Quantitative Prediction of El Niño Rainfall
For Southern California
~ The 2009-2010 El Niño ~

Sean Klein, Student Volunteer
Weather Service Forecast Office Los Angeles/Oxnard, California

Introduction

NOAA defines an El Niño as: *A phenomenon in the equatorial Pacific Ocean characterized by a positive sea surface temperature departure from normal in Niño Region 3.4 (i.e., 5°S-5°N, 170°W-120°W) greater than or equal in magnitude to 0.5°C averaged over three consecutive months (NOAA 2010).* This value is referred to as the ONI (Oceanic Niño Index). In recent history, a total of seventeen individual El Niño events have been identified using this definition. While this definition provides a convenient way of identifying and cataloging these climatologically significant events, the ONI is typically only reliable for predicting Southern California precipitation for strong El Niños (those with an ONI above 1.5°*C*). It is not descriptive enough to detail as to what to expect from any given El Niño event. Yet, it is precisely those details that private industry, government agencies, emergency managers and the public are interested in. For instance, in Southern California, whenever an El Niño event is anticipated, the public typically asks, *"How much rain can we expect in Southern California for a given winter season during El Niño?"*

But the research necessary to provide a specific quantitative prediction to answer this challenging question has been lacking. Past studies of the relationship between El Niño and Southern California precipitation relied on one or more of the established indices on ENSO (El Niño Southern Oscillation) intensity that were never intended for the prediction of extra-tropical precipitation (Ropelewski and Halpert 1986; Schonher and Nicholson 1989; Redmond and Koch 1991; Livezey et al. 1997; Dettinger et al. 1998; Andrews et al. 2004). Current El Niño indices are designed to study the direct effects of this oceanic temperature oscillation on the Tropical Pacific.

From these past studies, some correlation has been established between ENSO and Southern California precipitation (**Fig. 1**). As mentioned above, a strong correlation exists between the ONI and Southern California Precipitation during strong El Niño events. An inverse relationship applies for La Niña. In general, conditions that form during El Niño result in higher than average precipitation for Southern California. Conditions during La Niña generally produce below average precipitation for Southern California (though this paper does not focus on La Niña).

This paper will attempt to more accurately answer the question: *"How much precipitation can we expect in various regions of Southern California for a given winter season during El Niño?"* Specifically, this paper will identify the various types of El Niños, describe the characteristics of these different types of El Niño, and provide a quantitative prediction of precipitation for several locations in Southern California for the current (2009-10) El Niño event.

Mean State of Tropical Pacific Ocean

Over the Pacific Ocean, a number of key features of wind and water interaction are usually present (**Fig. 2**). The normal trade wind pattern carries warm equatorial water westward, piling it up in the Western Pacific and forming what is referred to as the Western Pacific Warm Pool. In stark contrast, on the eastern side of the Pacific Ocean the cold waters of the Humboldt or Peruvian current flow northward along the west coast of South America. As this current travels northward, it is deflected to the left and forced west along the equator resulting in the "cold tongue" formation evident in the Sea Surface Temperature (SST) pattern. It is these interactions that break down during an El Niño.

Types of El Niños

Historically, several researchers have attempted to categorize El Niños into two basic types depending on the specific location of their maximum SST anomalies (Larkin and Harrison 2005; Ashok et al. 2007; Weng et al. 2007; Kao and Yu 2009; Kug and Jin 2009). Type I, Cold Tongue, or Eastern Pacific El Niño's – as the name suggests – have their strongest SST anomalies in the Eastern Pacific, off the coast of South America. The name "Cold Tongue El Nino" refers to the anomalous warming of this region of ocean that is normally kept cool by the above mentioned processes. Type II, Warm Pool, Dateline, Modoki, or Central Pacific El Niños – again, as their names suggest – have their strongest SST anomalies in the Central Pacific, east of 150°E longitude. The "Warm Pool El Niño" designation implies a relationship with changes in the location of this warm water. The distribution between these two types of El Niños is fairly even (9 to 8).

With an eye to predicting Southern California precipitation, using only two categories is simply not sufficient to isolate the specific event characteristics that correlate well with particular storm tracks and ensuing precipitation totals. In order to predict actual precipitation amounts, it is necessary to break down El Niño events further. In this paper, El Niños will be divided into five distinct categories specifically designed to better isolate precipitation patterns. While it is well known that various feedback processes are responsible for the timing and distribution of the SST anomalies (Kelvin and Rossby waves, westerly wind anomalies and even a general weakening of the trade winds), these forcing mechanisms do not have much influence on seasonal precipitation patterns in Southern California in and of themselves. Simply stated, the way the warm water gets to where it is, is not the issue; rather, it is the intensity and distribution of these SST anomalies during the November through March time frame that has a distinct influence on winter precipitation patterns in Southern California. By breaking down El Niños into five distinct groups, it is possible to derive more reliable correlations that link these SST anomalies to specific precipitation patterns in California.

There is a major weakness that accrues with the subdivision of historical El Niños into five separate categories, however. That weakness is the unavoidable reduction of sample size along with the inherent loss of statistical significance. When the 17 events are broken down into five categories, the small sample size reduces the confidence in the resulting findings. Nevertheless, the available data sets still suggest a specific precipitation pattern associated with the most common variety of El Niño.

Borrowing from the analysis method of Kug, Jin and An **(**Kug et al 2009**)**, the various historical El Niño events are categorized by the Niño regions in which they exhibited statistically significant SST anomalies. The types of El Niño are categorized by and named after the corresponding Niño Regions (3, 3.4, 4) in which an anomaly of greater than one standard deviation is observed for at least one month in the time period from November to February of that El Niño's rainy season (**Fig. 3**).

The most common type of El Niño is the (3, 3.4, 4) anomaly. Because of its relatively higher frequency, the majority of focus will be on this variety of El Niño. As the designation suggests, this type of El Niño has a fairly uniform distribution of SST anomalies across the entire Pacific Ocean. For this reason, the (3, 3.4, 4) type El Niño will hence forth be referred to as the "Basin-Wide El Niño." For this type of event, the greatest anomalies are typically found in Niño Region 3 and slowly decrease as one progresses west with anomalies turning negative west of 160°E longitude.

Seager et al. (2003) suggest that anomalous equatorial heating of the Tropical Eastern and Central Pacific Ocean during El Niño produces an increased rising motion of warm, moisture-laden air above this same region of equator. The result is anomalous, twin high pressure centers aloft in the East-Central Pacific centered at about 15° latitude north and south of the equator. Anomalous upper-level winds form poleward of these twin anti-cyclones (Seager et al 2005). For the Northern Hemisphere, this supports the formation of a sub-tropical jet that passes over Northern Mexico and the Southwestern United States. For the Southern Hemisphere this means the formation of a sub-tropical jet that passes over Northern Chile and Southern Peru. The sub-tropical jet usually acts as a barrier preventing eddies broken off from the polar jet from migrating into the tropics, but with the sub-tropical jet displaced southward, these eddies are able to migrate further south (north in the southern hemisphere). This repositioning of eddies equator-ward of their normal location results in an unbalance of momentum flux; specifically a positive anomaly in the sub-tropics. This positive momentum flux, essentially an increase in pressure at the upper levels, strengthens the twin-upper level anti-cyclones and forces air at the upper levels to flow into the tropics.

The outward flow of air at the upper levels causes a rising air motion in the mid latitudes. Seager et al. (2009) showed that the rising air creates cooling in the upper levels and further enhances precipitation brought by the more southerly storm track**.** This study used a non-linear storm track model to successfully simulate the conditions described above. While the above mentioned atmospheric response occurs in most El Niños, it does so strongly <u>only</u> during Basin-Wide events. Such El Niño events occurred eight times ending in the following years: 1958, 1966, 1973, 1983, 1992, 1998, 2003, and 2007.

Precipitation Correlations vs. Temperature Anomalies

The following discussions will look at the correlation that exists between the various types of El Niños and precipitation in Southern California:

a. **Basin-Wide El Niños (3, 3.4, 4).** During Basin-Wide El Niños the highly uniform distribution of the SST anomalies results in a uniform atmospheric response to the equatorial ocean warming. It can be shown that the strongest predictor of increased precipitation in Southern California during these events, however, is not the SST anomalies – but the 200 mb height anomaly at 15°N latitude. The relationship between these height anomalies and Southern California precipitation can be approximated using a simple quadratic function. When the multiple sites are averaged together, an impressive correlation is apparent between 200 mb geo-potential heights and precipitation (**Fig. 4**).

   Above average precipitation occurred in 75% of the 8 cases, and in those 6 cases, the average precipitation was 164% of normal. For downtown Los Angeles, the average Basin-Wide El Niño produced an average seasonal rainfall that was 135% of normal.

b. **Niño Region (3.4+4) Events.** The next most common type of El Niño is the (3.4, 4) anomaly. As the name suggests, this type of El Niño shows statistically significant SST anomalies in the Central and East-Central Pacific. In this group, there are only three events, one having lasted for two seasons. Because the 1986-87 event occurred over two successive seasons, the precipitation for the two years are averaged together as one season. From the limited sample size, the average (3.4, 4) type El Niño produced rainfall 156% of normal. Above average precipitation occurred in 2 of the 3 events and in these two events, precipitation was 213% of normal. Unlike the Basin-wide variety, this type of El Niño shows little correlation between the strength of the subtropical anticyclone and total winter-time precipitation. The zonal flow apparent with the storm track of all-region El Niños (as a result of the anti-cyclones) is much less apparent.

c. **Niño Region (3.4) Events.** Three of the El Niños recorded since 1950 showed statistically significant SST anomalies in Niño Region 3.4, only. In this type of El Niño, no large pressure anomalies were observed in the subtropics. The precipitation in these three events was consistently dry – ranging from 29% to 58% of average, with a mean of only 46% of normal winter-season rainfall. While there were only 3 events in this category, they were amongst the 6 driest El Niño events ever to have occurred in recent Southern California history.

d. **Niño Region (4) Events.** Two El Niños had statistically significant SST anomalies in Niño region 4, alone. A sample size of 2 speaks for itself, but both events produced extremely high precipitation: They averaged 269% of average precipitation. These are the two wettest El Niño's on record and thus warrant further investigation.

e. **No Significant Anomaly Events.** The 1951-52 El Niño showed no significant SST anomaly in any Niño region. Furthermore, it produced no significant anti-cyclonic anomalies in the subtropics. While this single event produced above normal (203%) winter time precipitation, no conclusions are possible since it was a single event.

As a result of the various SST distributions and the response or lack thereof, each of the 4 varieties exhibits its own mean sub-tropical jet stream flow. The "All-Region" variety of El Niño's exhibits a very zonal flow. The jet tends to move across the Pacific from west to east without significant weakening or meandering in its path. The (3.4 + 4) variety El Niño exhibits a mostly zonal flow, but exhibits significant weakening as the jet migrates west to east as well as an increase in meandering in its path. The (4) type and more significantly the (3.4) type El Niño's show almost none of the characteristics of upper-level flow seen in the Basin Wide variety (**Fig. 5**).

Basin-Wide El Niño

The following discussions will center on the Basin-Wide variety of El Niño because these are most common and, therefore, the most likely to produce statistically significant results. While the SST distribution of these eight events is similar, each one is unique (**Fig. 6, 7, 8, 9**).

