13.7 MANIFESTATION OF THE PACIFIC DECADAL OSCILLATION SHIFT OF 1976 IN ALASKAN CLIMATOLOGY

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1. INTRODUCTION

In 1976, the climate regime of the Pacific Ocean basin underwent a dramatic shift. The effects on the climate of this shift were first noted soon after the event (Namias 1978) but its true climatological significance could not be fully known until well after the event. Throughout the 1990s, numerous studies were conducted to examine the nature and consequences of the natural variability in the Pacific, including the shift (Graham 1994, Trenberth and Hurrell 1994, Zhang et al 1997) as well as research conducted in an attempt to determine this shift's specific influences upon a wide variety of environmental, ecological, oceanic, and atmospheric variables, including climate (Miller et al 1994, Mantua et al 1997, Hare and Mantua 2000)

The term Pacific Decadal Oscillation (hereafter PDO) and the concept of a PDO Index was introduced by Mantua et al. (1997) in a discussion of Pacific climate variability in relation to salmon production in Alaska and the Northwest United States. It was demonstrated that the cyclic nature of the salmon catch in separate regions displayed a response to variation in atmospheric and oceanic circulation. The PDO Index is defined as the leading principal component of the North Pacific sea surface temperature variability on a monthly scale. Sea surface temperatures poleward of 20°N are the basis of the analysis. During the year of 1976, the index of the PDO underwent a shift from one of strongly negative phase to one of strongly positive phase. The general circulation and temperature differences witnessed during each of the phases is generally well known, but a fine scale study to understand specific climatological effects within Alaska, including the differing regional effects and responses to the abrupt change, has not been conducted.

The present study is an effort to clearly discern the specific manner in which the regime shift was experienced throughout Alaska. It is generally known that the positive phase of the PDO, or "warm" phase, results in higher than normal Gulf of Alaska sea surface temperatures, and a southerly flow into Alaska (Hare et al 1999) and the negative phase, or "cool" phase generally results in higher than normal pressure in the Aleutians and northerly and westerly flow over Alaska. The magnitude and sudden nature of the shift in the PDO Index is paralleled by strong local temperature increases in Alaska, suggesting that significant local changes in other meteorological variables should be seen as well (Bowling 1991**).** Changes in those local variables were examined at a cross-section of stations in Alaska, with representation from each of the four major climate regions that make up the state, those being the South, the Interior, the West and the Arctic. The regions used are the same as those defined by Stafford, Wendler, and Curtis (2000) and are shown with the stations used in Figure 1.

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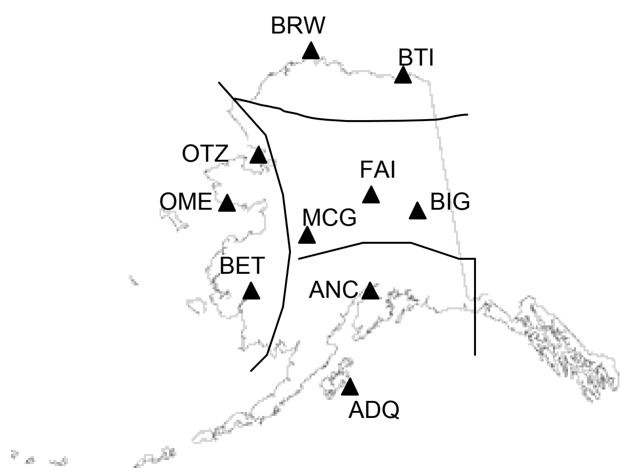


Figure 1. Locations of stations used and climate regions (South Region: ANC=Anchorage, ADQ=Kodiak. Interior Region: FAI=Fairbanks, MCG=McGrath, BIG=Big Delta. West Region: BET=Bethel, OME=Nome, OTZ=Kotzebue. Arctic Region: BRW=Barrow and BTI=Barter Island)

2. DATA, METHODS AND RESULTS

2.1 PDO Index.

Due to the large interannual variability of the surface meteorological observations, a study period of sufficient length previous to and following the shift is required. Hence, the mean of a time period of 10 years each has been chosen to minimize the effect of interannual variability. To isolate the shift itself, 1976 was excluded from the various analyses as it was the year in which the regime shift occurred and it does not fit well in either period. The PDO Index is maintained by Nathan Mantua at the University of Washington and is offered on a monthly time scale for the time period 1900 to present. This dataset can be accessed via the following website http://jisao.washington.edu/pdo/PDO.latest. Figure 2 displays the time series of the PDO Index for our selected study period of 1966 to 1986. The "cool" phase, consisting of mainly negative index values (blue) is seen to dominate the first period from 1966-1975 and the "warm" phase (red) is prevalent during the second period of 1977-1986. In the interest of brevity, the 1966-75 period will be referred to as Period 1 and 1977-86 as Period 2.

