THE FLORIDA STATE UNIVERSITY

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STATISTICAL ANALYSIS RELATING EL NIÑO (EL VIEJO) EVENTS TO MONTHLY TEMPERATURE AND PRECIPITATION DEPARTURES IN THE PACIFIC NORTHWEST

By

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ABSTRACT

A thesis presented on the relations of El Niño (warm events) and El Viejo (cold events) to temperature and precipitation departures in the Pacific Northwest, specifically Oregon and Washington. A statistical analysis is performed on the meteorological data for the past 100 years, and results are generated for the use in operational long term forecasting. The results found in this research show the highest significance for temperature and precipitation departures in the Pacific Northwest occurring in the winter months following El Niño (El Viejo) events. There are also fairly strong relations in spring and fall months. The lowest significance occurs in the summer months, where there is little or no significance for most areas in the Pacific Northwest. Winter months following warm events show the highest significance, specifically for warmer than normal conditions. February's following cold events also show high significance for colder than normal conditions. Generally cooler than normal conditions are shown following cold events throughout the year. Generally warmer than normal conditions are found following warm events, especially north of central Oregon in the winter and spring months. Precipitation significance is not as strong and is dependent on the time of year whether drier or normal conditions are expected following a specific event.

1. Introduction and Background

This study examines the affects both El Niño (warm phase) and El Viejo (cold phase) have had on monthly rainfall and temperature departures in the Pacific Northwest using a statistical analysis on the data from 1895 through 1989. Note that the cold phase is often referred to as "La Niña", but in this research the term "El Viejo" will be used.

Previous works have shown a relationship between El Niño years (warm phase) and the winter season snowfall in the Northwest. Specifically, Ferber *et al.* [1993] found that significantly less (more) snowfall occurs in the Puget Sound region following El Niño (El Viejo) years. Also, Halpert and Ropelewski [1992] demonstrated that there is a relationship between northwest temperatures and El Niño Southern Oscillation (ENSO) for the winter season. A weaker relationship was shown to exist for precipitation for the same season [Ropelewski and Halpert, 1986].

Horel and Wallace [1981] found relations only for the winter months in the northwestern part of the United States and southwestern Canada relating ENSO and 700 Mb heights.

So, if there are such strong relationships that occur in the winter months following an El Niño (El Viejo) event in the Pacific Northwest, are there any relationships that exists between El Niño (El Viejo) events and other times of the year?

This research attempts to find temperature and precipitation relationships to El Niño (El Viejo) and the Pacific Northwest by dividing the year into months instead of seasons, then performing a statistical analysis on the data
to El Niño (El Viejo) and the Pacific Northwest by dividing the year into months instead of seasons, then performing a statistical analysis on the data

set for each month following an El Niño or El Viejo. Also in this research, the Pacific Northwest is divided into separate sections to determine if there is more significance in certain areas following an El Niño (El Viejo) event. Figures 1 and 2 display the divisions analyzed in this research, along with the average annual precipitation and temperatures from 1895-1989 for each region.

The first major division of the Pacific Northwest is the Cascade Mountains (figure 1, area 5 in Washington and area 4 in Oregon). These mountains tend to block most of the moisture associated with Pacific cold fronts from traveling to the leeward side, causing more of a maritime weather regime west of the Cascades and a continental regime to the east. Many eastern areas still experience winds with Pacific weather fronts, mainly due to downslope features in the terrain, but precipitation amounts are generally light. The exception to this is when a warm front is moving into the area from the south, with a southeast gradient causing upslope conditions along the eastern parts of the Cascades and thus higher precipitation amounts. These weather patterns will be analyzed according to the results of the statistical analysis and how El Niño (El Viejo) may play a role in the weather patterns.

The Olympic Mountains in the northwest part of Washington divide the true maritime coastal weather regime and the Puget Sound Lowlands. One can see that the true coastal regime (figure 1, area 1 in Washington) receives over three times the precipitation compared to the northwest interior of Washington (figure 1, area 2 in Washington). This is mainly caused by a rainshadow affect of the Olympic Mountains due to a predominantly southwesterly flow during precipitation events. The Puget Sound Lowlands

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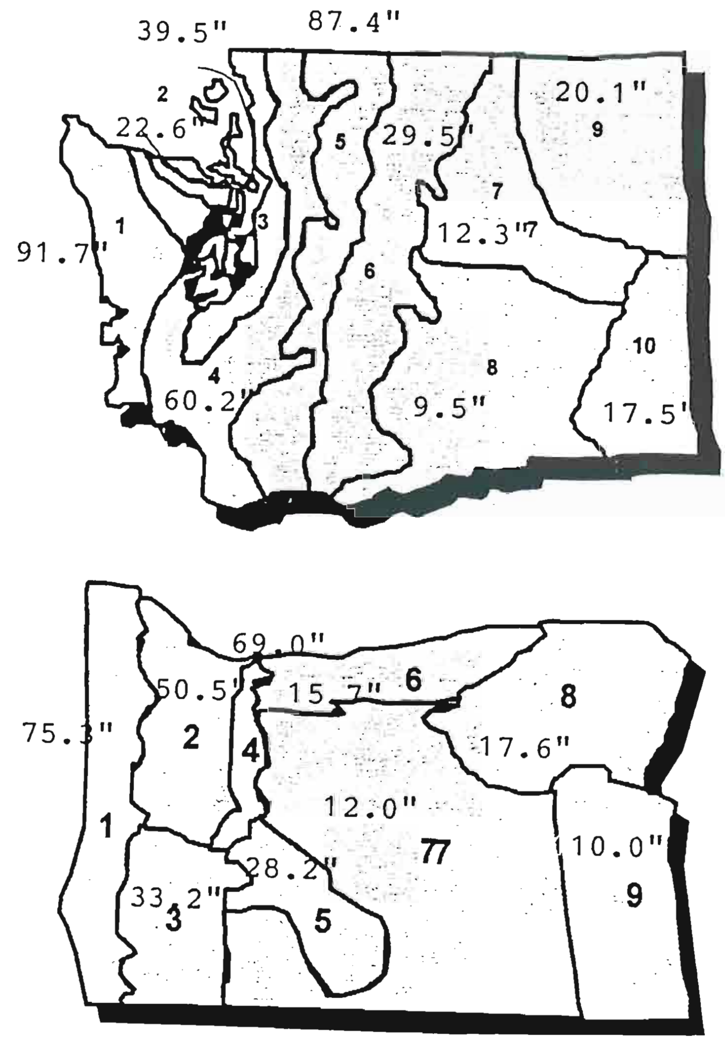


Figure 1: Average precipitation.

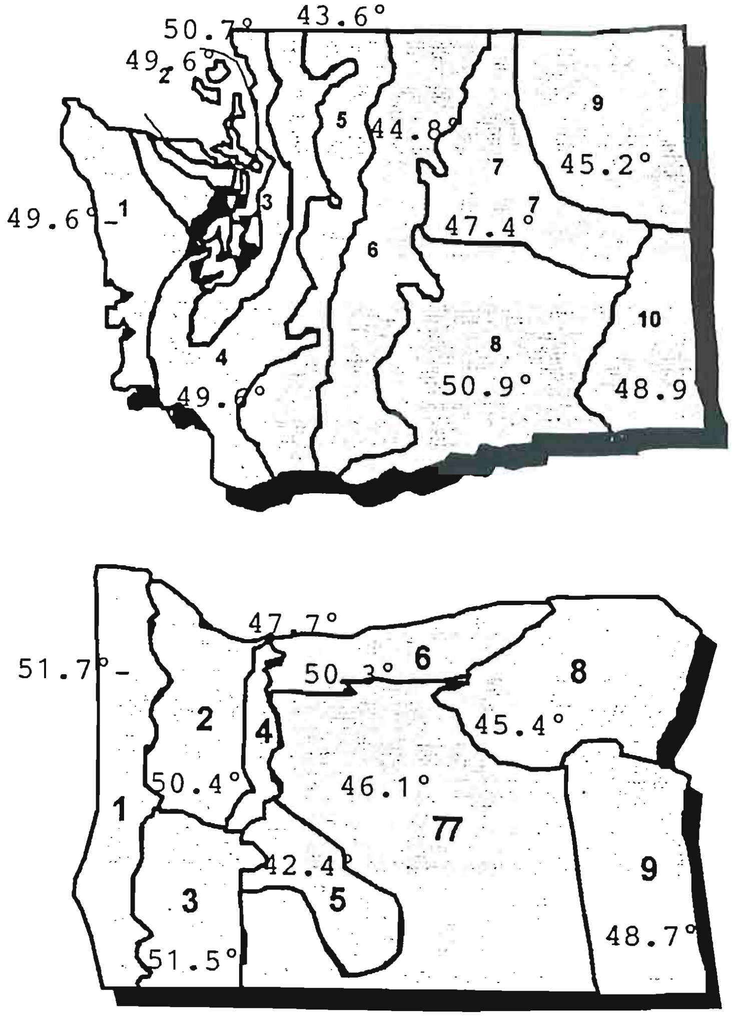


Figure 2: Average temperature.

(figure 1, area 3 in Washington) has slightly more rainfall than the northwest interior, since the rainshadow effect is mainly north of Central Puget Sound. Also, there is a local weather feature which develops generally in the central to north Puget Sound region due to the terrain and a convergence of winds. This local weather feature, known as the Puget Sound Convergence Zone (PSCZ), causes about twice as much rainfall annually in north Sound areas versus north areas of the San Juan Islands. Occasionally south parts of the San Juan Islands will receive slightly more rainfall due to this PSCZ, but generally, the affects are south of the San Juan Islands. Thus, although the Puget Sound Lowlands and the San Juan Islands are to the west of the Cascades and do possess some maritime characteristics, there are still differences from the true coastal regime.

The Olympics end in the southern third of the state with a fairly flat land mass for about 50 miles until the Coastal Range of southern Washington and Oregon. This fairly flat area in southwest Washington (figure 1, area 4 in Washington) allows for much higher precipitation amounts compared to the Puget Sound Lowlands and northwest interior.

An anomalous area to the west of the Cascades is the Willamette Valley in the northwest part of Oregon (figure 1, area 2 in Oregon). A major factor contributing to the overall weather scheme in the Willamette Valley is the Columbia Gorge, linking a path to the eastern part of the state and allowing for much cooler (warmer), continental air to seep into the region in the winter (summer) compared to other western Oregon and Washington locations.

Areas east of the Cascades also have different overall weather patterns due

(summer) compared to other western Oregon and Washington locations.

Areas east of the Cascades also have different overall weather patterns due

to terrain and location. The east slopes of the Cascades in Washington (figure 1, area 6) have much lower precipitation amounts compared to the western and central portions, although still higher precipitation amounts than the central locations of the Okanogan Big Bend area (figure 1, area 7 in Washington) and the Central Basin area (figure 1, area 8 in Washington).

The Okanogan Big Bend area in the northern part of Washington (figure 1, area 7) is a mountainous region, although not as large of a range as the Cascades. This mountainous region picks up more moisture than the Central Basin areas (figure 1, area 8 in Washington), although not as much as the Cascades due to its inland location and lower elevation. The Okanogan valley part of the region is an anonymously dry area, but the mountains surrounding the valley pick up more moisture, thus causing a higher precipitation average for the entire region. The Central Basin region has an arid climate with the lowest annual precipitation average in the state of Washington. In the winter, temperature inversions cause extended periods of fog and low clouds in the Central Basin region causing little variation in temperature for several days or even weeks. Average temperatures in the winter in the Central Basin area are greatly affected by snow cover. If there is snow cover already in place when an inversion sets up, the average temperature will be much cooler than if there were no snow cover in place. Thus, snow cover may also be a factor with temperature departures due to El Niño (El Viejo) events, depending if there is snow cover in place when the weather pattern develops which follows an El Niño (El Viejo).

Northeastern Washington (figure 1, area 9) will also experience

Nino (El Viejo).

Northeastern Washington (figure 1, area 9) will also experience

temperature inversions, along with fog and low clouds in the winter, although the northeastern areas will scour more easily than the Central Basin due to winds or a weather system passing through the area. Also, the Rocky Mountains are just to the east of northeastern Washington, causing higher precipitation amounts for this area compared to the Central Basin due to upslope conditions.

The Blue Mountains (figure 1, area 10 in Washington), located in the southeastern part of Washington, also cause some upslope conditions, with higher precipitation amounts than the Central Basin, but lower precipitation amounts than the northeast due to location.

Generally, areas further south are drier than northern locations with similar topography since weather systems tend to travel a more northern route (due to the Pacific low in the winter months). Annual precipitation averages demonstrate this for the coasts of Oregon and Washington, with the Washington coast on average receiving over 15 inches of precipitation more than the Oregon coast (figure 1). This is also true for the southwestern part of Oregon. The terrain does not differ significantly from its neighbor to the north, the Willamette Valley, but precipitation averages are much lower in the southwestern part of the state simply due to location.

Then why does the lowest annual precipitation average occur in the Central Basin region of Washington? This is simply due to terrain. Most moisture is completely blocked by the Cascades directly to the west of the Central Basin area. North Central Oregon, directly to the south of the Central Basin region contains the Wallowa Mountains which cause slightly higher
Central Basin area. North Central Oregon, directly to the south of the Central Basin region contains the Wallowa Mountains which cause slightly higher

precipitation averages. South Central Oregon also has a few small mountain ranges within its boundaries to cause slightly higher precipitation averages than the Central Basin area of Washington.

Southeastern Oregon is almost as dry as the Central Basin region, but there is a small mountain range just to the east (the Owyhee Mountains) causing upslope conditions in the rare events that there is moisture available, and thus slightly higher precipitation averages than the Central Basin.

Annual temperature averages for the Pacific Northwest are rather deceptive, especially east of the Cascades due to extremities in temperature from summer to winter, along with overnight and afternoon differences. Summers (winters) east of the Cascades are much warmer (cooler) than western areas due to the continental affects, but yearly averaged temperatures are fairly similar west and east of the Cascades (figure 2).

Hence with such different types of weather patterns east and west of the Cascades, will the Cascades divide the western and eastern parts of the state into different weather patterns following an El Niño or El Viejo? How much of an effect will latitude have on the effects of the weather patterns following these events? This research attempts to answer some of these questions to provide a guideline for long term forecasting in the Pacific Northwest for a particular area.

2. Data

The data used for this research was taken from the National Climatic Data Center (NCDC) CD-ROM products. Specifically, monthly temperature and precipitation data was used from 1895 through 1989, dividing the Pacific Northwest region into several sections, as shown in figure 1. First order weather stations have been used, along with cooperative weather stations staffed by volunteer weather observers. Note that over the 95 years the data spans that observation sights as well as measuring devices have been moved. Whether the change in location is 2 meters or 2 kilometers, there will be discontinuities in the data. Discontinuous inhomogeneities due to these inconsistencies are minimized using the methodology of Karl and Williams [1987]. Temperature bias must also be corrected since the weather observation stations did not all record data from midnight to midnight. Hence, a multilinear regression model developed by Karl *et al.* [1986] is used to correct for any temperature bias in the data.

Temperature and precipitation departures were calculated for each month from the raw data and used in the analysis. Monthly rainfall amounts and temperatures for Washington and Oregon were examined and statistically compared to historical averages for that particular station for that particular month.

An "El Niño" or "El Viejo" event was classified using the definitions of Quinn *et al.* [1987] and Halpert and Ropelewski [1992], respectively. Note that due to data availability there are slight differences in the definitions of these opposite events. The "El Niño" definition is based on sea surface temperatures
due to data availability there are slight differences in the definitions of these opposite events. The "El Niño" definition is based on sea surface temperatures

Table 1: Categorization of El Niño and El Viejo Years.

El Niño Years	El Viejo Years
1896, 1899, 1902, 1905	1904, 1909, 1910, 1915
1907, 1911, 1914, 1917	1924, 1928, 1938, 1950
1918, 1923, 1925, 1930	1955, 1956, 1964, 1970
1932, 1939, 1940, 1943	1971, 1973, 1975, 1988
1951, 1953, 1957, 1965	
1972, 1976, 1982, 1987	

at the equator, while the "El Viejo" definition is based on the Southern Oscillation pressure differences between Tahiti and Darwin. The differences are slight, but noted here. Since there is a lag time associated with El Niño affects from the equator to the Pacific Northwest, one year has been added to the defined El Niño (El Viejo) years in table 1 for this research. Hence, for the El Niño year 1957, September 1958 is the month categorized as an El Niño for this study.

