16.7 **RELATIONSHIPS BETWEEN CLIMATE VARIABILITY AND THE STATISTICS OF WINTER PRECIPITATION EXTREMES IN THE UNITED STATES**

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1. INTRODUCTION

It is increasingly clear that a better understanding of the linkages between climate and weather is needed since many decision making processes in society are directly tied to weather "events". In this paper, we will investigate the effects of two of the climate systems' most prominent patterns of variability in the Northern Hemisphere, namely the El Nino-Southern Oscillation and the Arctic Oscillation (Thompson and Wallace, 1998) on precipitation probability distribution function (PDF), especially on the extreme precipitation over the conterminous United States. Previous studies have shown that ENSO related impacts on seasonal mean precipitation are profound over portions of the US (Ropelewski and Halpert, 1986, 1996; Kiladis and Diaz 1989; etc). Thompson and Wallace (2001) showed that the AO has strong impacts on regional climate. The primary concern of this paper is with ENSO, AO and combined (ENSO, AO) sensitivity of the tail of the daily precipitation distribution. Emphasis is placed on geographical patterns of this sensitivity for boreal winter (January - March 1950-1999).

2. DATA ANALYSIS

The study exploits 50-years (JFM 1950-1999) of daily precipitation data (Higgins et al. 2000) over the conterminous United States. The precipitation anomalies are obtained by removing the annual cycle which is computed from the 30-day running mean of the daily mean climatology from 1971-2000. In this study, wet days are defined as those with daily precipitation rate at a particular location greater than 1 mm day^{-1}, heavy precipitation days are defined as those in the upper 10% of the distribution based on the precipitation anomalies.

The seasonal classification of El Niño and La Niña events used in this study is identical to that used by the Climate Prediction Center / National Centers for Environmental Prediction (CPC/NCEP) and found on their website (http://www.cpc.ncep.noaa.gov/ products/ analysis_monitoring/ensostuff/ensoyears.html). Composites keyed to El Niño (La Niña) episodes are based on the moderate and strong events, with the remaining years being classified as ENSO-neutral (i.e. including the weak El Niño and La Niña winters). Standardized daily AO index is computed based on the methodology of Thompson and Wallace (2000) and displayed on the CPC webpage at http://www.cpc.ncep.noaa.gov/products/precip/CWlink/ daily_ao_index) for the period JFM 1950-1999. High (low) index phases of the daily AO index occur when it exceeds +0.5 (-0.5) standard deviations, otherwise a day is defined as AO-neutral. .

3. LINKAGE BETWEEN CLIMATE VARIABILITY AND DAILY PRECIPITATION

Here we examine how ENSO and the AO are related to daily precipitation statistics by looking at the composites keyed to each ENSO and AO phase. The focus is on changes in the frequency of wet days and in the average intensity of daily precipitation (in mm day^{-1}); For each composite of ENSO and AO, the percentage change in frequency of wet days and the percentage change in average intensity of daily precipitation relative to the normal is shown.

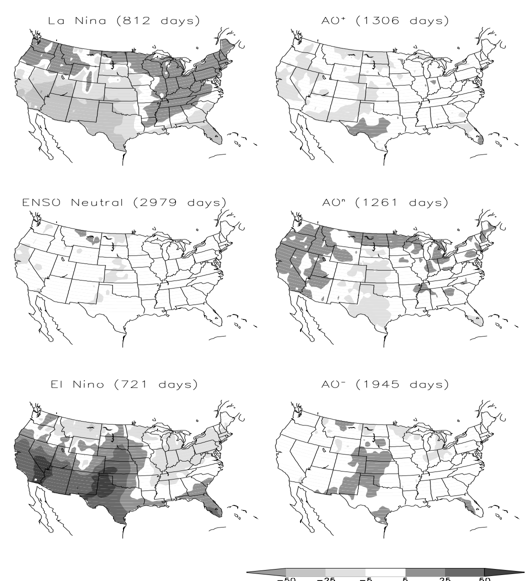

Fig. 1 Percent change in the frequency of wet days (> 1 mm day^{-1}) relative to normal by ENSO phase (left column) and AO phase (right column) based on JFM 1950-1999. The number of days in each composite is indicated in parentheses.

