CLIMATE INDUCED CHANGE IN THE STANDARD DEVIATE OF SNOW DEPTH AND WATER EQUIVALENT

by

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ABSTRACT

Data from 72 snow courses selected throughout the Anglo Pacific Coast of North America were analyzed in order to document the existence of a dramatic climate induced change in the standard deviate of snow depth and water equivalent that began in 1976. Temporal and spatial comparisons were made between each of the 72 snow courses. A pronounced decrease in the standard deviate of snow depth and water equivalent was evident for the courses located throughout the Pacific Northwest. The results suggest that the step-like anomaly ended after 1987, quite possibly coinciding with the end of a sustained El Niño warming trend and the return of a La Niña cooling trend resulting from the Southern Oscillation cycle in the tropical Pacific Ocean.

INTRODUCTION

In the mid-1970's a notable shift in a substantial number of climatically influenced variables, such as the salmon catch in Alaska, the atmospheric CO_2 over the South Pole, the salinity of Puget Sound, the wind speed in Medford, Oregon, the conductivity of the Snake River (Ebbesmeyer et al., 1991), and the depth of the Rocky Mountain snow pack (Changnon et al., 1990) were observed and reported. It has been hypothesized that this abrupt climate shift was caused by a sustained El Niño warming trend that persisted from 1976 until the return of a La Niña cooling cycle in 1988 (Kerr, 1992a).

This study focuses on a climate induced shift in the standard deviate of snow depth (SND) and snow water equivalent (SWE) measured on April 1st of each year (USDA, 1963-1993). The area of interest was the Anglo Pacific Coast of North America, a region composed of the American states of California (CA), Oregon (OR), Washington (WA), and Alaska (AK), the Canadian province of British Columbia (BC), and the Canadian territory of Yukon (YK). The independent analysis of the 72 selected snow courses allowed for the determination of both spatial and temporal trends for regions of the Pacific Coast. An approximate shift for any given region was determined by averaging the standard deviate shifts for the stations located within it. A spatial comparison of the stations allowed for the determination of whether the shift in SND and SWE standard deviates varied by location, was consistent throughout the Pacific Coast, or showed a random distribution.

In order to conduct temporal comparisons, three time scales of varying lengths are studied. All three time scales were centered around 1976, the year that the shift in standard deviates occurred. The shortest time span, the seventeen years from 1968-84, follows the research of the 40 environmental variables conducted by Ebbesmeyer et al. (1991). A second time scale from 1965-87 corresponded to the 1988 return of a La Niña cooling cycle which had been absent for over a decade (Trenberth, 1990). A third scale, the maximum scale, incorporated the longest time span for the available data.

Comparison of the shift in standard deviate for SND and SWE for the three temporal scales could aid in the determination of why the standard deviate shift occurred. The possible linkage of the shift in SND and SWE standard deviates to the El Niño/Southern Oscillation (ENSO) would increase the likelihood of accurate predictions of SND and SWE, since computer models are becoming increasingly accurate in their ability to foretell an El Niño by approximately two years (Kerr, 1992b).

APPROACH AND DATA

SND and SWE data were obtained from 72 snow courses throughout the Anglo Pacific Coast of North America (Figure 1). SND is the measured snow depth and SWE is the quantity of water that is contained in a standardized column of snow. SND and SWE were chosen as the environmental variables for three reasons; 1) by concentrating on two variables it is possible to make spatial comparisons between the snow courses in order to determine where the shift in standard deviate was strongest, 2) there is an abundance of snow data available throughout the Pacific Coast, and 3) snow is one of the few environmental variables that remains independent of anthropological affects. April 1st SND and SWE data were chosen because of their consistency and availability for a large number of snow courses. Also, the April 1st measurement is frequently used to predict the available water supply for the following hydrologic year, and consequently a change in the standard deviate of April 1st SND and SWE would affect regional water supply availability (USDA, 1983-1993).

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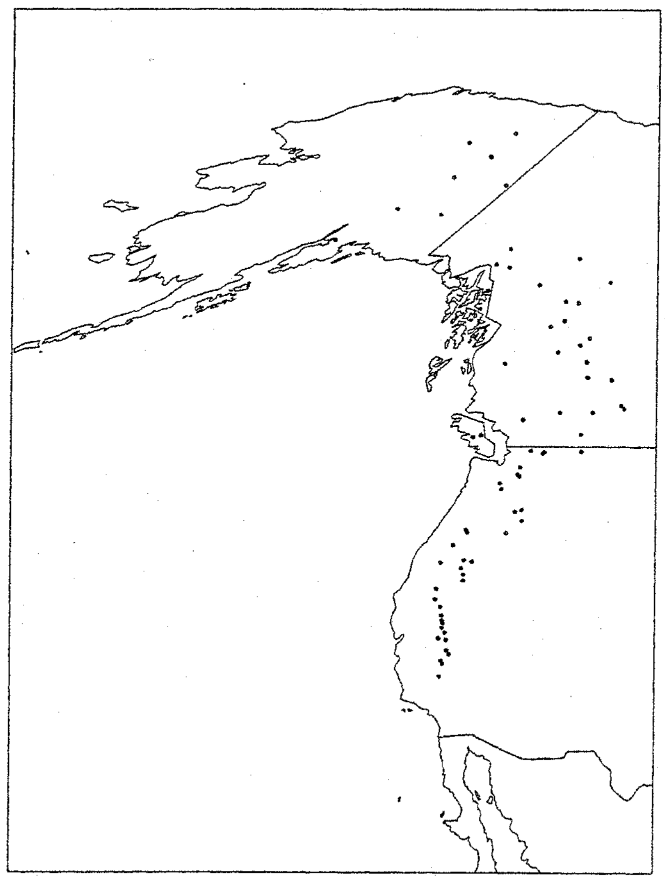