El Niño years have also been classified as weak (W), moderate (M), strong moderate (M+), strong (S), and very strong (VS) (Quinn *et al.* [1987]). Further classifications were also made, grouping the M+, S, and VS classifications into one category and performing the analysis to determine if the strength of the El Niño event plays a role in the effect of temperature and precipitation departures in the Pacific Northwest.
the strength of the El Niño event plays a role in the effect of temperature and precipitation departures in the Pacific Northwest.

3. Technique

Each year from 1895-1989 was categorized as "El Niño", "El Viejo", or "neutral" as described in the previous chapter. El Niño years were further classified into "strong" and "weak" categories, using the definition of Quinn *et al.* [1987] as a guideline. Monthly temperature and rainfall departures were analyzed for significant differences from normal using a statistical analysis for each category (i.e. El Niño, Strong El Niño, or El Viejo).

Standard deviations were computed for each group of data, using the equation

$$\sigma = \sqrt{\sum \frac{x^2}{N} - \sum \left(\frac{x}{N}\right)^2}, \tag{1}$$

where σ is the standard deviation, x is the value (either the temperature or rainfall departure from normal), and N is the number of cases in each category. After standard deviations were computed for monthly temperature and rainfall departures from normal for El Niño years, strong El Niño years, and El Viejo years, a test of significance was performed for each category.

The general hypothesis used for the test of significance states: There is a "certain percentage" confidence level that "a particular month" following an El Niño (El Viejo) year will be drier (wetter, colder, warmer) than normal. A value Z was computed to test this hypothesis using the formula

$$Z = \frac{(u - u_x)\sqrt{N}}{\sigma}, \tag{2}$$

where u is the mean of the category being tested (i.e. the sample mean); u_x is
the mean of all years from 1895-1989 for the temperature de...

where u is the mean of the category being tested (i.e. the sample mean); u_x is the mean of all years from 1895-1989 for the temperature departure or

Table 2: Level of significance for a one-sided test with regards to a critical value Z.

Level of significance	Critical value of Z
0.100	< -1.28 or > 1.28
0.050	< -1.645 or > 1.645
0.010	< -2.33 or > 2.33
0.005	< -2.58 or > 2.58
0.002	< -2.88 or > 2.88

precipitation departure for that particular month (i.e. the population mean); σ is the standard deviation calculated from equation 1; and N is the number of cases for the particular category being tested. A "one sided" test was used on the data, where Z was compared to the values in table 2 to determine if the data was statistically significant, and to what degree of confidence. Thus, if $Z = 1.30$, there would be a 90% confidence level that the data was statistically significant. If $z > 2.88$ or $z < -2.88$, there would be a 99.8% confidence level that the data was statistically significant. The closer Z is to zero, the more "normal" it is, and thus less significant. A value of Z equal to zero would mean no significance in the data exists.

A "two sided" test was also used on the data, with table 3 showing the critical values of Z for this test. To calculate Z, the same procedure is used as a one-sided test, but both "tails" of the normal table are included in a two-sided test, thus there is not quite as high of significance as a one-sided

a one-sided test, but both "tails" of the normal table are included in a two-sided test, thus there is not quite as high of significance as a one-sided

Table 3: Level of significance for a two-sided test with regards to a critical value Z.

Level of significance	Critical value of Z
0.100	< -1.645 or > 1.645
0.050	< -1.96 or > 1.96
0.010	< -2.58 or > 2.58
0.005	< -2.81 or > 2.81
0.002	< -3.08 or > 3.08

test. Results for the two-sided test are also included in the next chapter, although a composite table is used. Instead of 9 sections for Oregon and 10 sections for Washington, each state is divided into two areas, namely west of the Cascades and east of the Cascades (the Cascade Mountain region is included in the western division). If any significance above a 90% confidence level is recorded in that particular area, the result is included in the composite table. Hence, there is not as much detail to significance or region as in the figures for the one-sided tests, but the composite tables for the two-sided tests do show a general pattern of the results, discussed in the next chapter.

4. Results

4.1 One-sided test

Results for a one-sided test are displayed in figures 4 through 42. Washington and Oregon are laid out geographically with Washington located to the north of Oregon. Each state is divided into several sections, numbered 1-7 for Washington and 1-7 for Oregon, hence all descriptions below detail if the area is in Washington or Oregon. Figure 3 defines the legend of figures 4 through 42 Composite tables for a two-sided test are shown in figures 43 through 46 in the next section.

El Niño years, temperature departures

Both Oregon and Washington show strong relations of warmer than normal conditions for January's following El Niño years (figure 4). In fact, the entire state of Washington shows over 99% confidence levels of warmer than normal conditions, and all of Oregon shows at least 90% confidence levels of warmer than normal conditions, with many areas in Oregon showing 99% confidence levels. February's also show strong relations of warmer than normal temperatures following an El Niño for the entire state of Washington and the north and west parts of Oregon. Southern Oregon shows no temperature significance for February's following a warm event (figure 5). It is interesting to note that the strongest significance of warmer than normal conditions continuing for the longest time frame occurs in northern areas. This suggests there is more storm activity in the southern areas that would limit the afternoon heating, which agrees well with the precipitation departure results there is more storm activity in the southern areas that would limit the afternoon heating, which agrees well with the precipitation departure results

of drier than normal conditions to the north, but no significance to the south.

Only a couple of areas in northern Washington show warmer than normal conditions for March's following an El Niño, specifically northeastern Washington and the Puget Sound Lowlands. April shows strong relations of warmer than normal temperatures again both in Oregon and Washington (figure 6). There is still some relation of warmer than normal conditions into May, although not as strong as April (figure 7). June's following warm events also show some weaker relations of warmer than normal temperatures in far eastern Washington, otherwise no temperature relations exist for summer months following El Niño's in Oregon or Washington.

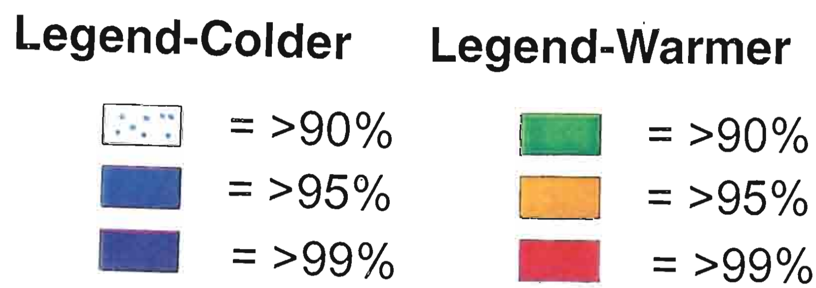
Annually both Oregon and Washington show warmer than normal conditions following an El Niño, except for the Puget Sound Lowlands area (figure 8). Note that the Puget Sound Lowlands does show significantly warmer than normal conditions for January and February's following El Niño's, but the other months filters out this relation when comparing the entire year.

El Niño years, precipitation departures

There is some minor significance of drier than normal conditions following warm events from January through March, although the strongest relations do not occur until April's following El Niño's. January's show drier than normal conditions for the mountains in Washington, southwestern Washington, the northwest corner of Washington, and northeastern Oregon (figure 9). February's following warm events show drier than normal conditions for much

northwest corner of Washington, and northeastern Oregon (figure 9). February's following warm events show drier than normal conditions for much

Temperature Legend



Precipitation Legend

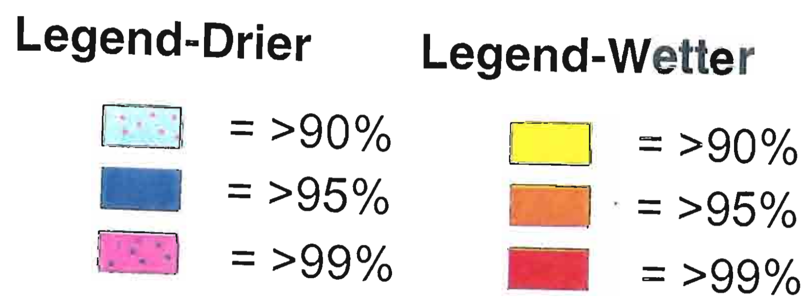
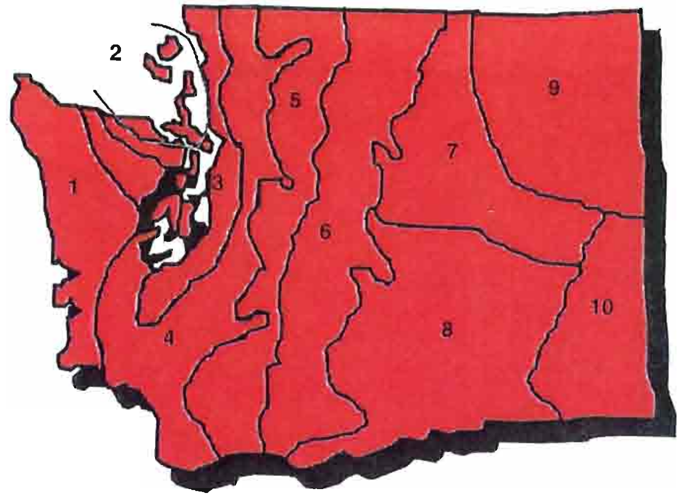


Figure 3: Temperature and precipitation legends.



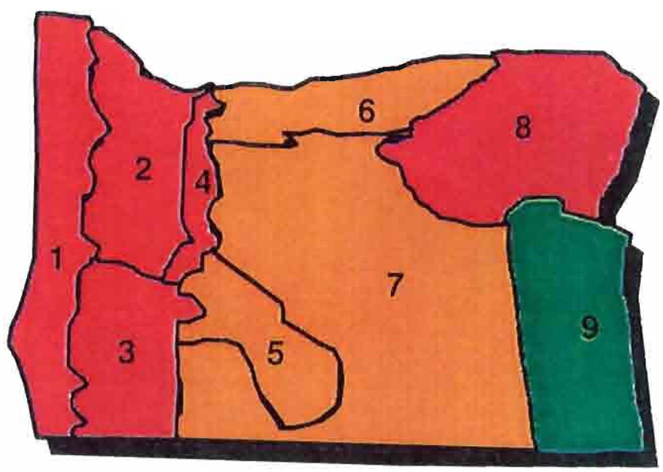


Figure 4: El Niño years - January temperature significance. Colored regions are as defined in figure 3.

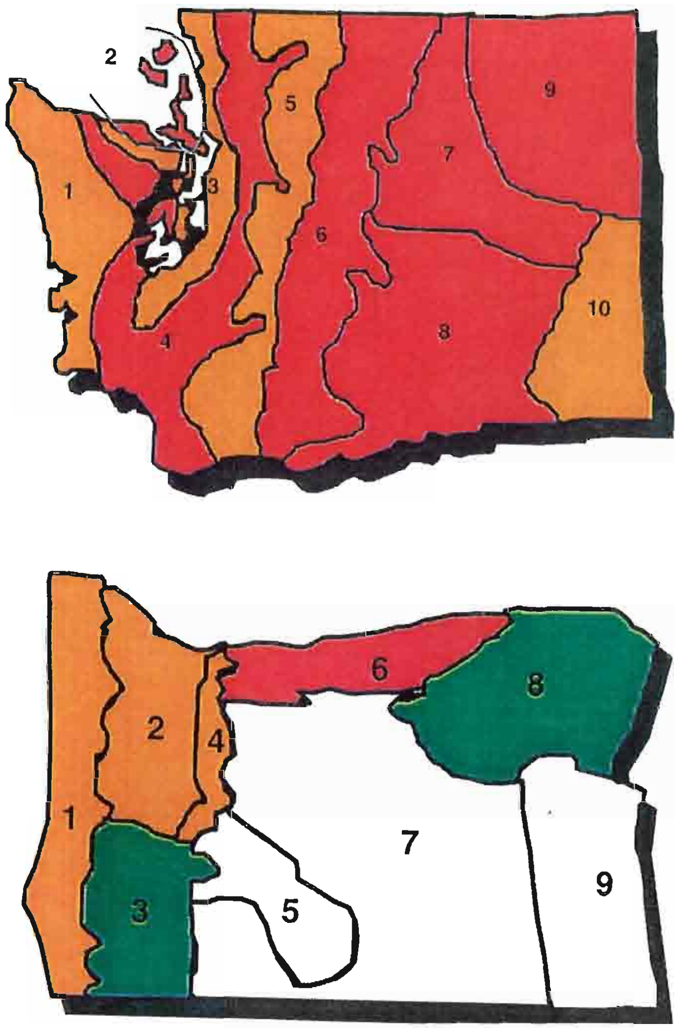


Figure 5: El Niño years - February temperature significance. Colored regions are as defined in figure 3.

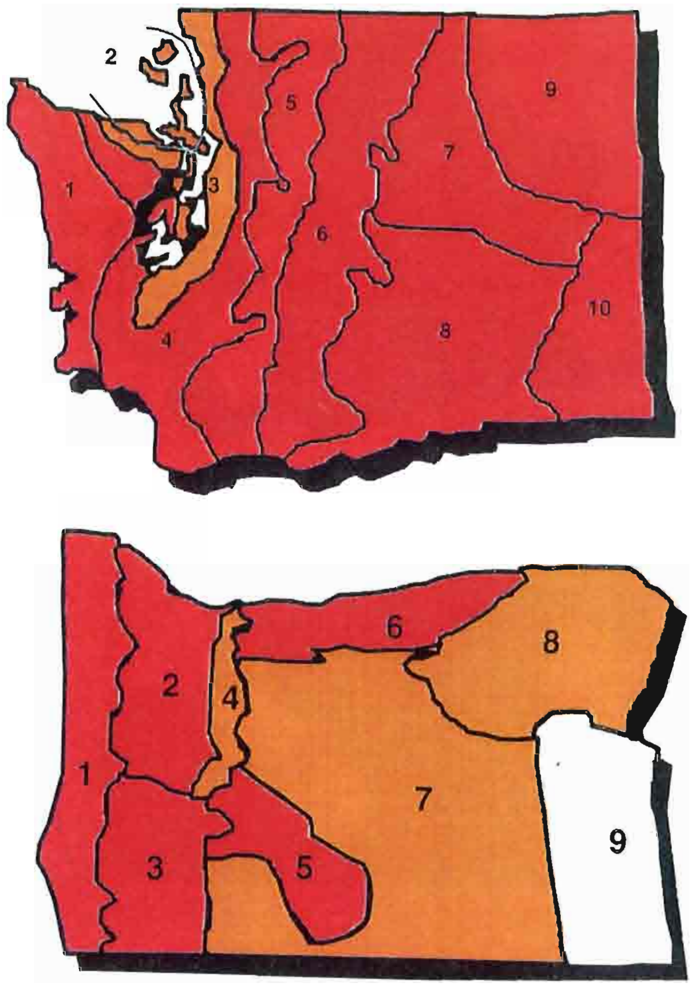


Figure 6: El Niño years - April temperature significance. Colored regions are as defined in figure 3.

