David Greenland, Department of Geography, University of Oregon. Eugene, Oregon 97403-1251.

The Pacific Northwest Regional Context Of The Climate of the H. J. Andrews Experimental Forest

Abstract

The H.J. Andrews (HJA) Experimental Forest, Oregon, Long-Term Ecological Research (LTER) site is a key research location in the Pacific Northwest (PNW). This paper endeavors to place the climate of the HJA into its regional context. Multiple regression analysis is used to create a synthetic record of monthly total precipitation (back to 1911) and monthly mean temperature (back to 1890). The observed (1973-1991) and synthetic (1911-1972) record is analyzed. Major features in the record are compared to the findings of other investigators particularly with respect to drought occurrence, recent warming, step functions and the tree ring record. The regional context of the HJA is addressed by relating its climate record to nearby climate divisional records and zonal and meridional indices of the general circulation of the atmosphere as well as commonly used teleconnective indices. GCM-related indices are found to be quite well related to the HJA climate record in winter but not in summer. Since most vegetative growth takes place in the spring and summer months, the ecological implications of this should be noted. There are quite strong relationships between the HJA winter water year precipitation and annual and January mean temperatures and the values of synoptic (regional) scale indices. No relationships are found for July. The Central North Pacific (CNP) index is a particularly well correlated with January and annual temperatures at the HJA. This is indicative of the importance of the magnitude and position of the Aleutian low pressure cell to the HJA temperatures. There is a weak but definite signal between the Southern Oscillation (SOI) index and the climate of the HJA such that during many warm events (El Niño years) the winter water year precipitation at the HJA Forest is relatively low and the annual mean temperatures are relatively high. During cold events (La Niña) the winter water year precipitation at the HJA Forest is relatively high, especially in the winter water year following a calendar year with a cold event, and the annual mean temperatures are relatively low. Overall, it is concluded that the climate of the HJA Forest is representative of the climate of the northern Cascades and their foothills in particular, and of the PNW in general.

Introduction

An enormous amount of basic and applied research has been performed at the H.J. Andrews (HJA) Experimental Forest, Oregon, Long-Term Ecological Research (LTER) site. Much of it has led to the development of current forest management policies. A number of projects are underway with the goal of scaling up findings at the HJA to a landscape or regional scale (Cohen *et al.*, 1992). It is important to establish how representative the site is of the Pacific Northwest (PNW) region. One way in which to approach the examination of representivity is to inquire how representative the climate of the site is compared to that of the PNW region as a whole? This paper seeks to investigate this question.

The H.J. Andrews Experimental Forest (HJA) is a 6400 ha forest of Douglas Fir, Western Hemlock, and Pacific Silver Fir located in the central portion of the western slope of the Cascade mountain range of Oregon. The forest is one of 18 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. Consequently there is an immense legacy of research resulting from the participation in these research programs (McKee. *et al.*, 1987, Blinn *et al.*, 1988). Future LTER-related activities ensures the continuing scientific importance of the site.

A number of steps are taken in this paper in order to seek to answer the question of how representative is the climate of the HJA compared to that of the PNW as a whole? First the HJA climate will be briefly reviewed and an introduction is given to the aspects of the larger scale climate with particular emphasis on the importance of atmosphere—ocean interactions over the Pacific Ocean. Next, since the record of the HJA primary meteorological station is rather short, it is necessary to extrapolate it back in time and create a synthetic record. The observed (1973-1991) and synthetic (1911-1972) record is analyzed to identify some of its major features. These features are compared to the findings of other investigators particularly with respect to drought occurrence, recent warming, step functions and the tree ring record. The regional context of the HJA is then addressed by relating its climate record to nearby climate divisional records and zonal and meridional indices of the general circulation of the atmosphere as well as commonly used teleconnective indices.

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Background Information

The Climate of HJA

Climatological information has been collected at the site since 1951 with a continuous, electronically sensed, record from May 1972. The observing system is composed of a primary meteorological station and a network of satellite temperature and precipitation recording stations. The primary meteorological station of HJA is at an elevation of 426 m (1397 ft) at latitude 44° 15′ N and longitude 122° 10′ W. HJA occupies the Lookout Creek watershed which ranges from 420 to 1630 m (1378 to 5346 ft) and drains into the Blue River. Below 1050m (3444 ft), the Western Hemlock zone is found and is characterized by Western Hemlock and Douglas Fir. Above 1050m (3444 ft) the Pacific Silver Fir zone is established (Bierlmaier and McKee, 1989).

Bierlmaier and McKee (1989) have described the HJA climate as being 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 one low pressure zone and frontal storm after another during the 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 the establishment of a ridge of high pressure along the coast and the eastern Pacific. This season is characterized by highly stable air and low precipitation amounts. During the period 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. The annual average precipitation was 2302 mm (90.6 ins) 71% of which fell from November through March. At 1203 m (3946 ft) annual precipitation rises to 2785 mm (109.7 ins). Above 1050 m (3444 ft) a persistent snowpack up to 4 m (13 ft) deep may form and last into June (Bierlmaier and McKee, 1989). Further details of the climatography of HJA may be found in Emmingham and Lundburg (1977 – quoted by (Bierlmaier and McKee, 1989)), Waring *et al.* (1978), and McKee and Bierlmaier (1987).

The regional climate of Oregon and the PNW and the importance of the Pacific Ocean Regional climatologies of the Oregon and the Pacific Northwest (PNW) have been given by Phillips (1960), Sternes (1960), the PNW River Basins Commission (1969) and Loy *et al.*, (1976). No understanding of the climate of the PNW would be complete without reference to the seminal role played by interactions between the ocean and 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 long 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 principal component analysis (PCA)(Walsh and Richman, 1981) and teleconnections and in dynamic climatology increasingly by the use of General Circulation Models (GCMs) 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 PNW are based on the Southern Oscillation Index (SOI), the Pacific-North American Index (PNA) and the Central North Pacific Index (CNP). These three indices exhibit a certain degree of intercorrelation (Cayan and Peterson, 1989). It should also be remembered that the strength of the teleconnective patterns is not necessarily stable over time. Ropelewski and Halpert (1986) have shown that depending on the data used, the PNW is either in, or is on the southern edge of, an area having lower rainfalls 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 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 describes the amplitude of the 700 mb flow pattern over the U.S. which has a basic pattern of troughs of low pressure in the eastern Pacific and the eastern U.S, and a ridge of high pressure over the Rocky Mountain cordillera. The meridional extreme of the pattern produces positive PNA values (and potentially more SW winds over the HJA) while the zonal extreme produces negative PNA values (and potentially more W winds over the HJA). Yarnal and Diaz (1986) demonstrated how strongly positive PNA and negative (reverse) PNA patterns are associated respectively with warm and cold El Niño Southern Oscillation (ENSO) events and, in turn, with precipitation and temperature anomalies on the west coast of North America.

