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PRECIPITATION PATTERNS OVER THE MIDWESTERN UNITED STATES DURING EL NIÑO AND LA NIÑA EVENTS

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Abstract The present study documents daily and extreme precipitation over the Midwestern United States during El Niño months (WEM) and La Niña months (CEM) using station rainfall and the NCEP/NCAR reanalysis data for the period of 1987-1999 through U-test and composite analysis. The ENSO effect shows less of an influence on extreme precipitation when compared to its effect on daily precipitation. This means that the influence of El Niño and La Niña is not related to precipitation intensity. Comparing the atmospheric conditions in WEM (CEM) with those in NTM, it was found that changes in circulation activity account for the precipitation decrease in WEM and CEM, and the increase in WEM but not the precipitation increase in CEM. The precipitation increase in CEM cannot therefore be accounted for with respect to large scale phenomena.

Key words: El Niño, Midwestern United States, precipitation teleconnection, U-test

1. Introduction

The links between El Niño and precipitation patterns over the middle and high latitude regions of the United States have been examined as follows. The relationships between ENSO and the monthly precipitation totals and average temperatures are described by Ropelewski and Halpert (1986). Over the Midwestern United States, it has been hypothesized that rainfall events are influenced by ENSO. Trenberth *et al.* (1988) documented that the 1988-89 La Niña was one of the contributing factors to the 1988 summer drought in the United States. Bell and Janowiak (1995) demonstrated that ENSO was an indirect contributor to the overall magnitude and extent of the Midwest flood of 1993. The influence of ENSO on daily rainfall over the Midwestern United Sates was also examined. Gershunov and Barnett (1998) investigated the effect of ENSO on extreme precipitation and temperature over the United States. In the Ohio-Mississippi River valley, heavy rainfall events were found more frequently during La Niña winters.

As seen above, ENSO-related precipitation has most often been quantified in terms of monthly or seasonal precipitation. Gershunov and Barnett (1998) reported on the effects of ENSO on daily precipitation over a contiguous region of the United States but reported only on wintertime precipitation and concentrated on the period of 1950-1993.

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The purpose of this study is to provide an assessment of the monthly and geographical extent of an ENSO-related response in daily precipitation amount over the Midwestern United States for the period of 1987-1999, a time in which El Niño and La Niña events occurred frequently. Two kinds of precipitation, daily precipitation and extreme precipitation are considered. To discriminate with respect to ENSO, all months are divided into El Niño (warm), La Niña (cold) and neutral months, and the differences in precipitation between El Niño (La Niña) and neutral months are determined by the U-test (to a significance level of 5%). Additionally, circulation patterns during El Niño and La Niña months will be examined, and the causes of precipitation variability and its relation to El Niño and La Niña events will be investigated.

2. Data and Method

The Observational data is taken from the daily precipitation dataset from the NOAA Climate Prediction Center (CPC) recorded at 101 stations. These stations are 80% complete for the period of 1987-1999 across the Midwestern United States. The Midwest is defined as the 13 states of North Dakota, South Dakota, Nebraska, Kansas, Minnesota, Iowa, Missouri, Wisconsin, Illinois, Indiana, Kentucky, Michigan, and Ohio (Fig. 1). This area experienced summer flooding in 1993. In order to investigate the links between atmospheric circulation patterns and rainfall anomalies, the NCEP/NCAR (The National Center for Environmental Prediction / National Center for Atmospheric Research) global atmospheric reanalysis data (Kalnay *et al.* 1996), covering a 13-year period from January 1987 to December 1999, was consulted. The monthly 500-hPa height data and the 200-hPa u-component wind data are used to describe the atmospheric circulation patterns. The El Niño / La Niña months were defined by Trenberth (1997) and each month is divided into El Niño, La Niña and neutral months (Table 1). All months not categorized as El Nino or La Nina are defined as neutral months. El Niño (warm) event months are referred to as "WEM", La Niña (cold) event months, as "CEM", and neutral months as "NTM". Therefore, for example a July in which El Niño occurs is referred as WEM (7).

