P2.4 THE IMPACT OF TROPICAL CYCLONE REMNANTS ON THE RAINFALL OF THE NORTH AMERICAN SOUTHWEST REGION

by

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1. INTRODUCTION

New Mexico has a mild, arid or semiarid, continental climate characterized by low annual precipitation, abundant sunshine, low relative humidity, and a relatively large annual and diurnal temperature range. The State's topography consists mainly of high plateaus, with numerous mountain ranges, canyons, valleys, and normally dry arroyos. Average elevation is about 1,400 m above sea level. The principal sources of moisture for the scant rains and snows that fall on the state are the Pacific Ocean, and the Gulf of Mexico. Average annual precipitation ranges from less than 20 cm over much of the southern desert to over 45 cm at higher elevations.

Summer rains fall almost entirely during brief, but frequently intense thunderstorms. It is common for over 90 percent of the summer monthly rainfall to fall in less than 5 days. In general, a southeasterly circulation from the Gulf of Mexico brings moisture into the state, and strong surface heating combined with orographic lifting as the air moves over higher terrain produce the thunderstorms. The location of the Gulf of Mexico high-pressure system is critically important for location of the monsoonal moisture and summer precipitation in the North American southwest. July, August, and September are the rainiest months over most of New Mexico, producing, on average, approximately 45 percent of the annual moisture. However, in years where the large-scale pattern is shifted so that the high lies over or to the west of New Mexico, as little as 20% of the annual rainfall has fallen in these months.

An additional source of tropical moisture is occasionally advected into the North American southwest region from the Eastern Pacific and Gulf of Mexico in the form of tropical cyclone remnants. These mesoscale systems make landfall on the Mexican, Texan, or Californian coastline and, if the synoptic conditions are favorable, advect over the U.S. southwest. Although the tropical cyclone-strength winds rapidly diminish upon making landfall, these systems still carry a large quantity of tropical moisture and, upon interaction with mountainous topography, have the potential to drop copious amounts of precipitation. However, these systems are traditionally difficult to forecast accurately due to the nature of their interaction with the midlatitude flow.

This study is part of the North American Monsoon Experiment (NAME) (Gutzler et al. 2004), which is looking at predictability of warm season rain in the North American Monsoon (NAM). In this study we will investigate the impact that tropical cyclone remnants from the Eastern Pacific have on precipitation in the arid southwest U.S. We will study their climatological impact, and the nature of the large-scale circulations that advect them across the southwest U.S. and the associated rainfall patterns. An associated paper will describe the effect of the tropical cyclone remnants that advect in from the Gulf of Mexico. The data and methodology used in this study will be described in section 2, some climatological results will be presented in section 3, a description of the large-scale patterns associated with tropical cyclone remnants in the southwest U.S. and their associated rainfall patterns will be presented in section 4, and a summary and conclusions will be provided in section 5.

2. DATA AND METHODOLOGY

Data used in this study include best track data from the National Hurricane Center (NHC), monthly highlights from the National Weather Service (NWS) office in Albuquerque, climate

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summaries from the NWS Western Regional Climate Center, daily precipitation data for several stations across the southwest, primarily in New Mexico, GOES infrared imagery, and Nexrad radar images from the National Climate Data Center, gridded precipitation analyses from the National Center for Environmental Prediction (NCEP) and global analyses from the NCEP/NCAR (National Center for Atmospheric Research) reanalysis.

Cases of tropical cyclone remnants from 1992 – 2004 that cross into the southwest are identified using NHC best tracks, infrared imagery, and the monthly highlights. The cases are separated into precipitating and non-precipitating cases using the daily precipitation data from various stations located across the southwest and Nexrad imagery. Statistics are compiled from these data, and the areal extent of the precipitation is produced from the NCEP gridded data for each case.

NCEP/NCAR reanalysis analyses are used to examine the large-scale patterns associated with each case. The cases are separated into strong cases, weak cases, and non-precipitating cases based on the rainfall amounts. Each case is then examined for characteristic large-scale midlatitude patterns and the nature of the interaction between the TC remnants and the midlatitude flow. Composites of each type are created and examined in detail in section 4.

