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EL NIÑO: IS IT JUST A BUNCH OF HOT WATER?

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Introduction

For centuries, fishermen off the coast of South America noticed that periodically, the normally cool waters where they fished became unusually warm. The appearance of this unusually warm water typically occurred near the end of the year, around Christmas time. These fishermen called the phenomenon El Niño, with means *The Little One* (or Christ child) in Spanish. This warmer water replaced the normally cool water, causing the fish that the fishermen depended on to die or migrate northward, and also brought with it torrential rains which fell on the normally arid land.

This phenomenon, at one time thought to affect only the ocean along the narrow strip of water near the coast of Peru, is now recognized as a large-scale oceanic warming that affects most of the tropical Pacific. The meteorological effects of El Niño extend far beyond the Pacific Ocean, with its impacts being felt around the globe in the form of deviations from typical weather patterns. Some normally arid regions become abnormally wet, while other areas, which typically have reliable and abundant rainfall, experience drought.

So how does the atmosphere, especially those portions thousands of kilometers away from the eastern Pacific Ocean, know about the warming of these waters during an El Niño event? What causes the El Niño phenomenon? How is it related to the Southern Oscillation? How often do they occur? What effects does El Niño have on the world's weather pattern? This Technical Attachment will address these questions, while also investigating the role that El Niño plays in the western United States.

The Development of El Niño

Normal Conditions

During normal, or non-El Niño years, the winds at the surface of the Pacific Ocean near the equator blow from the northeast and the southeast, converging and then moving westward. These winds are called the tradewinds because they blow so regularly that trade ships could depend on them to transport their cargo across the ocean.

These tradewinds drive the ocean currents, causing a flow of surface water in the same direction, from east to west, along the equatorial regions of the Pacific Ocean. As the water is transported to the west, it is warmed daily by solar energy. Thus, the movement of the near surface ocean water by the wind causes warm surface water to build up across the western Pacific. This upper layer, consisting of the sun-warmed water, is fairly well mixed due to the tradewinds, and is known as the mixed layer. The region which separates the warmer water of the mixed layer from the colder deep ocean water is called the thermocline.

The warm water buildup and the strong surface winds over the western tropical Pacific create a thermocline of approximately 100 meters or more in depth below the surface. Additionally, due to the transport of water to the west, sea levels across the western Pacific are on the order of a half meter higher then across the eastern Pacific Ocean. Meanwhile, over the eastern Pacific, a process known as upwelling is occurring near the coast of South America. Since the winds are blowing predominately from the east and essentially 'pushing' the surface water to the west, cold deep ocean waters move upward, or upwell, off the coast of South America to replace the water which is being driven westward. This produces a shallow thermocline of approximately 10-50 meters deep throughout this region. These upwelled waters are rich in nutrients and produce some of the most productive fishing waters in the world.

In the warmer waters of the western Pacific, the warm surface waters and the strong tradewinds cause large amounts of water to evaporate from the surface of the ocean. The evaporation of the warm, moist air causes the air to rise and create an area of atmospheric low pressure near the surface. This low pressure system is known as the Indonesian Low. The rising air leads to the formation of intense thunderstorms, ultimately producing heavy rainfall over the western Pacific convergence zone. Since air is rising across the western Pacific through these large clusters of thunderstorms, and mass must be conserved because of the laws of physics, this rising air must sink someplace. Just as in the ocean, through the process of upwelling, a circulation develops in the atmosphere which allows for air to rise in the western Pacific, and sink over the eastern Pacific. This sinking air is stable and creates an atmospheric high pressure system over the eastern Pacific. This also inhibits the development of clouds and thunderstorms, leading to the arid climates seen across western South America. Due to the difference in atmospheric surface pressure between the east and the western portions of the Pacific Ocean, the wind will naturally blow from high pressure to low pressure, or from east to west, which continues to keep the tradewinds blowing. As the wind blows westward, it picks up moisture from the evaporating and warming oceans, allowing for the redevelopment of thunderstorms over the western Pacific. This pattern of air movement from east to west along the surface and from west to east aloft is known as the Walker Cell circulation and represents the east-west component of the large-scale tropical circulation pattern (Fig. 1). In this circulation pattern, the atmosphere drives the ocean and the ocean drives the atmosphere in a truly coupled mode of behavior.

