Science and Technology Infusion Climate Bulletin
NOAA's National Weather Service
38th NOAA Annual Climate Diagnostics and Prediction Workshop
College Park, MD, 21-24 October 2013

Could the 2012 Drought Have Been Anticipated? – A NASA NEWS Initiative

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1. Introduction

The 2012 drought that engulfed most of North America set many records, surpassing by most measures even the severity of the 1988 drought (Kimery 2012). Numerous press and governmental resources have documented the extent and tremendous impact of the 2012 drought in the United States[1]. An assessment report of the NOAA Drought Task Force (Hoerling *et al.* 2012) summarized that the drought – primarily that covering the central Great Plains during May-August of 2012 (Fig. 1a) – resulted mostly from natural atmospheric variations. They concluded: "neither ocean states nor human-induced climate change appeared to play significant roles" and so, the drought could not have been predicted.

Here we ask: If not predictable, could the 2012 drought nonetheless have been "anticipated"? In other words, we examine in a comprehensive manner – *i.e.* beyond just the forecast schemes – how this drought developed and whether or not there were signs that could foretell such drought.

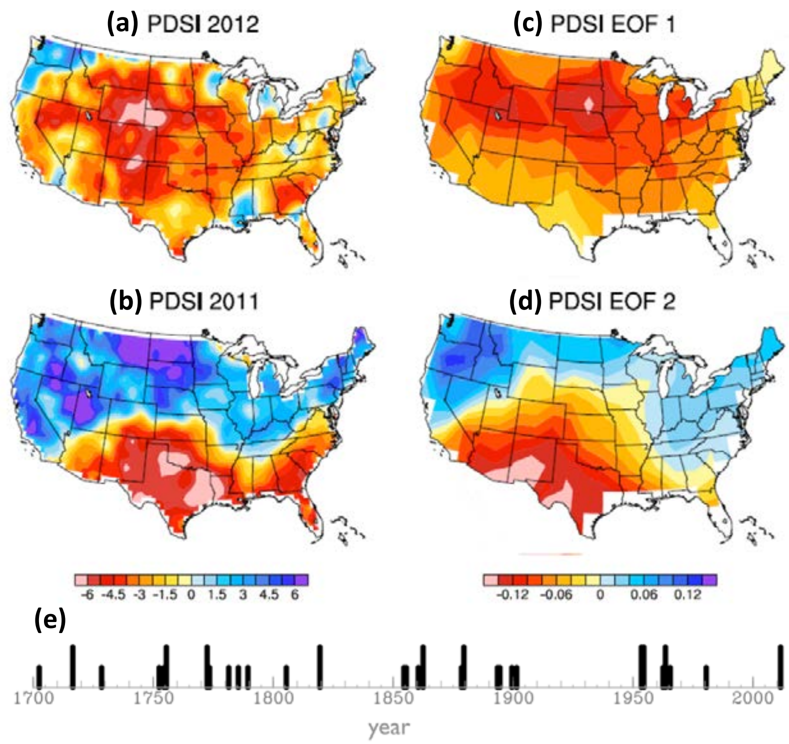

Fig. 1 May-July (MJJ) PDSI during (a) 2012 and (b) 2011, in comparison with (c) EOF1 and (d) EOF2 of the MJJ PDSI from 1900 to 2012. (e) The occurrence of which PC2 is followed by PC1 when both PCs exceed two (one) standard deviation plotted as long (short) sticks, based upon the North American Drought Atlas tree-ring data.

This paper summarizes relevant research efforts by members of the NASA NEWS Working Group on Extremes. These efforts examine the 2012 drought from several key aspects: (a) the large-scale pattern and its recurrence over North America; (b) precipitation and synoptic regimes over the Great Plains; (c) the contributions of ocean surface temperatures, land processes, and radiative forcing in drought formation and

[1] New York Times - http://topics.nytimes.com/top/news/science/topics/drought/
USDA - http://www.ers.usda.gov/topics/in-the-news/us-drought-2012-farm-and-food-impacts.aspx#.UqD-RWRDtLs
The Economist – http://www.economist.com/node/21559381

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prolongation; (d) the role of ET fluxes, and our ability to simulate them accurately; and (e) potential predictability and model scenarios for drought recovery. These studies, in hindsight, suggest that factors leading to the 2012 drought did reveal signs that could have helped anticipate its occurrence.