3. CLIMATOLOGY

Figure 1 shows the number of TC remnants that crossed into the southwest U.S. from the Eastern Pacific by month during the period 1992-2004 and stratifies them into precipitating and non-precipitating cases based on the precipitation that was carried into the southwest region. Remnants of thirty-four TCs crossed into the southwest region during 1992-2004. On average 2.6 TC remnants impact the southwest each year bringing between 0 and 31% of the annual rainfall[1] with an average 11.4%. The average number of days that are impacted annually are 4.2 with a maximum of 11 days in 1993 and a minimum of 0 days in 1997, 2000, and 2002[2].

[1] Figures are for the Albuquerque Sunport (KABQ), Albuquerque, NM. NWS-COOP station 290234.

4. LARGE-SCALE PATTERNS

Examination of the general circulation pattern of the eastern North Pacific reveals a pattern that is dominated in the tropical regions by the intra-tropical convergence zone (ITCZ) and a midlatitude regime that is dominated by upper-level troughs. During June and July, these troughs generally remain well to the north, but as the Northern Hemisphere summer progresses from late summer into autumn, these troughs protrude further south and interactions between these troughs and tropical cyclone remnants that are moving northward become more likely. An additional factor (not necessarily separate from the previous statement) is that tropical cyclone tracks in the eastern North Pacific tend to shift from westward, to more northwestward later in the season. Thus, the chance of interaction with midlatitude troughs increases as the season progresses. This is reflected in the histogram in Fig. 1 with more TC remnants crossing into the southwest region later in the season.

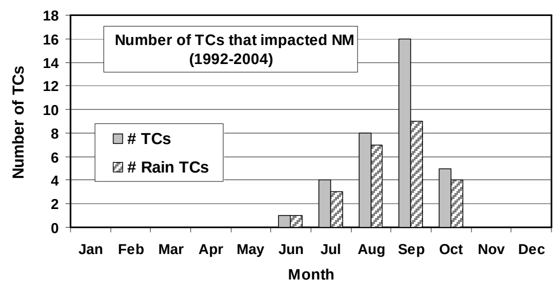

Figure 1: Histogram of the number of TCs that impacted the southwest region during the period 1992-2004 by month. The solid bars indicate total number of TCs that moved over the southwest. The hatched bars indicate the number that brought rain somewhere in the southwest region.

Tropical cyclones that move northward into the midlatitude regime go through a transition known as extratropical transition (ET). The ET of tropical cyclones is a common problem in basins with tropical cyclones (e.g., Jones et al. 2003) and is complicated by the nonlinear interactions between the tropical cyclone and midlatitude circulations. (e.g., Ritchie and Elsberry 2003; 2006). Forecasting of these systems is extremely difficult over the ocean because of the dependence of accurately predicting the interaction between the TC and upper-level trough on an accurate prediction of the track acceleration as the TC moves into the midlatitude westerlies. In this case, an added difficulty of predicting over-land effects is included. We would like to identify characteristic patterns associated with these TC remnants as a forecaster aid to predicting track and rainfall associated with TC remnants that move into the desert southwest region.