As mentioned earlier, the more uniform distribution of SSTs found in the Basin-Wide El Niño events promotes a more uniform atmospheric response. Because waters in both the Central and Eastern Equatorial Pacific Ocean are normally warmer with this variety of event, more evaporation and – usually – more precipitation occurs there. As convection increases in the Central and Eastern Equatorial Pacific, negative OLR anomalies form along the equatorial Central Pacific. These negative anomalies are bracketed by positive OLR anomalies that form to the west, over the Philippine Sea, and to the east, just southeast of Hawaii. The wettest El Niños (**Fig. 10b**), show a significantly larger area of anomalous convection over the Eastern and Central Pacific compared to the two dry events (**Fig. 10a**), where the OLR anomalies were more isolated to the Tropical Central Pacific. Rising air in the locations of low OLR (indicating high cloud tops) collides with the tropopause, compresses and spreads out and away from the equator – thereby increasing heights in the upper levels of the tropics (**Fig. 11**). This uneven heating response begins the growth of the twin anti-cyclones described earlier.

The strength of the resulting 200 mb Geo-Potential Height (GPH) anomaly shows a very strong contrast between the wettest and driest El Niño events. While the location of the anomalies is nearly identical, the wettest El Niños showed GPH anomalies approximately twice that of the driest Basin-Wide El Niños (**Fig. 12**). The fact that height anomalies are related to above normal water temperatures in and around Niño Region 3.4, explains the lack of precipitation during the 2006-07 El Niño (when SST anomalies were fairly weak), but does not explain the minimal height anomalies in the 1965-'66 El Niño where SSTs in the Niño Region 3.4 peaked at 1.84°C above normal, and averaged 1.44° C above normal from November to February. Seasonal correlation of 200 mb GPH to anomalous warming in each of the four Niño Regions is evident in composites (**Fig. 13**). Notice the stronger correlation between anomalous warming in Niño Regions 3 and 3.4 and the 200 mb height field – and a much less impressive correlation to anomalous heating in Niño Regions 1+2 and 4. The correlation in Niño Region 3.4, while striking, is not as impressive as that with 200 mb Height Anomaly (Fig. 4).

Basin-Wide Outliers

Of the eight Basin-Wide El Niños, six were considered wet. The other two: 1965-66 and 2006-07 seasons, were dry outliers. The two events, as expected, had very weak anti-cyclone couplets. One clue to why this was so can be seen by looking at the 850 mb flow patterns.

While the SSTs in the Niño Region 3.4 were extremely warm for the 1965-66 El Niño event, 850 mb westerly wind anomalies were fairly weak. Maximum westerly wind anomalies averaged 3.3 m/s during the Dec-March Period (**Fig. 15**). One possibility is that without these strong westerly winds, the enhanced convection remained isolated along the dateline, unable to produce the compression necessary to form the anomalous GPH anomalies north of Niño Regions 3.4 and 3. The same can be said of the 2006-'07 El Niño regarding winds. It actually had anomalous easterly winds in the Central Pacific (**Fig. 16**). The difference is striking when compared to the winds during the 6 wet events where westerly wind anomalies averaged over 6 m/s during the same period (**Fig. 17**).

2009-10 El Niño

While not included in the above analysis, the current (2009-10) El Niño met the criteria for a Basin-Wide El Niño. Based on height anomalies, SST anomalies, and upper level winds, the 2009-10 El Niño looked to be one of the wettest of its type – likely drier than the '83 and '98 events – but wetter than any of the other 6 episodes. The wide distribution of anomalously warm equatorial waters and the existence of strong westerly wind bursts across the Central Pacific were both consistent with a Basin-Wide El Niño (**Fig. 18**). The high level of negative Outgoing Longwave Radiation (OLR) anomalies over the dateline region suggested increased convection and precipitation in that region. The high level of positive OLR anomaly over the Northeast Tropical Pacific suggested a lack of cloud cover. Both conditions are consistent with a Basin-Wide El Niño (**Fig. 19**). A zonal jet was present over the North-Eastern Pacific Ocean as well as anomalously positive heights directly to the south. Both of these conditions were consistent with a Basin-Wide El Niño (**Fig. 20**). In February, conditions began to turn less favorable. SSTs began to fall off, followed by a decrease in all key indicators (**Fig. 21**). By March, 200 mb heights near Hawai'i were near normal, and the El Niño began to resemble a 3.4 El Niño more than a Basin-Wide variety (**Fig. 22**).

Conclusion

This study shows that there is no simple answer to the question: *"How much rain can we expect in Southern California for a given winter season during El Niño?"* There are many possible answers depending on the variety of El Niño. One identified by NOAA as a "weak" El Niño can produce record winter precipitation in Southern California (winter of 2002-03), while one identified as "strong" can produce sparse winter totals (winter of 1965-66). The 2009-10 El Niño appeared likely to produce significant rainfall totals through the winter. Based on the resulting 200 mb GPH anomaly for the Northern Hemisphere (**Fig. 23**), accumulated precipitation during the December to March period for Downtown Los Angeles was expected to be about 124-144% of average (**Fig. 24**). In the end, the totals were only 112% of average. In the month to month break-down, the rainfall totals were as follows: December: 145% of average, January: 146% of average, February: 126% of average, March: 20% of average. The other stations also trended to the dry side of the prediction. The dryer than expected conditions could be a result of a larger than expected variability or the inevitable result of making predictions from such a small sample size. As more El Niños occur, predictions will inevitably increase in precision.

More research and modeling is necessary to fully determine why some strong El Niños produce the characteristic strong anti-cyclonic couplet while other strong El Ninos produce very weak couplets. That being stated, whether the anti-cyclonic anomaly is the causation for Southern California precipitation or is merely correlated to unknown phenomena responsible for the increase in precipitation, it does appear to be an extremely helpful long-range forecasting tool.

The dissection of what normally are referred to as weak or moderate El Niño's into distinct groups will hopefully shed some light on the inconsistency in precipitation patterns for this group of El Niño's. With such a small sample to work with, our knowledge of the ENSO cycle as a whole is incomplete to say the least. With further study, the atmospheric responses to this multi-decadal process will continue to come into better focus.

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Data Sets and Figures

SST Data for Figs. 3, 13 provided by: CPC: Monthly Atmospheric and SST Indices. Web site at: http://www.cpc.noaa.gov/data/indices/

Santa Barbara County Rainfall data provided by County of Santa Barbara: Public Works. Web site at: http://www.countyofsb.org/pwd/pwwater.aspx?id=3790

San Luis Obispo County Rainfall data provided by San Luis Obispo County Water Resources. Web site at: http://www.slocountywater.org/site/Water%20Resources/Data/maps/precipitation.htm

Ventura County Rainfall data provided by County of Ventura Watershed Protection District. Web site at: http://portal.countyofventura.org/portal/page?_pageid=876,1686932&_dad=portal&_schema=PORTAL

Los Angeles County Rainfall data provided National Climatic Data Center. Web site at: http://www7.ncdc.noaa.gov/IPS/lcd/lcd.html?_page=0&state=CA&_target1=Next+%3E

All reanalysis data and images provided by the NOAA/OAR/ESRL PSD, Boulder, Colorado, USA. Web site at: http://www.esrl.noaa.gov/psd/

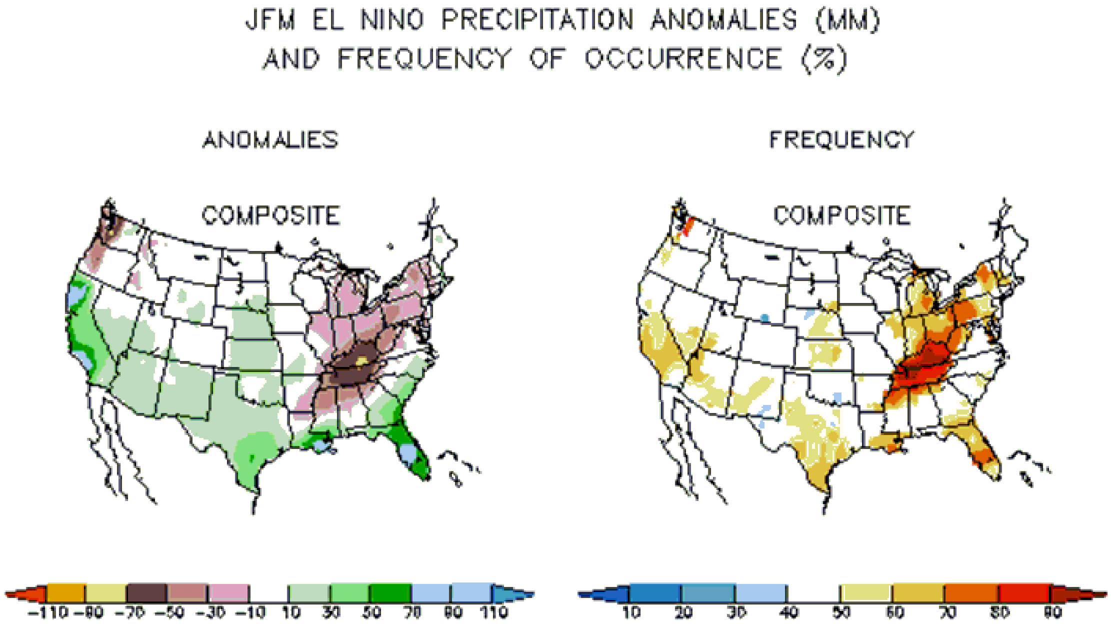

Figure 1

Composite of mean El Niño precipitation anomaly for Jan-Mar time period

Figure provided by NOAA/CPC : El Niño Expert Discussion/Assessment
(http://www.cpc.noaa.gov/products/precip/CWlink/MJO/enso.shtml#discussion)

