Science and Technology Infusion Climate Bulletin
NOAA's National Weather Service
39th NOAA Annual Climate Diagnostics and Prediction Workshop
St. Louis, MO, 20-23 October 2014

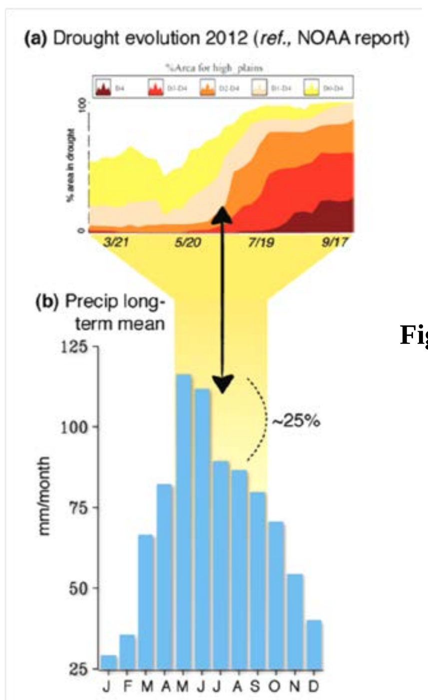
An Enhanced Seasonal Transition That Could Have Intensified Droughts in the Central U.S.

S.-Y. Simon Wang[1], Joseph Santanello[2], Hailan Wang[2], Daniel Barandiaran[1], Rachel Pinker[3], Siegfried Schubert[2], Robert R. Gillies[1], Robert Oglesby[4], Kyle Hilburn[5], Ayse Kilic[6], and Paul Houser[7]

[1]Utah Climate Center / Dept. Plants, Soils and Climate, Utah State University, Logan, UT
[2]NASA Goddard Space Flight Center, Greenbelt, MD
[3] Dept. Atmospheric and Oceanic Science, University of Maryland, College Park, MD
[4]Dept. Earth and Atmospheric Sciences, University of Nebraska-Lincoln, Lincoln, NE
[5]Remote Sensing Systems, Santa Rosa, California
[6]Dept. Civil Engineering and School of Natural Resources, University of Nebraska-Lincoln, Lincoln, NE
[7]Dept. Geography and GeoInformation Science, George Mason University, Fairfax, VA

1. Introduction

The summer drought of 2012 in the central United States is instructive regarding one unique feature, that is, its rapid intensification during the early summer (Hoerling *et al.*, 2013; Hoerling *et al.*, 2014). A figure from the NOAA report (Hoerling *et al.*, 2013), shown here in Fig. 1a, depicts the rapid expansion of drought conditions in Wyoming, Colorado, Kansas, Nebraska and South/North Dakota, evolving over a mere month from moderate to severe status (categorized as per the U.S. Drought Monitor). The timing of this drought's rapid intensification coincided with a subseasonal feature of widespread drying: Climatologically, precipitation in the central U.S. generally is reduced by about 25% from June to July, as shown in Fig. 1b by the long-term monthly rainfall averaged over the central U.S. Such a rainfall reduction occurs in association with the development of the North American Monsoon (NAM) and the concurrent formation of the upper-level anticyclone over the western U.S., nudging the jet stream northward. The precipitation difference of July minus June (Fig. 1c), **denoted hereafter as "July-June"**, depicts a distinct zone of rainfall reduction to the north and east of the NAM region, covering the Central Plains and the Great Plains. While this seasonal rainfall reduction is a well-known phenomenon (Barlow *et al.*, 1998; S.-Y. Wang and Chen, 2009), the extent to which a progression of



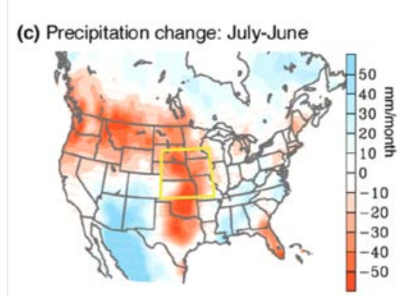


Fig. 1 (a) Drought evolution during 2012 obtained from the NOAA report (*Hoerling et al. 2013a*) showing percent of areas under negative PDSI from March to September 2012. (b) Long-term (1971-2000) mean monthly precipitation over the Central Plains over the domain as outlined in (c). (c) The long-term July-minus-June precipitation change over North America.

