Regional Context of the Climate of H.J. Andrews Experimental Forest, Oregon

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H.J. Andrews Experimental Forest is a 6400 ha forest of Douglas fir, western hemlock, and Pacific silver fir located in, and typical of, the central portion of the western slope of the Cascade mountain range of Oregon. The forest is one of 19 sites in the Long-Term Ecological Research (LTER) program sponsored by the National Science Foundation (Franklin *et al* 1990). During the 1970s it was a representative site in the Coniferous Forest Biome Project of the U.S. International Biological Program. It was originally established in 1948 as an Experimental Forest of the U.S. Forest Service. An immense legacy of research has resulted from the participation of Andrews Forest in these programs (McKee *et al* 1987, Blinn *et al* 1988). Future participation in LTER ensures the continuing scientific importance of the site.

Climatological information has been collected at Andrews Forest since 1951, with a continuous, electronically-sensed record since May 1972. The observing system is composed of a primary meteorological station and a network of satellite temperature and precipitation recording stations. Because of the scientific significance of Andrews Forest, it is important to investigate the temporal variability of annual and seasonal temperature and precipitation values at the site and identify past times of anomalous climatic conditions. It is also important to establish quantitatively the relationships between the climate of Andrews Forest and that of its surrounding area and, hence, place the climate of Andrews Forest into its regional context.

Climate of Andrews Forest

The primary meteorological station of Andrews Forest is at an elevation of 426 meters (1397 feet) at latitude 44° 15' N and longitude 122° 10' W. Andrews Forest occupies the Lookout Creek watershed, which ranges from 420 to 1630 meters (1378 to 5346 feet) and drains into Blue River. Below 1050 meters (3444 feet) is the Western Hemlock zone, characterized by western hemlock and Douglas fir. Above 1050 meters (3444 feet), the Pacific Silver Fir zone is established (Bierlmaier and McKee 1989).

Bierlmaier and McKee (1989) have described Andrews Forest climate as wet and fairly mild in winter and warm and dry in summer. They emphasize the role of the polar front jet stream in funneling into the area

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one low pressure zone and frontal storm after another during winter. Precipitation comes mainly from cold or occluded fronts. The storms are slowed by the Coast and Cascade ranges and are, consequently, of long duration and low intensity. The summer season is dominated by establishment of a ridge of high pressure along the coast and the eastern Pacific. Consequently this season is characterized by highly stable air and low amounts of precipitation. During 1973 to 1984, the average annual temperature was 8.5°C (47.3°F). Monthly temperatures ranged from 0.6°C (33.1°F) in January to 17.8°C (64.0°F) in July. Annual average precipitation was 2302 millimeters (90.6 inches), 71 percent of which fell from November through March. At 1203 meters (3946 feet) annual precipitation rises to 2785 mm (109.7 in). Above 1050 meters (3444 feet) a persistent snowpack up to 4 meters (13 feet) deep may form and last into June (Bierlmaier and McKee 1989). Further details of the climatography of Andrews Forest may be found in Emmingham and Lundburg (1977, quoted by Bierlmaier and McKee 1989), Waring *et al* (1978), and McKee and Bierlmaier (1987).

Regional Climate of Oregon and the Pacific Northwest and Importance of the Pacific Ocean

Regional climatologies of Oregon and the Pacific Northwest have been given by Phillips (1960), Sternes (1960), Pacific Northwest River Basins Commission (1969), and Loy *et al* (1976). No understanding of this climate would be complete without reference to the seminal role of interactions between the ocean and the atmosphere in the area of the northern Pacific Ocean and, to some degree, the tropical and southern parts of the Pacific as well. Namias pioneered this concept in a series of important papers (1959, 1968, 1969, 1971, 1972, 1978, 1979, 1981). More recently, the ocean/atmosphere interconnections have been treated in synoptic climatology through the use of PCA *(principal component analysis)* (Walsh and Richman 1981) and teleconnections and in dynamic climatology increasingly by the use of GCMs *(General Circulation Models)* of the atmosphere and ocean.