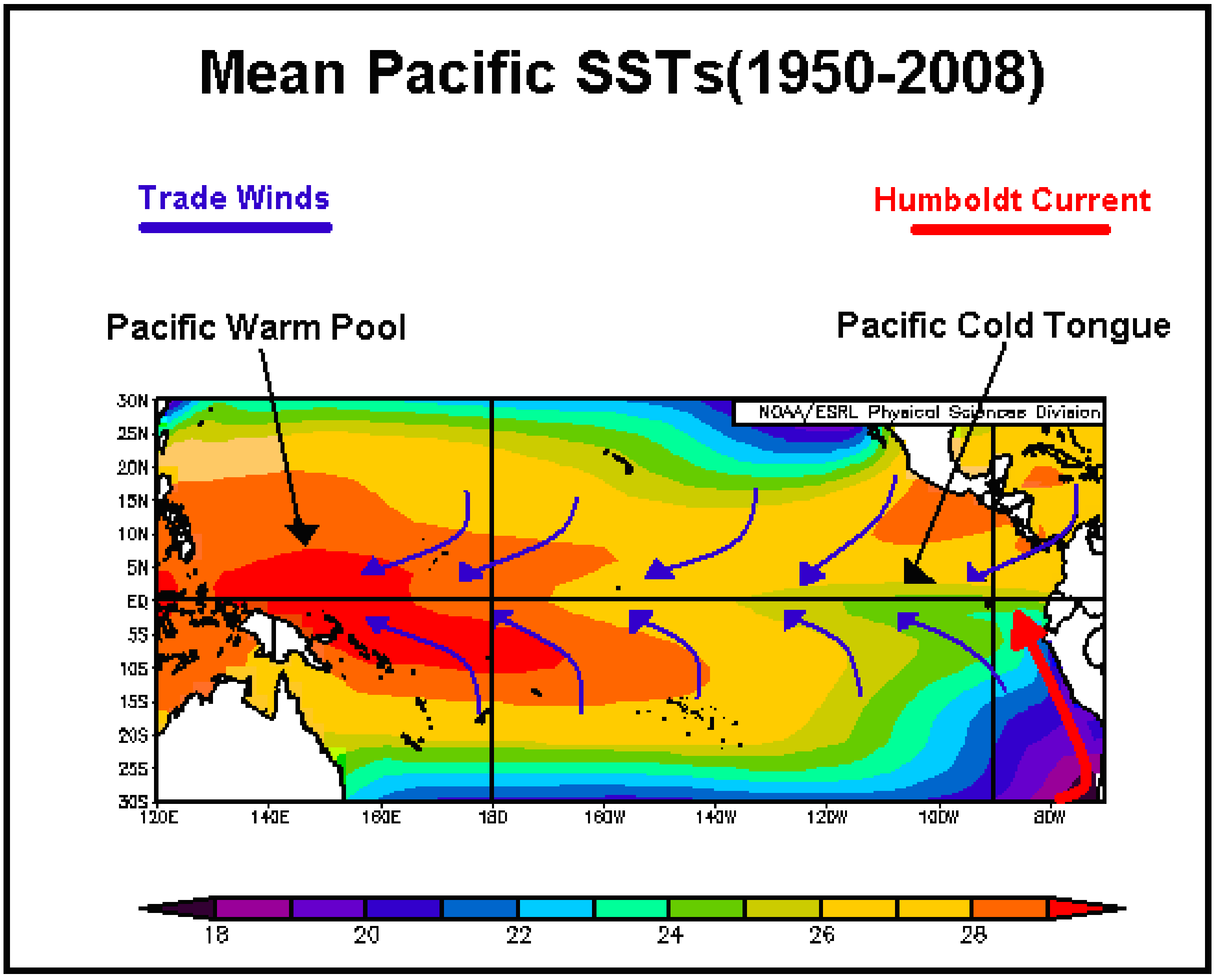

Figure 2

Mean sea surface temperature (°C) pattern over the Pacific Ocean for the period 1950 to 2008.

Data/image provided by or modified from those provided by the NOAA/OAR/ESRL PSD, Boulder, Colorado, USA, from their Web site at http://www.esrl.noaa.gov/psd/

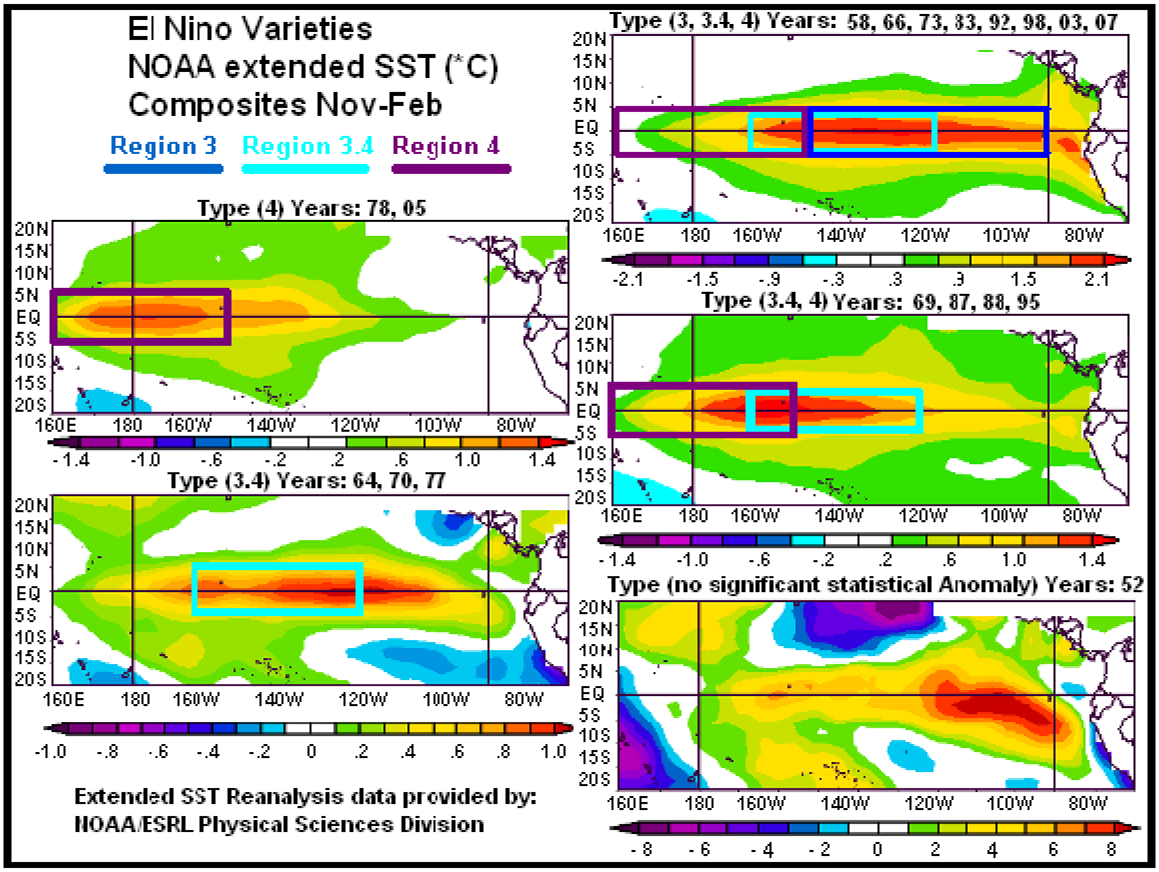

Figure 3

Five El Niño event types, as follows: going counter-clockwise from upper left (4 only), (3.4 only), (no statistically significant anomaly), (3.4, 4), and (3, 3.4, 4). Overlaid on the images are colored boxes identifying the 3 Niño regions used in this paper to classify El Niño's.

Data/image provided by or modified from those provided by the NOAA/OAR/ESRL PSD, Boulder, Colorado, USA, from their Web site at http://www.esrl.noaa.gov/psd/

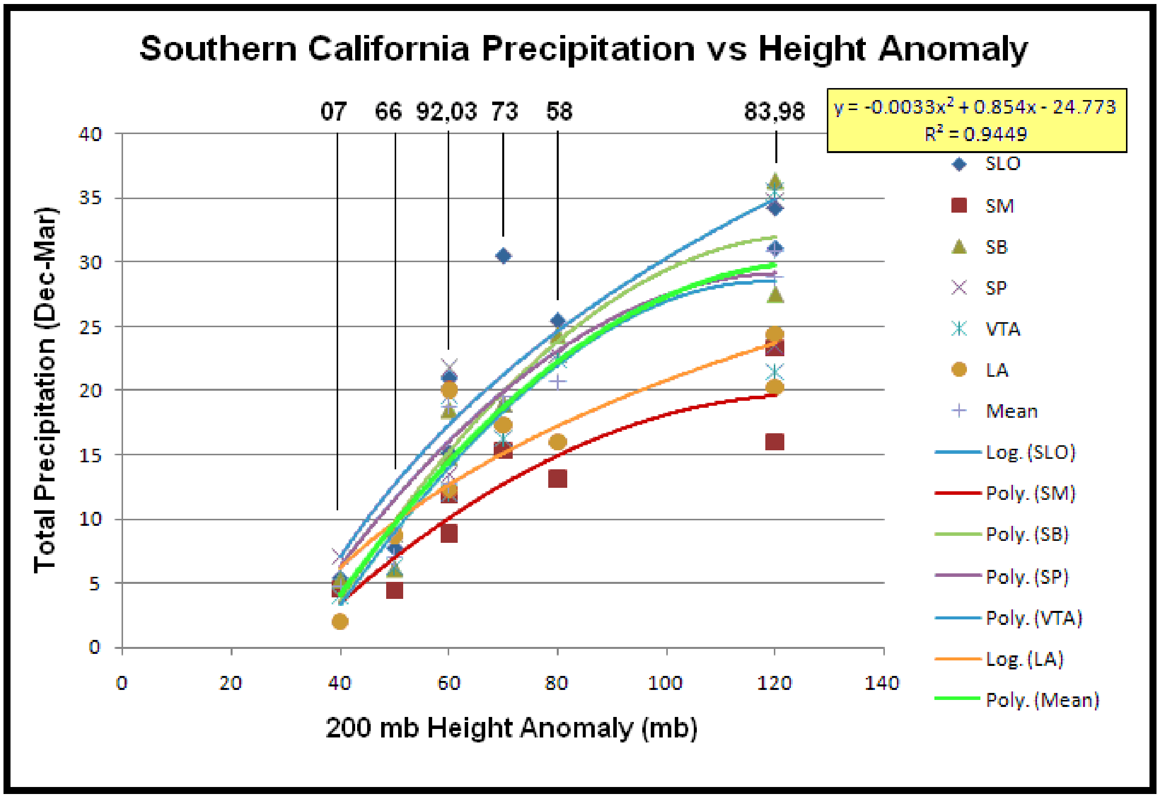

Figure 4

Scatter plot of the eight El Niño events in question graphed separately as the Total Precipitation vs. 200mb Geo-Potential Height (GPH) Anomaly from December to March for six individual locations. These locations were: the Los Angeles Civic Center, the Ventura County Government Center, Santa Paula Limoneira Ranch, the Santa Barbara Airport, the Santa Maria Airport, and the Cal Poly Campus in San Luis Obispo.

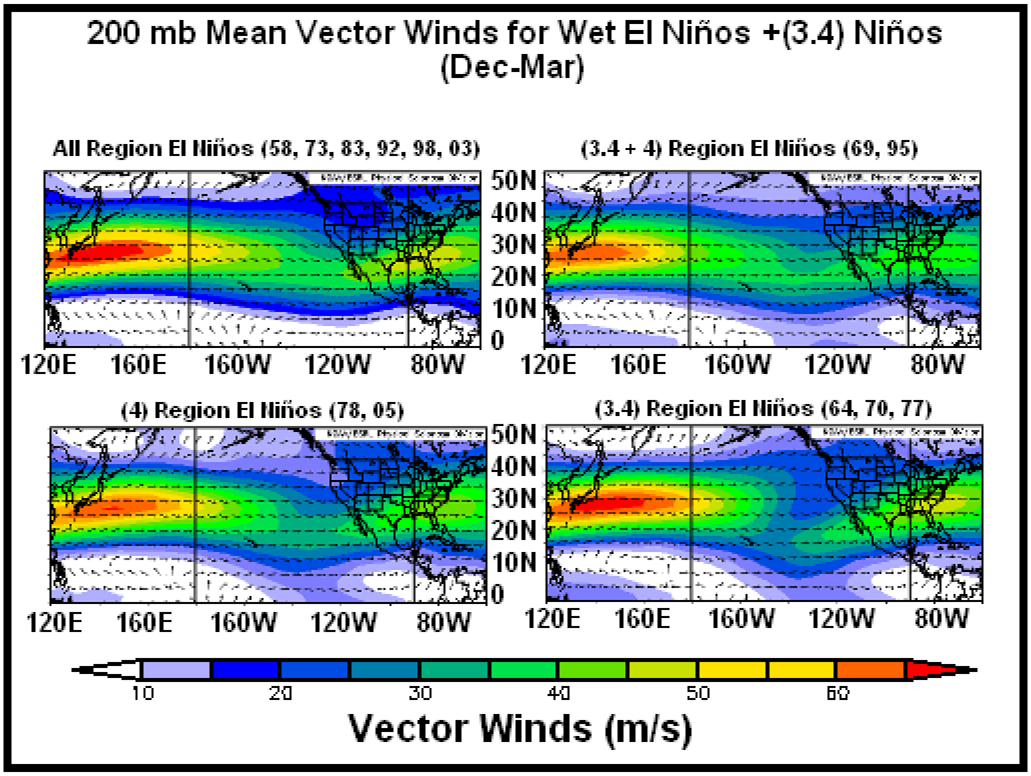

Figure 5

Mean flow of the jet stream at 200mb for the 4 El Niño Types. With exception of the bottom right diagram [(3.4) El Niño's], dry El Niño years have been exempt from the reanalysis.

