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WINTERTIME TEMPERATURE ANOMALIES IN ALASKA CORRELATED WITH ENSO AND PDO†

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ABSTRACT

Wintertime (November–March) surface air temperatures at 14 stations throughout the state of Alaska are correlated with the Southern Oscillation Index and the Pacific Decadal Oscillation index, for the years 1954–2000. On the seasonal and monthly timescales, the principal results are: (i) During El Niño winters, temperatures are near normal in western Alaska but significantly warmer than normal for the eastern two-thirds of the state. (ii) La Niña winters produce significant below normal temperatures statewide. (iii) Temperature patterns produced during El Niño, La Niña, and neutral winters are modified by the concurrent state of the North Pacific sea-surface temperature anomalies, as indicated by the Pacific Decadal Oscillation index.

On the sub-monthly timescale, temperatures across Alaska are to the first order correlated with the alternating zonal to meridional Pacific/North American pattern. Analysis of daily winter temperatures at Fairbanks indicates that cold anomalies are more frequent and are longer in duration than warm anomalies, primarily due to radiational cooling of the boundary layer and the subsequent formation of deep temperature inversions. The development of strong inversions over the interior of Alaska limits the response of temperatures to changes in the synoptic-scale flow pattern. Warm anomalies in contrast to cold anomalies, are primarily a function of warm air advection, therefore temperatures during warm anomalies fluctuate in phase with changes in the synoptic-scale flow. Ultimately, air temperatures across Alaska are a function of: synoptic-scale forcings, radiative cooling of the boundary layer as well as local and regional effects such as downslope and drainage winds. Published in 2001 by John Wiley & Sons, Ltd.

KEY WORDS: Alaska; Aleutian low; El Niño–Southern Oscillation; Pacific Decadal Oscillation; Pacific/North American pattern; temperature anomalies; temperature inversions

1. BACKGROUND

Wintertime surface air temperature anomalies in Alaska fluctuate significantly on timescales that range from 1 to 3 weeks, with an occasional event lasting in excess of 3 weeks. Due to Alaska's vast size and its position downstream of the Aleutian low, significant warm and cold temperature anomalies can occur either region wide or statewide. Watson (1974) has identified four climate regimes within Alaska (Figure 1). The majority of the state consists of either polar maritime or polar continental regimes, with an Arctic regime north of the Brooks Range. The fourth climate regime occurs in Southcentral, and is considered transitional because it separates the maritime regime to the south from the continental regime to the north. Note that throughout this paper the term 'temperature anomaly', unless specified otherwise, will signify a departure from normal temperature larger than one standard deviation for seasonal, monthly or daily data.

Over the years a number of studies have identified the fundamental circulation and climate signals that occur in the extratropical North Pacific (Rogers, 1981; Wallace and Gutzler, 1981; Douglas *et al.*, 1982;

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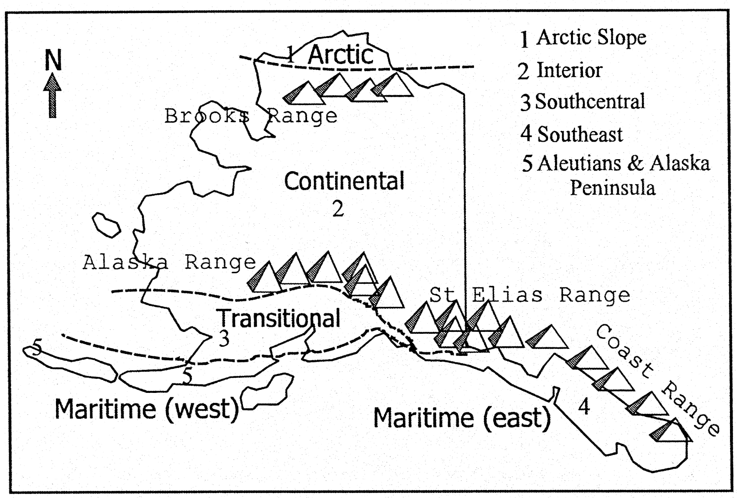

Figure 1. Climate regimes of Alaska

Trenberth, 1990; Renwick and Wallace, 1996; Mantua *et al*., 1997), and which greatly influence winter surface air temperatures (hereafter referred to as temperatures) in Alaska. The most prominent features are the El Niño–Southern Oscillation (ENSO), the Pacific Decadal Oscillation (PDO), and the Pacific/North American (PNA) pattern.

In a study of sea-level pressure and temperature differences between the Aleutian Islands and western Canada, Rogers (1981) found that when the Aleutian low was positioned near the southern tip of the Alaska Peninsula, December–February temperatures were well below normal in the Aleutians, but well above normal in western Canada. Conversely, when the Aleutian Low was located near the Kamchatka Peninsula, well to the west of its normal position, temperatures in the Aleutians were well above normal.

Rogers also found that the Aleutian Low was typically 8 hPa deeper during warm anomalies (in the Aleutian Islands), when compared to cold anomalies. An abnormally deep Aleutian low positioned over the Bering Sea advects a considerable amount of warm air over Alaska via southwesterly flow, while cold air advection occurs over most of western Canada. The 'see-saw' nature of pressure and temperature fields between the North Pacific and western North America was termed the North Pacific Oscillation (NPO). Frequency analysis showed that NPO was highly variable in time with no coherent long-term trend (Rogers, 1981).

In a study of sea-level and 500-hPa height anomalies across the Northern Hemisphere, Wallace and Gutzler (1981) helped to elucidate several teleconnection patterns (simultaneous correlations at different locations). They identified four important teleconnection pattern centres located in the North Pacific and North America. They also defined the Pacific/North American index as a linear combination of the normalized 500-hPa height anomalies at these four pattern centres. A negative index (− PNA) indicates that the flow across the eastern North Pacific and western North America is predominately zonal (with the polar jet stream typically positioned between 45° and 50°N), while the positive mode (+ PNA) occurs in association with strong meridional flow. They also found that teleconnections at 500 hPa were considerably stronger than those which occur at sea-level. The PNA pattern changes on a variety of timescales, ranging from days (baroclinic waves) to weeks (persistent planetary pattern) as a result of fluctuations in the strength of the Hadley Cell circulation, changes in the strength and position of the polar jet stream (Blackmon and Lee, 1984; Trenberth, 1990; Leathers *et al*., 1991), and possibly due to sea-surface temperature (SST) anomalies (Deser and Blackmon, 1995).

Wallace and Gutzler also found that the Aleutian low is typically 10–15 hPa deeper during positive modes of the PNA pattern. During negative modes, the Aleutian low often becomes elongated, with the primary low positioned in the central or western Bering Sea, and a secondary weaker low positioned in the Gulf of Alaska.

