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THE IMPACT OF THE EL NINO SOUTHERN OSCILLATION ON THE COASTAL REGIONS OF THE EASTERN PACIFIC WITH AN EMPHASIS ON THE 1997-1998 CALIFORNIA RAINFALL PATTERNS

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1. INTRODUCTION

The El Nino Southern Oscillation (ENSO) is a perturbation of the ocean-atmosphere system in the South Pacific, which has significant consequences for weather all over the world. Among these consequences are heavy rainfall and destructive flooding along the Eastern Pacific coastline and drought in the Western Pacific regions. Under normal, non-ENSO conditions, the atmosphere and ocean in Western Pacific are in a state in which a number of physical conditions are observed. These are normally characterized by: atmospheric pressure distribution, wind flow patterns, ocean currents and ocean temperatures. Specifically the atmospheric pressure observations show that during non-ENSO conditions, lower pressures are found over the Western Pacific and higher pressures are found over the South Eastern Pacific. The Southern Oscillation Index (SOI) is a measure of this pressure differential and takes into account the pressure difference between Darwin, Australia and Tahiti. (www.elnino.noaa.gov/researc.html) The trade winds, which are a result of the pressure difference, blow from the eastern to the western Pacific between the latitudes of 10-25^{o} north and south of the equator. These winds gather warm surface water in the west so that the sea surface is about one half of a meter higher in the Indonesian region than it is at Ecuador. The sea surface temperature is also higher in the west by about eight degrees Centigrade (^{o}C) and cooler temperatures along the South American coast due to an upwelling of cold water from deeper levels in the Eastern Pacific. This cold water is nutrient rich, supporting high levels of primary