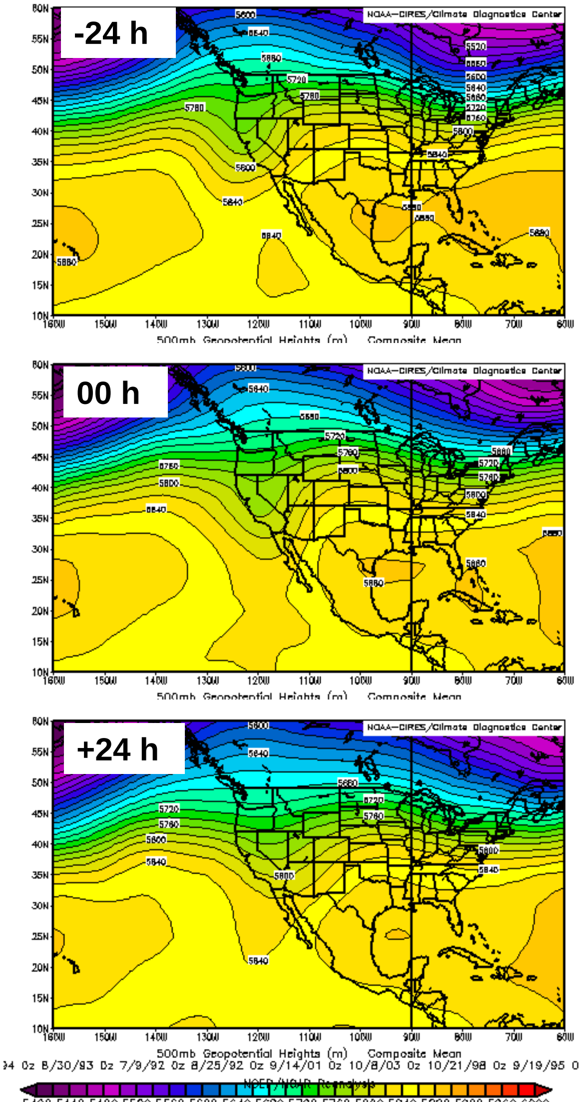

Figure 2: Composites of 500-mb geopotential height analyses for the full trough interaction. The 00 time is based on the time of maximum 24-h rainfall recorded at KABQ.

5. CASES

Thirty-four cases of TC remnants that crossed into or impacted the southwest region are examined for characteristic rainfall and large-scale patterns that can be exploited in aiding forecasters. We emphasize that there is considerable variability among the cases in terms of where across the southwest rainfall occurs. However, to aid in identifying patterns

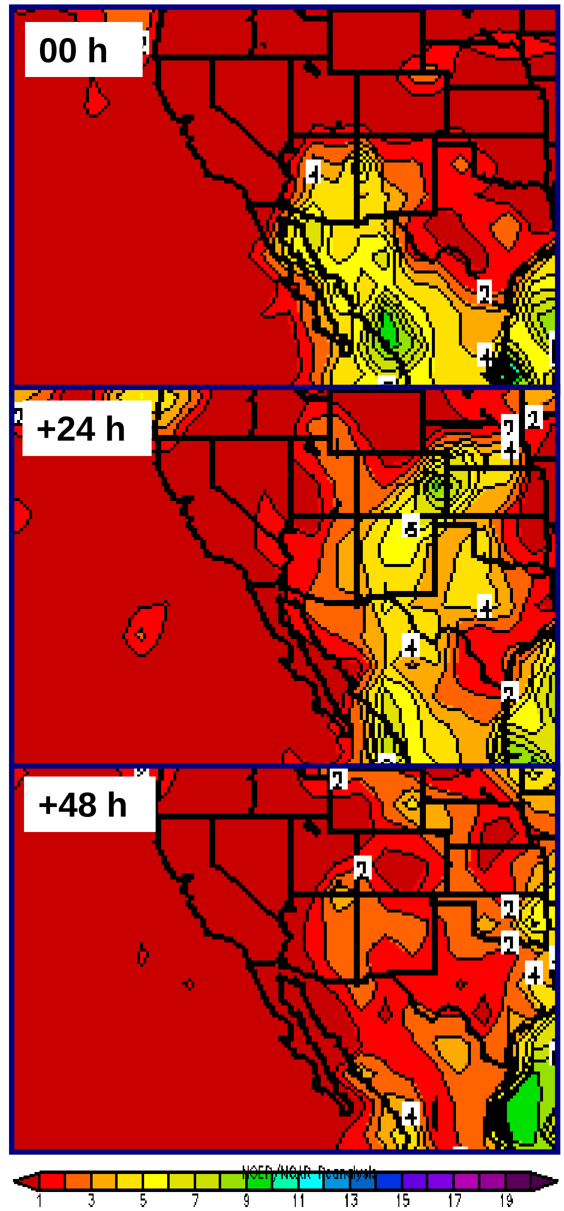

Figure 3: Composites of precipitation rate for the full trough interaction.

that will help discriminate this rainfall variability we begin by first dividing the cases into those that produce heavy rainfall in New Mexico compared with those that do not. The groups are then further subdivided based on the large-scale pattern, particularly in reference to whether a trough is present or not. The behavior of these systems varies considerably depending on the timing, location, and amount of interaction between the TC remnants and upper-level trough. These divisions are subjective and open to some interpretation. We intend to apply some statistical methods to more robustly separate the patterns.

In all, five characteristic patterns are subjectively identified based on the large-scale pattern. These include: full trough interaction; partial trough interaction; missed trough interaction; and no trough present. The full trough interaction is further divided into a “trough interaction and a cutoff low interaction.

