An Analysis of the Classic Arctic Outbreak Event of Late December 2008-Early January 2009

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The 2008-2009 winter was characterized by colder than normal temperatures and above normal snowfall for each month from October through March. While there was no one significant snow event that overshadowed any other this past winter, a bitterly cold Arctic outbreak that persisted for more than two weeks brought the coldest temperatures in a decade to the Anchorage area, and grabbed headlines around the world for extreme cold in interior parts of the state. This analysis will show how the outbreak developed and how it was able to persist for a prolonged period of time.

1. Summary of temperatures and records from the outbreak

The following table is a breakdown of temperatures and extremes at Anchorage during the two week Arctic outbreak.

Date	Maximum Temperature	Minimum Temperature	Departure from Average
25-Dec	16	7	-5
26-Dec	17	9	-4
27-Dec	15	9	-5
28-Dec	10	-3	-12
29-Dec	3	-10	-19
30-Dec	-1	-10	-21
31-Dec	-3	-12	-23
1-Jan	-1	-15**	-24
2-Jan	-7	-16**	-27
3-Jan	-6*	-16**	-27
4-Jan	-6	-18**	-28
5-Jan	0	-15	-23
6-Jan	-6*	-14	-26
7-Jan	-10	-19**	-30
8-Jan	4	-16	-22
9-Jan	3	-9	-19
10-Jan	3	-11	-20
11-Jan	9	-5	-14
12-Jan	19	8	-1
13-Jan	28	16	+7

*-Indicates a record low value for that particular date.
**-Indicates tying or setting of the lowest temperature of this decade (2000-2009).

Though it is arbitrary as to when the outbreak began and ended based on the numbers, the temperature at Anchorage dropped below zero degrees during the evening hours of December 29th, and remained below zero until January 8^{th} except for a one-hour period during the afternoon of January 5^{th} when the temperature managed to make it to 0.4 degrees briefly during the mid afternoon hours. This represented the longest streak of sub-zero days since 30 January – 5 February 1999.

Additionally, the eleven-day streak (29 Dec – 8 Jan) with the minimum temperature falling to -10 degrees or lower from the official reporting station at the National Weather Service office on Sand Lake Road was the longest such streak since 17-29 December 1961. Therefore, while there were no record low minimum temperature values set at the official temperature station in Anchorage, the duration of the cold in terms of minimum temperatures at or below -10 degrees was the longest such stretch in 47 years.

2. Analysis

a.) Mid-tropospheric height composite analysis

To understand the origins of this Arctic outbreak in Alaska, it is usually a good idea to look at mid-tropospheric heights, specifically at 500 millibars (mb). [The troposphere is the lowest layer of the Earth's atmosphere, and where most of what we call weather occurs. The stratosphere is the layer of the atmosphere above the troposphere which is usually characterized by dry, clear, and stable weather conditions ranging from ~6-50 km above the surface of the Earth in northern latitudes.] We use the height field to tell us where planetary waves (i.e., troughs and ridges) are located and their strength and orientation, as well as where winds are blowing surface low and high pressure systems that affect our day-to-day weather. Winds well above the surface at the mid-troposphere level blow parallel to the height contours, with highest heights to the right and lower heights to the left of the wind direction. Also, the stronger the height contours are packed together in close proximity, the stronger the winds.

For this particular outbreak, the atmospheric wave pattern underwent a significant change in late December from a less amplified pattern to a highly amplified blocking pattern across the higher latitudes of the Northern Hemisphere. A look at mid-tropospheric geopotential heights and anomalies (Images 1 and 2) averaged over the period from 27 December 2008 – 11 January 2009 shows that ridges in the wave pattern were located to the west of Alaska over eastern Siberia and to the east of Alaska from northeastern Canada through Greenland and into northwestern Europe. A deep trough was located along the Alcan border area extending into northwestern Canada. Notice how the two ridges extending towards each other from opposite sides of the hemisphere forced the lowest heights with respect to normal to the south into northwestern North America. This is typical for most Arctic outbreaks, as otherwise the Arctic air mass would be modified by warmer sea surface temperatures if it originated from any other direction.

The reason why a trough in the atmosphere aloft almost always means colder temperatures near the surface is because the average temperature of any vertical column of air is dependent on its vertical thickness. For instance, if a ridge aloft moves overhead, the thickness of a vertical column of air between the top of a specified layer of air in the middle troposphere and the ground will increase, thus meaning that the average temperature of that layer must also increase. A trough overhead means that the thickness between the same given layer of the troposphere and the ground must decrease, meaning the average temperature of that layer must also decrease. Other parameters such as the amount of cloud cover, winds, and solar radiation also play key roles in determining the temperature at any one time at the *surface*, however. Mostly clear skies with calm winds and a lengthy period of darkness such as frequently experienced in Alaska during meteorological winter, as well as a deep upper low or trough directly overhead (to eliminate pressure gradients and thus winds), usually results in very cold temperatures due to strong radiational cooling.