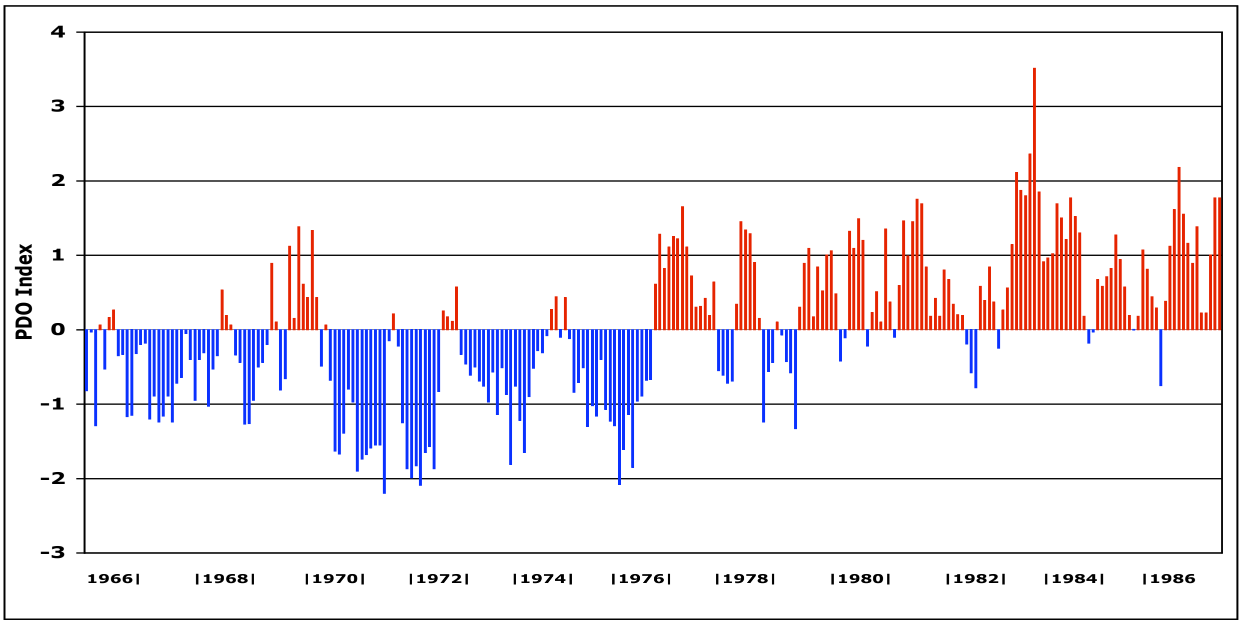


Figure 2. Time series of the monthly values of the Pacific Decadal Oscillation (PDO) Index for the period 1966-1986. Note the shift in the index during mid-1976.

Using the monthly index values, mean seasonal and annual values of the PDO Index for Period 1 and Period 2 were calculated and the results are displayed in Table I along with the change between the two periods (ΔPDO). It should be noted that the greatest change in the value of the PDO Index was witnessed during the winter and spring months.

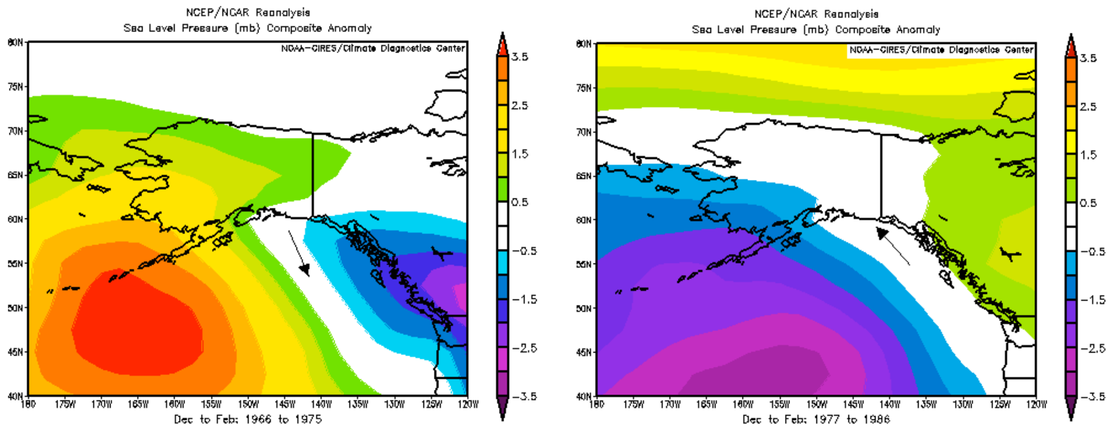
Table I. Average seasonal and annual values of the PDO Index and the difference (Period 2 – Period 1)

	Spring	Summer	Autumn	Winter	Annual
Period 1	**-0.78**	**-0.56**	**-0.52**	**-0.77**	**-0.65**
Period 2	**1.02**	**0.56**	**0.41**	**0.66**	**0.66**
ΔPDO	**+1.80**	**+1.12**	**+0.93**	**+1.43**	**+1.31**

2.2 Sea level pressure and geopotential height.

The primary signature of the positive "warm" phase of the PDO is the intensification of low pressure located near the Aleutian Islands, which in turn has a profound effect upon the synoptic meteorology of Alaska. In contrast to this, the negative "cool" phase is associated with a higher than normal sea level pressure of the Aleutian Low. These effects seem to be especially pronounced during the winter months (Bond and Harrison 2000).

By accessing the NCAR/NCEP reanalysis from Kalnay et al. (1996) through the NOAA-CIRES Climate Diagnostics Center, we obtained maps of the sea level pressure anomaly for the winters of Period 1 and Period 2. Furthermore, the geopotential height field anomaly maps for the same period are presented to identify changes in the upper atmospheric conditions that would have an effect upon surface variables. The results are displayed in Figures 3a,3b and 4a, 4b. The added black arrows denote the mean geostrophic flow.