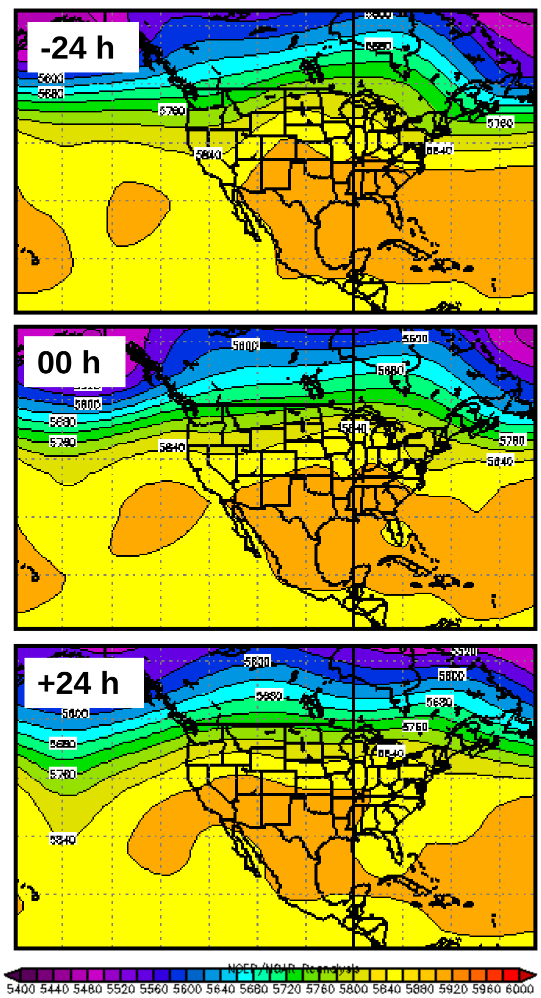

Figure 4: Composites of 500-mb geopotential height analyses for the partial trough interaction. The 00 time is based on the time of maximum 24-h rainfall recorded at KABQ.

5.1 Full trough interaction

As the name implies, the “full trough interaction” involves an interaction between the TC remnants and a midlatitude trough in which the TC is completely absorbed into the trough (Fig. 2). These systems tend to be highly mobile, and move through the southwest region rapidly, bringing brief, but heavy rainfall (Fig. 3) in a long elongated meridionally-oriented strip similar to that expected out of a well developed midlatitude trough. These systems tend to be more likely to bring rain to the eastern portions of the southwest region, New Mexico and into Texas, but they are notoriously hard to predict as the location of rainfall is critically dependent on the track and amount of moisture carried from the Pacific Ocean.

This category has 14 members from 1992-2004. Average rainfall at the Sunport over this data set was 0.66 inches. This set is subdivided into two equal-member categories: trough (0.84 inches/storm) and cutoff low (0.5 inches/storm).

5.2 Partial Interaction

The partial interaction category resembles the full trough composite described above. The main difference is that generally the trough is already moving north and east past the TC when the TC gets close enough to be affected by the trough Thus, the TC makes a connection with the trough through the outflow layer for a short period before the trough moves too far east. There are 6 cases identified in this category with an average rainfall at the Sunport of 0.13 inches /storm.

Figure 4 shows the 500-mb height analyses for this case. The trough of interest has already moved onto the coast at -24 h. A ridge can be seen building west from the mainland over the eastern Pacific. This combined with the high mobility of the trough results in a splitting away of the TC. Often, just low-level remnant of the TC can be observed still spinning in the eastern Pacific in visible satellite imagery.

5.3 Missed Interaction

The missed interaction category resembles the partial trough composite described above. The main difference is that, in general, the trough has already moved east of the TC when the TC gets close enough to be affected by the trough

Thus, although there was potential for an interaction to occur, no interaction does occur between the TC and the trough because the phasing is off. This case is difficult to forecast because of the inherent uncertainty in the phasing of the two systems. There are 5 cases in this category and they bring, on average, 0.01 inches of rainfall per storm at the Sunport.

