THE INFLUENCE OF WEATHER VARIATION ON REGIONAL GROWTH OF DOUGLAS FIR STANDS IN THE U.S. PACIFIC NORTHWEST

Charles E. Peterson[1] and Linda S. Heath[2]
[1]Environmental Research Laboratory
200 S.W. 35th Street
Corvallis, Oregon 97333, USA

[2]USDA Forest Service
Pacific Northwest Research Station
P.O. Box 3890
Portland, Oregon 97208 USA

Abstract. In this paper we examine the influence of precipitation and temperature deviations on regional volume growth rates in even aged, onnen.,ed second gxowth Douglas fir (Pseudotsuga menziesii [Mirb.] Franco) stands. 'Between 1969 and 1986, average volume growth rates in natural stands of coast Douglas fix in western Washington and Oregon were negatively correlated with high summer temperatures and positively correlated with higher temperatures during the non growing season. Results support the hypothesis that cool wet summers and mild winters contribute to high productivity of conifers in the Pacific Northwest.

1. Introduction

Over 50 yr ago, Schumacher and Meyer (1937) noted that foresters should have knowledge of the general effects of climate on tree growth, particularly when judging tree response to a silvicultural treatment, even though the relation between growth and climate realistically would be "probable or conjectural." . In the Pacific Northwest, drought frequently limits tree growth during the summer (Brubaker, 1980; Lassoie et a1., 1985). The mild wet winters are generally thought to be a primary reason for the high productivity of conifers (Franklin and Dyrness, 1973; Emmingham and Waring, 1977). Previous studies of climate effects on Douglas fir growth in the Northwest have used individual trees as the primary sampling unit (e.g., Brubaker, 1980; Graumlich et a1., 1989). However, the influence of yr to yr variations in weather conditions on regional growth patterns, particularly at the stand level, has not been addressed.

In this paper, we investigate the influence of precipitation and temperature deviations on regional variation in volume increment of evenaged stands of second growth Douglas fir. Since the stands we analyzed are typical of those receiving operational fertilizer treatments in the Pacific .Northwest, our interest in potential effects of weather variations on forest productivity extends to possible effects on both magnitude and duration of growth PAI (periodic annual increment) in response to N (nitrogen) fertilizer. The long term commitment to a management regime, such as operational fertilization, is often based on results from relatively short term (5 to 10 yr) research trials (Miller et a1., 1986). Although regional growth responses of Douglas fir (Pseudotsuga menziesii [Mirb.] Franco) to fertilizer have been analyzed for associations with soil properties (Peterson et al., 1984) and

differences among physiographic areas (Peterson and Hazard, in press), the potential influences of temperature and precipitation have not been investigated. Thus, our analysis of PAI from stands fertilized and stands not fertilized represents a primary step in this direction. Our objectives were to address two broad questions:

(1) To what degree are changes in regional stand growth rates associated with changes in either temperature or precipitation?
(2) Do the effects of temperature or precipitation on growth rates differ in summer or winter seasons?

2. Materials and Methods

2.1 Precipitation and temperature data

Precipitation and temperature observations are available for western Oregon and western Washington as divisional averages (US Environmental Data Service, 1969 1986), where divisions are intended to represent areas of similar climatological characteristics. The division boundaries and locations of individual weather stations are shown in Figure 1. Since the total annual precipitation and average annual temperature of the divisions varied considerably over time, average deviations from normal were calculated for each division. Within divisions, "normal" averages were calculated over a 30 yr period and adjusted to be representative for the current observation site by the US Environmental Data Service (19691987), where normal temperature and precipitation were based on all available weather records. A negative deviation indicates a drier or cooler year than average and positive deviations' indicate a year wetter or warmer than average. Although.our analyses used weather deviations, the average temperature and total precipitation data that occurred in this region for 1969 to 1986 are given in Table I.

Table I

Temperature and precipitation data for western Washington and western Oregon from 1969 to 1986; range is among regional weather divisions.

