P2.1 CAN U.S. WEST COAST CLIMATE BE FORCAST?

Steve LaDochy*, Jeffrey N. Brown and Mattias Selke
California State University, Los Angeles

William C. Patzert, JPL NASA

1. Introduction

The tropical Pacific Ocean influences local, regional and global climates. Its variability can be used to anticipate changes in the atmosphere on an inter- and intra-annual time scale (Zhang et al. 1997; Livezey et al. 1997). The ENSO signals show prominence in seasonal and interannual temperature and precipitation records throughout North America (Ropelewski and Halpert 1986). Stronger relationships show interdecadal variability. Castro et al. (2001) show how Pacific SSTs influence the North American Monsoon. They show that ENSO effects are strong when in phase with the PDO, but weak when out of phase. That is, that ENSO related teleconnection patterns with climate anomalies are more consistent when El Nino occurs during the positive phase of PDO and La Nina occurs during the PDO negative phase (Gershunov and Barnett 1998). In their study of the strength of ENSO teleconnections with western U.S. precipitation, McCabe and Dettinger (1999) also found that positive PDO periods tended to weaken the teleconnection relationships. Updated standardized values for the PDO index are derived as the leading PC of monthly SST anomalies in the North Pacific Ocean, poleward of 20N. The monthly mean global average SST anomalies are removed to separate this pattern of variability from any "global warming" signal that may be present in the data (Zhang et al. 1997; Mantua et al. 1997). Pacific decadal SST variability has also been linked to U.S. droughts, floods and streamflow amounts (Nigram et al. 1999; Cole and Overpeck 2002; Pizarro and Lall 2002; Gray et al. 2003). Pacific teleconnection patterns, as shown by the PNA (Pacific North American Index) have been shown to even disrupt the Atlantic Multidecadal Oscillation signal in winter Mississippi Valley stream flow (Rodgers and Coleman 2003).

* *Corresponding author address*: Steve LaDochy, Dept. of Geography, Calif. State Univ., Los Angeles, CA 90032; e-mail: sladoch@calstatela.edu.

West coast climate is influenced directly by its watery neighbor. The strongest atmospheric influence of the PDO shows up in the strength of the Aleutian low (Mantua et al., 1997). Sea Level Pressure (SLP) changes in the Pacific are linked to changes in surface winds, and hence SSTs, upper ocean temperature and heat content, mixed layer depth and thermocline depth (Schwing et al. 2002; Miller et al. 1994). These then are related to changes in climate along the west coast of the Americas (Montecinos and Purca 2003). The strong correlations between short term through decadal Pacific oceanic and atmospheric conditions with North American climate makes it possible to attempt long range forecasting for the U.S. west coast. This paper looks at the feasibility in long-range prediction of temperatures and precipitation along the U.S. west coast by utilizing the strong relationships between Pacific oceanic and atmospheric indices with coastal climates.

2. Data and Methodology

In order to forecast long-range west coast climatic conditions, the authors look at Pacific Ocean SSTs and atmospheric circulation patterns, both in the tropics and extratropical latitudes and see how they have explained temperature and precipitation variabilities in the past. Pacific oceanic and atmospheric data, along with west coast climatic data, were provided by the online Climate Diagnostics Center (CDC) Correlations web pages (see http://www.cdc.noaa.gov/USclimate/Correlation/) . We chose monthly values of relevant Pacific oceanic and atmospheric indices for 1948-2002 for most analyses, along with 1895-2002 monthly records for some climatic data and ENSO events. Temperature and precipitation data is included for West coast climate divisions of California, Oregon and Washington (Fig. 1). Each of the Pacific indices was correlated with temperature and precipitation to show strength of relationships, seasonally and annually. Since the rainy season is mainly during the cooler seasons, and the Water Year (July 1-June 30) differs from calendar year, correlation with