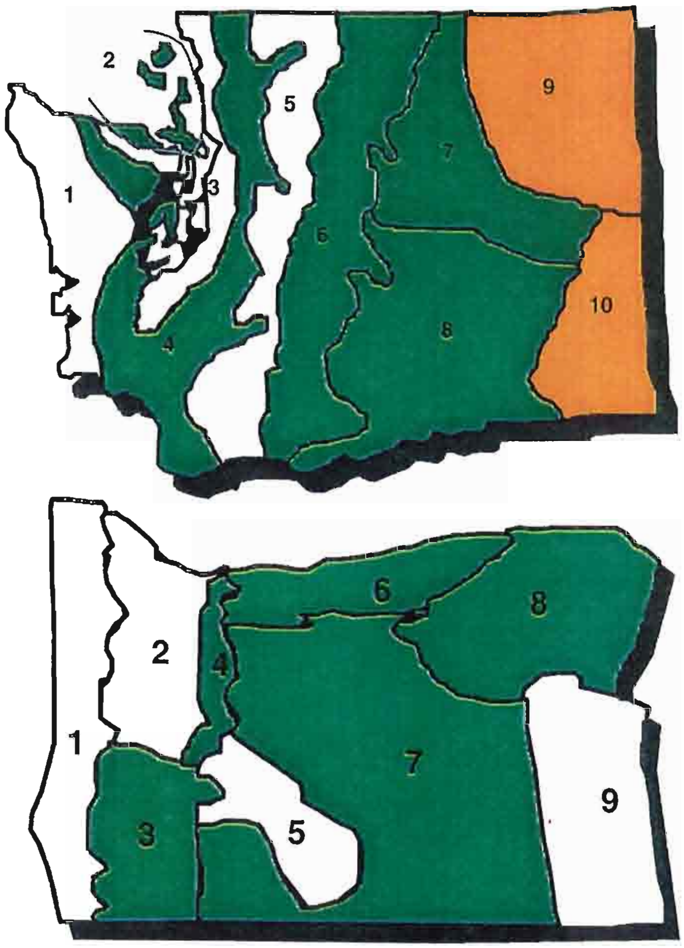


Figure 7: El Niño years - May temperature significance. Colored regions are as defined in figure 3.

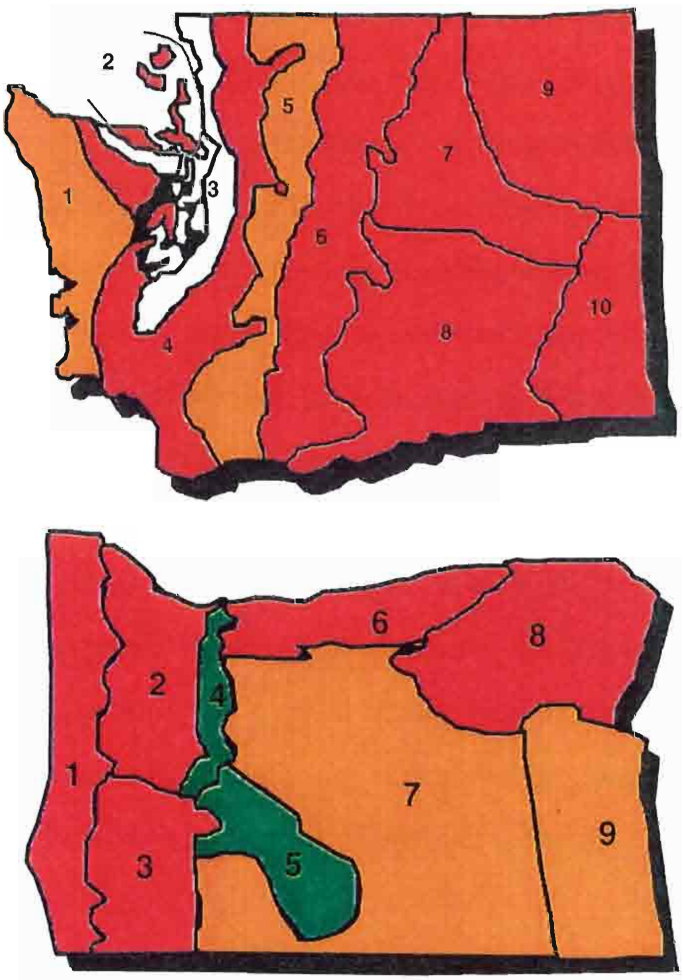


Figure 8: El Niño years - annual temperature significance. Colored regions are as defined in figure 3.

of western Washington (figure 10). March's following El Niño's show drier than normal conditions only in the Oregon Cascades.

April's show strong significance following El Niño years for drier than normal conditions for both Washington and Oregon (figure 11). No significance exists for the summer months for precipitation departures in Oregon or Washington following warm events. The next significance for precipitation departures does not occur until September, which only shows 90% confidence levels of wetter than normal conditions in the Okanogan Big Bend area. November's following El Niño years show wetter than normal conditions in much of eastern Washington and the north central part of Oregon (figure 12). Western areas show no significance in November's following warm events which would suggest some type of upper level disturbance develops to the east of the Cascades, causing upslope conditions in eastern parts of the state, but normal rainfall amounts west of the Cascades.

December's show weak significance of wetter than normal conditions in the Okanogan Big Bend area, otherwise no significance exists in Oregon or Washington.

A frequent weather pattern to set up following El Niño years for the first part of the year is for weather systems to split. Hence, in the late winter and spring months following a warm event, weather systems tend to split north and south of the Pacific Northwest (at least as far south as the precipitation and temperature results indicate), with drier and warmer than normal conditions in these areas that the storms bypass.

conditions in these areas that the storms bypass.

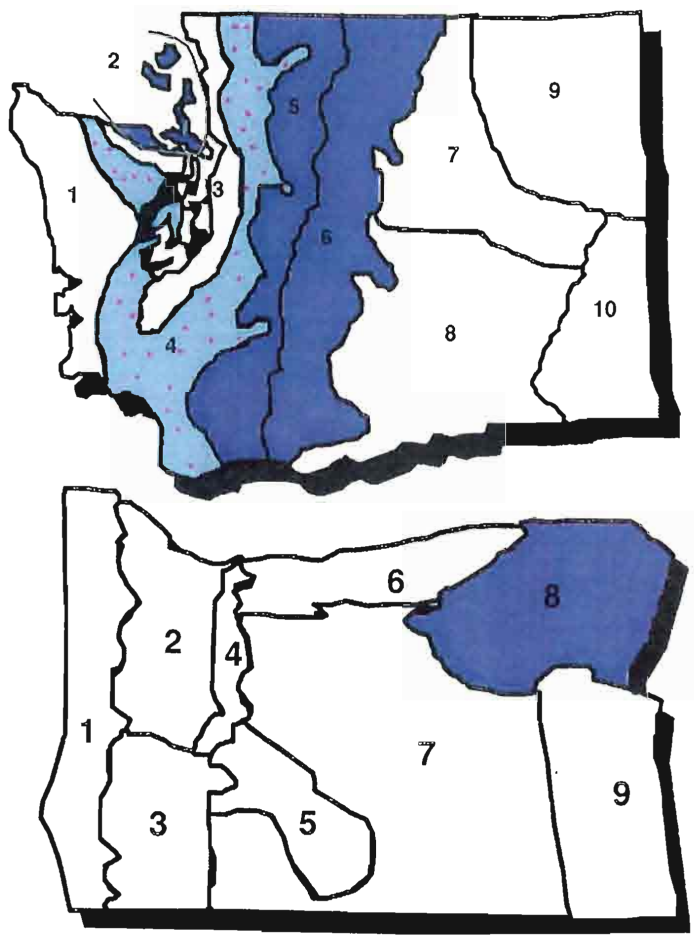


Figure 9: El Niño years - January precipitation significance. Colored regions are as defined in figure 3.

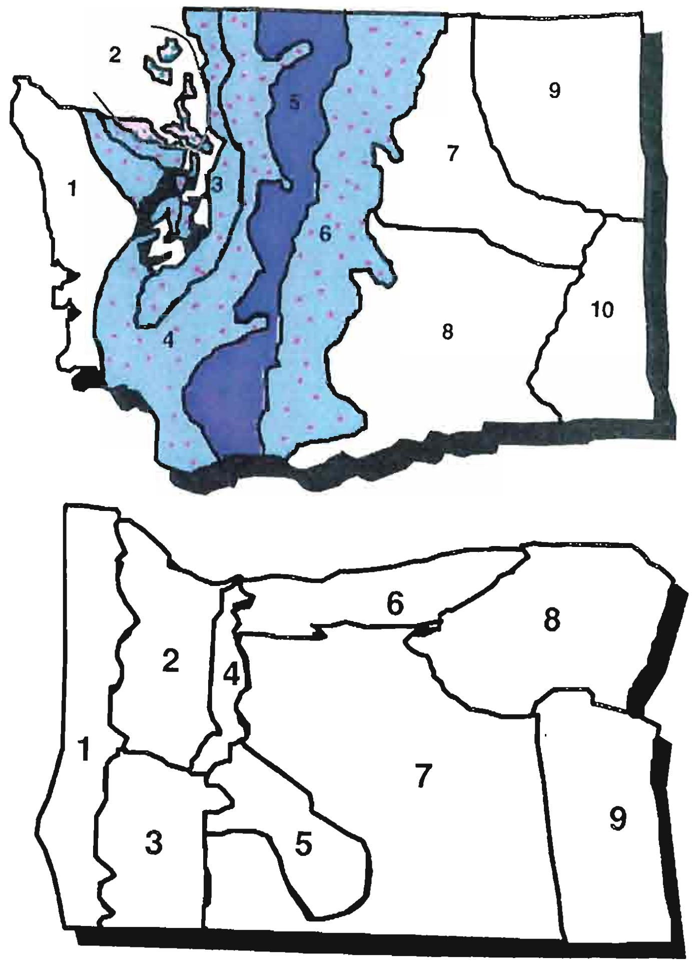


Figure 10: El Niño years - February precipitation significance. Colored regions are as defined in figure 3.

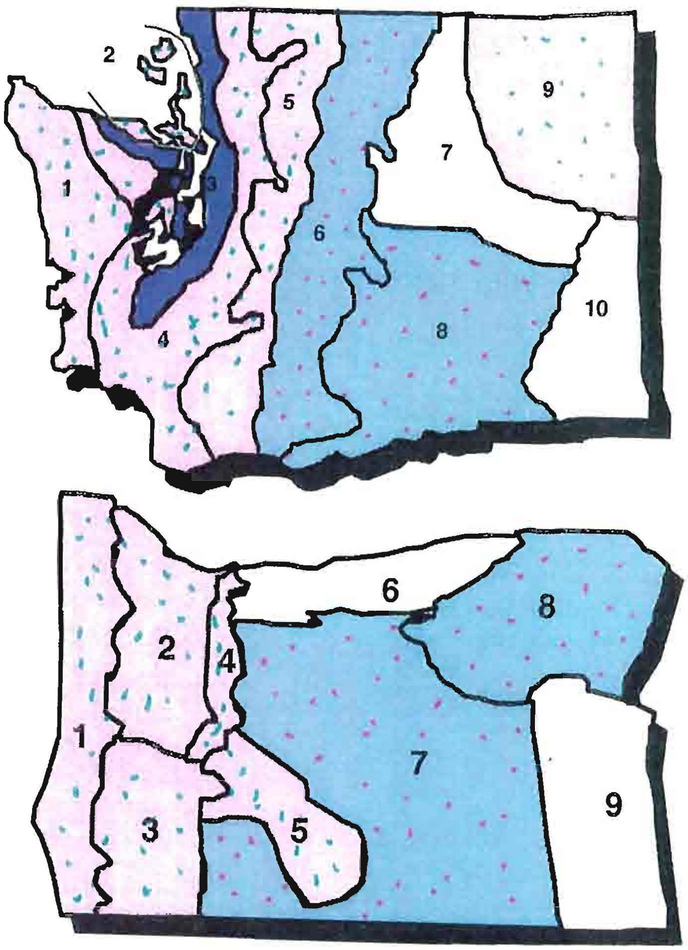


Figure 11: El Niño years - April precipitation significance. Colored regions are as defined in figure 3.

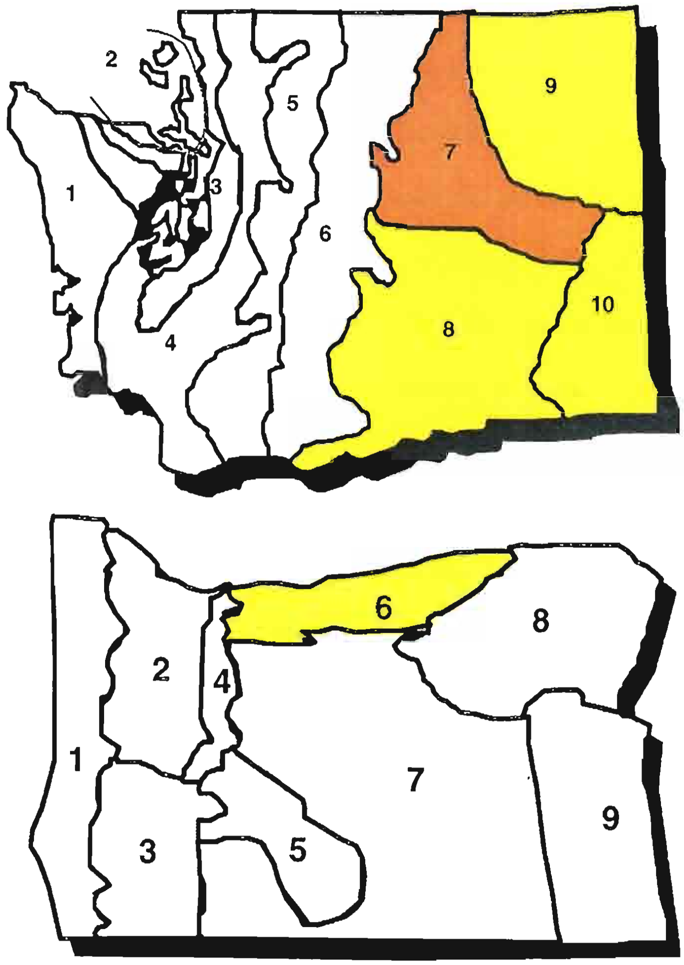


Figure 12: El Niño years - November precipitation significance. Colored regions are as defined in figure 3.

Strong El Niño years, temperature departures

Similar to January's following El Niño years, January's following strong El Niño years show strong significance of warmer than normal conditions for both Washington and Oregon, with stronger significance for eastern Oregon than normal El Niño years (figure 13). February's following strong El Niño years also show significance of warmer than normal conditions in most areas in Washington and northern Oregon, although not as strong as significance as normal El Niño years show (figure 14). March's following strong El Niño years show weak significance of warmer than normal conditions for many areas in Washington, but no significance exists for the entire state of Oregon (figure 15).

April's following strong El Niño years still show significance of warmer than normal temperatures for most areas in Washington and western Oregon, but not as much significance as normal El Niño years show (figure 16). The biggest difference for April's following strong El Niño years is that eastern Oregon does not show any significant in temperature departures, while most areas in eastern Oregon do show significance following normal El Niño years. May's following strong El Niño years are very similar to May's following normal El Niño years, with warmer than normal conditions in most areas (figure 17).

June's following strong El Niño events show much stronger relations than normal El Niño years for more areas with warmer than normal conditions (figure 18). A transition occurs following strong El Niño years in southeastern Oregon in July's, with a 90% confidence level of cooler than normal conditions (figure 19).

Oregon in July's, with a 90% confidence level of cooler than normal conditions (figure 19).

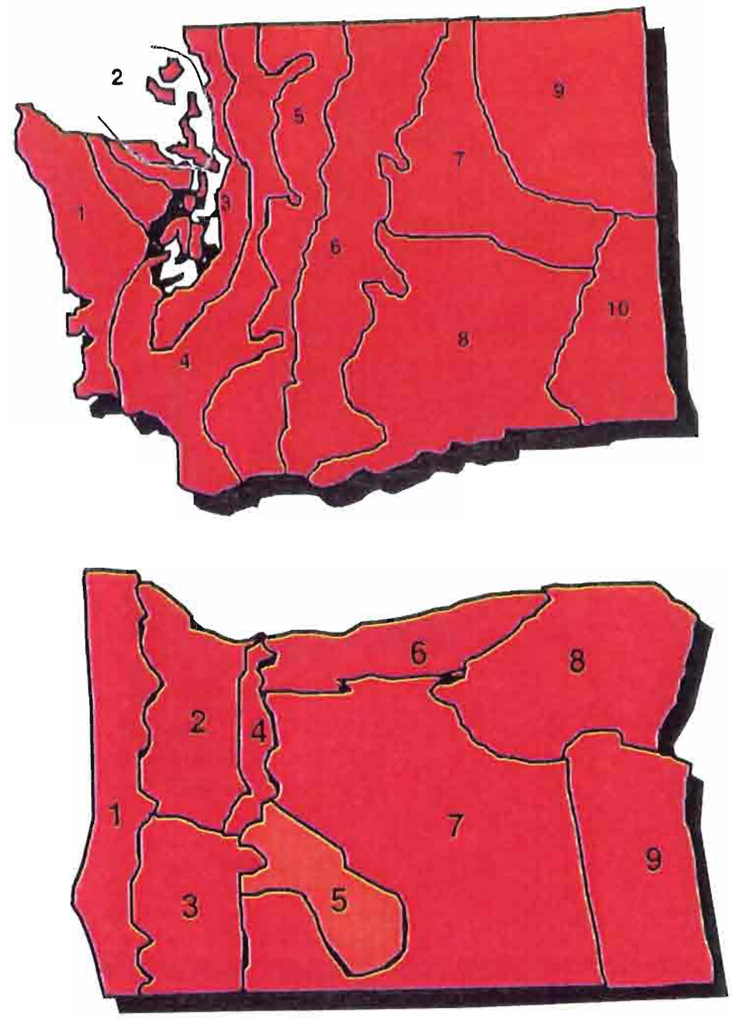


Figure 13: Strong El Niño years - January temperature significance. Colored regions are as defined in figure 3.

