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Subseasonal Prediction of Warm Season Drought in North America

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1. Introduction

The subseasonal prediction of warm season drought in North America remains a great challenge. The prediction skill of North American drought during warm season, the drought development in particular, in current operational drought forecast system is rather limited. This study attempts to explore potential sources of predictability for subseasonal development of warm season drought over North America by focusing on the role of leading modes of subseasonal atmospheric circulation variability. These leading modes are often present in the form of stationary Rossby waves, and have been shown to be crucial in the development of many recent short-term warm season climate extremes over North America (Schubert *et al.* 2011).

2. The physical processes by which stationary Rossby waves lead to subseasonal drought development

The physical processes through which stationary Rossby waves affect drought development over North America was investigated by performing a case study of the 20 May – 15 June 1988 stationary Rossby wave event (Wang *et al.* 2017). During this event (Fig. 1), severe dry conditions developed quickly over central North America upon the arrival of stationary Rossby waves, leading to the severe 1988 North American drought. Using the NASA GEOS-5 Atmospheric General Circulation Model (AGCM) and a data assimilation

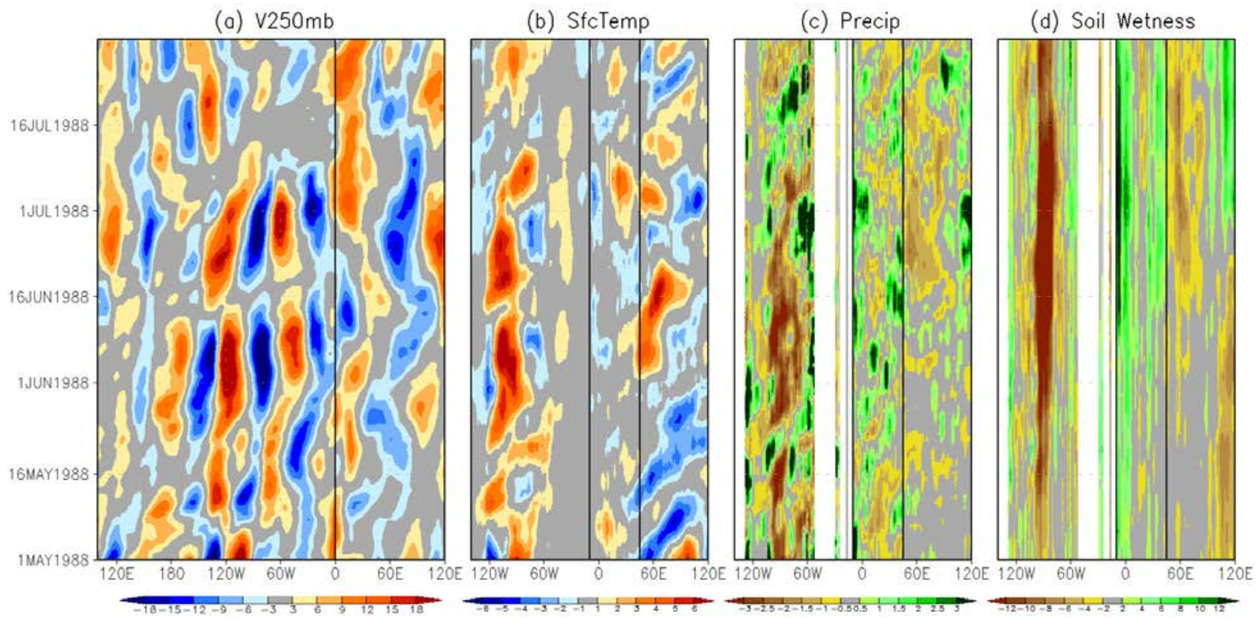

Fig. 1 Evolution of (a) MERRA daily 250-hPa meridional wind (m s^{-1}) averaged between 40ºN-60ºN west of 0º and 50ºN-70ºN east of 0º, with a 10-day running mean smoother applied, (b) MERRA daily surface temperature anomalies (K), (c) MERRA-Land daily precipitation anomalies (mm day^{-1}), and (d) MERRA-Land daily surface soil wetness anomalies (%), averaged between 30ºN-50ºN west of 10ºW, between 35ºN-55ºN for 10ºW-45ºE, and between 50ºN-70ºN east of 45ºE, with a 5-day running mean smoother applied, during the period 1 May – 31 July 1998.