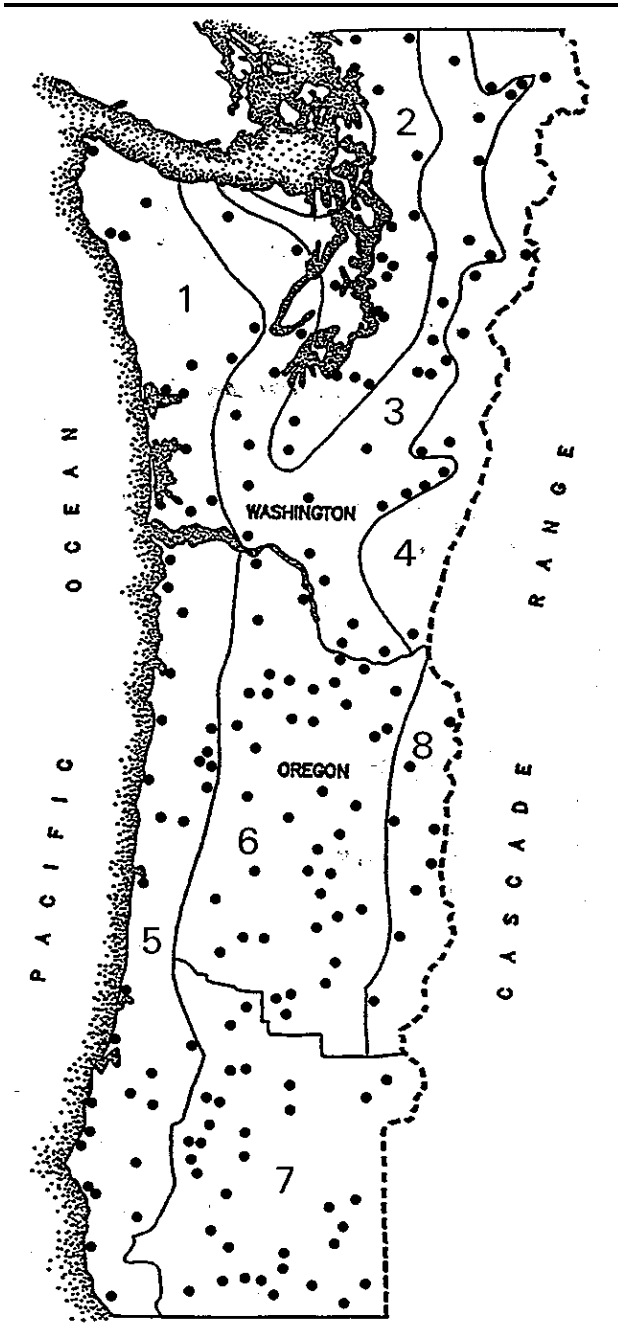| Period	Precipitation (mm)		Temperature (°C)	
	Total	Range	Average	Range
Winter (October-April)	1425	278-2782	6	1-10
Summer (May-September)	297	37-669	15	12-18
Winter plus Summer	1721	518-3249	10	6-12

Figure 1. Distribution of weather stations (•) by similar climatological characteristics in western Washington and western Oregon; lines delineate eight regional weather divisions.

Divisional weather averages were considered appropriate for the overall analysis since they have been found to correlate more closely with growth data at a given location than have weather observations from the nearest individual weather station (Blasing et a1., 1981). Average deviations were calculated for the summer season, defined as the 5 me period from May through September (Griffith, 1960), as well as the "nongrowing" season (October through April).

2.2   Stand selection and treatment

The growth data made available from the Regional Forest Nutrition Research Project (Hazard and Peterson, 1984) were collected from 78 field installations located in well stocked, second growth stands of at least 80% Douglas fir stocking by basal area (McCardle et al., 1930). Individual tree volume was estimated using tarifs (Turnbull et a1., 1972). Initial stand conditions are given in Table II. Each installation contained six plots of at least 0.04 ha, with 50 or more trees per plot. Each of three fertilizer treatments was applied to two plots (i.e., replicated). at each installation; the treatment levels were 0, 224, and 448 kg of N ha 1 applied as urea. After eight growing seasons, 224 kg N ha 1 were applied to one randomly selected replicate of each initial treatment at every installation. A second application of fertilizer was applied to half the plots at each installations after 8 yr. Therefore, in order to examine average PAI at each installation influenced by initial treatment only, the data are based on averages from two plots per treatment for the first eight growing seasons (four 2 yr periods) and one plot thereafter.