Figures 3a and 3b. a) 1966-75 winter SLP anomaly b) 1977-86 winter SLP anomaly

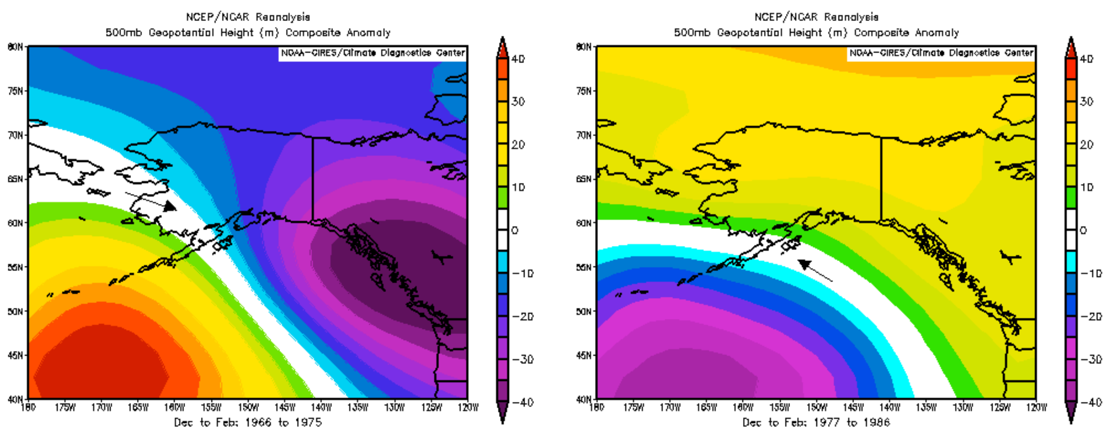


Figure 4a and 4b. a)1966-75 winter 500 hPa geopotential height anomaly b) 1977-86 winter 500 hPa geopotential height anomaly

Table II. Change (Period 2 - Period 1) in SLP (hPa) for Alaskan regions by season and for the year

	Spring	Summer	Autumn	Winter	Annual
South	**-0.9**	**+0.9**	**+0.1**	**-1.4**	**0.0**
Interior	**-1.2**	**+0.8**	**-0.4**	**-2.4**	**-0.8**
West	**-1.6**	**+0.3**	**-0.8**	**-2.8**	**-1.2**
Arctic	**0.0**	**+0.6**	**+0.4**	**-0.8**	**0.0**

The sea level pressure (SLP) anomaly field shows a decrease in the intensity of the low pressure of the Aleutian Low for the first period, which leads to an additional northerly wind component of cold air to Alaska. For Period 2, an intensification of the Aleutian Low can be observed, leading to an additional southeasterly wind component of warmer air into the Alaskan region. These changes are reflected in the sea level pressure changes that were observed at stations in all Alaskan regions (Table II). In winter the largest decreases in atmospheric pressure were observed in all regions. In the summer the opposite trend occurred, however, the magnitude of the change is less than the winter values.

2.3 Temperature

Temperatures on annual, seasonal, and monthly basis were analyzed. In general, the second time period showed higher temperatures when compared to the first period, a result to be expected. The temperature increase was especially well pronounced in winter and spring. Mean annual values are presented in Table III.

Table III. Mean of annual temperatures (°C) and the temperature change (Period 2 - Period 1) at 10 selected stations in Alaska

	ANC	ADQ	FAI	MCG	BIG	BET	OME	OTZ	BRW	BTI
Period 1	**1.6**	**4.1**	**-3.3**	**-4.2**	**-3.2**	**-2.2**	**-3.9**	**-6.4**	**-12.8**	**-12.6**
Period 2	**3.3**	**5.9**	**-1.8**	**-2.9**	**-1.4**	**-0.8**	**-1.8**	**-4.8**	**-11.9**	**-11.9**
ΔT	**+1.7**	**+1.8**	**+1.5**	**+1.3**	**+1.8**	**+1.4**	**+2.2**	**+1.6**	**+0.9**	**+0.7**

All selected Alaskan stations showed a temperature increase; within each climate region the observed temperature increases were fairly uniform. Southern and Western Alaska, areas in which the maritime influence is strong, showed the greatest temperature increase of close to 2°C, followed by Interior and Arctic Alaska. This geographic dependency of the decrease in the magnitude of warming is not unexpected given that the Pacific influence decreases with distance from the ocean. However, when the changes of seasonal temperatures are examined by region, variations in the magnitude of change are witnessed (Table IV).

Table IV. Mean of seasonal and annual temperatures (°C) and the temperature change (Period 2 - Period 1) by region

		Spring	Summer	Autumn	Winter	Annual
South	Period 1	2.0	12.3	3.0	-6.2	2.8
	Period 2	3.8	13.1	4.2	-2.9	4.6
	ΔT	**+1.8**	**+0.8**	**+1.2**	**+3.3**	**+1.8**
Interior	Period 1	-2.3	14.4	-4.2	-22.4	-3.6
	Period 2	-1.0	14.2	-3.5	-18.0	-2.0
	ΔT	**+1.3**	**-0.2**	**+0.7**	**+4.4**	**+1.6**
West	Period 1	-7.3	10.1	-2.6	-17.1	-4.2
	Period 2	-5.9	10.8	-1.5	-13.2	-2.5
	ΔT	**+1.4**	**+0.7**	**+1.1**	**+3.9**	**+1.7**
Arctic	Period 1	-17.2	2.8	-10.1	-26.4	-12.7
	Period 2	-17.3	3.3	-9.4	-24.3	-11.9
	ΔT	**-0.1**	**+0.5**	**+0.7**	**+2.1**	**+0.8**

Winter displayed the greatest change in temperatures for all regions. This is, of course, the season, at which advection of warm air from the South is of special importance. The Interior showed the largest change with an increase of 4.4°C, followed by Western and Southern Alaska, with 3.9°C and 3.3°C respectively, while the analysis of the Arctic data gave a value of 2.1°C. At the first look it might be astounding that Interior Alaska showed a larger temperature change than Southern and Western Alaska, however, the climate here is much more continental, having a much larger annual temperature variation because it is less under the maritime influence than the coastal stations. In general, the temperature increase becomes smaller in the warmer seasons. In summer the sun is at relative high elevation angles and the days are long, diminishing the influence of advection. Interior Alaska displayed actually a slight decrease in the summer temperature.