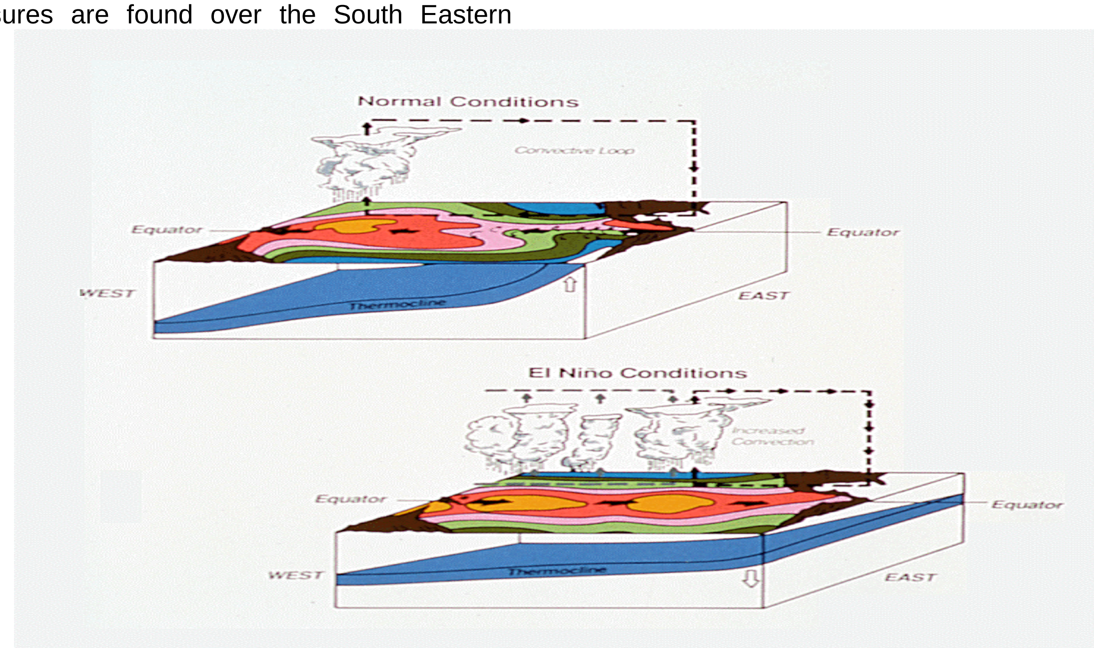

Figure 1. This image is a schematic cross sections of the Pacific Ocean under normal conditions (top) and ENSO conditions (bottom). Shown are the SST patterns with orange corresponding for SSTs greater than 29^{o}C and with a 1^{o}C contour interval. The thermocline is visible in blue and the change in tropical atmospheric convection is shown in the form of organized thunderstorm activity. (www.ucar.edu/publications/lasers/elnino/Figure_4.html)

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productivity, diverse marine systems and major fisheries. During an ENSO event, the SOI shows a reversal in the pressure differential between Darwin and Tahiti. This reversal across the tropics causes the trade winds to relax in the central and western Pacific leading to a depression of the thermocline in the eastern Pacific, and an elevation of the in the west, as depicted in figure 1. This depression in the east reduces the upwelling and cooling of the ocean surface off the coast of South America resulting in the reduction of the supply of nutrient rich water to the euphotic (sunlight) zone. This manifests itself in a drastic decline in the productivity of commercial fishing in the region. In addition, weather patterns in the tropical region shift eastward, resulting in increased rainfall over the migrating warmer seas. The eastward displacement of the heat source results in large changes in the global atmosphere circulations, which in turn force change in regions far removed from the tropical Pacific.

2. RESEARCH

Observations of condition in the Tropical Pacific are considered essential for the prediction of short-term climate variations. To provide necessary data, the National Oceanic and Atmospheric Administration (NOAA) operates a network of buoys, which measure temperature, currents and winds in the equatorial band. Figure 2 shows a comparison of SSTs over a number of ENSO episodes. The data was taken using this network. In addition, to predict ENSO episodes, scientists study data gathered from past episodes in an attempt to establish common behaviors. This is a particularly difficult task as each past ENSO event shows a great variation in initiation and duration. However, researchers have found that precipitation and temperature anomalies appear consistent between episodes.
(www.pmel.noaa.gov/toga-tao/el-nino-story.html)

A common trait of ENSO is the disruption of normal tropical rain patterns, which are caused by the disruption in the tropical atmospheric circulation. For example, the jet streams in the subtropics are much strong during and ENSO episode than they are during normal years. Along with the stronger jet, extra-tropical storms and frontal systems follow paths that are substantially different from non-ENSO patterns the result being temperature and precipitation variations in many regions of the world.

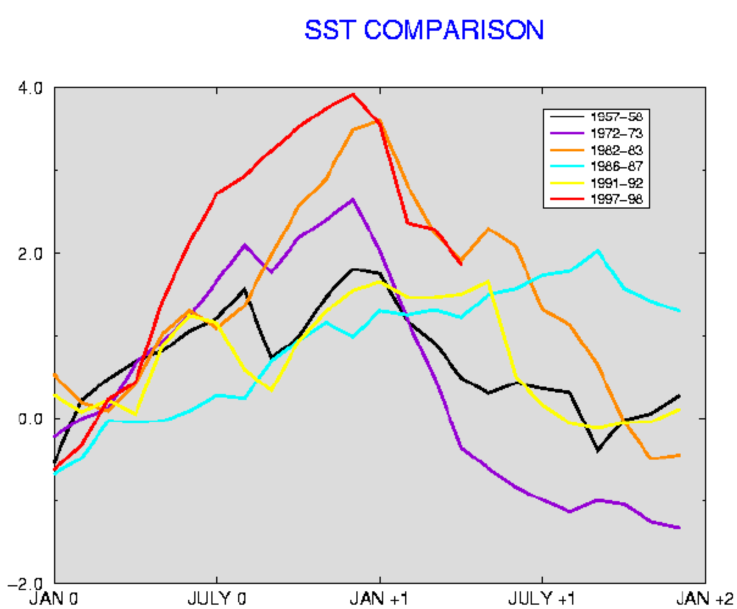

Figure 2. This is a graph of SST anomalies for the eastern tropical Pacific region for six strong ENSO events. This data seems to suggest that the 97-98 episode may have been the strongest of the last century, however data was not efficiently acquired prior to the 1980's. Thus many feel it is not known if the 97-98 episode was indeed the strongest. (www.twister.sfsu.edu/elnino/Graphics/spr98.n3.gif)