Data/image provided by or modified from those provided by the NOAA/OAR/ESRL PSD, Boulder, Colorado, USA, from their Web site at http://www.esrl.noaa.gov/psd/

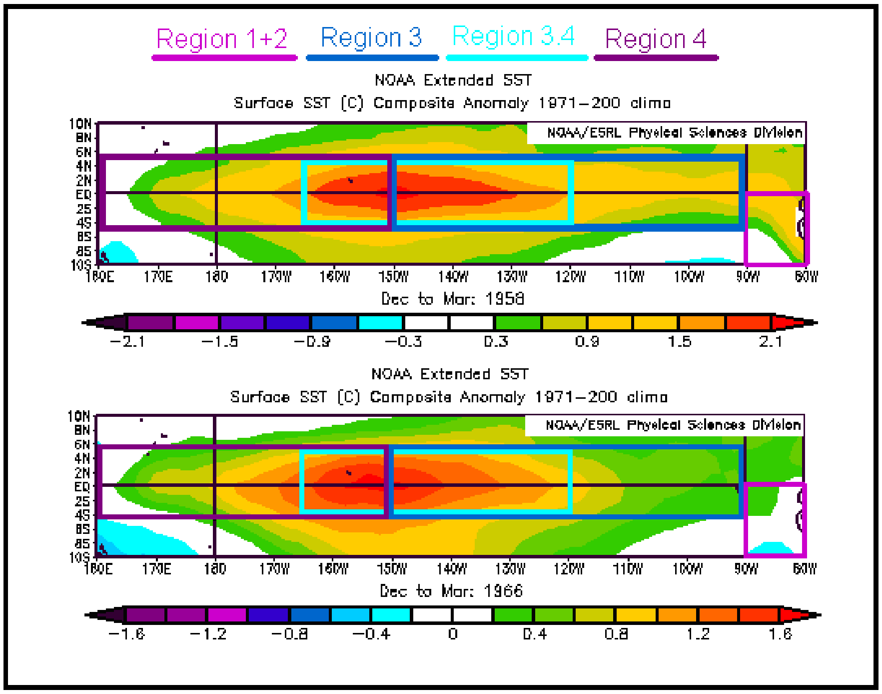

Figure 6

Reanalysis of SST Anomaly for the two El Nino events ending in the years 1958 and 1966. The colored boxes identify specific Niño Regions as labeled.

Data/image provided by or modified from those provided by the NOAA/OAR/ESRL PSD, Boulder, Colorado, USA, from their Web site at http://www.esrl.noaa.gov/psd/

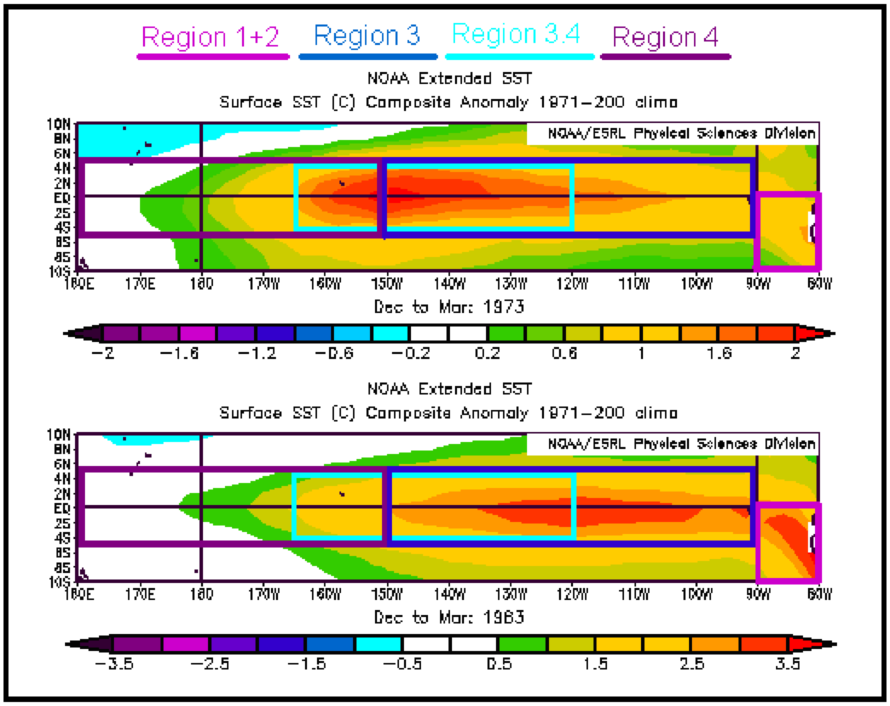

Figure 7

Reanalysis of SST Anomaly for the two El Nino events ending in the years 1973 and 1983. The colored boxes identify specific Niño Regions as labeled.

Data/image provided by or modified from those provided by the NOAA/OAR/ESRL PSD, Boulder, Colorado, USA, from their Web site at http://www.esrl.noaa.gov/psd/

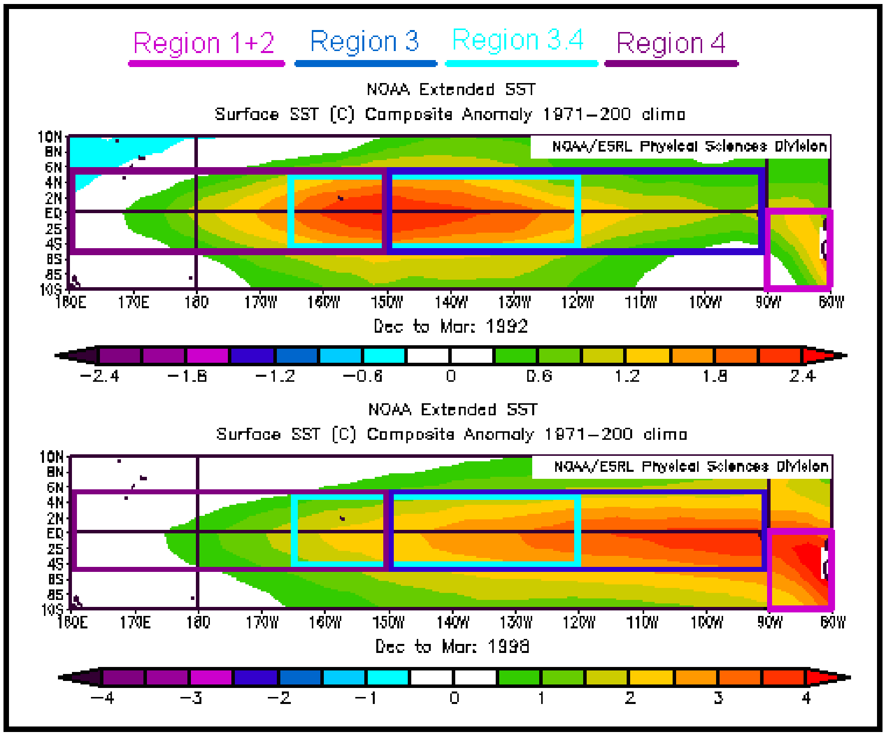

Figure 8

Reanalysis of SST Anomaly for the two El Nino events ending in the years 1973 and 1983. The colored boxes identify specific Niño Regions as labeled.

Data/image provided by or modified from those provided by the NOAA/OAR/ESRL PSD, Boulder, Colorado, USA, from their Web site at [*http://www.esrl.noaa.gov/psd/*](http://www.esrl.noaa.gov/psd/)

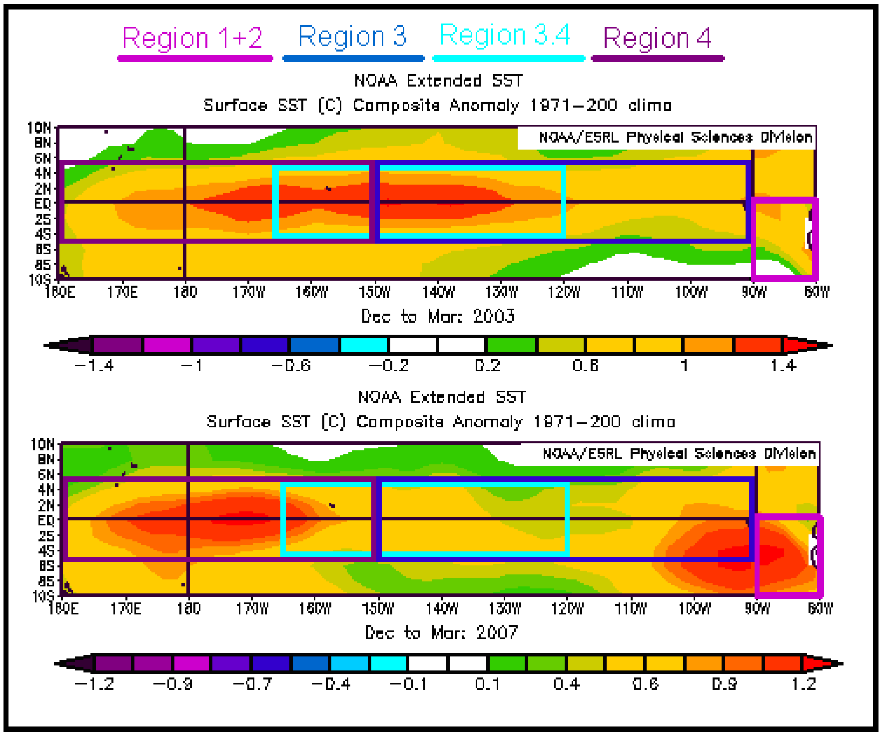

Figure 9

Reanalysis of SST Anomaly for the two El Nino events ending in the years 1973 and 1983. The colored boxes identify specific Niño Regions as labeled.

Data/image provided by or modified from those provided by the NOAA/OAR/ESRL PSD, Boulder, Colorado, USA, from their Web site at http://www.esrl.noaa.gov/psd/

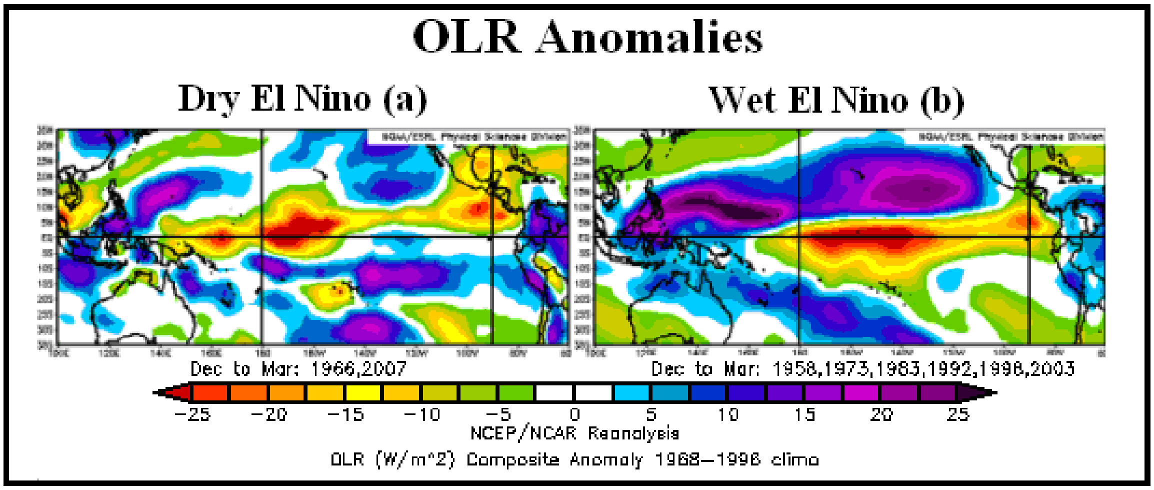

Figure 10

Tropical Pacific OLR anomaly during the November through March time period for the eight Basin-Wide El Niño events.