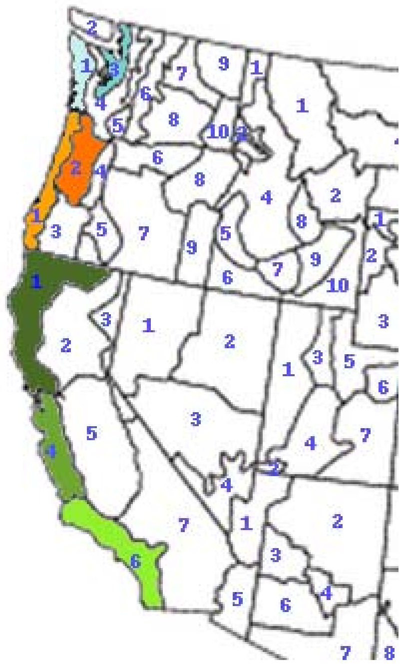

Fig. 1 Study area showing the west coast climatic divisions.

annual precipitation was done using Water Year totals. Indices showing the strongest influences were evaluated at progressing leads of 1 to 12 months, to show the best temporal relationships with regional temperatures and precipitation. To estimate the magnitudes of anomalies for temperatures and precipitation, divisional temperature and precipitation anomalies were calculated from the 1895-2000 record for El Nino and La Nina years during positive and negative phases of the PDO. Based on the 1948-2003 NCEP reanalyses maps of atmospheric circulation, we also derived composites for SLP, 500 mb geopotential heights, and 250 mb windspeeds, for high and low values of PDO, SOI, NP and WPI.

3. Results

Coastal temperatures.

PDO dominates the influences on California temperatures, annually and seasonally. Table 1 (see appendix) shows that PDO accounts for about 50% of interannual temperature variability for the 3 coastal climate divisions. Figure 2 indicates that the PDO-temperature relationship is consistently strong throughout the western U.S. The relationship remains highly significant with leads of up to 2 seasons. Coastal Oregon and Washington show similar, though slightly

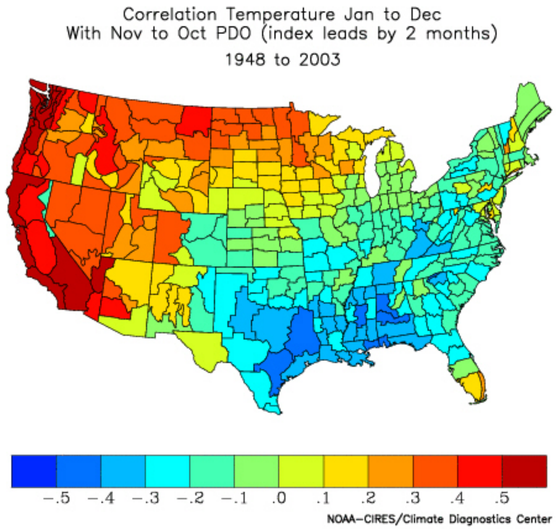

Fig. 2 Correlations by climatic divisions between Nov. – Oct. PDO values and annual (Jan-Dec.) temperatures.

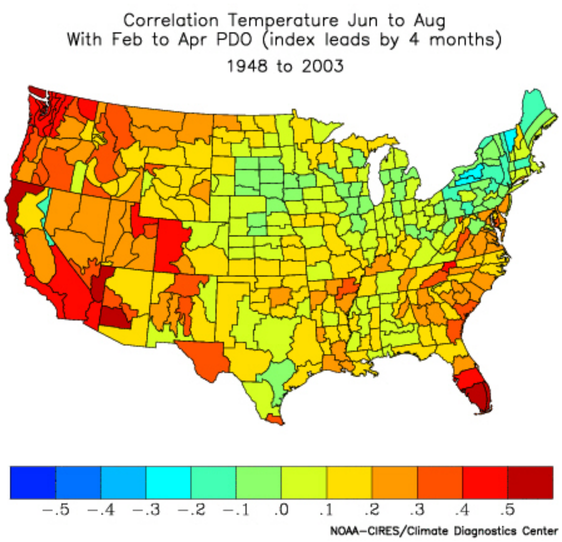

Fig. 3 Correlations by climatic divisions between Feb.-Apr. PDO values and summer (June-Aug.) temperatures.

lower correlations for the same leads. The PDO also explains seasonal temperature variability, although not as well as with interannual values. California summer temperatures are explained best among the seasons (Fig. 3), while winter temperatures are the least explained by PDO. The relationships remain highly significant for up to 2 seasons lead times (Fig. 4). For coastal Oregon and Washington, PDO values up to 1 season explain spring temperatures the best,