Cayan and Peterson (1989) designed the CNP index as being the mean sea level pressure (MSLP) over the region 35-55° N and 170° E to 150° W. They show that streamflow in the West have correlations in the range 0.3 to 0.6 SLP with anomalies in the North Pacific. During times of a weak CNP streamflows are high in Washington and Oregon. During times of a strong CNP the polar front jet stream flows north of the PNW and times of below average streamflow are observed. This is also often observed during El Niño events (See Cayan and Peterson, 1989, Figure 9). All of the synoptic studies indicate quite clearly the linkages which exist between SSTs and particular pressure and teleconnective patterns in the Pacific Ocean and various aspects of climate on the West Coast and the in the PNW.

Compilation of the Synthetic Record

It was first necessary to extrapolate the HJA climate record backwards in time. The stations most likely to give information for extrapolation were selected as being Corvallis, Cottage Grove, Eugene, Leaburg, McKenzie Bridge, and Cascadia. The station history of each of these was scrutinized for continuity using information for Oregon from Redmond (1985). Following analysis of pre and post move observations it was decided not to use the Eugene record. Multiple regression analysis was used to find the monthly values of mean temperature and total precipitation at the HJA from values at the stations which had been selected resulting from these screening procedures.

Precipitation

Precipitation data for the HJA site was obtained from five stations; Corvallis, Leaburg, McKenzie Bridge, Cascadia, and Cottage Grove. The multiple regression analysis identified good correlation in monthly and annual precipitation values between the stations. All regression equations were significant at the 99% level as assessed by their F values. Regression equations were computed for different sets of stations for three separate time periods which were determined by the length of record of the stations. The time periods were 1936-1972, 1919-1935, and 1910-1918. Table 1 shows the monthly range of r^2 and standard error of estimate (SEE) values for these time 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 (mm) for multiple regression equations used to obtain monthly total precipitation at the H. J. Andrews Experimental Forest. Co is Corvallis, L is Leaburg, M is McKenzie Bridge, Ca is Cascadia, CG is Cottage Grove. All r^2 values significant at 99% level.

1936-1972 Co,L,M,Ca,CG		
Monthly r^2	0.89 to 0.98	SEE 7.6 to 46.0
Annual r^2	0.93	SEE 124.7
WatYr r^2	0.98	SEE 81.8
1919-1935 Co,Ca,CG		
Monthly r^2	0.83 to 0.94	SEE 8.4 to 53.9
Annual r^2	0.91	SEE 134.1
WatYr r^2	0.96	SEE 95.5
1910-1918 Co		
Monthly r^2	0.47 to 0.86	SEE 10.9 to 87.4
Annual r^2	0.61	SEE 255.3
WatYr r^2	0.77	SEE 214.1

A similar analysis was performed for precipitation values in the form of water year data. Following Johnson and Dart (1982) the water year is defined as the period October 1 to the next September 30 and the year is numbered for the year which includes the 9 month period. So the 1940 water year runs from October 1, 1939 to September 30, 1940. The analysis was also performed for the winter part of the water year (October to April). The selection of seasons this way follows the approach of Johnson and Dart (1982) and has obvious practical and hydrological advantages. As might be expected the water year and winter water year correlations carry a higher degree of accuracy than those for the calendar year. The values found in the present report are of the same order and are consistent with the findings of Johnson and Dart (1982 pp. 104-111) who worked on the whole state of Oregon.

Temperature

The same five predictor stations employed for estimating precipitation values were investigated using their average annual data between 1973 and 1991 for their efficiency in simulating temperature values. Correlation coefficient, SEE, and significance values between the five stations and the

TABLE 2. Stations used, range of regression coefficients and standard error of estimates (°C) for multiple regression equations used to obtain mean monthly temperature at the H. J. Andrews Experimental Forest. Co is Corvallis, L is Leaburg, M is McKenzie Bridge, CG is Cottage Grove. All r^2 values significant at 99% level except where noted.

1936-1972 Co,L,M,CG		
Monthly r^2	0.69 to 0.92	SEE 0.47 to 1.02
Annual r^2	0.50 (95.0%)	SEE 0.57
1917-1935 Co,CG		
Monthly r^2	0.57 to 0.84	SEE 0.41 to 1.00
Annual r^2	0.49	SEE 0.53
1890-1916 Co		
Monthly r^2	0.56 to 0.84	SEE 0.59 to 1.09
Annual r^2	0.49	SEE 0.52

Andrews data indicated that the data from Cascadia had a detrimental effect on 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.

Simulated monthly mean temperature and total precipitation data verified well against an actual observed independent data set for the period 1951 to 1972 from Watershed #2 in the HJA Forest. It was concluded that the simulated temperature and precipitation series have an accuracy level which certainly justifies further temporal and spatial analysis of the data.