The GCMs, by definition, deal with the atmosphere at the global scale. PCA and teleconnective studies, on the other hand, can be designed to investigate particular parts of the world and those studies relevant for the Pacific Northwest are based on the Southern Oscillation Index, the Pacific-North American Index, and the Central North Pacific Index. These three indicies exhibit a certain degree of intercorrelation (Cayan and Peterson 1989).

The strength of teleconnective patterns is not necessarily stable over time. Ropelewski and Halpert (1986) have shown that, depending on the data used, the Pacific Northwest is either in or on the southern edge of an area having lower rainfall when El Niños are in progress and in many of the months following the El Niño maximum.

Wallace and Gutzler (1981) were the first to introduce the PNA *(Pacific-North American)* index. However, the PNA index designed by Leathers *et al* (1991) following Yarnal and Diaz (1986) is the one used in this study. The PNA index describes the amplitude of the 700-mb flow pattern over the United States, which has a basic pattern of low pressure troughs in the eastern Pacific and eastern United States, and a high pressure ridge over the Rocky Mountain cordillera. The meridional extreme of the pattern produces positive PNA values (and potentially more southwesterly winds over Andrews Forest), while the zonal extreme produces negative PNA values (and potentially more westerly winds over Andrews Forest). Yarnal and Diaz (1986) demonstrated how strongly positive PNA and negative (reverse) PNA patterns are associated, respectively, with warm and cold ENSO *(El Niño Southern Oscillation)* events and, in turn, with precipitation and temperature anomalies on the west coast of North America.

Cayan and Peterson (1989) defined the CNP *(Central North Pacific)* index as the MSLP over the region 35-55°N and 170°E to 150°W. They show that streamflow in the West has correlations in the range 0.3 to 0.6 SLP with anomalies in the North Pacific. During times of a weak CNP index, streamflows are high in Washington and Oregon. During times of a strong CNP index, the polar front jet stream flows north of the Pacific Northwest, and below-average streamflow is observed. Often, this is also the case during El Niño events (see Cayan and Peterson 1989, Figure 9).

All of the synoptic studies indicate quite clearly the linkages between SSTs and particular pressure and teleconnective patterns in the Pacific Ocean and various aspects of climate on the West Coast and in the Pacific Northwest.

Data Processing and Analysis

Data were screened for temporal continuity of the observing station and preprocessed to make them available for analysis. Stations deemed most likely to provide pertinent information were Corvallis, Cottage Grove, Eugene, Leaburg, McKenzie Bridge, and Cascadia. The history of each station was scrutinized for continuity using station histories for Oregon from Redmond (1985). After analysis of pre- and post-move observations for Eugene, that record was dropped. Data from Andrews Forest were provided from the Long-Term Ecological Research section of the Forest Science Data Bank in the Forest Sciences Laboratory at Corvallis. Precipitation data for the primary meteorological site for 1973 through 1978 were taken from Bierlmaier and McKee (1989). The Oregon Climate Service provided data for the NWS stations, the Willamette Valley and Northern Cascade climate divisions of Oregon, and most SOI values. Supplementary SOI values were provided by Dr. R. Cerveny of the Department of Geography at Arizona State University. PNA values were provided by Dr. D. Leathers of the Department of Geography at the University of Delaware.

Regression Analysis

Multiple regression analysis was used to find the monthly values of mean temperature and total precipitation at Andrews Forest from values at the selected stations. The same multiple regression function was used to produce all correlation coefficients in this paper, and correlation coefficient values are reported as positive irrespective of whether they are positive or negative.

Precipitation Data

The multiple regression analysis identified good correlation in monthly and annual precipitation values between the five stations. All regression equations were significant at the 99 percent level, as assessed by their F values. Regression equations were computed for different sets of stations for three time periods determined by the length of station records. The time periods were 1936 to 1972, 1919 to 1935, and 1910 to 1918. Table 1 shows the monthly range of r^2 and standard error of estimate values for these periods. The sum of the 12 monthly totals is used for the annual total value.