Klein (1985) attempted to derive a set of multiple regression equations to predict monthly temperature anomalies in Alaska and western Canada using 700-hPa heights and the previous month's temperature anomaly. His regression equations were moderately successful at predicting monthly anomalies; more importantly however, he concluded that 700-hPa height anomalies have a lower correlation with temperature anomalies when compared to similar processes that occur in mid latitudes. This results from the fact that wintertime temperatures at high latitudes are greatly influenced by persistent inversions, layers of low-level stratus clouds, as well as any snow and ice cover that may be present. Klein also found that month-to-month temperature persistence was largest in coastal climates and smallest in continental climates. Fluctuations in winter temperatures in northern North America were also studied by Diaz (1986). Using point correlation maps and principal component analysis (PCA), he found that, in general, the correlation between monthly surface temperature anomalies and monthly 700-hPa height anomalies was lowest in the spring (March–May).

In a study of short-term ENSO-like climate variation in the central North Pacific, Zhang *et al*. (1996) found that between 1977 and 1993, SSTs over a considerable part of the region had been below normal, which also corresponded with lower wintertime 500-hPa heights as well. In addition, the authors noted that the frequency of the positive mode of the PNA pattern had increased during this period, and as a result, wintertime temperatures over Alaska and western Canada had been abnormally warm.

Several studies have suggested that the Aleutian low deepens during El Niño winters (Graham, 1994; Renwick and Wallace, 1996), resulting in more persistent southwest flow into Alaska from the North Pacific, producing warmer winters over most of the state. In a study of mid-tropospheric blocking over the North Pacific, Renwick and Wallace (1996) found that the frequency of blocking episodes that occur over the central North Pacific and Bering Strait region decreases substantially during El Niño winters.

Mantua *et al*. (1997) described the correlation between the PDO and the climate of western North America. The PDO consists of a 20–30 year cycle of warm (negative mode) and cold (positive mode) SST anomalies that occur in the central North Pacific. When SSTs in the central North Pacific are anomalously cool (warm), SSTs in the Gulf of Alaska and along most of the west coast of North America are anomalously warm (cold). As a result, temperatures in Alaska are typically anomalously warm (cool) when North Pacific SSTs are anomalously cool (warm). The authors also found that the highest correlation between the PDO index and wintertime temperatures occurred in northwestern North America.

In summary, there are two distinct climate signals (PDO, ENSO) and one circulation pattern (PNA), that occur in the extratropical North Pacific and which significantly influence wintertime temperatures in Alaska. Since these three signals operate on different timescales, there should be considerable signal interference. El Niños and La Niñas, which typically have a duration of 1–2 years, are superimposed over the 20–30 year PDO signal. Likewise, both the PDO and ENSO signals modify the frequency and positioning of the PNA pattern, which operates on a timescale of days to weeks (Renwick and Wallace, 1996). Temperatures across Alaska, however, are not strictly a function of long or short-term synoptic-scale weather patterns, as this paper will demonstrate. Additional influences include 'local-effects'; for example, downslope and drainage winds, as well as intense radiative cooling of the boundary layer. Due to the interference of the two climate signals, the prevailing synoptic-scale weather pattern and associated 'local-effects', wintertime temperature patterns in Alaska display significant fluctuations on a variety of timescales.

2. PURPOSE OF STUDY

Due to the 3200 km east–west and 1700 km north–south geographic extent of Alaska, as well as the states' position downstream (east–northeast) of the Aleutian low, generalizations about the impacts of interseasonal and interannual climate variations on temperature and precipitation, which are prevalent in literature, need to be carefully examined. *The purpose of this paper is to refine the linkage of climate signals (ENSO, PDO) and the dominant circulation pattern (PNA), with wintertime surface air temperatures in Alaska. Particular attention is paid to the correlation between climate indices and temperatures.*

3. DATA CONSIDERATIONS

Data used for this study were obtained from the National Weather Service, Alaska Region, but are more easily viewed at the Western Region Climate Center website (www.wrcc.dri.edu/summary/climsmak.html). The period under investigation begins in November 1954 and extends through to March 2000. These particular years were selected because they represent the most temporal and spatially coherent climate dataset available for Alaska. Figure 2 shows the 14 climate stations used in this study. Several of these stations have climate records that date back to the early 1920s; however, prior to the mid-1950s it is difficult to obtain a comprehensive enough dataset to perform statewide analysis (Stafford *et al*., 2000).

Between 1954 and 2000, approximately 99.8% of the possible monthly station temperature records were available. During those years there were a number of station moves, and inevitable changes in temperature sensors; however, there was no attempt to reconcile these changes in this study (see Jones *et al*., 1986 for discussion). The justification for not attempting to adjust temperature data is that whatever effect station re-location and sensor changes have on the temperature record, these perturbations are small compared to the large temperature anomalies considered in this study. In cases where there were missing data, there was no attempt to interpolate using adjacent stations since outside of urban areas, climate data in Alaska are very sparse. In cases where a monthly mean temperature was missing, which for example did occur on several occasions, the seasonal mean (Nov–Mar) was constructed using 4 months of data instead of the normal 5 months.

ENSO (Philander, 1983; Rasmusson and Wallace, 1983) and PDO (Mantua *et al*., 1997) indices are described elsewhere in the literature and on the Web (www.cdc.noaa.gov/ENSO, www.bom.gov/au/climate). The most commonly used measurement of ENSO events is the Southern Oscillation Index (SOI). There are several ways to calculate this index; the one used in this study can be found online at www.wrcc.dri.edu/enso/ensodef.html. This particular index is based on the mean of the Jun–Nov values (standardized monthly SOI values can be found at ftp://ftp.cgd.ucar.edu/pub/shea/soi_dir/SOI). The SOI index does not always correspond with SST anomalies in the equatorial Pacific. For example, during the winter of 1999–2000 the SOI index pointed toward a neutral value ($+0.40$), while SSTs in the central equatorial Pacific indicated a weakening La Niña. For purposes of this study, from the winter of 1954–1955 to 1999–2000, based on the Jun–Nov average index there were 10 La Niñas ($\text{SOI} > +0.50$), 14 El Niños ($\text{SOI} < -0.50$), and 22 neutral years ($\text{SOI} \leq \pm 0.50$).

