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Why Do Some La Niña Years in the Southern Great Plains Have Droughts and Other Not?

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1. Introduction

La Niña has long been related to the droughts in the Great Plains (*e.g.*, Trenberth *et al.*, 1988; Ting and Wang, 1997; Dai *et al.*, 1998; Schubert *et al.*, 2004; Seager *et al.*, 2005a; Seager *et al.*, 2005b; Schubert *et al.*, 2009 ; Seager *et al.*, 2014). Such abnormal SSTs and their consequent diabatic heating excite wave trains from the tropical Pacific to North America, placing an anomalous high over the southern U.S. and also shifting the Pacific storm track northward and reducing local moisture transport by the Great Plains low-level jet and thus summer precipitation. The recent severe 2010-2011 drought over the Southern Great Plains (SGP) is related to a strong La Niña event during the winter and spring, along with other factors such as atmospheric internal variability (Seager *et al.*, 2014).

However, not all La Niña events lead to droughts in the SGP. For example the 1973-1975 La Niña event actually led to increased rainfall over the eastern Plains and the Gulf coast, and climate models failed to reproduce this rainfall change probably due to their strong sensitivity to ENSO (Schubert *et al.*, 2004; Lau *et al.*, 2006; Seager and Hoerling, 2014). What factors lead to the different rainfall responses in the area during La Niña years? Seager and Hoerling (2014) have suggested that random atmosphere variability and other SST anomalies, *e.g.*, tropical Atlantic and Indian ocean, may overcome the influence of the tropical Pacific. This issue is examined here in more details. We focus on the circulation and SSTA patterns that lead to dry conditions in the SGP during La Niña years.

2. Methodology

2.1 Datasets

To understand how circulation pattern and moisture convergence differ for the La Niña dry and non-dry years, winds, geopotential height, and specific humidity are analyzed from the NCEP/NCAR reanalysis

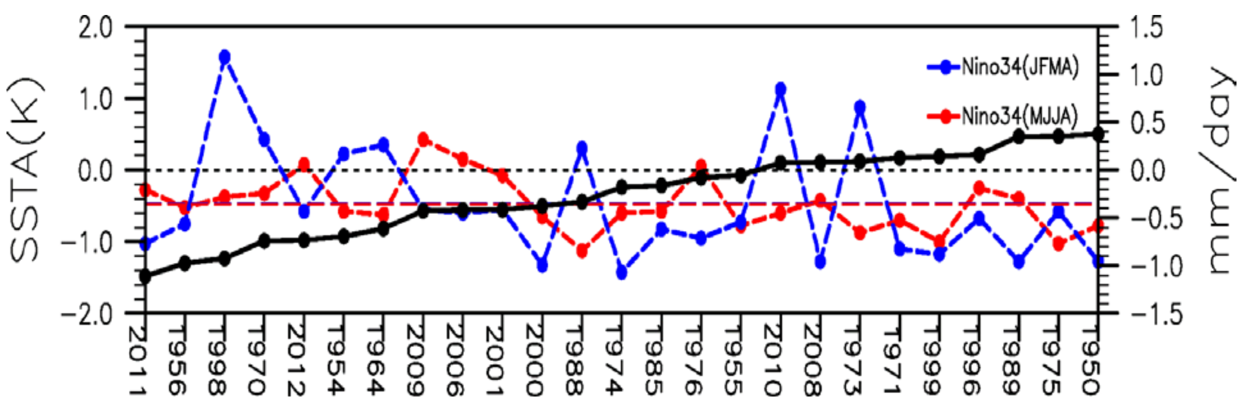

Fig. 1 Time series MJJA precipitation of La Niña years averaged in the SGP (see the black box in Fig. 2) along with CPC 3-month running mean Niño3.4 SSTA during JFMA (*i.e.*, centered in JFMA; blue) and MJJA (red) from 1950-2012. Rainfall anomalies are reordered from the driest to the wettest years.

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(Kalnay *et al.*, 1996; Hereafter NCEP1) from 1948-2013. The reanalysis is chosen because of its long data record. Its horizontal resolution is 2.5º by 2.5º.

The climatic Research Unit (CRU) TS3.21 (UEACRU, Jones and Harris, 2013) monthly precipitation on a 0.5º latitude by 0.5º longitude grid from 1901-2012 is used to examine precipitation variations. The Niño3.4, Atlantic Multidecadal Oscillation (AMO), Pacific Decadal Oscillation (PDO) and North Atlantic Oscillation (NAO) indices from Climate Prediction Center (CPC) from 1948 (or 1950) to 2013 are used to identify La Niña years and SST and circulation anomalies. The Hadley Centre Sea Ice and Sea Surface Temperature data set (HadISST; Rayner *et al.*, 2003) on a 1º by 1º grid from the UK Met Office is used to examine SST patterns.