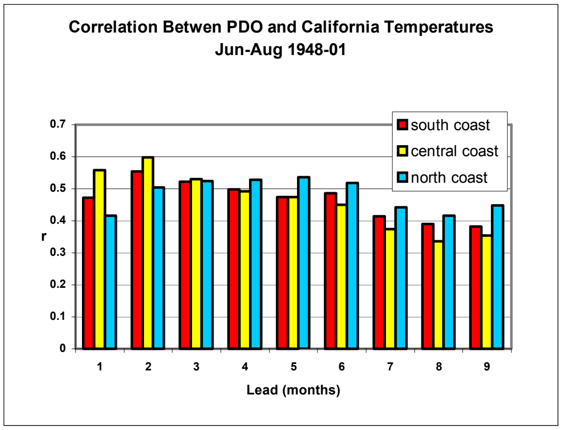

Fig. 4 Correlations between PDO seasonal values and CA climatic divisions summer (June-Aug.) temperatures at monthly leads of 2-12 months.

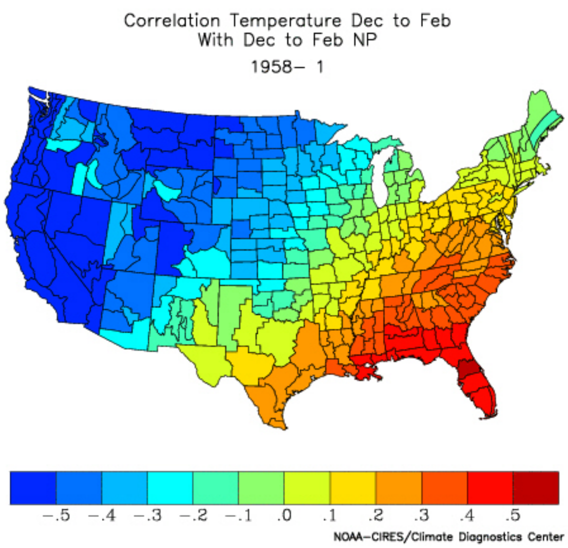

Fig. 5 Correlations by climatic divisions between winter NP values and winter (Dec.-Feb.) temperatures.

followed by winter, fall and summer temperatures. All relationships are highly significant at .001 or better.

Besides PDO, the NP Index also explains coastal temperature variability well. This is not surprising as the two extratropical indices are highly correlated (see http://www.cdc.noaa.gov/Correlations/table.html). NP explains nearly 50% of interannual variability for all divisions along the west coast. Seasonally, NP Index explains up to 64% of winter temperature variability along the coast, with spring and fall variability also well explained, nearly as well as PDO (Fig. 5). Summer temperatures are not as well explained by NP, whereas PDO does much better. For California divisions, PDO values are better at explaining temperature variability interannually and seasonally. Oregon and Washington coastal temperatures are better explained by PDO interannually and during summers, while NP is better for the other seasons.

Looking at the last two phase periods of the PDO, cold (negative) phase during 1951-1976, and the warm (positive) phase from 1977-1997, temperatures for all west coast divisions show consistently cooler temperature departures from the long term mean (1895-2000) for the first period, and consistently warmer departures for the latter period (Table 2). The departures are greatest for southern California and generally decrease heading north.

Coastal precipitation.

The SOI shows the greatest influence on rainfall variability on the southern coast, although the

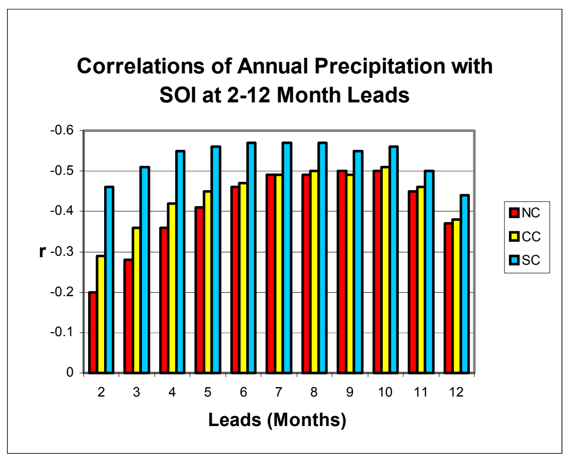

Fig. 6 Correlations between SOI July-June values and annual (July-June) precipitation for CA climatic divisions at monthly leads of 2-12 months.