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technology called "replay"[1], we designed a series of AGCM hindcast experiments to isolate the contributions to this event from: (i) the atmosphere and land initial conditions in late May 1988, (ii) the observed stationary wave sources over the western Pacific, (iii) the correct model simulation of mean jet stream over the North Pacific, and (iv) soil moisture feedback over North America.

The results show the crucial importance of the strong mean jet stream over the North Pacific for guiding and constraining wave energy propagation path and speed and thereby providing a potential source of predictability. For the 20 May – 15 June 1988 stationary Rossby wave event investigated here (Fig. 2), the

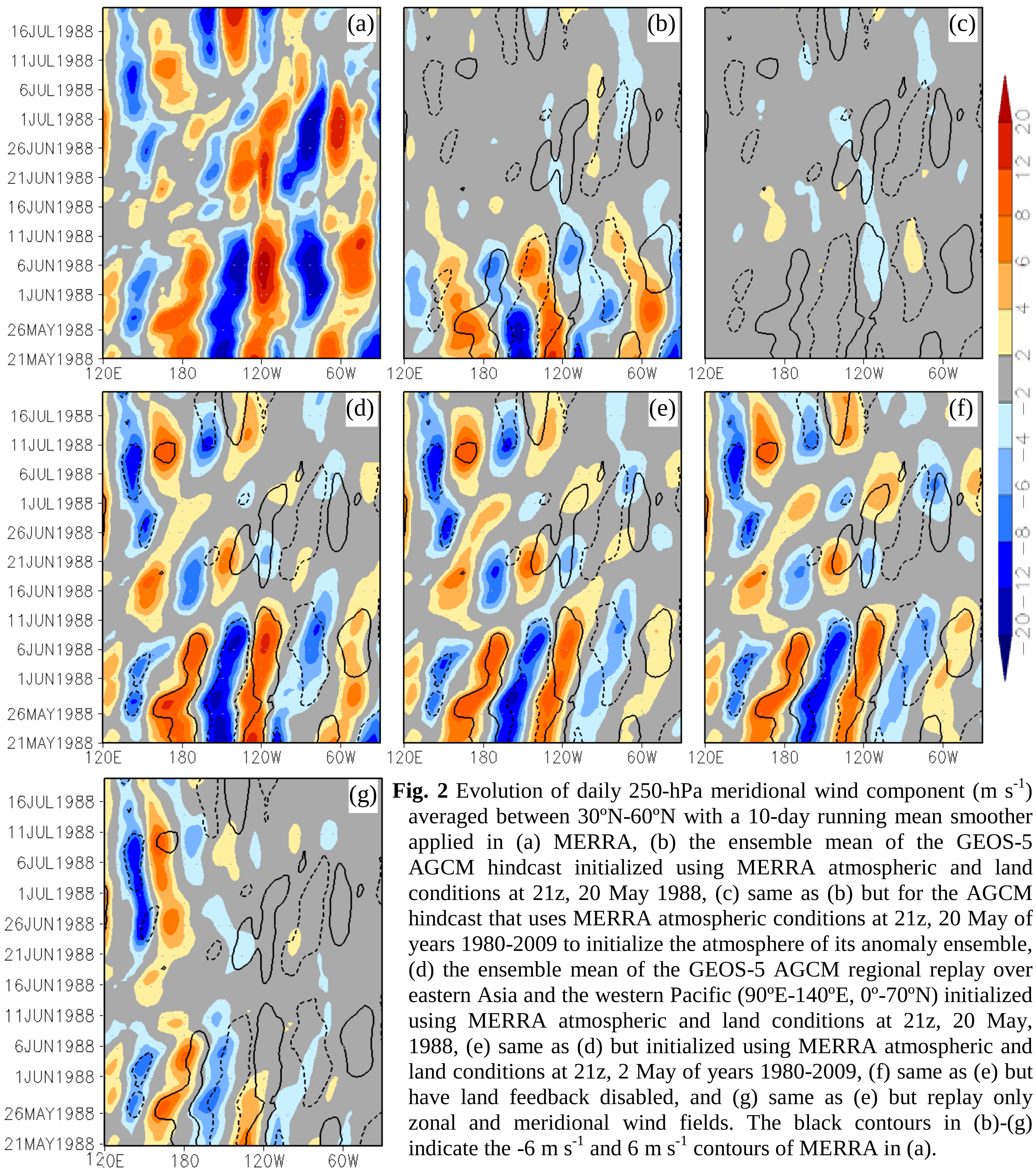

Fig. 2 Evolution of daily 250-hPa meridional wind component (m s^{-1}) averaged between 30ºN-60ºN with a 10-day running mean smoother applied in (a) MERRA, (b) the ensemble mean of the GEOS-5 AGCM hindcast initialized using MERRA atmospheric and land conditions at 21z, 20 May 1988, (c) same as (b) but for the AGCM hindcast that uses MERRA atmospheric conditions at 21z, 20 May of years 1980-2009 to initialize the atmosphere of its anomaly ensemble, (d) the ensemble mean of the GEOS-5 AGCM regional replay over eastern Asia and the western Pacific (90ºE-140ºE, 0º-70ºN) initialized using MERRA atmospheric and land conditions at 21z, 20 May, 1988, (e) same as (d) but initialized using MERRA atmospheric and land conditions at 21z, 2 May of years 1980-2009, (f) same as (e) but have land feedback disabled, and (g) same as (e) but replay only zonal and meridional wind fields. The black contours in (b)-(g) indicate the -6 m s^{-1} and 6 m s^{-1} contours of MERRA in (a).

[1] In the replay approach, the model atmosphere is constrained either fully or in part using existing reanalysis data; any subset of variables in any region of the world can be used.