Table 1
STATIONS USED, RANGE OF REGRESSION COEFFICIENTS, AND STANDARD ERROR OF ESTIMATES FOR MULTIPLE REGRESSION EQUATIONS USED TO OBTAIN MONTHLY TOTAL PRECIPITATION AT H. J. ANDREWS EXPERIMENTAL FOREST

Water Year = October to September (Johnson & Dart, 82)
All r^2 values significant at 99% level

		r^2	Standard Error of Estimates *(inches)*
1936 - 1972 Corvallis, Leaburg, McKenzie Bridge, Cascadia, Cottage Grove			
	Monthly	0.89 to 0.98	0.30 to 1.81
	Annual	0.93	4.91
	Water Year	0.98	3.22
1919 - 1935 Corvallis, Cascadia, Cottage Grove			
	Monthly	0.83 to 0.94	0.33 to 2.12
	Annual	0.91	5.28
	Water Year	0.96	3.76
1910 - 1918 Corvallis			
	Monthly	0.47 to 0.86	0.43 to 3.44
	Annual	0.61	10.05
	Water Year	0.77	8.43

A similar analysis was performed for water year periods. Following Johnson and Dart (1982) the water year is defined as October 1 to the next September 30 and is numbered for the year in which it ends. The analysis was also performed for the winter part of the water year (October to April). This selection of seasons follows the approach of Johnson and Dart (1982) and has obvious practical and hydrological advantages. The water year and winter water year correlations carry a higher degree of accuracy than those for the calendar year. The values found in this report are of the same order and consistent with the findings of Dart and Johnston (1982, pages 104-111), who worked on the whole state of Oregon.

Temperature Data

The same five predictor stations were scrutinized for efficiency in simulating temperature, using their average annual data from 1973 to 1991. Correlation coefficient, standard error of estimates, and significance values between the five stations and the Andrews Forest data indicated data from Cascadia impaired the strength of the regression equations. Cascadia was, therefore, omitted for the rest of the analysis. The range of individual monthly regressions (Table 2) displays slightly lower correlations than for precipitation, but still shows strong values.

Table 2
STATIONS USED, RANGE OF REGRESSION COEFFICIENTS, AND STANDARD ERROR OF ESTIMATES FOR MULTIPLE REGRESSION EQUATIONS USED TO OBTAIN MEAN MONTHLY TEMPERATURE AT H. J. ANDREWS EXPERIMENTAL FOREST

All r^2 values significant at 99% level except where noted.

		r^2	Standard Error of Estimates (°F)
1936 - 1972 Corvallis, Leaburg, McKenzie Bridge, Cottage Grove			
	Monthly	0.69 to 0.92	0.84 to 1.83
	Annual	0.50 (95.0%)	1.02
1917 - 1935 Corvallis, Cottage Grove			
	Monthly	0.57 to 0.84	0.73 to 1.80
	Annual	0.49	0.96
1890 - 1916 Corvallis			
	Monthly	0.56 to 0.84	1.06 to 1.97
	Annual	0.49	0.93

Analysis of the Synthetic and Observed Record

Simulated monthly mean temperature and total precipitation data verified quite well against an observed independent dataset from Watershed 2 in Andrews Forest. The simulated temperature and precipitation series were determined to have an accuracy level that justifies further temporal and spatial analysis of the data.

Precipitation

The regression analysis described above was used to produce a set of observed and synthetic monthly and annual precipitation values for Andrews Forest for 1910 to 1991 (continuous from 1913). The total annual water year precipitation record from 1911 to 1991 displayed considerable interannual variability.

