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Factors Driving the Persistence of ENSO-Led Winter Rainfall Deficits into Late-Spring and Early-Summer over Texas

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1. Introduction

The 2011 exceptional drought over Texas was unusual because of its rapid intensification over the late-spring/early-summer 2011. Combined reservoir storage across the state dropped by 20%, and more regionally, in less than one year. Such a rapid reduction in reservoir storage, in a system designed to cope with multi-year droughts, caught water managers by surprise. Improved predictability of drought intensification in the spring could help decision makers, tasked with water resources management, adopt suitable measures to both reduce

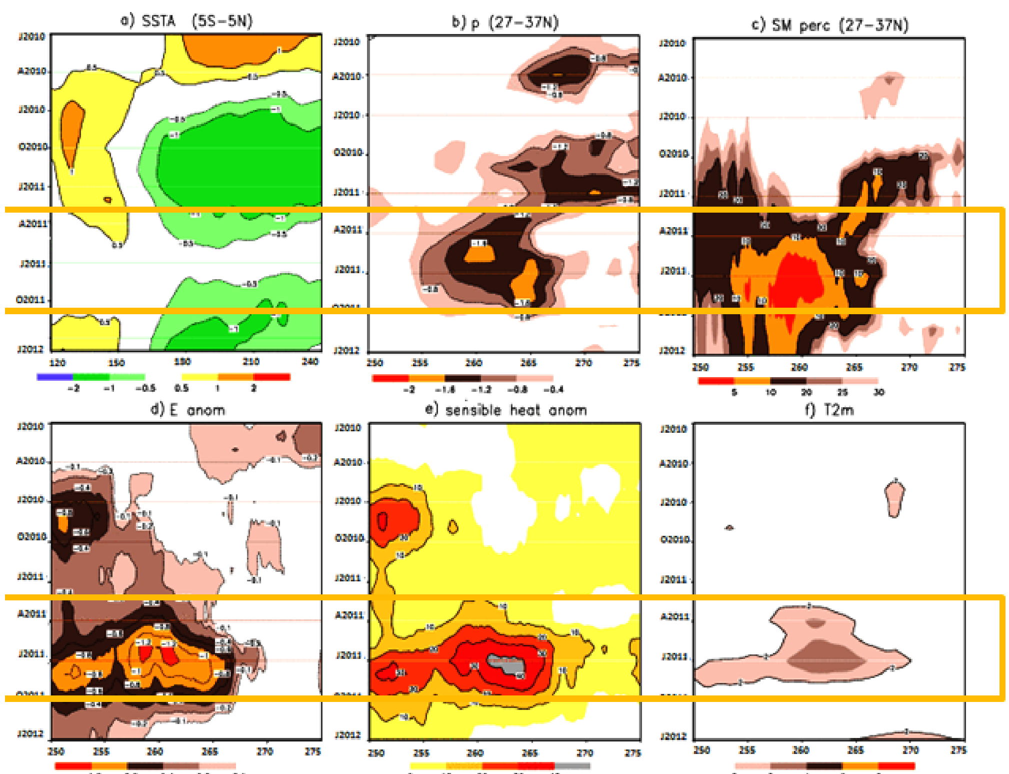

Fig. 1 Time-longitude plots of (a) sea surface temperature anomalies in the Nino3.4 region, (b) rainfall anomalies, (c) soil moisture percentiles, (d) evaporation anomalies, (e) sensible heat anomalies and (f) 2-meter temperature anomalies over Texas. SSTs are from the ERSST2 dataset (Smith *et al.* 1996) and precipitation is from the CPC unified precipitation dataset (Xie *et al.* 2010). Anomalies are calculated from a 1950-2010 climatology. Soil moisture percentiles, evaporation and sensible heat anomalies, and 2-meter temperature anomalies are from NLDAS based surface hydrology fields available at http://www.cpc.ncep.noaa.gov/products/Drought/Monitoring/.

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evaporative loss from reservoirs and prepare contingency plans to cope with an impending reduction in water supply over the summer. We investigate factors that led to the spring intensification of the drought with the aim of improving drought predictability for Texas.