(a) 2 driest El Niños in group

(b) 6 wettest El Niños in the group

Data/image provided by or modified from those provided by the NOAA/OAR/ESRL PSD, Boulder, Colorado, USA, from their Web site at http://www.esrl.noaa.gov/psd/

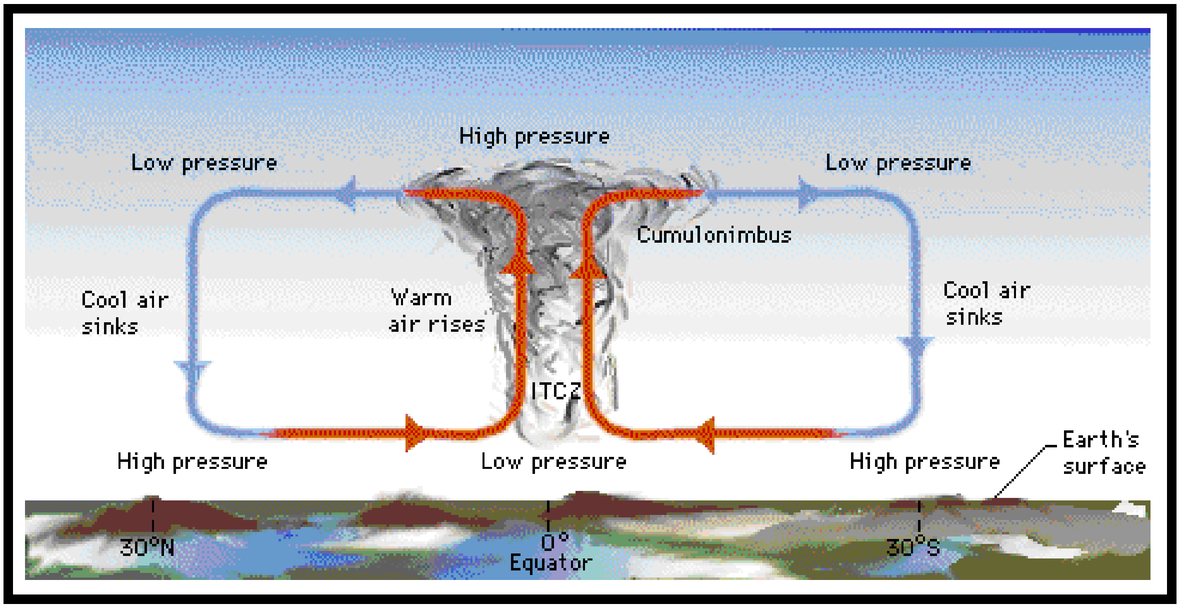

Figure 11

Tropical feedback process known as the Hadley Cell.

Image Provided by Microsoft Encarta Online Encyclopedia. Web site at: http://images.encarta.msn.com/xrefmedia/zencmed/targets/illus/ilt/T642138A.gif

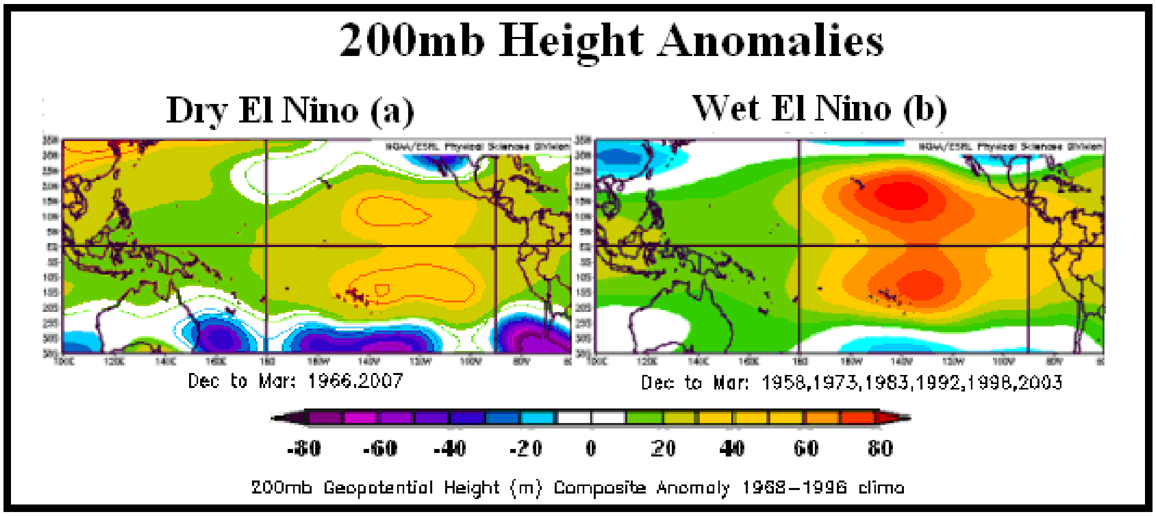

Figure 12

Composite of 200mb GPH anomalies for the eight Basin-Wide El Nino events.
(a) two driest events (1965-‘66 and 2006-’07)
(b) composite of the six wettest events

Data/image provided by or modified from those provided by the NOAA/OAR/ESRL PSD, Boulder, Colorado, USA, from their Web site at http://www.esrl.noaa.gov/psd/

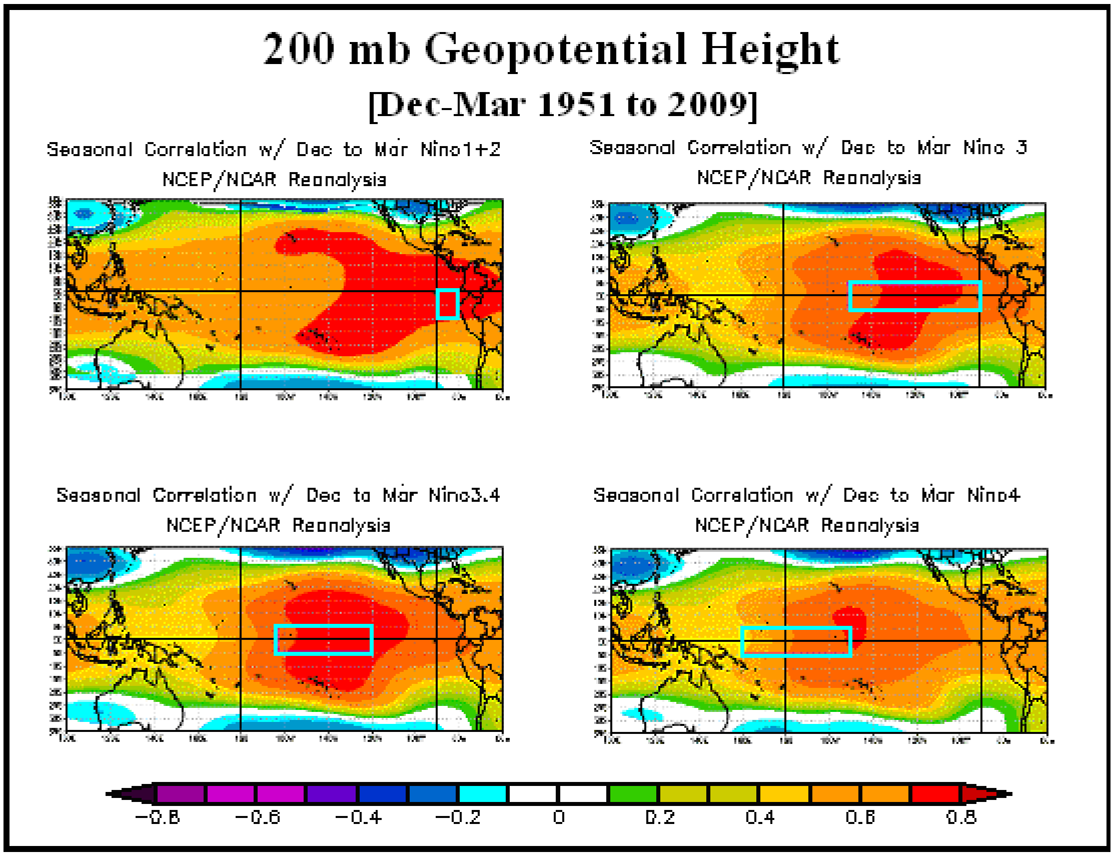

Figure 13

Seasonal correlation of 200mb GPH to anomalous warming in each of the four Niño Regions.

Data/image provided by or modified from those provided by the NOAA/OAR/ESRL PSD, Boulder, Colorado, USA, from their Web site at http://www.esrl.noaa.gov/psd/

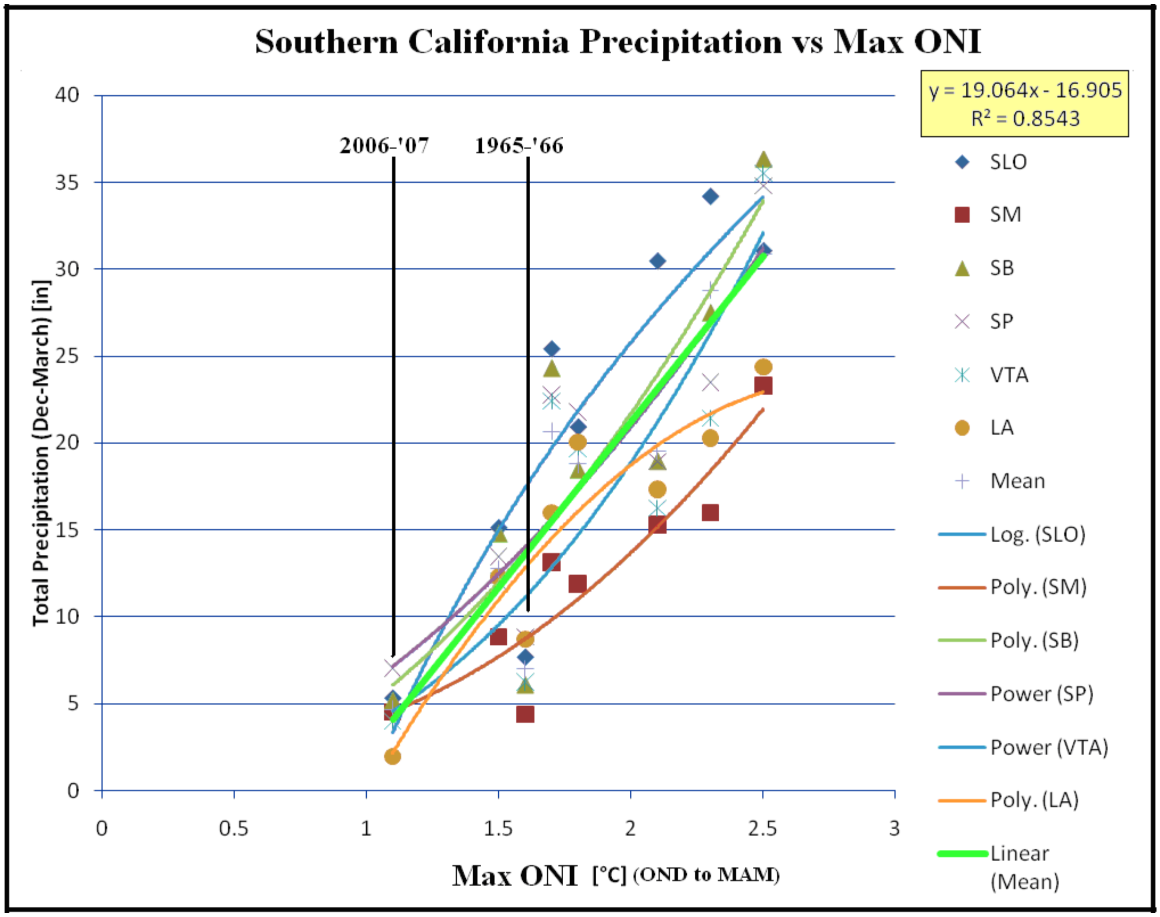

Figure 14

Scatter plot of the relationship between the Maximum ONI (for Basin-Wide Events) and Southern California precipitation (accumulated Dec-Mar.).