2. Results and Discussion

a. Drought pattern and recurrence

A unique aspect of the 2012 drought is that it evolved from the 2011 drought that devastated the southern Great Plains (Fig. 1a, b). This precursor drought was associated with La Niña (Seager *et al.* 2013). The central Great Plains therefore experienced consecutive drought conditions from 2011 to 2012 (which continued at least through March 2013). First, the Empirical Orthogonal Function (EOF) analysis of the Palmer Drought Severity Index (PDSI) (Dai *et al.*, 2004) for the period of 1900-2012 indicated that the first two leading patterns of drought are similar to the recent ones – *i.e.* EOF1 with a widespread pattern (Fig. 1c) corresponds to the 2012 drought, while EOF2 with the dipole pattern (Fig. 1d) resembles the 2011 drought. The apparent correspondence between the EOFs and the recent droughts suggests that a drought evolution similar to that occurring from 2011 to 2012 may not be unique. To examine further, we plotted the occurrence of when the second principal component (PC2) leads the PC1 – in the sense that the 2011 drought led the 2012 one. The dataset used here is the PDSI derived from tree rings (the North American Drought Atlas; Cook et al., 2004). The result is shown in Figure 1e with the long (short) bars indicating that both PC1 and PC2 are positive and both exceed two (one) standard deviation. It appears that the evolution of droughts like the 2011-2012 succession did occur sporadically in the past (Fig. 1e).

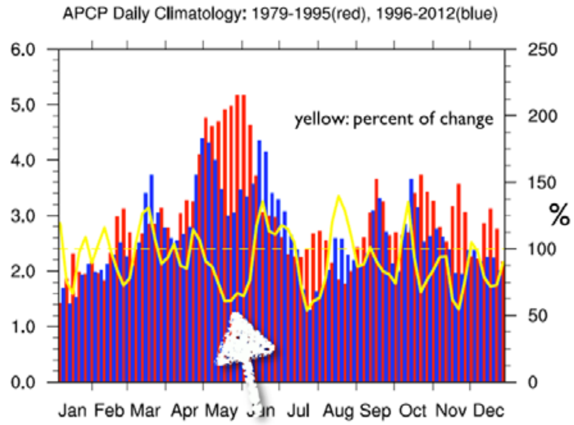

Fig. 2 5-day mean precipitation over the Oklahoma-Texas region for the period 1979-1995 (red) versus 1996-2012 (blue), and the percent difference between the two periods (yellow line). Note the large decline in May.

b. Recent trends in precipitation and LLJ

Over the central U.S., the warm-season precipitation migrates from the southern Great Plains in spring to the upper Midwest in summer, providing crucial growing-season water along its path. Both rainfall and convective storm activity reach their maximum in May and June in the southern Great Plains forming a precipitation center over the Oklahoma-Texas region (Wang and Chen 2009). This rainfall maximum is depicted in Figure 2 by the elevated spring precipitation peaking in May. Observations indicate, however, that over the past three decades the amount of spring precipitation has declined. Figure 2 shows time series of pentad precipitation averaged for Oklahoma-Texas over the period