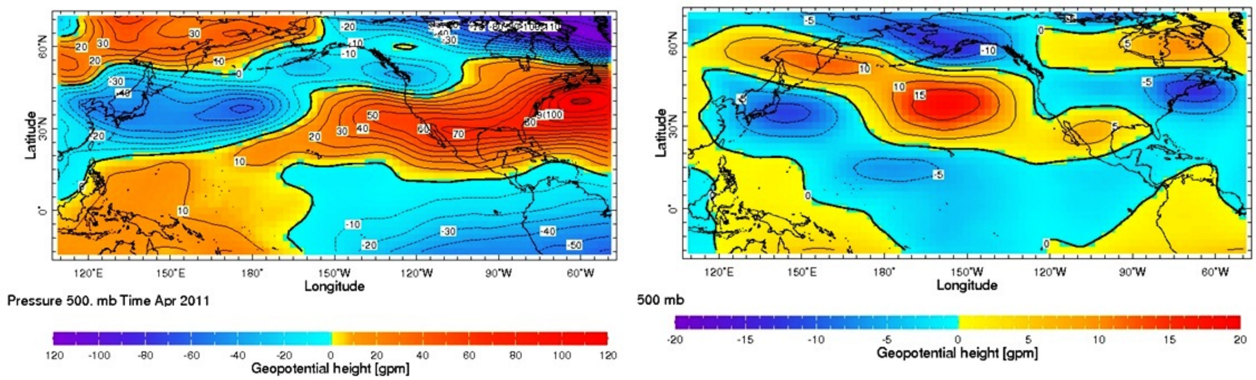

Fig. 2 (a) 500 hPa height anomalies in April 2011 and (b) 500 hPa height anomaly composite in 23 La Niña years. Dataset used is NCEP-R1 (Kistler *et al.* 2001) with 1981-2010 climatology. Zonal means have been removed.

2. Spring intensification of the drought

La Niña conditions played an important role in the initiation of the drought in the fall of 2010. Rainfall deficits over Texas commenced in the fall of 2010 coincident with the La Niña event that began in the summer of 2010 and peaked in the fall of 2010 (Fig. 1, panels a-b). The most marked reduction in rainfall and soil moisture occurred from April 2011 onwards and peaked in the summer of 2011 (Fig. 1, panels b-c). With the reduction in rainfall and soil moisture, there was a reduction in evaporation and an increase in sensible heating and surface (2 meter) temperature (Fig. 1, panels d-f). The reduction in evaporation and the increases in sensible heating and 2-meter temperatures are also most prominent from April 2011 onwards.

Why is April an important milestone for the drought event of 2011? April happens to be the normal start of the rainfall season over Texas and, in 2011 we see a drastic reduction in rainfall right at the start of the rainfall season. Rainfall in April can be from the passage of frontal systems and from convective storms. Therefore, we examined large-scale circulation anomalies induced by La Niña, the local thermodynamic environment over Texas and synoptic events as candidate factors driving April rainfall deficits.

3. Large-scale circulation anomalies induced by La Niña

The ridge at 500 hPa in April 2011 over Texas (Fig. 2(a)) was stronger and had a more zonal pattern over the Pacific compared with the composite pattern of 500 hPa height anomalies in 23 La Niña years from 1949 to the present (Fig. 2(b)).

4. Local thermodynamic factors and synoptic events

There was a sudden sharp increase in convective inhibition at the end of April 2011 (Fig. 3 – red line). An interesting feature to note from past intense drought events is that there is a similar increase in convective inhibition – albeit not as strong as in 2011 – in the drought events of 1918, 1925 and 1956.

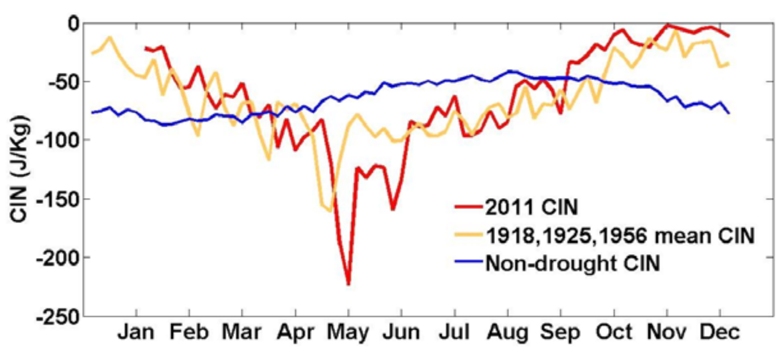

Fig. 3 Pentadal convective inhibition (CIN) in 2011 (red), mean convective inhibition in drought years of 1918, 1925 and 1956 (orange) and mean convective inhibition in non-drought years (blue). Dataset for 2011 convective inhibition is CFSv2 realtime data available from 1 February onwards (Saha *et al.* 2011). Dataset for historical droughts and non-droughts is the NOAA/ESRL/PSD 20th Century Reanalysis (Compo *et al.* 2011).