Figure 1. Distribution of the 72 snow courses selected throughout the Anglo Pacific Coast of North America

Data for the province of British Columbia (BC) and the Yukon territory (YK) were obtained from the Ministry of Environment, Lands, and Parks and the Department of Indian and Northern Affairs. Data for the Pacific Coast of the United States were obtained from the Soil Conservation Service, U. S. Department of Agriculture, and the California Department of Water Resources.

Snow courses were selected based upon the following criteria: length of available record, a minimum number of years missing data, and location of the snow course. Preference was given to courses that had been continuously recording data from 1960 through the present. In some regions, most noticeably in AK and northern BC where records were not available throughout the desired time scale, courses with the longest available records were chosen. Stations with complete records were desired for study, and therefore courses with the least number of years with missing data were selected. Concerning the location of the snow course, two or three snow courses were preferred for each degree of latitude from 35°N to 68°N. However, in AK and northern BC there were a sparse number of courses with reliable records, making the number of courses per degree of latitude low in these regions.

METHODOLOGY

To study the shift in standard deviate of SND and SWE for each station, an approach similar to that followed by Ebbesmeyer et al. (1991) was chosen. A sample calculation sheet is shown Table 1 and a brief explanation of these calculations follows. The shift in SWE and SND standard deviates was considered to begin in 1976. In order to compare the standard deviate shift for each temporal scale, an equal number of years was analyzed before and after 1976. For example, analysis of the 1968-1984 scale entailed the comparison of the eight pre-shift years of 1968-1975 with the eight post-shift years of 1977-1984.

The first step of our calculations was to determine the mean, x_m, for the SWE and SND data for each of the three temporal scales studied. A standard deviation was calculated for each temporal scale for the data from the pre-shift years, σ_1, and the data from the post-shift years, σ_2.

STATION NAME: TENQUILLE LAKE								
YEARS	DEPTH (in)	Vi (1960-92)	Vi (1965-87)	Vi (1968-84)	SWE (in)	Vi (1960-92)	Vi (1965-87)	Vi (1968-84)
1960	87.0	-1.103			35.8	-0.914		
1961	139.0	0.774			59.5	0.945		
1962	83.1	-1.245			34.5	-1.016		
1963	118.1	0.020			44.2	-0.253		
1964	135.0	0.632			60.4	1.016		
1965	94.1	-0.847	-0.869		37.0	-0.819	-0.814	
1966	105.1	-0.449	-0.489		48.2	0.059	0.024	
1967	155.9	1.386	1.265		68.6	1.659	1.553	
1968	142.9	0.916	0.816	0.753	57.4	0.782	0.715	0.731
1969	137.0	0.703	0.612	0.553	54.6	0.562	0.505	0.521
1970	74.8	-1.544	-1.535	-1.561	26.8	-1.619	-1.578	-1.566
1971	142.1	0.888	0.789	0.726	53.5	0.476	0.423	0.438
1972	131.1	0.490	0.408	0.352	57.2	0.766	0.700	0.716
1973	111.8	-0.207	-0.258	-0.303	44.1	-0.263	-0.283	-0.268
1974	168.1	1.826	1.686	1.609	69.8	1.755	1.645	1.662
1975	103.1	-0.520	-0.557	-0.598	41.7	-0.451	-0.463	-0.448
1976	159.1				66.3			
1977	81.9	-1.663	-1.452	-1.285	23.7	-2.288	-1.959	-1.696
1978	102.0	-0.727	-0.672	-0.621	41.9	-0.536	-0.485	-0.409
1979	71.3	-2.159	-1.865	-1.637	28.0	-1.881	-1.617	-1.397
1980	99.6	-0.837	-0.764	-0.699	40.9	-0.627	-0.562	-0.476
1981	93.7	-1.112	-0.993	-0.895	33.1	-1.387	-1.201	-1.035
1982	110.6	-0.323	-0.336	-0.335	44.3	-0.304	-0.290	-0.239
1983	106.7	-0.506	-0.489	-0.465	40.4	-0.684	-0.610	-0.518
1984	96.1	-1.002	-0.902	-0.816	39.0	-0.817	-0.722	-0.616
1985	95.7	-1.021	-0.917		38.8	-0.836	-0.738	
1986	131.9	0.669	0.490		50.2	0.266	0.189	
1987	109.4	-0.378	-0.382		47.6	0.019	-0.018	
1988	112.6	-0.231			39.8	-0.741		
1989	121.3	0.173			45.7	-0.171		
1990	98.4	-0.892			40.9	-0.627		
1991	137.8	0.945			55.7	0.798		
1992	105.1	-0.580			48.6	0.114		