Trends represented by the 5-year running mean of the same data plainly showed the prolonged and severe drought of the 1930s and the wetter years of the late 1940s and the 1950s. The record exhibits greater variability in more recent years, with two peaks of precipitation centered on 1973 and 1984 and droughts centered on the late 1970s and one that persisted at least through 1991. Both droughts, as judged by the value of water year precipitation, were as severe as the drought of the 1930s, but at least the 1970s drought did not last as long.

The variations of precipitation at Andrews Forest found here match quite well the trends in the Willamette Valley described by Johnson and Dart (1982), who also note high interannual variability and, correspondingly, relatively few groupings of wet or dry years for western Oregon.

Temperature

The observed and synthetic annual mean temperature record for Andrews Forest from 1890 to 1991 also showed considerable interannual variability. Analysis in terms of 5-year running means displayed a warming trend between the beginning of the record and the early 1940s, punctuated by two cool periods in the early 1910s and the early 1920s. Another cool period is seen from the late 1940s to the mid-1970s, with the exception of one warm year (1958). A warming trend is seen from the mid-1970s to the present. The magnitude of this trend, at least up to 1991, is similar to that of the warming trend at the beginning of the century.

Bradley (1982) notes that 1921 to 1935 stand out over the western United States as anomalously warm in the context of the last 100 years. The Andrews Forest data do show high temperatures during this time. At Andrews Forest, 8 of these 15 years have above mean (1890-1991) temperatures, and 3 of the years exceed the mean by 1 standard deviation. Comparison of individual years of high and low temperatures for Oregon as a whole identified by Bradley is not easily possible in the absence of Bradley's data in tabular form. Comparison of low- and high-temperature winters for selected West Coast stations (Roden 1989) shows that, more often than not, Andrews Forest values parallel the coastal values.

Recent Warming

Since there is considerable evidence of a trend of increasing minimum temperatures over the last two to three decades (Karl *et al* 1988), the Andrews Forest record was examined to see if it contained this signal. Maximum, minimum, mean seasonal, and mean annual temperatures were regressed against year number for 1973 through 1991. At Andrews Forest, this period had not only increasing minimum temperatures but increasing maximum and mean temperatures as well. Of ecological importance is the fact that the greatest increases occurred in spring (March, April, May), possibly affecting growth rates. The warming is also seen at Corvallis and Cottage Grove, although not quite as intense and not during winter. Again, the magnitude of this recent warming trend is similar to one that took place at Andrews Forest at the beginning of the century.

Step Functions

Several investigators have identified step functions in certain of the meteorological time series during the period of modern record. Ebbesmeyer *et al* (1991) have investigated a step function in biogeophysical time series of the Pacific Northwest and the Pacific in 1976. Leathers and Palecki (1992) have identified a step function in the value of the PNA index during the late 1950s and centered on about 1957. The 1957 step was also noticed in records of the mean height of sea level along the West Coast (Namias 1972). An analysis was performed to investigate whether such steps exist in the climatic data for Andrews Forest.

First, the difference of the means before and after the steps were tested using a 2-tailed t test. Using the means of the 8 years before and after the 1976 step, there was a significant difference (99% level) in Andrews Forest annual mean temperatures. A significant difference (99% level) was also displayed in annual mean temperatures when 15-year means either side of 1976 were taken. No significant difference was seen in the winter water year precipitation values at Andrews Forest when 8-year means were taken either side of 1976, but a significant difference (95% level) was found in these values when a 15-year mean either side of 1976 was selected.

No significant differences were found in Andrews Forest annual mean temperatures or winter water year precipitation between 18-year means or 8-year means either side of 1957. At first this result seems hard to explain, since there is a weak relationship between the PNA values and Andrews Forest precipitation and temperature values (Table 3). However, this relationship is seen more in winter values than in annual values. Perhaps more important is the fact that Leathers and Palecki (1992) show that the 1957 PNA step is seen most clearly in the southeastern United States center of action of the PNA index rather than either of the two centers closer to the Pacific Northwest.