An examination of lowertropospheric circulation anomalies shows that there were anomalously strong westerly winds at 850 hPa in April 2011 (Fig. 4). Wind speeds during the bursts of abnormally strong westerlies at the end of April 2011 were more than twice the climatological wind speed for that time of year (Fig. 5 (b)). At the same time as the anomalous westerlies, we see an increase in surface temperature and dewpoint (Fig. 5(a)), negative relative vorticity (Fig.5(c)) and increases in 500 hPa height (Fig. 5(d)) implying that the westerlies advected temperature and negative vorticity eastward. The high terrain to the west of Texas had abnormally high surface temperatures in March and April, with anomalies reaching 5 ºK (not shown). Therefore, thermal advection due to increased westerly flow over a warmer-than normal terrain in the spring increased convective inhibition and contributed to the establishment of a 500 hPa height anomaly (*i.e.* the mid-tropospheric high pressure system) in late-April 2011.

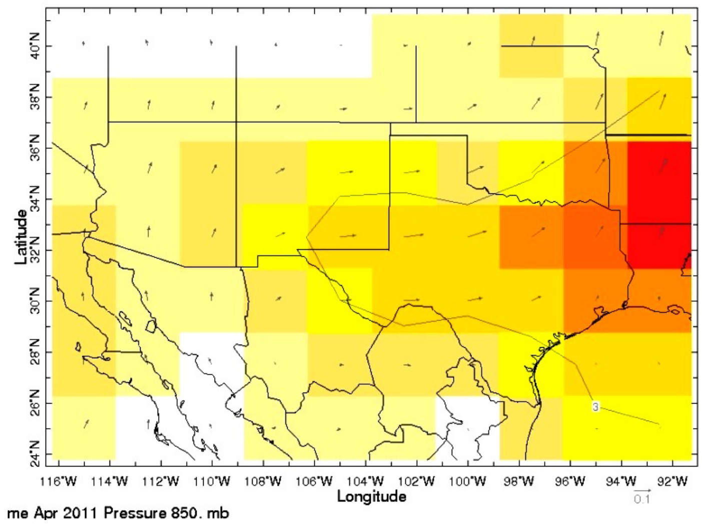

Fig. 4 Vector wind anomaly at 850 hPa in April 2011 showing the westerly flow over Texas. Dataset used is NCEP-R1 with anomalies calculated from a 1981-2010 climatology.

We find that the anomalous strengthening of the zonal winds at 850 hPa is a characteristic feature in the 12 severe-to-extreme droughts experienced over Texas since 1895 that had persistent negative rainfall anomalies from winter through summer (Fig. 6). Results suggest that February SST anomalies in the central Pacific, specified by the NINO4 index, is an important driver of the low level westerly wind anomalies in April over Texas.