Analysis Of The Synthetic And Observed Record

Precipitation

The total water year precipitation record from 1911 to 1991 displays considerable interannual variability (Figure1). The trends represented by the five year running mean of the same data plainly show the prolonged and severe drought of the 1930s and the wetter years of the late 1940s and the 1950s (Figure 2). The record exhibits greater variability in more recent years with two peaks of precipitation centered on 1973 and 1984 with droughts centered on the late 1970s and one which persisted through, at least, 1991. In the case of both the most recent drought and that of the 1970s, as judged by the value of water year precipitation, both were as severe as the drought of the 1930s

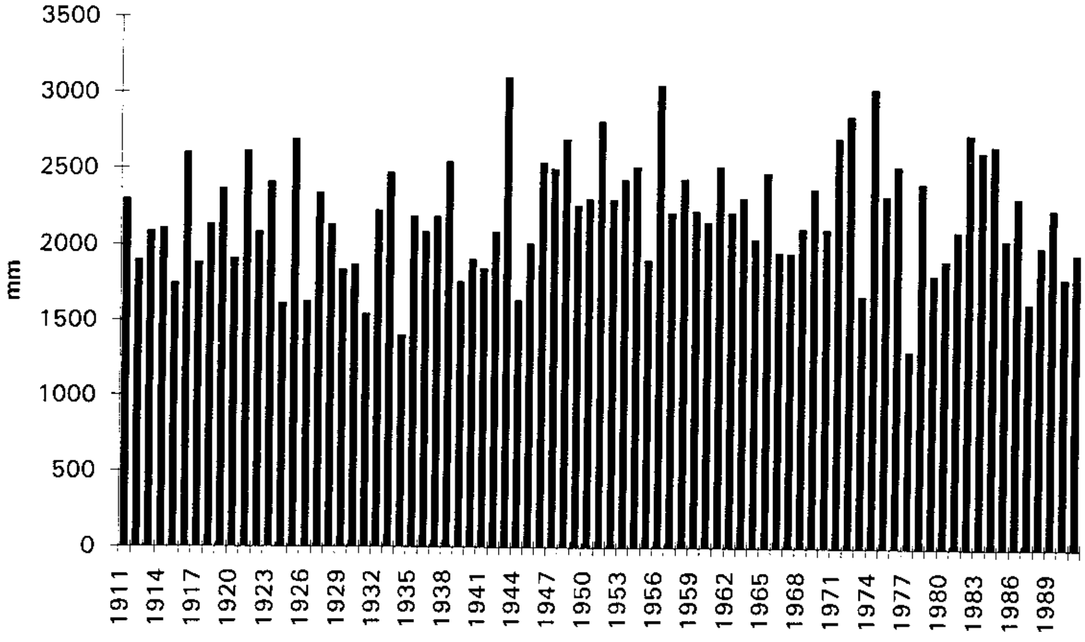


Figure 1. Total annual precipitation by water year at the H.J. Andrews Experimental Forest Primary Meteorological Site 1911-1991. Values prior to 1973 are obtained by regression analysis.

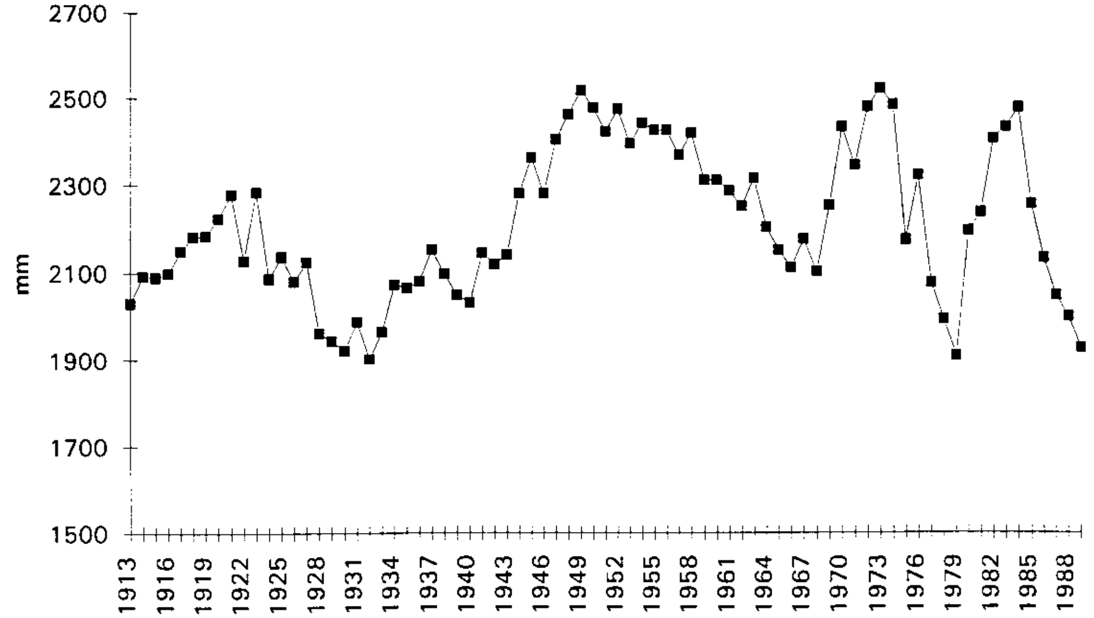


Figure 2. Five year running mean of water year total precipitation at the H.J. Andrews Experimental Forest Primary Meteorological Site 1911-1991. Values prior to 1973 are obtained by regression analysis.

but at least the 1970s drought did not last so long. The variations of precipitation at the HJA found here match quite well trends in the Willamette Valley described by Johnson and Dart (1982). Johnson and Dart 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 the HJA from 1890-1991 also shows considerable interannual variability (Figure 3). Five year running means exhibit 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 respectively (Figure 4). A cool period is seen from the late 1940s to the mid 1970s with the exception of one warm year (1958). Finally, a warming trend is seen from the mid 1970s to the present time. However, 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 1921-35 stand out over the Western U.S. as anomalously warm in the context of the last 100 years. The HJA data do show high temperatures during this time. 8 of the 15 years of this period at HJA have above (1890-1991) mean temperatures with 3 of the years exceeding the mean by 1 standard deviation (SD). A 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 a tabular form. A comparison of low and high temperature winters for selected West Coast stations (Roden, 1989) shows that more often than not the HJA values parallel the coastal values.