Table 3
CORRELATION COEFFICIENT VALUES BETWEEN
ANNUAL, JANUARY, AND JULY MEAN TEMPERATURE AND PRECIPITATION TOTALS
AT H.J. ANDREWS EXPERIMENTAL FOREST AND SELECTED GENERAL CIRCULATION INDICES,
1948 TO 1987

	Precipitation					
	Annual or Winter Water Year		January		July	
Variable Regressed Against	r^2	Significance Level (%)	r^2	Significance Level (%)	r^2	Significance Level (%)
PNA Annual	0.08	<95				
PNA Winter Water Year	0.25	99				
PNA			0.16	95	0.00	<95
CNP Annual	0.04	<95				
CNP Winter Water Year	0.17	99				
CNP			0.10	95	0.06	<95
CNP Annual (1914-1990)	0.03	<95				
CNP Winter Water Year (1914-1990)	0.21	99				
CNP (1914-1990)			0.11	99	0.03	<95

	Temperature					
	Annual or Winter Water Year		January		July	
Variable Regressed Against	r^2	Significance Level (%)	r^2	Significance Level (%)	r^2	Significance Level (%)
PNA	0.12	95	0.40	99	0.11	95
CNP	0.45	99	0.40	99	0.04	<95
CNP (1910-1990)	0.44	99	0.31	99	0.05	95

There is evidence in Andrews Forest record for the 1976 step but not for the PNA-related 1957 step. However we interpret the Andrews record in terms of pre- and post-1976 values, it is clear that 1976 was a marked turning point at Andrews Forest for both temperature and precipitation. For about 15 years before 1976, the annual temperature trend had been downward. Since 1976, the trend has been upward. In absolute terms, the 1977 water year (which includes the winter of 1976-77) had the lowest precipitation values in the entire record, with generally higher values both before and after 1977. The 5-year running mean of these data places the turning point two years later. Clearly the atmosphere changed to a different mode of operation in the mid-1970s, and this change is well represented in Andrews Forest data as well as in data for many other parts of the Pacific Northwest.

The Tree Ring Record

The general temporal variation that Graumlich (1987) reports in a study of tree ring width data for the present century in her defined Western Lowlands and Columbia Basin (but not the Southern Valleys) divisions is similar to the Andrews Forest precipitation record. Data from Andrews are generally consistent with those of Graumlich and tend to suggest that her findings for earlier years, back to 1640, would also apply to Andrews Forest.

More confidence should be attributed to runs of dry (and presumably wet) years rather than to individual years. One reason for this is the masking of extreme values in the simulated Andrews Forest data, related to the least squares analysis methodology. Graumlich finds marked droughts in the Columbia Basin around 1680, in the 1750s, 1780s, 1790s, 1840s, 1865 to 1895, and in the 1920s and 1930s. Wet periods occurred from 1695 to 1715, 1740 to 1760, and 1810 to 1835. The wet and dry periods were similar in the Western Lowlands, except that the duration of droughts was less. Hatton (1989) found similar results from a tree ring record at Lost Forest, in the eastern end of the Fort Rock Basin in Lake County in central Oregon.

Graumlich and Brubaker (1986) analyzed a tree ring record for Longmire, Washington, and commented that temperatures between 1900 and 1940 were higher than any other 40-year period. Andrews Forest temperature data for the present century also display high temperatures during this time and, thus, imply that earlier "warm" periods in the Washington record also occur at Andrews Forest. These warm periods were 1655-1670, 1690-1695, and 1825-1830. "Cool" periods in the Longmire record were 1610-1630, 1640-1650, 1695-1760, 1800-1808, 1840-1850, and 1875-1895.