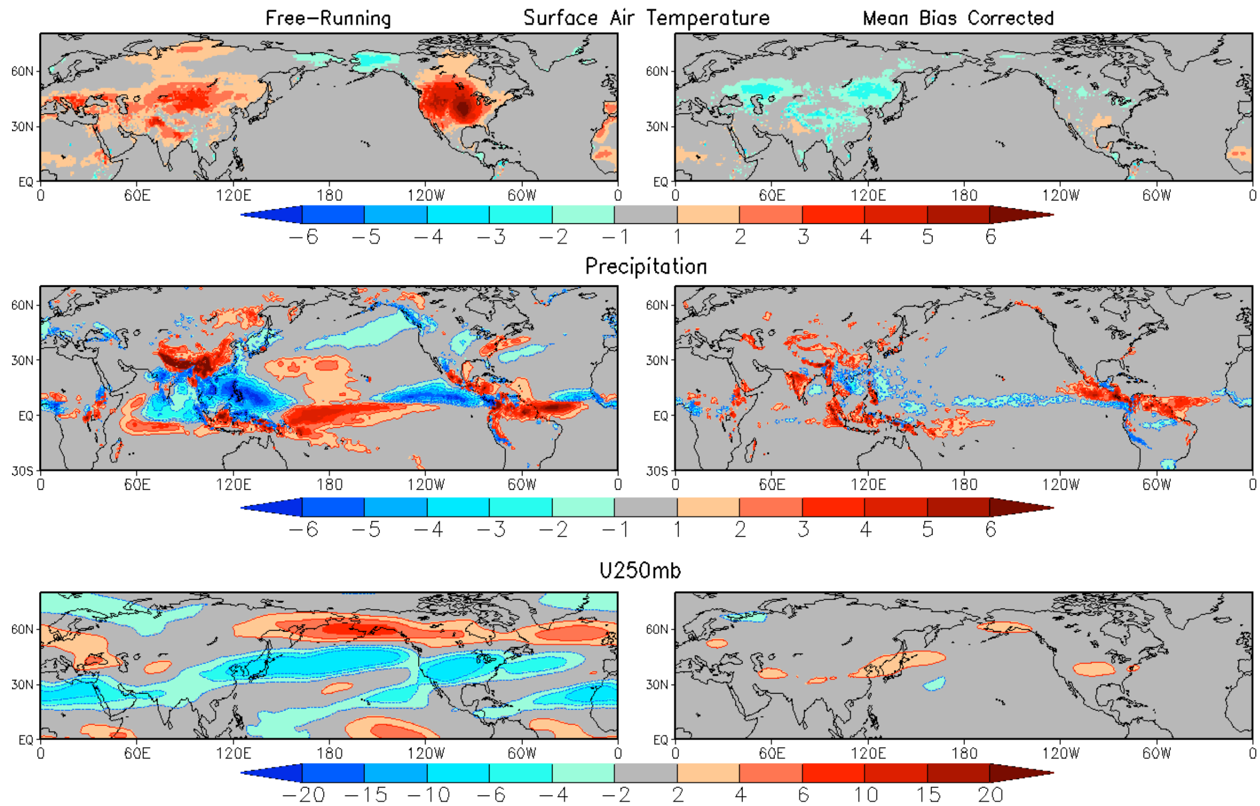

Fig. 3 Mean model bias in precipitation (mm/day), surface air temperature (K) and zonal wind at 250mb (m/s) in the GEOS-5 free-running AGCM (left panels) and the GEOS-5 AGCM that has mean bias corrected (right panels), during JJA. The AMIP simulations over 1980-2014 are used to obtain the AGCM climatology. MERRA2 is used for model validation.

free-running model hindcast skill (Fig. 2b) is limited to only about one week, beyond which the hindcasted waves show westward retrograde displacement instead of remaining quasi-stationary as in the observations (Fig. 2a), due to the considerably weaker mean model jet over the North Pacific than the observed (Fig. 3 bottom left panel). With the mostly corrected (through regional replay of all basic model variables to MERRA over East Asia and western Pacific) North Pacific mean jet (Fig. 2d, 2e), our results show that convective anomalies over the western Pacific do produce a predilection for sustained upper-level high anomalies over central North America about one to two weeks later. Such high anomalies subsequently lead to strong local precipitation deficits, soil dryness and surface warming, and thereby to severe drought conditions there (not shown). When the north Pacific mean jet bias is only partially corrected (through regional replay of only zonal and meridional winds to MERRA over East Asia and western Pacific) (Fig. 2g), the waves show slower eastward energy propagation across the north Pacific, and the subsequent circulation anomalies over North America not only show a rather weak magnitude but also are in the wrong locations. The soil moisture feedback is found to be unimportant during the event.

Since it usually takes about two weeks for the wave energy to propagate across the North Pacific to reach North America, these waves can potentially serve as a source of subseasonal forecast skill in these downstream locations. To access this skill, however, it would be critically important for a forecast model to correctly simulate the mean Northern Hemisphere (NH) jet streams, not only their location and shape but also their magnitude, in order to allow the correct simulation of wave propagation (path and speed) across the northern oceans. The forecast model also needs to be able to predict sources of the stationary Rossby waves.