Table II

Average initial stand conditions across all 78 field installations

Variable	Minimum	Maximum	Mean	Standard Deviation
Breast-height age	8	55	30	10
Site index (m)*	21.8	46	35.8	5.1
Percent Douglas fir	62	100	92	9
Basal area (m^2 ha^{-1})	5.9	80.5	45.6	11.6
Total cubic volume (m^3 ha^{-1})	14	1234	440	203

*   50 yr base from King (1966)

2.3   Measurement schedule

For logistical reasons, approximately half of the installations were established, fertilized, and measured in the fall of 1969 (Figure 2), with the remaining installations established, fertilized, and measured in

with the remaining installations established, fertilized, and measured in the fall of 1970. Installations were measured every 2 yr between October and May. In order to match weather and growth data over 2 yr periods, the establishment year was taken into account.
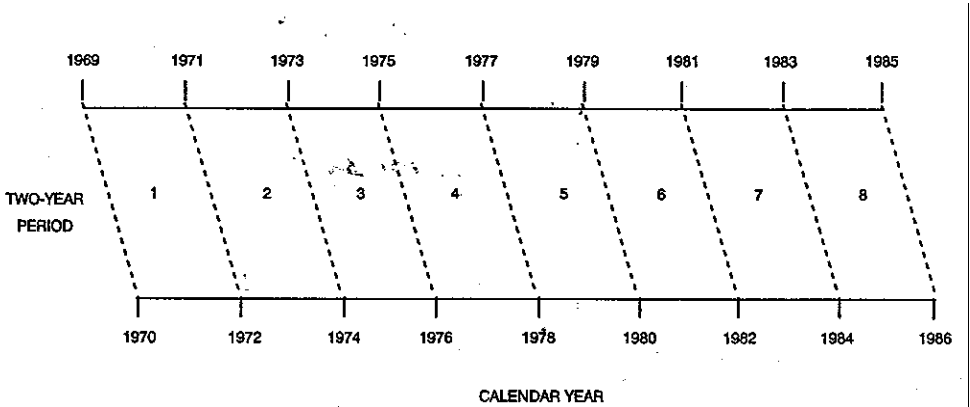

Figure 2. Remeasurement schedule for field installations established and first measured in the fall of 1969 and 1970.

2.4. Analytical approach

Total PAI of both fertilized and, non fertilized stands were correlated with weather deviations. The 78 field sites used in this study are arrayed in Table III by weather division, establishment half, and measurement period. Cell means were computed for use in the analyses, yielding a total of n = 112 observations. Although there was some expected attrition of field installations with each successive measurement period, the vast majority of installations were available for remeasurement and analysis.

To minimize correlations of observations over time, first order differences (change in growth and weather values from one time period to the next) were computed for PAI (n = 98). Correlations between firstorder differences of PAI and first order differences in temperature and precipitation deviations were computed, to determine if PAI changes from one growth period to the next were associated with changes 'in average weather deviations. In all correlation analyses, growth and weather data were grouped according to field measurement periods. Individual correlations were run for fertilizer treatment, weather factor, and season. Pearson correlation coefficients were computed along with significance probabilities of the correlations under H_0: |R| = 0.

Table III

The number of field installations by weather division, establishment half and measurement period

Weather Division	Estab. Half	Two-year measurement period							
		1	2	3	4	5	6	7	8
1	1	5	5	5	5	5	5	5	4
	2	5	5	5	5	5	5	5	5
2	1	3	3	3	3	3	3	3	2
	2	2	2	2	1	1	1	1	1
3	1	11	11	10	9	8	7	7	6
	2	4	4	4	3	2	2	2	2
4	1	0	0	0	0	0	0	0	0
	2	4	4	4	4	4	4	4	4
5	1	5	5	5	5	5	5	5	4
	2	10	10	10	10	10	10	8	7
6	1	12	12	12	12	10	10	10	10
	2	7	7	7	7	4	4	3	2
7	1	1	1	1	1	1	1	1	1
	2	6	6	6	6	5	5	4	4
8	1	0	0	0	0	0	0	0	0
	2	3	3	3	3	3	3	3	3
Total		78	78	77	74	66	65	61	55

Since growth and weather data are computed as 2 yr means, some loss in sensitivity of weather effects due to averaging of variation is unavoidable. However, because of natural variation in annual tree growth and variability associated with subsampling for tree heights, estimates of volume PAI for these stands are generally acknowledged to be less reliable if the remeasurement period is less than 2 yr. Finally, since the changes in temperature or precipitation are correlated with growth increments from a wide range of stand conditions, the correlations should not be inferred for individual stands or aggregates of stands.