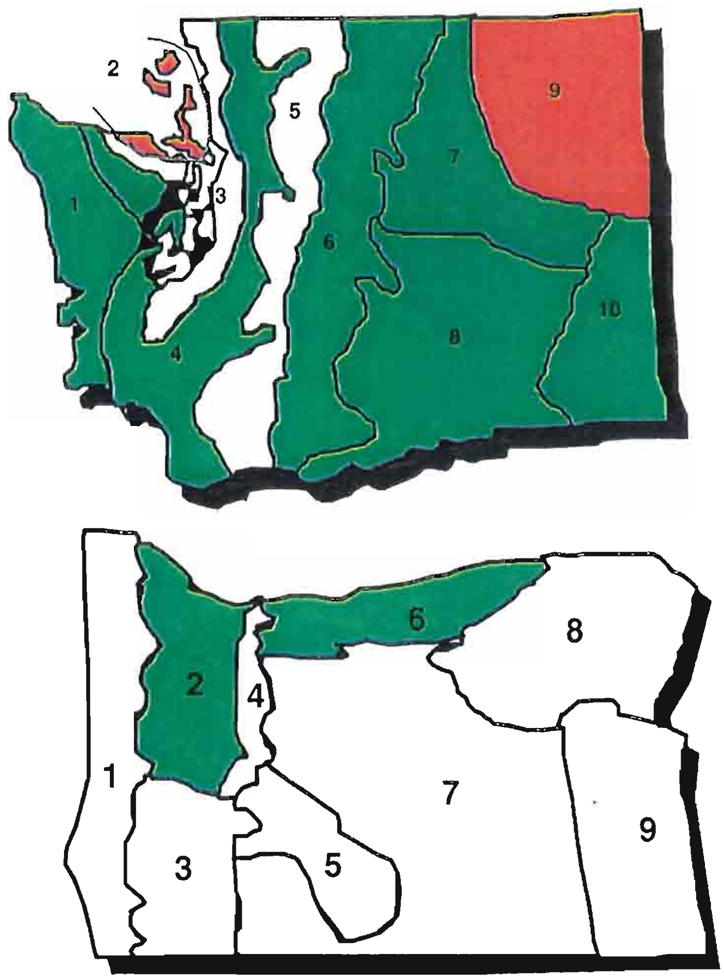


Figure 14: Strong El Niño years - February temperature significance. Colored regions are as defined in figure 3.

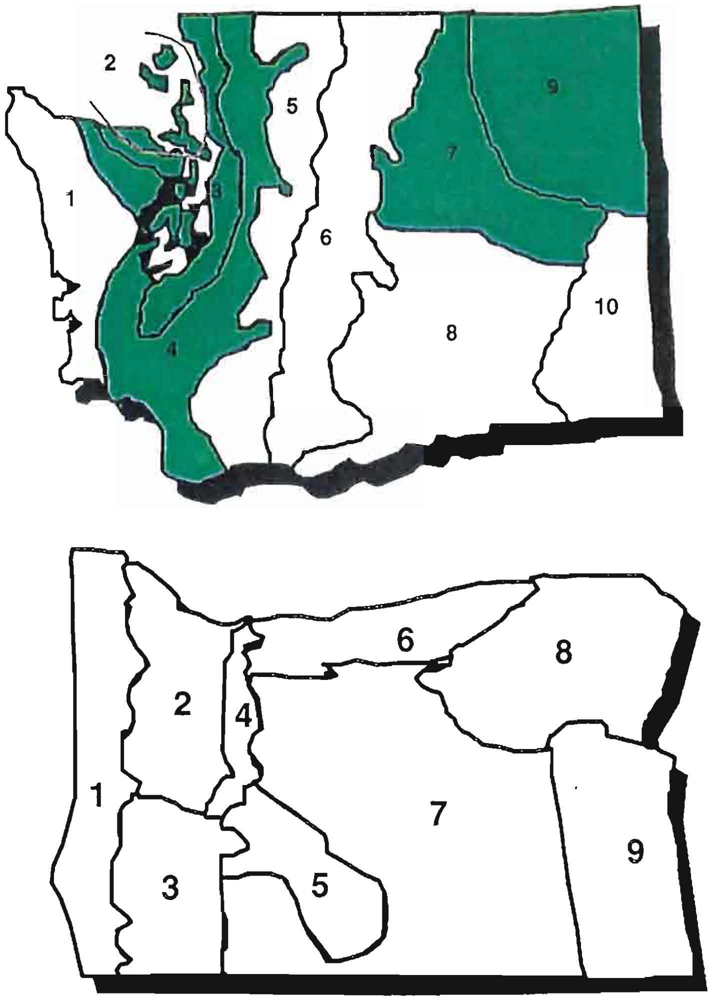


Figure 15: Strong El Niño years - March temperature significance. Colored regions are as defined in figure 3.

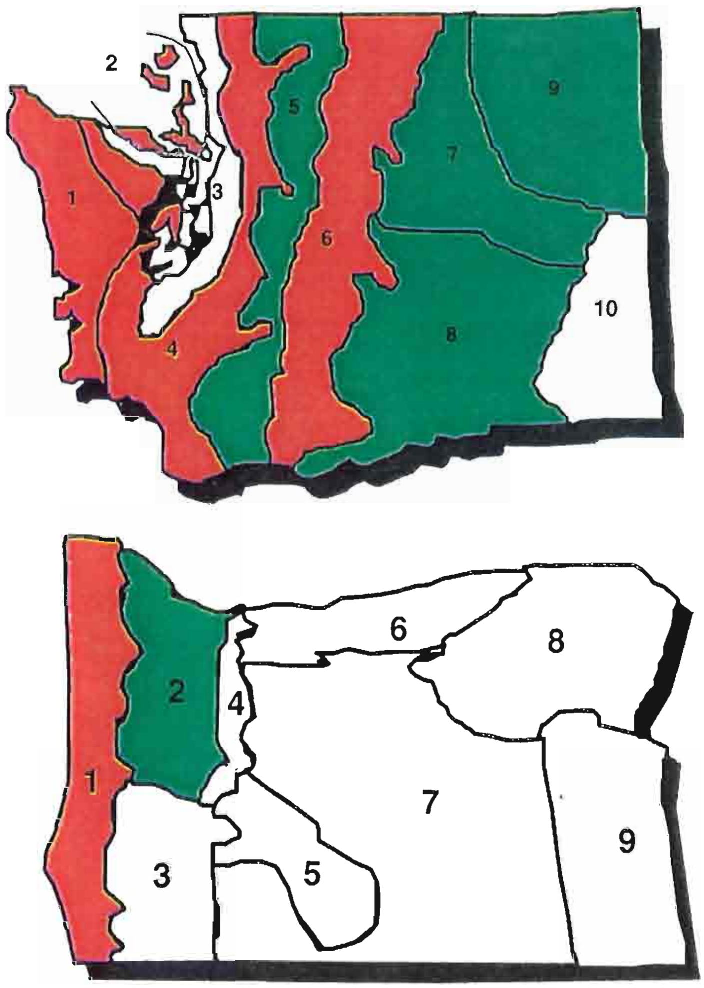


Figure 16: Strong El Niño years - April temperature significance. Colored regions are as defined in figure 3.

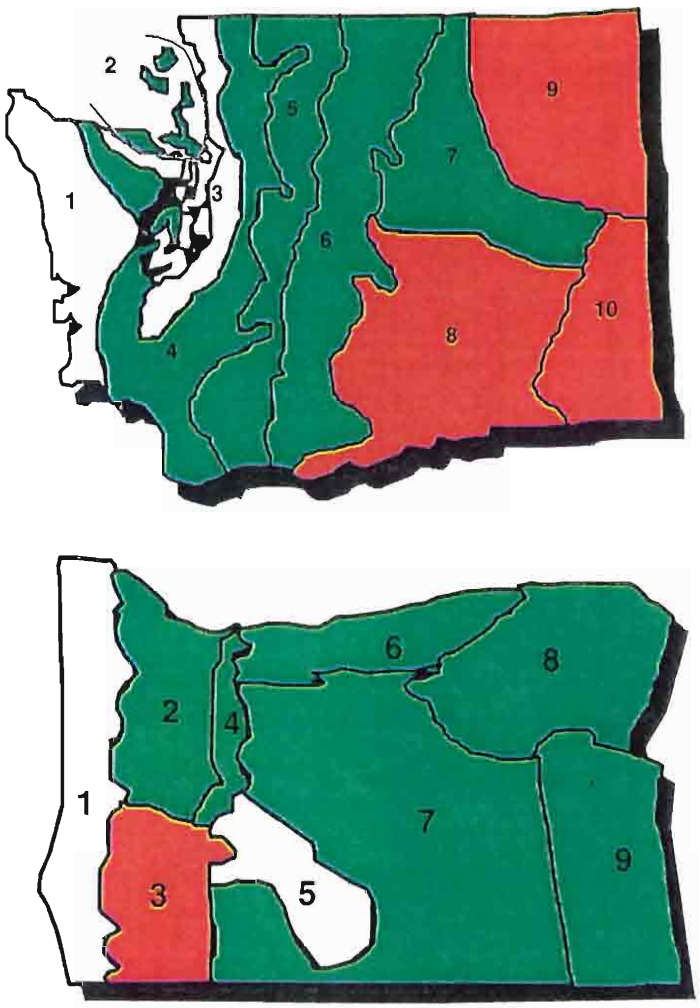


Figure 17: Strong El Niño years - May temperature significance. Colored regions are as defined in figure 3.

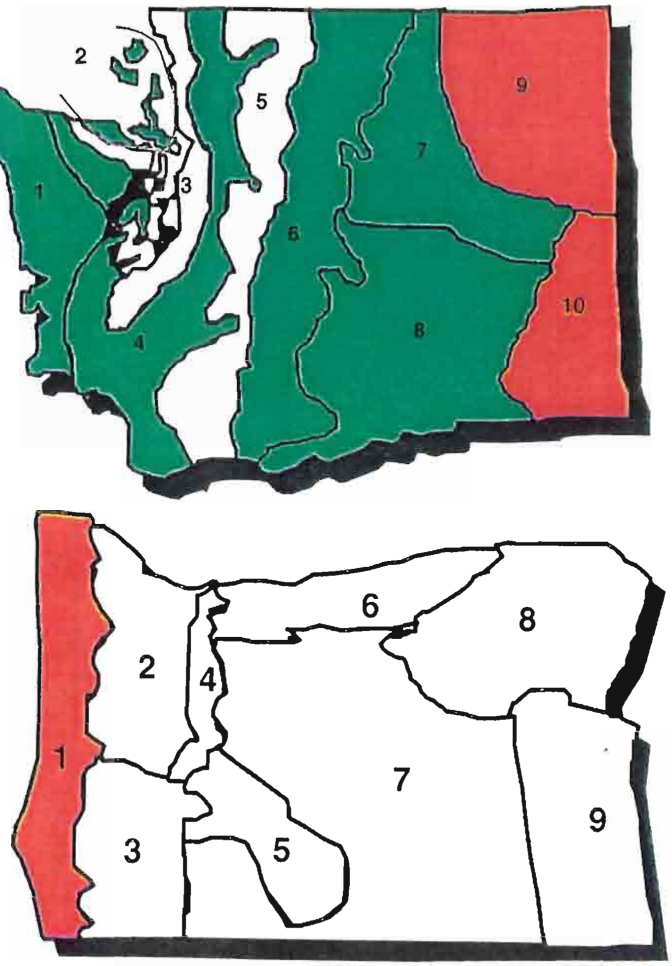


Figure 18: Strong El Niño years - June temperature significance. Colored regions are as defined in figure 3.

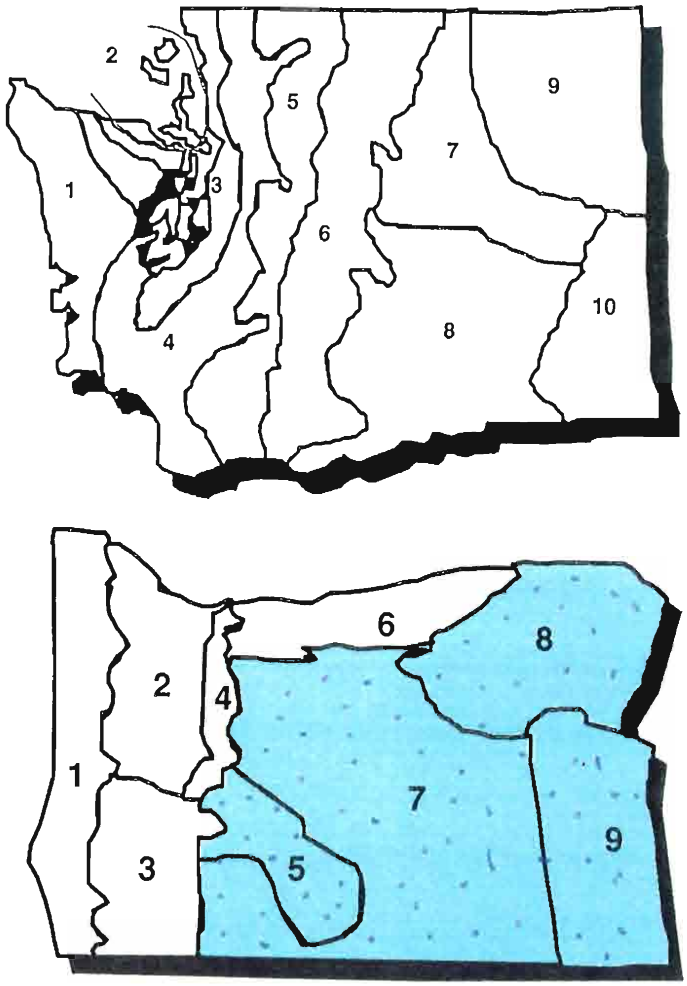


Figure 19: Strong El Niño years - July temperature significance. Colored regions are as defined in figure 3.

No other significance exists for the summer months following strong El Niño's, but there is some weak significance for cooler than normal conditions by September for much of eastern Oregon (figure 20, while normal El Niño years show 90% confidence levels of cooler than normal conditions in Septembers in the Oregon High Plateau area only.

November's and December's following strong El Niño's show warmer than normal conditions for much of Oregon and Washington (figures 21 and 22), although no significance was found for the same areas for the same time frame for normal El Niño years. Annual results following strong El Niño's are similar to annual results following normal El Niño's, with warmer than normal conditions in most areas of Washington and Oregon (figure 23).

Strong El Niño years, precipitation departures

Unlike normal El Niño years, January's following strong El Niño years do not show any precipitation significance for either Washington or Oregon. February's following strong El Niño years show significance of drier than normal conditions only in the far northwest corner of Washington, while normal El Niño years show much higher significance for much of western Washington. March's following both strong El Niño's and normal El Niño's show drier than normal conditions in the Cascades Mountains of Oregon. March's following strong El Niño years show additional significance for much of western Washington of drier than normal conditions (figure 24).