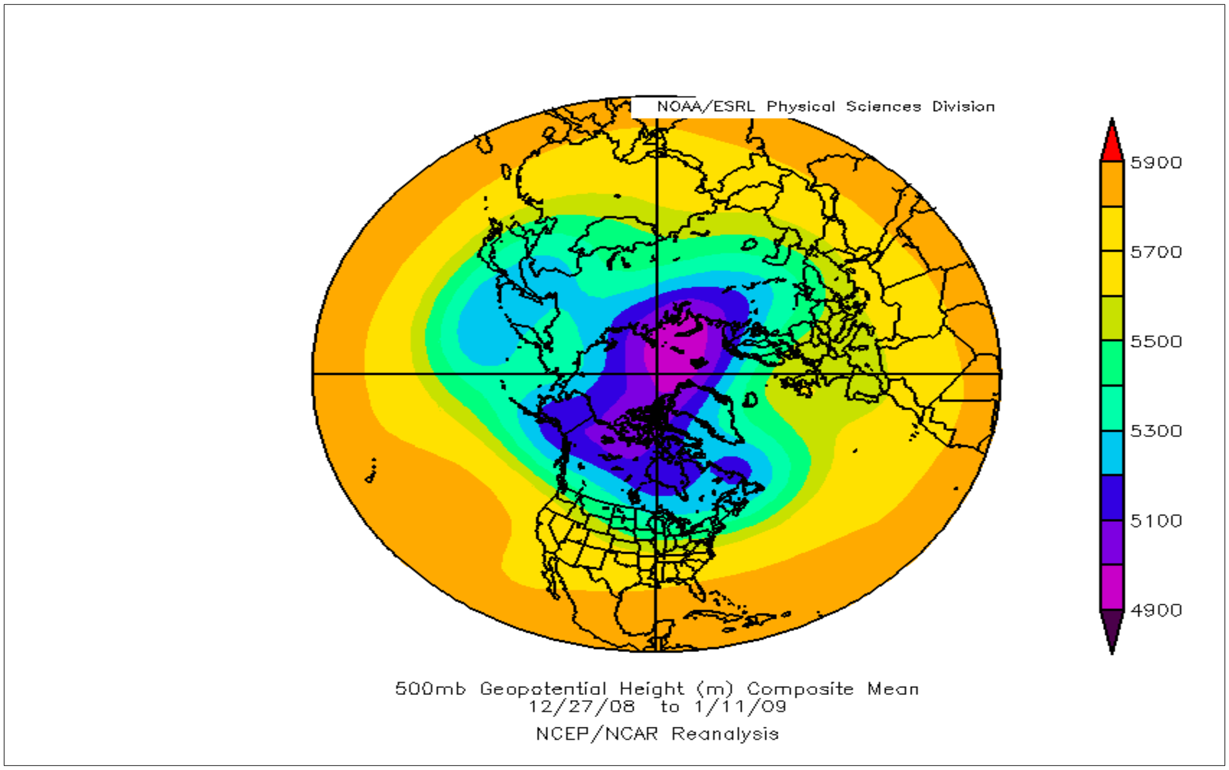

Image 1. Mid-tropospheric geopotential heights showing the Northern Hemispheric atmospheric wave pattern averaged across the outbreak period, from 27 December 2008 – 11 January 2009.