MEAN Vi :	PRE-1976	0.115	0.187	0.219		0.179	0.243	0.255
	POST-1976	-0.643	-0.828	-0.965		-0.647	-0.801	-0.912
SHIFT:		**-0.758**	**-1.015**	**-1.183**		**-0.826**	**-1.044**	**-1.168**

YEARS	MEAN DEPTH	SIGMA 1	SIGMA 2
1960-1992	117.544	27.685	21.434
1965-1987	119.273	28.966	25.744
1968-1984	120.743	29.433	30.231

YEARS	MEAN SWE	SIGMA 1	SIGMA 2
1960-1992	47.441	12.743	10.359
1965-1987	47.865	13.340	12.317
1968-1984	47.665	13.317	14.106

Table 1. Sample calculation for the determination of the shift in standard deviate of snow depth and water equivalent.

We then proceeded to find a normalized value for the SND and SWE data, designated v_i, for each time scale from the following equation,

$$v_i = (x_i - x_m)/\sigma_n$$

where x_i is the data value for the i^{th} year and σ_n is the standard deviation for the pre-shift years when n = 1 and is the standard deviation for the post-shift years when n = 2.

After the data was normalized, the mean of the normalized data was found for the pre-shift years, v_{m1}, and for the post-shift years, v_{m2}, for each of the three temporal scales. Finally, the shift in standard deviate, d, was calculated by the following equation,

$$d = v_{m2} - v_{m1}$$

By repeating these calculations we are able to determine the shift in standard deviate for the 72 snow courses, the three independent temporal scales for each station, and the SND and SWE data for each station.

When data was missing from a station's records, the year without available data was considered to be nonexistent. Therefore, the calculated mean, x_m, only includes the years with available data. Similarly, the mean of the normalized data values, v_m, would also include only the years with available records.

The data was normalized in order to allow for the comparison of the shift in standard deviate in the SND and SWE data to other climatically sensitive variables.