April's following strong El Niño years show strong significance for drier than normal conditions in western parts of Oregon and Washington

April's following strong El Niño years show strong significance for drier than normal conditions in western parts of Oregon and Washington

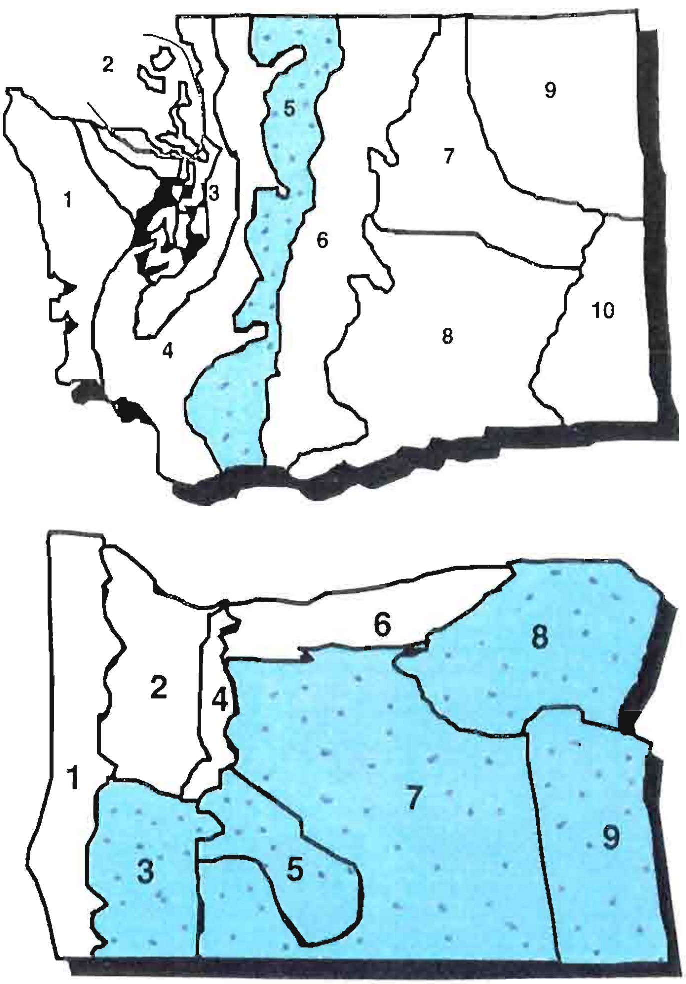


Figure 20: Strong El Niño years - September temperature significance. Colored regions are as defined in figure 3.

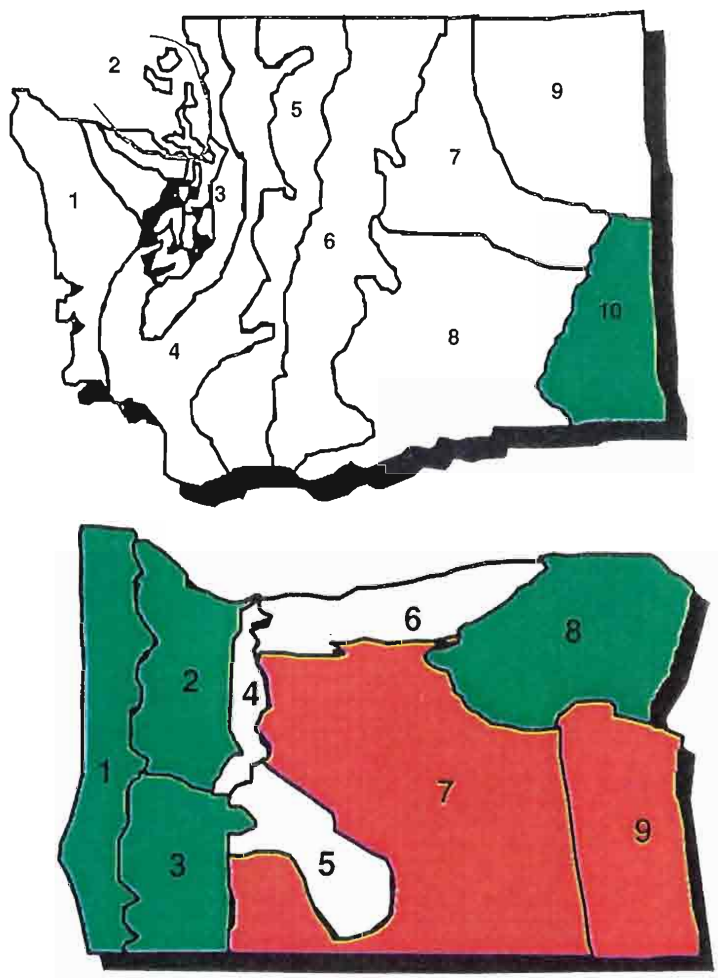


Figure 21: Strong El Niño years - November temperature significance. Colored regions are as defined in figure 3.

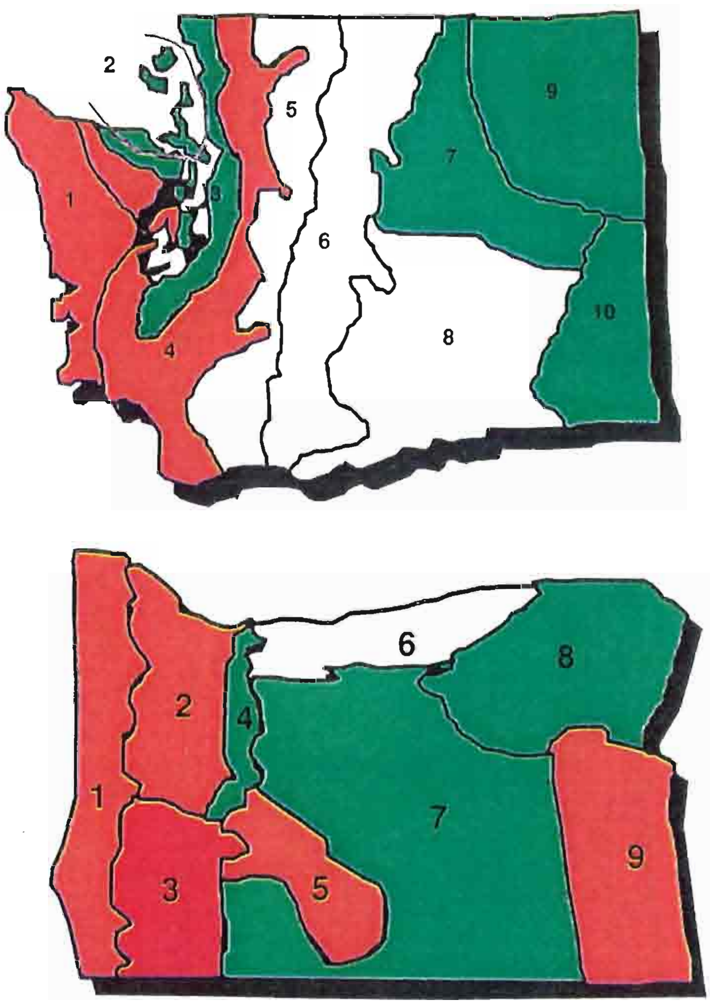


Figure 22: Strong El Niño years - December temperature significance. Colored regions are as defined in figure 3.

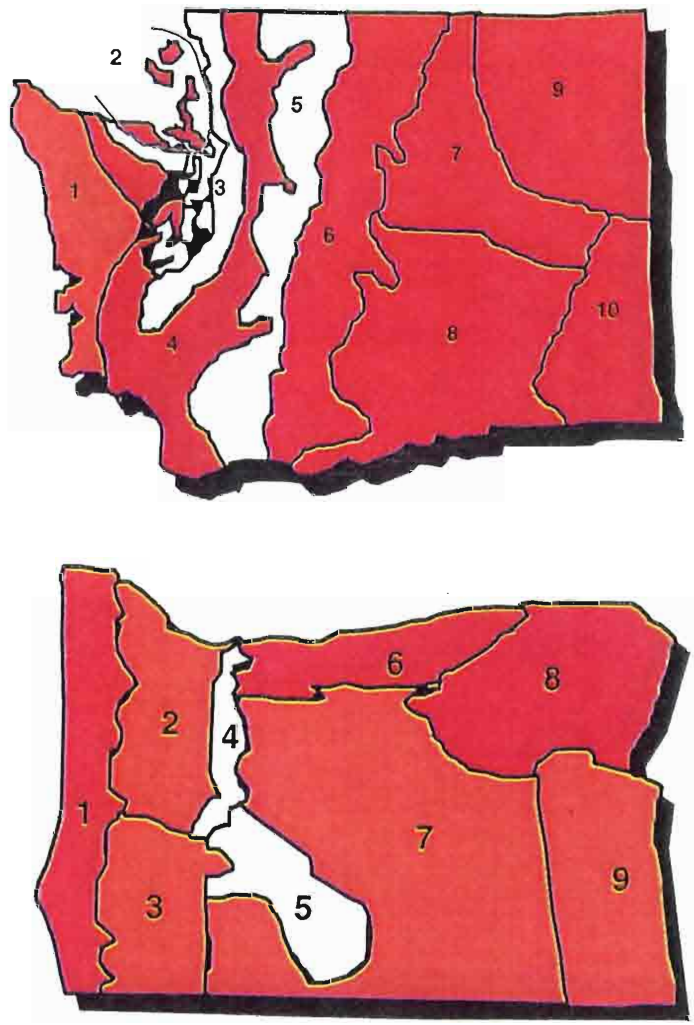


Figure 23: Strong El Niño years - Annual temperature significance. Colored regions are as defined in figure 3.

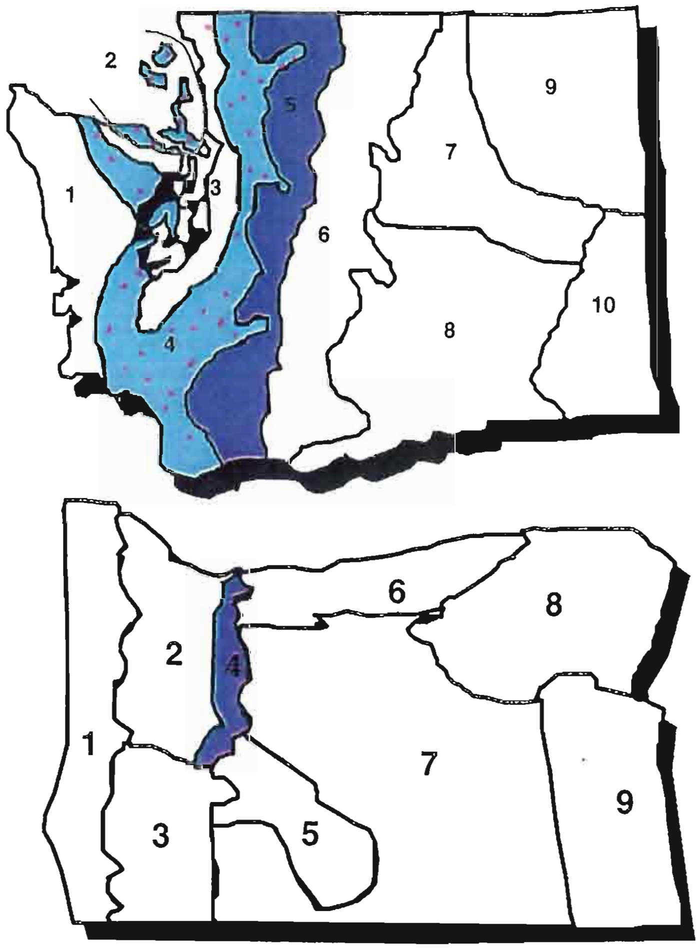


Figure 24: Strong El Niño years - March precipitation significance. Colored regions are as defined in figure 3.

(figure 25), but little or no significance exists east of the Cascades following strong El Niño's, as it does following normal El Niño's.

There is some weak significance for a few areas in Oregon and Washington showing wetter than normal conditions in summer months following strong El Niño years, although no significance exists for summer months following normal El Niño's. Specifically, July's show wetter than normal conditions for much of eastern Washington (figure 26). There is weak significance for wetter than normal conditions in August's following strong El Niño's at the Oregon coast.

September's following both normal and strong El Niño years show wetter than normal conditions in the Okanogan Big Bend area of Washington, and strong El Niño years show wetter than normal conditions in the northeast corner of Oregon (figure 27). No relations exist elsewhere until November. November's following strong El Niño years show wetter than normal conditions in eastern Washington, similar to normal El Niño years, but November's following strong El Niño years also show wetter than normal conditions as far south as the Oregon-California border east of the Cascades (figure 28). November's following normal El Niño years only show wetter than normal conditions in north central parts of Oregon.

Annually, strong El Niño years show wetter then normal conditions in eastern Washington, otherwise no significance exists. For normal El Niño years, the only significance is for drier than normal conditions in the Oregon Cascades.

Although there are many similarities in the results between strong El Niño

Cascades.

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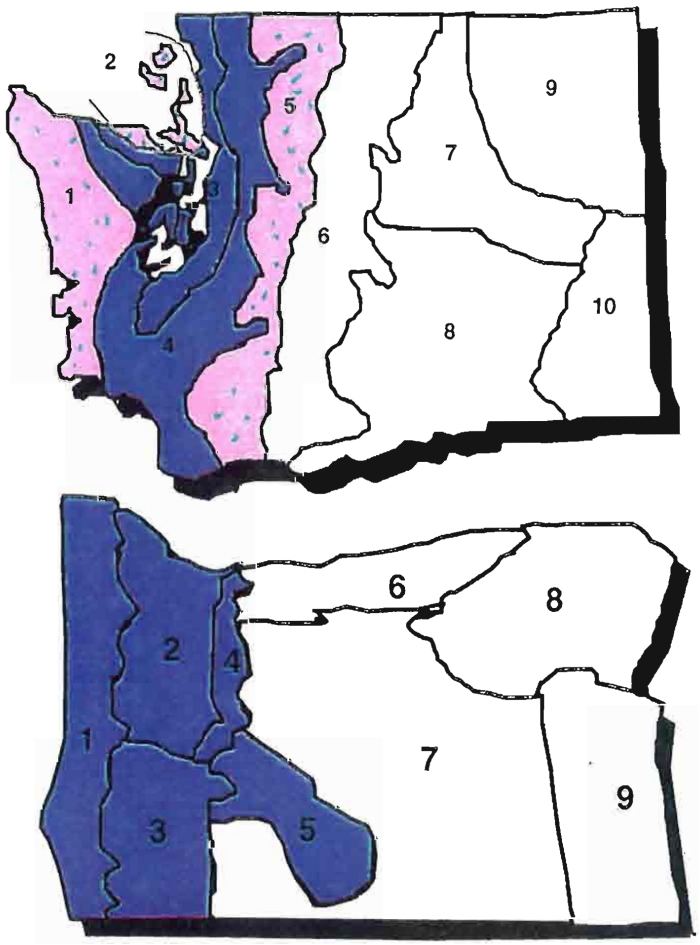

Figure 25: Strong El Niño years - April precipitation significance. Colored regions are as defined in figure 3.

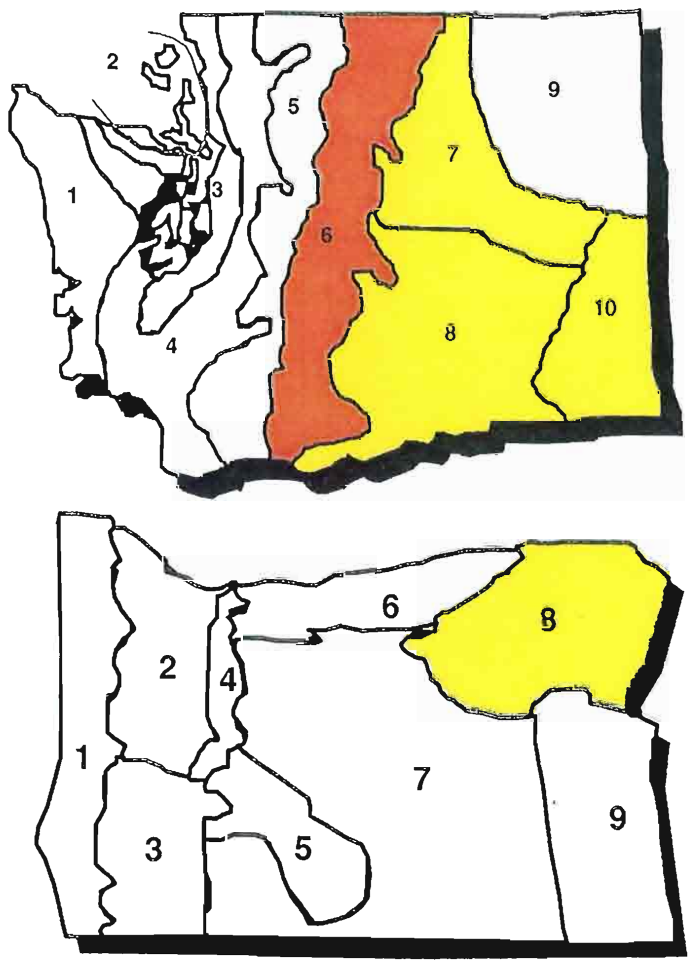

Figure 26: Strong El Niño years - July precipitation significance. Colored regions are as defined in figure 3.

