El Niño evolves synergistically with Eurasian spring snow cover reduction to trigger a positive summer Eurasian teleconnection (EU) pattern that favors anomalous northerly and air sinking over North China. As seen from Fig. 2g, CFSv2 generally captured the positive EU circulation pattern across Eurasia, which led to a well-captured drought pattern over North China but with an underestimation of intensity. Meanwhile, comparing the performances of predicted sea surface temperature (SST) between four best and four worst cases, little difference were found for the predicted SST anomalies, which both agreed with the observed SST anomaly well, suggests that a strong El Niño signals can be predicted by the dynamical climate forecast model quite well (Figs. 2e, f). However, it does not necessarily mean that it will increase the predictability of the extreme summer drought in North China. In fact, the composite of the four best members was more skillful than the full ensemble mean in terms of the prediction of the positive EU pattern (Fig. 2h), while the four worst composite totally failed to capture such circulation pattern (Fig. 2i) and thus missed the drought (Fig. 2c). Indeed, our results showed that a dynamical-statistical forecasting approach that combines both the low- and high-latitudes precursors is more skillful than the dynamical forecasting at long lead (Wang *et al.* 2017).

4. The role of human interventions on hydrological drought forecasting

We also assessed the effects of human interventions on the drought propagation based on five decades (1961-2010) of naturalized and observed streamflow datasets over a heavily managed river basin, the Yellow River basin in northern China. After calibrating the Variable Infiltration Capacity (VIC) land surface hydrological model grid by grid, the impact of human intervention on the hydrological drought predictability is being explored within the ESP/VIC and NMME/VIC forecasting framework that has been established over the Yellow River basin (Yuan 2016; Yuan *et al.* 2016). Overall, the nonlinear response of hydrological drought to meteorological drought has been increased by human activities, and the response time also increases especially during the summer seasons. We use the Brier Score (BS) to evaluate the probabilistic forecast skill for the ensemble hydrological droughts within a set of 29-year (1982-2010) hindcasts (Fig. 3). In natural conditions, BS values increases along with the increase in lead times. And the NMME/VIC outperforms the ESP/VIC by decreasing BS 11%-26% in the first month and by 3%-14% in the second and third months. While in anthropocene, both ESP/VIC and NMME/VIC perform better than the natural cases, and the forecast skill does not decrease over lead times. This indicates that besides climate predictability, taking account of human interventions is of great importance for hydrological drought forecasting (Yuan *et al.* 2017).

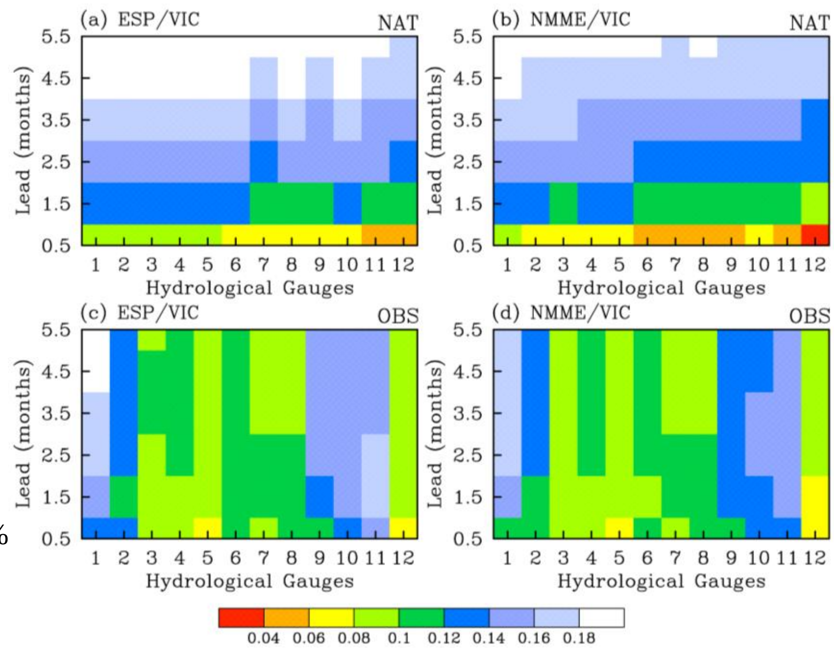

Fig. 3 Brier score (BS) for ensemble hydrological drought forecasts from a climatology method (ESP/VIC) and the climate-model-based approach (NMME/VIC) against VIC offline simulated (a, b) and observed (c, d) streamflow at different leads over the Yellow River basin during 1982-2010. For the verification against observed streamflow, the forecasts have been post-processed. (Yuan *et al.*, 2017)

5. Summary

As the climate becomes warmer and the human interventions become more intensive, both the risk for flash drought and the severity of hydrological drought are increasing, which call for more attention for combining traditional multi-scale drought predictability studies (*e.g.*, exploring canonical oceanic and land precursors) with a decision maker-oriented research. Therefore, effectively linking the advances in hydro-climatological predictability with drought mitigation and adaptation is a grand challenging in a foreseeable future.

Acknowledgements. This work was supported by the National Natural Science Foundation of China (No. 91547103), National Key Research and Development Program (2016YFA0600403), China Special Fund for

Meteorological Research in the Public Interest (Major projects) (GYHY201506001), CAS Key Research Program of Frontier Sciences (QYZDY-SSW-DQC012), and the Thousand Talents Program for Distinguished Young Scholars.

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