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Atmospheric Chemistry and Physics
Discussions

Interactive comment on "Drier spring over the US Southwest as an important precursor of summer droughts over the US Great Plains" *by* Amir Erfanian and Rong Fu

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We would like to thank the anonymous reviewer for taking the time to review our manuscript. We appreciate the constructive comments and suggested improvements and have revised the manuscript accordingly. Below are our point-by-point responses to the reviewer's comments.

Response to Anonymous Referee #1

"This study investigates the causes of the 2011 Southern Great Plains (SGP) and 2012 Northern Great Plains (NGP) droughts during JJA by performing a systematic atmo-

spheric moisture budget analysis. The analysis reveals the key role of zonal advection of moisture in the preceding season (MAM) in leading to the drought condition in JJA. Through a simple correlation analysis (e.g. in Fig. 12), the study points out the importance of dry conditions in the SW US during MAM for droughts in the GP during JJA. The paper is overall neatly written and enjoyable to read, the results are cleanly presented. The finding on the importance of zonal thermodynamic moisture advection is interesting."

Response: Thanks for the feedback.

"The key finding on the importance of dry condition in the SW US during MAM for dry conditions in the GP in JJA, however, appears shaky, it needs to be substantiated with further evidence. Please see my specific comments below.

1. Title: "Drier spring over the US Southwest as an important precursor of summer droughts over the US Great Plains". The title appears to be based on Fig. 12, but the inference on the importance of dry spring over the U.S. Southwest as a precursor of summer droughts over the US Great Plains from Fig. 12 is not very convincing for the following reasons:"

Response: We agree that the original title did not reflect the full content of the manuscript (which is primarily focused on the moisture budget analysis and the role of zonal thermodynamic advection in the onset of GP summer droughts) and we have revised the title as "The role of dry zonal advection in summer drought onset over the US Great Plains " to address this concern.

"1) while the temporal correlation between JJA precipitation over the NGP and MAM precipitation over the SW US is statistically significant, it is based on all the cases, regardless of the sign and amplitude of the precipitation anomalies. If one focuses on dry cases only, the good correspondence between NGP precipitation during JJA and SW US precipitation during MAM is only shown for a limited number of cases (e.g. 1989, 2002, 2012, 2013), it is unclear whether the statistical relationship between the two regional precipitation still stands;"

Response: The correlation coefficient for dry-only samples (20 cases with PNGP-JJA <0.0) is considerably higher (0.54) than that calculated for all samples. It should be mentioned that the colors representing the NGP and US SW time series in Figure 12b legend were mistakenly reversed. We fixed the legend in the revised manuscript and apologize for any potential confusion caused by this mistake.

"2) the SW US region is traditionally considered to cover the states of UT, CO, AZ and NM only. The SW US defined in Fig. 12 (black box in Fig 12a) appears to extend too far north. If limiting the SW US to cover the states of UT, CO, AZ and NM only, would the correlation results in Fig.12 change?"

Response: We limited the southern and northern boundaries of the US SW region to the areas suggested by the reviewer and the results (Figure 1) indicate negligible changes as compared to those presented in Figure 12.

"3) Fig.12 only suggests the relationship between MAM precipitation in the SW US and JJA precipitation in the NGP. It doesn't suggest any relationship for the JJA precipitation in SGP. It thus appears inappropriate to suggest that the MAM precipitation in the SW US can serve as a precursor for the precipitation in the GP as a whole."

Response: We agree. The title and the text have been revised to address this comment.

"2. Figure 2: the precipitation in the reanalyses are model dependent and are subject to deficiencies in the assimilation models used. How does the reanalysis precipitation in Fig. 2 compare with precipitation from observations (e.g. CPC gauge-based precipitation)?"

Response: The MERRA2 precipitation used in Figure 2 is bias-corrected against observational precipitation and compares reasonably well against the CPC gauged-based precipitation over the US (Gelaro et al. 2017).

Gelaro, Ronald, Will McCarty, Max J. Suárez, Ricardo Todling, Andrea Molod, Lawrence Takacs, Cynthia A. Randles, et al. 2017. "The Modern-Era Retrospective Analysis for Research and Applications, Version 2 (MERRA-2)." Journal of Climate 30 (14): 5419–54. https://doi.org/10.1175/JCLI-D-16-0758.1.

"3. Line 448: This study uses moisture budget analysis to show the importance of zonal moisture advection in MAM (due to dry anomaly in regions to the west) for both the 2011 and 2012 drought events. Droughts are known to be typically caused by anomalous subsidence induced by upper-level anticyclonic circulation anomalies (e.g. Namias 1983). The 2011 and 2012 droughts also appear to have upper-level high anomalies occurring during their developing periods. Some discussions on how the zonal moisture advection may or may not connect to the upper-level high anomalies would be helpful."