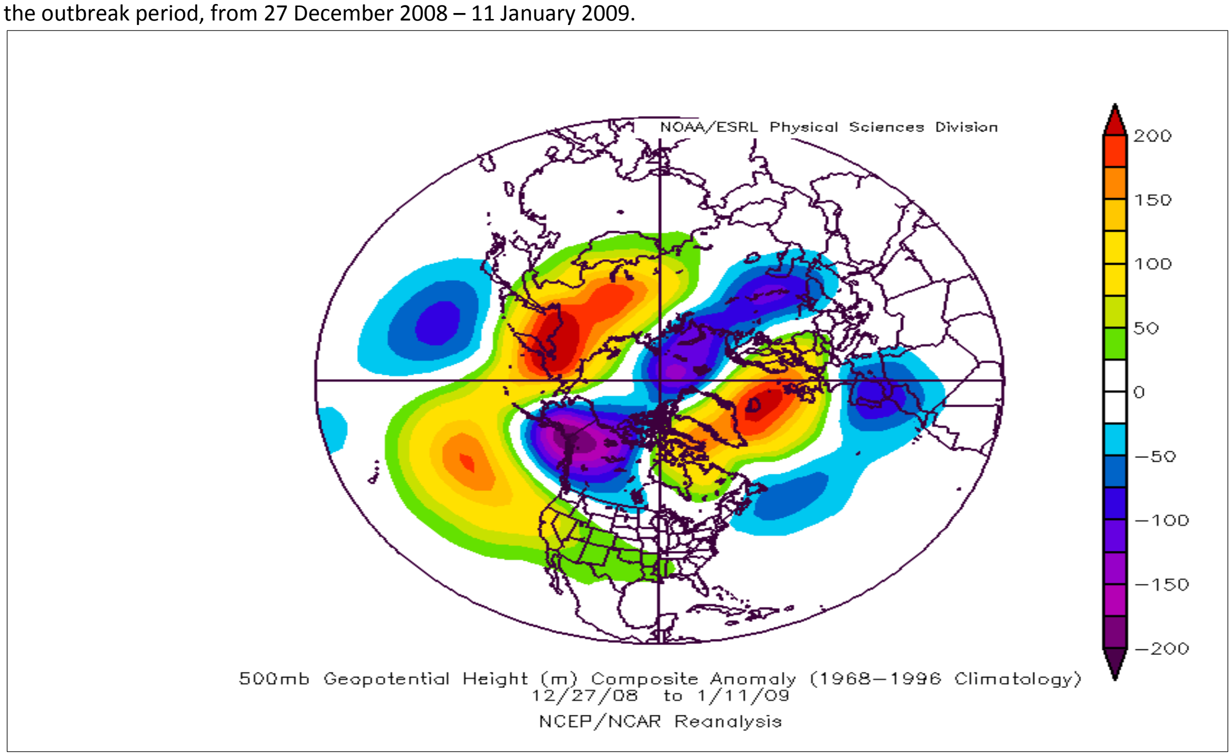

Image 2. Mid-tropospheric geopotential height anomalies based on climatology from 1968-1996 for the outbreak period.

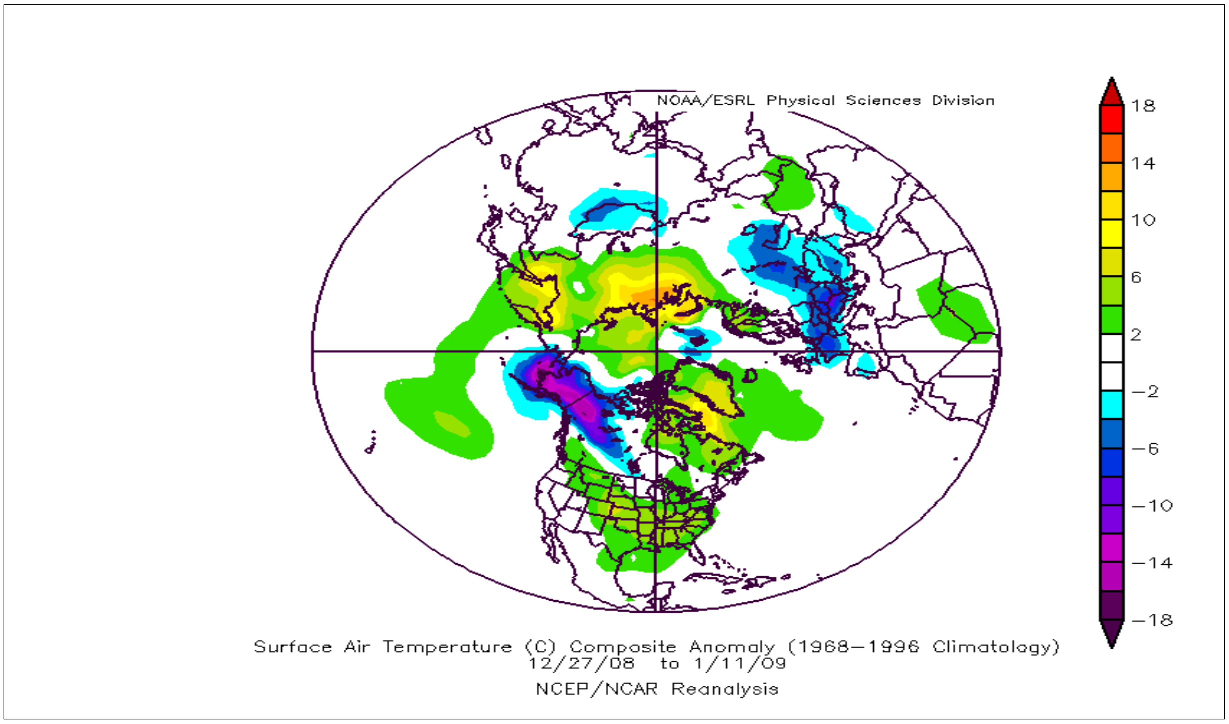

Image 3. Northern Hemispheric temperature (in degrees Celsius) composite anomalies averaged over the outbreak period showing southern Alaska and northwestern Canada experienced the coldest anomalous temperatures in the entire Northern Hemisphere. To obtain the anomalies in degrees Fahrenheit, multiply by 1.8.

3. The Role of the Stratosphere in Classic Arctic Outbreaks in southern Alaska

a.) Background Material

As we are all aware, the polar regions of the globe experience the least amount of direct sunlight throughout the year due to the Earth's tilt on its axis and its nearly spherical shape. This allows for reflection of solar radiation back into space by the atmosphere, especially during the winter months when the sun is at an extremely low angle and daylight exists for less than a third of the day. Optimal radiational cooling also exists due to the existence of semi-permanent ice caps in the Arctic region and seasonal snow and ice cover as well as the lack of solar radiation to offset radiation given off by the Earth itself. This results in the polar regions (Arctic and Antarctic) being the coldest locations on Earth.