Correspondence to: S.-Y. Simon Wang, Utah Climate Center / Dept. Plants, Soils and Climate, Utah State University, Logan, UT; Email: simon.wang@usu.edu

drying may have amplified has not been examined.

The extremity and extensive impacts of summer droughts such as was the case in 2012 have prompted a number of studies. It was thought that the lack of prominent large-scale forcing factors in the tropics, such as that of ENSO, is a probable reason that has impeded climate forecast models' prediction of the 2012 drought (Hoerling *et al.*, 2014; H. Wang *et al.*, 2014). In this study, our goal was to examine possible forcing factors other than ENSO, with emphasis on regional drivers and mechanisms that may be related to the rapid advancement/expansion of drought (such as that in 2012) including the role of land-atmosphere interactions, circulation patterns, their interaction and, subsequently, how some or all of these may have changed.

2. Surface conditions

The linear trend of the post-1979 change in the July-June (*i.e.* July minus June) precipitation difference (*from Climatic Research Unit monthly precipitation dataset, (Harris et al., 2014)*) is shown in Fig. 2a. In comparison with Fig. 1c, the precipitation deficit from June to July is noticeably intensified in the northern part of the U.S., covering both the Central Plains and the northern Rockies. Around Iowa, Nebraska and part of Illinois, the precipitation reduction has diminished twofold when compared to that of the 1980s. Likewise, the linear trend of the July-June PDSI difference (Fig. 2b, *derived from PRISM temperature and precipitation data, (Daly et al., 1994)*) indicates that drought conditions have tended to intensify over the Central Plains and the northern Rockies during the June-to-July transition. A trend analysis conducted on the difference between the averages of May and June (MJ) and July and August (JA) (not shown) also yielded a similar result in both precipitation and PDSI.