By studying past episodes, researchers have found that mid-latitude low pressure systems become more vigorous, drawing abnormally warm air into Alaska, Western Canada and the northernmost portion of Western United States. (Cayan 1999) It was also noticed that storms are more active along the coast of Southern California. This results in increased precipitation than statistically normal in these regions.

One of the most comprehensive recent studies of ENSO conditions occurred as a result of the Tropical Ocean-Global Atmosphere (TOGA) program. (www.ogp.noaa.gov/enso/ toga.html) Over its ten-year lifetime (1985-1995) TOGA made major strides toward understanding the ENSO phenomenon. In particular, TOGA demonstrated the feasibility of operational seasonal to interannual climate prediction of equatorial Pacific SST anomalies. Based on numerical models that simulate in a rudimentary manner, the physics of the coupled tropical ocean-atmosphere system, clarified the nature of the planetary-scale atmospheric response to the anomalies.

In order to predict an ENSO episode, scientists are constantly following the weather patterns around the world. At the first sign of a disturbance, they focus their attention at that point to monitor whether an anomaly with develop or not. ENSO is one of the most important coupled ocean-atmosphere phenomena to cause global climate variability on interannual time scales. Attempts to monitor ENSO are based on the Multivariate ENSO Index (MEI). (Ralph 2003) This index is derived from six variables observed over the tropical Pacific. These variables are: sea level pressure, zonal and meridional components of the surface wind, SSTs, surface air temperatures and total cloudiness fraction of the sky. Figure 3 shows a comparison of the MEI for six strong ENSO events.

These observations have been collected and published in Comprehensive Ocean-Atmosphere Data Sets (COADS) for many years. The MEI is computed separately for each of twelve sliding bi-monthly seasons (Dec./Jan, Jan./Feb., etc). After filtering the individual variables into clusters, the MEI is calculated as the first unrotated principle component (PC) of all six observed fields combined. This is accomplished by normalizing the total variance of each field first then extracting the first PC of the combined fields. In order to keep the MEI comparable, all seasons are standardized with respect to each reference period. The MEI is extended into the first week of the following month based on near-real time marine ship and buoy observations. (Ralph 2003) As an ENSO develops, it perturbs marine life in the Pacific and influences weather patterns throughout the world