El Niño Conditions

During El Niño conditions, this Walker Cell circulation breaks down. The pressure difference between the eastern and western Pacific begins to diminish and as the gradient relaxes, so do the trade winds. This creates less convergence and less transport of surface water westward, allowing for less thunderstorms in the western Pacific, which weakens the Walker Cell circulation even more. Eventually, the ocean-atmosphere coupled system reaches a critical point, and the warm water, which is at a higher elevation than the cool water near South America, begins to move eastward in a wave of warm water. As the tradewinds decrease, so does the upwelling along the South American coast, allowing for water there to begin to warm through solar insolation. This drives the thermocline downward, cutting off the return of cooler, nutrient rich waters from below, which disrupts the fishing and local economy of the area. As can be seen, this develops into a feedback loop, where the pressure gradient continues to decrease, further weakening the tradewinds. This allows for less upwelling, allowing the ocean to warm more, creating even less of a pressure gradient. As all of this goes on, the slow wave of warm water from the western Pacific continues to move to the east. As the warm water moves into the central and eastern Pacific, the thunderstorms associated with this warm pool follow as well. This shifts the circulation to one where the rising motion is in the central and eastern Pacific, and the air is forced to sink over the western Pacific and eastern portions of South America (Fig. 2).

The atmospheric response to El Niño is called the Southern Oscillation. The Southern Oscillation was discovered by Sir Albert Walker (namesake of the Walker Circulation cell) in the 1930s. What he found was an inverse relationship between surface pressure at two sites: Darwin, Australia, and the South Pacific island of Tahiti. High pressure at one site was almost always concurrent with lower pressure at the other, and vice versa. The pressure pattern was found to reverse itself every few years, hence the term Southern Oscillation. Jacob Bjerknes in 1969 extended Walker's findings into the vertical portion of the atmosphere, ultimately discovering the broad east-west tropical circulation cell, which he called the Walker Circulation cell in honor of Sir Albert. This reversal of surface pressure was due to El Niño, which is why the complete coupled phenomenon is now formally called El Niño /Southern Oscillation, or ENSO. Although the Southern Oscillation and the El Niño are closely related, an El Niño may occur independently or at the same time as a Southern Oscillation. When the two coincide, however, the result is a large global atmospheric and oceanic event.

ENSO is a periodic, yet highly variable, phenomenon, occurring every two to seven years. Sometimes the warm waters generated by an El Niño flow all the way across the Pacific. The 1982-83 event increased surface water temperatures near Peru by up to 4 degrees C (7 degrees F). In the much weaker event of 1986-87, the warm water flowed eastward only as far as the mid-Pacific (near 170 degrees W) and raised the temperatures there a modest 1 degree C (1.8 degrees F). In still other cases, warm anomalies first appear off the coast of Peru and then progress westward to meet the preexisting warm pool which is moving eastward. A typical ENSO event lasts for 14-22 months, ending when there is no longer enough warm water to sustain the cycle, and conditions return to normal.

So why does ENSO occur? Scientists have yet to answer this question completely, but the most popular theory is that the time scale for ENSO is linked to the width of the Pacific Ocean, and the time it takes for 'information' to propagate across the Pacific. This 'information' is in the form of non-uniform heating, pressure gradients, and the variability of the tradewinds. Most current theories of ENSO involve planetary-scale equatorial waves. The time it takes these waves to cross the Pacific is one of the factors that sets the time scale and amplitude of the ENSO event. The Pacific Ocean tries to respond on an annual time scale (with the solar cycle), but it can't because it's too wide. The narrower width of ocean basins, like the Atlantic and the Indian Ocean, means that these large-scale waves can cross those basins in less time, so that the ocean can adjust more quickly to the 'information' that it receives. Conversely, wind variations in the Pacific Ocean excite waves that take a long time to cross the basin, so that the Pacific Ocean adjusts to wind variations more slowly. This slower adjustment time allows the ocean-atmosphere system to drift further from equilibrium than in the narrower ocean basins, with the end result that ENSO events are needed to return the system to equilibrium.

The Effects of ENSO on Global Weather Patterns

If the normal non-ENSO atmosphere is thought of as a river, containing locations where the fluid is flowing fast, like water around rocks, then the ENSO-affected atmosphere can be thought of as that same fluid, with a few more large rocks placed in it. These 'rocks' have the effect of changing the location and size of the resulting fast flow, or jet streams, establishing patterns of weather that differ from the 'norm'. The large area of warm water in the Pacific, typically restrained to be in the western portion, acts as a large heat source for the atmosphere, creating jet streams and storm tracks which occur in a certain pattern and distribution on average. When this large area of warm water is allowed to spread out throughout the Pacific, until it is the size of the United States, or larger, the jet streams and storm tracks are altered in ways that are not explicitly forecastable. Thus, the information that the eastern Pacific Ocean is a few degrees warmer than normal is quickly relayed to the atmosphere, by the development of new pressure patterns which quickly affect the weather upstream and downstream from the eastern Pacific Ocean, until the entire global weather pattern is affected. In other words, the eastward displacement of the atmospheric heat source overlaying the warmest water results in large changes in the global atmospheric circulation, which in turn forces changes in weather in regions far removed from the tropical Pacific.