In order to clarify the impact of El Niño and La Niña on daily precipitation over the Midwestern United States, monthly percentile precipitation measured at each station was taken as

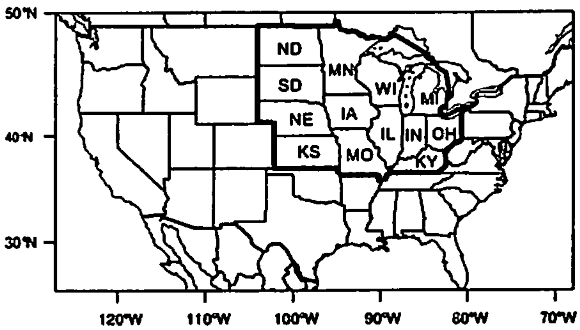

Fig. 1 Study area. North Dakota, South Dakota, Nebraska, Kansas, Minnesota, Iowa, Missouri, Wisconsin, Illinois, Indiana, Kentucky, Michigan, Ohio

Table 1 Listings of El Nino and La Nina events

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1987	+	+	+	+	+	+	+	+	+	+	+	+
1988	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1989	−	−	−	−	−	−						
1990	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1991			+	+	+	+	+	+	+	+	+	+
1992	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1993		+	+	+	+	+	+	+	+			
1994	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1995	+	+	+						−	−	−	−
1996	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1997				+	+	+	+	+	+	+	+	+
1998	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1999	−	−	−	−	−	−	−	−	−	−	−	−

*Plus and minus signs indicate El Nino and La Nina events, respectively.

an indicator of precipitation intensities. In this paper both daily precipitation and extreme precipitation are considered. All rain events including zero precipitation are defined as daily precipitation. Precipitation in excess of the 90th percentile is defined as extreme precipitation. Daily precipitation events were divided into WEM, CEM, and NTM from January to December. The U-test was then employed to assess the differences between WEM (CEM) and NTM with respect to daily precipitation amounts. The same analysis was performed on the extreme precipitation events. Though temperature is assumed to have a normal distribution, precipitation is not normally distributed and often exhibits a tendency for a skewed distribution. As the U-test is a non-parametric examination, it can be adapted to the analysis of precipitation. The analysis was performed for each month to a significance level of 5%. Additionally, in order to examine the circulation patterns in El Niño and La Niña months, 500-hPa height and 200-hPa u-component wind anomalies between WEM (CEM) and NTM were taken.

3. Results

Figure 2 shows the results of the U-test when applied to daily precipitation in WEM and CEM. Upright and inverted triangles indicate stations where daily precipitation increased and decreased, respectively. Crosses denote that there is no significant difference. In such an analysis, it is possible to identify which months are affected by El Niño and La Niña events. The months in which daily precipitation tend to increase (decrease) are referred to as "increased (decreased) months", and are represented by the sign (−). One month is selected as the representation for each of the 4 categories (WEM+, WEM−, CEM+ and CEM−) and displayed. The WEM increased months (Fig. 2a) are WEM+(Mar), WEM+(Jul), WEM+(Aug) and WEM+(Oct), and the WEM decreased months (Fig. 2b) are WEM−(Jan) WEM−(Jun) and WEM−(Dec). The increase is pronounced during summer with the decrease becoming apparent during winter. The CEM increased months (Fig. 2c) are CEM+(Apr), CEM+(Aug), and CEM+(Oct) and decreased months (Fig. 2d) are CEM−(Mar), CEM−(May), CEM−(Jun), CEM−(Sep), CEM−(Nov) and CEM−(Dec). The spatial patterns during increased months in CEM are similar to one another. The stations reporting decreased precipitation are mainly located on the eastern parts of the Midwest (Fig. 2d). This result