The La Niña composites show increases in the frequency of wet days (Fig. 1, top left) and in the average intensity of daily precipitation (Fig. 2, top left) over the Pacific Northwest, the northern tier-of-states, the Appalachians and portions of the Northeast and decreases in the frequency of wet days and in average intensity over the southern tier of the United States. This is consistent with the increased variability in the strength of the Pacific jet stream over the eastern North Pacific, with the mean jet position entering North America in the northwestern United States / southwestern Canada. The

El Niño composites show increases in the frequency of wet days (Fig. 1, lower left) and in the average intensity of daily precipitation (Fig. 2, lower left) in the southern tier of the United States and decreases in the frequency of wet days along the northern tier of the states extending from the Pacific Northwest to the Northeast which is due to the pronounced eastward extension and equatorward shift of the Pacific jet stream.

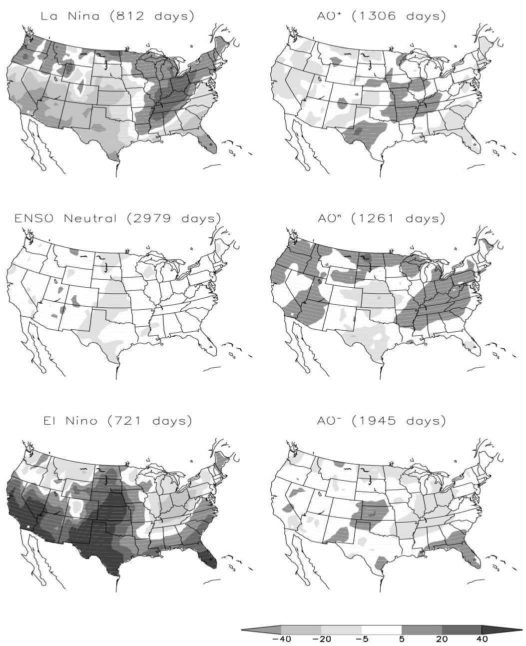

Fig. 2 Same as Fig. 4, except for percent change in daily mean precipitation

ENSO-neutral winters feature a weakening of the Pacific jet stream as it approaches the west coast of North America and active polar and subtropical jet streams extending over the North American continent, consistent with an increase in day-to-day precipitation (and temperature) variability. However, they are not associated with significant changes in the frequency of wet days (Fig. 1, middle left) or in the average intensity of daily precipitation (Fig. 2, middle left).

The positive polarity of AO phase is characterized by a strengthening of polar vortex and anomalous ridging in midlatitudes. Over the United States the high index phase is associated with a westward extension of the subtropical western Atlantic anticyclone over the southeastern United States, contributing to anomalously dry conditions in the southeast and moist conditions in the enhanced southerly flow over portions of Texas and the central Mississippi Valley (Fig. 2, top right). The western United States, especially California, appears to be anomalously dry due to a northward shift of the main storm track (Fig.1 and 2, top right). However changes in the frequency of wet days associated with the positive phase of the AO are relatively small (Fig. 1, top right). The low index phase of the AO is associated with a precipitation signal that is generally in the opposite sense in the southeastern United States (Figs. 1 and 2, lower right), reflecting a weaker than normal subtropical anticyclone and anomalous northwesterly flow from the northern Plains towards the Tennessee Valley.

4. COMBINED EFFECTS OF ENSO AND AO

While ENSO-related influences on precipitation are larger than AO-related ones when each mode is considered separately (compare ENSO and AO impacts in Figs. 1 and 2), we find that the AO-related impacts are relatively larger when the combined effects of ENSO and the AO are considered (Fig. 3). For example, the Pacific Northwest experiences an increase in the frequency of wet days (Fig. 3, left column) for (C, AO^+) and (C, AO^n), but not for (C, AO^-). Further inspection of Figs. 3 reveals many other significant regional differences. The (N, AO^+) composites are associated with increases in frequency and average intensity of daily precipitation over the Midwest / Tennessee Valley while the (N,AO^-) composite is associated with negative anomalies (Fig. 3 middle column). Clearly this is linked to the strength and westward extent of the subtropical western Atlantic anticyclone.