Thus, ENSO tends to create global atmospheric circulations which alter the normal course of the day-to-day storms which would occur with or without ENSO. When composite studies are done, looking at global patterns which have occurred during other ENSO events in the past, some features which are similar throughout many ENSO events can be found. These features, or teleconnections, are links between the equatorial and high latitudes via quasi-permanent features such as low and high pressure cells, causing those characteristics which we attribute to ENSO, such as drought or flood. Changes in statistical properties of storms (for example, their frequency, strength, origin, and tracks) account for the bulk of ENSO's signal in precipitation and surface temperature at higher latitudes. Since each El Niño event has a unique signature in its sea surface temperature lifecycle, each ENSO event has a unique, and at the present, unforecastable effect on the day-to-day weather pattern.

Even with this uniqueness, some teleconnections have been discovered which generally hold true for most ENSO events. Figure 3 shows some of these statistical correlations in terms of significantly wetter, drier, or warmer correlations with major ENSO events. Among these teleconnections are droughts in Central America, Phillippines, Indonesia, Africa, and Australia. Large-scale brush fires and forest fires are often associated with these droughts as well. Heavy rainfall and flooding becomes more prevalent in the southeastern United States, Cuba, portions of western and southern South America, and in portions of west-central Africa. During the current ENSO event, the village of Pringluan, along the central coast of Java, has been left without water as Indonesia's worst drought in the last 50 years takes hold. Wildfires are burning unchecked over many portions of the country. Meanwhile Chile, which is normally one of the worlds most arid areas, is being drenched with waves of heavy rainstorms. Floods and landslides have caused five countries in Latin America to declare national emergencies due to the devastation.

ENSO also affects the number of tropical storms which develop during a given year. During ENSO events, there are typically an increased number of tropical storms and hurricanes in the eastern Pacific and a decrease in the Gulf of Mexico and the Atlantic Ocean. This has been true with the current ENSO event.

ENSO Effects Over the Western Region

As mentioned above, even though every ENSO event is unique, teleconnections have been found which tend to hold true for many of the major ENSO events of the past. It has been found that the ENSO teleconnections found in the United States are most clearly seen in the winter season. Intense rainfalls have been recorded in the western United States during ENSO events, while portions of the northern tier of states tend to enjoy well above normal temperatures and drier winters. In addition, the occurrence of tropical systems impacting the Western Region during the fall months of an ENSO event tend to increase as well. This has already been the case this year. Perhaps of most importance for the Western Region, however, is the additional water vapor which becomes available to storm systems over the eastern Pacific during ENSO events. For example, this fall, the Microwave Limb Satellite Sounder is detecting an unusually large build-up of water vapor in the atmosphere at heights of approximately eight miles (12 kilometers) over the central-eastern tropical Pacific. This amount of water vapor hasn't been seen since the last strong ENSO winter of 1991-92. As storm systems move eastward from the central Pacific, this water vapor may become available to allow extra tropical moisture to become entrained into these systems for potentially heavier rainfalls.

However, every ENSO event is unique, and there are clear exceptions to these teleconnections which have occurred in the past, and will occur in future ENSO events. Thus, it is unwise to say conclusively that any particular ENSO event will create these particular signals, but rather, these signals are only preferred, and any particular ENSO event may differ significantly from it. The bottom line is that we still do not know what a particular ENSO event will do, until that event is over. We can only say that there is a good probability of a particular signal being felt during an ENSO event, based on past events.

Figures 4-9 show deviations in temperature and precipitation which have been recorded during previous ENSO events. NDJ represents the November through January period of time, JFM represents the January through March period of time, and MAM represents the March through May period of time. As can be seen by the figures, the temperature signals show that typically ENSO events keep the northern sections of the Western Region warmer than normal, with this warmth spreading throughout the Western Region after January. In terms of precipitation, the southern sections of Western Region tend to be wettest during ENSO events, with the northern sections of the Western Region remaining drier than normal, especially in the JFM period. However, much of the variability of ENSO events, in terms of precipitation, lies in how far north the wet regime develops. Thus, in the areas of northern California, Nevada, and Utah, the signal is much less clear on what kind of ENSO event to expect. Therefore, it is clear from these figures that the further north or south one lives in Western Region, especially in the JFM period, the higher probability you have for these signals to verify, with the least amount of confidence throughout the central portion of the Western Region. Again, it is important to remember that these are probabilities, NOT actual forecasts.