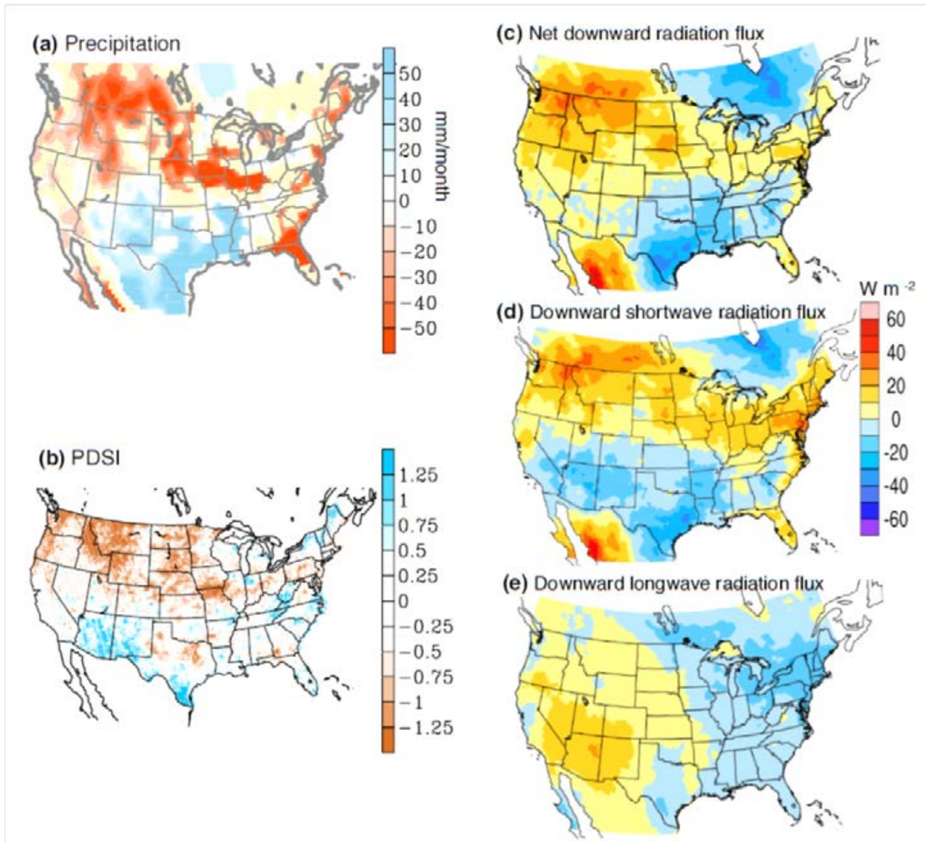


Fig. 2 Linear trends in the July-June difference of (a) precipitation (CRU data), (b) PDSI (PRISM data), (c) net downward radiation flux, (d) downward shortwave radiation flux, and (e) downward longwave radiation flux (NLDAS-2 data). (In (a) the red and blue colors are significant at the 99% level.)

Another factor worth noting is the trend in the July-June net downward radiation flux at the surface (Fig. 2c) – derived from NLDAS-2 data (Xia *et al.*, 2012). The increased (positive) trend in the July-June net downward radiation flux reveals a pattern very similar to the decreased (negative) trend in precipitation, i.e. meridionally elongated pattern with a particularly strong increase in the northern Rockies and the northern Great Plains. The pattern of net downward radiation flux results primarily from the change in downward shortwave radiation (DSWR) flux (Fig. 2d) caused by change in cloud cover or cloud thickness. In comparison, the trend in the July-June downward longwave radiation (DLWR; Fig. 2e) depicts an east-west dipole pattern with increased radiation in the southwest and decreased radiation in the northeast. The net result indicates that the central U.S. received either increased shortwave radiation in July or decreased radiation in June, or a combination of both. These changes are accompanied by a concurrent increase in 2-m air temperature (T2m) and 700-200mb thickness (not shown), suggesting enhanced ridge formation in this region.