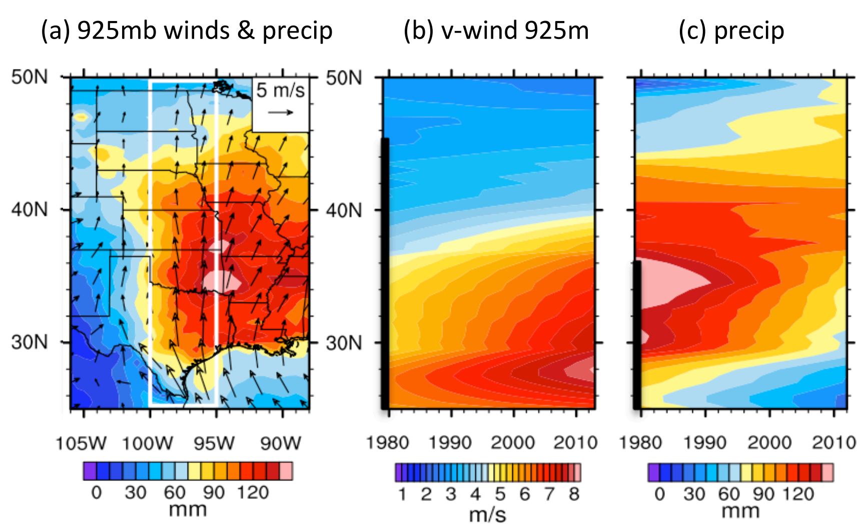

Fig. 3 a) May climatology for precipitation (shaded) and 925mb wind field (vectors) and Latitude-time Hovmöller trend plots for b) 925mb v-wind, c) total precipitation. Latitudes in which the regression coefficient is significant at 95% confidence are indicated along the y-axis. (After Barandiaran *et al.* 2013)

1979-1995 versus that for 1996-2012, along with the percent difference between the two periods. There is a clear reduction in April-June (AMJ) rainfall, particularly the entire month of May during which deficits of as much as 50% are observed (Barandiaran *et al.* 2013). This rainfall reduction suggests decline of a vital water source during the rainy season in the Oklahoma-Texas region, and also makes the region more susceptible to drought during the summer.

A key atmospheric circulation systems closely connected to the region's seasonal precipitation is the Great Plains Low-Level Jet (GPLLJ), which is primarily a transient pattern of nocturnal strong winds just above the surface. The GPLLJ transports abundant amounts of water vapor from the Gulf of Mexico and provides moisture convergence at its northern edges, facilitating the formation of convective precipitation. Focusing on May, Figure 3a depicts the climatological precipitation overlaid with 925-mb wind vectors for geographical reference; the white box indicates the sub-region over which averages are calculated in subsequent panels. The trend for all latitudes is calculated using linear least-squares regression for 6-hourly 925mb v-wind strength of each month (Fig. 3b) and monthly total precipitation (Fig. 3c). There is an apparent increase in the strength of the v-wind between 30°N-35°N including the Gulf of Mexico (*i.e.* upstream of the GPLLJ). North of 40°N the increasing trend becomes very small, to near zero. These v-wind changes accompany a northward migration of the maximum gradient of v-wind speed, and the resultant convergence at the exit region of the GPLLJ. Correspondingly, the changes in total precipitation reveal a northward migration, leading to drying in the central and southern Great Plains (Barandiaran *et al*. 2013).

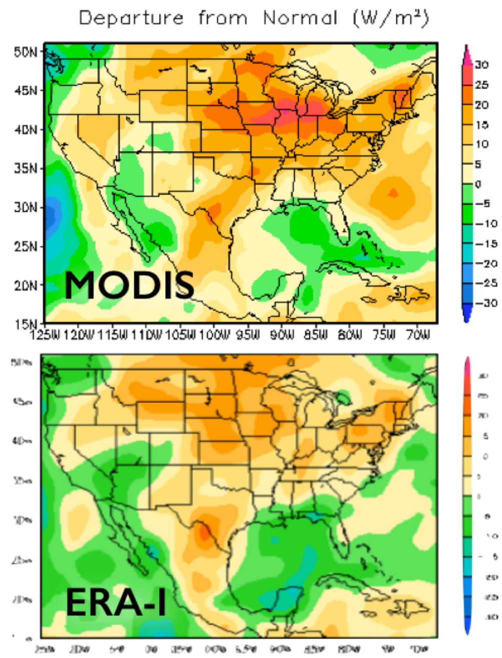

Fig. 4 (top) May-August shortwave radiation anomaly from MODIS (from 10 year mean); (bottom) shortwave radiation anomaly from ERA-Interim reanalysis.