The PDO index is based on monthly SST anomalies which occur in the North Pacific, north of 20° (Mantua *et al*., 1997). The normalized values typically range from -3.00, which indicates abnormally warm water in the central North Pacific, to $+3.00$ for abnormally cool water. An index value around zero indicates near normal conditions. Once again note that SST trends along the coast of western North

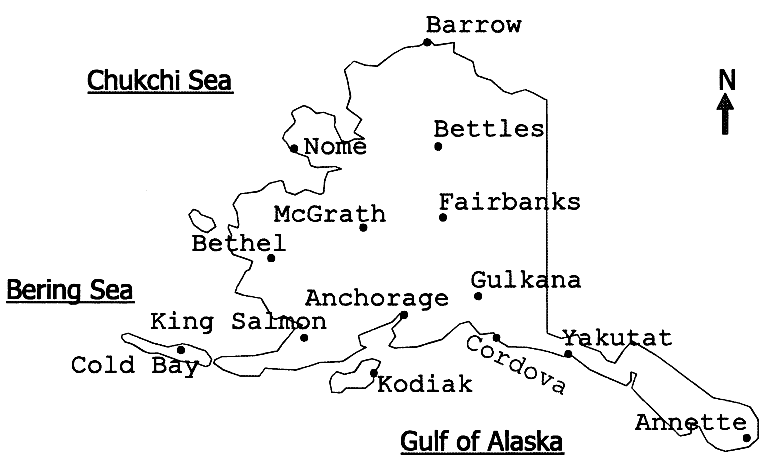

Figure 2. Location of the 14 climate stations used in this study

America, including the Gulf of Alaska, are frequently 180° out of phase with trends in the central North Pacific.

4. TEMPERATURE TRENDS

Nov–Mar mean temperatures for six stations are shown in Figure 3. Note that these plots represent four different Alaskan climate regimes. The thin line shows the seasonal average while the thick line represents a 5-year running mean. Two conclusions are immediately apparent: (i) large interannual temperature shifts are common; and, (ii) between the years of 1975 and 1977 there was a major wintertime warming across most of the state. The mid-1970s temperature increase is concurrent with a shift from a negative to positive mode of the PDO (Mantua *et al.*, 1997).

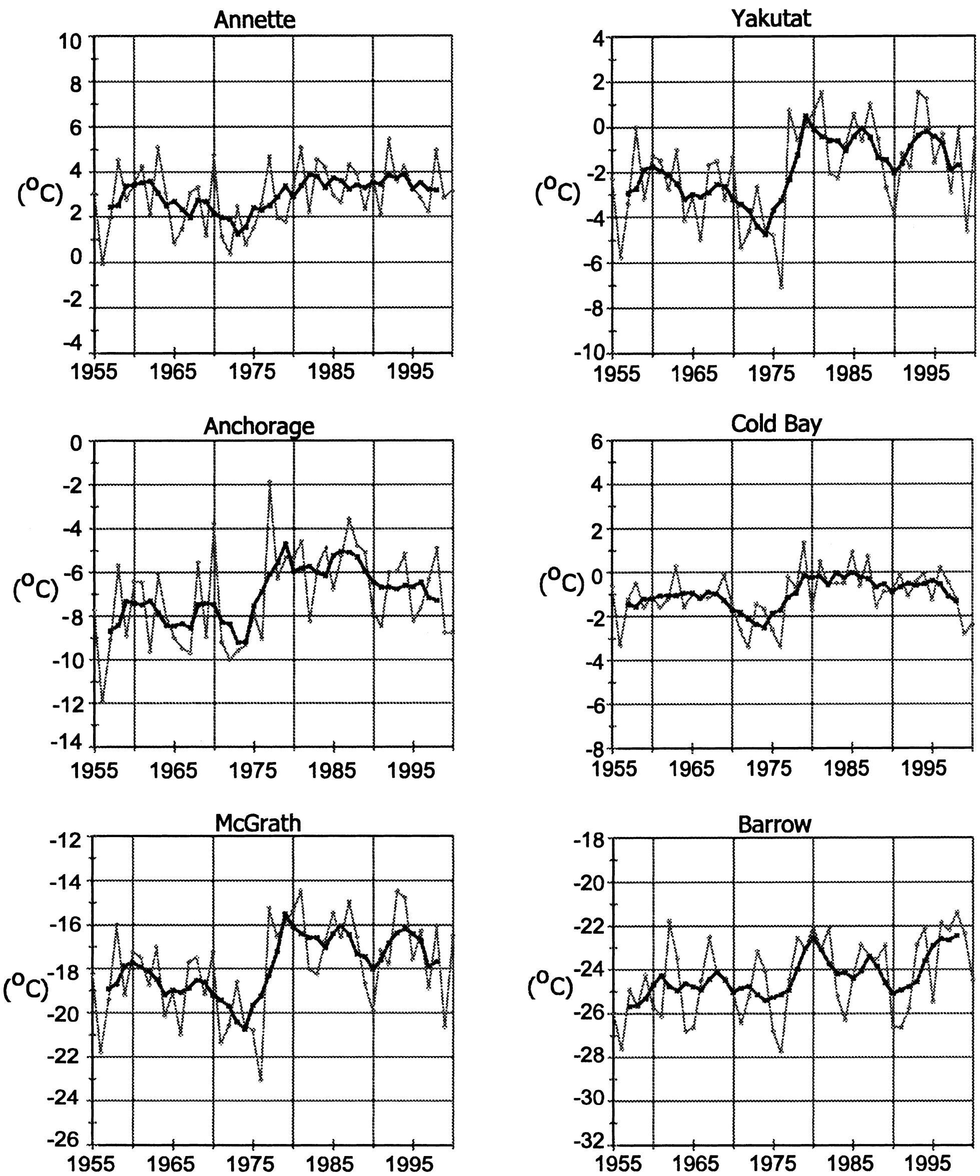

Figure 3. Mean Nov–Mar air temperatures (thin line) and 5-year moving mean (thick line)

It is noteworthy that the Arctic Slope, which is represented by Barrow, experienced a major warming between the years of 1976 and 1978 as well. Temperature data from Barter Island weather service office (not shown), which was closed in 1988, also indicate a substantial temperature increase during this same period (Stafford *et al*., 2000). This suggests that on occasions the Arctic Slope is influenced by atmosphere/ocean temperature anomalies that occur in the North Pacific and Bering Sea. Note that since 1992 temperatures at Barrow (as well as at Prudhoe Bay: a co-operative climate station which began collecting data in 1986), have once again risen substantially. Whether this is a long-term trend remains to be determined (see Kelley *et al*., 1982; for historical review Curtis *et al*., 1998).

5. INFLUENCE OF ENSO SIGNAL

In order to understand better the linkage between ENSO modes and winter temperatures in Alaska, mean Nov–Mar temperatures (1954–1955 through 1999–2000) have been correlated with the SOI index, with the results displayed in Figure 4. Two SOI indices were used: the first is based on the Jun–Nov mean, while the second uses the Nov–Mar mean. The correlation routine is based on a simple linear correlation coefficient (r), where a value of $+1$ indicates a perfect linear correlation between the SOI index and the mean Nov–Mar temperature at a given station. For each climate station a correlation coefficient with an absolute value >0.37 indicates a relationship significant at the 99% level using an F-test.

