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What Is the Variability in US West Coast Winter Precipitation during Strong El Niño Events?

Arun Kumar and Mingyue Chen
Climate Prediction Center, NOAA/NWS/NCEP, College Park, Maryland

1. Introduction

The equatorial Pacific Ocean was in a strong El Niño state after late 2015. The amplitude of warm sea surface temperatures (SSTs) over the region associated with El Niño-Southern Oscillation (ENSO) was similar to previous El Niño events in 1982-83 and 1997-98, which were the strongest El Niño events in the past 60 years.

The climate in the United States (US) is significantly influenced by El Niño events. The anticipated influence on the US winter precipitation that includes above normal precipitation conditions across the southern US and below normal conditions over the northern part of US, however, was not observed. In contrast to expected El Niño response, the observed precipitation anomalies in the 2015/16 winter were above normal over Pacific Northwest and were below normal over the entire California. A question that is addressed in this analysis is: How different could be the west coast winter precipitation on an event-to-event basis from the typical El Niño composite mean (or the El Niño response) pattern?

In this analysis, we utilize data from large set of hindcasts and real time forecasts from National Centers for Environmental (NCEP) Climate Forecast System version (CFSv2). A sample size that exceeds 8000 seasonal mean outcomes for differing forecast SST conditions is used to address the question of event-to-event El Niño variability in California seasonal mean rainfall.

2. Data

The model forecast data used in this study includes 3-month seasonal means (OND, NDJ, and DJF) of winter precipitation and SST. The hindcast data is 30 years (1982-2011) and is combined with 4 years (2012-2015) real-time forecasts from the NCEP's CFSv2 (http://cfs.ncep.noaa.gov; Saha *et al*., 2014). For hindcasts, there are four forecasts of nine months every 5th day starting at January 1st each year. In real-time configuration, CFSv2 has four forecasts of nine months every day. By collecting forecasts from all lead times for a specific target season (Chen and Kumar, 2015), there is a sample of 5040 in hindcasts (30 years hindcasts * 7 different month leads * 6 initial dates per month * 4 members per start date) and approximately a sample of 3360 in real-time forecasts (4 years forecasts * 7 different month leads * 30 initial dates per month * 4 members per start date).

Based on an ensemble 8400 members for each target season, the variability of winter precipitation over the US west coast during strong El Niño events was examined. In the model forecasts if one defines strong El Niño as forecast members with the 3-month-mean Niño3.4 SST anomalies at least two times of their standard deviation then out of 8400 members there are 592, 498, and 316 strong El Niño events for OND, NDF, and DJF, respectively.

3. Results

To quantify the dependency in the west coast precipitation response to ENSO, we binned the area averaged precipitation over the regions of California and the Pacific Northwest (PNW) according to the predicted amplitude of the Niño3.4 SST index. This analysis uses the entire forecast sample of 8400. For each SST bin, shown in Fig. 1 are mean precipitation anomaly (the red bars) and the spread (the blue whiskers) in precipitation for forecast samples in each bin. The figure is arranged from strong negative to strong positive

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Correspondence to: Arun Kumar, Climate Prediction Center, NOAA/NWS/NCEP, 5830 University Research Court, College Park, MD; E-mail: arun.kumar@noaa.gov.

values of Niño3.4 SST index for OND, NDJ, and DJF. Figures 1a-c are for the California precipitation and Figs. 1d-f are for the PNW precipitation. The sample size for each bin is shown in the bottom panels of Fig. 1. The magnitude of spread is the standard deviation of individual members in the bin with respect to the ensemble mean of samples in the bin.

For the precipitation over the region of California, the mean precipitation signal increases from negative anomaly for cold phase of ENSO to positive anomaly for warm episodes with larger amplitudes during warm SSTs. The amplitude of precipitation anomalies, *i.e.*, the strength of the precipitation response to ENSO signal increases from OND to DJF. An important point to note is that the magnitude of spread is generally greater than that of signal even in DJF when the signal is the strongest. This implies that the outcome of precipitation for one specific season can be very different from the mean response.

In general, the amplitude of the mean signal increases quasi-linearly with increasing amplitude of SSTs, and the wet signal shows larger amplitude than that of dry signal. It is interesting to note that the spread for individual outcomes does not change from neutral to strong ENSO conditions. These results have been noted in earlier studies, for example, Hoerling and Kumar (1997), Chen and Kumar (2015) for the quasi-linearity of the signal, and Kumar *et al.* (2000), Peng and Kumar (2005) for the constancy of noise.