Because the coldest geographic regions on Earth are found at the poles, it makes sense that the lowest atmospheric pressure for each hemisphere will also be found at the poles. This means that as one travels from the North Pole to the Equator in a straight line, the pressure will increase as latitude decreases. Thus, there is a semi-permanent low at the poles aloft (sometimes called the polar vortex), and semi-permanent ridging near the equator in the upper levels of the atmosphere. This difference in pressure, combined with the Earth's rotation on its axis, produces wind, which is the primary parameter responsible for transporting weather patterns around the globe.

Because of the Earth's rotation and what is known as the Coriolis Effect, we know that the wind flows in a counter-clockwise manner around the polar vortex in the Northern Hemisphere. Thus, planetary waves are transported in a west-to-east manner by the jet stream, moving weather fronts and low pressure systems that are responsible for producing most of the unsettled weather that occurs outside of the tropical regions. Research by authors has been able to show that the polar vortex varies in strength and orientation from day-to-day and even season-to-season as well, which affects the nature of the hemispheric tropospheric wave pattern and can play a large role in what regions experience the coldest temperatures, especially during the winter season. For instance, a very strong and small polar vortex will confine very cold Arctic air over the North Pole, thus allowing for warmer temperatures from the tropics to move northward into the mid-latitudes and even sometimes into the Sub-Arctic (which is where most of Alaska south of the Arctic Circle resides). A larger, yet weaker polar vortex allows for cold air to be transported out of the Arctic into the sub-Arctic and mid-latitudes and can result in bitter cold temperatures across parts of the landmasses in those regions, yet milder conditions in the Arctic and sometimes Sub-Arctic regions.

Occasionally, before the polar vortex moves back towards the Arctic near the North Pole, a slight strengthening of the vortex occurs resulting in the coldest periods of an outbreak, frequently producing record low temperatures. These episodes usually only last a few days, and many times occur just before a pattern change takes place, though not always. The following section will take a detailed look at the coldest period of the outbreak in early January to examine how the stratosphere played an important role on temperatures near the surface.

b.) Recent Research

Much research has been conducted over the last couple of decades as to how planetary waves can influence, and be influenced by, waves in the stratosphere. Some authors (Baldwin and Dunkerton, 1999; Perlwitz and Harnik, 2004; Thompson et al., 2006) have suggested that middle and upper stratospheric zonal-mean zonal wind anomalies can play a key role in determining the planetary wave pattern in the troposphere. For instance, the presence of anomalously weak zonal winds in the stratosphere at and above the 50-mb level has been shown to reflect large tropospheric planetary waves that enter the stratosphere back down into the troposphere which can result in warming of temperatures in the lower troposphere. On the other hand, the presence of extremely high anomalous zonal winds in the middle to upper stratosphere has been shown to result in the downward propagation of stratospheric planetary waves into the lower stratosphere, and then occasionally into the lower troposphere, resulting in anomalously low geopotential heights at the 1000-mb level (analogous to sea-level pressure near the surface), and thus increasing the potential for extremely cold temperature anomalies at the surface because of the compression of the vertical atmospheric column.

c.) Analysis

To gauge how the stratosphere played a key role in the Arctic outbreak of 28 Dec 2008 – 11 Jan 2009 the geopotential heights through the depth of the atmosphere as well as the zonal-mean zonal wind anomalies in the mid-stratosphere were examined. The soundings from Anchorage were used to understand how stratosphere-troposphere coupling takes place during these Arctic outbreaks.

Beginning around 30-31 December 2008, a notable change in the characteristic temperature pattern in the mid-troposphere through the stratosphere began to take place.