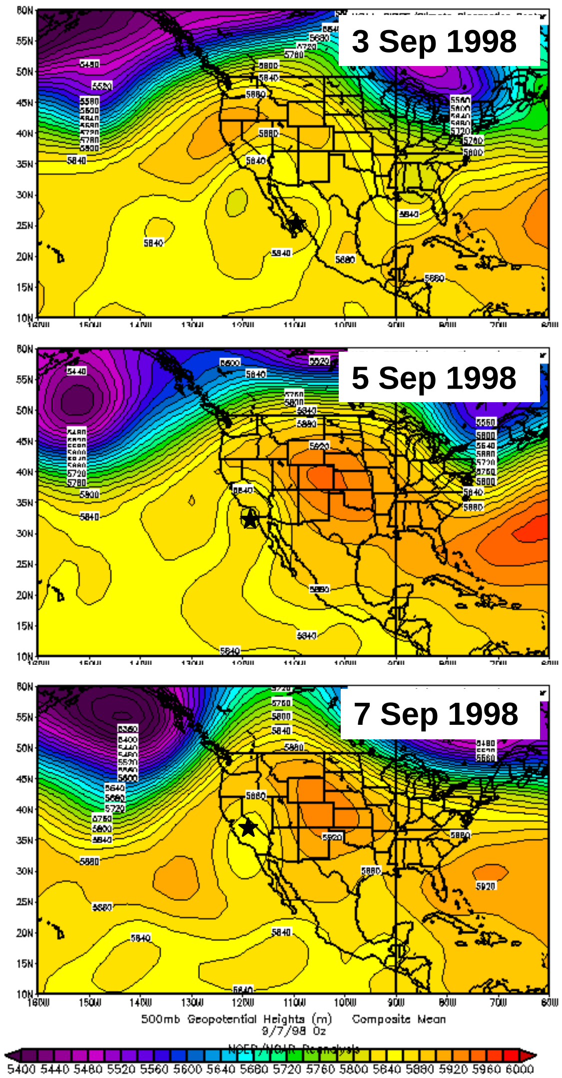

Figure 5: 500-mb geopotential height analyses for Hurricane Isis (1998). The approximate location of Isis is indicated with the solid black star.

5.4 No Trough

As the name implies, the "no trough interaction" category involves a midlatitude circulation pattern in which there is no trough that can be identified as having any chance of interacting with the TC. The tropical cyclone is clearly moving into a ridge pattern (e.g., Fig. 5). There are 8 cases in this category with an average rainfall at the Sunport of 0.14 inches /storm. Six of the cases produced less than 0.1 inch.

This category is best described by a single case study because of the extreme variability in these cases. The majority of these cases propagate north into California and Arizona where most of the associated rainfall occurs. It is very rare (two cases) that these cases influence New Mexico. These TCs move very slowly and in some cases can become quite large (in terms of their cloud coverage). Thus, rainfall can be very widespread and continue for long periods of time

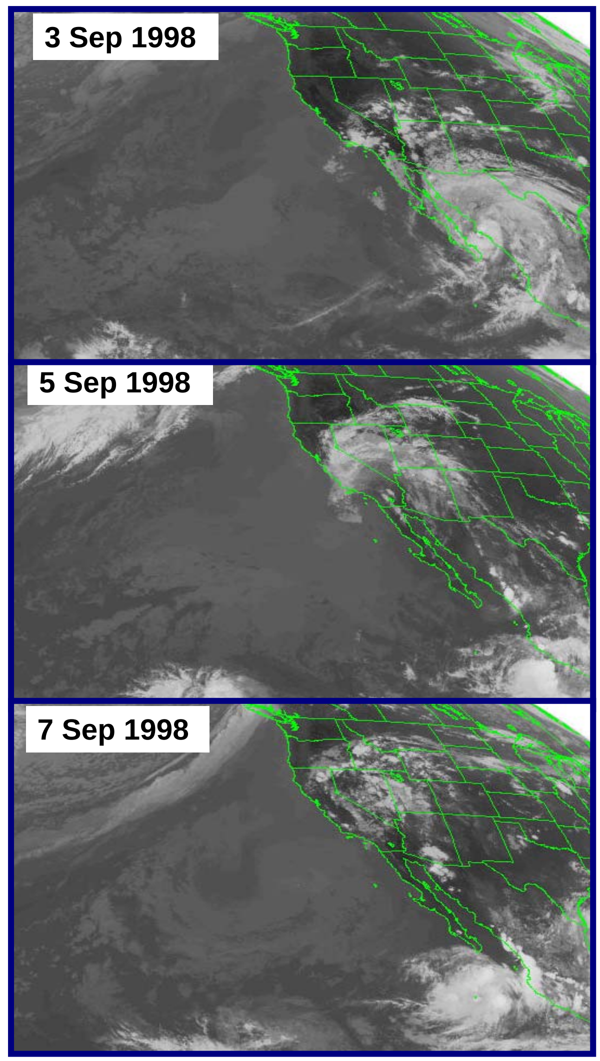

Figure 6: GOES IR imagery for the times corresponding to Figure 5.