STATE (TERRITORY)	STATION NAME	LATITUDE	YEARS AVAILABLE	YEARS MISSING	SHIFT IN STANDARD DEVIATE MAXIMUM	1965-87	1968-84
AK	ARCTIC VILLAGE	68°07'	1964-88		0.264	0.206	0.125
AK	CHANDALAR LAKE	67°30'	1964-88		-0.174	-0.182	-0.078
AK	FORT YUKON	66°35'	1964-88		-0.447	-0.462	-0.201
AK	MT. RYAN	65°15'	1962-90		-0.940	-1.082	-1.195
AK	EAGLE VILLAGE	64°47'	1965-87		-0.467	-0.467	-0.551
AK	MONAHAN FLAT	63°18'	1964-88		0.463	0.316	0.167
AK	MENTASTA PASS	62°54'	1962-90		0.286	0.171	-0.019
AK	ARCTIC VALLEY #1	61°14'	1964-88		-0.091	-0.268	-0.348
YK	WHITEHORSE AIRPORT	60°42'	1965-87	'70,'72	-0.039	-0.039	0.159
YK	WATSON LAKE AIRPORT	60°07'	1965-87		-0.661	-0.661	-0.376
BC	LOG CABIN	59°46'	1960-92		0.968	0.585	0.349
BC	ATLIN LAKE	59°34'	1964-88		-0.266	-0.115	-0.272
BC	SUMMIT LAKE	58°39'	1964-88	'72,'73	0.504	0.565	0.230
BC	DEASE LAKE	58°26'	1965-87		-0.130	-0.130	-0.258
AK	SPEEL RIVER	58°09'	1965-87		-0.901	-0.901	-0.898
BC	PULPIT LAKE	57°32'	1963-89		-0.476	-0.590	-0.496
BC	WARE (LOWER)	57°24'	1961-91	'69,'77	-0.113	-0.516	-0.644
BC	TUTIZZE LAKE	56°19'	1963-89		-0.734	-0.737	-0.487
BC	KAZA LAKE	56°02'	1963-89	'66,'81	-0.536	-0.575	-0.381
BC	PINE PASS	55°21'	1961-91	'64	-0.070	-0.349	-0.443
BC	MCLEOD LAKE	54°56'	1960-92		-0.365	-0.718	-0.527
BC	FORT ST. JAMES	54°29'	1960-92		-0.911	-1.087	-0.870
BC	LONGWORTH (UPPER)	53°57'	1960-92	'89	-0.135	-0.500	-0.631
BC	KIDPRICE LAKE	53°51'	1960-92		-0.107	-0.346	-0.696
BC	BARKERVILLE	53°03'	1960-92		-0.816	-1.054	-1.090
BC	YELLOWHEAD	52°54'	1960-92		-0.801	-1.144	-1.199
BC	FIELD	51°23'	1960-92		-0.149	-0.482	-0.347
BC	MARBLE CANYON	51°12'	1960-92		-0.614	-1.026	-0.986
BC	REVELSTOKE	50°59'	1960-92		-0.899	-0.921	-0.594
BC	PORCUPINE RIDGE	50°58'	1962-90	'83	-1.027	-1.111	-1.225
BC	TENQUILLE LAKE	50°32'	1960-92		-0.826	-1.044	-1.168
BC	KOCH CREEK	49°43'	1960-92		-0.851	-1.028	-0.733
BC	FORBIDDEN PLATEAU	49°39'	1960-92		-0.968	-1.133	-1.339
BC	UPPER THELWOOD LAK	49°32'	1960-92	'63	-1.054	-1.331	-1.388
WA	DEVILS PARK	48°45'	1960-92		-0.819	-1.211	-1.214
WA	BUNCHGRASS MEADOW	48°41'	1960-92		-0.859	-1.012	-0.759
WA	SALMON MEADOWS	48°40'	1961-91		-0.756	-0.827	-0.704
WA	RUSTY CREEK	48°32'	1960-92		-0.923	-1.075	-1.023
WA	MERRITT	47°47'	1961-91		-0.899	-1.083	-1.199
WA	BLEWETT PASS #2	47°21'	1960-92		-0.846	-1.068	-1.141
WA	STEMILT SLIDE	47°17'	1960-92		-0.698	-0.946	-1.002
WA	GROUSE CAMP DISC.	47°16'	1961-91		-0.411	-0.466	-0.486
WA	CAYUSE PASS	46°52'	1960-92		-0.960	-1.070	-1.001
WA	AHTANUM R.S.	46°31'	1960-92		-0.548	-0.666	-0.835
OR	LUCKY STRIKE	45°17'	1963-89		-0.790	-0.956	-0.858
OR	ARBUCKLE MT.	45°11'	1960-92		-0.576	-0.528	-0.389
OR	TIPTON	44°40'	1960-92		-0.671	-0.589	-0.574
OR	DEAD HORSE GRADE	44°10'	1960-92		-1.101	-1.147	-1.194
OR	NEW DUTCHMAN FLAT 2	44°00'	1960-92		-0.782	-0.782	-0.804
OR	ROCK SPRINGS	43°59'	1962-90		0.103	0.364	0.499
OR	NORTH UMPQUA	43°17'	1960-92		-1.131	-1.177	-1.276
OR	FINNLEY CORRALS AM	42°27'	1960-92		-0.505	-0.367	-0.512
OR	SHERMAN VALLEY AM	42°21'	1960-92		-0.208	-0.003	-0.323
OR	BEAVER DAM CREEK	42°17'	1960-92		-0.575	-0.493	-0.704
CA	STATE LINE AM (CA)	41°59'	1961-91		-1.148	-0.942	-0.865
CA	CEDAR PASS	41°35'	1961-91		0.028	-0.044	-0.418
CA	BARBER CREEK	41°14'	1961-91		-0.245	-0.191	-0.323
CA	BURNEY SPRINGS	40°47'	1959-93	'68	-0.632	-1.207	-1.372
CA	HUMBUG SUMMIT	40°11'	1959-93		-0.188	-0.410	-0.391
CA	EUREKA LAKE	39°46'	1959-93		-0.536	-0.717	-0.521
CA	DONNER SUMMIT	39°19'	1961-91		-0.177	-0.157	-0.066
CA	RUBICON #2	39°00'	1961-91		-0.246	-0.225	-0.179
CA	TRUCKEE, UPPER	38°52'	1961-91	'87	-0.434	-0.271	-0.289
CA	BLUE LAKES	38°36'	1961-91		-0.286	-0.256	0.000
CA	LEAVITT MEADOWS	38°20'	1962-90		-0.115	0.160	0.301
CA	BEEHIVE MEADOWS	38°00'	1959-93		-0.112	-0.142	0.010
CA	TIOGA PASS	37°55'	1961-91	'81,'86	0.317	0.554	0.892
CA	ROSE MARIE	37°19'	1959-93		0.215	0.299	0.403
CA	BISHOP PASS	37°06'	1959-93		0.141	0.162	0.185
CA	GRANT GROVE	36°44'	1959-93	'85	-0.049	-0.184	-0.121
CA	GIANT FOREST	36°34'	1959-93		-0.049	-0.173	-0.106
CA	DEAD HORSE MEADOW	35°52'	1959-93		-0.142	-0.257	-0.389

Table 2. Summary of shift in standard deviate of snow water equivalent arranged by latitude of the snow course.