strength of the relationships is weaker than that for temperatures as shown in Table 3. The interannual variability of coastal California precipitation is best explained by SOI. Though highly significant at .001, SOI explains nearly 40% of the variance. The strongest relationships occur at 2 to 3 seasons lead in SOI before subsequent rainfall (Fig. 6). The inverse relationship between SOI and precipitation is strongest for southern California and weakens as you go north, reversing to a positive relationship for the northwest (Mantua et al.

1997). For the northwestern coastal divisions, the SOI is not the best predictor for precipitation,

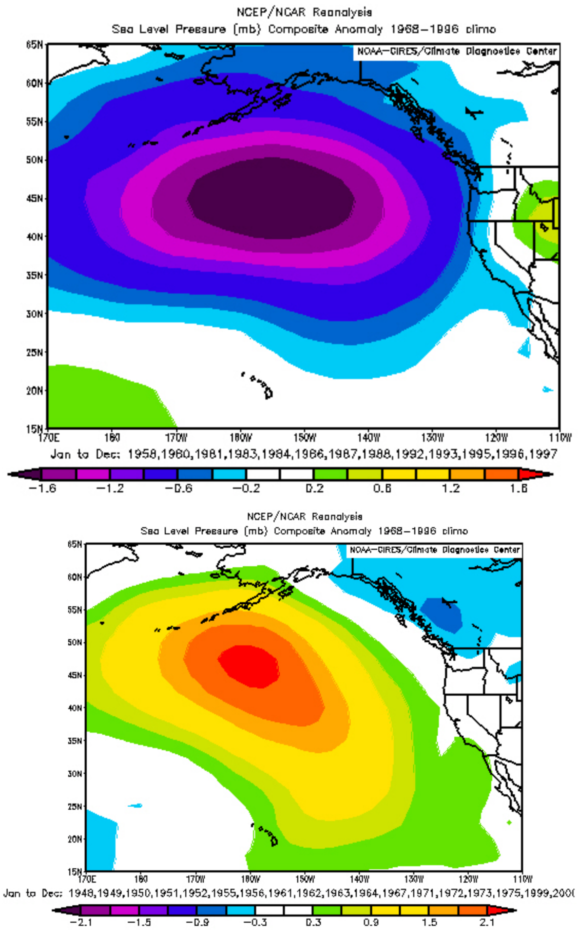

Fig. 7 Composite annual SLP anomaly charts for PDO years with values at top equal to and greater than 0.5, and at bottom equal to and less than –0.5.

interannually nor seasonally. Coastal Oregon's interannual precipitation is best explained by PDO, while for inland Oregon and coastal Washington, WP with 1 season lead explains the greatest variability in precipitation. Winter seasonal precipitation is best explained by tropical Pacific indices for all coastal divisions, with EPO explaining nearly 25% of variability in southern California with similar correlation for coastal Washington. Central and northern California's winter rainfall is best explained by TNA, while coastal Oregon is best explained by PNA. For coastal California, seasonal correlations decrease from winter through fall, with strongest relationships holding for southern California. The best indices for explaining seasonal variations are mostly tropical SSTs (SOI, EPO, TP EOF). All correlations are highly