Conclusions

Is El Niño just a lot of hot water? Clearly it is not. ENSO represents an excellent example of the interaction which occurs between the ocean and the atmosphere, and their combined effects on the global climate. The possible interrelationship between El Niño and global weather patterns, based on the simultaneous droughts in the Soviet Union, Africa, Australia, and Central America, was first realized in the 1972-73 ENSO event. However, based on climatological records, ENSO events have been occurring for centuries and are not related to anthropogenic activities. ENSO results in redistribution of rains over the globe, possibly allowing for the release of potential energy which is built up in the ocean-atmospheric system due to the vast width of the Pacific Ocean. Due to the unique nature of the distribution of sea surface temperatures during each particular El Niño event, each ENSO event is unique and individual, leading to errors in predictability. Thus, only probabilities of a particular signal, such as heavy rains, or warm winter temperatures can be made, as opposed to an exact forecast. Since ENSO is still a relatively new concept, the exact reasons for its development and demise are still not clearly known. Improvements in tropical-ocean observations will help to advance research on ENSO events. This 1997-98 event will be the most observed global event ever recorded in history. The future of current research, based on data which will be gathered over the next year, points to the day when ENSO events will be much more reliably predicted with months of advanced notice. Since ENSO is a naturally occurring event, we cannot hope to control it, but rather, we can hope to understand the process and forecast its development and its impacts across the globe.

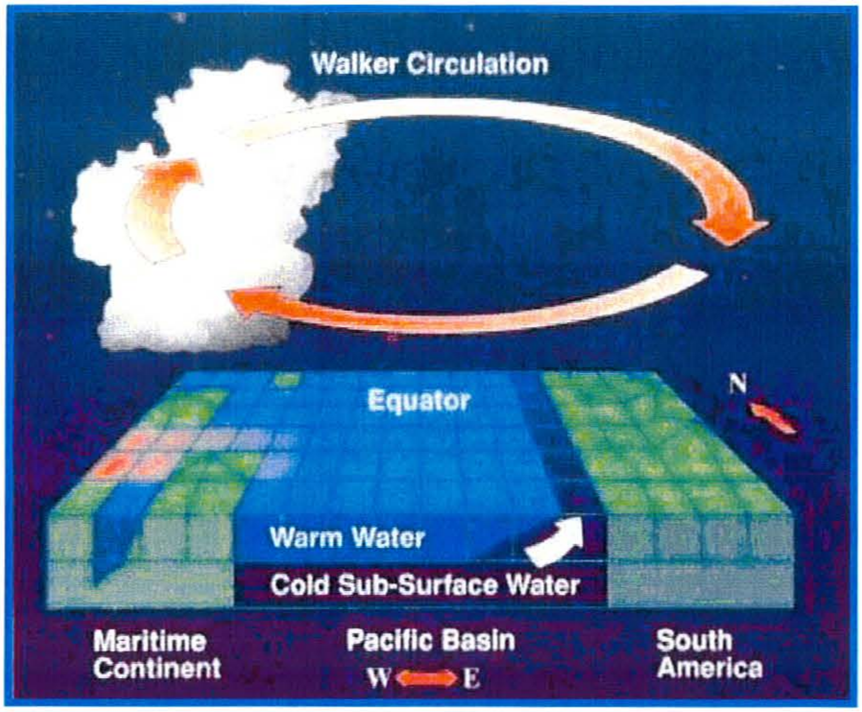

Figure 1: Typical Walker Cell Circulation showing the general circulation pattern during non-El Niño years.