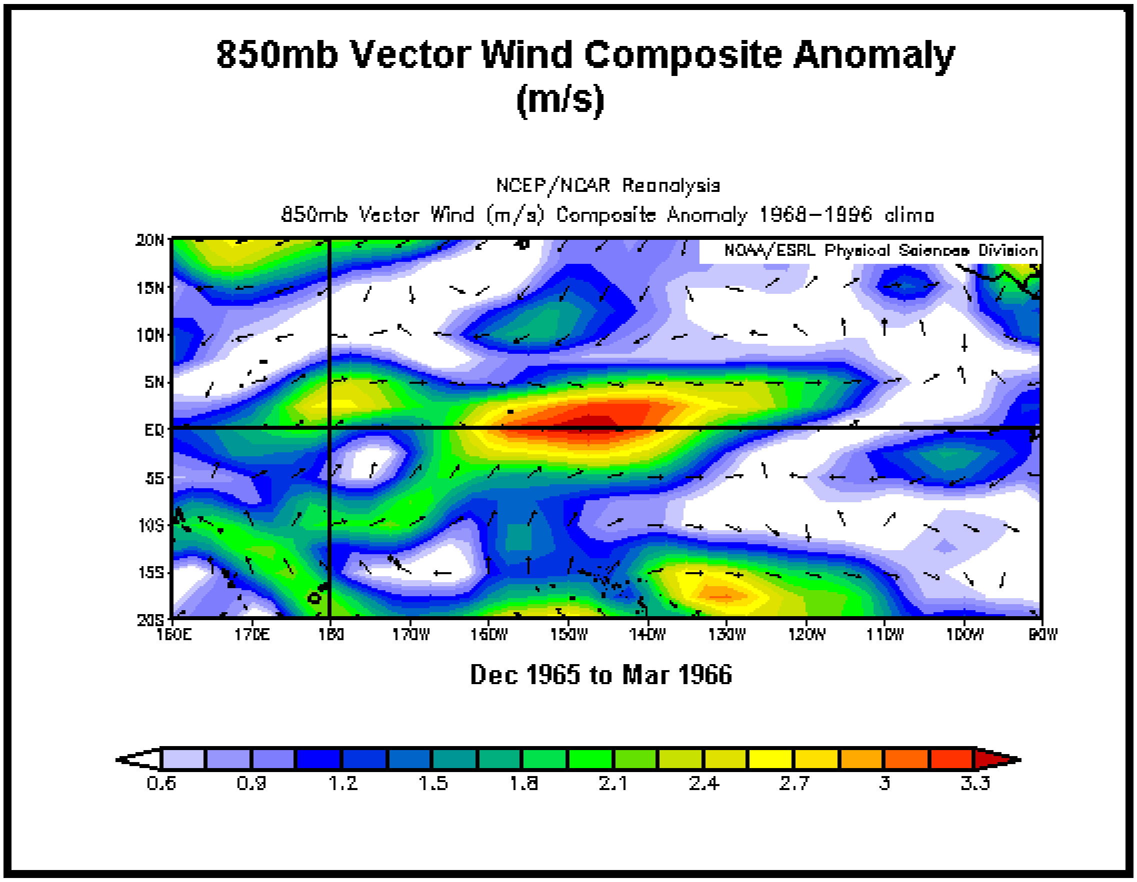

Figure 15

Westerly wind bursts along the Equatorial Central Pacific during the 1965-66 El Niño.

Data/image provided by or modified from those provided by the NOAA/OAR/ESRL PSD, Boulder, Colorado, USA, from their Web site at http://www.esrl.noaa.gov/psd/

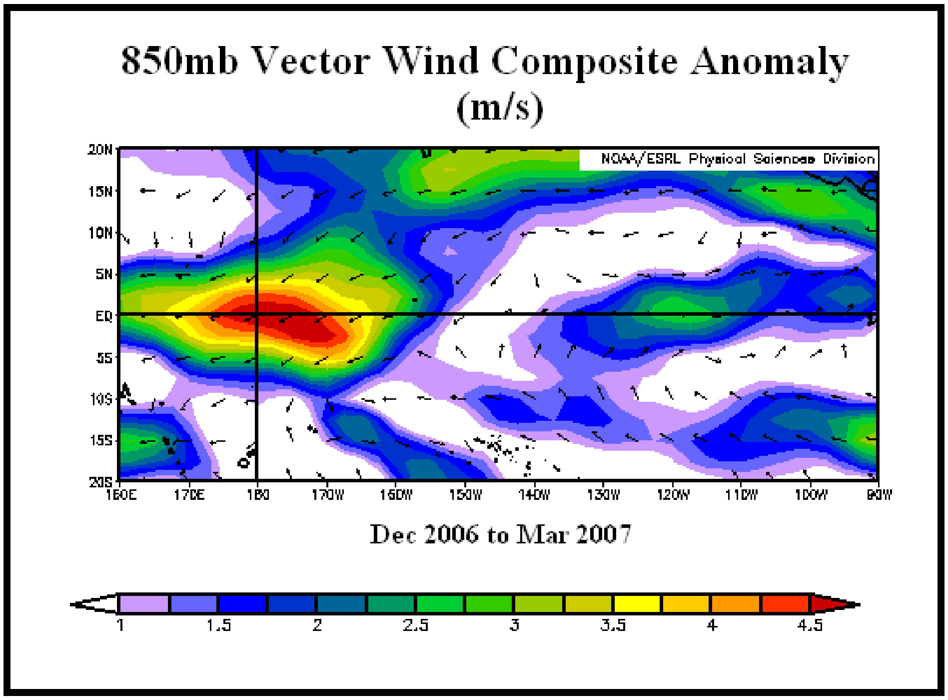

Figure 16

Lack of westerly wind bursts during the 2006-07 El Niño. The strongest wind anomalies were easterly during the Dec-March Period

Data/image provided by or modified from those provided by the NOAA/OAR/ESRL PSD, Boulder, Colorado, USA, from their Web site at http://www.esrl.noaa.gov/psd/

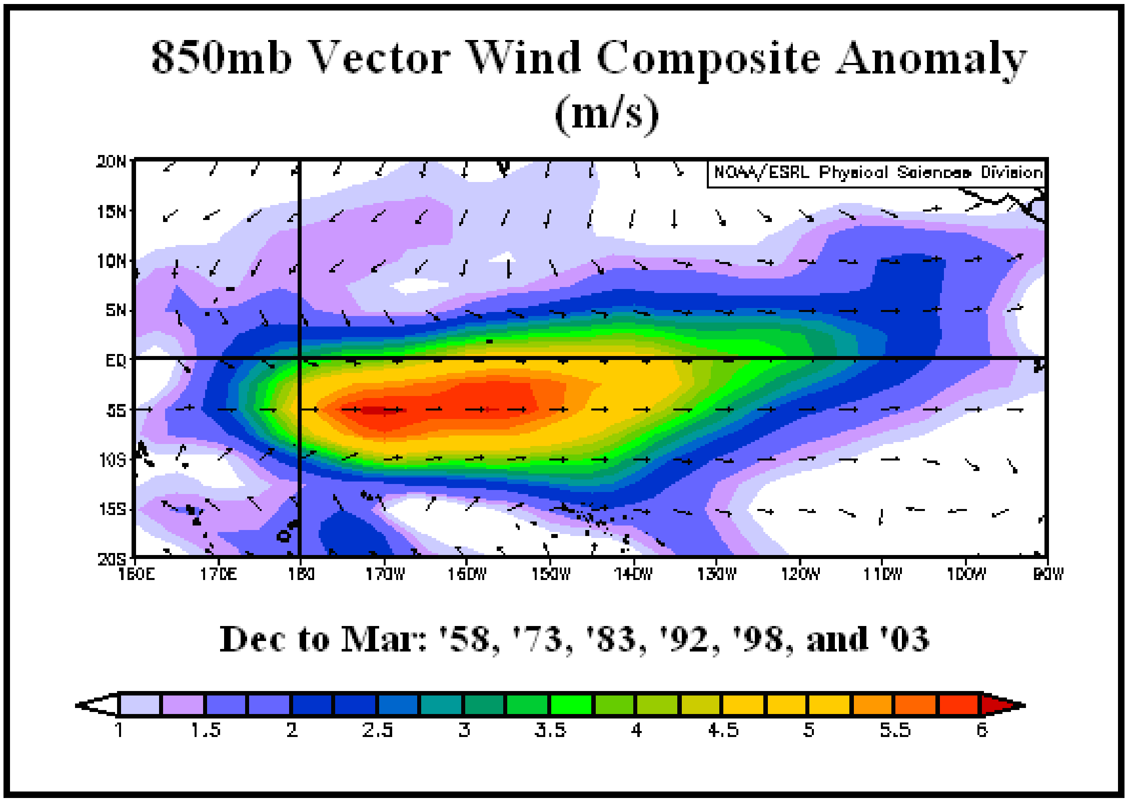

Figure 17

Composite of westerly wind bursts along the Central Pacific during the wet Basin Wide El Niños.