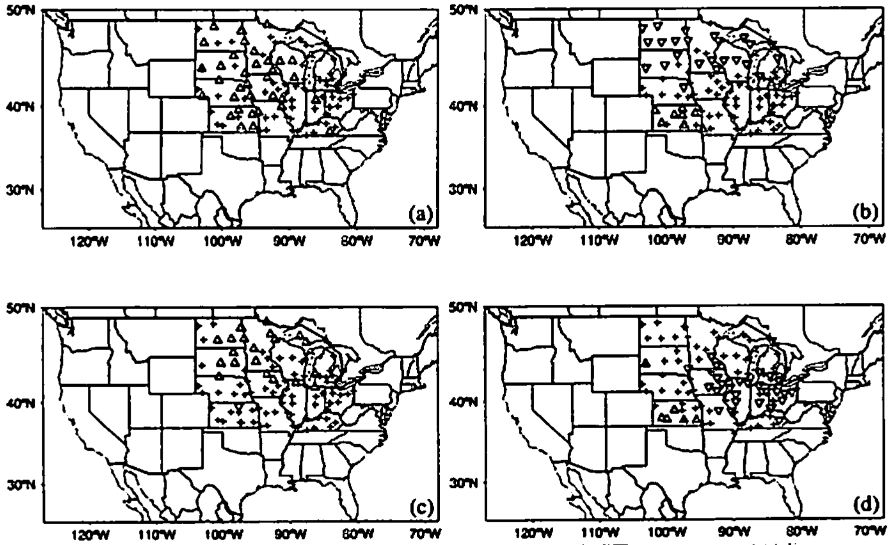

Fig. 2 Daily precipitation characteristics on WEM and CEM. (a) WEM+(Jul), (b) WEM-(Dec), (c) CEM+(Oct) and (d) CEM-(Jun). Upright and inverted triangles indicate stations where daily precipitation increased and decreased, respectively. Crosses represent stations that there is no significant difference.

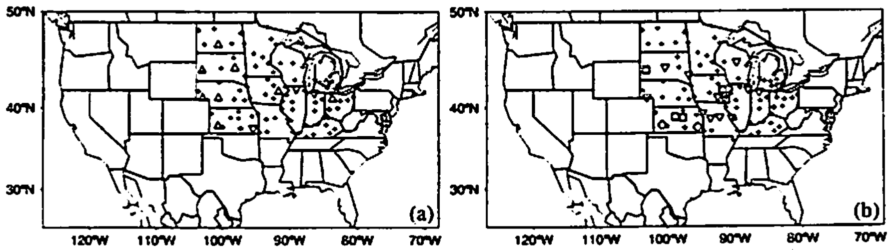

Fig. 3 Extreme precipitation characteristics on WEM and CEM. (a) WEM+(Jul) and (b) CEM-(Feb). Same as Fig. 2. Squares (diamonds) represent the station where lack of CEM (NTM) data.

is consistent with Trenberth *et al.* (1988), whose report showed that the northern Plains experienced dry conditions from April to June 1988. They suggested that the primary cause of the drought was a change in the atmospheric circulation across North America brought about as a teleconnection from changes in SSTs in the tropics. From this, it is possible that this area tends to experience a precipitation decrease during La Niña. There is a characteristic tendency for the northern part of the Midwest to exhibit above normal precipitation (Fig. 2c) during CEM+. On the contrary, these spatial patterns are not shown during WEM+ and WEM−.

Figure 3 shows the results of the U-test when applied to extreme precipitation in WEM and CEM. As mentioned earlier, extreme precipitation is defined as events above the 90-percentile. Extreme precipitation events were divided into WEM, CEM and NTM. In the case of certain stations, the U-test could not be applied because of a lack of data. To conduct the U-test correctly an excess of 4 data points are needed. Squares (diamonds) represent the stations with insufficient data to generate CEM (NTM) results. The ENSO signals are apparent during only 4 of the months, WEM+(Jul), WEM−(Aug), CEM−(Feb) and CEM+(Apr). In the light of daily precipitation anomalies presented in Fig. 2, extreme precipitation is not greatly affected by ENSO. Additionally, WEM−(Aug) shows an opposite tendency in daily precipitation. It becomes apparent that El Niño and La Niña have a strong effect on daily precipitation but it does not follow that this effect transfers to that of extreme daily precipitation.