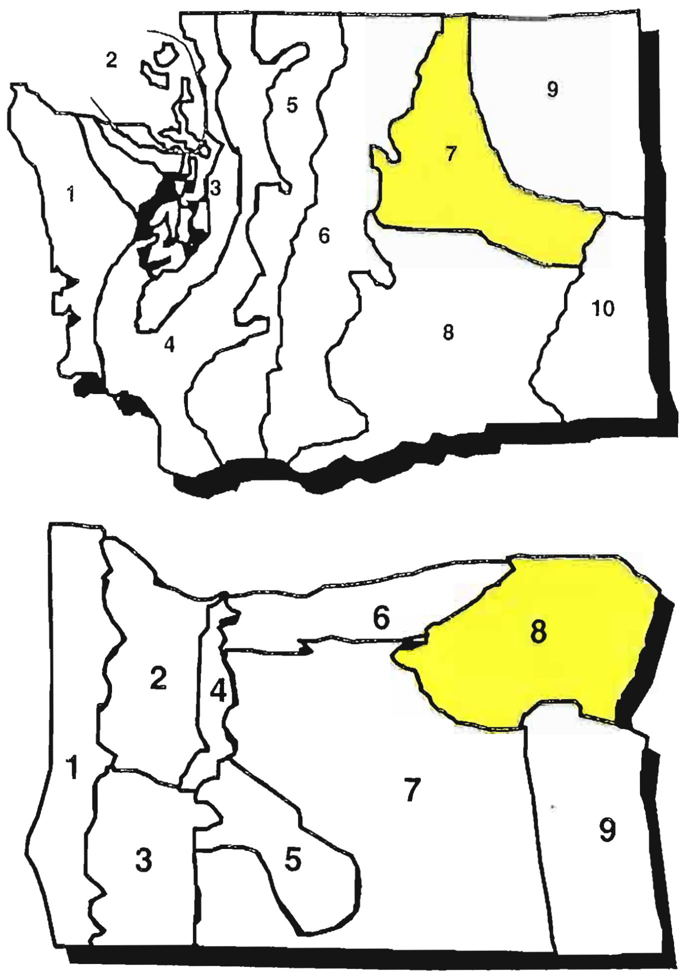

Figure 27: Strong El Niño years - September precipitation significance. Colored regions are as defined in figure 3.

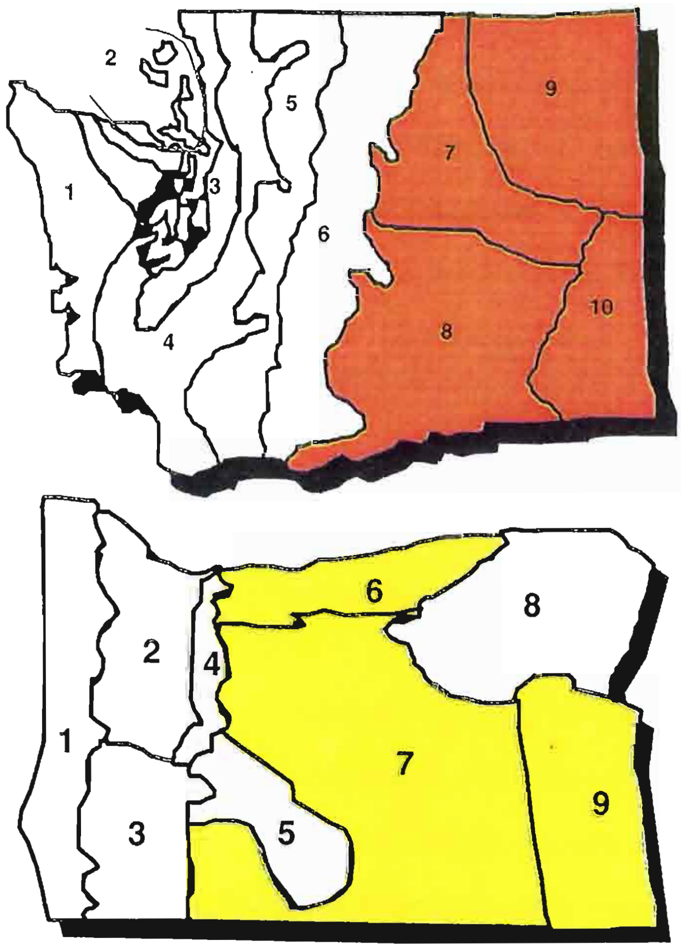

Figure 28: Strong El Niño years - November precipitation significance. Colored regions are as defined in figure 3.

years and normal El Niño years, many differences do exist which can be attributed to a couple of factors. The obvious factor is the strength of the El Niño, but another factor is due to the fact that strong El Niño years are a subset of the El Niño years category, hence there are fewer strong El Niño's compared to normal El Niño's. The number of events does play a role in significance, with stronger significance directly proportional to the number of cases. Thus, in some instances, strong El Niño years do not show as high of significance as normal El Niño years simply due to the number of cases.

El Viejo years, temperature departures

January's following El Viejo years show significance of cooler than normal conditions at both the Oregon and Washington coasts and a few other western locations (figure 29), but the strongest temperature relations for El Viejo years occur in February's.

February's following El Viejo years show a strong relation of cooler than normal temperatures in the Pacific Northwest, with the strongest relations occurring west of the Cascades (figure 30). Of the western areas, the highest significance for cooler than normal conditions occurs in western Washington and northwestern Oregon, with 99% confidence levels along the Washington coast, southwest Washington, the Puget Sound Lowlands, the San Juan Islands, Washington Cascades, the Willamette Valley, the Oregon Cascades, and the Oregon Coast. There are also relationships east of the Cascades, but not quite as strong. Eastern locations show 90-95% confidence levels of being cooler than normal. The lowest significance of cooler than normal conditions
not quite as strong. Eastern locations show 90-95% confidence levels of being cooler than normal. The lowest significance of cooler than normal conditions

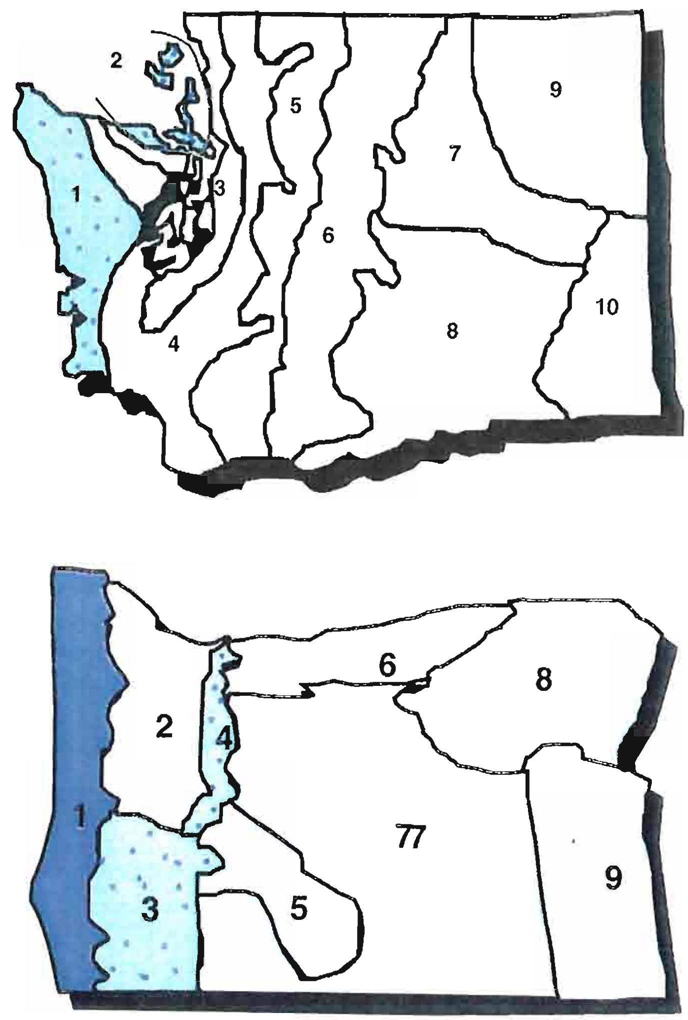

Figure 29: El Viejo years - January temperature significance. Colored regions are as defined in figure 3.

occurs in southeast areas, with 90% confidence levels. One could conclude from these results that the highest significance in February's following El Viejo events occurs in the north and west, with some significance of cooler than normal conditions existing in all areas of Oregon and Washington.

A transition in the weather pattern appears to occur to the south in March's following El Viejo events, with warming temperatures in southern Oregon (figure 31). No significance is found for the state of Washington.

April's show weak confidence of cooler than normal conditions for the southeast corner of Oregon, otherwise no significantly cooler or warmer conditions exists after March in the Pacific Northwest until June. The Oregon coast, the Willamette Valley, the Oregon Cascades, the San Juan Islands, southwest Washington, and northeastern Washington all show significance for cooler than normal conditions in June's following an El Viejo (figure 32). No relations exist for temperature departures from July through September. Cooler than normal conditions return to most areas of Oregon and Washington in October's following cold events (figure 33). No significant temperature relations exist in November's or December's.

Annually, the San Juan Islands, the Washington and Oregon coasts, the Oregon Cascades, and northeastern Washington show 90% confidence levels of cooler than normal conditions following a cold event (figure 34).

Thus, the strongest significance for temperature departures following an El Viejo event in the Pacific Northwest occurs in February, with the significance being for cooler than normal conditions. There is a shift in the weather pattern for March, with a weak relation of warmer than normal departures in
being for cooler than normal conditions. There is a shift in the weather pattern for March, with a weak relation of warmer than normal departures in

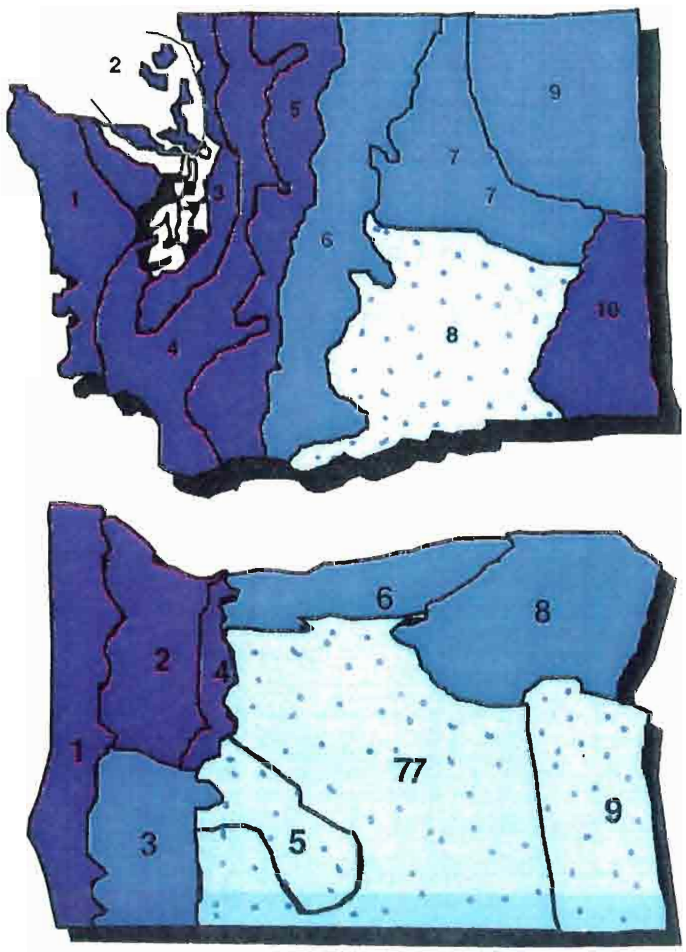

Figure 30: El Viejo years - February temperature significance. Colored regions are as defined in figure 3.

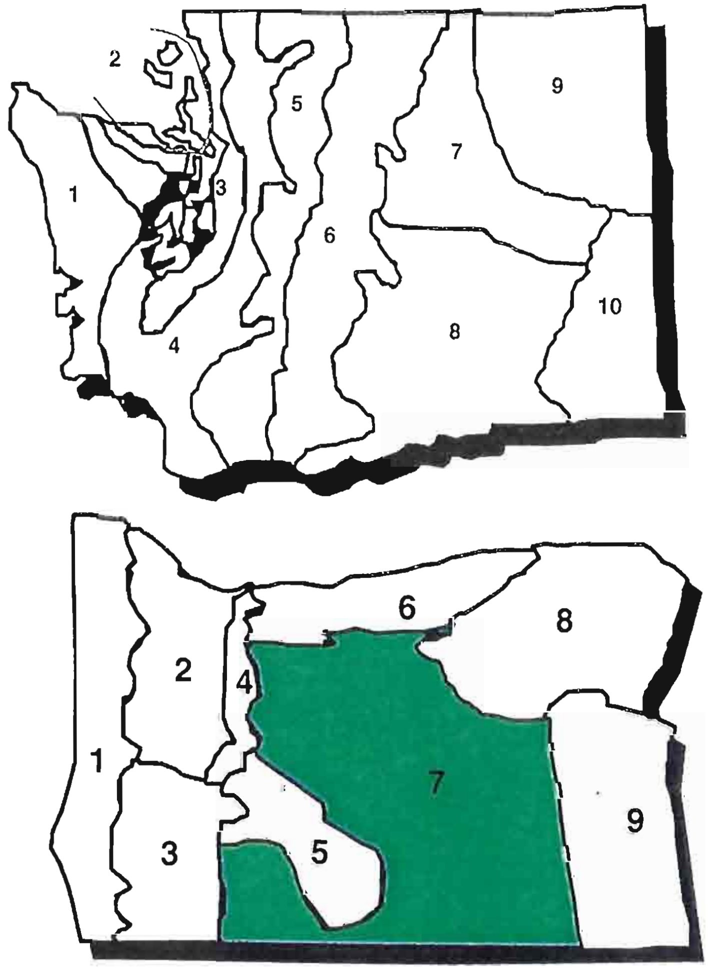

Figure 31: El Viejo years - March temperature significance. Colored regions are as defined in figure 3.

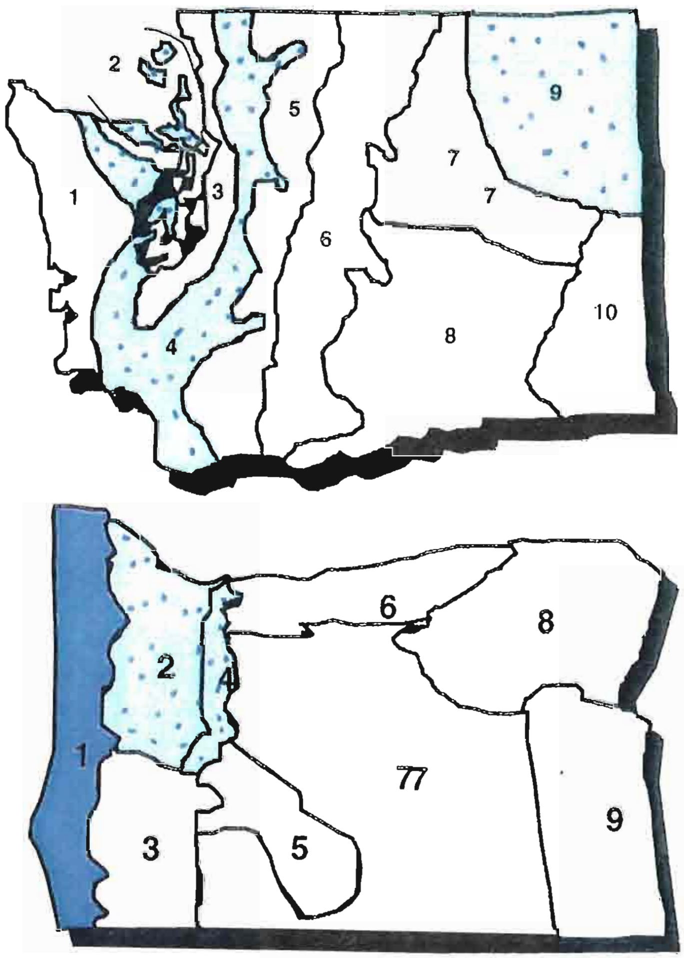

Figure 32: El Viejo years - June temperature significance. Colored regions are as defined in figure 3.