All of the coefficients in Figure 4 are negative suggesting that during El Niño winters (negative SOI indices), temperatures in Alaska are typically above normal, and conversely cooler than normal during La Niña winters. Note however that the magnitude of r at most stations indicates a low-to-moderate correlation between the value of the SOI index and the amplitude of the temperature anomaly. In addition, correlations between Nov–Mar temperatures and the concurrent Nov–Mar average SOI index are lower overall, when compared to the correlations using Nov–Mar temperatures and the Jun–Nov index. This result suggests that there is a considerable time lag between anomalies in the equatorial Pacific and subsequent anomalies that occur at higher latitudes in the extratropical North Pacific (Chen, 1982).

In order to determine the impact that each ENSO mode has on winter temperatures, departure from normal seasonal temperatures for each of the 14 climate stations are stratified according to whether they occurred during El Niño, La Niña, or neutral winters, and are displayed in Table I. Station-by-station comparison between El Niño and neutral years shows that some stations are warmer during El Niño winters, while other stations are warmer during neutral winters. Overall, stations in the western third of the state (Nome, Bethel, Cold Bay) are slightly cooler during El Niño winters as compared to neutral winters. In the eastern two-thirds of the state El Niño winters are warmer than neutral winters as indicated in Table I and Figure 5.

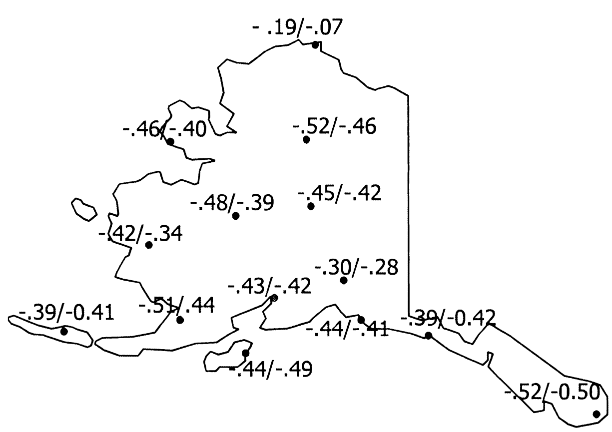

Figure 4. Linear correlation coefficients for Nov–Mar temperatures and SOI index for Jun–Nov/Nov–Mar

Table I. Mean and standard deviation (SD) of Nov–Mar departure from normal temperatures (°C) stratified by ENSO mode

Station	El Niño		Neutral		La Niña	
	Mean	S.D.	Mean	S.D.	Mean	S.D.
Barrow	+0.1	1.5	+0.5	1.5	−0.9	1.9
Bettles	+1.3	2.0	+0.4	1.9	−2.5	1.6
Nome	+0.3	1.6	+0.8	1.6	−2.3	1.4
Fairbanks	+1.0	2.5	+0.4	2.2	−2.4	1.2
McGrath	+0.7	1.9	+0.7	1.6	−2.7	1.3
Bethel	+0.2	1.7	+0.9	1.6	−2.4	1.3
Cold Bay	+0.2	0.7	+0.5	0.9	−1.3	1.0
King Salmon	+0.8	1.7	+0.8	1.8	−2.9	1.5
Anchorage	+1.1	2.1	+0.3	1.7	−1.9	1.3
Kodiak	+0.4	1.3	+0.5	1.0	−1.5	0.9
Gulkana	+0.8	2.8	+0.5	2.3	−2.1	1.4
Cordova	+0.9	2.4	+0.4	1.7	−2.1	1.3
Yakutat	+0.8	2.1	+0.3	1.8	−1.5	1.6
Annette	+0.8	1.2	+0.2	1.1	−1.5	1.0
Alaskan mean	+0.7	1.8	+0.5	1.6	−2.0	1.3

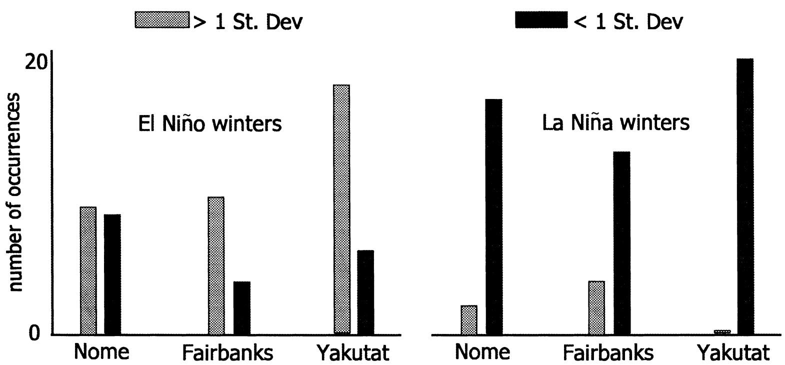

Figure 5. Number of occurrences in which the mean monthly temperature is above or below one standard deviation (1 S.D.), stratified by ENSO modes. The total number of months for: El Niño winters = 70, and La Niña winters = 50

The most notable El Niño in recent decades occurred during the winter of 1976–1977, when statewide Nov–Mar temperatures were 3.2°C above normal. The largest seasonal anomalies for this particular event occurred in Southcentral (Anchorage +5.0°C) and the Interior (Fairbanks +4.4°C). However, the months of January and February in western Alaska (Bethel +7.2°C, Nome +8.3°C), were some of the warmest on record.

La Niña winters produce significant cooling across the entire state as seen in Table I and Figure 6. Not only are the amplitudes of La Niña cold anomalies significantly larger than El Niño warm anomalies, but overall La Niña winters display considerably less variance as indicated by their smaller standard deviations. In a study of blocking episodes over the Bering Strait region, Renwick and Wallace (1996) found that 69% more days of blocking occurred during La Niña winters when compared with El Niño winters. A blocking ridge positioned over the Bering Sea or western Alaska favours cold air advection from the Russian Arctic over a large part of Alaska.

Since 22 of the winters between 1954 and 2000 are classified as neutral (Nov–Mar SOI $\leq \pm 0.50$), it is constructive to examine temperature anomalies that have occurred when the ENSO signal is weak. Statewide, mean monthly warm anomalies have a frequency around 19%, with cold anomalies near 13%.

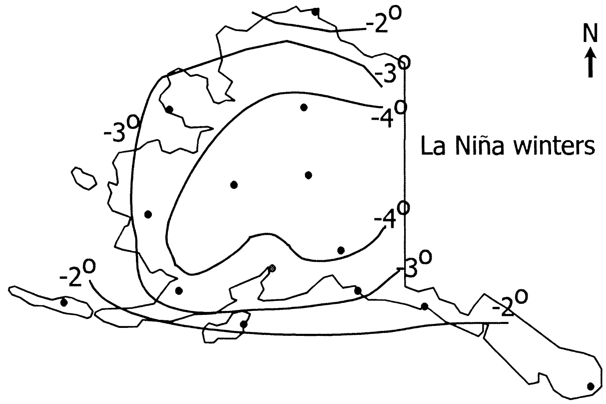

Figure 6. Mean January temperature anomaly (°C) for 10 La Niña winters between 1954 and 2000

When the frequency of monthly warm anomalies that occur during neutral winters is compared to those that occur during El Niño winters, an interesting pattern emerges. During neutral winters the frequency of monthly warm anomalies increases over southwestern and western Alaska (Cold Bay, Bethel, McGrath), and decreases over the southeast. There was no attempt to analyse mean monthly 500-hPa heights in this study; however, the temperature data do suggest that when the positive mode of the PNA does occur during neutral winters, the trough/ridge couplet that produces warm air advection is frequently positioned considerably west ($\sim 10°$ of longitude) of its 'typical' El Niño position.