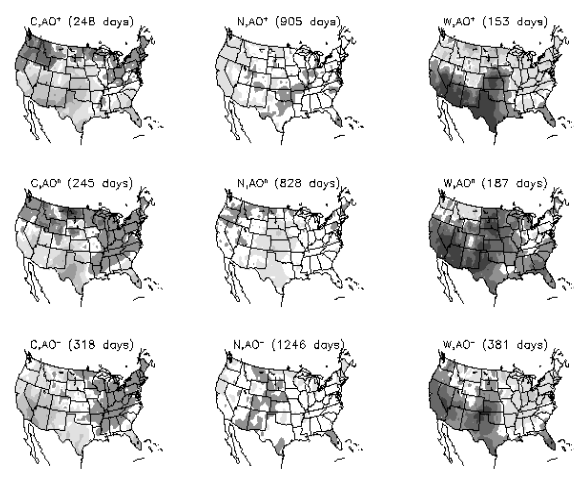

Fig.3 Same as Fig. 1, except for each combination of ENSO and AO phase.

5. LINKAGE BETWEEN CLIMATE VARIABILITY AND DAILY PRECIPITATION EXTREMES

In section 3 and 4 we saw that changes in the frequency of wet days for various combinations of AO and ENSO phases were associated with changes in the average intensity of daily precipitation in the same sense because the number of wet days in a certain period directly affect the average daily precipitation rate. However, when considering the heavy precipitation days, changes in frequency may or may not be associated with changes in the average intensity in the same sense.

As mentioned above, daily precipitation anomalies were ranked (locally) for the period JFM 1950-1999 and the heavy precipitation days were defined as those in the upper 10% of the anomalous time series. This implies that 9 heavy precipitation days would be expected to occur at a particular location in an average 90 day winter. For the ENSO and AO composites, the expected value is simply 10% of the total number of days in each composite based on the 50 year (JFM 1950-1999) period.

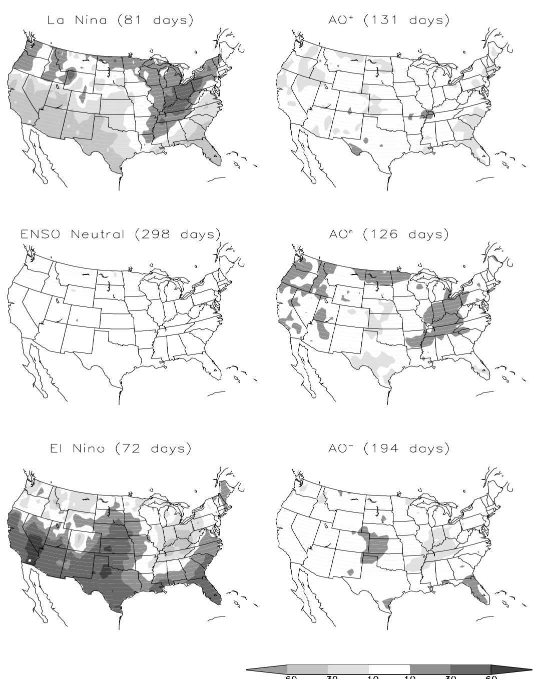

Fig. 4 JFM percent change in the frequency of heavy precipitation days (top 10%) over that expected by ENSO phase (left column) and AO phase (right column). The expected number of heavy precipitation days is indicated in brackets. Results are based on JFM 1950-1999. Unshaded areas indicate where the number of extremes is within 10% of the expected number. Dark (light) shaded areas indicate where the average number of extremes is greater (less) than expected.

Fig. 4 shows the spatial patterns of the percent change in the frequency of heavy precipitation days (top 10%) over that expected. The geographic patterns of the percent change in the frequency of heavy precipitation days for each ENSO phase (Fig. 4, left column) resemble geographic patterns for the percent change of wet days (Fig. 1, left column) and for the percent departure from normal (Fig. 2, left column). However, geographic patterns of the percent departure from normal in precipitation intensity for the heavy precipitation days do not show any organized large-scale structure (figure not shown). This suggests that changes in precipitation due to the heavy precipitation events are largely changes in frequency, not intensity. Geographic patterns of the percent change in heavy precipitation days during the high, low and neutral phases of the AO (Fig. 4, right column) are also qualitatively consistent with the patterns shown in Figs. 1 and 2. Overall, the patterns are much weaker than they are for ENSO.

6. SUMMARY

The diagnostic relationships highlighted in this study may be summarized as follows:

1. Aspects of the variability in winter precipitation and winter precipitation extremes are strongly tied to the leading modes of climate variability.

2. The combined effects of ENSO and the AO on the frequency and intensity of wet days and precipitation extremes are larger than the effects due to either of the modes separately.

This study shows that linkages between climate variability and daily precipitation extremes are pervasive, and hence that stronger collaboration between the climate and weather modeling communities is needed to ensure that these linkages are properly captured in models.

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