Effects of Cyclone Track on Precipitation Distribution Along the California Coastal Range and Sierra Nevada

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1. INTRODUCTION

The coastal and Sierra Nevada mountain ranges of California receive some of the heaviest precipitation amounts of any area in the United States. The geographical location and complex terrain of California (Fig. 1) make it susceptible to moist, tropical air associated with Pacific cyclones. The orography plays a key role in enhancing precipitation amounts, with some locations often receiving over 100mm in a 24-hour period. Many studies have investigated the interaction of approaching maritime air and the complex terrain (James and Houze 2005; Ralph et. al 2004; Doyle 1997; Neiman et al. 2004). However, most of these studies focus on Pacific cyclones which make landfall well north of California. In this study, we hypothesize that the track of cyclones in the vicinity of California effects the distribution and amount of precipitation occurring along the Coastal Range and Sierra Nevada.

2. BACKGROUND AND METHODOLOGY

Orographic precipitation has been studied in many locations throughout the world, including the European Alps, U.S. Rockies and Appalachians, and the Taiwan Central Mountain Range, among others. Many similarities have been documented in cases occurring in each of these locations. Lin et al. (2001) described several cases of heavy orographic precipitation throughout the world by common ingredients occurring in each case. Conclusions from their study found that ingredients of heavy orographic precipitation include, but are not limited to steep and favorable orographic geometry, high precipitation efficiency, a moist low level jet, unstable upstream flow, strong synoptic vertical motion, and quasi-stationary convective complexes. The study, however, did not include the mountain ranges surrounding the Central Valley of California. Many of these ingredients should be applicable to orographic precipitation in our study area, but may vary between cyclones of different tracks.

In order to classify track types, we use the National Center for Environmental Prediction (NCEP) North American Regional Reanalysis (NARR) dataset (Mesinger et al. 2006) for December through March, 1996-2005, as strong Pacific cyclones are most frequent during the winter season. Cyclones considered are those between 30°N and 43°N, as this brings the low center and its associated circulation into contact with the study area. For consistency, precipitation accumulations are totaled once the cyclones pass 135°W. To supplement the NARR data, satellite and rain gauge data, when available, are used to verify cyclone locations and precipitation totals, respectively. Cyclone locations are noted and plotted every 6-hours and precipitation totals end 6 hours after the cyclone has made landfall and the low pressure center and circulation center have become obscured by the terrain effects. The precipitation totals are then averaged.

Several recent studies have investigated the nature of upper-level flow patterns for certain types of events. James and Houze (2005) used stability as a criterion, and found that west-southwesterly flow produces the greatest orographic precipitation. Results from Ralph et al. (2005) concluded that there was a significant difference in upper level flow for high precipitation events for an El Nino year (1998) and a La Nina year (2001). In the La Nina year, upper-flow was more zonal with a 925mb low centered over the Gulf of Alaska, whereas the flow was more southwesterly with a 925mb low off the California Coast during the El Nino year. Other studies, including Lackmann and Gyakum (1999) and Galewsky and Sobel (2005), have found similar results of southwesterly flow for high precipitation events

For our study, we employ a simple compositing of geopotential height for the highest and lowest precipitation cases of each track type. The criterion for cases used in these composites is one standard deviation away from the mean precipitation for each track type.

3. TRACK CLASSIFICATION

Of the 63 total cases found from 1996-2005, three cyclone tracks within the domain are analyzed in this study: I) southwest to northeast, II) west to east, and III)

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northwest to southeast. Track I contains 12 cases, with the majority originating in the lower half of the domain. These cyclones tend to be the strongest, with the average minimum sea-level pressure being 994mb. A precipitation analysis of these cases reveals heaviest precipitation occurring along the coastal range and northern portions of the Sierra Nevada (Fig. 2). Two localized areas of high precipitation (average > 70mm) are also revealed, one at the northern extent of the central valley, and another just to the southeast. Both of these maximums coincide with climatological maximums in annual precipitation. The average maximum precipitation is 76mm.

Track II is the most common track, with 31 cases, the majority of which occur in the northern half of the domain. Precipitation analysis shows a similar structure to the distribution of track I, with maxima in the same locations and an average maximum precipitation amount of 54mm (Fig. 3). Track II storms were also strong in many cases, with the average minimum sea-level pressure being 997mb. The main differences between I and II are that very little precipitation occurs south of the San Francisco area, and more precipitation occurs along the northern most section of the coastal range.