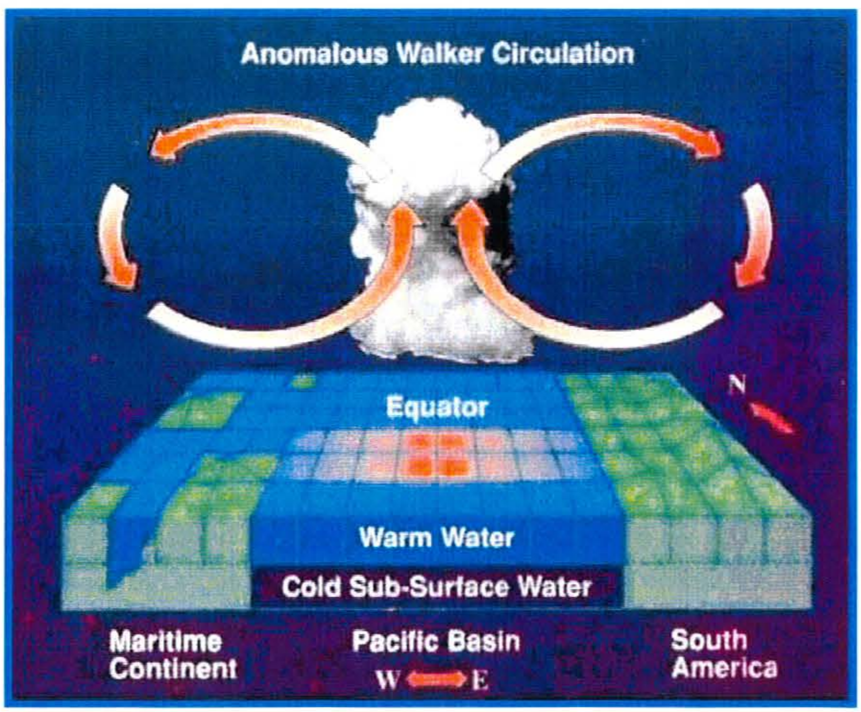

Figure 2: Anomalous circulation that develops during El Niño years showing upward motion over the warm pool of water in the central and eastern Pacific Ocean, and downward motion over Indonesia and Central South America.

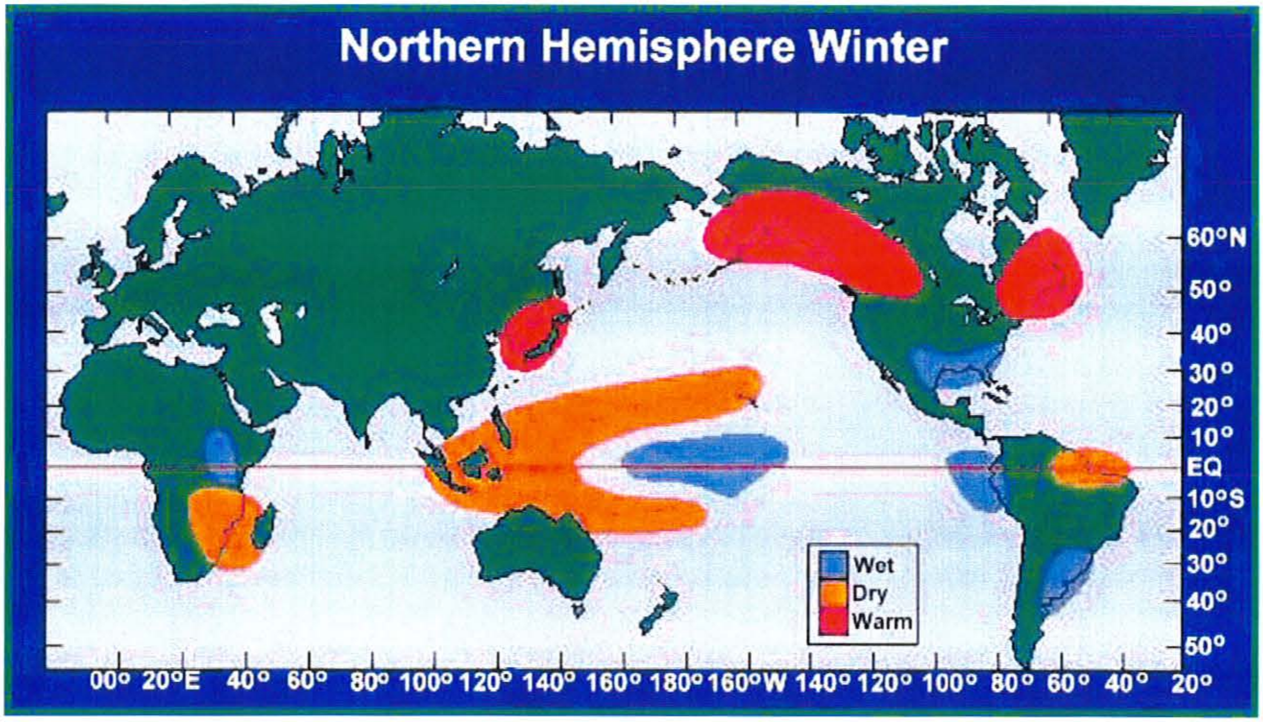

Figure 3: Teleconnection signals of ENSO during the Northern Hemisphere winter. Blue areas denote wetter than normal conditions, orange areas represent drier than normal conditions, and red areas indicate warmer than normal conditions.