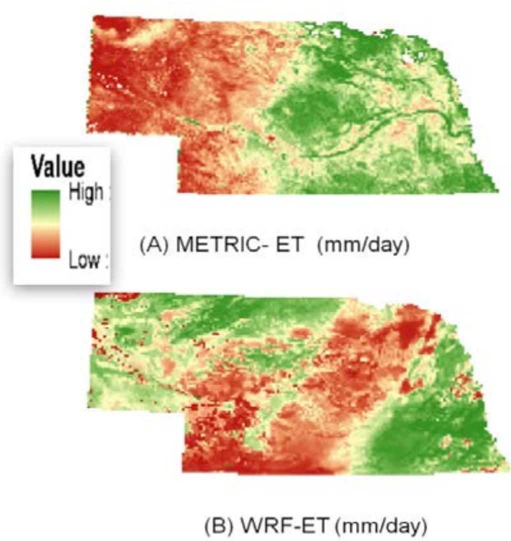

Fig. 5 Surface ET simulated for two days in August 2012 by (A) MODIS-METRIC model that includes irrigation, and (B) WRF-CLM model without irrigation leading to drying in farmed areas.

c. Forcings that initiate/enhance drought

[Radiative forcing] Another unique feature associated with the 2012 drought is its rapid development in early summer, coined "flash drought" by the NOAA report (Hoerling *et al.* 2012). In particular, the drought over the Northern Plains expanded rapidly during June and quickly formed dry to exceptional drought conditions. As shown in Figure 4, the rapid development of 2012 drought is associated with enhanced shortwave radiation input, as depicted by MODIS data and also seen in the ERA-I surface shortwave fluxes. The timing of intensive shortwave radiation anomalies coincides with the seasonal maximum of shortwave radiation, and the area is closely associated with the rainfall deficits (Wang and Chen 2009).

[Land forcing] Santanello *et al.* (2013) diagnosed the process and impacts of local land–atmosphere coupling during dry and wet extreme conditions in the U.S. southern Great Plains, through an evaluation of nine different land–planetary boundary layer (PBL) schemes coupled in a high-resolution regional model. Results show that the sensitivity of land–air coupling is stronger toward the land during dry conditions, while the PBL scheme coupling becomes more important during the wet regime. In other words, soil moisture impacts are felt via land-PBL interactions, where the atmosphere is more sensitive to dry soil anomalies while deep, dry PBL growth can lead to a persistent positive feedback on dry soils. Hubbard *et al.* (2013) meanwhile found that dry soil moisture conditions could strongly enhance the effects of remote SST forcing. Comparing remote sensing and modeling data, Ozturk *et al.* (2013) found that the evapotranspiration (ET) effect, which is linked to irrigation in the Northern Plains; this also feedbacks on drought intensity. Figure 5 demonstrates that, when it is dry, more irrigation is needed to grow the crops; then if the drought persists, the crop fails and less irrigation takes place on the dying plants. So, early in the drought irrigation modulates some of the land-air coupling impact of the drought; later on, the lack of irrigation does the opposite and land-air feedbacks can dominate.