Recent Warming

Since there has been considerable evidence of a trend for minimum temperatures to increase over the last two to three decades (Karl *et al.* 1988), the observed HJA record was examined to see if it contained this signal. Maximum, minimum, and mean seasonal and annual temperatures were regressed against year number for the period 1973-1991. The period at the HJA had not only increasing minimum temperatures but increasing maximum and mean temperatures as well. The fact that the greatest increases occurred in the spring (March, April, May) possibly affecting growth rates

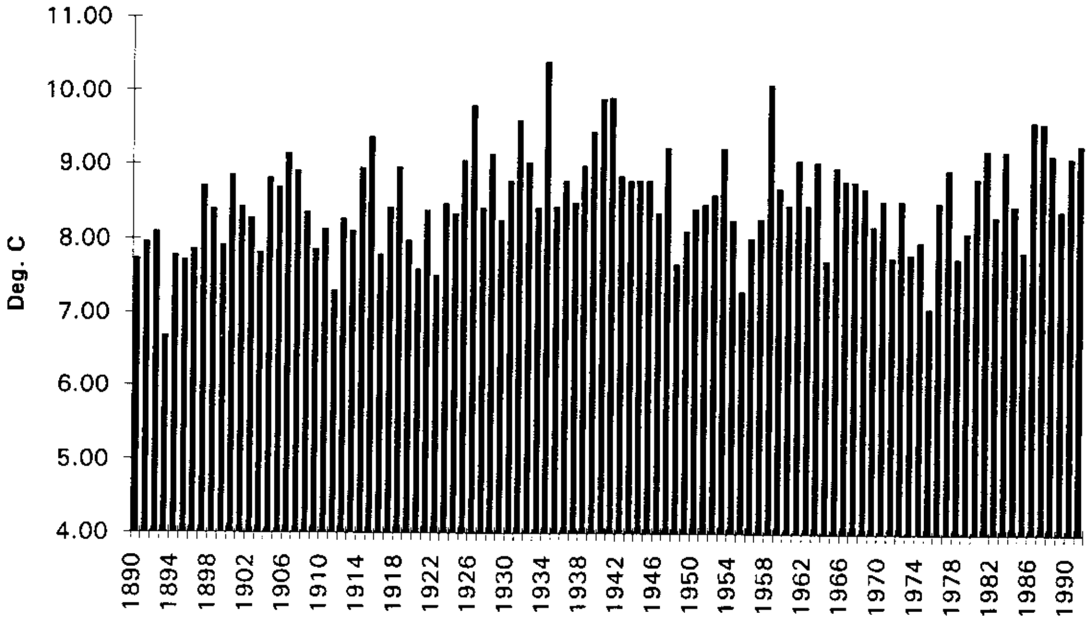


Figure 3. Mean annual temperature at the H.J. Andrews Experimental Forest Primary Meteorological Site 1890-1991. Values prior to 1973 are obtained by regression analysis.

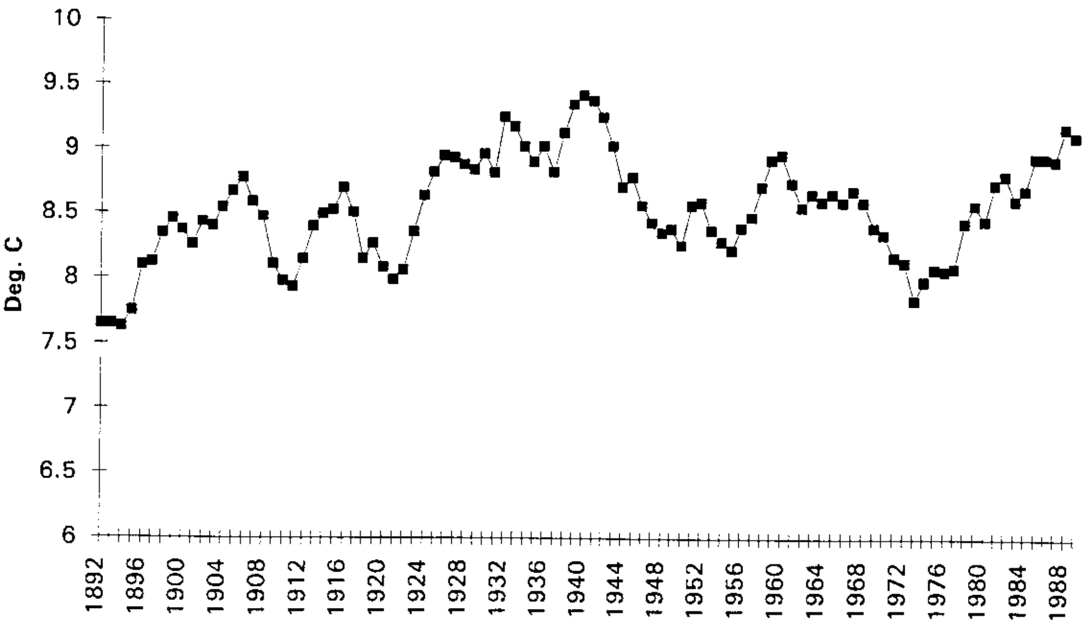


Figure 4. Five year running mean of mean annual temperature at the H.J. Andrews Experimental Forest Primary Meteorological Site 1890-1991. Values prior to 1973 are obtained by regression analysis.

at this time is of ecological importance. The warming is also seen at Corvallis and Cottage Grove although in not quite as an intense form and not during the winter season. It is important to reiterate that the magnitude of this recent warming trend is similar to one that took place at HJA 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 the modern record. Ebbesmeyer *et al.* (1991) have investigated a step function occurring in biogeophysical time series of the PNW and the Pacific in 1976. Leathers and Palecki (1992) have identified a step function occurring in the value of the PNA index during the late 1950s and centered approximately on 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 the HJA Forest.

First the difference of the means before and after the steps were tested using a two-tailed t test. Using the means of the 8 years before and after the 1976 step there was a significant difference (99% level) in the HJA 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 the HJA 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 HJA Forest annual mean temperatures or winter water year precipitations 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 HJA precipitation and temperature values (Tables 5 and 6). However, this relationship is seen more in winter values rather than 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 S.E. United States center of action of the PNA index rather than either of the two centers closer to the PNW.