3.   Results

3.1   Weather and PAI trends

The trends of total volume PAI across all 2 yr periods are given in Figure 3. Annual deviations in precipitation for the eight divisions of western Washington and western Oregon are presented in Figure 4 as an example of weather trends. Although there is some variation among the divisions, a regional pattern is clear: the divisions follow similar
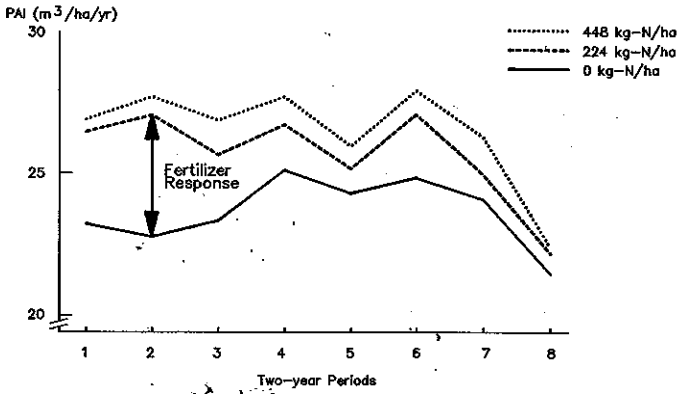
Figure 3. Average unadjusted volume PAI (m3 ha 1 yr 1) of Douglas fir by 2 yr periods following application of V fertilizer.
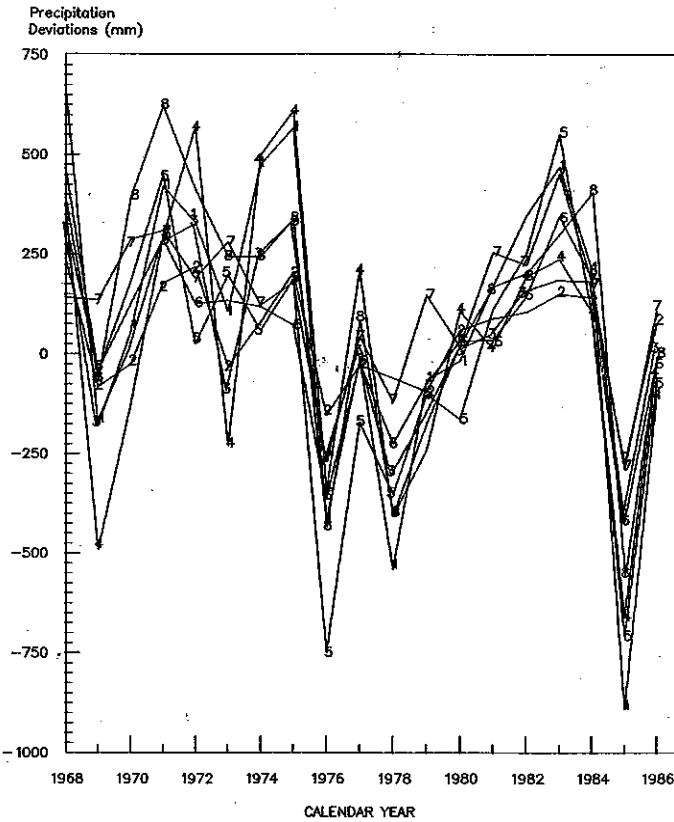

Figure 4. Precipitation deviations from normal (see Methods) for weather divisions 1 through 8 (see Figure 1) by calendar year.