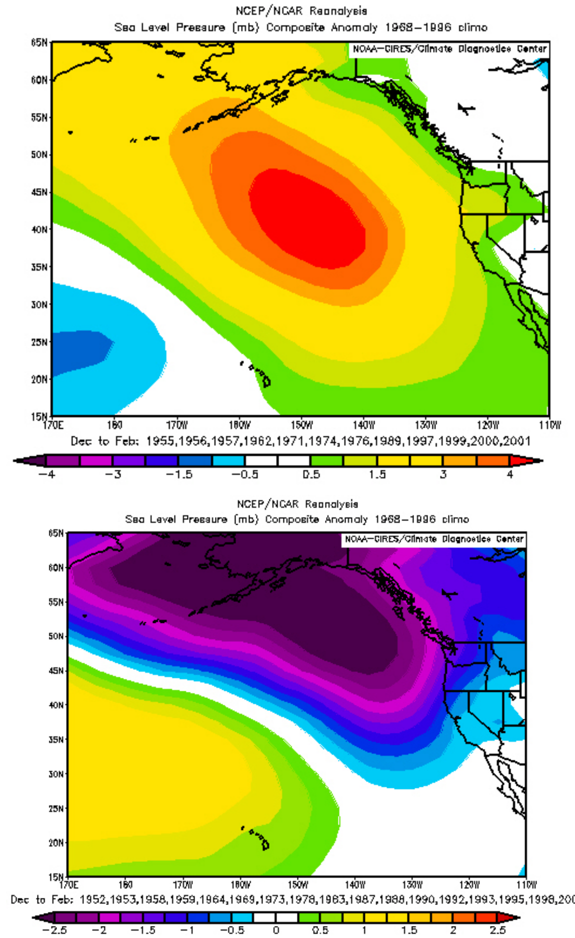

Fig. 8 Composite Dec.-Feb. SLP anomaly charts for SOI Dec.-Feb. with values at top equal to and greater than 0.5, and at bottom equal to and less than –0.5.

significant. Oregon and Washington coastal division precipitation also show highest correlations for winter, followed by fall, spring and summer. All correlations are highly significant, and opposite in sign from southern and central California. The best indices at explaining seasonal precipitation in the northwest differ from Oregon to Washington. Oregon's precipitation is explained better by higher latitude Pacific indices (PDO and PNA), while coastal Washington is better explained by tropical indices (SOI, TNA and EPO).

Looking at the magnitude of the ENSO influence on coastal precipitation, Table 2 shows departures from normal (1895-2000) for El Nino versus La Nina years both in-phase and out-of-phase with PDO periods. As stated before, departures are markedly greater for in-phase

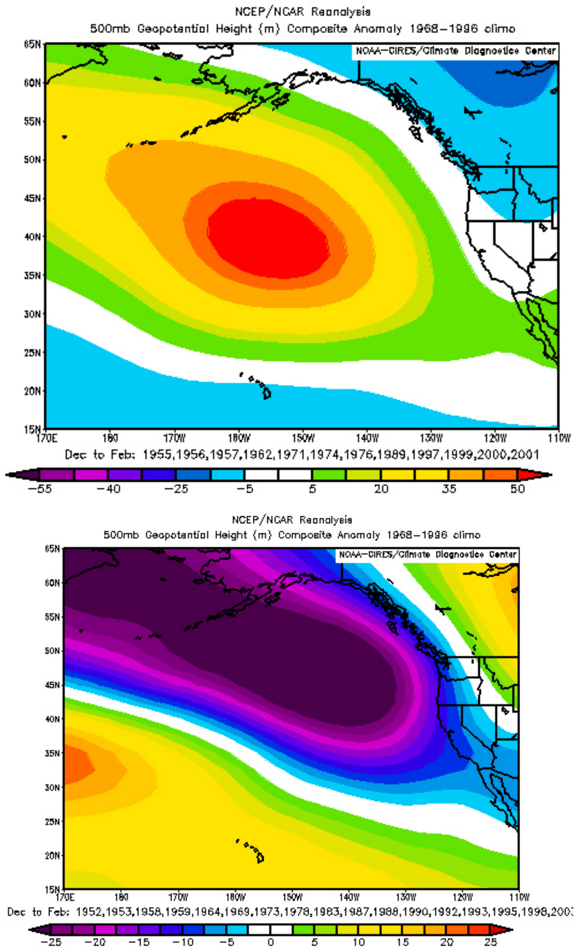

Fig. 9 Composite Dec.-Feb 500 mb geopotential heights anomaly charts for SOI Dec.-Feb. values at top equal to and greater than 0.5, and at bottom equal to and less than –0.5.

years (i.e. both negative or both positive SOI and PDO), with highest percentage increases during El Nino years during the warm PDO phase for southern California (over 150% of normal) and for coastal Oregon and Washington for La Nina years with the cold PDO phase. However, the ENSO teleconnections with west coast precipitation is weaker and less consistent for out-of-phase years (Schmidt and Web 2001). There are also fewer years to use for a reliable sample for out-of-phase years between 1950 and 2002.