Cyclones for track III storms occurred in 20 cases, originating in the northwestern portion of the domain. These cyclones were typically weaker (1007mb average sea-level minimum sea-level pressure) and produced less precipitation. In fact, the precipitation analysis for this track types shows sporadic and lighter average precipitation, with the average maximum being 43mm (Fig. 4). Very little precipitation accumulation is seen along the Sierra Nevada.

4. Upper Levels

Using the average maximum precipitation totals from before, the standard deviation is computed to isolate heavy and light events. From this, only events one standard deviation away from the mean were considered in the composites. This only proved useful for the most common type, being type II. Of the 31 type II cases, the four highest and lowest were used to create composites. Figure 5, showing the 500mb geopotential height composite for the four heaviest cases, illustrates a west-southwest flow with a 5340 decameter cut off low off the northwest U.S. coast. This is consistent with the previously mentioned similar studies. In contrast, the 500mb composite (Fig. 6) for the four lowest precipitation cases shows a much more southwesterly flow with no cut off low. While the flow is also from the southwest, there is no cut off low, and the height gradient is weaker than that of the heavy precipitation composite.

5. CONCLUSIONS

The track of Pacific cyclones in the vicinity of California plays a role in the distribution of precipitation along the coastal mountain range and the Sierra Nevada. Three track types produce three distributions, each having its own unique characteristics. An analysis of upper level flow composites shows that these cyclones are typically embedded in a trough, such that the flow is from the southwest, which pulls moist air northwestward toward California. Our composite, however does show a difference in the flow direction and height gradient between high and low precipitation events for track type II. The height gradient is stronger for high precipitation events, suggesting that the flow is stronger and there may be stronger dynamics involved.

6. Future Work

To further this research, more analysis of heavy orographic precipitation ingredients, similar to Lin et al. (2001) will be performed. The goal is understand how the circulation, instability, and progression of each track type affect the rainfall patterns. In addition, modeling will be performed to understand the role of the topography in the study area in the enhancement of precipitation.

7. Acknowledgements

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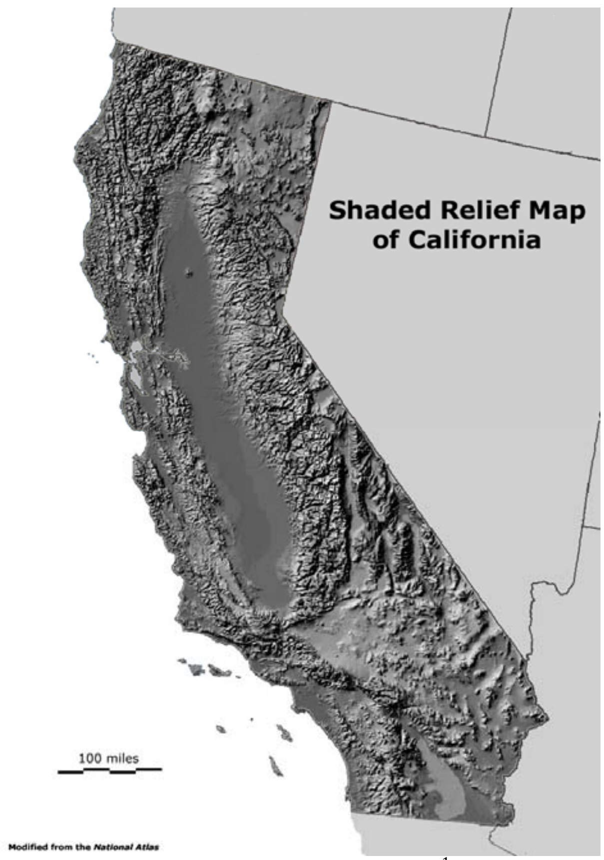

Figure 1: Shaded relief map of California[1].

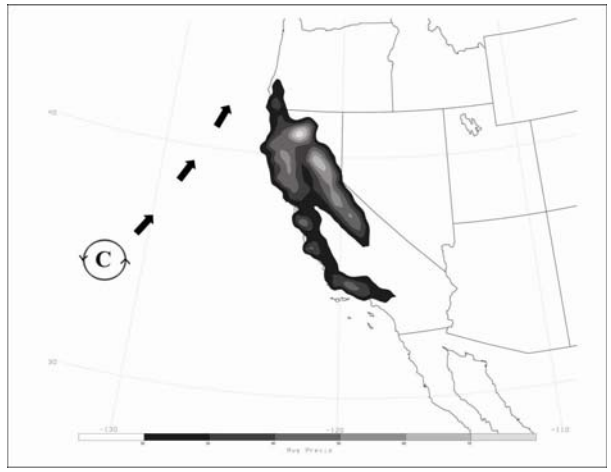

Figure 2: Average maximum precipitation (in mm) for type I track.