3. Circulations vs. remote forcing

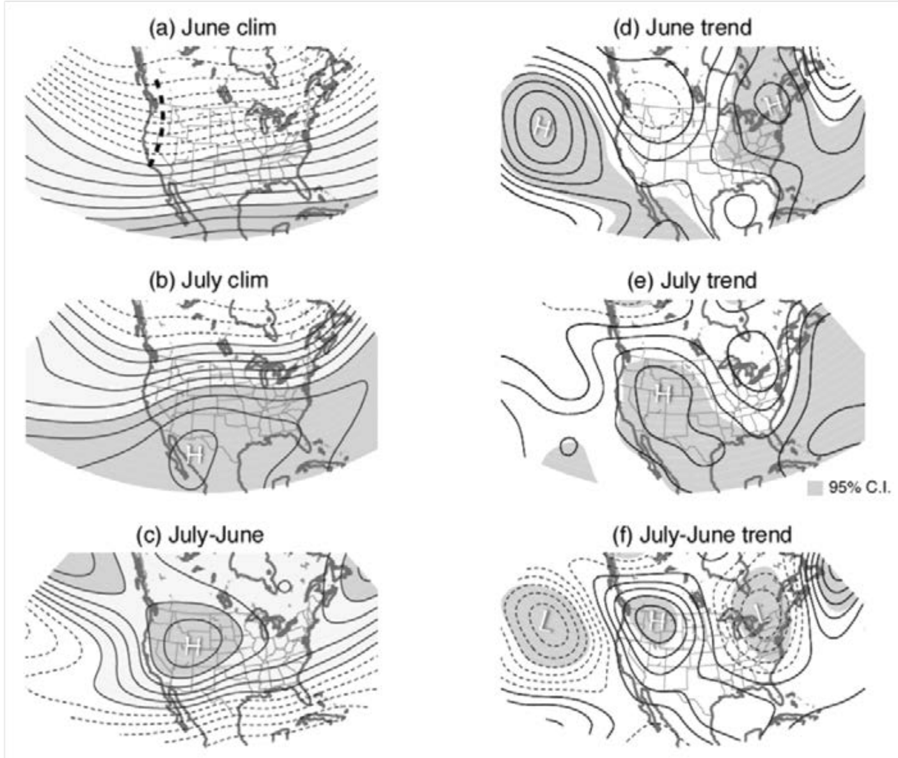


Fig. 3 Climatological streamfunction ($m^2\ s^{-1}$) at 200 hPa in (a) June, (b) July and (c) July-June transition, with a contour interval of 5x106 in (a),(b) and 2.5x106 in (c). The monthly streamfunction anomaly of the post-1979 trend in (d) June, (e) July, and (f) July-June transition, with a contour interval of 1.5x106 (total change of 1979-2011). Shadings in (d)-(f) indicate the regression coefficients significant at the 95% confidence interval. The bold dashed line in (a) indicates the stationary trough, while "H" and "L" indicates high and low pressure anomalies, respectively.

As previously noted, the development of the NAM is associated with a noticeable transition in upper-level circulations from the cold season regime (trough) to mid-summer regime (ridge); this is illustrated in Fig. 3 (*Circulation data: ensemble of MERRA, CFSR, ERA-Interim, and NCEP/DOE R-2*). In June, a stationary trough near the West Coast characterizes the upper-level circulation with the jet exit located over the Central Plains (Fig. 3a). In July, the monsoonal anticyclone develops, pushing the jet stream northward to about 50°N (Fig. 3b); consequently the circulation change from June to July forms an anticyclonic anomaly over the western U.S. (Fig. 3c) and creates subsidence over the Central Plains (Barandiaran *et al.*, 2013). The linear trends in these circulations (Figs. 3d-f) reveal an intensification manifest as a deepened western trough in June and enhanced western ridge in July. As a result, the July-June shift in the circulation (Fig. 3f) depicts an amplified ridge in the northwestern U.S. and a deepened trough in the northeastern U.S. The ridge corresponds well with increased surface warming and tropospheric thickening (noted earlier), and is also accompanied by increased subsidence at 500-hPa (*ref.*, Fig. 3). Such a change in the circulation is apparent as a distinct short-wave pattern with a zonal wave-5 structure, a feature of which has been found to suppress summer moisture in the central U.S. (S.-Y. Wang *et al.*, 2014).

Summer anticyclonic anomalies in western North America are frequently connected to remote forcing in the North Pacific and Asia (Barandiaran *et al.*, 2013). Thus, to explore the climatic forcing of the circulation patterns, Fig. 4a displays the trends in the July-June SST (*obtained from NOAA Extended Reconstructed SST*) and 200-hP streamfunction and reveals a marked similarity with the 2012 situation, suggesting a contribution of the post-1979 trend. The distinct short-wave train across the midlatitudes implies a link with remote forcing that triggers a circumglobal teleconnection, from which wave energy propagates zonally along the jet stream and affects North America (S.-Y. Wang *et al.*, 2014). Noteworthy is the weak tropical SST anomalies, and this feature is consistent with the lack of prominent tropical forcing in 2012 (Barlow *et al.*, 1998). By comparison, trends in the June and July circulation and SST (Figs. 4b and 4c) reveal a La Niña type of SST change in both months, consistent with previous studies of the global SST trends (Barlow *et al.*, 2001; S.-Y. Wang and Chen, 2009). However, July is accompanied by a stronger warming over the central North Pacific in comparison to June, while the circulation anomalies between the two months are quite different. June circulation exhibits a teleconnection emanating from the central tropical Pacific through the "PNA route", yet such a teleconnection is lacking in July.