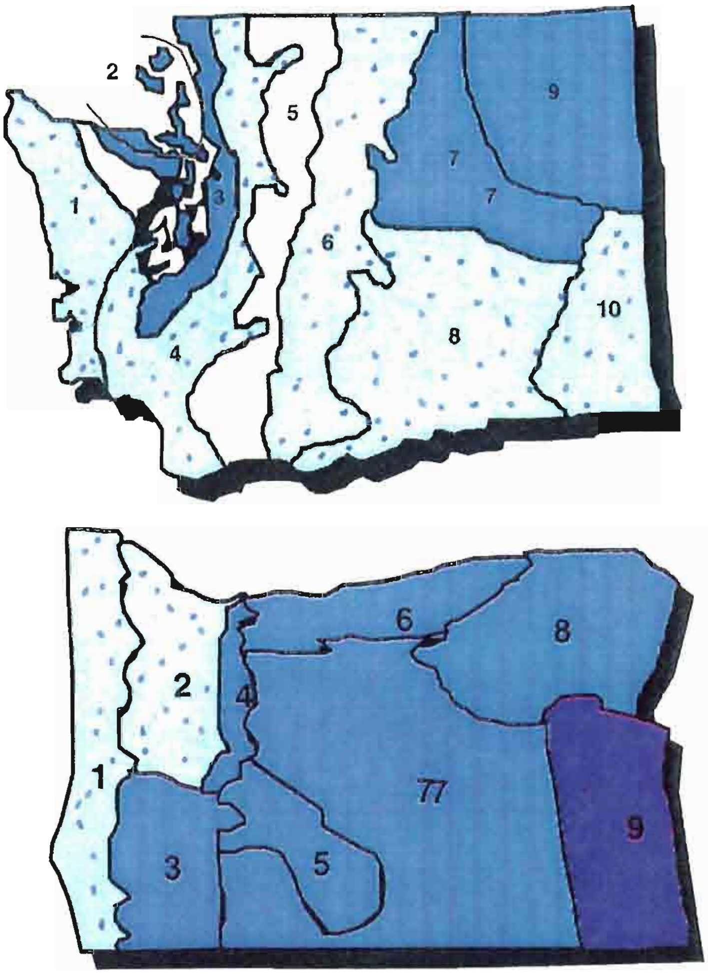

Figure 33: El Viejo years - October temperature significance. Colored regions are as defined in figure 3.

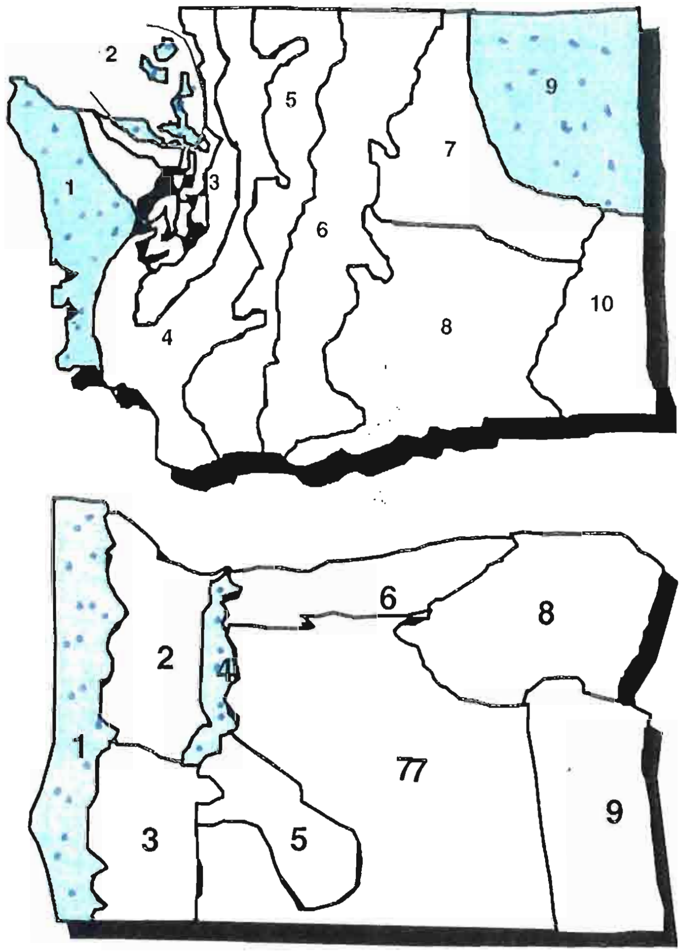

Figure 34: El Viejo years - annual temperature significance. Colored regions are as defined in figure 3.

southern parts of Oregon. June's following cold events show relations of cooler than normal conditions in many areas, otherwise minimal significance is found in the summer months. The fall months show a return of cooler than normal conditions, with most areas showing cooler than normal temperatures in October's following a cold event.

El Viejo years, precipitation departures

Several locations in Oregon and the far northwest corner of Washington show wetter than normal conditions for January's following cold events (figure 35).

The results for February's following cold events do not show as much significance in departures from precipitation as departures from temperature. Many areas east of the Cascades show drier than normal conditions with the strongest relations to the north (figure 36). The fact that February's following El Viejo's are generally cooler than normal throughout the Pacific Northwest and drier than normal in few eastern areas indicates a weather pattern of high pressure centered to the east, strong enough to keep weather systems from traveling east of the Cascades. This is the type of mean weather pattern Ferber *et al.* [1993] found to exist in the winter months in the Pacific Northwest.

Many areas are drier than normal in April's following cold events. The Washington and Oregon coasts, southwest Washington, the Blue Mountains, north central Oregon, northeast Washington, and the Cascades in Washington all show significance of drier than normal conditions (figure 37). Eastern Oregon also shows significance for drier than normal conditions, specifically in the southeastern part, along with the High Plateau area.

Oregon also shows significance for drier than normal conditions, specifically in the southeastern part, along with the High Plateau area.

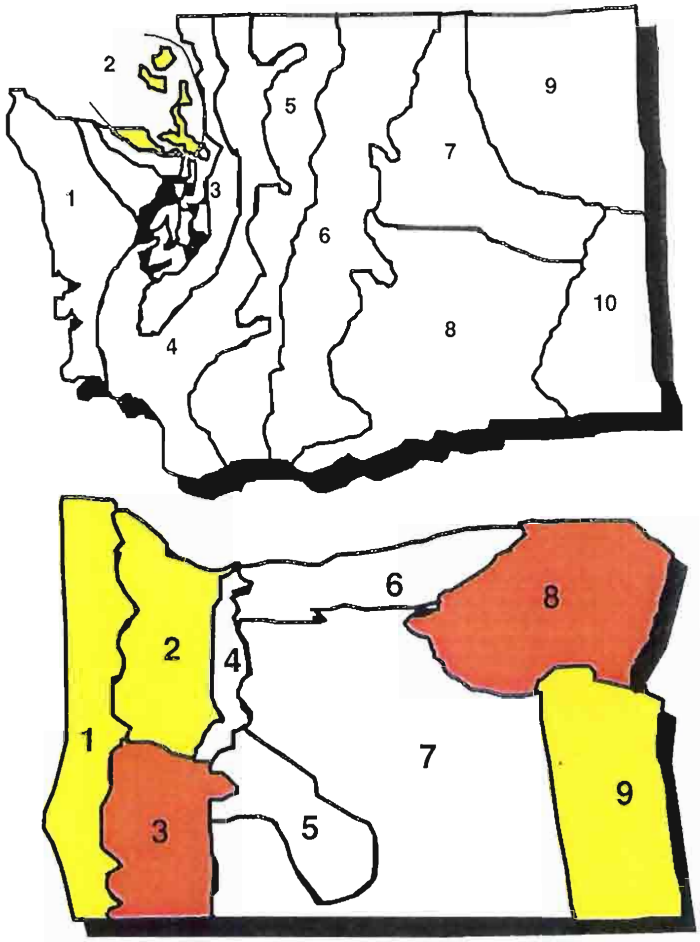

Figure 35: El Viejo years - January precipitation significance. Colored regions are as defined in figure 3.

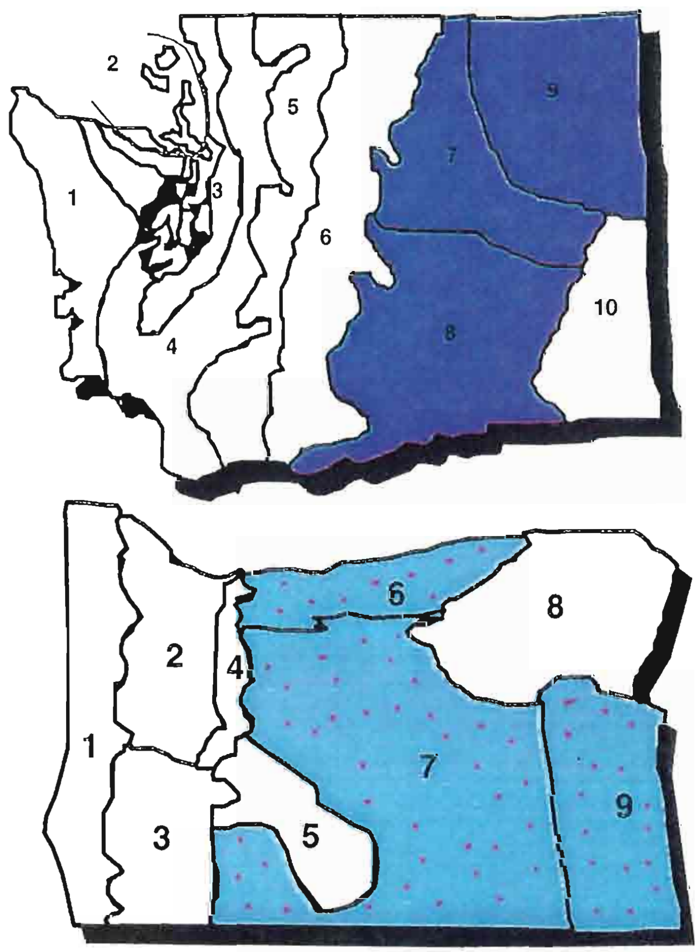

Figure 36: El Viejo years - February precipitation significance. Colored regions are as defined in figure 3.

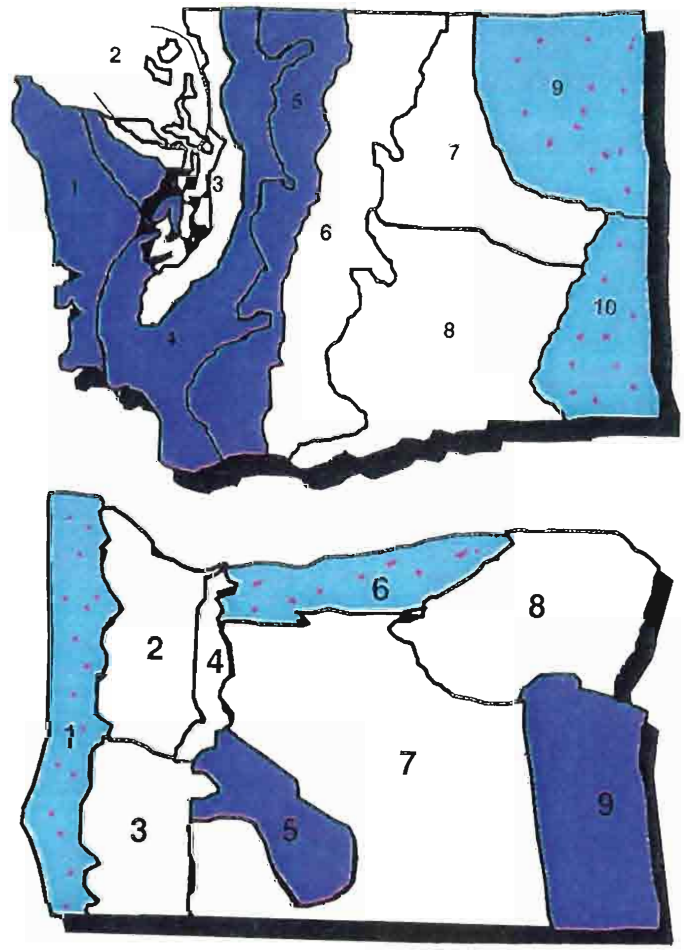

Figure 37: El Viejo years - April precipitation significance. Colored regions are as defined in figure 3.

June shows drier than normal conditions for much of Oregon (figure 38), although no significance for Washington. Again, a weather pattern likely sets up to the south in the early summer months which affects Oregon's precipitation departures, but not Washington's. Namely, it is likely that high pressure builds to the south, keeping areas in Oregon much drier than normal, but the ridge likely only develops far enough north to affect precipitation departures in Oregon and not Washington. Note that many areas show cooler than normal conditions in June's following an El Viejo, including areas in Washington. Part of the reason could be due to radiational cooling (at least in Oregon where there is also significance of drier than normal conditions), but there is likely a cooler air mass that settles into the region in season's following cold events, with lingering affects into the first part of the summer.

Just weak significance of drier than normal conditions exists for July's following El Viejo's in the far northeast corner of Washington. No precipitation significance exists in August.

September's following cold events show relations of drier than normal conditions for most of Washington, with the strongest significance in the eastern part of the state (figure 39). Northern parts of Oregon also show significance of drier than normal conditions. This trend of drier than normal conditions continues October and November, with the highest confidence levels occurring in November for the most locations in Washington and Oregon (figures 40 and 41). The ridge which likely builds into the area in the fall months, keeping these areas drier than normal breaks down by December, with no precipitation significance for Washington or Oregon. It is interesting
months, keeping these areas drier than normal breaks down by December, with no precipitation significance for Washington or Oregon. It is interesting

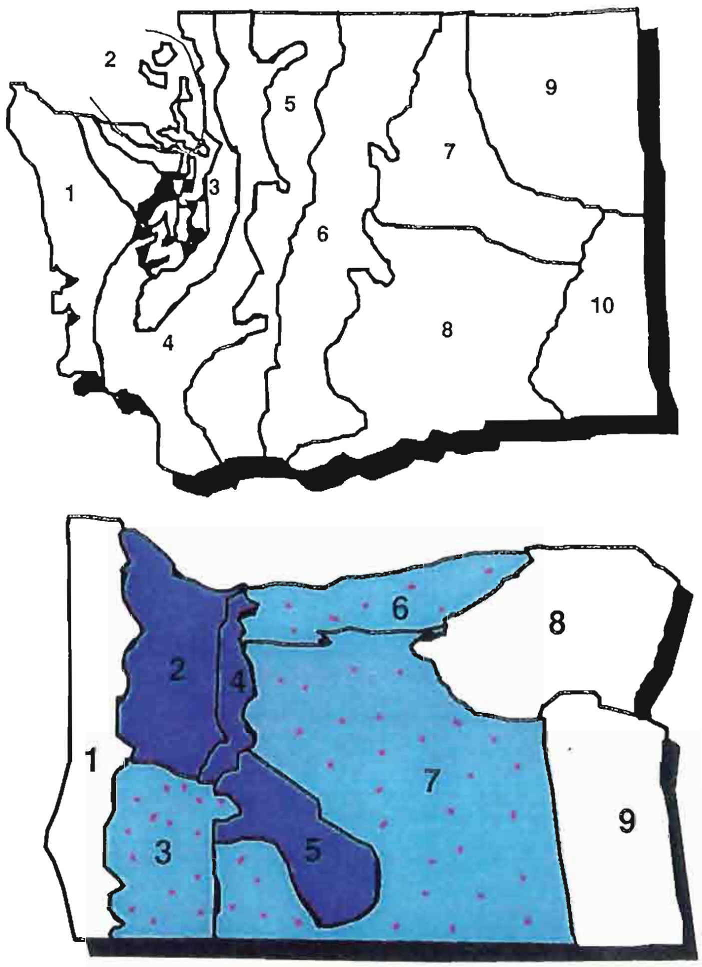

Figure 38: El Viejo years - June precipitation significance. Colored regions are as defined in figure 3.

to note that October's also show several areas with cooler than normal conditions. This is likely due to radiational cooling overnights, with a ridge keeping skies mostly clear.