4. Atmospheric conditions

Both Fig. 4 and Fig. 5 show the average height fields and anomalies at 500-hPa, and the average u-component winds and anomalies at 200hPa, respectively. In WEM+, the 500-hPa

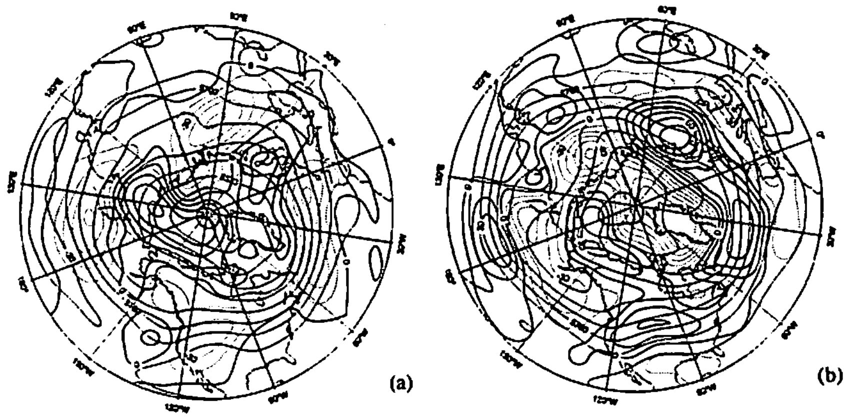

Fig. 4 The 500-hPa heights and anomalies for (a) WEM+(Jul) and (b) CEM-(Jun). Heights (anomalies) indicated by thin (thick) contours at interval of 60 m(15 m), with negative anomalies dashed. Anomalies are computed as departures from NTM.

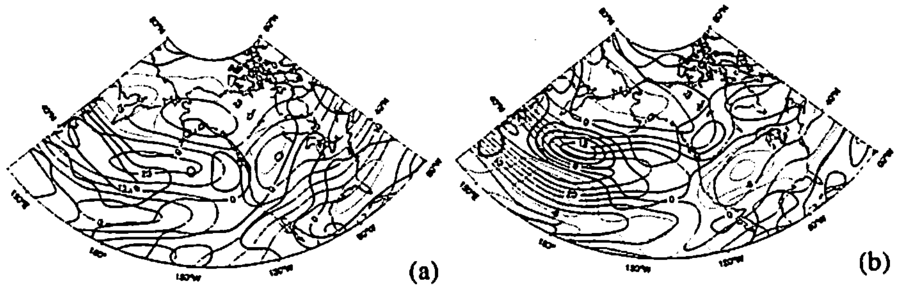

Fig. 5 The 200-hPa u wind components and anomalies for (a) WEM+(Jul) and (b) CEM-(Jun). U wind components (anomalies) indicated by thin (thick) contours at interval of 5 m/s (3 m/s), with negative anomalies dashed. Anomalies are computed as departures from NTM.

circulation was characterized by the negative anomalies over the North Pacific and from the Western to Midwestern United States (Fig. 4a). This anomalous circulation indicates above-normal cyclone activities over the middle latitudes of the North Pacific and a weakened ridge over the Western United States. Accompanying this condition, the jet stream from the North Pacific to the Midwest was stronger than normal (Fig. 5a). Thus, this zonal flow provided a duct for cyclones to propagate into the Midwest. One exception to this is in WEM+(Oct), when a strengthened ridge existed over the Western United States and a weakened jet was active from the North Pacific to the Midwest. Negative anomalies over the North Pacific were observed (not shown). In contrast, the circulation patterns for WEM−and CEM−are roughly the inverses of WEM+, whereby positive anomalies dominate much of the United States and a weakened jet stream over the Midwest was in effect (Fig. 4b, Fig. 5b). These conditions prevented the cyclone activity from entering into the Midwest. However, the patterns in CEM+ do not follow those of the WEM+. Although the jet stream over the Pacific and Midwest is similar to that in WEM+, positive anomalies affecting a contiguous area of the United States like those of CEM−, and negative anomalies over the north Pacific are not prominent at 500-hPa. These conditions differ from those in WEM+. It may be appropriate to consider that the cause of daily precipitation on WEM−, CEM−and WEM+ (except for WEM+(Oct)) are due to large-scale phenomena. The source of the increase in daily precipitation during CEM+ and WEM+(Oct), however, cannot be explained by synoptic scale phenomena.