2.2 Criteria for La Niña dry and non-dry years

Three-month running mean ERSST.v3bSST anomalies in the Niño3.4 region from the CPC are used to identify La Niña years. Since we are interested in La Niña events that occurred before or simultaneously with SGP summer rainfall anomalies, the following two criteria are used to decide such events: i) from DJF-MAM there are at least three consecutive over-lapping seasons with negative SSTA greater than -0.5 ºC, or ii) from AMJ-JAS there are at least two consecutive over-lapping seasons with negative SSTA greater than -0.5 ºC. Twenty-five La Niña years are so identified from1950-2013 (Figure 1).

To understand different rainfall responses during these La Niña events, two composites, namely, LaDry and LaNonDry, are formed corresponding to seven driest and wettest MJJA rainfall anomalies for the twenty-five La Niña years. MJJA average is chosen because SGP rainfall peaks from May to September, and MJJA precipitation contributes to about 44% of the total annual precipitation. The averaging also includes the early peak in May that may be more useful for agriculture planning.

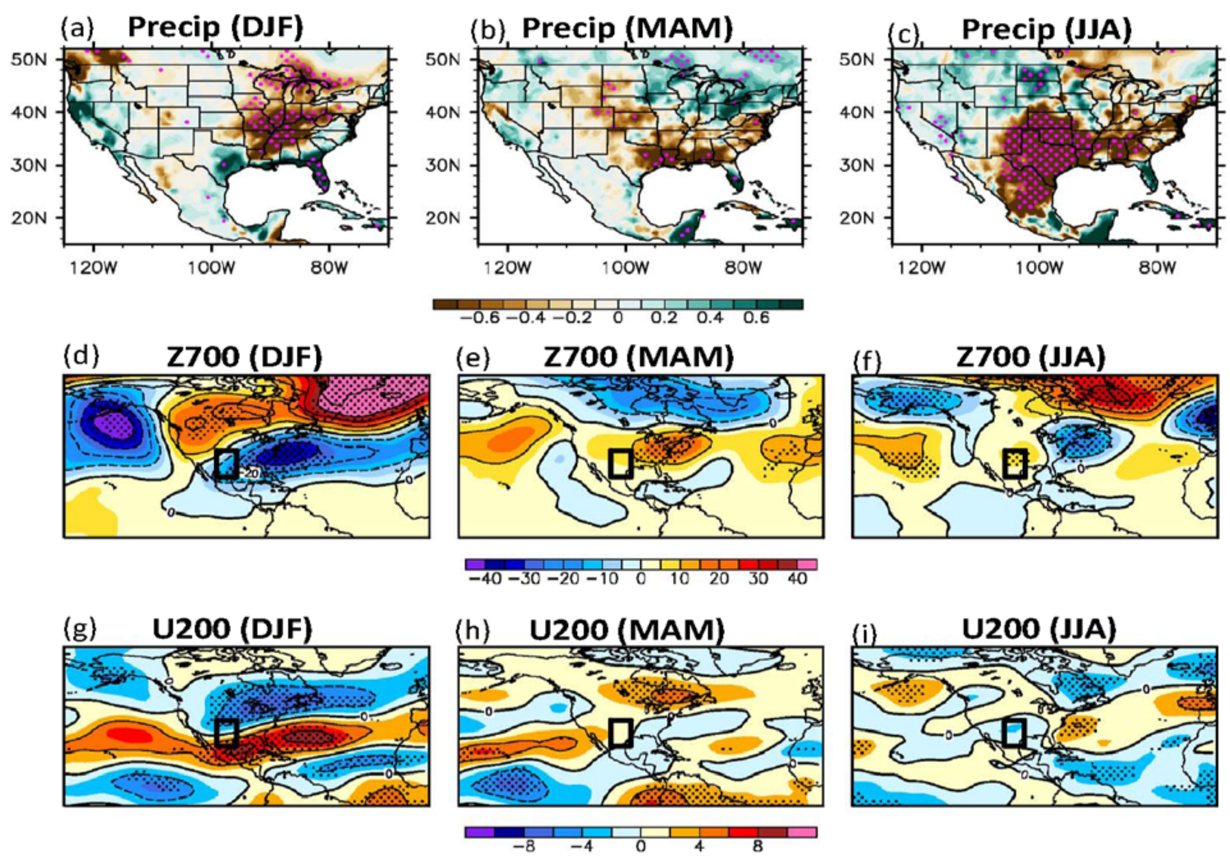

Fig. 2 (a)-(c) Precipitation (mm day^{-1}), (d)-(f) 700 hPa geopotential height (gpm) and (g)-(i) 200 hPa zonal wind (m s^{-1}) anomalies between the LaDry and LaNonDry composites from DJF to JJA. Areas significant at the 95% confidence level are dotted (Monte Carlo test).