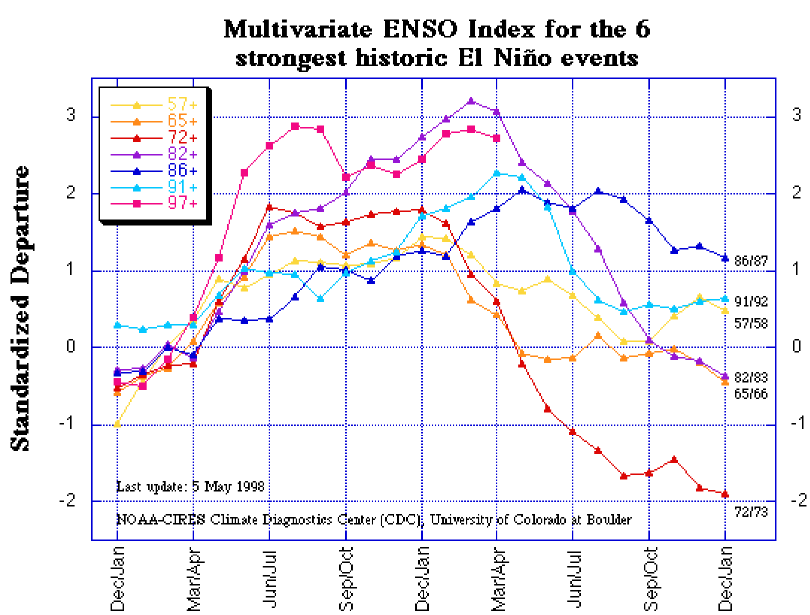

Figure 3. The MEI is a measure of the probability of ENSO conditions arising in the tropical Pacific, the more positive the index, the greater the likelihood of El Nino conditions. (www.twister.sfsu.edu/elnino/Graphics/comp.gif)

The variation in atmospheric and oceanic conditions during El Nino effect human beings in a big way such that researchers now take our understanding of El Nino a step further by incorporating the descriptions of these events into numerical prediction models. The data describing the present state of the ocean-atmosphere system is input into numerical models which run through the data and present possible outcomes of how the system might evolve over the next few years. The results thus far give a better indication of the climatic conditions that may prevail.

3. IMPACT

3.1 SOUTH AMERICA

Peru is a prime example of how even short term ENSO forecasts are valuable. In Peru, as in many developing countries in the tropics, the economy is highly sensitive to water and climate fluctuations. Warm years tend to be unfavorable for fishing, but good for farming as these years generally have a lot of rain. However strong ENSO years have also been marked by damaging floods along the coastal plains. Cold years are welcomed by fishermen but not by farmers, as these years do not have enough rain to sustain their crops. Such cold years often come on the heels of strong ENSO years. Hence, Peruvians have reason to be concerned not only about El Nino years but also about the extreme weather events that take place with in the full cycle. (Smith 1999)

Since 1982, forecasts of the upcoming rainy season have been issued each November based on observations of winds and water temperatures in the tropical Pacific and the output of numerical models. The forecasts are presented in terms of four possibilities: near normal conditions, weak ENSO, strong ENSO with flooding or cooler season with higher chances of drought. Once this forecast is issued farming and fishing representatives often meet with government officials in order to determine the appropriate combination of fishing and crops to sow in order to maximize the overall yield. Hence a forecast of an ENSO episode might induce the population to focus on farming more than fishing and for farmers to sow crops that thrive in wet regions instead of others that do better in dry regions.

Countries that have taken similar initiatives include Australia, Brazil, Ethiopia and India. Although tropical countries have the most of gain from successful ENSO predictions, for many countries outside of the tropics more accurate predictions would also benefit strategic planning in areas like agriculture, management of water resources and reserves of grain and fuel. (www.elnino.noaa.gov/researc.html)

Encouraged by the progress over the past couple of decades, researchers and governments in many countries are working together to design and build a global system for (1) observing the tropical oceans on a constant basis, (2) predicting ENSO and other irregularities and (3) making routine forecasts available to those who have need for planning purposes. This is analogous to how daily forecasts are available for the general public in order to plan for the day's weather. The ability to anticipate how much the climate will change from one year to the next will lead to better management of agriculture, water supplies, fishing and other resources.

3.2 NORTH AMERICA

The North Pacific wintertime atmospheric circulation is known to respond to the variations in the tropical Pacific atmosphere-ocean climate system, especially to ENSO. Past research on the impacts of ENSO on the extratropics has focused mostly on seasonal mean phenomena, such as geopotential height anomalies, shifts in mid-latitude storm tracks, and their impacts on precipitation and surface temperature. The ability to anticipate these impacts provides much, if not most, of our present skill in seasonal weather prediction over many parts of the world. By comparison, the influence of ENSO on the life cycles of individual extratropical baroclinic disturbances and their