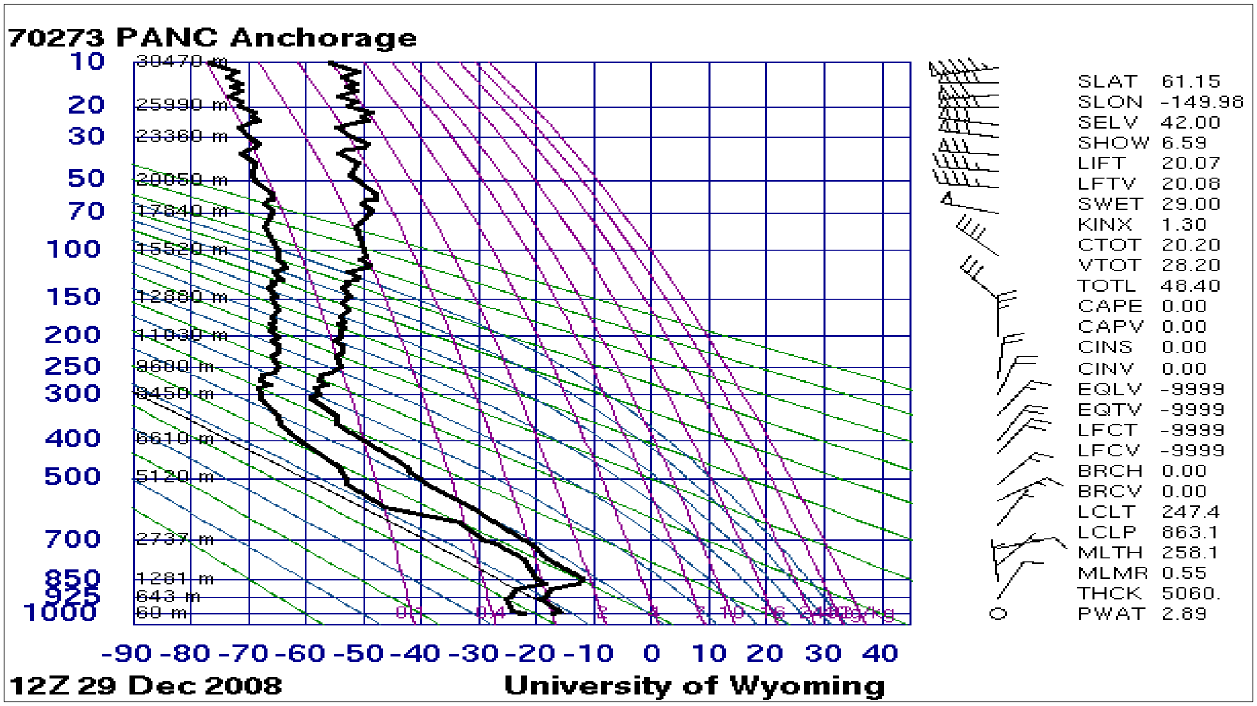

Image 4. The 12z sounding from 29 December 2008 showing a typical wintertime stratospheric temperature pattern (300-mb level upwards to 10-mb), where the temperature slowly increases or remains unchanged (isothermal) with height.

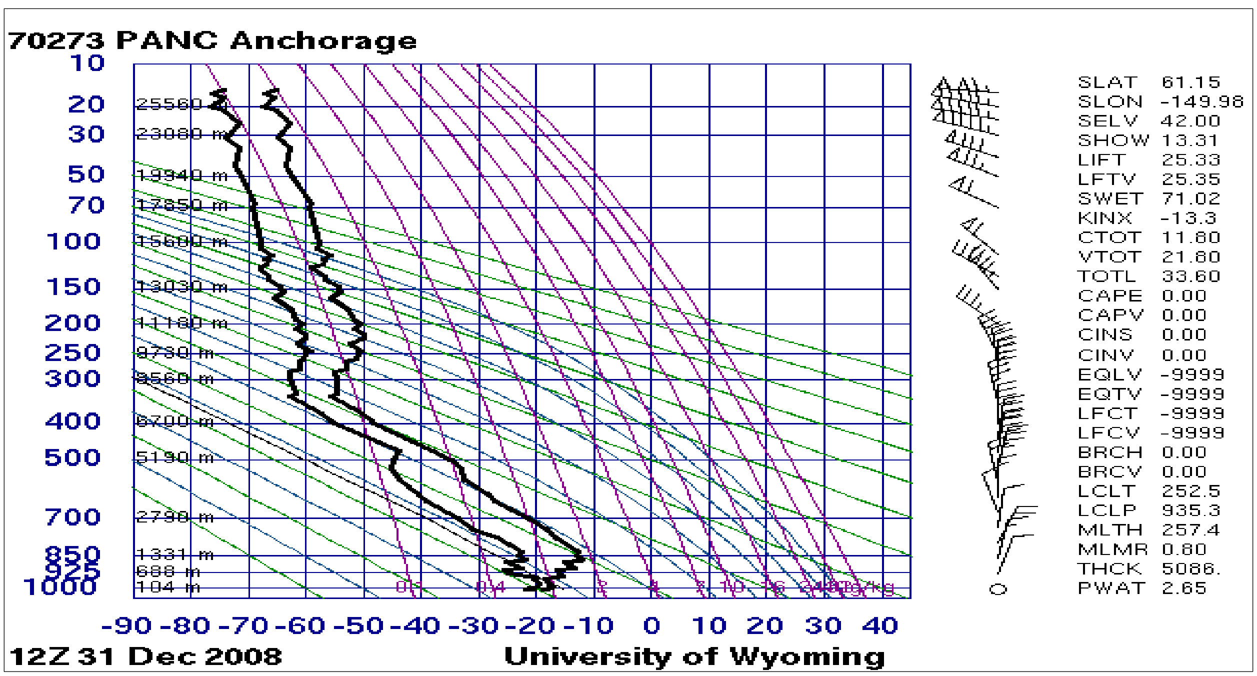

Image 5. The 12z 31 December 2008 sounding showing the stratospheric temperature pattern beginning to change to one from nearly isothermal or slowly increasing with height to one that is decreasing with height.

These changes started to occur as geopotential heights in the atmosphere began to decrease, indicating the approach of a portion of the polar vortex over the region from the north and east (Images 4 &5).

[One notable characteristic of the polar vortex is a reduction of ozone levels due to its customary location where sunlight is lacking in the Arctic regions during astronomical winter, as ozone requires ultraviolet rays to react with oxygen to produce ozone. The ozone layer absorbs the ultraviolet rays and releases heat into the atmosphere, which explains the characteristic isothermal or negative lapse rate.] Westerly (i.e., zonal) winds high in the middle to upper stratosphere (50-mb level and above) also began to increase markedly to well over 100 knots, indicative of an increasing tendency towards downward propagation of the polar vortex wave towards the lower stratosphere.