2.4 Wind Speed and Direction

Frequency analysis of the hourly wind direction and speed observations from the NCDC Surface Airways database were carried out to determine any changes that may have occurred in the low level flow in response to the aforementioned change in general circulation. The wind rose was divided into octants of 45°, centered on the cardinal direction, e.g. North represents a wind direction between 337.5° and 22.5°. The change in wind directional frequency as function of season and region is summarized in Table V.

Table V. Change (Period 2 - Period 1) in the wind direction frequency distribution by season for different Alaskan regions.

		N	NW	W	SW	S	SE	E	NE
South	Spring	+2.6%	+1.7%	-2.4%	+1.7%	-0.8%	+0.2%	-0.5%	-0.2%
	Summer	0.0%	+2.3%	-1.5%	+2.2%	-0.3%	+1.4%	+1.3%	-1.8%
	Autumn	+1.5%	+2.6%	-2.0%	+1.0%	+0.6%	+0.6%	-0.7%	-1.9%
	Winter	+2.8%	-1.9%	-2.4%	+0.3%	-0.2%	+2.2%	+1.7%	+1.4%
	Annual	+1.7%	+1.2%	-2.1%	+1.3%	-0.2%	+1.1%	+0.5%	-0.6%
Interior	Spring	+1.4%	-0.5%	-0.1%	-1.9%	-1.0%	-0.9%	+2.3%	-0.4%
	Summer	+0.8%	0.0%	-1.1%	-1.6%	+1.7%	-0.8%	+1.6%	+0.1%
	Autumn	-0.1%	0.0%	-0.2%	-0.9%	+0.1%	-2.3%	+3.5%	-0.2%
	Winter	+0.5%	0.0%	0.0%	-1.4%	-1.3%	-3.1%	+5.5%	+0.6%
	Annual	+0.6%	-0.1%	-0.3%	-1.5%	-0.1%	-1.8%	+3.2%	0.0%
West	Spring	-3.5%	-0.2%	+0.9%	-0.7%	+0.5%	-0.2%	+0.7%	+3.3%
	Summer	-5.0%	-2.7%	+1.8%	+1.2%	+0.7%	+1.7%	+2.2%	+0.4%
	Autumn	-4.5%	-0.8%	+1.4%	+0.6%	+0.3%	-0.7%	+1.8%	+2.8%
	Winter	-2.8%	0.0%	-0.6%	-1.3%	-2.0%	-1.2%	+5.9%	+3.4%
	Annual	-4.0%	-0.9%	+0.9%	0.0%	-0.1%	-0.1%	+2.6%	+2.5%
Arctic	Spring	+0.2%	+2.5%	-1.6%	-0.5%	-0.7%	-0.9%	+1.8%	-1.0%
	Summer	0.0%	+1.7%	-5.0%	0.0%	-0.2%	-1.4%	-3.3%	+7.5%
	Autumn	+0.1%	+2.0%	-1.7%	+1.6%	-2.1%	-1.8%	-5.0%	+6.9%
	Winter	+0.9%	+1.9%	-8.3%	-3.5%	-2.1%	+0.4%	+10.3%	+0.6%
	Annual	+0.3%	+2.0%	-4.2%	-0.6%	-1.3%	-0.9%	+0.9%	+3.5%

Table VI. Change (Period 2 - Period 1) in frequency of wind speed (m/s) by season for different Alaskan regions

		Calm	.5-1.5	2-3	3.5-4.5	5-6	6.5-7.5	8-9	9.5-10.5	11-12	12.5-13.5	>14
South	Spring	-2.4%	-8.8%	-0.5%	+3.9%	+2.9%	+2.2%	+1.1%	+0.4%	+0.5%	+0.5%	+0.3%
	Summer	-3.5%	-10.0%	+1.7%	+5.4%	+3.5%	+1.3%	+0.5%	+0.5%	+0.3%	+0.2%	+0.1%
	Autumn	-1.8%	-9.0%	+2.2%	+4.6%	+0.7%	+1.0%	+0.4%	+0.6%	+0.4%	+0.4%	+0.5%
	Winter	-3.9%	-9.5%	+3.7%	+4.9%	+0.7%	+2.2%	+1.6%	+1.6%	+0.5%	+0.4%	+0.1%
	Annual	-2.9%	-9.4%	+1.8%	+4.7%	+2.0%	+1.7%	+0.9%	+0.8%	+0.4%	+0.4%	+0.3%
Interior	Spring	+1.1%	+3.5%	-2.0%	-0.5%	-1.6%	-0.3%	-0.3%	-0.1%	+0.1%	0.0%	0.0%
	Summer	-0.8%	+5.8%	-1.9%	-1.9%	-1.3%	-0.1%	-0.1%	+0.2%	+0.1%	0.0%	0.0%
	Autumn	0.0%	+5.1%	-3.0%	-0.8%	-1.1%	-0.8%	-0.3%	0.0%	+0.4%	+0.2%	+0.2%
	Winter	-0.8%	+1.7%	-2.3%	0.0%	-0.1%	+0.1%	+0.6%	+0.5%	+0.6%	+0.1%	+0.1%
	Annual	-0.1%	+4.0%	-2.3%	-0.8%	-1.0%	-0.3%	0.0%	+0.2%	+0.3%	+0.1%	+0.1%
West	Spring	-0.8%	-0.8%	+1.4%	+0.7%	+1.0%	+0.3%	+0.1%	-0.5%	-0.7%	-0.3%	-0.4%
	Summer	-0.5%	-0.5%	+2.2%	+1.9%	+0.5%	-0.9%	-0.8%	-0.9%	-0.6%	-0.4%	-0.1%
	Autumn	-0.9%	-0.1%	-1.2%	+0.6%	+0.8%	+0.7%	+0.1%	+0.1%	0.0%	+0.1%	0.0%
	Winter	-1.5%	-0.9%	-2.7%	+0.4%	+2.0%	+2.9%	+2.2%	+0.5%	-0.3%	+0.1%	-0.4%
	Annual	-0.9%	-0.6%	-0.1%	+0.9%	+1.1%	+0.8%	+0.4%	-0.2%	-0.4%	-0.2%	-0.3%
Arctic	Spring	-0.3%	-1.5%	-2.5%	+0.7%	+2.6%	+1.8%	-0.5%	-0.6%	-0.3%	0.0%	-0.4%
	Summer	+0.4%	-0.8%	-3.0%	-0.6%	+1.3%	+2.3%	+0.8%	-0.2%	-0.1%	0.0%	0.0%
	Autumn	+0.3%	-1.1%	-2.4%	-0.5%	+1.6%	+1.6%	+0.3%	+0.5%	+0.2%	0.0%	-0.6%
	Winter	+0.3%	-2.4%	-6.4%	-2.3%	+2.2%	+4.2%	+2.1%	+1.8%	+0.6%	+0.8%	+0.4%
	Annual	+0.2%	-1.4%	-3.6%	-0.7%	+1.9%	+2.5%	+0.9%	+0.3%	+0.1%	+0.2%	-0.1%