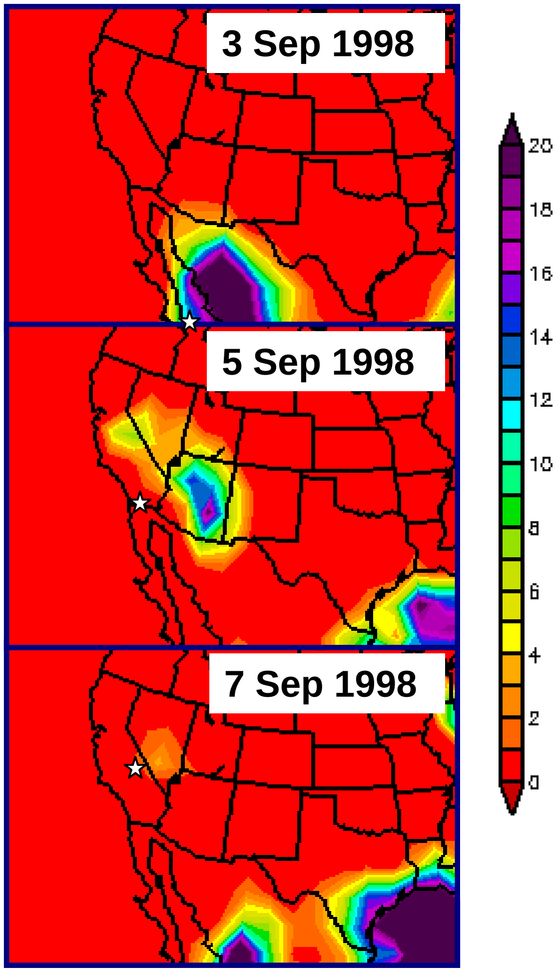

Figure 7: Precipitation rate analyses for Hurricane Isis (1998). The approximate location of Isis is indicated with the solid white star.

in these cases. The profiled case is Hurricane Isis from 1998 (Figure 5).

Hurricane Isis developed in the deep tropics and moved up the Baja Peninsula as a hurricane. With no penetrating trough in the midlatudes (Fig. 5), Isis propagated slowly up the Baja Peninsula and into Arizona and Southern California. NHC declared it dissipated at 0000 UTC 4 September. The IR image sequence (Fig. 6) clearly shows the system with the broadened asymmetric cloud shield by 5 Sep typical of TCs moving to higher latitudes and interacting with colder temperatures. Even though there may be no low-level wind signature any more, these disturbances of tropical origin still carry a lot of moisture and may still have an upper-level dynamic and temperature structure that resembles the upper-levels of a tropical cyclone. Within 24 h of Fig. 6c, the system is finally swept up into a fast moving midlatitude trough (Fig. 5c) and moved out of the area.

The rainfall maps highlight the differences with this category from the full trough interaction. Note the bulls eye of precipitation that follows the remnants of Isis up California and Arizona into Nevada (Fig. 7). Subsequent to this the system is whisked away by a fast moving upper-level trough.

6. DISCUSSION AND SUMMARY

Thirty-four eastern North Pacific tropical cyclone remnants that affected the rainfall in the southwest during 1992-2004 were investigated. On average 2.6 tropical cyclone remnants impact the weather in the southwest region. Preliminary results indicate that on average, one TC remnant from the Gulf of Mexico impacts the area every 2 years, typically New Mexico and western Texas.

The cases were investigated for common large-scale circulation and rainfall patterns. Four main patterns were identified: full trough interaction, partial trough interaction, missed trough, and no trough interaction. The patterns are characterized by the interaction the TC has with the midlatitude circulation. However, it is important to note that there are significant spatial differences in rainfall patterns and amounts associated with some of these types. For example, the full trough interaction brings the most rain to New Mexico, but is more likely to miss California and Arizona. The no trough scenario typically brings rains to California and Arizona, which can be heavy and of long duration, but misses New Mexico.

Future work includes increasing the data set. Currently 1988-1991 are being added from the eastern Pacific, and cases from the Gulf of Mexico are also being added. Future research includes investigating the individual cases along with their composite patterns for information that will help improve quantitative precipitation forecasts associated with these systems.

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