3. Analysis

SGP MJJA rainfall anomalies along with the Niño 3.4 SSTA in JFMA (blue) and MJJA (red) are shown in Figure 1. MJJA Rainfall deceases in about two-thirds of La Niña years，consistent with previous results that La Niña contributes to SGP drought. However, the linear relationship between Niño 3.4 SST and rainfall magnitude in these La Niña years is not very strong. MJJA rainfall has a weak negative correlation of -0.37 (significant at the 90% confidence level) with concurrent Niño 3.4 SSTA. In other words, drought is more likely to occur in weak La Niña years. Niño 3.4 SSTA in JFMA shows an even weaker negative influence (not significant) on MJJA rainfall.

The rainfall differences between the dry and non-dry years (Figs. 2a-c) generally resemble the patterns in dry years (not shown) but with greater magnitudes. Rainfall reduces over the Mississippi river basin and Midwest in DJF. The dry anomaly in the SGP establishes in MAM and intensifies in JJA.

The low-level circulation pattern in MAM shares some similarity with that in typical La Niña years (not shown). The main difference is that the location of anomalous high over the U.S. is centered at the east coast instead of the Gulf coast while the geopotential height over the subtropical and tropical Atlantic is increased (Fig. 2e), suggesting an influence from the North Atlantic. The upper-level jet stream is shifted northward over the U.S. but slightly southward over the Atlantic (Fig. 2h). In JJA, an anomalous high is located over the SGP with a low center over the eastern U.S. (Fig. 2f), while the Pacific jet stream is also shifted northward and thus favors the drought development (Fig. 2i).

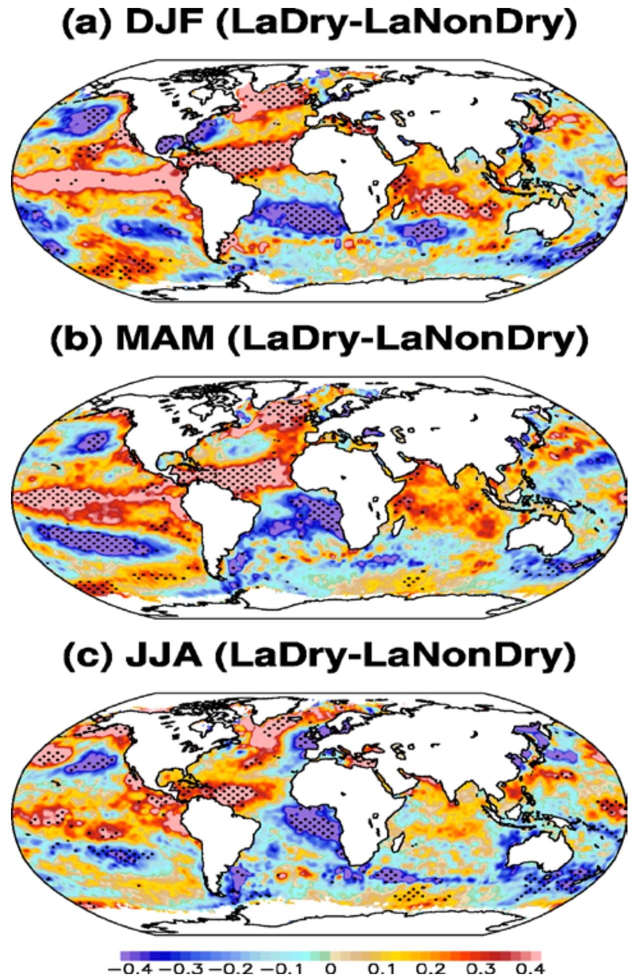

Fig. 3 Differences of SST (K) between the LaDry and LaNonDry composites. Areas significant at the 95% confidence level are dotted (Monte Carlo test).