STATE	STATION NAME	LATITUDE	YEARS	YEARS	SHIFT IN STANDARD DEVIATE		
(TERRITORY)			AVAILABLE	MISSING	MAXIMUM	1965-87	1968-84
AK	ARCTIC VILLAGE	68°07'	1964-88		0.413	0.306	0.142
AK	CHANDALAR LAKE	67°30'	1964-88		0.182	0.143	0.017
AK	FORT YUKON	66°35'	1964-88		-0.311	-0.387	0.028
AK	MT. RYAN	65°15'	1962-90		-0.960	-1.042	-1.101
AK	EAGLE VILLAGE	64°47'	1965-87		-0.343	-0.343	-0.397
AK	MONAHAN FLAT	63°18'	1964-88		0.363	0.236	0.077
AK	MENTASTA PASS	62°54'	1962-90		0.094	0.097	-0.027
AK	ARCTIC VALLEY #1	61°14'	1964-88		-0.354	-0.519	-0.621
YK	WHITEHORSE AIRPORT	60°42'	1965-87	'70,'72	0.308	0.308	0.416
YK	WATSON LAKE AIRPORT	60°07'	1965-87		-0.464	-0.464	-0.510
BC	LOG CABIN	59°46'	1960-92		0.758	0.647	0.251
BC	ATLIN LAKE	59°34'	1964-88		-0.165	-0.028	-0.225
BC	SUMMIT LAKE	58°39'	1964-88	'72,'73	0.165	0.263	0.235
BC	DEASE LAKE	58°26'	1965-87		-0.096	-0.096	-0.256
AK	SPEEL RIVER	58°09'	1965-87		-0.860	-0.860	-0.936
BC	PULPIT LAKE	57°32'	1963-89		-0.406	-0.504	-0.421
BC	WARE (LOWER)	57°24'	1961-91	'69,'77	-0.225	-0.576	-0.433
BC	TUTIZZE LAKE	56°19'	1963-89		-0.502	-0.569	-0.395
BC	KAZA LAKE	56°02'	1963-89	'66,'81	-0.513	-0.487	-0.396
BC	PINE PASS	55°21'	1961-91	'64	-0.415	-0.546	-0.681
BC	MCLEOD LAKE	54°56'	1960-92		-0.698	-0.820	-0.688
BC	FORT ST. JAMES	54°29'	1960-92		-0.860	-0.986	-0.804
BC	LONGWORTH (UPPER)	53°57'	1960-92	'89	-0.223	-0.435	-0.552
BC	KIDPRICE LAKE	53°51'	1960-92		-0.412	-0.531	-0.674
BC	BARKERVILLE	53°03'	1960-92		-1.004	-1.147	-1.239
BC	YELLOWHEAD	52°54'	1960-92		-0.682	-0.974	-1.092
BC	FIELD	51°23'	1960-92		-0.532	-0.805	-0.770
BC	MARBLE CANYON	51°12'	1960-92		-0.873	-1.029	-0.970
BC	REVELSTOKE	50°59'	1960-92		-0.982	-1.033	-0.732
BC	PORCUPINE RIDGE	50°58'	1962-90	'83	-0.864	-0.928	-1.111
BC	TENQUILLE LAKE	50°32'	1960-92		-0.758	-1.015	-1.183
BC	KOCH CREEK	49°43'	1960-92		-1.047	-1.076	-0.833
BC	FORBIDDEN PLATEAU	49°39'	1960-92		-1.066	-1.226	-1.303
BC	UPPER THELWOOD LAK	49°32'	1960-92	'63	-0.927	-1.286	-1.275
WA	DEVILS PARK	48°45'	1960-92		-0.725	-1.170	-1.185
WA	BUNCHGRASS MEADOW	48°41'	1960-92		-0.810	-0.898	-0.682
WA	SALMON MEADOWS	48°40'	1961-91	'84,'90	-0.664	-0.783	-0.620
WA	RUSTY CREEK	48°32'	1960-92	'83	-0.918	-0.958	-0.896
WA	MERRITT	47°47'	1961-91	'83	-0.868	-1.041	-1.104
WA	BLEWETT PASS #2	47°21'	1960-92		-0.830	-0.975	-0.922
WA	STEMILT SLIDE	47°17'	1960-92	'90	-0.575	-0.822	-0.734
WA	GROUSE CAMP DISC.	47°16'	1961-91	'65,'75	-0.432	-0.509	-0.397
WA	CAYUSE PASS	46°52'	1960-92	'80,'86,'91,'92	-0.957	-1.072	-1.094
WA	AHTANUM R.S.	46°31'	1960-92		-0.461	-0.582	-0.750
OR	LUCKY STRIKE	45°17'	1963-89		-0.419	-0.426	-0.130
OR	ARBUCKLE MT.	45°11'	1960-92		-0.321	-0.162	0.121
OR	TIPTON	44°40'	1960-92		-0.687	-0.600	-0.618
OR	DEAD HORSE GRADE	44°10'	1960-92	'84	-0.964	-0.977	-1.060
OR	NEW DUTCHMAN FLAT 2	44°00'	1960-92		-0.662	-0.604	-0.574
OR	ROCK SPRINGS	43°59'	1962-90		-0.054	0.192	0.383
OR	NORTH UMPQUA	43°17'	1960-92		-1.008	-0.987	-1.126
OR	FINNLEY CORRALS AM	42°27'	1960-92	'63	-0.484	-0.230	-0.345
OR	SHERMAN VALLEY AM	42°21'	1960-92	'83,'84,'91	-0.202	-0.081	-0.584
OR	BEAVER DAM CREEK	42°17'	1960-92	'63,'78	-0.584	-0.454	-0.548
CA	STATE LINE AM (CA)	41°59'	1961-91		-1.147	-0.928	-0.887
CA	CEDAR PASS	41°35'	1961-91		-0.167	-0.246	-0.490
CA	BARBER CREEK	41°14'	1961-91		-0.272	-0.216	-0.428
CA	BURNEY SPRINGS	40°47'	1959-93	'68	-0.391	-0.911	-1.265
CA	HUMBUG SUMMIT	40°11'	1959-93		-0.152	-0.381	-0.384
CA	EUREKA LAKE	39°46'	1959-93		-0.513	-0.576	-0.410
CA	DONNER SUMMIT	39°19'	1961-91		-0.060	-0.007	0.134
CA	RUBICON #2	39°00'	1961-91	'89	-0.277	-0.138	-0.018
CA	TRUCKEE, UPPER	38°52'	1961-91	'87	-0.246	-0.021	-0.101
CA	BLUE LAKES	38°36'	1961-91		-0.124	-0.081	0.220
CA	LEAVITT MEADOWS	38°20'	1962-90		-0.085	0.200	0.318
CA	BEEHIVE MEADOWS	38°00'	1959-93		-0.144	-0.113	-0.006
CA	TIOGA PASS	37°55'	1961-91	'81,'86	0.251	0.466	0.779
CA	ROSE MARIE	37°19'	1959-93		0.262	0.327	0.447
CA	BISHOP PASS	37°06'	1959-93		0.147	0.119	0.180
CA	GRANT GROVE	36°44'	1959-93	'85	0.070	0.054	0.063
CA	GIANT FOREST	36°34'	1959-93		-0.134	-0.263	-0.215
CA	DEAD HORSE MEADOW	35°52'	1959-93		0.010	-0.031	-0.075