4. Concluding remarks

Climatologically, precipitation in the central U.S. decreased by about 25% during the June-to-July seasonal transition. Since 1979, this precipitation reduction in the central U.S. has become more severe, having decreased twice as much in recent years. At the larger scale, examination of T2m and tropospheric circulation change indicated that dynamical forcing was present that enhanced subsidence in the central U.S. while, at the same time, suppressing rainfall. Such a long-term change has a potential effect to aggravate summer droughts. In particular, the analyses presented here indicated a marked resemblance between the June-to-July PDSI, precipitation, temperature and circulation shifts in their long-term change and those associated with the 2012 drought – one which was characterized by a rapid expansion over the Central Plains in early summer. As far as drought development is concerned, one important factor revealed from this study was land-atmosphere feedbacks over the U.S., *i.e.* the enhanced anticyclonic anomalies stationed over the western U.S. can lead to further reductions in precipitation and soil moisture in the Central U.S. In turn, the long-term changes in land surface moisture and temperature can sustain or amplify the evolution of the overlying anticyclonic circulation and precipitation deficit. In the long run, the land surface feedback to the atmospheric circulation anomalies is strong and can affect future drought expansion in the central U.S. These processes could help anticipate the evolution and extent of future drought in the central U.S., especially those that occur in spring and can worsen in summer.

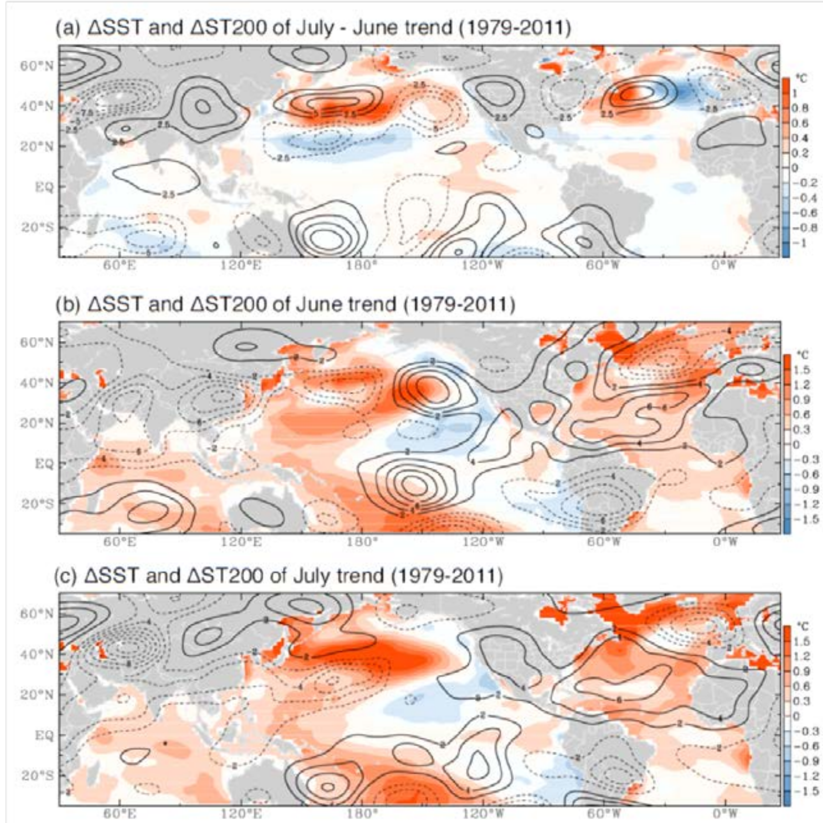


Fig. 4 (a) The anomalies of the July-June changes in 200-hPa streamfunction (contours) and SST (shadings) from the post-1979 trends, and the trends in monthly streamfunction and SST during (b) June and (c) July. Zero contours of the streamfunction are omitted. Contour intervals are 2.5x106 m^2 s^{-1} in (a) and 2x106 m^2 s^{-1} in (b) and (c).