4. Composite Weather Charts

As PDO and SOI were the best predictors for explaining temperature and precipitation variability along the west coast, we looked at the atmospheric conditions that were associated

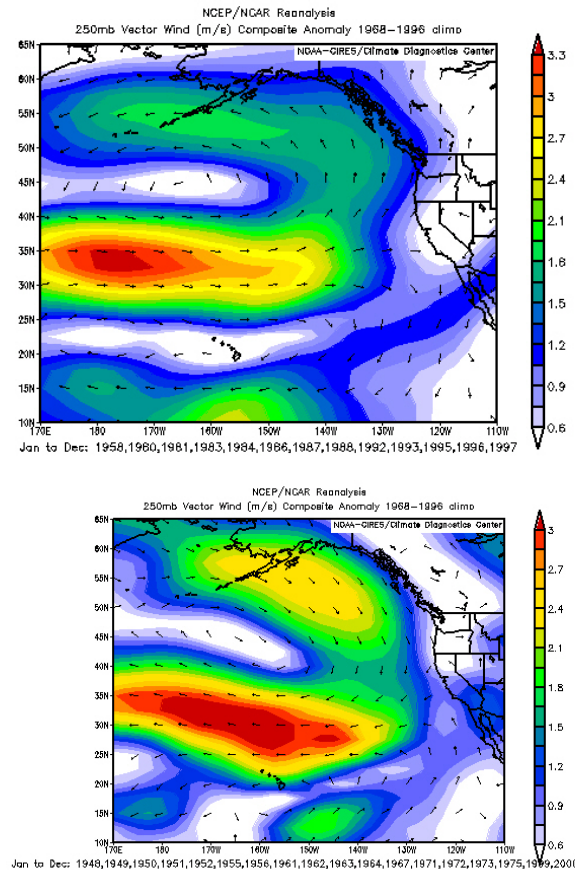

Fig. 10 Composite 250 mb vector winds anomaly charts for Dec.-Feb. PDO values at top equal to and greater than 0.5, and at bottom equal to and less than –0.5.

with more extreme values of annual and seasonal PDO and SOI values. Specifically, we looked at composites of the SLP, 500-mb geopotential heights, and 250-mb wind velocities for PDO values greater than 0.5 and less than –0.5. Each group represents approximately the upper and lower quarter of the 1948-2003 record. Similarly composite synoptic charts were examined for SOI values of greater than 0.5 and less than –0.5. SLP anomalies were marked lower in the North Pacific for the positive PDO composite than for the negative phase, as noted by Zhang et al. (1997). For the interannual patterns, PDO+ shows a deep Aleutian Low with lower pressures along the west coast. PDO- shows anomalously high SLP over the North Pacific, with lower anomalies over British Columbia (Fig. 7). The former pattern would be associated with more southerly flow along the west coast with higher SSTs, while the latter would produce stronger northerly coastal flows with upwelling and cooler SSTs. These circulation patterns for the PDO extremes explain the strong relationships with coastal temperatures. SLP anomalies for SOI show quite similar patterns to PDO. SOI- shows the deep Aleutian Low, while SOI+ has higher pressures over the North Pacific. These patterns are especially strong for the Dec.-Feb. SLP (Fig. 8). For the 500 mb. geopotential height anomalies, the Aleutian Low is stronger with PDO+, while the North Pacific has higher heights with PDO-. These patterns repeat for the seasons as well, although the anomalies are largest for annual means, followed by winter. Again, SOI- shows deeper Aleutian Lows, while SOI+ has strong higher heights over the North Pacific, especially for the July-June means and for winter (Fig. 9). Very similar results are found at 700 mb. height anomalies. Westerly flow in the upper atmosphere increases along the mid-latitudes of the Pacific, while jet streams and storm tracks shift farther south over the North pacific during SOI- winters (Redmond and Cayan 1999; Zhang et al. 1997). The 250 mb. vector wind means for PDO+ are generally stronger both in the western Pacific and over the southwest U. S., with a split jet into North America. PDO- has weaker subtropical jet and a slightly farther north polar jet (Fig. 10). The PDO+ polar jet is stronger for all seasons and further south along the west coast. These patterns are similar to those of SOI, though in the opposite sign, with SOI- having a stronger jet over the southern states, especially in winter.