trends and often behave as one. The same was true for temperature. The regional trends of temperature and precipitation deviations, averaged for 2 yr periods corresponding to establishment of growth installations, are presented in Figure 5 for October through April, May through September and October through September.
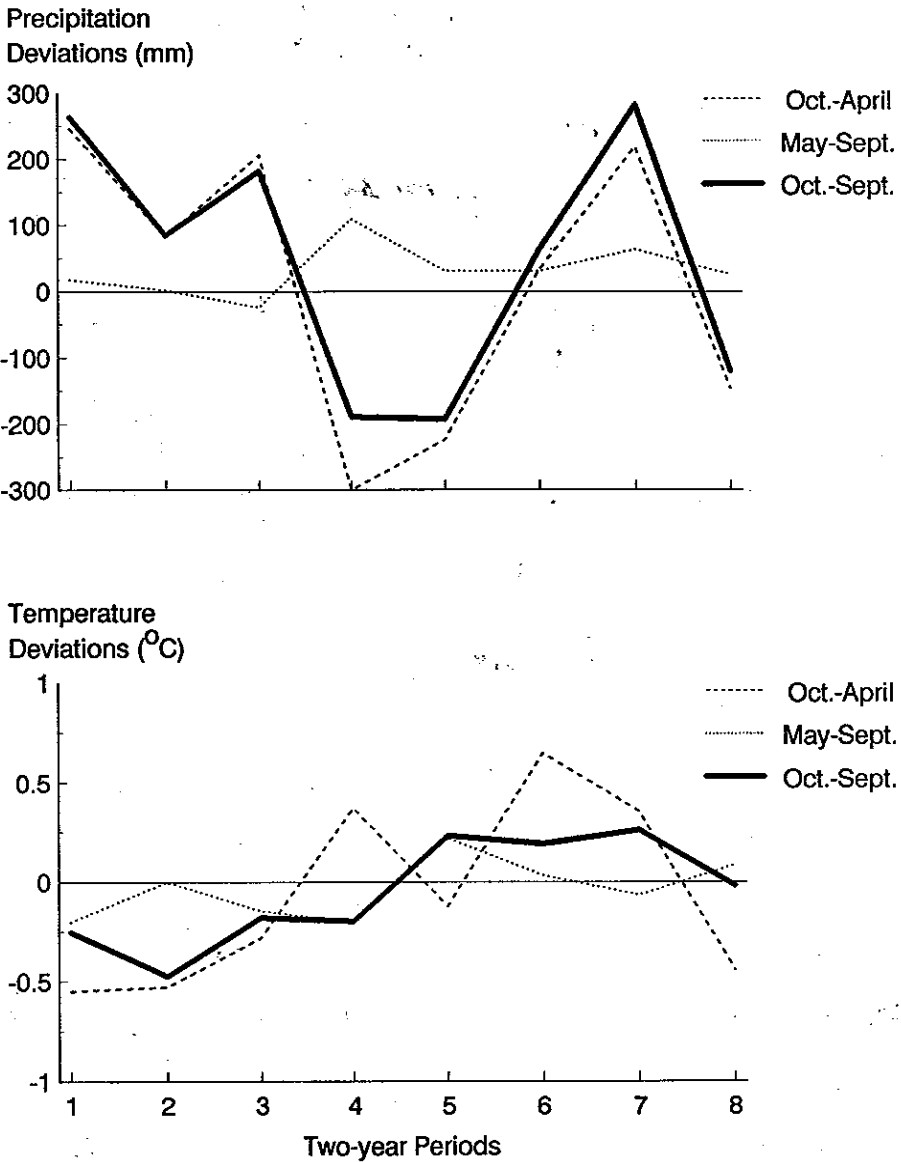

Figure 5. Regional deviations from normal (see Methods) of precipitation and temperature for growing and nongrowing seasons, by 2 yr periods.

3.2 Correlations

Pearson correlation coefficients and their probabilities were computed for fertilizer treatment, weather factor and season. The only correlation between precipitation and PAI was the positive correlation of deviations in summer precipitation with PAI of untreated stands (Table IV).

Table IV

Regional correlation coefficients from first-order differences of volume PAI and weather deviations for each fertilizer treatment and seasonal time period (p-values in parentheses).

Time Period	Treatment	Temperature Deviations	Precipitation Deviations
May-September summer season	0 kg-N/ha	-0.42913* 0.0001†	0.27005 0.0072
	224 kg-N/ha	-0.32265 0.0012	0.12815 0.2086
	448 kg-N/ha	-0.20358 0.0444	0.03327 0.7450
October-April winter period	0 kg-N/ha	0.38285 0.0001	-0.04176 0.6830
	224 kg-N/ha	0.45624 0.0001	-0.09777 0.3382
	448 kg-N/ha	0.32865 0.0010	-0.00971 0.9244
summer plus winter	0 kg-N/ha	0.21028 0.0377	0.03505 0.7319
	224 kg-N/ha	0.33120 0.0009	-0.06623 0.5170
	448 kg-N/ha	0.25090 0.0127	-0.00054 0.9958

*   Pearson Correlation Coefficients

†   Significance probability of the correlation under $H_0: |R| = 0$

Regarding temperature deviations, regional PAI was negatively correlated with high summer temperatures and positively correlated with higher temperatures during the non growing season. As evidenced by the correlation coefficients, the growing season temperature effects were smaller for stands that received the fertilizer treatment.