The differences of SST between the LaDry and LaNonDry composites show an anomalously warm SST over the tropical and high-latitude North Atlantic, resembling a positive AMO pattern (Figure 3). This pattern persists from winter to summer but with a weaker magnitude in summer. SST also decreases over the Gulf of Mexico in DJF but not in other seasons, which may contribute to the anomalous northerly flow from land to the Gulf. Southern Atlantic SST also decreases from DJF to JJA, indicating a northward shift of Atlantic ITCZ.

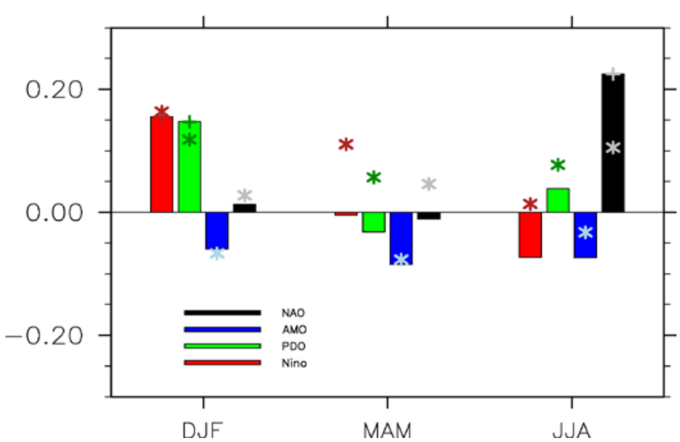

Fig. 4 Regression coefficients of SGP rainfall onto the standardized Niño 3.4 (red), PDO (green), AMO (blue), and NAO (black) indices in 25 La Niña years (bars) and from 1950-2012 (stars). Regression coefficients in La Niña years significant at the 90% confidence level are topped with a “+” sign.

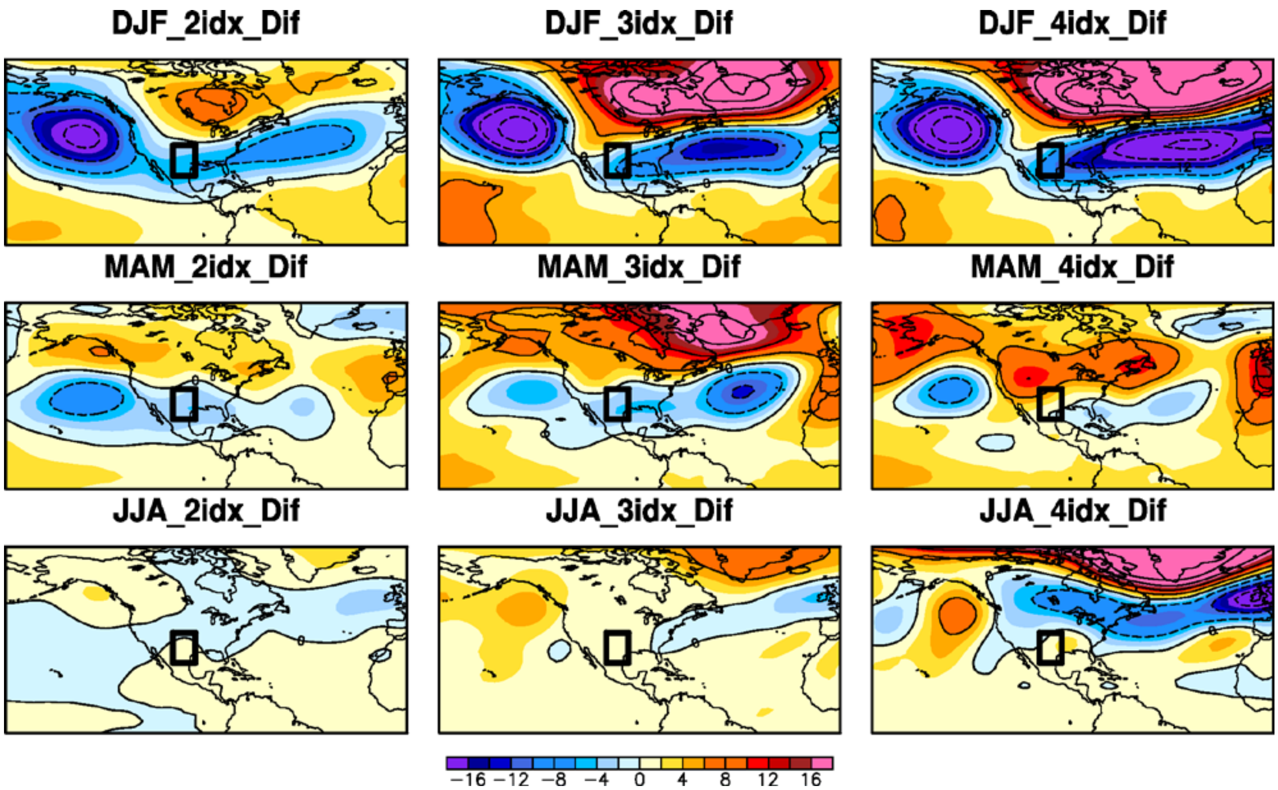

Fig. 5 Regressed 700 hPa geopotential height anomalies (gpm) between the LaDry and LaNonDry composites using PDO and Niño3.4 indices (left column), three SST based indices (middle column), and four indices (right columns).