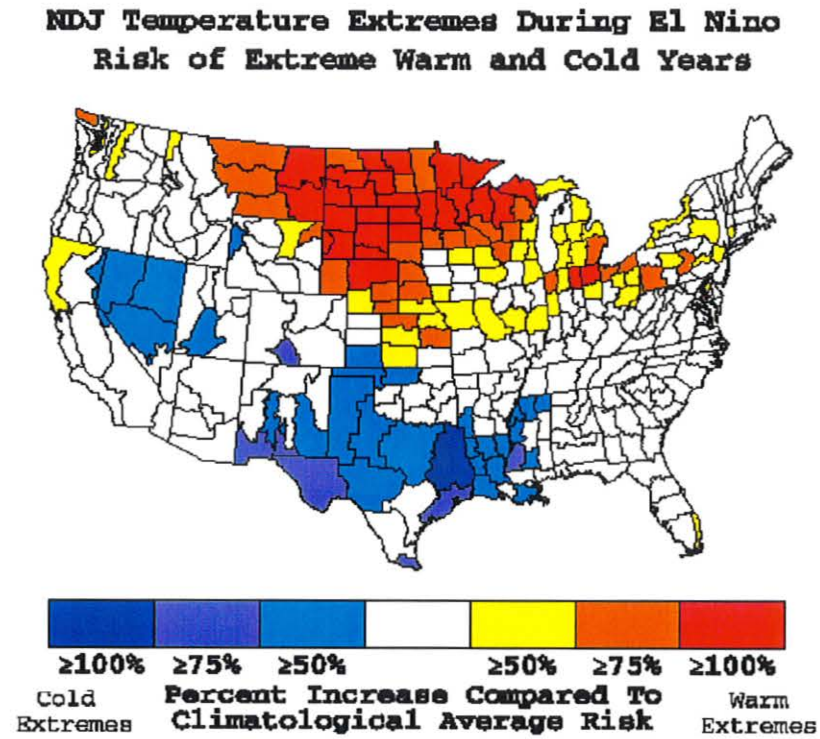

Figure 4: Temperature signals during ENSO events over the United States during November-January. Warm colors denote locations with a greater than 50% risk over climatology of having warmer temperatures than normal during the three month period of time. Cool colors denote those locations with a greater than 50% risk over climatology of having cooler than normal temperatures during the same three month period of time. This data and maps were created by the Climate Diagnostics Center.

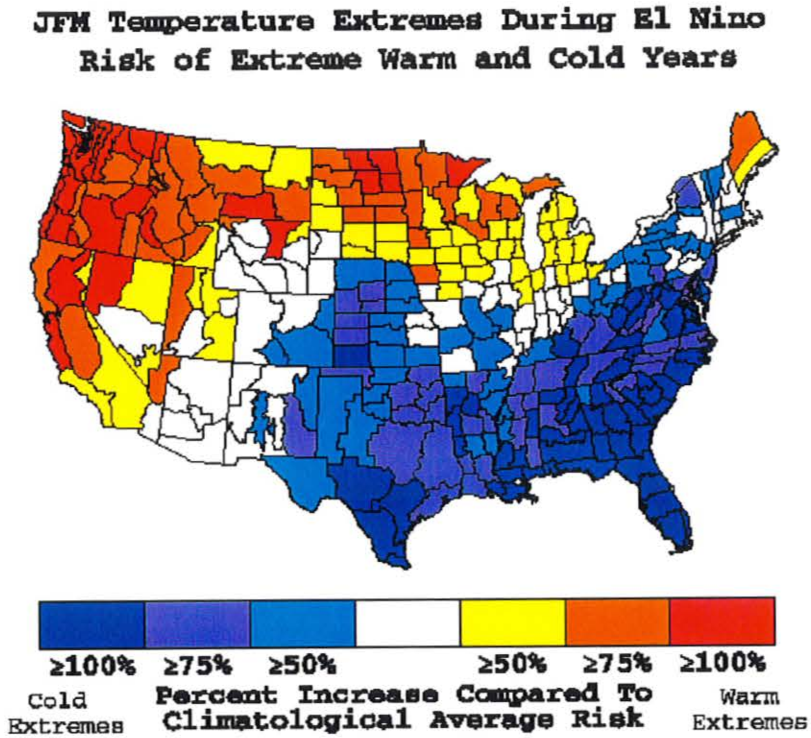

Figure 5: Precipitation signals during ENSO events over the United States for the period of November-January. Warm colors denote locations with a greater than 50% risk over climatology of being drier than normal during the three month period of time. Cool colors denote those locations with a greater than 50% risk over climatology of having wetter than normal precipitation during the same three month period of time. This data and maps were created by the Climate Diagnostics Center.