6. INFLUENCE OF PACIFIC DECADAL OSCILLATION

Even though researchers have known about short-term (years to decades) climate variation in the extratropical North Pacific for three-quarters of a century (Walker and Bliss, 1932; Klein *et al*., 1960; Namias, 1978), it has only been in more recent years, as larger dataset sets have become available, that considerable effort has gone into quantifying the impacts that these variations have on the climate of North America (Trenberth, 1990; Deser and Blackmon, 1995; Latif and Barnett, 1996; Bond and Harrison, 2000). Trenberth (1990) noted that starting with the winter of 1977, which corresponded to a shift from the negative to positive mode of the PDO, and continuing at least through 1988 when his study concluded, that the Aleutian low was 4 hPa deeper and positioned well to the east of its 'normal' position. Zhang *et al*. (1996) and Mantua *et al*. (1997) found that in general, wintertime air temperatures in and near the Gulf of Alaska varied in phase with the PDO. For example, when the PDO is in a positive mode, air temperatures in and near the Gulf of Alaska are warmer than normal, and conversely they are cooler during the negative phase. In a study of 500-hPa geopotential height anomalies, Bond and Harrison (2000) found that during the positive mode of the PDO, troughs were more frequent over the central North Pacific than ridges, while ridging was favoured during the negative mode.

In order to understand the effects that the PDO has on temperatures around the state, the correlation of two different time averaged PDO indices and temperatures, is displayed in Figure 7. Interior stations have the highest correlations of any of the climate regimes within the state. There is a significant increase in correlation when the Jun–Nov index is replaced by the Nov–Mar index, with the notable exceptions of Cold Bay and Barrow. Figure 7 is in agreement with the work of Zhang *et al*. (1996) as well as Mantua *et al*. (1997), indicating that there is at least moderate correlation between the PDO signal and winter temperatures in Alaska.

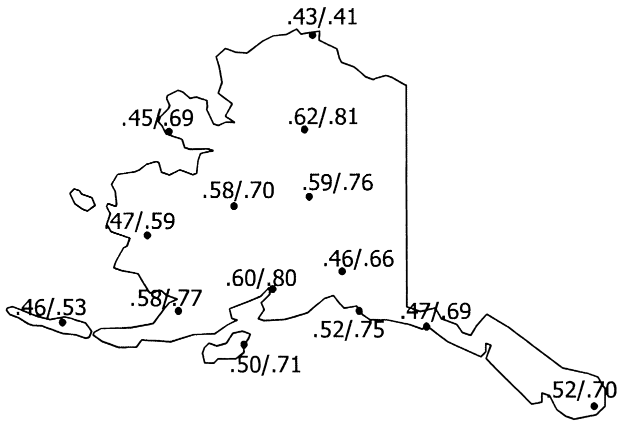

Figure 7. Linear correlation coefficients for Nov–Mar air temperatures and PDO index for Jun–Nov/Nov–Mar

7. COUPLED ENSO-PDO

Since the PDO can be considered a low-frequency varying climatic signal (duration of 20–30 years), with higher frequency ENSO events being superimposed (duration of El Niño and La Niña ~1–2 years, neutral ~1–5 years), it is probable that the impact of a given ENSO mode on temperatures, varies according to the mode of the 'background' PDO. Three of the 14 climate stations already used in this study (Nome, Fairbanks and Anchorage), have temperature records that span three modes of the PDO (1925–1946, 1947–1976, 1977–1997), while five stations span the latter two modes (Table II). Despite limited data, when Nov–Mar departure from normal temperatures (with respect to the 1954–2000 means) for El Niño events are averaged and the frequency of monthly anomalies are compiled, there is evidence that El Niños that occur during the positive phase of the PDO produce above normal temperatures, while those that occur during the negative PDO mode produce below normal temperatures.

La Niñas produce below normal temperatures regardless of the mode of the PDO. However, due to a decrease in the number of La Niñas since the mid-1970s, it is difficult to determine with any confidence whether La Niñas that occur during the negative phase of the PDO are cooler or warmer than those that occur during the positive phase.

For neutral winters which occur during the positive PDO mode (warm water along south coast of Alaska), the number of statewide monthly warm anomalies, when compared to the frequency of occurrence during negative PDO, increases two-fold while the number of cold anomalies is approximately

Table II. El Niño anomalies (°C) stratified by PDO mode[a]

	+PDO (1925–1946)			−PDO (1947–1976)			+PDO (1977–1997*)		
	(°C)	Cold	Warm	(°C)	Cold	Warm	(°C)	Cold	Warm
Nome	+1.2	13	24	−0.4	19	14	+0.9	7	22
Bettles	NA	–	–	−0.2	20	10	+1.9	9	22
McGrath	NA	–	–	−1.4	21	11	+1.7	10	24
Fairbanks	+1.1	17	25	−0.8	26	12	+2.2	9	21
Bethel	NA	–	–	−0.7	23	8	+0.9	8	22
Anchorage	+1.6	13	20	−1.1	30	8	+1.7	11	23
Yakutat	NA	–	–	−0.5	26	9	+1.3	12	22
Annette	NA	–	–	+0.1	25	10	+1.0	11	23

[a] Cold and warm columns indicate the number of monthly anomalies that occurred during the given time period.
* Note: a possible shift in the PDO occurred in 1997.

halved. These results are similar to the findings listed in Table II, in which El Niños that occur during positive PDO, are warmer than those which occur during a negative PDO.

Additional insight into seasonal temperature patterns can be obtained through the use of principal component analysis (Kutzbach, 1967; Richman, 1986; Jolliffe, 1990). Figure 8 shows the coefficients of the first two principal components (PC), which account for 86% of the variance. The data used to construct Figure 8 are based on the mean Nov–Mar (1954–2000) departure from normal temperatures (covariance matrix) for the 14 climate stations used throughout this study. There was no attempt made to interpolate station values to a uniform grid (Karl *et al.*, 1982), since these stations are approximately evenly spaced across the state. The first PC (Figure 8(a)) 'explains' 71% of the dataset variance and indicates that the amplitude of temperature anomalies at Interior stations is considerably larger than for stations along the coast. The second PC (Figure 8(b)) implies that a large part of the remaining variance is due to very significant east–west differences across the state. For example, when a temperature anomaly occurs in the southeast or eastern part of the state, frequently a concurrent anomaly of the opposite sign occurs in the western third of the state.