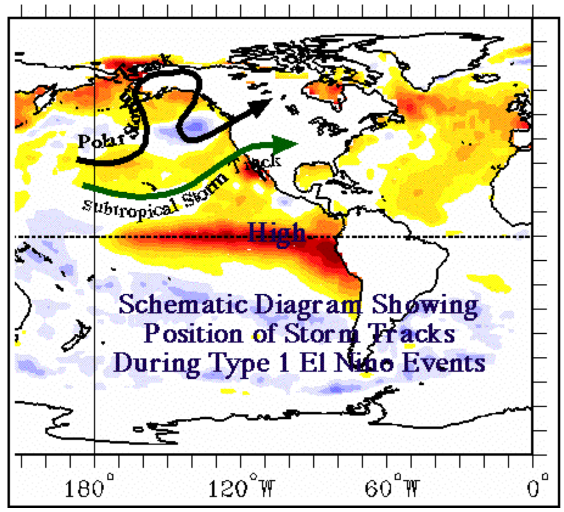

Figure 4. Typical storm tracks superimposed on an SST map. (www.pmel.noaa.gov/toga-tao/el-nino-story.html)

fronts and precipitation has received less attention.

During an ENSO episode, a much stronger than normal sub-tropical jet stream extends across the Pacific Ocean and across the southern continental US (CONUS). Figure 4 shows merging storm tracks which generally happen during ENSOs with strong SST anomalies, much like the event that took place in 1995. (Masutani 1999) This subtropical jet initiates weather systems across the southern tier of states bringing with it tropical moisture. As a result rainfall is more frequent in southern California, especially when the El Niño is very strong. (Mo 1999) Wetter than normal conditions also are likely across the Gulf Coast into Florida. Increased west winds associated with the subtropical jet inhibit the development of tropical storms in the Atlantic Ocean typically by enhancing shear profiles in that region of the tropics. Tropical storms that do form tend to curve to the north before reaching the mainland. The polar jet is also stronger than normal resulting from a warm mid-troposphere in the central to eastern Pacific. The latent heating causes positive height anomalies in the Pacific which teleconnects to somewhat persistent trough formation further to the east. The extent of this trough formation across the CONUS is less well-correlated due to factors in the northern Atlantic. If the ridge extends to the Pacific Northwest, drier conditions may result. Across the rest of the U.S., the jet stream is stronger than normal, but generally zonal and often variable.

The strong zonal polar jet keeps the coldest air in place over Canada most of the time which may result in temperatures across the northern Plains and the Great Lakes to be warmer than normal. These warm conditions often extend into the Northeast, although not always. Cold air which remains in Canada often builds, becoming even colder than usual. If this air is brought southward in transitory waves, cold outbreaks can still be significant in the CONUS. (Cayan 1999) The strong polar jet usually contains frequent storms but relatively weak. The strong subtropical jet prevents a northward surge of the warmest and most moist air in place across the Gulf Coast states. However, a few times during the winter the two strong jets merge (or phase). This typically results in the development of major winter storms. This all means that El Niño winters can still produce significant winter weather events just like non-El Niño winters.

The canonical pattern of warm phase winter precipitation anomalies over the continental U. S. has been evaluated by several authors. The occurrence of an increase in precipitation along the Gulf Coast has been noted. It was also found that the northwestern states that are generally drier and the coastline of central California have received increased precipitation. (Cayan 1999) Also composite winter anomalies reveal statistically significant increases in the median of the warm phase precipitation distribution occur along the Gulf Coast with local anomaly maxima in south Texas and Florida. In southern Canada, dry regions are shown to extend south of the border into the northern Rocky Mountain states and the Great Lakes region; however, only a few locations have a significant median shift towards less precipitation.