The intensification of the Aleutian Low from Period 1 to Period 2 resulted in more frequent easterly winds in most seasons and for all of the regions. The Western region saw consistent decreases in the northerly and northwesterly winds while seeing consistent increases in easterly and northeasterly winds. The Southern region and Interior region saw similar increases in the occurrence of winds with an easterly component. Additionally, the Arctic experienced increases in winds with a northerly component in all seasons. Wide variation in the change of easterly winds was seen in the Arctic with a 10.3% increase during the winter season and a 5.0% decrease during the autumn.

Again, the stronger Aleutian Low supports the observed increase in wind speed, found for seasonal and annual values. Both the frequency of calms decreased and higher wind speed classes increased in frequency. This is especially well pronounced in winter and spring.

2.5 Cloudiness

Analysis of the average seasonal and monthly cloudiness revealed mostly minor changes, with some notable exceptions, one being the winter in the South Region. In winter, such changes are of special importance for the temperature regime. The low amount of incoming solar radiation combined with the possibility of a high amount of radiational cooling in the IR region if skies are clear defines winter temperatures. An increase in cloudiness during the winter months will result in surface temperature increases. Average cloudiness on a seasonal scale showed increases over all regions during the winter with the greatest increase of 11% in the Southern region when the two periods are compared. Every region with the exception of the South saw decreases in cloudiness during the spring months.

2.6 January

A maximum in warming was observed in winter when compared to other seasons (see Table IV). However, the warming was not uniform for the winter months. Of most dramatic note is the increase observed at the Interior stations during January. The mean January temperature in Fairbanks, Big Delta, and McGrath during the time period 1966 to 1975 were -28.4°C, -25.8°C, and -26.6°C, respectively, while mean January temperatures of -18.4°C, -15.1°C, and -18.5°C were seen at the three stations in the period 1977 to 1986, yielding a mean temperature warming of close to **10°C for the 10 year averages!**

Table VII. Temperature change (Period 2 - Period 1) for November through March in °C

	Nov	Dec	Jan	Feb	Mar
ANC	+1.2	+1.0	**+8.1**	+1.6	+3.2
ADQ	+1.4	+2.4	**+5.1**	+1.4	+3.6
FAI	+1.7	+2.5	**+10.0**	+2.6	+3.6
MCG	+1.8	+2.5	**+8.1**	+0.1	+3.2
BIG	+1.7	+1.2	**+10.7**	+1.8	+3.1
BET	+1.7	+4.3	**+6.4**	+1.7	+4.4
OME	+2.7	+3.6	**+5.6**	+2.6	+3.8
OTZ	+2.8	+2.9	**+6.0**	+2.8	+2.2
BRW	+0.8	+1.5	**+2.7**	+2.7	+2.4
BTI	+0.8	-0.8	**+3.3**	+3.6	-1.7

Table VII shows the temperature changes during the months of November through March. While Interior Alaska showed the greatest change, the temperature changes observed in Southern and Western Alaska are large with values of around 6°C. Only Arctic Alaska gave about half this value, which is still substantial. The station changes in mean January surface temperatures found are displayed onto the difference in mean temperatures as found in the NCEP/NCAR reanalysis in Figure 5.

Table VIII. Changes (Period 2 – Period 1) in mean monthly SLP (hPa)

	Nov	Dec	Jan	Feb	Mar
ANC	-0.8	+3.2	**-6.3**	-0.9	-2.3
ADQ	-1.3	+3.8	**-7.6**	-0.7	-2.6
FAI	-1.6	+2.0	**-9.0**	-0.3	-3.0
MCG	-2.6	+1.6	**-9.6**	+0.2	-3.3
BIG	-1.1	+2.5	**-9.0**	+0.1	-2.7
BET	-4.4	-0.6	**-11.6**	+0.6	-5.1
OME	-3.5	-0.3	**-9.1**	+1.2	-3.8
OTZ	-2.1	+0.9	**-7.4**	+0.9	-2.6
BRW	+0.2	+1.6	**-3.0**	-0.6	-0.6
BTI	-0.1	+1.6	**-3.9**	-0.6	-1.2

January shows of all winter months by far the strongest change in atmospheric surface pressure. In general, a cyclic pattern can be observed, with relatively large negative changes (intensification of the Aleutian Low) in November, January and March, but little, sometimes even positive change in December and February.