Thus it may be concluded that there is evidence in the HJA 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 the year 1976 was a marked turning point at the HJA for both temperature and precipitation. For approximately 15 years prior to 1976 the annual temperature trend had been downward. Since that time the annual temperature trend has been upwards. 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 1977 and after it. The five 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 the HJA data as well as that of many other parts of the PNW.

The Tree Ring Record

The general temporal variation which 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 HJA precipitation record. Data from HJA are generally consistent with those of Graumlich and tend to suggest that her findings for earlier years back to 1640 would also be applicable to the Andrews. More confidence should be attributed to runs of dry, and presumably wet, years rather than for individual years. One reason for this is the masking of extreme values in the simulated HJA data which is related to the least squares analysis methodology. Graumlich finds marked droughts occurring in the Columbia Basin around 1680, and in the 1750s, 1780s, 1790s, 1840s, 1865-1895, and in the 1920s and 1930s. Wet periods occurred from 1695-1715, 1740-1760, and 1810-1835. Examination of Graumlich's graphical data indicates that in the 1750s there were individual years of both extreme wetness and drought. 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 located 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 the temperatures between 1900 and 1940 were higher than any other extended 40 year period. HJA temperature data for the present century also display high temperatures during this time and thus give rise to the implication that earlier "warm" periods found in the Washington record also occur at the HJA Forest. These warm periods occurred between 1655-1670, 1690-1695, and 1825-1830. "Cool" periods in the Longmire record occurred between 1610-1630, 1640-1650, 1695-1760, 1800-1808, 1840-1850, and 1875-1895.

The Regional Context

Climate Divisional Data

The synthetic and observed precipitation data for the HJA site for the period 1915 to 1991 were compared by correlation techniques on a month by month and annual basis with precipitation data from the Willamette Valley (OR2) and the Northern Cascades (OR4) Oregon Climate Divisions. There exists a slight degree of autocorrelation since data from some of the stations in the divisions were used to simulate part of the HJA data set. However, the autocorrelation is very small as 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 Divisions. 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 relation between the HJA site and both the Willamette Valley and the 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 the summer months. On the basis of these values the precipitation at the Andrews 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. The monthly correlation coefficients between the temperature values of the climatic divisions and the HJA 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 HJA data were compared with general circulation indices designed to relate to the PNW region following an approach of Wigley *et al.* (1990) and Jones (1991) who were interested in the question of how to estimate regional values of projected climate change from the projected values at grid points on the coarse network of points used by current GCMs. The indices were constructed for use with a data set of reconstructed monthly MSLP developed by Jones *et al.* (1987). The data for North America is 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 which happens to be in the center of Oregon and not far from the HJA. 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. In order 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 3) 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 HJA temperature and precipitation values and the circulation indices in January but no correlation in July (Table 4). This is to be expected given the more vigorous general circulation in the Northern hemisphere winter and the low absolute amount of precipitation at the HJA in summer. In order 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

TABLE 3. Correlation coefficient values between annual mean temperature and winter water year precipitation totals at the HJA and selected general circulation indices.

Variable Regressed Against	r^2	Significance Level (%)
Winter water year precipitation 1914-1980		
Central Oregon Pressure	0.24	99
Zonal Index	0.15	99
Meridional Index	0.03	<95
Annual mean temperature 1890-1980		
Central Oregon Pressure	0.01	<95
Zonal Index	0.01	<95
Meridional Index	0.36	99

TABLE 4. Correlation coefficient values between January and July mean temperature and precipitation totals at the HJA and selected general circulation indices for the period 1914-1980.

Variable Regressed Against	Jan		July	
	r^2	Sig Level %	r^2	Sig Level %
Precipitation				
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				
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

Jones found for the general location of the HJA. In summary, the relationships in winter are much stronger than those in summer. The implication of these results is that output values predicted by GCMs for the general area of the PNW may be applied to the HJA with more confidence in the winter season than in summer. Most vegetative growth takes place in the spring and summer months therefore projections made from GCMs for the PNW for the growing season should be treated with some caution.

PNA and CNP Indices

Correlations were also made between the HJA data and the PNA and the CNP indices for the period 1948-87. The results (Figure 4. top, Figure 5. top, Tables 5 and 6), in the context of this kind of synoptic climatological analysis, indicate quite marked correlations between HJA winter water year precipitation and both indices. Precipitation at the HJA for January, representing the winter months, also displays a weak but significant correlation with both indices. No relationships are seen for July, representing the summer months, or for the

TABLE 5. Correlation coefficient values between Annual, January and July mean precipitation totals at the HJA and selected general circulation indices for the period 1948-1987.

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

TABLE 6. Correlation coefficient values between Annual, January and July mean temperature at the HJA and selected general circulation indices for the period 1948-1987.