The pattern of precipitation anomalies during the winter of 1997 is similar to the Global Historical Climatology Network (GHCN) historical composite, with the notable exception of California. (Andrews 2004) In the GHCN composite, percent changes in precipitation over California are small, while the 97-W winter precipitation anomalies reveal that many stations in California received over 150% more

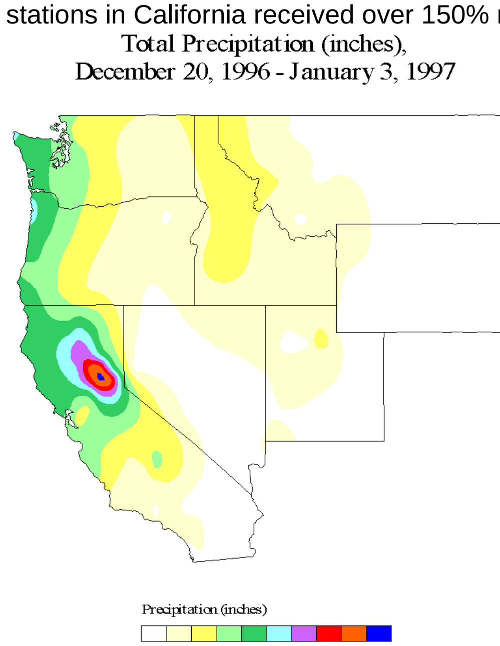

Figure 5. Map of precipitation over the western United States showing heavy rainfall in the Pacific Northwest. (www.tornado.sfsu.edu/geosciences/elnino/elnino.html#Flooding)

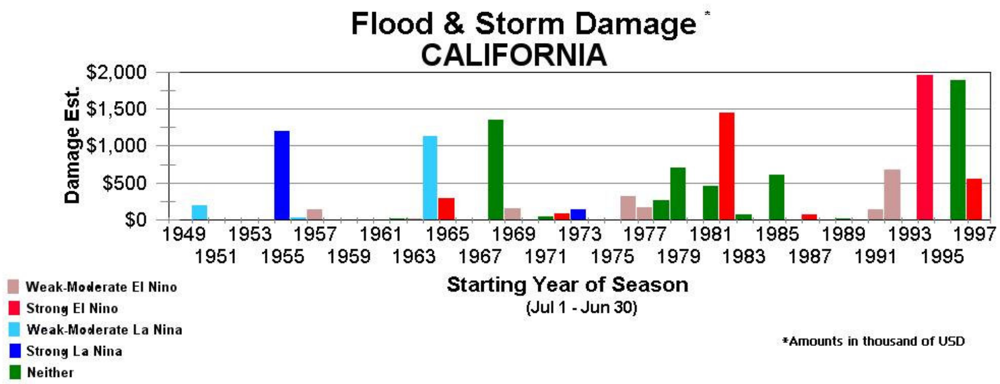

Figure 6. This figure shows estimated flood and storm damage in California over a number of ENSO years. (www.wdc.ndin.net/cali_flood.html)

precipitation than expected for a warm phase. The majority of this precipitation occurred in February 1998 when five stations in the Southwest received over a 300% increase in their monthly total precipitation. For the winter of 1997, most California precipitation totals are in the 95 percentile of both the warm and neutral phase distributions, and many had positive precipitation anomalies over California and Nevada rank as the largest of the past ten warm events. (Andrews 2004)

One explanation for the precipitation anomalies over California in the 1997 warm phase winter not agreeing with the GHCN composite is due to the highly variable nature of the onshore flow from event to event. During some warm phases, typically the strong events, onshore flow and heavy precipitation occur in California, while during other warm phases, the onshore flow occurs over the Baja Peninsula leaving California high and dry. The result is a GHCN composite with near zero anomalies over southern California. (Mo 2000) The location of the anomalous Pacific Ocean warm pool to variability in warm phase precipitation patterns over the eastern U. S., and it is likely that shifts in the warm pool position will also impact precipitation over California through modifications in the jet stream patterns.

The pattern of dry anomalies over the northern states and wet conditions along the West Coast during the winter of 1997 is similar to the historical norm. (Mo 1999) The heavy precipitation exceeds the composite warm phase conditions, with numerous stations having rainfall total in the 95th percentile of both the warm and neutral phase distributions. Rainfall totals for the winter of the 1997 exceeded those of nine historical warm event winters.