This cyclic pattern can be seen quite well for three of the four climatological regions of Alaska. Only Arctic Alaska does not follow well this pattern. This might be explained by the region's great distance from the circulation centers that seem to govern the lower latitude portions of the state. In general, the monthly temperature changes observed in at least 3 of the 4 climatic zones is similar to the cycle of surface pressure, below normal pressure coinciding with above normal temperature, and January and March experiencing the larger temperature increases than compared with December and February. In Figure 6, the mean monthly deviations in temperature are plotted against the mean monthly deviation in sea level pressure. As could be deduced from Table VII, above normal temperature are well correlated with below normal pressure. It can be seen from the figure, that this relationship is well established for all regions but Arctic Alaska. In general, a surface pressure of about 1 hPa below normal results in a temperature of 1°C above normal.

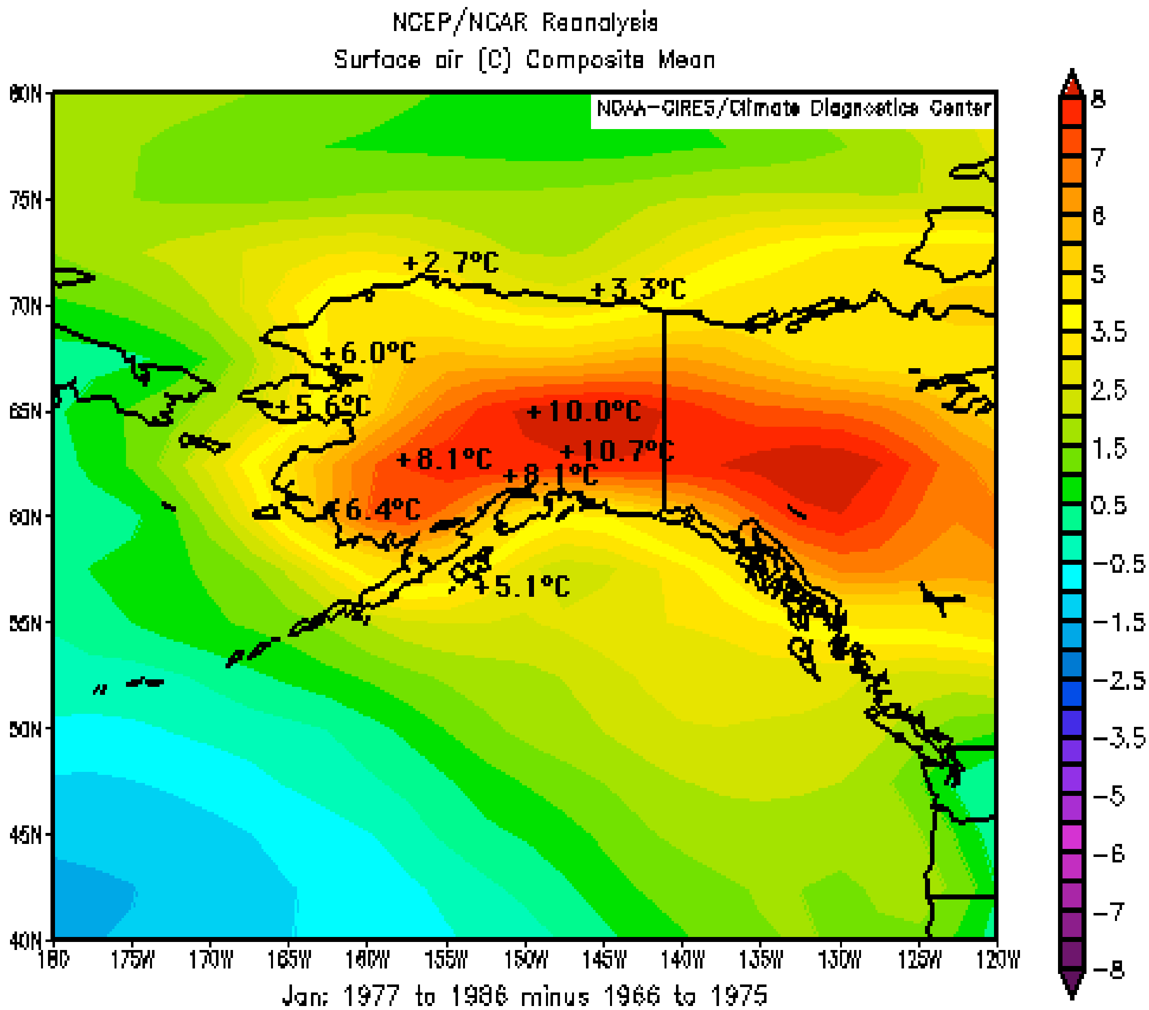


Figure 5. Change (Period 2 - Period1) in mean January temperatures from reanalysis with the observations of the surface stations inserted.