5. Conclusions

West coast temperature and precipitation anomalies are significantly related to Pacific indices and can be predicted in advance with a high level of confidence. The PDO and NP indices can explain a large percent of variability in both annual and seasonal temperatures with leads of one to three seasons. PDO values explain California annual and summer temperatures best, though all seasons are well explained. Coastal Oregon and Washington temperatures also show high correlations with both PDO and NP values with leads up to two seasons in advance. Coastal precipitation relationships with Pacific indices are all highly significant, although the southern coast has an inverse relationship to that of the northern coast divisions. The SOI explains nearly 40% of the variability of southern California's annual precipitation with decreasing amounts explained towards the north. Seasonally, tropical Pacific indices are best at explaining winter, spring, summer and fall precipitation in that order. Oregon annual precipitation is best explained by PDO, with winter showing the highest correlations, followed by fall, summer, and spring, all highly significant. Washington's coastal precipitation is best explained by WP, annually, with winter showing highest seasonal correlations with tropical Pacific indices, followed by fall, spring and summer. Annual anomalies show largest percentage increases in precipitation along the southern coast during El Niños with warm PDO phase, while northern coast divisions show the largest increases in precipitation during cold PDO phase La Niñas. The total swing in departures between the two extreme combinations of PDO/ENSO values is not only impressive in both amounts and percentages, but also represent a significant impact on water supplies for these populous coastal divisions. Although highly significant, precipitation variability is not as well explained as temperatures. It has been suggested that it may have to do with observation inaccuracies in the historical precipitation data (Groisman and Legates 1994) and that the complex terrain of the western U.S. produces large differences in the distribution of storm totals. This and the fact that most recording stations are located at lower elevations may lead to weaker relationships. However, ENSO and extratropical Pacific indices still have significance in predicting west coast temperature and precipitation. With the probable PDO-phase continuing for at least this decade, it would be prudent to expect more cool anomalies with more frequent La Niña events. Overall means would suggest wetter than normal conditions along the northern coast, with drier years to the south.

6. Acknowledgements

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Appendix: Tables

Table 1. Maximum Correlation Coefficients Between Temperatures and Pacific Indices. Lead in months in parentheses

	Climatic Divisions						
	CA6	*CA4*	*CA1*	*OR1*	*OR2*	*WA1*	*WA3*
Time Periods							
Jan.-Dec.	.727 PDO (+0)	.762 PDO (+0)	.728 PDO (+0)	.705 PDO (+0)	.559 PDO (+0)	.688 PDO (+0)	.628 PDO (+0)
Dec.-Feb.	.558 PDO (+0)	.569 PDO (+0)	.585 PDO (+0)	-.800 NP (+0)	-.602 NP (+0)	-.750 NP (+0)	-.681 NP (+0)
Mar.-May	.502 PDO (+12)	.465 PDO (+1)	.426 PDO (+1)	.678 PDO (+0)	.619 PDO (+0)	.722 PDO (+0)	.719 PDO (+0)
Jun.-Aug.	.555 PDO (+2)	.598 PDO (+2)	.536 PDO (+5)	.481 PDO (+2)	.345 PDO (+4)	.508 PDO (+2)	.466 PDO (+4)
Sep.-Nov.	-.507 NP (+2)	-.571 NP (+2)	-.492 NP (+1)	-.593 NP (+1)	-.480 NP (+1)	-.566 NP (+1)	-.492 NP (+1)

Table 2. Temperature and Precipitation Anomalies for ENSO Extremes and PDO Phase

a. Temperature Anomalies from 1895-2000 Means

Climate Divisions	*CA6*	*CA4*	*CA1*	*OR1*	*OR2*	*WA1*	*WA3*
El Nino Yrs. Warm PDO (7 yrs)	.86	.67	.77	.71	.89	.91	.94
El Nino Yrs. Cold PDO (4 yrs)	-.86	-.47	-.34	.06	-.02	.14	.08
La Nina Yrs. Warm PDO (3 yrs)	.09	-.03	.33	-.15	.07	-.31	-.35
La Nina Yrs. Cold PDO (10 yrs)	-.43	-.57	-.59	-.75	-.46	-.87	-.74
Cold PDO Yrs. 1951-1976	-.54	-.37	-.50	-.31	-.26	-.33	-.31
Warm PDO Yrs. 1977-1997	.93	.64	.81	.52	.46	.57	.54

b. Precipitation Anomalies from 1895-2000 Means (Inches), % of normal in parentheses