Response: Point well-taken. We added such discussions in the revised manuscript (the last paragraph of the discussion section, L487): "... Previous studies have also identified an anomalous high and anticyclonic vorticity in the upper troposphere as an atmospheric driver of summer droughts over central North America (Chang and Wallace, 1987; Namias, 1991; Lyon and Dole, 1995; Cook et al., 2011; Donat et al., 2016; Fernando et al., 2016). For the two droughts of SGP 2011 and NGP 2012, the anomalies of 700 mb (and also 350 mb) height feature a dipole pattern with an anomalous low over the northwestern North America and an anomalous high over the southeastern US (Figure S5). This dipole pattern seems to be a part of a larger wave-like pattern extended over North Pacific and was also detected in correlation maps between the anomalies of (south and north) GP zonal thermodynamic advection and geopotential height at 700 mb (not shown). A comprehensive understanding of the large-scale drivers of the zonal moisture advection over the GP can provide valuable information about the underlying mechanisms and predictability of the GP summer droughts and is a focus of our ongoing research."

"4. Figures 10-12 are used to establish the connection between MAM zonal thermodynamic moisture advection and the development of GP droughts in the following JJA. Some discussions of possible physical processes by which the former (MAM zonal moisture advection) leads to the latter (JJA droughts in GP) would be helpful. The atmosphere does not have much memory: any atmospheric anomalies in MAM would presumably disappear in about 2 weeks. Is it possible that land plays some role (in sustaining the effect of MAM anomalies through JJA) here?"

Response: Yes. The free-tropospheric drying in spring and early summer acts as a drought onset mechanism and a positive land-atmosphere feedback would sustain/intensify the initial dry conditions toward the end of summer. We have included a full paragraph discussing this mechanism in detail (L426 to L442): "The temporal evolution of RH during the SPG 2011 and NGP 2012 droughts reveals a transition of the maximum dry anomalies of RH from the free-tropospheric levels in spring to the lower troposphere and boundary layer in summer. A positive land-atmosphere feedback could facilitate this shift by perpetuating the initial dry land surface conditions in spring to the severe drying and warming in summer. In this mechanism, an anomalously lower precipitation and lower FCC would lead to a relatively drier surface and enhanced insolation in late spring. As a result, ET would decline steadily in the following months leading to a significant decrease in surface latent heat flux (estimated about 50 w.m-2 for the 1988 summer by Lyon et al. 1995), which is largely balanced by an increase in upward sensible heat flux and air temperature. The hotter-drier surface would intensify the decline of boundary layer and lower tropospheric humidity causing further decrease of precipitation in summer. This feedback mechanism was found to be responsible for intensification of several extreme cases of summer drought and heat waves over the US interior plains (Chang and Wallace, 1987; Hao, 1987; Namias, 1991; Lyon and Dole, 1995; Saini et al., 2016). The anomalous warming of the PBL in summer can also increase the difference between the surface temperature and dew point (T-Td) resulting in elevation of the level of free convection (LFC), increase of convective inhibition energy (CIN), and suppression of deep convection (Hao, 1987; Myoung et al., 2010)."

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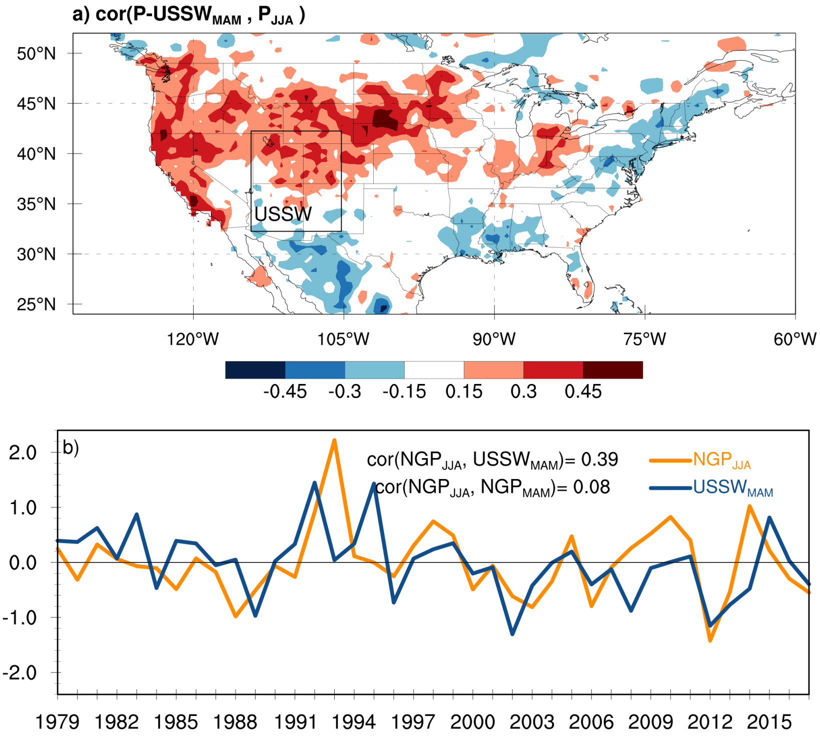

Fig. 1. Figure 1. Same as Figure 12 but calculated for the US SW region (denoted with the box in a) with new boundaries (22D-42D N and 105D-114D W).