8. MONTHLY TEMPERATURE SHIFTS

On occasions there are large month-to-month shifts in temperature anomalies in Alaska, of which five examples have been displayed in Table III. These values were generated by calculating the mean monthly

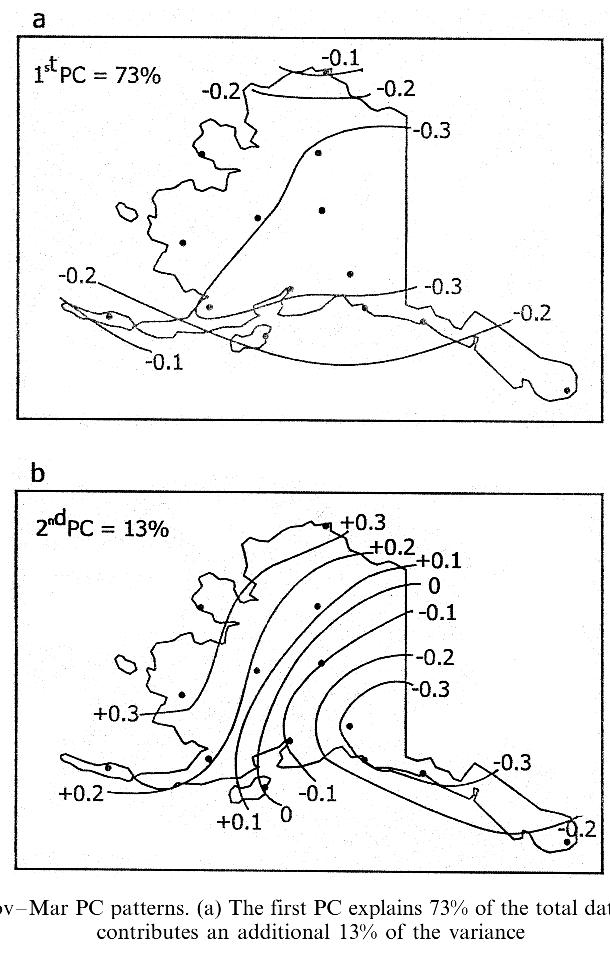

Figure 8. Coefficients of the Nov–Mar PC patterns. (a) The first PC explains 73% of the total dataset variance. (b) The second PC contributes an additional 13% of the variance

Table III. Month-to-month statewide temperature (°C) shifts

Feb 1965	−4.7	Mar 1965	+5.1				
Dec 1969	+5.1	Jan 1970	−3.8	Feb 1970	+4.2		
Dec 1980	−5.3	Jan 1981	+9.0	Feb 1981	+2.8		
Jan 1985	+8.3	Feb 1985	−2.3				
Nov 1988	−2.5	Dec 1988	+2.8	Jan 1989	−5.8	Feb 1989	+3.5

departure from normal temperature for each of the 14 climate stations. Spatial averaging smooths the data, masking some very large station anomalies. For example, in December 1988 McGrath had an anomaly of +7.6°C, which was followed in January 1989 by an anomaly of −10.8°C. Temperature anomalies are, of course, not restricted to periods of a month in length; however, monthly statistics make for convenient statistical analysis.

Inspection of month-to-month temperature shifts indicates a wide spectrum of responses: in some cases the entire state experiences a large anomaly, while others only have a regional impact. For example January 1996 was a very cold month for stations in the eastern half of the state, while temperatures were near normal in western Alaska. In January 2000, temperatures in western Alaska were well below normal while the rest of the state was near normal. In February of that same year, monthly mean temperatures were one to two standard deviations above normal for all of Alaska south of the Brooks Range. Interior climate stations typically have anomalies that are two to three times larger in amplitude than maritime stations, primarily due to radiational cooling and the lack of an oceanic influence.

In order to gain an understanding of rapid shifts in large temperature anomalies that occasionally occur, case studies of the December 1980 cold anomaly and the January 1981 warm anomaly are briefly presented. Mean sea-level pressure and 500-hPa heights for these 2 months are displayed in Figure 9. In December, the surface low was further southeast than normal, allowing cold air to move into the state from the north–northwest. At 500 hPa, the low centre was positioned to the south of the Aleutian Islands.

During January in contrast, the surface low was about 8 hPa deeper than in December and was centred over the eastern Aleutians. The mean position of the 500-hPa trough was near the Kamchatka Peninsula, well to the west of its December position. The westward relocation of the low centre from December to January produced a large amount of warm air advection in Alaska.

At 300 hPa the mean position of the polar jet stream during the month of December was well to the south of Alaska (not shown). In fact the jet entered North America through British Columbia. In January, the jet moved northward and was on average positioned directly over Alaska and the Yukon Territory; in large part due to a persistent ridge of high pressure that was located over western North America. The contrast in flow patterns from December to January is what one would expect with a major shift from the negative to positive mode of the PNA pattern. Departures from normal temperatures at Fairbanks for each day during the winter of 1980–1981 are shown in Figure 10. Except for the cold anomaly that occurred between 5 and 30 December, this was a particularly warm winter. A fundamental question that must be addressed is: are these large shifts in temperatures in anyway related to changes or trends in either the ENSO or PDO signals? Table IV shows the trends of both the SOI and PDO indices for the months leading up to and during the winter of 1980–1981. The SOI index for the summer/autumn leading this winter was −0.38 (neutral) while the PDO was in a weak positive mode. There is evidence of a temporary shift in the sea-level pressure pattern in the equatorial Pacific (SOI) as well as in SSTs in the central North Pacific (PDO) during the months of December and January. Understanding how the temporary monthly 'shifts' in these indices are linked to the December versus January temperature anomalies, remains a topic of discussion and future work (Trenberth, 1990; Bond and Harrison, 2000).