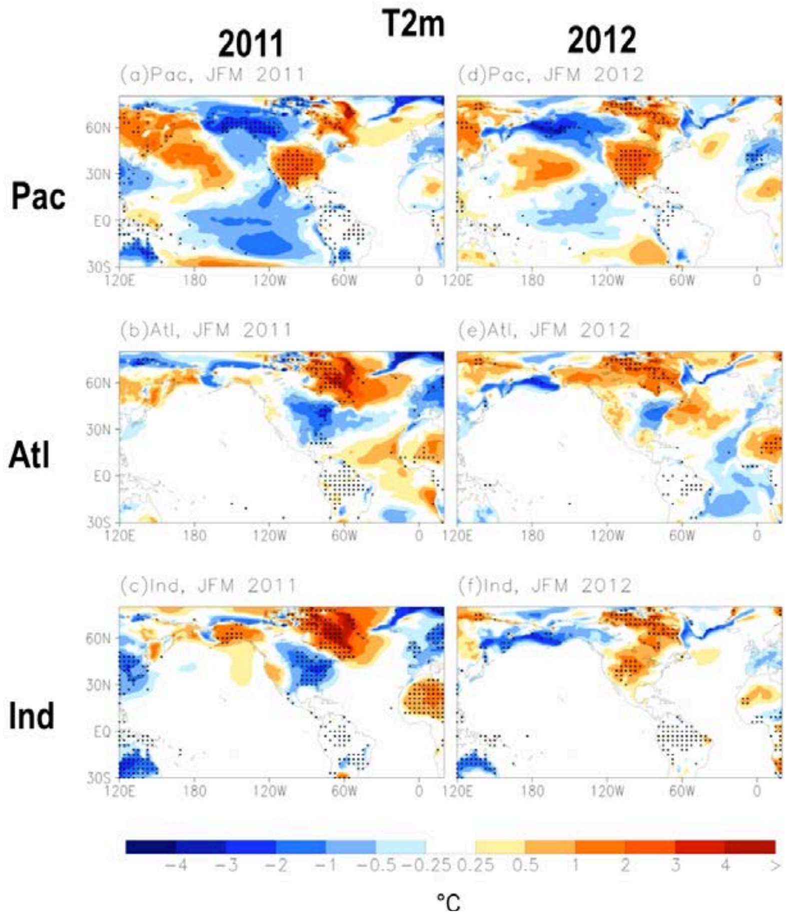

Fig. 6 JFM ensemble mean T2m response to SST forcing in individual ocean basins based on GEOS-5 ensembles initialized in November of the previous year, for SST in (top-bottom) for Pacific, Atlantic, and Indian Ocean. (From H. Wang *et al.* 2013)

[Teleconnection forcing] As was noted in the NOAA Drought Task Force report, the 2012 drought lacked substantial ocean forcing in the tropical Pacific given the ENSO neutral status. Using the NASA GEOS-5 model, H. Wang *et al.* (2013) found that the winter-spring response over the U.S. to the Pacific SST is remarkably similar for years 2011 and 2012 (Fig. 6a, d) despite substantial differences in the tropical Pacific SST. The pronounced winter and early spring temperature differences between the two years (warmth confined to the south in 2011 and covering much of the continent in 2012) primarily reflect differences in the contributions from the Atlantic and Indian Oceans, with both acting to cool the east and upper mid-west during 2011 (Fig. 6b, c), while during 2012 the Indian Ocean reinforced the Pacific-driven continental-wide warming and the Atlantic played a less important role (Fig. 6e, f). During early summer the development of a stationary Rossby wave over the North Pacific – an atmospheric process – produced the record-breaking precipitation deficits and heat in the Central Plains in the middle of summer. S.-Y. Wang *et al*. (2013) further indicated that, particularly in July, the seasonal pattern of stationary Rossby waves has changed since 1979 in a way that favors the type of short-wave circulation anomalies that produce heat and dry conditions over the Northern Plains. This latter finding coincides with the climatological maximum of radiative forcing in July.

d. Potential predictability

The modeling study by H. Wang *et al.* (2013) suggested that the 2012 drought would not have benefited from long-lead prediction, as the full extent of the event was not forecasted until one month prior. This implies that the stationary Rossby waves that reinforce the drought occurred at intra-seasonal timescales. Such forcing of Rossby waves is triggered by submonthly vorticity transients (Schubert *et al.* 2011) and varies month-by-month (S.-Y. Wang *et al.* 2013), hence the difficulty in predicting them at longer than these relatively short lead times. However, once the Rossby waves develop, the perturbation downstream would establish and frequently last for an extensive period of time, about 2-6 weeks (Schubert *et al.* 2011). In other words, short-term climate prediction from 2 weeks to 2 months may be the only remedy for predicting "flash drought" such as that of 2012. H. Wang *et al.* (2013) have demonstrated the potential of Rossby waves in providing early-warning of heat waves in the U.S. during the 2012 drought.

e. Drought recovery

An often overlooked question concerns the processes by which drought recovers. Drought management would benefit greatly if more risk-based information is available on how a region in drought may recover, *e.g.*, the likelihood of recovery under different precipitation scenarios and the related uncertainty. As discussed earlier, several factors such as the initial moisture condition, the amount and timing of precipitation, and the temperature control the recovery process. In view of the aforementioned limit in forecast skills of the 2012 drought, Pan *et al.* (2013) proposed a probabilistic framework to assess drought recovery that is based on the joint distribution between cumulative precipitation (which is the main driver for recovery) and a soil moisture–based drought index.