3. NASA GEOS-5 model bias correction

The standard GEOS-5 AGCM, like many other current models, provides weak and disoriented NH jet streams, and displays considerable biases in tropical convection and surface temperature (Fig. 3, left panels).

These biases limit the use of free-running GEOS-5 GCM for simulation and prediction of stationary Rossby waves and their effect over North America. In order to correct the GEOS-5 AGCM bias, we have applied 6-hourly climatological (1980-2015) Incremental Analysis Updates (IAU) tendencies from MERRA-2 to model basic state variables in a free-running GEOS-5 AGCM. By doing so, we are able to successfully (though artificially) correct much of the model bias. Substantial improvements are seen in model simulation of mean climate (Fig. 3) as well as weather and climate variability across many time scales.

Using a similar IAU-based approach, we have recently developed a bias-corrected NASA GEOS-5 coupled forecast system. Here a coupled replay was first performed, in which the model atmosphere is constrained to be close to MERRA-2 while letting the model ocean freely evolve. The mean atmospheric bias in the GEOS-5 coupled model was then corrected by applying the 6-hourly climatological IAU corrections from the coupled replay (1980-2014). The bias correction approach has been shown to successfully remove much of the coupled model bias in SST, precipitation and large-scale atmospheric circulation.

4. Model prediction of stationary Rossby waves and the impact of model bias

Using the standard GEOS-5 AGCM and the mean bias corrected GEOS-5 AGCM, we have performed two suites of comprehensive daily hindcasts for warm seasons of 18 years (1988, 1998, 2000-2015). A comparison of these two suites of hindcasts over North America shows that the bias correction leads to considerable skill improvement for the prediction of atmospheric circulation and surface air temperature but only marginal improvement for precipitation (Fig. 4). An examination of individual drought events, such as the 2012 Great Plains flash drought, shows that the bias correction can improve the forecast skill by up to 9