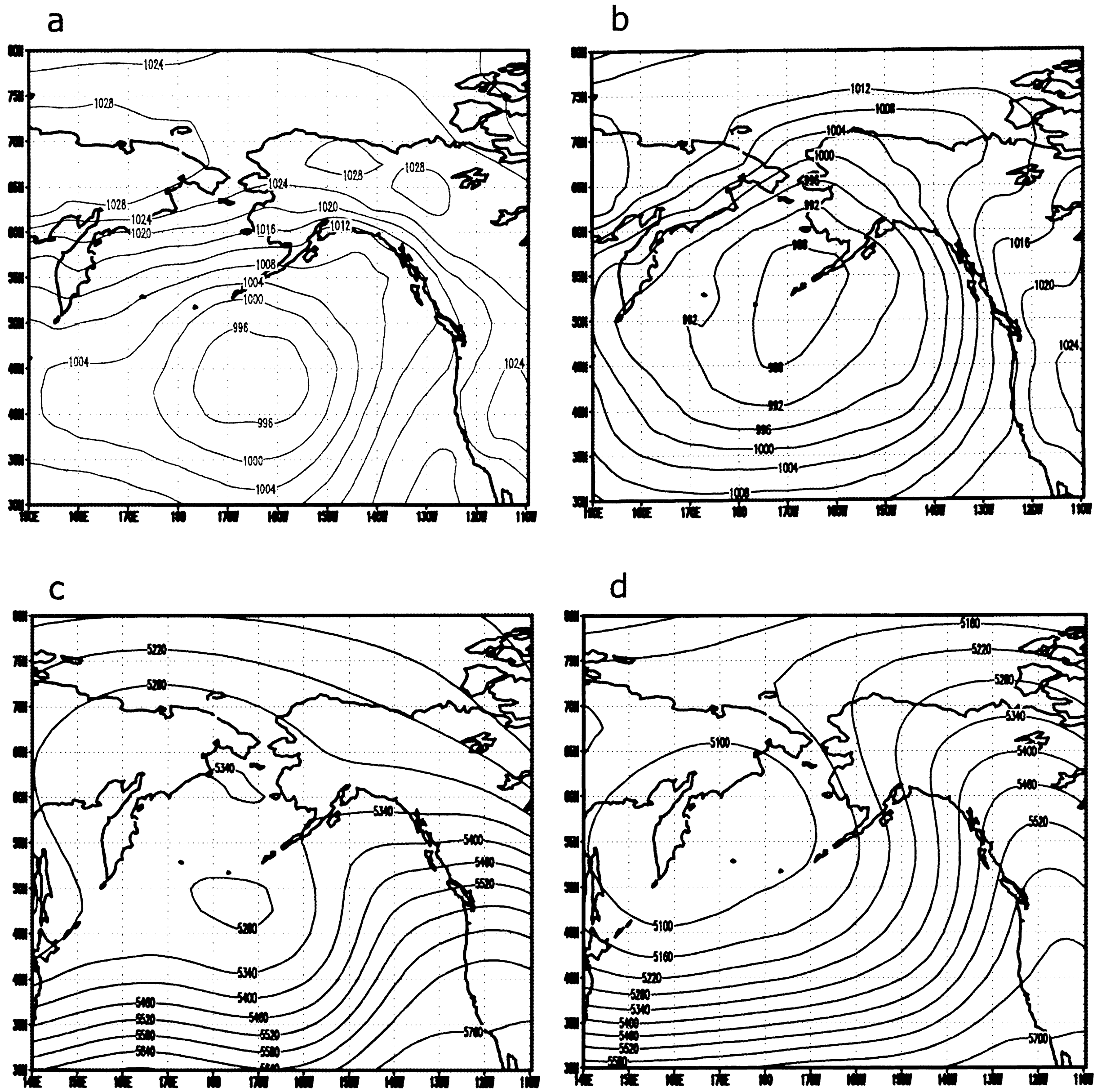

Figure 9. Monthly mean sea-level pressure for: (a) December 1980; (b) January 1981, contour interval of 4 hPa. Monthly mean 500-hPa heights for: (c) December 1980; (d) January 1981, contour interval of 60 m. (From NCEP/NCAR reanalysis provided by the Climate Diagnostic Center www.cdc.noaa.gov)

9. DAILY TEMPERATURE ANALYSIS

In order to understand better sub-monthly temperature anomalies, daily mean temperatures, standard deviations and departures from normal were calculated for all days between 1 November and 31 March at Fairbanks and Yakutat, for the 1954–2000 period. These particular stations were selected because Fairbanks is representative of the central Interior, while Yakutat represents the maritime (east) regime. The seasonal mean standard deviation for daily temperatures is approximately 8.3°C at Fairbanks and 4.7°C at Yakutat. As a result, daily warm and cold anomalies (warm and cold days) are defined as a daily departure from normal of $\geq \pm 8.3$°C for Fairbanks and $\geq \pm 4.7$°C for Yakutat.

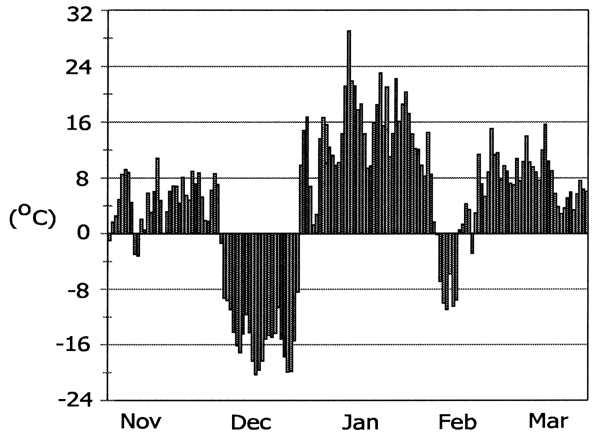

Figure 10. Departure from normal temperatures (°C) at Fairbanks during November 1980–March 1981 period

Table IV. June 1980–March 1981 climate indices

	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar
SOI	−0.7	−0.4	0.0	−0.9	−0.4	−0.8	−0.5	0.4	−1.0	−3.4
PDO	−0.2	0.2	0.5	0.1	1.4	0.4	−1.0	0.6	1.5	1.0

Table V shows the mean number of cold and warm anomaly days per winter season at Fairbanks and Yakutat, stratified by ENSO mode. It is interesting to note that the reason El Niño winters are on average warmer than neutral winters (compare with Table I and Figure 5), is because of a reduction in the number of cold anomaly days during El Niño winters, while the number of warm anomaly days remains virtually unchanged. Closer inspection of the data shows that the number of days where the daily mean temperature is above normal but less than one standard deviation above normal, increases during El Niño winters compared to neutral winters. Therefore, monthly and seasonal mean temperatures are higher during El Niño winters than during neutral winters, but the number of anomalously warm days does not increase significantly from neutral to El Niño winters.

As Table V indicates, there are major differences between La Niña winters and neutral winters. The number of cold days increases substantially at both Fairbanks and Yakutat during La Niña winters, while the number of warm days, although they still occur, are greatly reduced. The ratio of cold anomaly days to warm anomaly days is of the order of 2.6:1 at Fairbanks and 3.8:1 at Yakutat.