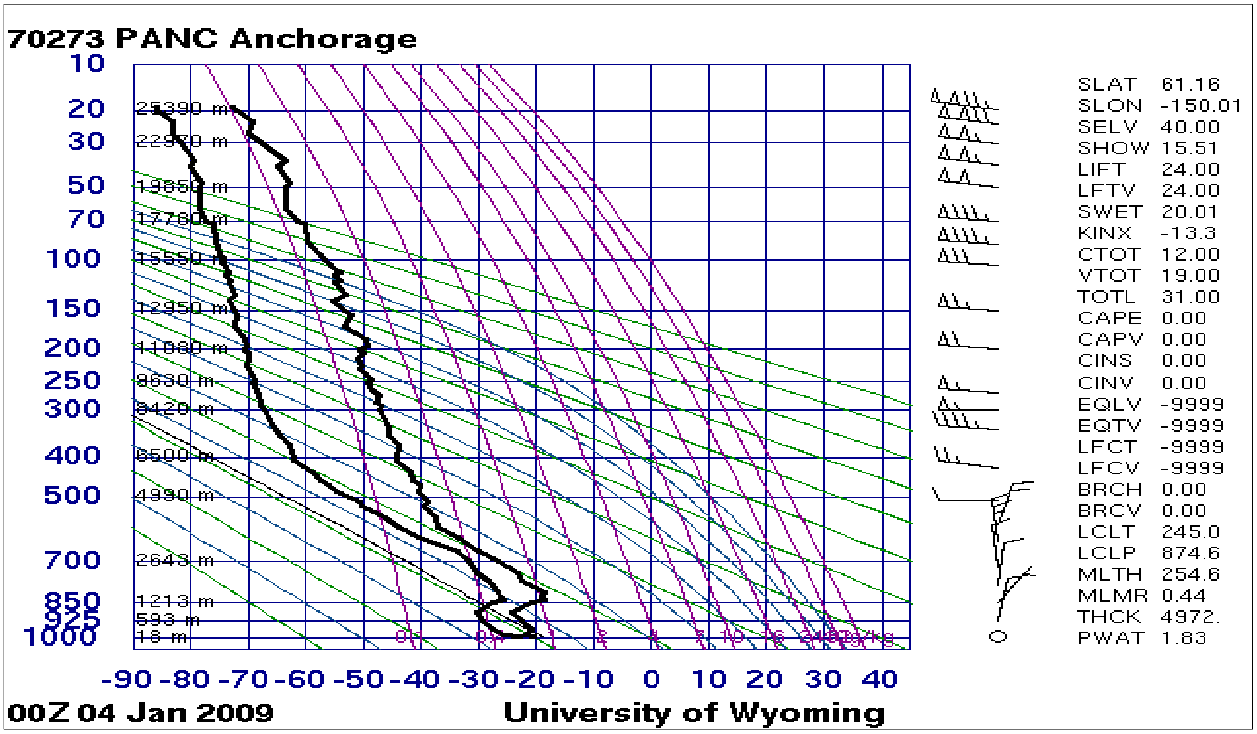

Image 6. The 00z 4 January 2009 sounding shows nearly complete coupling of the troposphere and stratosphere, with temperatures steadily decreasing with height above the lower troposphere. Mid to upper stratospheric westerly winds have now increased to over 100 knots, which indicates the potential for strong downward propagation of the polar vortex wave into the lower troposphere.

The tropopause, which separates the troposphere and the stratosphere, is practically indiscernible as the stratospheric wave has descended into the middle troposphere by 00z 4 January 2009 (Image 6). This is indicative of intense stratosphere-troposphere coupling, somewhat similar to the concept of a tropopause fold, which has been known to occur in the mid-latitudes behind very intense cyclones where the stratosphere can descend almost all the way to the surface.

An examination of the daily mean height anomalies from the 10-, 30-, 50-, 70-, 100-, and 1000-mb levels (not shown, but available upon request), the strongest relative negative geopotential height anomalies propagated downward from the highest levels of the stratosphere (10-30 mb levels) on 2 January all the way to near the surface at the 1000-mb level on 4-5 January. This also corresponds perfectly with the onset of extremely high anomalous 50-mb level zonal winds to allow for downward propagation of the stratospheric polar vortex towards the surface (Images 7 and 8). However, it is somewhat interesting to note that the 5-6 January two-day period was notably warmer than the 3-4 January period and the 7-8 January period, when the downward propagation of the polar vortex wave would suggest that the 5-6 January period could have been the coldest of the Arctic outbreak. Northerly winds blowing down from the Susitna Valley were able to clip the west side of Anchorage for most of the day on the 5th.