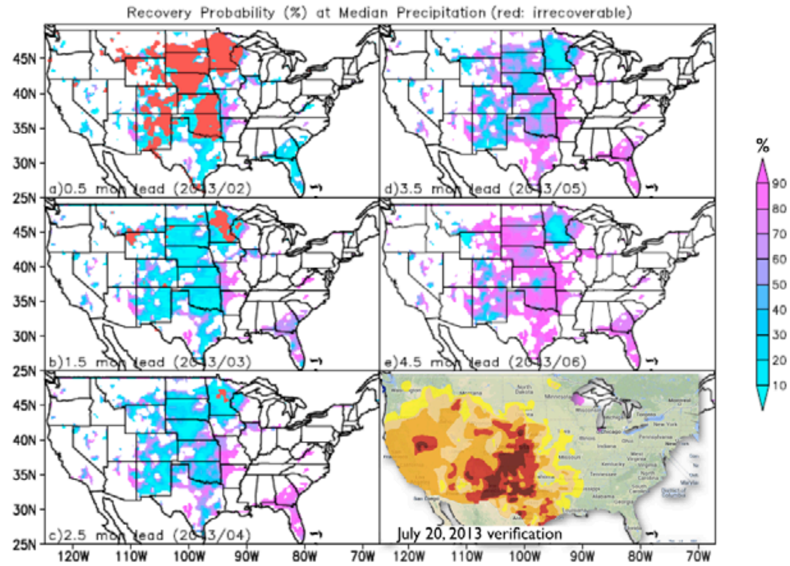

Fig. 7 Maps of the probability of drought recovery under the median (p = 50%) cumulative precipitation scenario. Red colored areas are those unable to recover from drought under any cumulative precipitation scenario, and empty colored areas are those not in drought ($\theta > \theta_{drought}$) as of 1 February 2013. (a–e) The results for lead times of 0.5–4.5 months. (From Pan *et al.* 2013)

Figure 7 shows maps of recovery probability under the median cumulative precipitation scenario staring in February 2013. The smaller the value, the less likely it is to recover and the higher the probability (risk) that the area remains in drought. At one-month lead, large parts of Central and Northern Plains are irrecoverable, and the recovery probability is very low. Most areas start to be recoverable from the 1.5 month onward (Fig. 7b), but the recovery probability is low (10%–20%). The recovery probability increases at 2.5 and 3.5 months until it reaches the 80% level at the 4.5 month lead (very likely to recover if median cumulative precipitation is received for 6 months). As shown in the lower right corner (verification), by July 2013 most of the Northern Plains has indeed recovered from drought, although the southwestern states remained in drought. The results suggest that a probabilistic analysis for drought recovery can provide indispensable risk information for drought managers.

3. Concluding Remarks

The 2012 drought was unique in terms of the rapidity, with which it developed, the lack of "classic" oceanic forcing patterns, and the association with record heat waves in the Central U.S. Through our collective efforts it was found that the 2012 drought did, however, show signs of precursors, albeit without a long lead time. First, the succession of a "dipole" drought pattern like that in 2011 followed by the widespread drought pattern like that in 2012 is not unprecedented; in fact it has repeatedly occurred over the past 300+ years. Model experiments suggested that the tropical Atlantic and Indian Ocean status (instead of the Pacific) helped initiate drought conditions in spring 2012. Second, since 1979 the GPLLJ has strengthened making the critical spring/rainy season over the central and southern part of the Great Plains drier than ever. Third, the timing of the drought development in June and heat wave in July coincides with the seasonal drying in the Central Plains, enhancing shortwave radiation while reducing ET; this further exacerbated the drought as it persists towards the middle of summer. Fourth, the state of the soil moisture can precondition, enhance, and prolong drought conditions. Human activities such as irrigation may partially offset this. Finally, a standing pattern of stationary Rossby short waves developed in the late spring/early summer season, producing the anticyclone anomaly that later occupied the Central U.S. for the rest of summer.

Although it is difficult to foresee the initiation of a specific stationary Rossby wave pattern, once it develops the standing pattern of short waves did persist for an extensive period of time, thus providing potential sources for short-term/intraseasonal climate prediction – *i.e.* early warning. In summary, prediction of the 2012-like drought is not without hope but more emphasis will need to be on intraseasonal timescales. Furthermore, predicting the recovery of drought is equally important and this has been shown to be feasible.

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