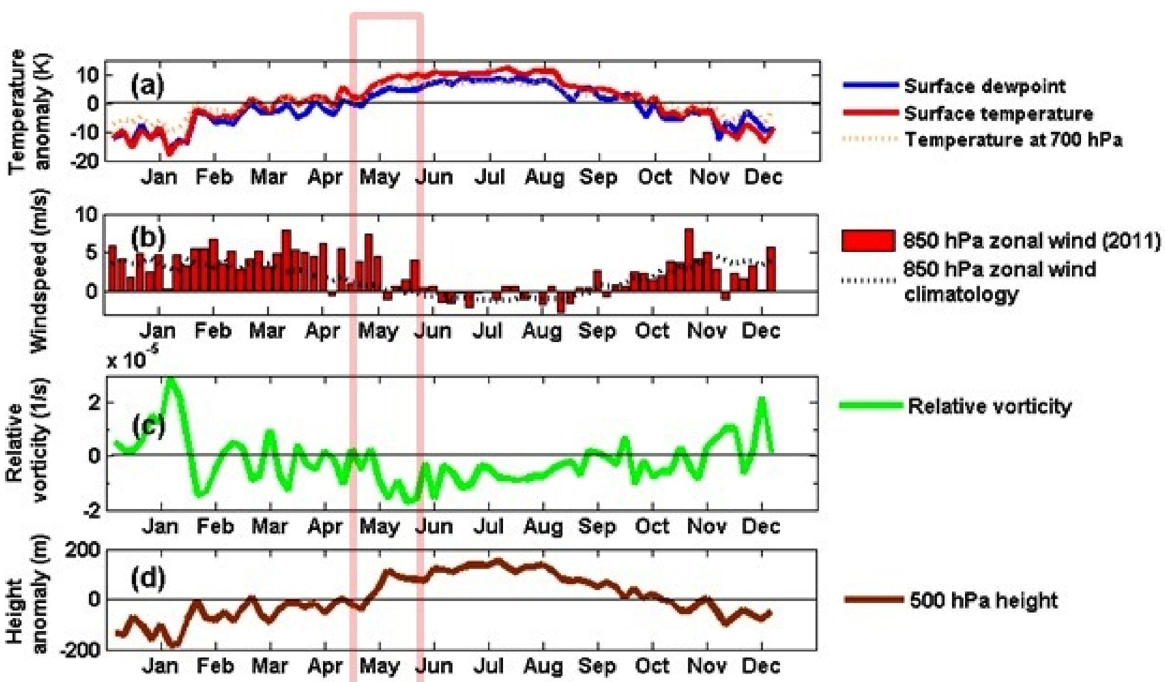

Fig. 5 Area-averaged (for the domain of Texas) pentadal surface temperature and dewpoint and temperature at 700 hPa (a), pentadal zonal winds at 850 hPa in 2011 and climatology (b), pentadal relative vorticity anomalies (c), and pentadal 500 hPa height (d). Data are from NCEP-R1 fields with anomalies calculated from a 1981-2010 climatology.

5. Conclusion

La Niña induced a reduction in winter precipitation over Texas in DJF 2010/2011. This led to a cumulative decrease in column soil moisture from the winter through the spring of 2011 that drove increases in sensible heating and surface temperature. La Niña also induced the mid-tropospheric high at 500 hPa that set up large scale subsidence over Texas. Surface heating due to soil moisture deficits and large-scale subsidence increased convective inhibition in late-spring. The sharp increase in convective inhibition in late-April and early-May was due to strengthened westerlies at 850 hPa that advected warm and dry air eastward from the Mexican Plateau and west Texas. The finding that strengthened westerlies at 850 hPa in April in past intense drought events as well has implications for improving drought predictability. Soil moisture feedback can influence summer drought intensity when rainfall deficits (hence, soil moisture deficits) are established in winter/spring. This finding underscores the need for improved real-time monitoring of soil moisture.

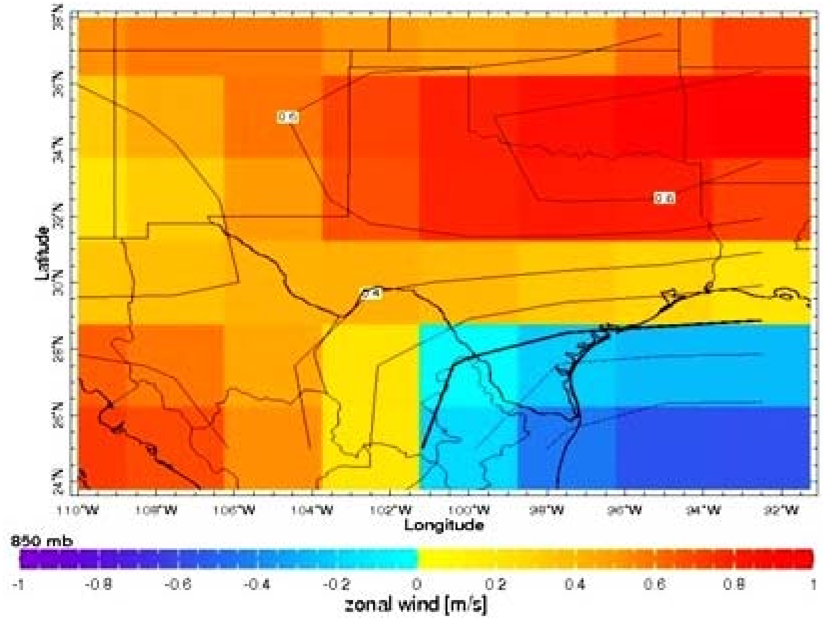

Fig. 6 Anomalous zonal wind composite for 12 severe-to-extreme drought years with rainfall deficits in winter through summer. Data are from NCEP-R1 with a 1981-2010 baseline climatology use in the calculation of anomalies.

The findings reported in this summary are included in an article currently in review by *PNAS-Plus*.

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