For the PNW precipitation, the anomaly changes from positive in cold phase of ENSO to negative in

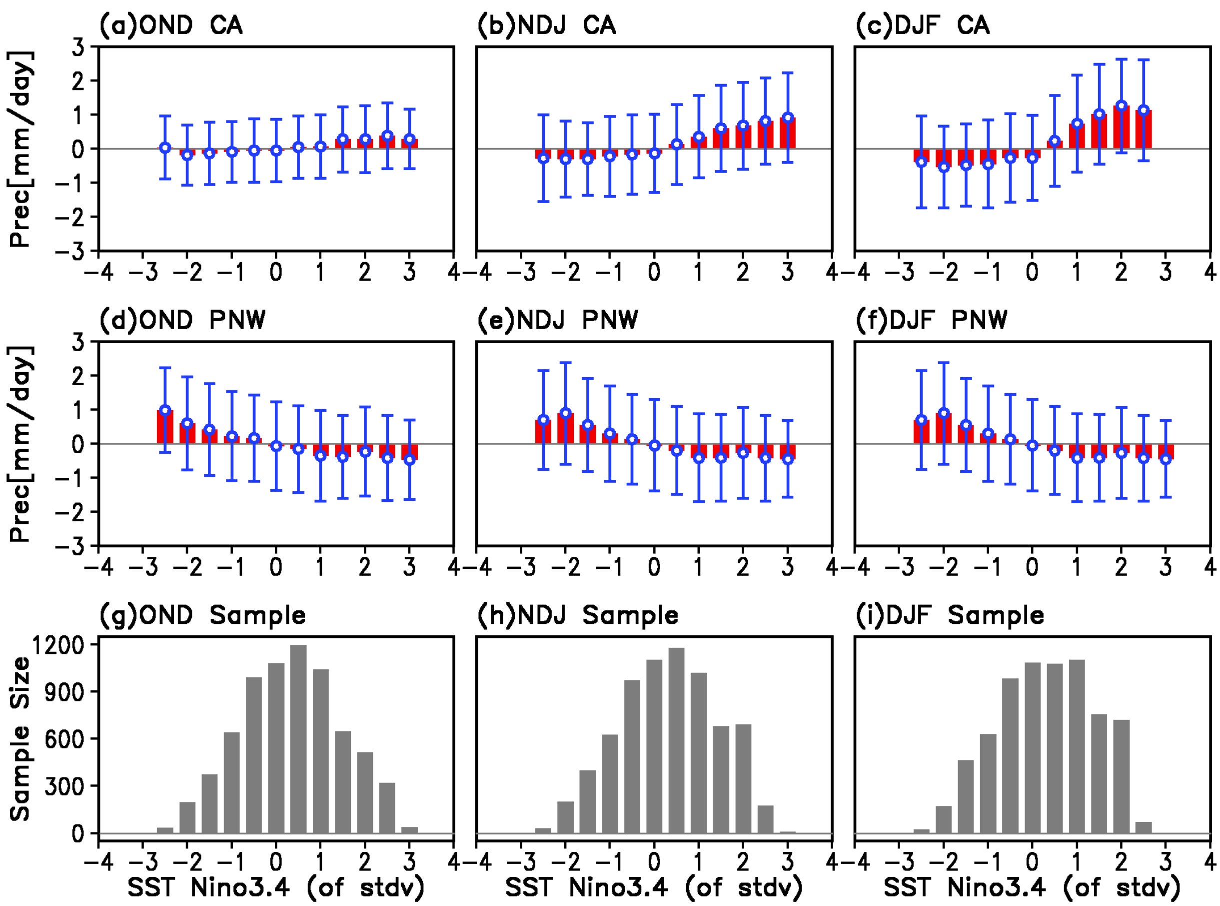

Fig. 1 The areal-mean precipitation ensemble mean anomaly averaged in each bin of Niño3.4 SST index (the red bars) and the spread of individual members from the ensemble mean in the same bin (the blue whiskers). The bin width of the Niño3.4 SST index is 0.5 of its standard deviation and the red bars are shown in the middle of the bin. Panels a, b, and c are for the region of California during OND, NDJ, and DJF, respectively. Panels d, e, and f are for the region of Pacific Northwest (PNW; 118—126^{o}W, 43—50^{o}N). The gray bars in the panels of g, h, and i are the corresponding sample size for each SST bins during each season.

warm phase of ENSO, which is in opposite sign to the California precipitation. The PNW precipitation also shows less seasonality in the ENSO signal and smaller magnitude of the ratio of the signal to noise.

To further illustrate the behavior in mean response and spread from event-to-event, the PDF of seasonal mean precipitation for strong El Niño events is compared with its climatological PDF. The results are shown in Figs. 2a, c, and e for the California precipitation and Figs. 8b, d, and f for the PNW precipitation.

In response to strong SST anomalies in El Niño events, the California precipitation probability density function (PDF) moves towards the right of its climatological PDF and the probability for extreme wet event are increased. Consistent with Fig. 1, the largest separation between the PDFs is for the DJF.

As the spread during El Niño does not change much across different PDFs, an increase in probability for positive precipitation anomalies over CA is mainly due to the PDF shift. However, we note that the spread among ensemble members during extreme El Niño events is still appreciably large, and implies that even during strong El Niño events, although the probability of positive precipitation anomalies over California is enhanced, there is still a considerable probability to have negative anomalies. This variability in the seasonal mean outcomes for individual seasons is a limiting factor on the level of predictability.