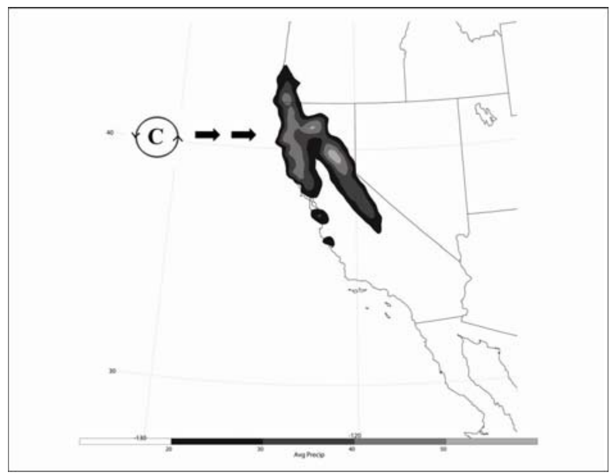

Figure 3: Same as Figure 1 except for type II track.

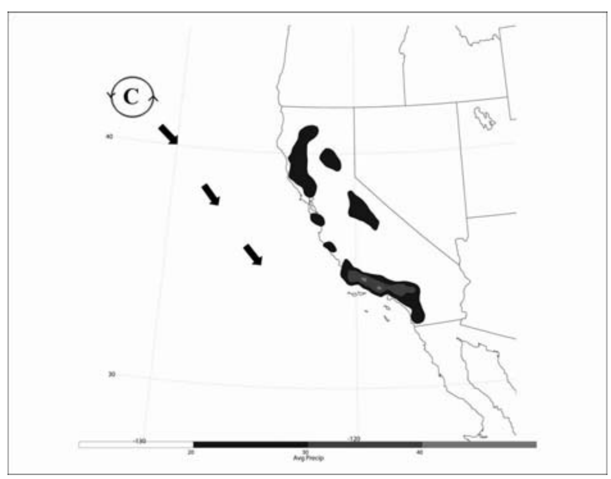

Figure 4: Same as Figure 1 except for type III track

[1]Courtesy of the U.S Geological Survey: *http://education.usgs.gov/california/resources.html*

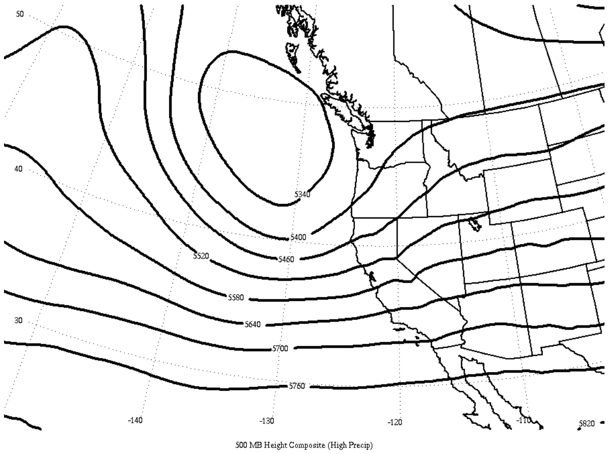

Figure 5: 500mb composite geopotential height for the heaviest precipitation events associated with track type II.

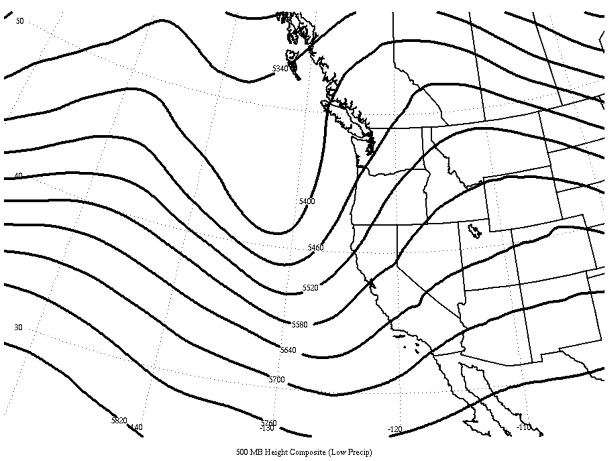

Figure 6: Same as in Figure 4 except for the lowest precipitation events.