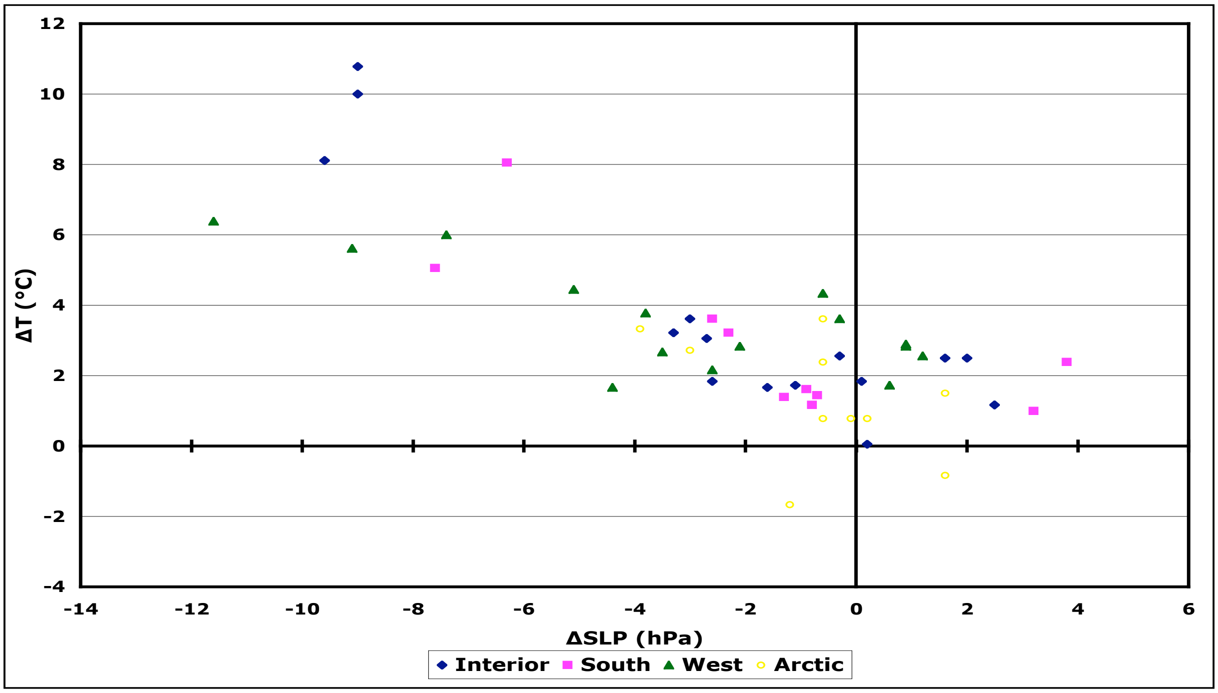


Figure 6. Scatter plot of change (Period 2 - Period 1) of mean monthly T vs. mean monthly SLP for November through March

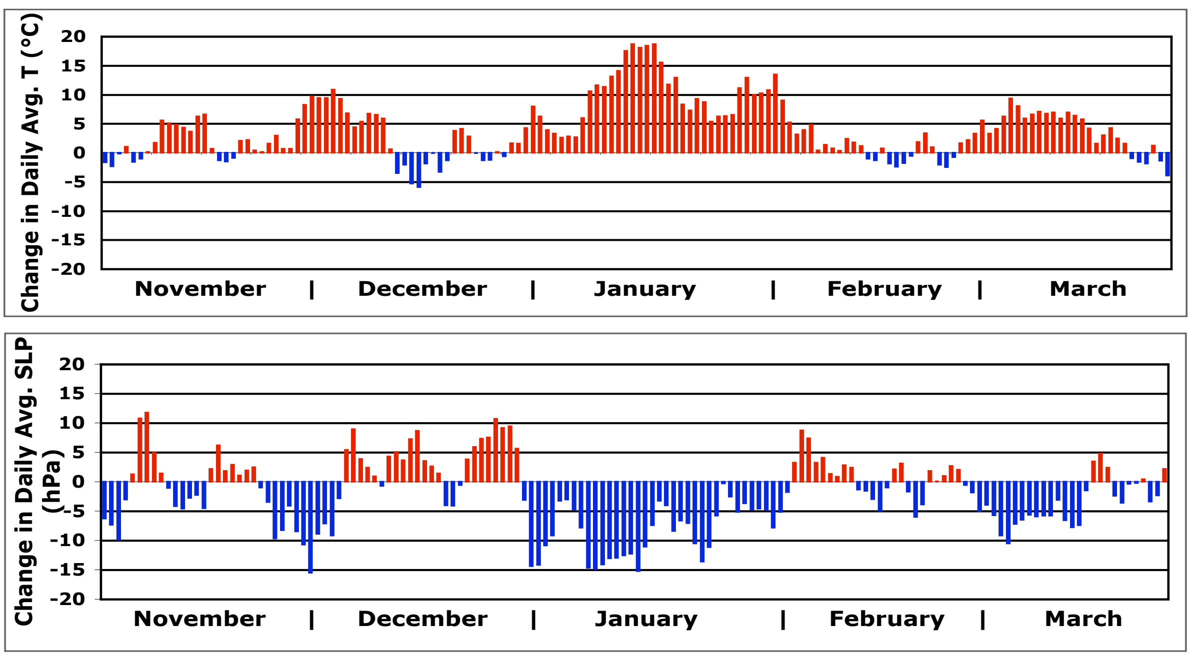


Figure 7a and 7b. a) Change (Period 2 - Period 1) in mean daily temperature at Fairbanks, November through March, b) Change (Period 2 - Period 1) in mean daily SLP at Fairbanks, November through March

However, monthly mean values lose detail, hence for one station (Fairbanks) we plotted the change (Period 2 – Period 1) in daily mean temperature and the change in atmospheric surface pressure. Each data point represents the difference of the mean of 10 values, e.g. the temperature on 1 January was averaged between 1966-1975, and for the period 1977-1986, and the difference of these two values is the temperature value for the 1 January presented in the figure. It can be seen that warm temperatures are associated with below normal atmospheric pressure, while cold spells occur when atmospheric pressure is above normal. Note the strong changes which have occurred in January.

Increases in wind speed and changes in direction during January are also to be noted. Big Delta experienced a 20% increase in winds from the east and 3% to 5% increases in winds ranging from 8 to 14 m/s. The other cold winter months saw smaller increases in easterly winds. Increases in January wind speeds at other stations follow suit with the cycle, with March wind speed increases close behind.