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

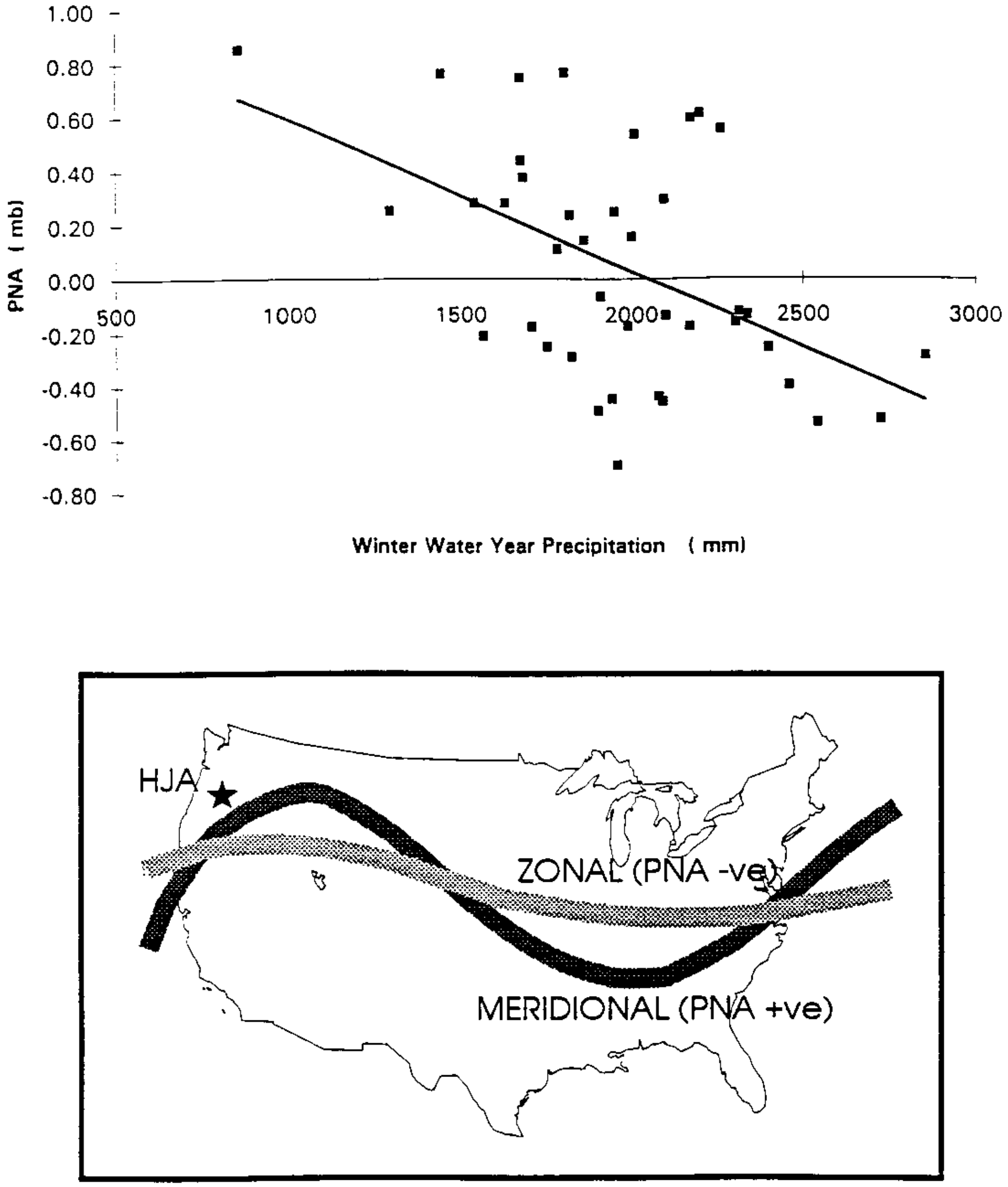
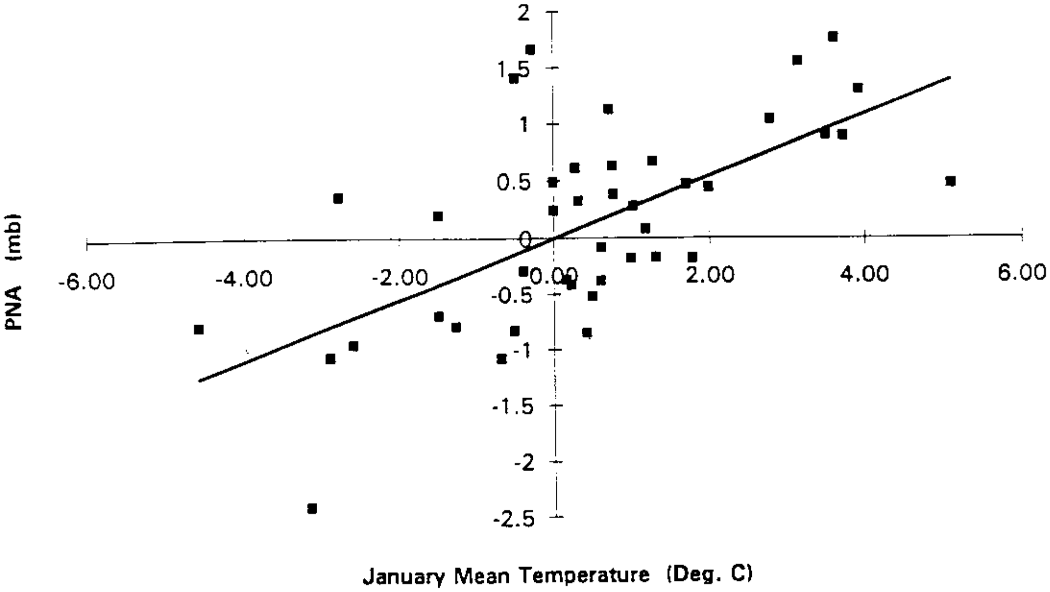


Figure 5. Top: The relationship between total winter water year (WWY) precipitation at the H.J. Andrews Experimental Forest and the PNA index value for the same period. Bottom: a conceptualization (following Leathers *et al.* 1991) of the character of the 700 mb westerly flow over the United States accompanying positive and negative values of the PNA index. 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 the HJA) gives rise to relatively dry conditions.

calendar year totals of precipitation. Annual and January mean values of temperature exhibit a very strong correlation with the CNP index. The relationship of January mean temperatures to the PNA index is also very strong while the relationships for the year and for July are not so strong but are