Annually, both Washington and Oregon show many areas significantly drier than normal (figure 42). The highest significance is found in the Blue Mountains, the Central Basin area in Washington, and north central Oregon for drier than normal conditions. Much of Oregon shows at least some significance annually of being drier than normal following an El Viejo event.

4.2 Two-sided test

Results for the two-sided test are not quite as strong as those for the one-sided test, although the results are similar (figures 43- 46). Western Washington shows more significance of drier than normal conditions than Eastern Washington for El Niño years. Similar results are shown for strong El Niño years, except the eastern area shows wetter than normal conditions in November's.

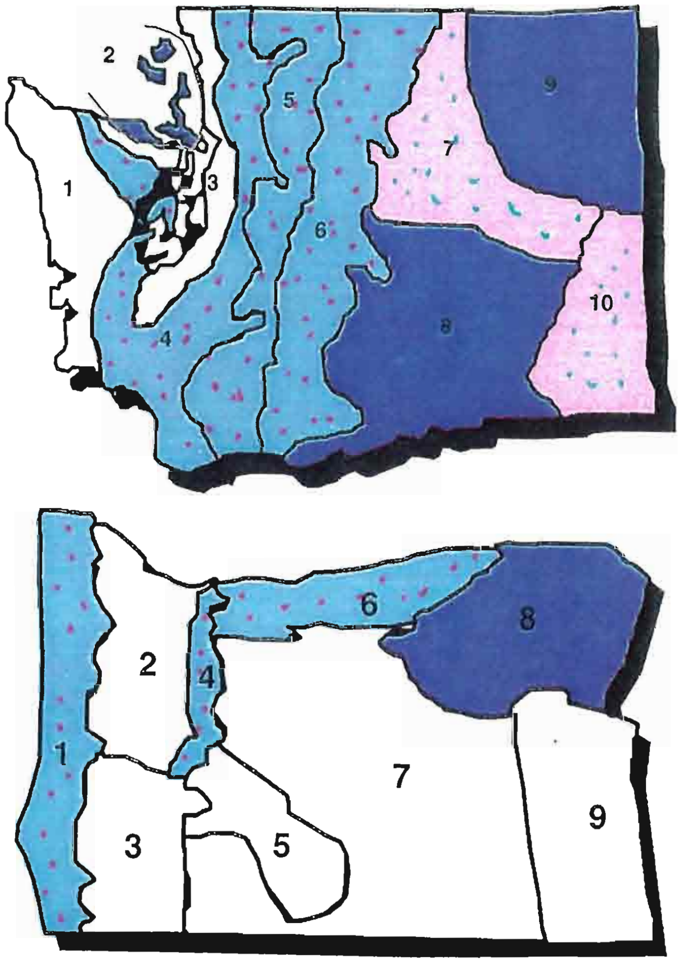

Figure 39: El Viejo years - September precipitation significance. Colored regions are as defined in figure 3.

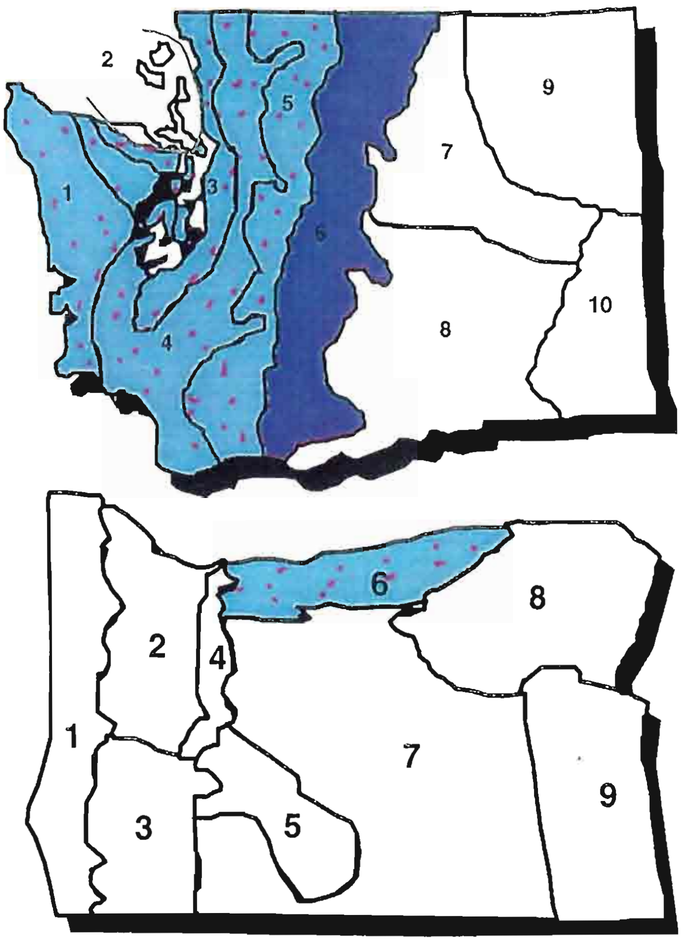

Figure 40: El Viejo years - October precipitation significance. Colored regions are as defined in figure 3.

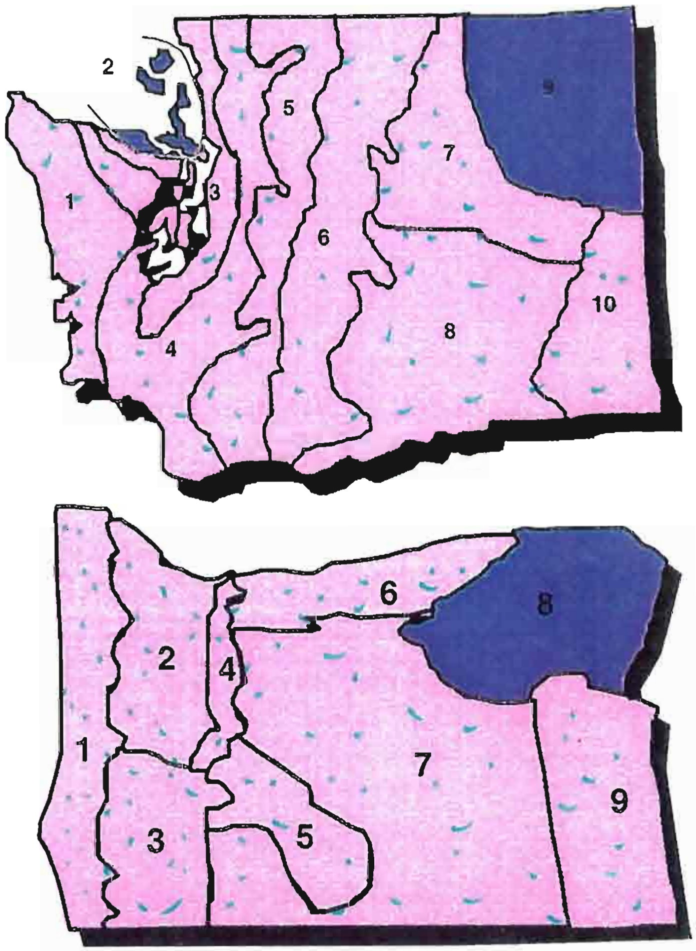

Figure 41: El Viejo years - November precipitation significance. Colored regions are as defined in figure 3.

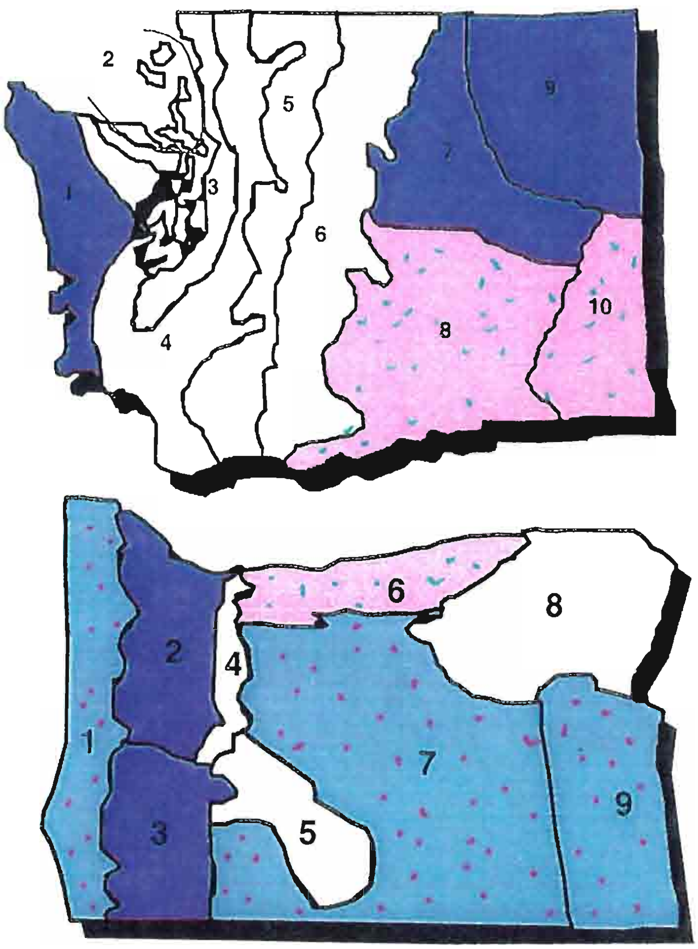

Figure 42: El Viejo years - annual precipitation significance. Colored regions are as defined in figure 3.

	El Niño	*Strong El Niño*	*El Viejo*
January	T+, P-	T+	
February	T+, P-	T+, P-	T-
March		P-	
April	T+, P-	T+, P-	P-
May			
June			
July			
August			
September			P-
October			T-
November			P-
December		T+	
Annual	T+	T+	

LEGEND:
T : Temperature departure
P : Precipitation departure
+ : Above normal
- : Below normal

Figure 43: Western Washington composite summary.

	El Niño	*Strong El Niño*	*El Viejo*
January	T+	T+	
February	T+	T+	T-, P-
March	T+		
April	T+, P-	T+	
May	T+	T+	
June		T+	
July		T+	
August			
September			P-
October			T-, P-
November	P+	T+, P+	T-, P-
December		T+	
Annual	T+	T+, P+	T-, P-

LEGEND:
T : Temperature departure
P : Precipitation departure
+ : Above normal
- : Below normal

Figure 44: Eastern Washington composite summary.

	El Niño	*Strong El Niño*	*El Viejo*
January	T+	T+	T-, P+
February	T+		T-
March		P-	
April	T+, P-	T+, P-	
May			
June		T+	T-, P-
July			
August			
September			
October		P-	T-
November			P-
December		T+	
Annual	T+	T+	P-

LEGEND:
T : Temperature departure
P : Precipitation departure
+ : Above normal
- : Below normal

Figure 45: Western Oregon composite summary.

	El Niño	*Strong El Niño*	*El Viejo*
January	T+, P-	T+	P+
February	T+		T-
March			
April	T+, P-	P-	P-
May			
June			P-
July		T-	
August			
September		T-	P-
October			T-
November		T+	P-
December		T+	
Annual	T+	T+	P-

LEGEND:
- T : Temperature departure
- P : Precipitation departure
- + : Above normal
- - : Below normal

Figure 46: Eastern Oregon composite summary.

5. Conclusions

As has been found in previous works, the highest significance for temperature and precipitation departures in the Pacific Northwest found in this research also occurs in the winter months following El Niño (El Viejo) events. There are also fairly strong relations in early spring and fall months. The lowest significance occurs in the summer months, where there is little or no significance for most areas.

Both temperature and precipitation significance do exist for the Pacific Northwest following El Niño (El Viejo) events, as this study demonstrates, but temperature significance is much stronger compared to precipitation significance. This also agrees well with previous works, specifically that of Ropelewski and Halpert [1986], although higher precipitation significance has been found in this study in the Pacific Northwest compared to their findings. The most likely reason for the stronger temperature significance is due to sensitivity to precipitation departures. One heavy shower can offset the entire trend of the general weather pattern for a particular month following a specific event (El Niño or El Viejo). On the other hand, temperature departures are not so sensitive to daily variations of the general weather patterns, and thus temperature departures show more significance with a statistical analysis.

Similar results are also found when comparing this study to that of Sittel [1994]. Sittel uses a straight forward temperature difference between El Niño (El Viejo) years and neutral years across the United States. His definition of the El Viejo is slightly different than the definition in this study, so most of the differences between Sittel's work and this study occur for El Viejo events.
the El Viejo is slightly different than the definition in this study, so most of the differences between Sittel's work and this study occur for El Viejo events.

There are also minor differences for the El Niño results, although the results match up fairly well between the separate studies. Warmer than normal conditions are found in both works for most areas in Washington and Oregon in the winter and spring months following an El Niño. Both works also show no relations west of the Cascades after June's following El Niño years, but warmer than normal conditions east of the Cascades. Precipitation results also show good agreement between the two studies, with drier than normal conditions in the winter and spring months for most areas, then no relations for the summer months. There is a difference between the studies for November's following El Niño's. This work shows wetter than normal conditions northern areas east of the Cascades, while Sittel's work shows no relation. This may be due to the filtering of the data caused by Sittel's tri-monthly intervals instead of single monthly intervals, as used in this study. Also, an average does not necessarily indicate that statistical significance exists. One exceptional year may offset the entire group of data using an average, while a statistical analysis will not be so greatly affected by an isolated extraordinary data value. Both works show similar results for winter months following El Viejo events, with cooler than normal conditions. The summer months also show similar results with weak relations of cooler than normal conditions. There are a few differences that exist for precipitation results following cold events. This work shows drier than normal conditions for April and June's in many regions in Washington and Oregon, but Sittel's work does not indicate this. The summer months are similar, though, with no relations existing in either work.

does not indicate this. The summer months are similar, though, with no relations existing in either work.

This research has already been used in operational forecasting, serving clients of Northwest Weathernet, Incorporated with considerable economical savings. Specifically, the equatorial waters began cooling in the summer months of 1995, with an El Viejo event developing. With the use of the results from this research, a forecast of a cooler than normal winter saved the gas companies tens of thousands of dollars. Anticipating a cooler than normal winter, the gas companies bought the gas at considerably cheaper rates in the fall before the cold winter actually began. (It is interesting to note that most of Washington and Oregon's temperatures were well below normal in February of 1996, as could be determined using the results of this research.)

5.1 Future work

Data used in this research is available across the United States mainland, thus a similar project is possible using the entire lower 48 states. Research has begun on this project and is expected to be completed in the near future.

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Degrees

B.S. in Meteorology, 1990, Florida State University

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Experience

Northwest WeatherNet, Seattle, Washington. Meteorologist. Forecast weather for the Pacific Northwest for various private and governmental clients. Have completed a study on El Nino for long term forecasting in the Pacific Northwest. 1994-present.

Great Lakes Weather, Wausau, Wisconsin. Broadcast Meteorologist. Broadcast forecasts for the Wausau area on television, radio broadcasts across the Great Lakes region. Also forecast for several clients across the Great Lakes region, including utility companies and ski resorts. 1993-1994.

1993-1994.

Georgia Tech, Atlanta, Georgia. Research assistant analyzing data from a GC instrument. Promoted to senior data analyzer, which includes analyzing data for a project with General Motors and the Environmental Protection Agency (EPA). 1993.

Honors

Most outstanding senior academically, Florida State University, 1990.

Oregon Scholar Award, 1986.

Member of National Honor Society

Memberships

Member of Chi Epsilon (Meteorology Honor Society).

Personal information

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