Climate Divisions	*CA6*	*CA4*	*CA1*	*OR1*	*OR2*	*WA1*	*WA3*
El Nino Yrs.	8.79	6.77	6.27	-.80	1.09	-1.32	-1.33
Warm PDO (7 yrs)	(151.1)	(132.0)	(115.1)	(98.9)	(102.1)	(98.6)	(96.7)
El Nino Yrs.	3.61	4.53	5.09	-4.17	-4.25	-5.56	-3.85
Cold PDO (4 yrs)	(121.0)	(121.4)	(112.3)	(94.5)	(91.6)	(94.0)	(90.4)
La Nina Yrs.	-5.77	-2.43	-2.90	.29	3.54	-.83	3.12
Warm PDO (3 yrs)	(66.4)	(88.5)	(93.0)	(100.4)	(107.0)	(99.1)	(107.8)
La Nina Yrs.	-5.26	-2.80	3.01	14.13	9.54	18.72	7.08
Cold PDO (10 yrs)	(69.8)	(90.8)	(102.3)	(111.7)	(112.0)	(114.4)	(113.9)
Cold PDO Yrs	-2.73	-2.08	-1.11	4.07	2.06	5.56	1.51
1951-1976	(84.1)	(90.2)	(97.3)	(105.4)	(104.0)	(106.0)	(103.8)
Warm PDO Yrs.	1.74	1.82	1.19	-.48	1.85	3.06	2.27
1977-1997	(110.1)	(108.6)	(102.9)	(99.4)	(103.6)	(103.3)	(105.7)

Table 3. Maximum Correlation Coefficients Between Precipitation and Pacific Indices. Lead in months in parentheses

	Climatic Divisions						
Time Periods	*CA6*	*CA4*	*CA1*	*OR1*	*OR2*	*WA1*	*WA3*
Jul.-Jun.	-.629	-.440	-.236	-.247	-.253	-.374	-.380
	SOI	SOI	SOI	PDO	WP	WP	WP
	(+4)	(+4)	(+4)	(+0)	(+2)	(+2)	(+2)
Dec.-Feb.	-.494	.438	.415	-.454	-.432	.479	.435
	EPO	TNA	TNA	PNA	PNA	EPO	EPO
	(+0)	(+0)	(+0)	(+1)	(+1)	(+0)	(+0)
Mar.-May	-.494	-.376	-.351	.317	.254	.317	-.312
	SOI	EPO	EPO	EPO	EOF	SOI	WP
	(+6)	(+2)	(+2)	(+1)	(+1)	(+4)	(+7)
Jun.-Aug.	.432	-.324	.427	.322	.386	-.250	-.244
	PNA	EPO	PDO	PDO	PDO	TNA	WP
	(+5)	(+2)	(+0)	(+0)	(+0)	(+2)	(+2)
Sep.-Nov.	.393	-.277	.353	-.374	-.352	-.367	.364
	TPSST	SOI	EPO	PDO	PDO	PDO	SOI
	(+2)	(+3)	(+4)	(+0)	(+0)	(+0)	(+2)

Table 4: Pacific Atmospheric and Oceanic Indices

For a complete description of these indices, see: http://www.cdc.noaa.gov/ClimateIndices/Analysis/

BEST	Combination of tropical Pacific SST, SLPs
EPO	Eastern Pacific Oscillation
MEI	Multivariate ENSO Index
Nino 1-4	Eastern tropical Pacific SSTs
NOI	Northern Oscillation Index
NP	North Pacific pattern
Pac. Warmpool	1st EOF SST W. tropical Pacific
PDO	Pacific Decadal Oscillation
PNA	Pacific North American Index
SOI	Southern Oscillation Index
TNA	Tropical N. Atlantic Index
TNI	Trans-Nino Index
Trop Pac EOF	1st EOF of SST E. tropical Pacific
WHWP	Western Hemisphere Warm Pool
WP	Western Pacific Index