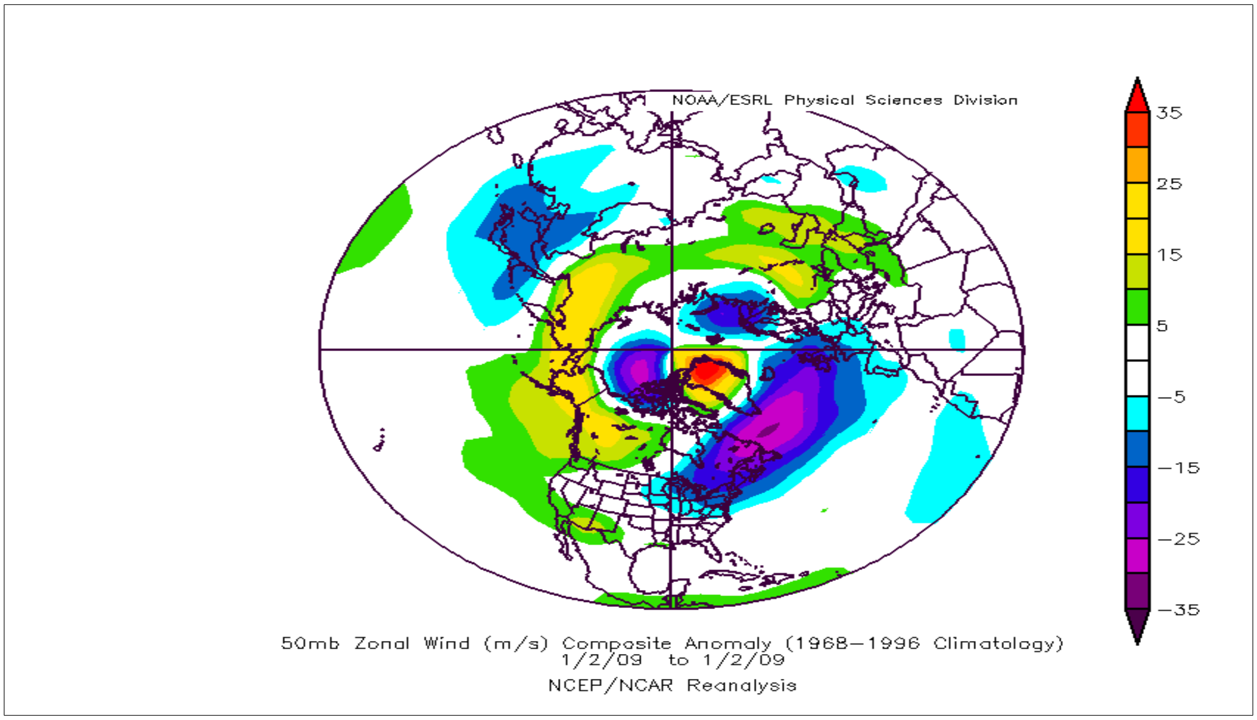

Image 7. 50-mb zonal wind anomaly based on 1968-1996 climatology showing moderate positive zonal wind anomalies over Alaska on 2 January 2009.