Table 3. Summary of shift in standard deviate of snow depth arranged by latitude of the snow course.

STATE (PROVINCE)	NUMBER OF SNOW COURSES	SHIFT IN STANDARD DEVIATE		
		MAXIMUM	1965-87	1968-84
AK/YK	11	-0.246	-0.306	-0.292
BC	23	-0.451	-0.643	-0.661
WA	10	-0.772	-0.942	-0.936
OR	10	-0.624	-0.568	-0.614
CA	18	-0.203	-0.222	-0.181

Table 4. Summary of the shift in standard deviate for snow water equivalent by location.

STATE (PROVINCE)	NUMBER OF SNOW COURSES	SHIFT IN STANDARD DEVIATE		
		MAXIMUM	1965-87	1968-84
AK/YK	11	-0.176	-0.230	-0.265
BC	23	-0.536	-0.660	-0.676
WA	10	-0.724	-0.881	-0.838
OR	10	-0.539	-0.433	-0.448
CA	18	-0.166	-0.153	-0.119

Table 5. Summary of the shift in standard deviate for snow depth by location.

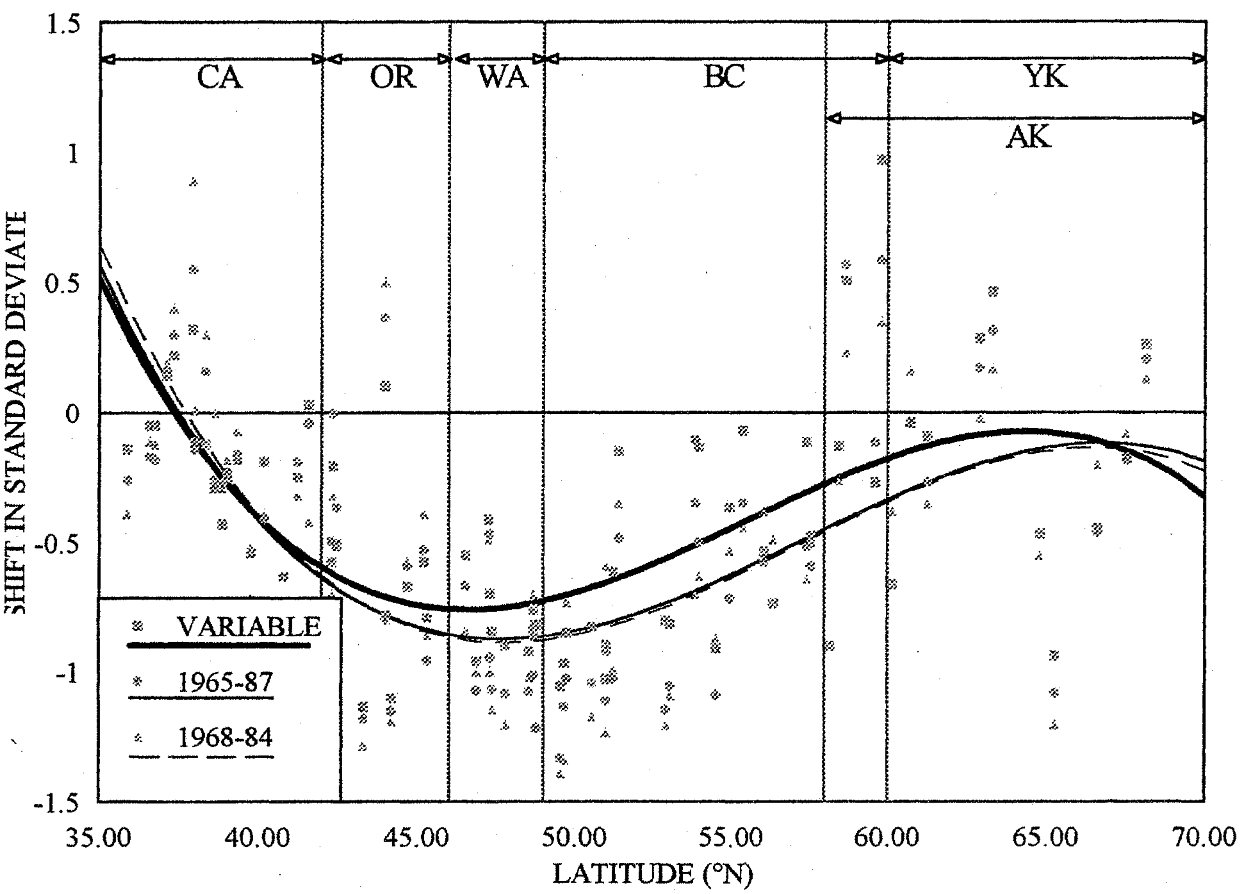

Figure 2. Third degree polynomial best-fit curve for the shift in standard deviate in snow water equivalent for the 72 snow courses studied.

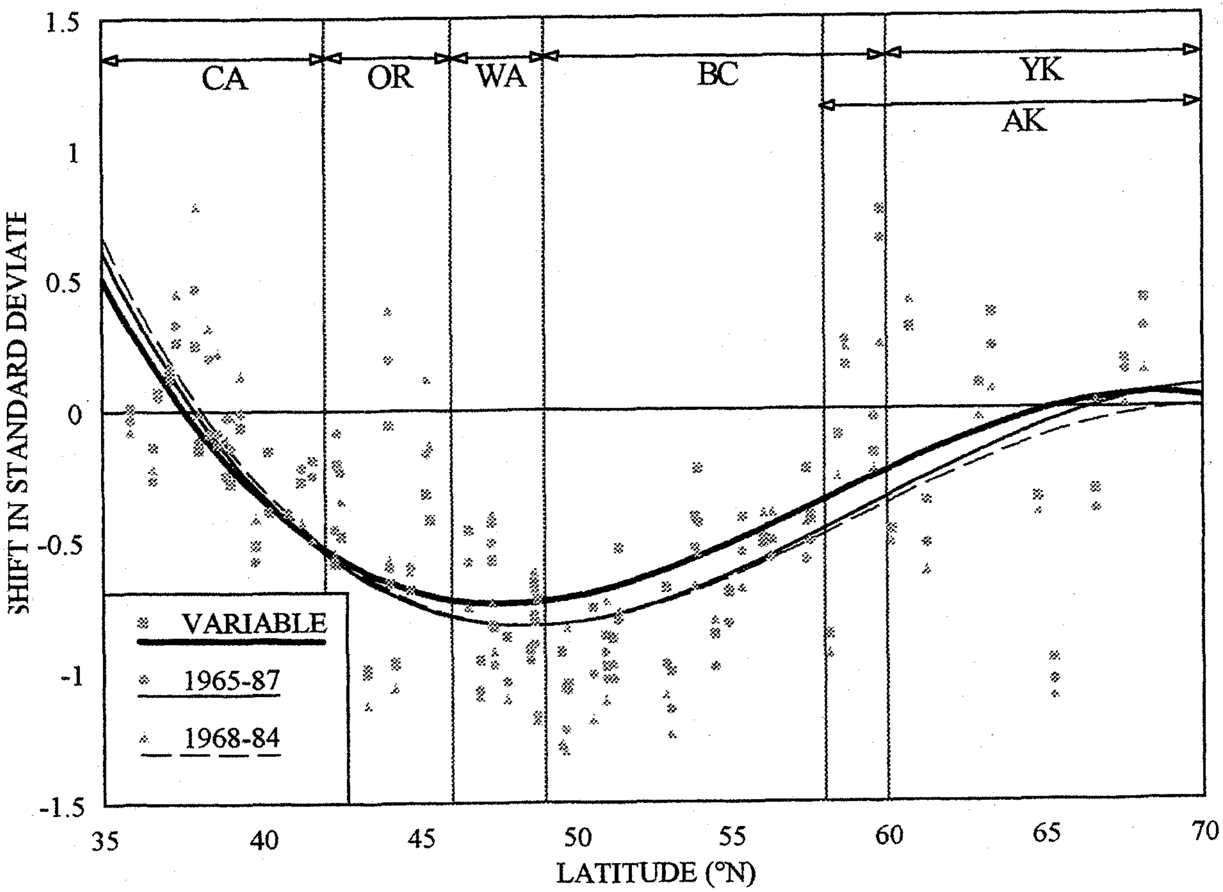

Figure 3. Third degree polynomial best-fit curve for the shift in standard deviate in snow depth for the 72 snow courses studied.