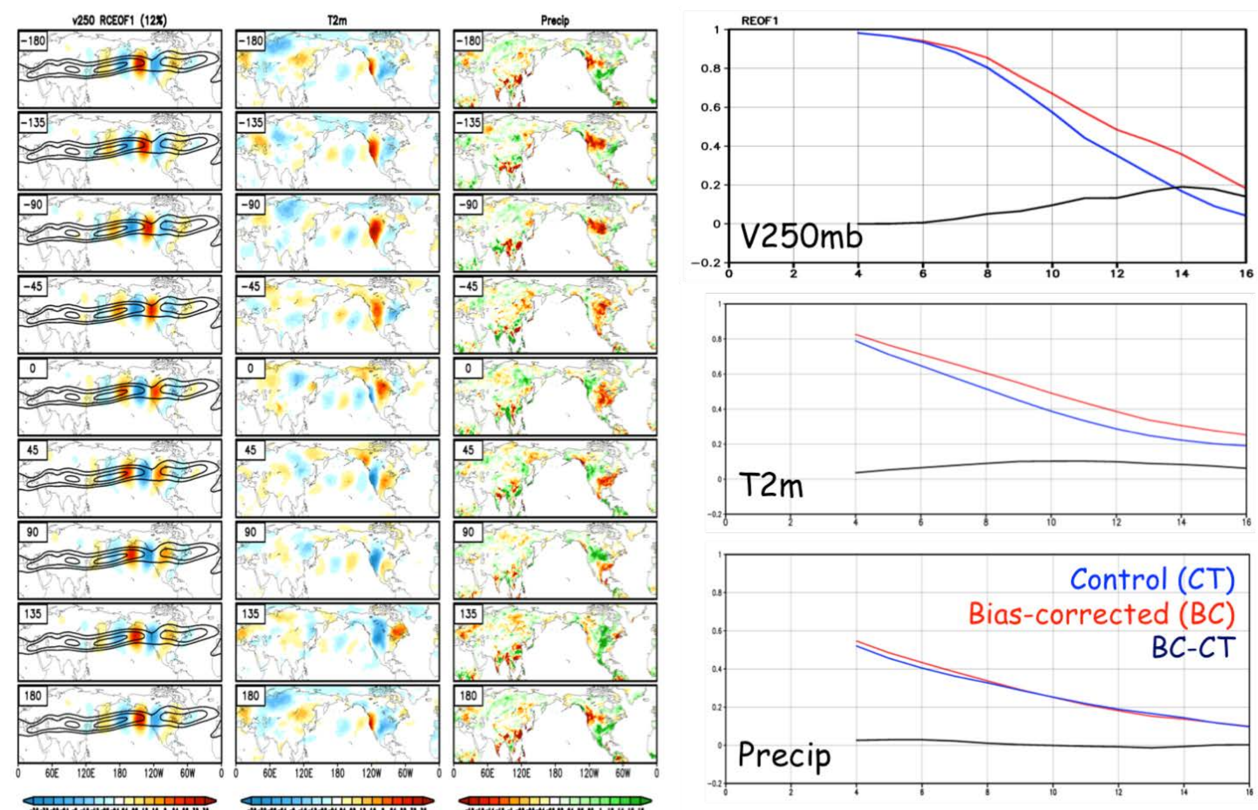

Fig. 4 Left panel: the first rotated complex EOF (12%) of MERRA-2 daily 250mb meridional wind (V250mb) in the NH during warm season; second panel from left: composites of MERRA-2 surface air temperature anomalies when the first rotated PC is above one standard deviation; third panel from left: same as the second left panel but for NCEP CPC precipitation composites. Right panels: the forecasting skills of V250mb (top), surface air temperature (middle) and precipitation (bottom) as a function of lead days in standard GEOS-5 AGCM (blue line), the bias corrected GEOS-5 AGCM (red line), and their differences (black line).

days (not shown). Currently, the impact of the bias correction in the GEOS-5 coupled forecast system on the subseasonal prediction of warm season drought over North America is under investigation.

5. Summary

This study investigates the physical processes by which stationary Rossby waves lead to subseasonal development of drought conditions over North America. It is found that stationary Rossby waves can serve as a potential source of predictability for subseasonal development of North American droughts. In order to properly represent the effect of stationary Rossby waves and exploit this source of predictability, a forecast model needs to be able to predict the source of the waves, and provides a correct simulation of the NH jet streams (location, shape, magnitude). Since the NASA GEOS-5 model, like many other current models, display considerable bias during boreal summer, an objective approach has been developed to correct much of the model bias, which subsequently improves the prediction skill of the stationary Rossby waves and their impact over North America.

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