Data/image provided by or modified from those provided by the NOAA/OAR/ESRL PSD, Boulder, Colorado, USA, from their Web site at http://www.esrl.noaa.gov/psd/

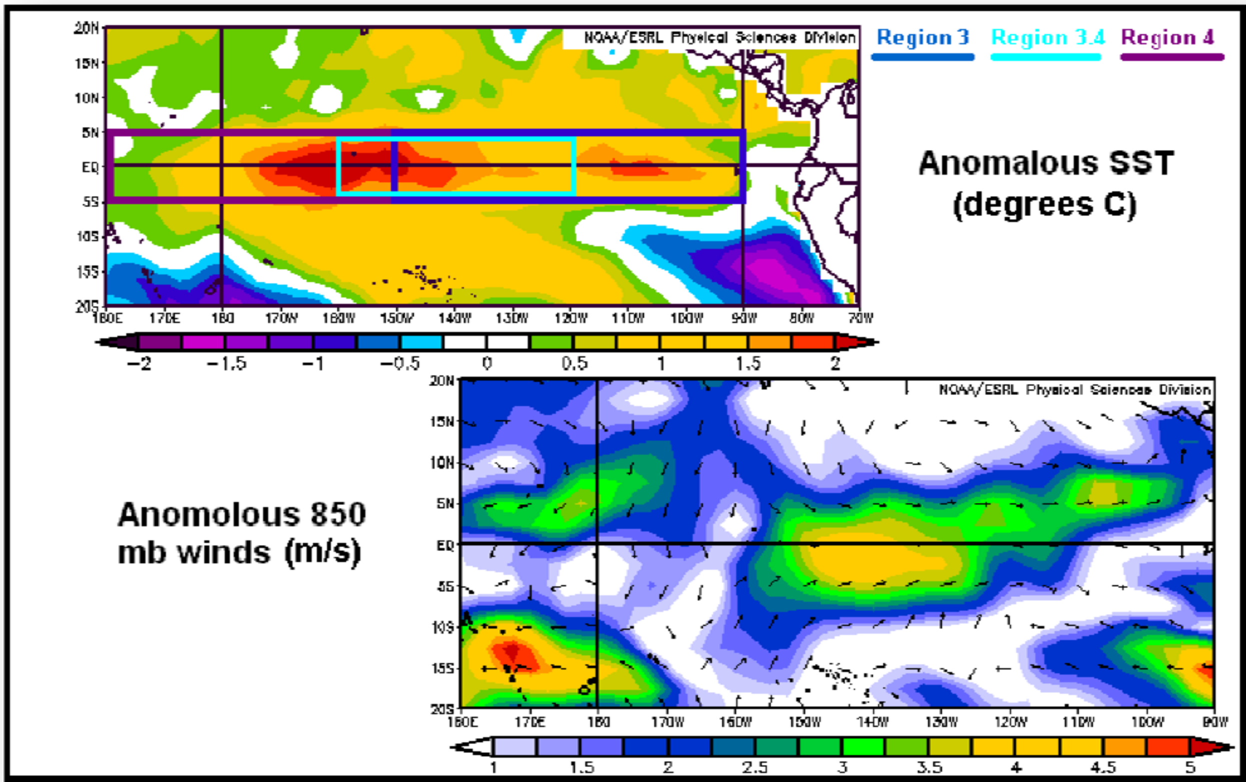

Figure 18

(At top) SST anomalies for the 2009-10 El Nino for the time period December 1st through January 25.
(At bottom) Westerly wind bursts for the same time period.

Data/image provided by or modified from those provided by the NOAA/OAR/ESRL PSD, Boulder, Colorado, USA, from their Web site at http://www.esrl.noaa.gov/psd/

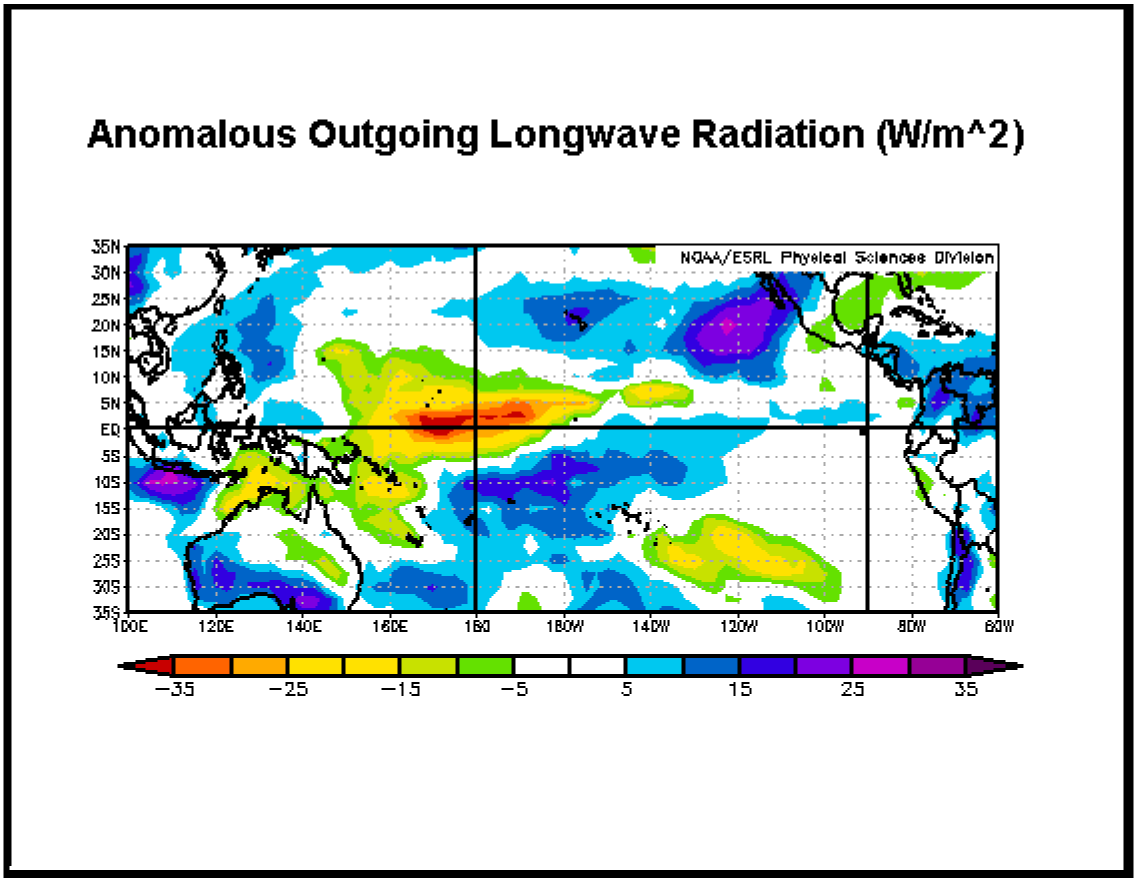

Figure 19

OLR Anomalies for the 2009-10 El Niño for the time period December 1st through January 25.

Data/image provided by or modified from those provided by the NOAA/OAR/ESRL PSD, Boulder, Colorado, USA, from their Web site at [*http://www.esrl.noaa.gov/psd/*](http://www.esrl.noaa.gov/psd/)

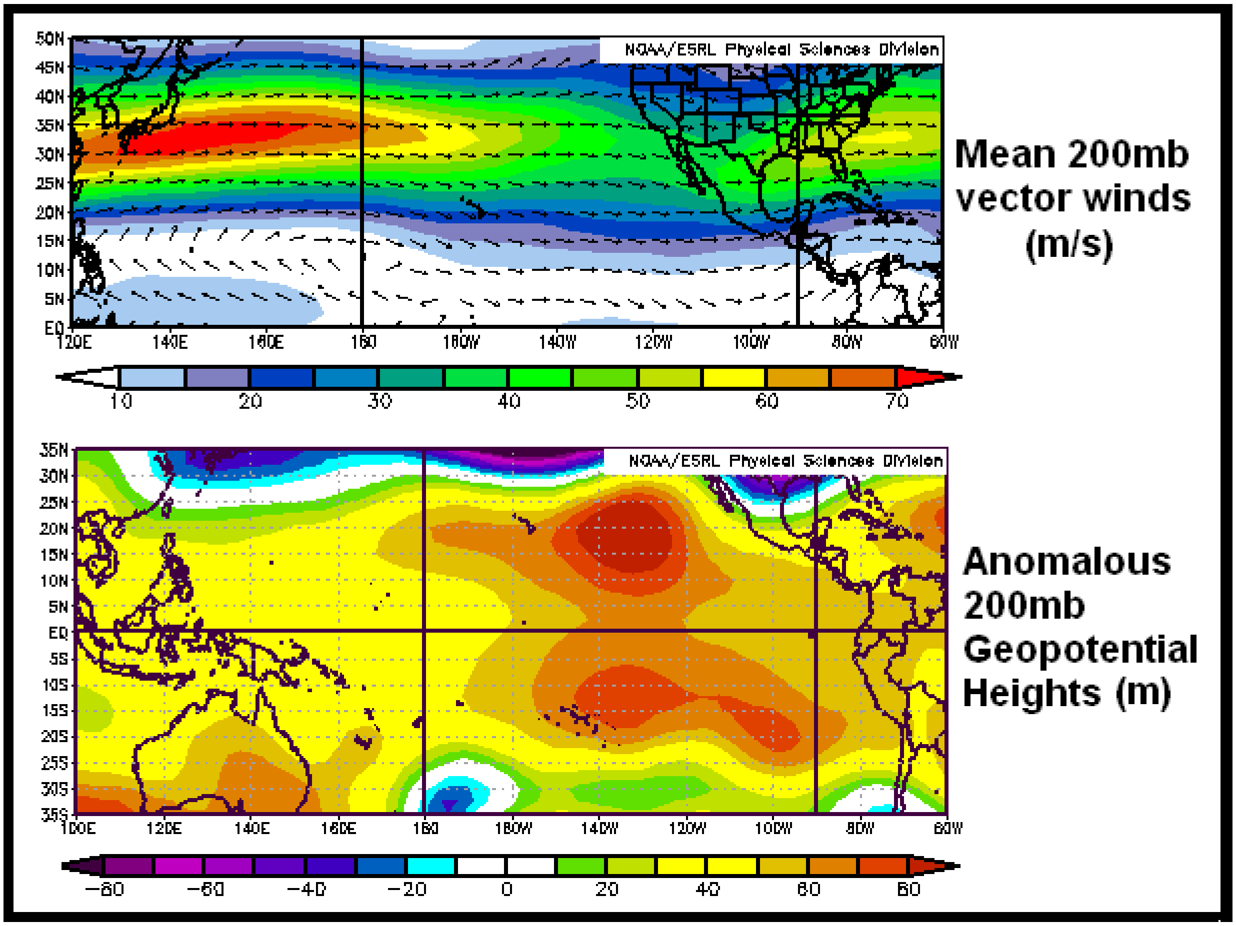

Figure 20

(At top) Mean Jet flow for the 2009-10 El Nino for the time period December 1st through January 25.
(At bottom) GPH Anomalies for the same time period.