The decay of the warm phase and consequential precipitation anomalies typically occurs in the boreal spring. Precipitation anomaly patterns for the spring to include a continuation of winter's dry anomalies in northwestern states and above-neutral precipitation along the West Coast. The GHCN spring composite anomalies agree with the previous findings; however analysis shows the largest percent changes in precipitation occurring over the Southwest. Statistically significant decreases in the median of the spring warm phase precipitation are concentrated over the Pacific Northwest, while significant shifts towards increased precipitation are scattered across the lower 48 states. (Masutani 1999) The precipitation anomaly patterns during spring 1998 are markedly different from the historical spring composite. In fact, seven Pacific Northwest stations received more precipitation in 1998 than occurred in the other nine warm phases. These anomalous wet conditions are likely a northward extension of the above-neutral precipitation found in California during the winter. (Smith 1999) The winter wet conditions over California continued in the spring of 1998.

Air temperatures during an ENSO winter are found to be warmer than neutral phase conditions over the northwest and north-central U. S., while the Southwest and portions of the Southeast tend to have cold anomalies. The winter anomalies reveal a similar pattern with the warm anomalies concentrated over Montana and the northern Plains. Significant differences in the GHCN warm and neutral phase means occur across the western states. In the spring, the temperature anomalies show a continuation of warmer than neutral temperatures over the northern states; however, the anomalies are weaker in magnitude and extend further east than during the previous season. (Smith 1999) Much like in the winter of 1997, the core of the warming that occurred in the spring of 1998 was over the Northwest. Historical warm phase patterns identify a region of cooler than neutral spring temperature anomalies over much of Texas and the Four Corners state.

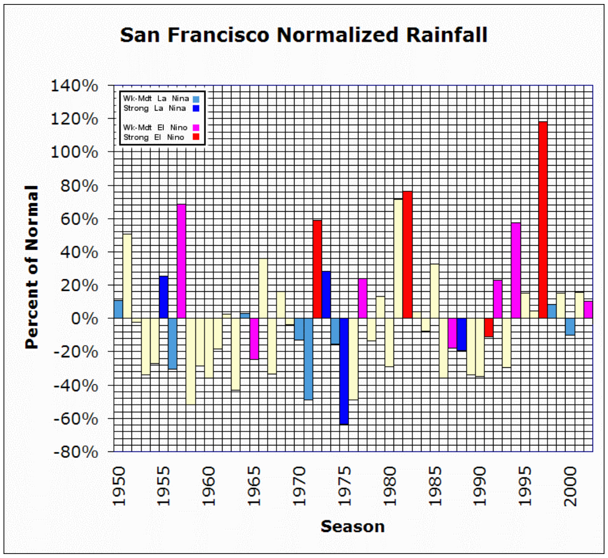

Figure 7. This is a normalized distribution of rainfall in San Francisco. Positive values are associated with ENSO years. (www.cpc.ncep.noaa.gov/products/analysis_monitring/impacts/enso.html)

4. CONCLUSION

Many issues remain to be addressed and much work needs to be done to optimize forecasts. In some cases the model's physics need refining, in others the parameters are not optimal. However research on ENSO events has improved greatly over the last couple of decades and the impact of this has helped countries better prepare for the extreme weather that comes with these anomalies. El Nino brings unexpected global effects, which include meteorological and oceanographical impacts. Many ENSO conditions can destroy lives and economics of many tropical countries. With each event comes changing weather systems and often times catastrophes associated with flooding. While it has yet to be determined what causes this phenomenon, researchers are determined to pull together all the data and various pieces that make up an ENSO event. Since the 1982-1983 event, great progress has been made in trying to understand it. Technological devices and forecasting agencies developed quickly over the last 20 years or so, and although no two El Nino is exactly alike, they share many similarities that provide precautionary indications that an event is eminent. When researchers are finally able to fully observe and predict El Nino, countries around the world will be able to take precautionary measures to reduce the social and economic impacts.

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