The Regional Context

Synthetic and observed precipitation data for Andrews Forest for 1915 to 1991 were compared by correlation techniques on a month-by-month and an annual basis with precipitation data from the Willamette Valley (OR2) and the Northern Cascades (OR4) Oregon Climate Divisions. There is a slight degree of autocorrelation, because data from some stations in the divisions were used to simulate part of the Andrews Forest dataset. The autocorrelation is very small; Cascadia, Corvallis, Cottage Grove, and Leaburg are just 4 of the 33 stations in the Willamette Valley Division, and McKenzie Bridge is just one of eight stations in the Northern Cascades Division. Consequently it is reasonable to assume that the small amount of autocorrelation does not markedly affect the results from this analysis.

For precipitation, the relevant r^2 values indicate a strong relationship between Andrews Forest data and both the Willamette Valley and Northern Cascades divisional data. Monthly correlation coefficient values range from 0.60 to 0.92. It is remarkable that high values are found even for summer months. On the basis of these values precipitation at Andrews Forest is slightly more related to the Northern Cascades division (in which it is located), but the high r^2 values indicate it is representative of the area covered by both divisions. Monthly correlation coefficients between temperature values of the climatic divisions and Andrews Forest are slightly lower than those for precipitation and range from 0.59 to 0.87. The Willamette Valley division has the higher correlation values in most cases. This may be due to the high degree of variation of temperature values in complex terrain associated with the wide variety of different microclimates.

General Circulation Indices

The observed and synthetic Andrews Forest data were compared with general circulation indices designed to relate to the Pacific Northwest region following an approach of Wigley *et al* (1990) and Jones (1991), who were interested in how to estimate regional values of projected climate change from the projected values at grid points on the coarse network used by current general circulation models. The indices were constructed for use with a dataset of reconstructed monthly MSLP developed by Jones *et al* (1987).

Data for North America are on a 5° latitude by 10° longitude grid. Following the approach by Jones (1991), three general circulation indices were developed. The first was simply a pressure index (SLP) at 45°N 120°W, a location in the center of Oregon not far from Andrews Forest. The second was a zonal index comprised of the difference in SLP between 40°N 120°W and 50°N 120°W. Positive values of this index indicate the general strength of westerly winds. The third index was a meridional index comprised of the difference in SLP between 45°N 120°W and 45°N 130°W. Positive values of this index indicate the general strength of southerly winds. These points differ somewhat from those employed in Jones' original study. To clarify the regression analysis, the value of the first index was modified by subtracting 1014 mb from each value.

The correlation coefficients for the temporally aggregated data (Table 4) indicate a slight correlation between the Central Oregon SLP and winter water year precipitation and between the meridional index and annual mean temperature, where southerly winds are expectedly associated with higher temperatures, but no other relationships are apparent. On the monthly time scale there is greater correlation of Andrews Forest temperature and precipitation values and the circulation indices in January but no correlation in July (Table 5). This is to be expected, given the more vigorous general circulation in the Northern Hemisphere winter and the low absolute amount of precipitation at Andrews Forest in summer.

Table 4
CORRELATION COEFFICIENT VALUES BETWEEN
ANNUAL MEAN TEMPERATURE AND WINTER WATER YEAR PRECIPITATION TOTALS
AT H.J. ANDREWS EXPERIMENTAL FOREST AND
SELECTED GENERAL CIRCULATION INDICES

Winter Water Year Precipitation, 1914-1980.		
Variable Regressed Against	r^2	Significance Level (%)
Central Oregon Pressure	0.24	99
Zonal Index	0.15	99
Meridional Index	0.03	<95

Annual Mean Temperature, 1890-1980		
Variable Regressed Against	r^2	Significance Level (%)
Central Oregon Pressure	0.01	<95
Zonal Index	0.01	<95
Meridional Index	0.36	99

Table 5
CORRELATION COEFFICIENT VALUES BETWEEN
JANUARY AND JULY MEAN TEMPERATURE AND PRECIPITATION TOTALS
AT H.J. ANDREWS EXPERIMENTAL FOREST AND
SELECTED GENERAL CIRCULATION INDICES, 1914-1980