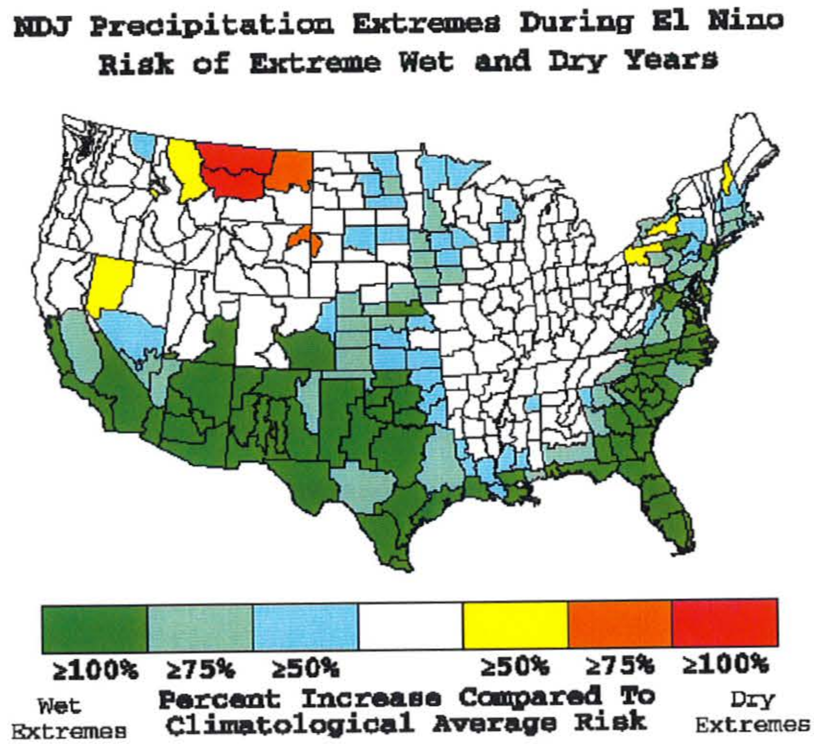

Figure 6: Same as for figure 4, except for the period January-March.

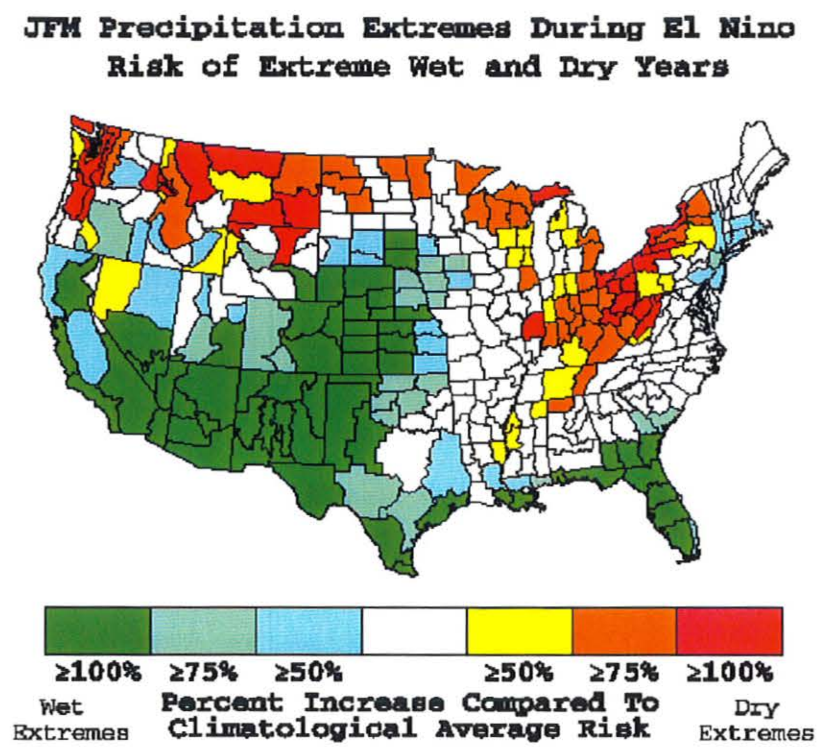

Figure 7: Same as for figure 5, except for the period January-March.