In the case of extreme precipitation, in WEM+(Jul), an intense month with respect to both daily and extreme precipitation, above-normal heights are seen in the east of the Midwest and below-normal are seen in the west of the Midwest (Fig. 4a). The usual synoptic environment associated with the occurrence of mesoscale convective complexes (MCC) is characterized by an upper trough to the west and an upper ridge to the east of the MCC region (Maddox 1983). Thus, the large-scale flow patterns in WEM+(Jul) are consistent with those associated with past major precipitation events causing flooding in the Midwest.

The links between extra tropical atmospheric circulation in WEM and CEM, and ENSO were also examined. From WEM(Dec) to WEM(Apr), a tropical-Northern Hemisphere (TNH) pattern is dominant in WEM. This is the most frequently occurring pattern during the periods of mature ENSO conditions (Barnston and Livezey 1987). During WEM(May)-WEM(Jun), the composites reflect both the breakdown of the TNH pattern and transition to the North Pacific (NP) pattern, which can be related to ENSO in March through to May (Bell and Janowiak 1995). In WEM(Jul) and WEM(Aug) the NP pattern dominated the circulation (Fig. 4a). In contrast to spring, the composites show the transition from the NP to the TNH pattern in WEM(Sep)-WEM(Nov). These circulation features agree with Livezey *et al.* (1997).

Positive anomalies over the continental United States (Fig. 4b) is a pronounced feature at the 500-hPa height in CEM. Lau and Peng (1992) showed that the high over the United States appeared from June to August during El Niño. On the other hand, from CEM(Dec) to CEM (Feb) the negative PNA pattern (Wallace and Gutzler 1981) dominated the circulation. This configuration is associated with the occurrence of positive anomalies over the midsection of the United States. Clara and Wallace (1990) describe the large-scale circulation over the tropical Pacific during warm and cold episodes. They suggested that several differences are apparent in the December-February patterns when compared to the July-November patterns in the case of warm episode composites. However the cold episode composite for December-February exhibits many of the same features observed during July-November. From these results, it is hypothesized that the circulation in all-CEM was dominated by positive anomalies over the Unites States.

5. Conclusion

In the Midwestern United States ENSO has a demonstrably less significant effect on extreme precipitation to that of daily precipitation. This is to say that El Niño and La Niña does not have a significant effect on precipitation intensity. Although Ropelewski and Halpert (1986) suggested that there was no signal over the Midwest, some ENSO signals were identified in this paper. This result is consistent with the suggestion made by Gershunov and Barnett (1998), which indicated that in ENSO-sensitive regions, seasonal temperature means and seasonal totals are not necessarily representative of regions with ENSO-sensitive frequencies of extreme temperature and precipitation events.

The responses of the atmospheric circulation to ENSO are evident both in WEM and CEM. In WEM almost year-round teleconnections appeared and the positive anomalies persisted over the United States in CEM. The salient features of circulation patterns are summarized below. In WEM − and CEM −, positive anomalies exist over much of the United States that are associated with a weakened jet stream at 200-hPa. This process is reversed in WEM+ (except for WEM+(Oct). As mentioned above, while circulation patterns of WEM+ and WEM − in daily precipitation tend to be roughly the inverse of each other except for WEM+(Oct), this is not true of CEM. These differences likely stem from differences in the scale of events causing precipitation to increase and decrease. Maddox *et al.* (1979) suggested that flood events over the Midwest are divided into synoptic events, frontal events and meso-high events. It appears that precipitation increases in CEM+ and WEM+(Oct), which cannot be explained by large-scale phenomena, are due to meso-scale phenomena.

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