	Precipitation			
	January		July	
Variable Regressed Against	r^2	Significance Level (%)	r^2	Significance Level (%)
Central Oregon Pressure	0.29	99	0.03	<95
Zonal Index	0.22	99	0.04	<95
Meridional Index	0.07	95	0.04	<95
All Three Indices	0.52	99	0.19	99

	Temperature			
	January		July	
Variable Regressed Against	r^2	Significance Level (%)	r^2	Significance Level (%)
Central Oregon Pressure	0.32	95	0.00	<95
Zonal Index	0.32	99	0.04	<95
Meridional Index	0.28	99	0.00	<95
All Three Indices	0.56	99	0.04	<95

To be more consistent with Jones' analysis, all three circulation indicators were used together in a multiple regression for January and July. This analysis yielded correlation coefficients of 0.56 (January temperature) and 0.52 (January precipitation), which is comparable to Jones' findings, and 0.04 (July temperature) and 0.19 (July precipitation), which is much lower than Jones found for the general location of Andrews Forest. In summary the relationships in winter are much stronger than those in summer. The implication of these results is that output values predicted by general circulation models for the general area of the Pacific Northwest may be applied to Andrews Forest with more confidence in winter season than in summer.

Pacific-North American and Central North Pacific Indices

Correlations were also made between Andrews Forest data and the PNA and the CNP indices for 1948 to 1987. The results (Table 3), in the context of this kind of synoptic climatological analysis, indicate quite marked correlations between Andrews Forest winter water year precipitation and both the PNA index and the CNP index. Precipitation at Andrews Forest for January, representing winter months, also displays a weak but significant correlation with both indices. No relationships are seen for July, representing summer months, or for the calendar year precipitation totals. Annual and January mean values of temperature exhibit a strong correlation with the CNP index. The relationship of January mean temperatures to the PNA index is also strong, but relationships for the year and for July, although significant, are not so strong. Redmond and Koch (1991) also found significant relationships between concurrent precipitation and temperature values in the Pacific Northwest and PNA values, with temperature having the strongest relationship.

Physically, when the PNA index is positive and high, a meridional circulation in the westerlies with a ridge of high pressure shunts storms to the north of Oregon (and Andrews Forest), giving rise to relatively dry weather. This situation also brings in warm air with relatively high temperatures from the southwest. When the PNA index is negative, the zonal circulation in the westerlies brings in storms from the Pacific Ocean, giving rise to wetter weather and somewhat lower air temperatures. These interpretations are also consistent with the CNP values, which when low indicate a well-developed Aleutian low pressure zone will guide storms northward to British Columbia but when high allow storms to travel more directly eastward into Washington and Oregon.

The advantage of using the CNP is that it has a long record dating back to 1899. Comparison of relationships between Andrews Forest data and the CNP index for the longer periods of 1910 or 1914 to 1990 (Table 3) indicates little difference in the correlation coefficients found for the shorter 1948-1990 period. This is encouraging, because it suggests the relationships are fairly stable over time and the time series are somewhat stationary.

Southern Oscillation Index

Direct comparison of winter water year Andrews Forest values and SOI values suggests a relationship in which low SOI values (warm event, El

Niño years) tend to be associated with low precipitation values at Andrews Forest and high SOI values (cold event, La Niña years) tend to be associated with high precipitation values at Andrews Forest. The relationship is clear, although it is not strong statistically (r^2=0.14, significant at 99%). The 1983 year, which had an extraordinarily strong low SOI value is a noteworthy outlier on the scattergram. Without the 1983 value, the relationship is stronger (r^2=0.23, significant at 99%). A similar, though stronger and reverse, relationship exists on an annual time scale between the SOI values and the annual mean temperature at Andrews Forest (with inclusion of the 1983 data point r^2=0.24, significant at 99%).