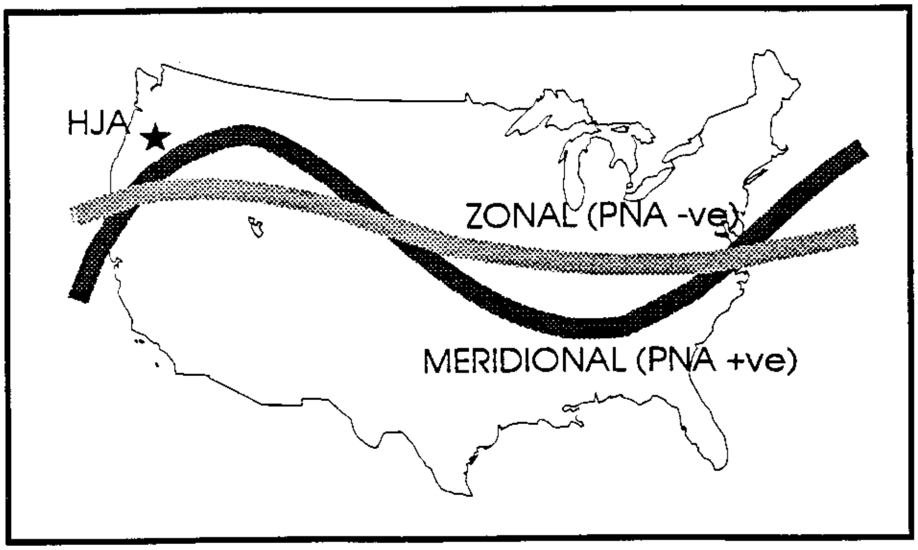


Figure 6. Top: The relationship between mean January temperature at the H.J. Andrews Experimental Forest and the PNA index value for the same period. Bottom: a conceptualization (following Leathers *et al.* 1991) of the character of the 700 mb westerly flow over the United States accompanying positive and negative values of the PNA index. When the PNA index is positive and high, a meridional circulation in the westerlies with a ridge of high pressure gives rise at the HJA to warm air from the southwest with relatively high temperatures.

significant. Redmond and Koch (1991) also found significant relationships between concurrent precipitation and temperature values in the PNW and PNA values with temperature having the strongest relationship.

Physically (Figs. 5 and 6 bottom), 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 the HJA) giving rise to relatively dry weather. This

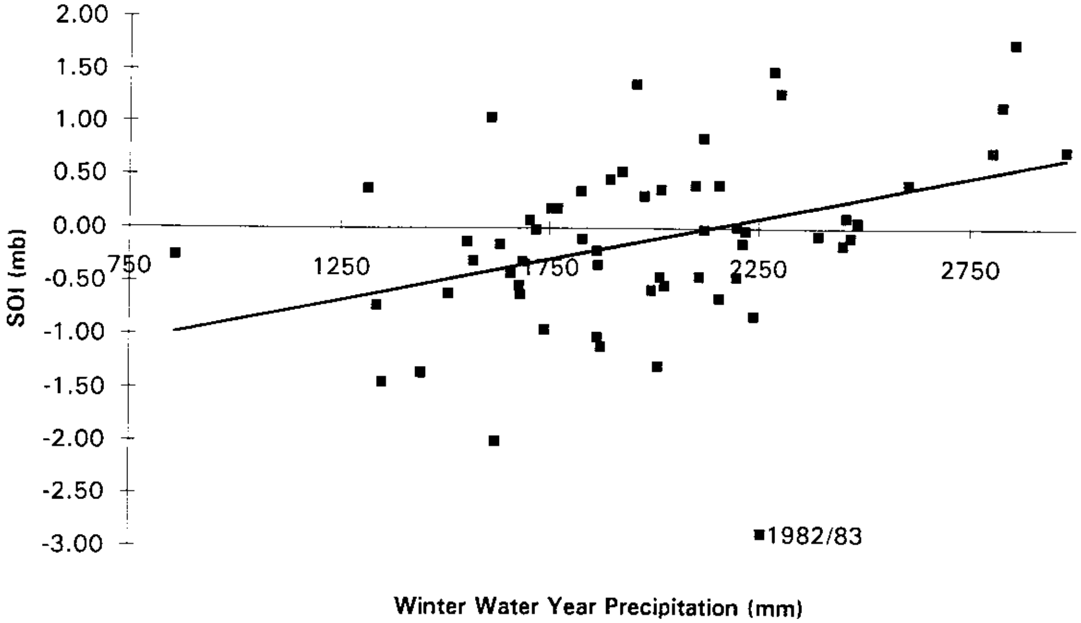


Figure 7. The relationship between winter water year (WWY) precipitation totals at the H.J. Andrews Experimental Forest and the values of the SOI index for the same period.

situation also brings in warm air from the southwest with relatively high temperatures. 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 rather lower air temperatures. These interpretations are also consistent with the CNP values which, when low, indicate that a well developed Aleutian low pressure zone will guide storms northwards to British Columbia but when high will allow storms to travel more directly eastwards into Washington and Oregon.

The advantage of using the CNP is that it has a long record dating back to 1899. Comparison of the relationships between HJA data and the CNP index for the longer periods of 1910 or 1914 to 1990 (Tables 5 and 6) indicates little difference in the correlation coefficients that were found for the shorter 1948-1990 period. This is encouraging because it suggests that the relationships are fairly stable over time and the time series are somewhat stationary.

SOI Index

Direct comparison of winter water year HJA 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 the HJA and high SOI values (cold event, La Niña years) tend to be associated with high precipitation values at the HJA (Fig 7). The relationship is clear although it is not very strong statistically ($r^2=0.14$, significant at 99%). The 1983 year which had an extraordinary 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 the HJA Forest (with the inclusion of the 1983 data point $r^2=0.24$, significant at 99%) (Figure 8).

Further light is given to this issue by examining HJA climate values for extreme SOI years. Two sets of extreme SOI years have been provided respectively 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 (Dec, Jan and Feb). During warm event winters, HJA precipitation is near average at 0.03 SD of the long term (1914-1991) mean and the temperature is well above (0.77 SD) the long term (1890-1991) mean. During cold event winters HJA precipitation is well above (0.69 SD) the long term mean and temperature is below it (-0.33 SD). Halpert and Ropelewski defined warm