CONCLUSION

The SWE and SND standard deviates for each of the 72 snow courses studied are listed in Table 2 and Table 3 respectively. From these tables it is apparent that the change in standard deviate for all of the stations in WA and OR were negative. A majority of the standard deviate shifts for the stations in CA, BC, YK, and AK were also negative. Table 4 summarizes the SWE standard deviates by state, province, and territory. The largest standard deviate occurs for the 10 stations located in WA. The pronounced standard deviate shift in WA is also evident in Figure 2, a plot of the standard deviate shift for SWE for the 72 snow courses for each of the three time scales. Third degree polynomial best fit curves were drawn through the shifts for each time scale in order to more easily identify spatial and temporal trends. For each of the three temporal scales, the largest decline in SWE standard deviate occurs for the snow courses located in WA and southern BC, with courses in OR and central BC also experiencing significant standard deviate shifts. The slope of the best fit curves in Figure 2 are larger for the courses located to the south of WA than for the stations located to the north of WA. Therefore, the shift in standard deviate for SWE is more spatially sensitive for CA and OR then it is for BC.

The shift in the standard deviate of SND has been summarized in Table 5 by state, territory, and province. It Figure 3 the change in standard deviate of SND for the 72 courses studied has been plotted for each temporal span and third degree polynomial best fit curves have also been constructed. Comparing Figure 2 to Figure 3, the best fit curves representing SND and SWE show a marked similarity. Therefore, the same conclusions can be made for the standard deviate shift for SND as were made for SWE, namely that a strong change in standard deviate for SND existed throughout the Pacific Northwest and lasted approximately a decade. One noticeable difference in the best fit curves for the standard deviate shift for SWE and SND is the relation of the best fit curve representing the maximum time scale to the best fit curves representing the 1968-84 and 1965-87 time scales. For SWE, the curve for the maximum scale shows a strong step back up to a zero shift in standard deviate, while the best fit curve representing the shift in standard deviate of SND for the maximum time scale does not show such a dramatic shift towards zero standard deviate. SWE appears to be more temporally sensitive to the climatically induced shift in standard deviate then Because the standard deviate shifts for SND and SWE are not identical, a shift in the standard deviate of SWE for a snow course would not correspond to an equivalent standard deviate shift for SND.

The length of records for stations in AK and YK seldom date back prior to 1964. Therefore, no specific comparisons could be made between the standard deviate shifts for SWE and SND observed in the maximum time scale and the 1965-87 time scale. Consequently, no comparisons between these two time scales could be made for this region north of approximately 60°N. From Figure 2 and Figure 3, it is apparent that the best fit curves of the standard deviate shifts for the 1968-84 and 1965-87 time scales are nearly identical. The marked similarity between the best fit curves for the 1968-84 and 1965-87 time scales implies that the standard deviate shift in SWE and SND was nearly constant throughout the decade proceeding its 1976 inception. However, the best fit curve of the shift in standard deviate for the maximum scale deviates from the curves for the two shorter time scales considerably from northern OR through northern BC. The shift of the best fit curve for the maximum time scale back toward a zero standard deviate line suggest that the climatically induced shift in the standard deviate for SWE and SND ends after 1987.

From Figure 2 and Figure 3 it is evident that the best fit curves of the standard deviate shifts for all three time scales nearly coincide. Because all three curves nearly coincide, it appears that the snow courses of CA are not temporally sensitive to the shift in standard deviate of both SWE and SND. The snow courses in CA are however spatially sensitive, with snow courses in northern CA experiencing a moderate negative change in SWE and SND standard deviate while courses in central CA experienced either a small positive or negative change.

The return of the La Niña cooling cycle in 1988, which brought an end to the decadal El Niño anomaly, it is apparent that this coincides with the end of the climatically induced shifts in the standard deviate of SND and SWE prominent throughout the Pacific Northwest. The Pacific Northwest shows a strong influence by El Niño on SWE and SND, as well as other climatically sensitive variables (Kahya et al., 1993). The shift in standard deviate of SND and SWE in CA and AK do not show any temporal sensitivity to the El Niño anomaly.

For the Pacific Northwest, future research is necessary to determine if the same climatically induced shift in standard deviate is evident during other El Niño/La Niña cycles. If the SND and SWE of snow courses in the Pacific Northwest region are consistently affected by the ENSO, then accurate prediction of an ENSO would consequently enable better predictions of SND and SWE.

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