The tropical Pacific SST is slightly warmer in dry years than non-dry years, mainly in DJF and MAM. In typical La Niña years, dry anomaly is located over the SGP in DJF and shifts northward to the northern Plains in JJA. A warmer Niño 3.4 SST indicates a weaker/slower seasonal northward migration of dry anomalies, favoring the development of drought in the SGP. An anomalous low SST over the mid-latitude North Pacific also persists from DJF to JJA, resembling a positive PDO pattern, while a symmetric negative SSTA is located over the South Pacific.

Figure 4 shows the regression coefficients of SGP rainfall onto the three SST based indices and NAO index during 1950-2012 (stars) and during 25 La Niña years (bars). This further verifies a weak but persistent influence of AMO on SGP rainfall in La Niña years from winter to summer. Influence of Niño 3.4 SST on rainfall is very weak in spring during La Niña and reverses to a negative relationship in summer. The NAO is the most important factor in JJA regardless of whether it is a La Niña year or not.

Figure 5 shows regressed 700 hPa geopotential height using different linear combinations of indices discussed above for the differences between the LaDry and LaNonDry composites. The left column shows the influences from the Pacific Ocean (*i.e.*, Niño3.4+PDO), middle column includes the influences of the North Atlantic and Pacific oceans (*i.e.*, Niño3.4+PDO +AMO) while the right column includes the influence of NAO.

The regressed pattern using Pacific indices shows relatively high correlations with the NCEP1 reanalysis in winter over the North Pacific-North America-North Atlantic (NPAA, 10º-60ºN, 30º-150ºW) region (uncentered pattern correlations 0.66) and the southern U.S. and its surroundings (USS, 20º-43ºN, 80º-120ºW; 0.63), but quite low or even negative correlations for spring and summer. Regressions using four indices have largely increased the correlations in both NPAA (*e.g.*, 0.87 in DJF and 0.62 in JJA) and USS (*e.g.*, 0.93 in DJF and 0.65 in MAM) regions except in summer when the patterns over the USS is better captured without the NAO index.

In La Niña dry years the above indices can explain about 63% of rainfall anomaly in MAM and 38% in JJA. Such a decrease of explanation from spring to summer suggests a contribution from factors other than SSTAs and NAO, such as soil moisture feedbacks and radiative feedbacks from the reduction of cloud that can amply the drought, and from random atmospheric variability. The wet anomaly in the summer is not captured and may also due to these factors. Overall, the rainfall differences between the dry and non-dry composites are explained by 36% in MAM and 23% in JJA with these indices.

4. Conclusions and discussion

- There are distinct circulation patterns between La Niña dry and non-dry years in the SGP. Droughts are associated with anomalous high geopotential height and subsidence over the SGP, along with an intensified northward moisture flux that transports moisture to the northern Plains and Midwest and a northward displacement of the North Pacific and Atlantic jet streams.
- Anomalous SST patterns are found between dry and non-dry years: i) a warm SSTA over the North Atlantic that resembles a positive AMO pattern; ii) a relatively warm Niño3.4 SST. Such an anomalous positive AMO pattern enhances the geopotential height over the northern Atlantic and thus strengthens and shifts the high center over the SGP toward the southeast, and it also modifies the location of subtropical jet streams. A weaker La Niña, by delaying the seasonal northward shift of the dry anomaly during MAM and JJA, also contributes to the development of drought in the SGP.
- Niño 3.4, PDO, AMO and NAO indices can largely reproduce the anomalous geopotential height patterns between dry and non-dry years in DJF but less in MAM and JJA mainly due to a worse representation of anomalous wet condition.
- Although previous studies have identified the role of the AMO in SGP drought, this analysis highlights its influences in La Niña years that contribute to the anomalous large-scale patterns that favor the development of drought. Thus improving model performance in simulating the influence of Atlantic SST on SGP rainfall may enhance the capability of drought modeling and prediction in this region.

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