4. Discussion

The variation in regional PAIs for all treatments was highly correlated with temperature deviations. PAIs correlated negatively with high temperatures in the growing season and positively with high temperatures in the non growing season. These results support the hypothesis that mild winters contribute to high productivity of conifers in the Northwest (Franklin and Dyrness, 1973; Emmingham and Waring, 1977).

  In contrast to the significant correlations between summer precipitation and the . PAI of untreated stands (Table IV), summer precipitation was not correlated with regional growth of fertilized stands. There is no clear physiological explanation for this result. It is probably an artifact reflecting the slight increase in summer precipitation over the last four measurement periods, coupled with an expected decline in' growth ,response to N fertilizer. Meaningful biological associations between patterns of response and weather over time will likely be confounded because response to N should diminish over time. Consequently, substituting space for time may be a preferred approach to analyzing influences of weather variations on growth responses to fertilizer.

5. Summary

Although neither the data used in the correlations nor the correlations themselves are sufficient to conclusively link weather deviations and regional growth patterns, the correlations suggest that between 1969 and 1986, average volume growth rates in natural unmanaged stands of Douglas fir in western Washington and Oregon:were significantly enhanced both by cool wet summer periods and by warmer temperatures during the non summer periods. The latter reflects a positive correlation between regional growth increments and high temperatures during the non growing season, which supports the hypothesis that mild winters contribute to high productivity of conifers in the Pacific Northwest.

Acknowledgments

References

Biasing, T.J., Duvick, DIN. and West, D.C.: 1981, Tree Ring Bull. 41, 37. Brubaker, L.B.: 1980, Ecology 61, 798.

Emmingham, W.H. and Waring, R.H.: 1977, Can. J. For. Res. 7. 165.

Franklin, J.F. and Dyrness, C.T.: 1973, Natural vegetation of Oregon and Washington. USDA For. Serv. Gen. Tech. Rep. PNW 8. 417 pp.

Graumlich, L.J., Brubaker, L.B. and Grier, C.C.: 1989, J. Ecol. 70, 405.

Griffith, B.G.: 1960, Growth of Douglas fir at the University of British Columbia Research Forest as related to climate and soil. Forestry

Bulletin No. 2, University of British Columbia, Vancouver, B.C. 58 pp.

Hazard, J. W. and Peterson, C. E.: 1984, Objectives and analytical methods of the Regional Forest Nutrition Research Project. Institute of Forest Resources, Contrib. 53, University of Washington, Seattle, WA. 23 pp.

King, J.E.: 1966, Site index curves for Douglas fir in the Pacific Northwest. Weyerhaeuser For. Pap. 8. 49 pp.

Lassoie, J. P., Hinckley, T.M., and Grier, C. C.: 1985, Coniferous forests of the Pacific Northwest. Physiological Ecology of North American Plant Communities. Chapman and Hall, New York.

McArdle, R.E., Meyer , W.H. and Bruce, D.: 1930, The yield of Douglas fir in the Pacific Northwest. USDA Tech. Bull. 201. 74 pp.

Miller, R.E., Barker, P.R., Peterson, C.E. and Webster, S.R.: 1986, Using nitrogen in the management of Douglas fir, i. regional trends of response, in Douglas fir: Stand .Management for the Future, Proceedings of symposium held in June, 1985, University of Washington, Seattle, WA.

Peterson, C.E. and Hazard, J.W.: For. Sci., in press.

Peterson, C.E. and Ryan, P.J. and Gessel, S.P.: 1984, Soil Sci. Soc. Am. J. 48, 162.

Schumacher, F.X. and Meyer, H.A.: 1937, J. Agric. Research 54, 79.

Turnbull, K. J., Little, G. R. and Hoyert G. E.: 1972, Comprehensive treevolume tarif tables. State of Washington, Dept. Of Natl. Resources, Olympia, WA.

United States Environmental Data Service: 1969 1986, Climatological data. State of Washington. United States Dept. of Commerce, Washington, D.C.