Table IX. Percent change (Period 2 - Period 1/(Period 1)) in mean monthly cloudiness, November through March

	Nov	Dec	Jan	Feb	Mar
ANC	+1.6%	+0.4%	**+33.9%**	-1.5%	+10.6%
ADQ	+8.8%	+2.9%	**+43.4%**	-8.7%	+7.8%
FAI	-4.6%	-9.0%	**0.0%**	-10.0%	-7.3%
MCG	+2.9%	+8.2%	**+37.5%**	-12.1%	+3.6%
BIG	+1.6%	+1.7%	**+23.4%**	+3.6%	+5.9%
BET	+3.0%	+3.3%	**+26.9%**	-13.2%	+11.1%
OME	+6.5%	+5.6%	**+9.3%**	-9.8%	-9.4%
OTZ	-6.3%	0.0%	**+10.0%**	-16.0%	-10.2%
BRW	+1.6%	0.0%	**+12.5%**	+11.4%	-2.4%
BTI	+1.6%	-10.0%	**-3.6%**	+12.8%	-2.2%

In January large changes in cloudiness were observed at many stations, as can be seen in Table IX. Anchorage, Kodiak, McGrath, Big Delta and Bethel all saw changes in cloudiness in excess of 20%. These five stations are located closest to the ocean at relatively southerly locations. Additionally, the cyclic nature of change discussed earlier again shows up, though not as strongly. February saw a decrease in cloudiness while March once again showing increases at many stations.

3. DISCUSSION AND CONCLUSIONS

The interrelation of the changes observed in different meteorological parameters displays the complexity of the atmospheric reaction to oceanic variation. Variations in the PDO Index are related to the intensity of the Aleutian Low. Above normal PDO Index values normally lead to an intensification of the Aleutian Low. This increase in cyclonic activity is accompanied by a decrease in sea level pressure, increase in the wind speed and change in its direction, as well as an increase in cloudiness. Combined, these changes have a substantial effect on the surface temperature, especially in winter. The effects of the different changing meteorological parameters on surface temperature are complex. There are at least 3 obvious connections:

1) An intensification of the circulation will advect more heat to high latitudes, at which in winter little or no global radiation is received. This could be verified by the increase in surface winds.

2) Increased heat advection also brings more moisture to high latitudes. When this water vapor condenses, clouds are formed. Increased cloud amount has a strong influence on the surface radiation budget, especially in winter, when solar radiation is weak and the IR radiation dominates the net radiation. Clouds substantially increase the IR back radiation of the atmosphere. Increased cloudiness has been observed.

3) A more positive surface radiation budget weakens the surface inversions that are very frequent in winter in Alaska. This radiatively weakened inversion can be easier destroyed by the increased circulation intensity by forced mixing, bringing the warmer air aloft to the surface. Curtis et al. (2003) showed a decrease in the inversion frequency for Barrow, Alaska.

All three above parameters will lead to increases in surface temperatures. Combined they explain the immense warming of 10°C observed in January from one decade to the next in the Interior, a value far beyond that which can be explained by increased CO_2 and other green house gases.

Acknowledgements

This research was supported through State of Alaska grant funding to the Alaska Climate Research Center and by the International Arctic Research center as part of NSF grant OPP 0002239. The insight and contributions that Martha Shulski leant to this manuscript are greatly

appreciated, and the authors would like to express their gratitude.

4. APPENDIX

A large amount of fine-scale analysis was conducted upon numerous meteorological variables throughout the course of this study. Space restraints prevent us from presenting all of them in this manuscript. The complete set of results can be accessed via our website at the URL: http://climate.gi.alaska.edu/PDO/

References

Bond, N.A. and D.E. Harrison, 2000: The Pacific Decadal Oscillation, air-sea interaction and central north Pacific winter atmospheric regimes. *Geophys. Res. Letters*, **27**, 731-734.

Bowling, S. A., 1991: Problems with the use of climatological data to detect climatic change at high latitudes. International conference on the role of the polar regions in global change: Proceedings of a conference held June 11-15, 1990 at the University of Alaska Fairbanks, Volume 1, 206-209

Curtis, J., B. Hartmann and G. Wendler, 2003: Climate Variability for Arctic Alaska. *Proceedings of the 7th Conference on Polar Meteorology and Oceanography*, Hyannis, MA, AMS, this volume.

Graham, N.E., 1994: Decadal-scale climate variability in the tropical and North Pacific during the 1970s and 1980s: observations and model results. *Climate Dynamics*, **10**, 135-162.

Hare, S.R., N.J. Manuta, and R.C. Francis, 1999: Inverse Production Regimes: Alaska and West Coast pacific salmon. *Fisheries*, **24**, 6-14.

Hare S.R. and N.J. Mantua, 2000: Empirical evidence for North Pacific regime shifts in 1977 and 1989. *Progress in Oceanography*, **47**, 103-145.

Kalnay E, and 21 co-authors, 1996: The NCEP/NCAR Reanalysis 40-year Project. *Bull. Amer. Meteo. Soc*, **77**, 437-471.

Mantua N.J., S.R. Hare, Y. Zhang, J.M. Wallace, and R.C. Francis, 1997: A Pacific interdecadal climate oscillation with impact on salmon production. *Bull. Amer. Meteo. Soc*, **78**, 1069-1079.

Miller A.J., D.R. Cayan, T.P, Barnett, N.E. Graham, and J.M. Oberhuber,1994: The 1976-77 climate shift of the Pacific Ocean. *Oceanography*, **7**, 21-26.

Namias, J., 1978: Multiple causes of the North American abnormal winter of 1976-77. *Mon. Wea. Rev*., **106**, 279-295.

Staffod, J., G. Wendler, and J. Curtis, 2000: Temperature and Precipitation of Alaska: 50 Year Trend Analysis. *Theor. Appl. Climatol*., **67**, 33-44.

Trenberth, K.E. and J.W. Hurrell, 1994: Decadal atmosphere-ocean variations in the Pacific. *Climate Dynamics*, **9**, 303-319.

Zhang, Y, J.M. Wallace, and D.S. Battisti, 1997: ENSO-like Interdecadal Variability: 1900-93. *J. Climate*, **10**, 1004-1020.