The 1954–2000 daily departure from normal temperature dataset for Fairbanks and Yakutat indicates that 27% more cold anomaly days occurred at each station than warm anomaly days. In addition, the number of consecutive days that can be classified as being anomalously cold is considerably larger than warm anomalies. For example, at Fairbanks there were 32 cold anomalies with a duration of at least 10 days between the years of 1954 and 2000 (16 events at Yakutat). During the same period, there were 15

Table V. Mean number of cold and warm anomaly days stratified by ENSO mode

	Fairbanks		# years	Yakutat	
	Cold	Warm		Cold	Warm
El Niño	23	26	14	20	26
Neutral	30	27	22	25	23
La Niña	46	18	10	42	11

Table VI. Standard deviations of heights and surface air temperatures during five cold and five warm temperature anomalies

	700 hPa (m)	500 hPa (m)	Temp (°C)
Yakutat			
Cold	70	88	2.2
Warm	61	76	1.4
Fairbanks			
Cold	117	138	2.8
Warm	66	74	3.2

warm anomalies with a duration of 10 or more days (six events at Yakutat). If Fairbanks and Yakutat are representative of their respective climate regimes, then there is a significant increase in the frequency and duration of cold anomalies statewide, when compared to warm anomalies, despite the occurrence of fewer La Niñas (10) then El Niños (14). This result indicates that winter temperatures in Alaska are influenced by considerably more than synoptic-scale flow patterns.

In their study of blocking episodes over the North Pacific during varies ENSO modes, Renwick and Wallace (1996) found that 10–30 day bandpass 500-hPa height variances were considerably larger during La Niña winters when compared to El Niño winters. To gain further insight into the influence that mid-tropospheric height changes have on surface temperatures, standard deviations of 700- and 500-hPa heights during five cold and warm anomalies at both Fairbanks and Yakutat were analysed in the current study. These 10 anomalies were selected at random; however, the minimum requirements were that the mean daily departure from normal temperature be $\geq \pm 8.3$°C at Fairbanks and $\geq \pm 4.7$°C at Yakutat, for a minimum of 10 consecutive days. The results are shown in Table VI. The most noteworthy result is that both the 700- and 500-hPa height standard deviations at Fairbanks during cold anomalies are approximately twice as large as what occurs during warm anomalies. However, the standard deviation of surface air temperatures is slightly smaller for cold anomalies. This result implies that due to intense radiational cooling of the boundary layer, once a cold anomaly forms, surface air temperatures become to a large degree invariant to all but the largest fluctuations in the mid-tropospheric flow pattern (Klein, 1985). This is not, however, true for warm anomalies, which are a direct function of the mid-tropospheric pattern. In fact many warm anomalies in the Fairbanks region, occur in conjunction with downsloping winds from the Alaska Range (southerlies). It should also be noted that frequently at the conclusion of a cold anomaly, there is a 2 or 3 day lag period from the start of a large synoptic-scale pattern shift, to the dissipation of the inversion and a significant warming at the surface. Lag periods are a function of the depth and strength of the inversion, as well as the ability of lower tropospheric winds to produce substantial mixing.

At Yakutat, in contrast to Fairbanks, there is minimal difference in the standard deviations of the heights between cold and warm anomalies, although a noticeable temperature difference. During warm anomalies the flow is predominately from the south; this maritime influence produces very consistent temperatures over Yakutat. During cold anomalies, however, low-level flow frequently consists of drainage winds emanating from the St. Elias Mountains to the north. These winds produce larger temperature deviations as they change direction and speed over Yakutat Bay. Inversions do form over Yakutat during cold anomalies; however, they are not as strong or persistent as those that form in the Interior.

10. CONCLUSIONS

Seasonal and sub-seasonal temperature patterns and anomalies in Alaska are essentially a function of three elements: (i) the state of the North Pacific climate signals (ENSO, PDO); (ii) the specific PNA pattern (polar jet stream) that dominates over a given time period, and; (iii) what might be termed ‘local effects', which include radiative cooling and local winds (downslope, drainage). The superimposition and interaction of these elements is what is responsible for producing the very broad spectrum of temperature responses across the state.

When wintertime temperatures are stratified by ENSO modes, El Niño winters in the western third of the state (west coast, Kuskokwim Basin, Aleutian Islands, and southern half of the Alaska Peninsula) are frequently cooler than neutral winters, while the remaining two-thirds of the state is generally warmer than neutral winters. This is especially true in the Southeast, where the frequency of warm monthly anomalies during El Niños is two to three times that of cold anomalies. Due to the superimposition of El Niños on the background PDO signal, El Niños that occur during the negative PDO mode typically produce cooler temperatures than those that occur during the positive PDO mode. La Niña winters produce below normal temperatures across the entire state. The amplitude of temperature anomalies is largest in the Interior where the oceanic influence is minimal, and radiational cooling is large.

North of the Brooks Range the impact of the ENSO signal appears to be weak overall. This does not mean that El Niños and La Niñas have no influence on temperatures over the Arctic Slope. At Barrow for example, of the 14 El Niños that occurred during the period under investigation, two produced significant warm anomalies and one produced a significant cool anomaly, while the remaining 11 events had little influence on temperatures. Significant cold anomalies have occurred during four La Niñas, with one warm anomaly occurring during the La Niña of 1998–1999.

There is low-to-moderate correlation between temperatures and the leading (Jun–Nov) PDO indices; however, when the concurrent PDO indices are used, the correlation increases substantially across most of the state. This result suggests that SST anomalies that occur in the central and northern North Pacific have a large influence on winter temperatures in Alaska. SST anomalies directly influence seasonal temperatures in coastal zones due to the large heat capacity of the ocean. They indirectly influence seasonal and sub-seasonal temperatures throughout the state, by regulating the dominate flow patterns (higher frequency of $+$PNA during $+$PDO) and subsequent synoptic-scale advection.

On the sub-monthly timescale, the statewide temperature pattern at any given time is in part a function of the position of the surface and mid-tropospheric low (trough) centres. When the flow pattern shifts from zonal ($-$PNA) to meridional ($+$PNA), the low centre frequently becomes anchored over the central or eastern Gulf of Alaska (145–140°W). This produces warm advection over Southeast, Southcentral and the eastern half of the Interior, but cold advection over the western third of the state. In contrast, when the low centre is positioned near the Alaska Peninsula (160°W), warm advection typically occurs statewide, with the possible exception of the Southeast.

Cold anomalies over the central Interior are more frequent and are longer in duration than warm anomalies, in large part due to radiational cooling and the subsequent formation of deep temperature inversions. The presence of strong inversions over the Interior limits the influence that mid-tropospheric pattern changes have on surface air temperatures across the region.

Modest skill in seasonal (wintertime) temperature forecasting should be possible at the beginning of winter using both the summer/autumn SOI index and the autumn PDO index. However, due to low-to-moderate correlation between either one of these two indices and temperature anomalies, the magnitude of the indices cannot be used to predict the amplitude of the subsequent temperature anomaly via regression equations.

With respect to climate signals, the highest degree of seasonal predictability occurs during La Niñas that are concurrent with the negative mode of the PDO. This is a result of the increase in frequency of negative PNA pattern (zonal) during negative modes of the PDO (Bond and Harrison, 2000). The combination of climate signals that produces the lowest predictability is more difficult to establish due to the highly variable nature of the PNA pattern during El Niño and neutral winters.

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