Acknowledgements. This study was supported by the NASA Energy and Water cycle Study (NEWS).

References

Barandiaran, D., S.-Y. Wang, and K. Hilburn, 2013: Observed trends in the Great Plains low-level jet and associated precipitation changes in relation to recent droughts. *Geophys. Res. Lett.*, **40**, 2013GL058296.

Barlow, M., S. Nigam, and E. H. Berbery, 1998: Evolution of the North American Monsoon System. *J. Climate*, **11**, 2238-2257.

——, ——, and ——, 2001: ENSO, Pacific decadal variability, and US summertime precipitation, drought, and stream flow. *J. Climate*, **14**, 2105-2128.

Daly, C., R. P. Neilson, and D. L. Phillips, 1994: A statistical-topographic model for mapping climatological precipitation over mountainous terrain. *J. Appl. Meteor.*, **33**, 140-158.

Harris, I., P. D. Jones, T. J. Osborn, and D. H. Lister, 2014: Updated high-resolution grids of monthly climatic observations – the CRU TS3.10 Dataset. *Int. J. Climatol.*, **34**, 623-642.

Hoerling, M., S. Schubert, K. Mo, and H. B. A. AghaKouchak , J. Dong, M. Hoerling, A. Kumar, V. Lakshmi, R. Leung, J. Li, X. Liang, L. Luo, B. Lyon, D. Miskus, K. Mo, X. Quan, S. Schubert, R. Seager, S. Sorooshian, H. Wang, Y. Xia, and N. Zeng, 2013: An Interpretation of the origins of the 2012 central Great Plains drought. Edited by NOAA/CPO/MAPP, 44 pp. [Available online at http://cpo.noaa.gov/ClimatePrograms/ModelingAnalysisPredictionsandProjections/MAPPTaskForces/DroughtTaskForce/2012CentralGreatPlainsDrought.aspx]

——, J. Eischeid, A. Kumar, R. Leung, A. Mariotti, K. Mo, S. Schubert, and R. Seager, 2014: Causes and predictability of the 2012 Great Plains drought. *Bull. Amer. Meteor. Soc.*, **95**, 269–282.

Wang, H., S. Schubert, R. Koster, Y.-G. Ham, and M. Suarez, 2014: On the role of SST forcing in the 2011 and 2012 extreme U.S. heat and drought: A study in contrasts. *J. Hydrometeor.*, (in press).

Wang, S.-Y., and T.-C. Chen, 2009: The late-spring maximum of rainfall over the U.S. Central Plains and the role of the low-level jet. *J. Climate*, **22**, 4696-4709.

——, D. Barandiaran, K. Hilburn, P. Houser, B. Oglesby, M. Pan, R. Pinker, J. Santanello, S. Schubert, and H. Wang, 2014: Could the 2012 drought have been anticipated?–A NASA NEWS initiative. *Climate Prediction S&T Digest*, 38th NOAA Annual Climate Diagnostics and Prediction Workshop, College Park, MD, National Oceanic and Atmospheric Administration. 58-63. [Available online at http://docs.lib.noaa.gov/noaa_documents/NWS/NCEP/CDPW/38th_2014.pdf]

Xia, Y., K. Mitchell, M. Ek, J. Sheffield, B. Cosgrove, E. Wood, L. Luo, C. Alonge, H. Wei, and J. Meng, 2012: Continental-scale water and energy flux analysis and validation for the North American Land Data Assimilation System project phase 2 (NLDAS-2): 1. Intercomparison and application of model products. *J. Geophys. Res.: Atmospheres (1984–2012)*, **117**, D03109, doi:10.1029/2011JD016048.