Further light is given to this issue by examining Andrews Forest climate values for extreme SOI years. Two sets of extreme SOI years have been provided by Yarnal and Diaz (1986) and Halpert and Ropelewski (1992). Yarnal and Diaz identified a number of warm (El Niño) and cold (La Niña) event winters (December, January, February). During warm event winters, Andrews Forest precipitation is near average, at 0.03 standard deviation of the long term (1914-1991) mean and the temperature is well above (0.77 SD) the long-term (1890 to 1991) mean. During cold event winters, Andrews Forest precipitation is well above (0.69 SD) the long-term mean and temperature is below it (-0.33 SD).

Halpert and Ropelewski defined warm event years as those in which the SOI index value remained in the lower 25 percent of the distribution for five months or longer and similarly defined cold event years by using the upper 25 percent of the distribution. By these definitions, at Andrews Forest during warm event years, the annual precipitation is near the long-term mean (-0.02 SD), the winter water year precipitation is slightly above the long-term mean (0.15 SD), but the following winter water year is markedly below the long-term mean (-0.32 SD). Also during warm event years, Andrews Forest temperatures are well above the long-term mean (0.45 SD). During cold event years, Andrews Forest annual precipitation is well above the long-term mean (0.48 SD), although the winter water year precipitation is near the long-term mean (-0.05 SD). Most striking, however, is that during cold event years, the following winter water year is 0.88 standard deviation above the long-term mean. Also, during the cold event years the annual mean temperature is notably below (-0.37 SD) the long-term mean.

Thus, it seems there are definite relationships such that during many warm events (El Niño years) the winter water year precipitation at Andrews Forest is relatively low and annual mean temperatures are relatively high. During cold events (La Niña years) winter water year precipitation at Andrews Forest is relatively high, especially in the water year following a calendar year with a cold event, and annual mean temperatures are relatively low.

These findings are consistent with those of Yarnal and Diaz (1986) and Redmond and Koch (1991). The latter noted that, for the Pacific Northwest as a whole, precipitation is low and temperature is high during low

SOI values with the opposite also being true. Interestingly, they found the relationship tended to be strongest in the mountainous climate divisions. They point out that a combination of low precipitation and high temperature values implies a smaller than average snowpack during El Niño years.

With one exception, there were no significant correlations in either precipitation or temperature when the data were lagged at monthly intervals. The exception was a weak relationship between Andrews Forest January precipitation and the SOI value of the previous March (r^2=0.10, significant at 95%). The relationship is interesting enough to pursue later, using seasonal rather than monthly data.

Conclusions

Researchers at most LTER sites would benefit by having a climate record at their sites extended back into the last century. The foregoing discussion provides a model methodology for local climate analysis and synthesis at LTER sites. While synthesis by regression analysis is not new, placing the site into its regional context by using relationships with Climatic Division data and local and hemispheric general circulation indices does provide a new method of viewing the local climatic environment. This methodology will become increasingly important as LTER sites begin to scale up to landscape and regional levels.

It cannot be assumed *a priori* that any single LTER site will relate well to the larger regional climatic environment. This has been demonstrated, for example, in the case of the Niwot Ridge, Colorado, LTER site (Greenland and Swift 1991).

Comparisons of Andrews Forest climate with values from nearby Climatic Divisions, and local and hemispheric general circulation indices all suggest the climate of Andrews Forest is well representative of the climate of the northern Cascades and their foothills in particular and of the Pacific Northwest in general. The only exception is that as one moves to the larger, geographic-scale indices, the relationships become weaker and even non-existent in summer months. The reason is that during summer Andrews Forest is usually dominated by a ridge of high pressure and the processes of microclimatology tend to dominate those of larger scales. In contrast, in winter with the expansion of the high energy circumpolar vortex into mid-latitudes, and with our growing awareness of the linkages between tropical and extra-tropical circulation, it is not surprising that Andrews Forest is well coupled with these hemispheric-scale events. This coupling has important implications for the climate of Andrews Forest one, two, or possibly more seasons ahead, thus allowing a new dimension in planning ecological experiments.

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