The PNW ENSO precipitation PDF shifts to the left of its climatology PDF. However, the magnitude of the shift is much smaller compared with that over the California, so that, the precipitation predictability over the PNW is much less than that over the California.

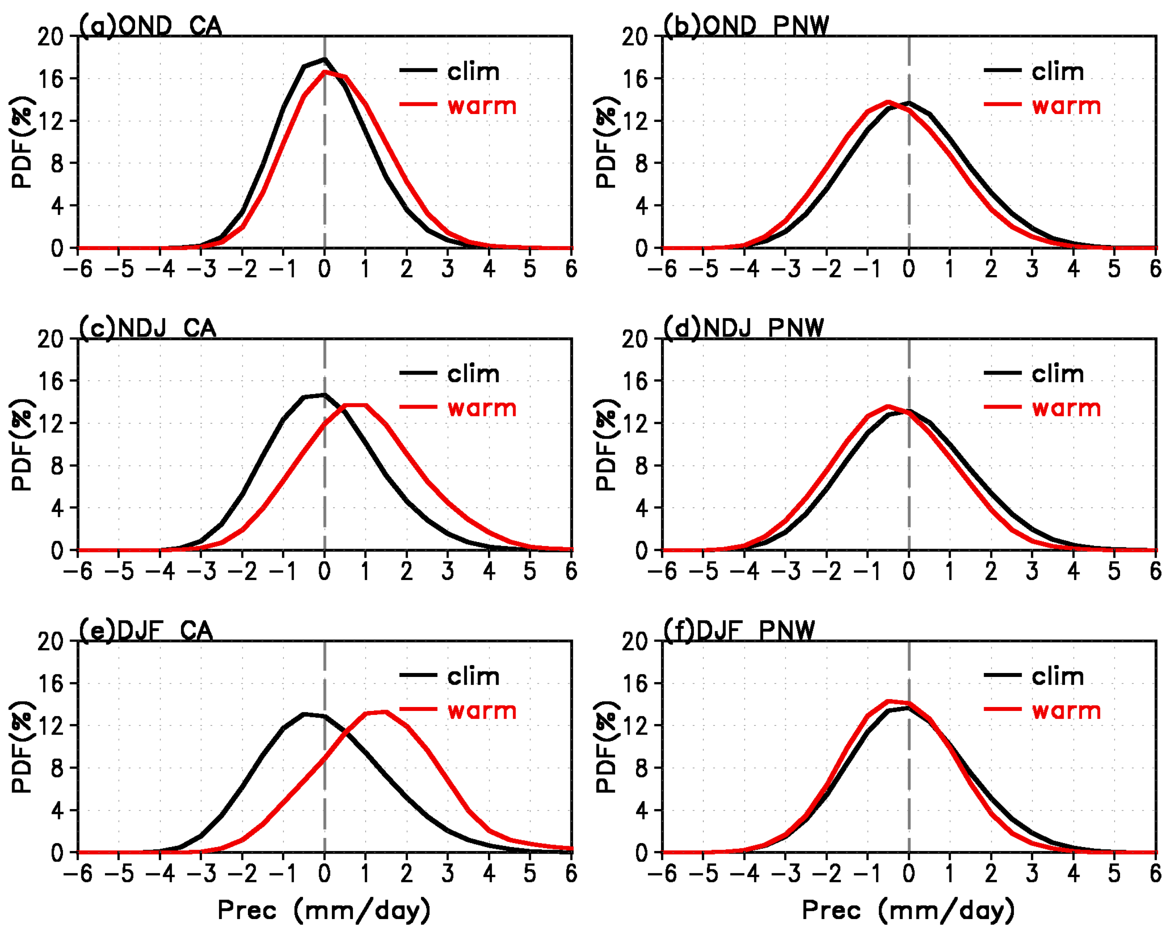

Fig. 2 The PDF of precipitation anomalies for strong El Niño events (red) and its climatological PDF based on all members (black) during seasons of OND, NDJ, and DJF. Panels a, c, and e are for the region of California, and b, d, and f are for the region of PNW (118—126°W, 43—50°N).

4. Summary

The analysis based on a large sample of seasonal means demonstrated that the seasonal mean precipitation signal over the west coast of US during strong El Niño events, although was consistent with the documented signal with negative anomalies over the northern Pacific Northwest and positive anomalies over the southern region that include California, it was within the range of possible seasonal mean outcomes. This is because for individual forecasts the variability in seasonal mean precipitation is very large. As a consequence, there will be an appreciable probability for seasonal mean precipitation anomaly to have its sign opposite to the mean response to El Niño. This interplay between the precipitation response to El Niño, and event-to-event variability, even during strong El Niño events, can account for the fact that seasonal mean precipitation along the west coast of US during the strong El Niño event of 2015/16 was opposite to the expected ENSO response.

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