Data/image provided by or modified from those provided by the NOAA/OAR/ESRL PSD, Boulder, Colorado, USA, from their Web site at http://www.esrl.noaa.gov/psd/

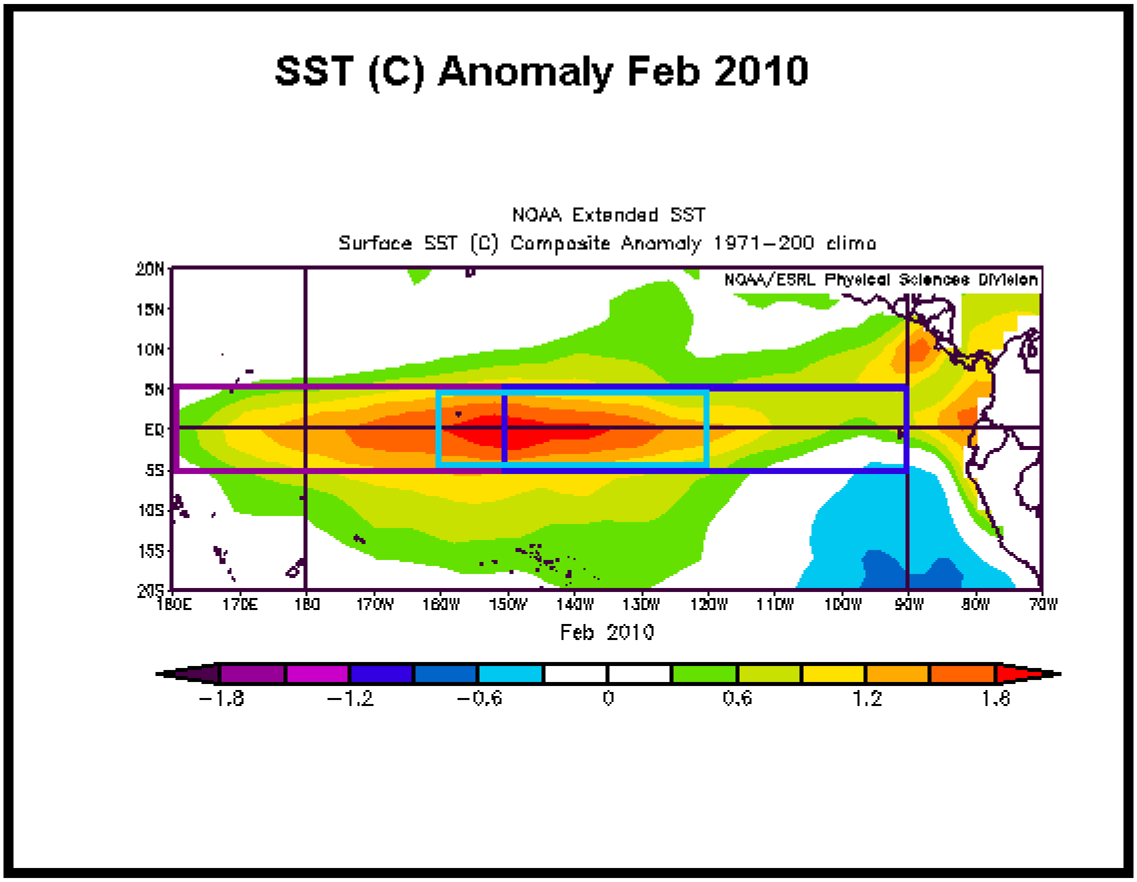

Figure 21

SSTs decreased across Central Pacific during February

Data/image provided by or modified from those provided by the NOAA/OAR/ESRL PSD, Boulder, Colorado, USA, from their Web site at [*http://www.esrl.noaa.gov/psd/*](http://www.esrl.noaa.gov/psd/)

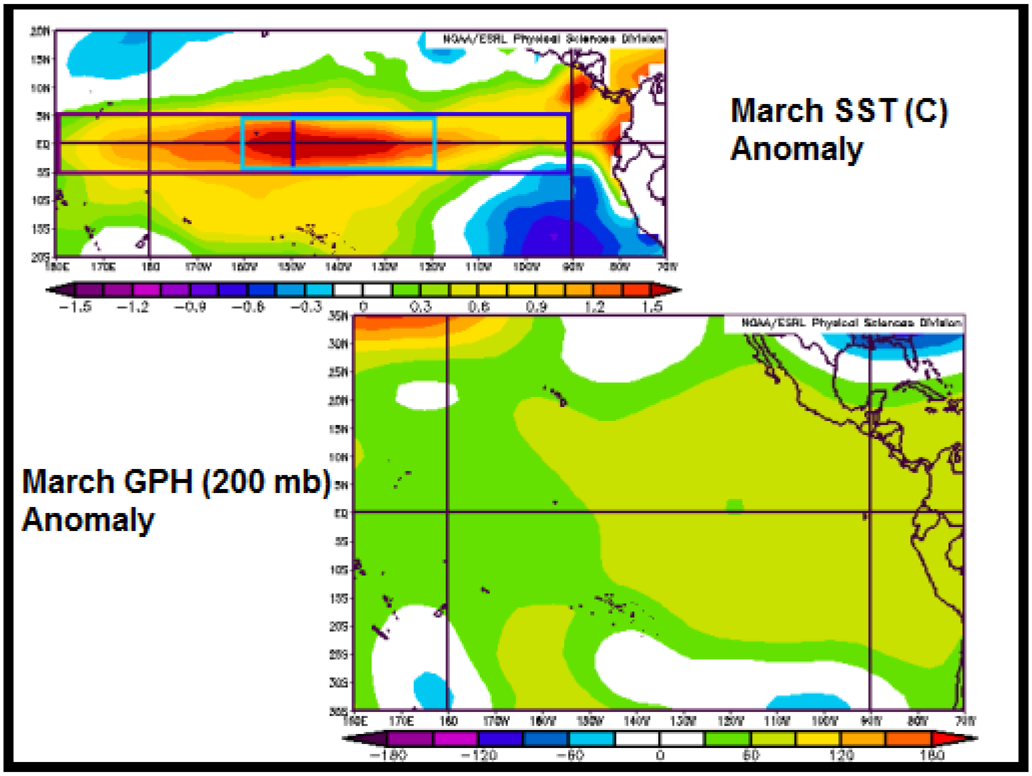

Figure 22

Continued waning of warm SSTs over Central Pacific and accompanied weakening of 200 mb GPH Anomaly.

Data/image provided by or modified from those provided by the NOAA/OAR/ESRL PSD, Boulder, Colorado, USA, from their Web site at http://www.esrl.noaa.gov/psd/

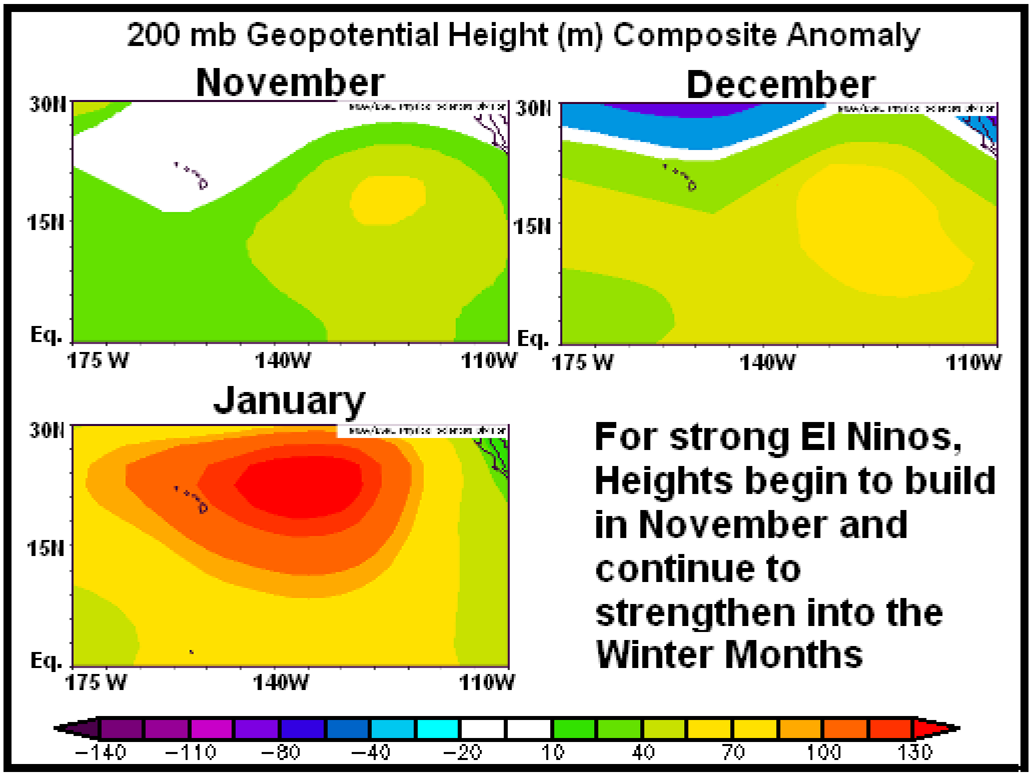

Figure 23

Development of the Northern Pacific upper-level Anti-Cyclone heading into Current (2009-10) Northern Hemisphere Winter.

Data/image provided by or modified from those provided by the NOAA/OAR/ESRL PSD, Boulder, Colorado, USA, from their Web site at http://www.esrl.noaa.gov/psd/

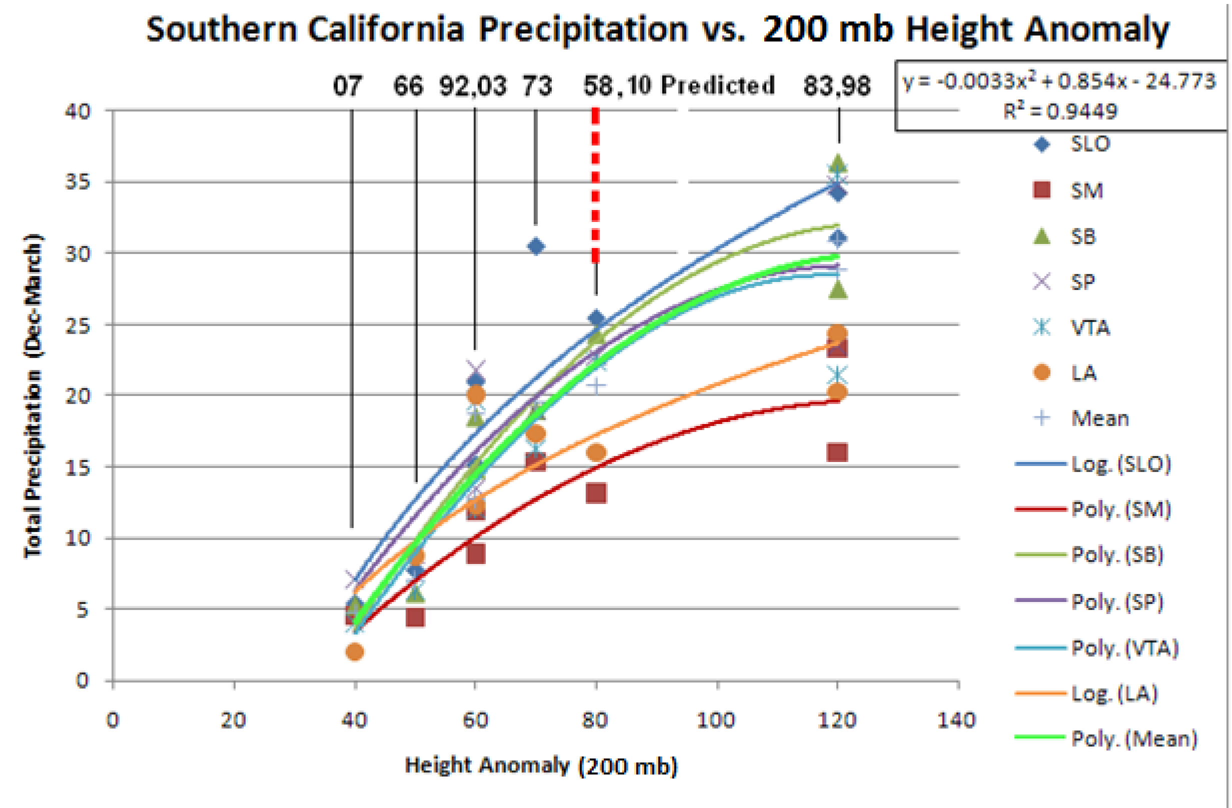

Figure 24

Scatter-plot and trends of 8 Basin-Wide El Niños and predicted precipitation for 2009-10 El Niño based on Dec-March 200 mb GPH Anomaly