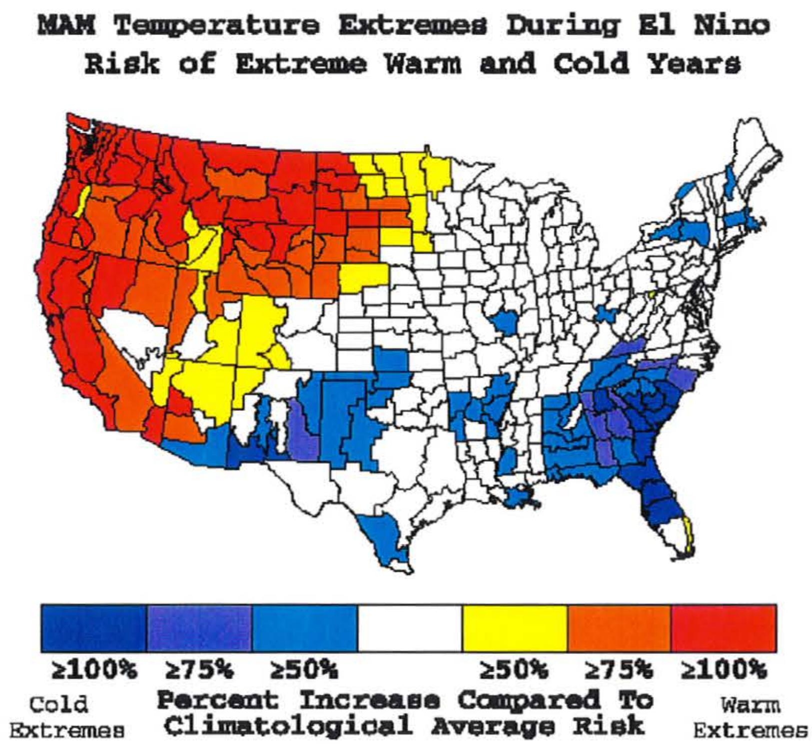

Figure 8: Same as for figure 4, except for the period March-May.

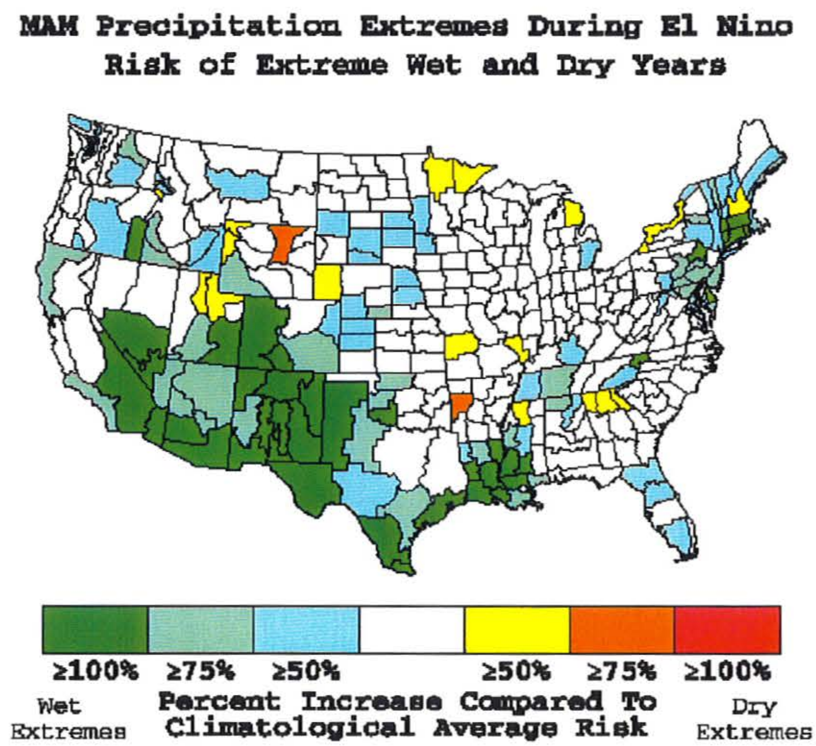

Figure 9: Same as for figure 5, except for the period March-May.