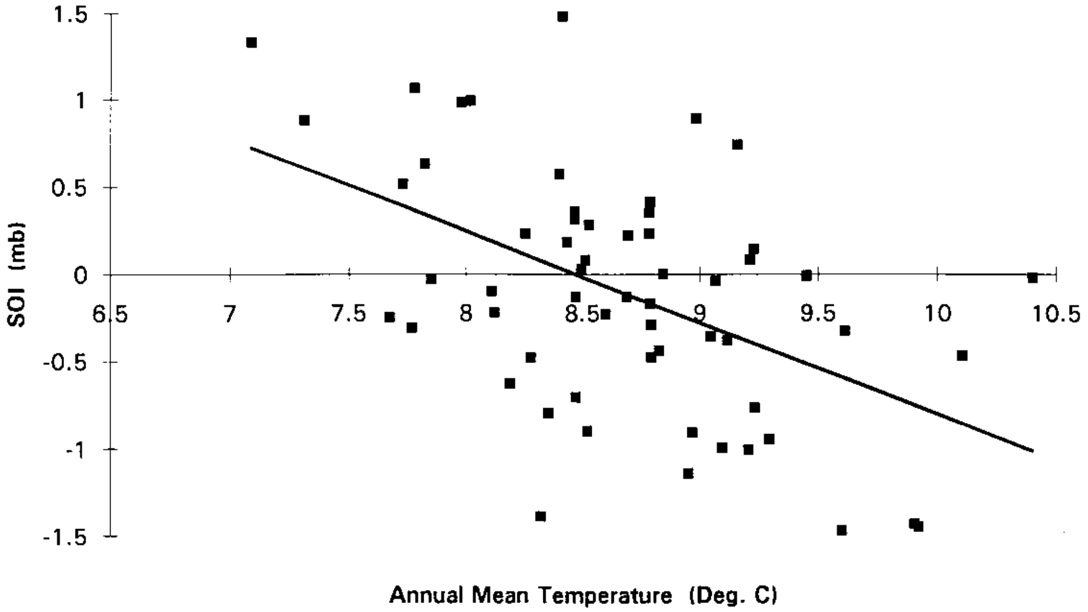


Figure 8. The relationship between annual mean temperature at the H.J. Andrews Experimental Forest and the values of the SOI index for the same period.

event years as those in which the SOI index value remained in the lower 25% of the distribution for 5 months or longer and similarly defined cold events years by using the upper 25% of the distribution. By these definitions, at the HJA 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, HJA temperatures are well above the long term mean (0.45 SD). During cold event years HJA 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 SD 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 the HJA Forest is relatively low and the annual mean temperatures are relatively high. During cold events (La Niña years) the winter water year precipitation at the HJA Forest is relatively high, especially in the winter water year following a calendar year with a cold event, and the 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 for the PNW as a whole that precipitation is low and temperature is high during low SOI values with the opposite also being true. Interestingly they found that 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 HJA January precipitation and the SOI value of the previous March (r^2 = 0.10 significant at 95%). The relationship is interesting enough to pursue at a later time using seasonal as opposed to monthly data.

Conclusions

The most important findings of this study may be summarized as follows:

1) It is feasible to extend backwards in time, records of mean monthly precipitation and mean monthly temperature.

2) The synthetic record shows considerable interannual variability both in precipitation and in temperature.

3) The warming of approximately the last two decades is, so far, no greater than a similar warming which took place at the beginning of the century. The recent warming is found not only in minimum temperatures but also in maximum and mean temperatures. It is found in all seasons but is most marked in spring. For the most part it is paralleled by, but is greater than, the warming at Corvallis and Cottage Grove.

4) The drought of the late 1980s and early 1990s was similar in magnitude to that of the mid 1970s and similar in magnitude but not, so far, duration of that to the 1930s.

5) Both the precipitation and the temperature record at the HJA are in general agreement with what is known from other studies of temporal changes in Oregon and the PNW.

6) The HJA record agrees in general with the tree ring record of the larger scale region.

7) There is evidence that a step function at 1976 which has been found in other biophysical time series in the PNW also occurs in HJA precipitation and temperature values. There was no evidence found in these values for a step function centered on 1957.

8) The climate record of the HJA is closely related to that of the Willamette Valley and Northern Cascades climatic divisions of Oregon.

9) Local GCM-related indices are quite well related to the HJA climate record in winter but not in summer. Hence, we can have some confidence that whatever climatic change is projected by GCMs for the PNW will be applicable in large measure to the HJA Forest in winter and for the winter water year. The implication of these results is that output values predicted by GCMs for the general area of the PNW may be applied to the HJA with more confidence in the winter season than in summer. However, most vegetative growth takes place in the spring and summer months therefore projections made from GCMs for the PNW for the growing season should be treated with some caution.

10) By the standards usually applied in synoptic climatology there are quite strong relationships between the HJA winter water year precipitation and annual and January mean temperatures and both the PNA and the CNP indices. No relationships are found for July. The CNP index is a particularly well correlated with January and annual temperatures at the HJA. This is indicative of the importance of the magnitude and position of the Aleutian low pressure cell to the HJA temperatures.

11) There is a weak but definite signal between the SOI (ENSO) index and the climate of the HJA such that during many warm events (El Niño years) the winter water year precipitation at the HJA Forest is relatively low and the annual mean temperatures are relatively high. During cold events (La Niña) the winter water year precipitation at the HJA Forest is relatively high, especially in the winter water year following a calendar year with a cold event, and the annual mean temperatures are relatively low.

Researchers at most LTER sites, except those where long period records already exist, would benefit by having a climate record at their sites extended back into the last century. The foregoing discussions provide a model methodology for local climate analysis and synthesis at LTER sites. While synthesis by regression analysis is not new, the placement of the site into its regional context by using relations 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 as is the case for the HJA. It should be noted that 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, for the Niwot Ridge, Colorado, LTER site (Greenland and Swift, 1991).

The original question of how representative is the HJA climate of that of the PNW as a whole has largely been answered by the foregoing analyses. Comparisons of the HJA climate with values from nearby Climatic Divisions, and local and hemispheric general circulation indices all suggest that the climate of the HJA Forest is well representative of the climate of the northern Cascades and their foothills in particular and of the PNW in general. However as one moves to the larger geographic scale indices, the relationships become less strong and even non-existent in the summer months. The reason for this is that during these months the HJA 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 circulations, it is not surprising that the HJA is well coupled with these hemispheric scale features. Although focused mainly on the winter months this coupling has important implications for the climate of the HJA one or two, or possibly more, seasons ahead and thus allowing a new dimension in planning ecological experiments.

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