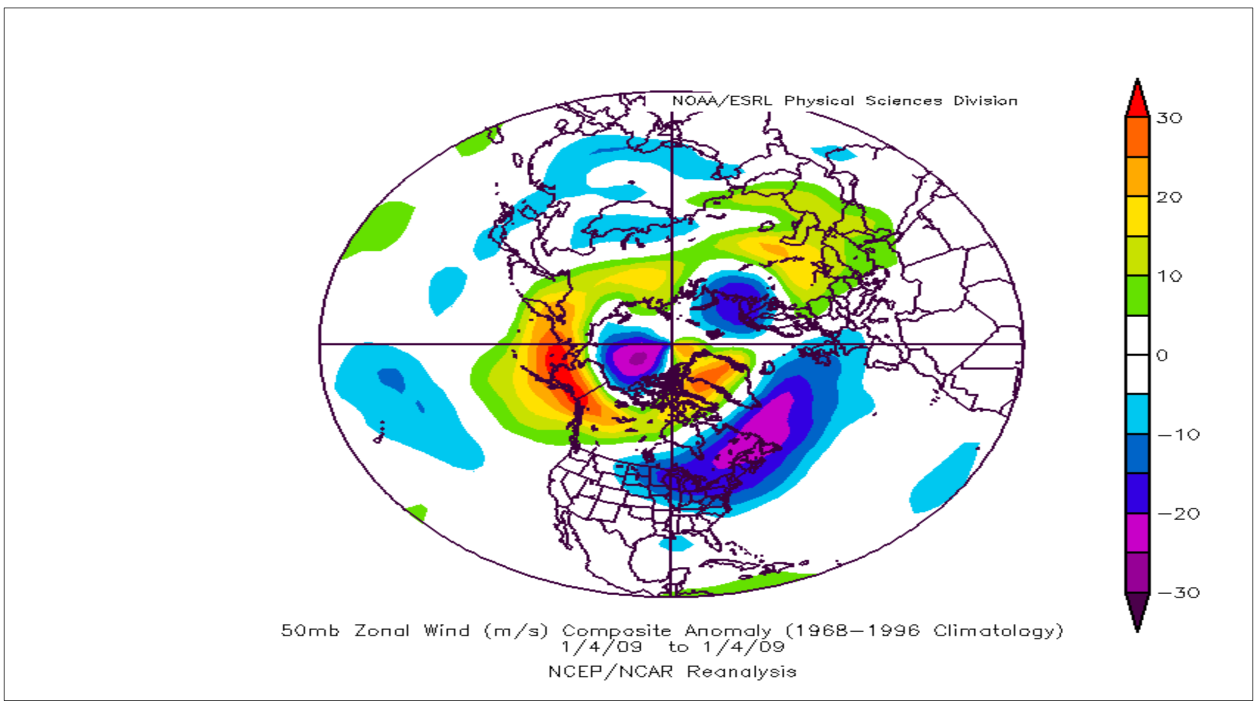

Image 8. 50-mb zonal wind anomaly as in Image 7 showing abnormally large positive zonal wind anomalies over southern Alaska on 4 January 2009.

As a result, enough mixing took place to result in a pronounced warm-up of temperatures on the 5th (to 0.4 degrees Fahrenheit at the official Anchorage station) relative to surrounding days and the subsequent morning's minimum temperature (-14 degrees F) was likely warmer than it otherwise would have been. Otherwise, a speculative look at the data suggests that the winds on the 5th *might* have resulted in saving Anchorage from experiencing what would have been the coldest day or two of the outbreak period.

4. Conclusion

Alaska experienced an unusually prolonged Arctic outbreak from late December 2008 through the first ten days of January in 2009. The coldest temperatures of the outbreak occurred during the 1-8 January 2009 period, but it was mentioned how near-surface mixing with winds that clipped western Anchorage on the 5th resulted in a brief warming episode that interrupted the extreme cold for a few hours. In fact, most of Anchorage did not experience these winds and resultant near-surface mixing, and thus stayed well below zero degrees.

To get a classic Arctic outbreak into south-central Alaska, it is well-known that a blocking pattern must be in place across the Northern Hemisphere. In this case, as in many previous other Arctic outbreak cases, large blocking ridges or cut-off highs present over the Bering Sea and over the North Atlantic Ocean region build towards each other from opposite sides of the Northern Hemisphere, resulting in pushing a portion of the polar vortex from its semi-permanent and preferred location over the Arctic southward into northwest Canada and parts of eastern Alaska.

This brief write-up has hopefully demonstrated how the coldest temperature anomalies coincided fairly well with the arrival of a portion of the stratospheric polar vortex into the region as indicated by the lowest geopotential heights compared to climatology residing just to the north and east of southern Alaska. Very strong zonal winds in the mid- to upper stratosphere were able to push the stratospheric polar vortex wave all the way down to the surface. This was primarily shown through the display of three soundings from Anchorage, one from before the Arctic outbreak showing a typical wintertime atmospheric sounding, followed by two soundings during the outbreak showing how stratosphere-troposphere coupling took place and resulted in the downward propagation of the planetary wave.

It is the goal of this write-up and subsequent presentation that a new method to determine when an extremely anomalous Arctic cold outbreak will take place, and when the coldest temperatures of the outbreak period are most likely to occur. The following is a brief list of some of these tools.

1. Extremely cold Arctic air masses of long duration making it down to Anchorage usually, but not always, result from blocking ridges over the Bering Sea or eastern Siberia as well as over northeast Canada, Greenland, and the North Atlantic Ocean, pushing some portion of the wintertime polar vortex into northwest North America. This provides the north to northeasterly flow aloft that ushers in very cold air without influence or modification from large bodies of water surrounding most of Alaska. Global forecast models usually forecast these occurrences extremely well.

2. When the atmospheric pattern in #1 occurs, look for the possibility of abnormally strong zonal winds greater than 100 knots from the 50-mb level and above from the Anchorage (and even from other Alaska) soundings that can clue the forecaster into the possibility of fairly rapid downward propagation of the stratospheric polar vortex wave all the way to the surface.

3. The tell-tale signs of significant stratospheric-tropospheric coupling indicative of the downward propagation of the stratospheric polar vortex all the way to the surface are:

a.) the sounding temperature pattern changing from nearly isothermal in the stratosphere to a notable decrease in temperature with height similar to that of the troposphere (positive lapse rate), and beginning at the top of the stratosphere and working its way downward over the course of a day to a few days beforehand.

b.) a nearly indiscernible tropopause near or below the 500-mb level, or where the mid-troposphere usually resides.

c.) a notable decrease in 1000-mb level heights (analogous to sea-level pressure) given little change in the synoptic pressure pattern.

4. When all three of the above factors are satisfied, and with a lack of winds to prevent boundary layer mixing and thus warming near the surface, the daily average temperature anomalies will usually be at least 20 degrees or more below normal, and near record or record cold temperatures are increasingly likely. In general, outbreaks of this magnitude are a once or twice in a decade type of occurrence over the last 50 years or so.

A more detailed, comprehensive paper and presentation will be forthcoming as we approach the next winter season, specifically to compare this Arctic outbreak with other cold outbreaks to further pinpoint which parameters to look for to improve prediction of such prolonged cold spells and near-record breaking temperatures. Further research will also be conducted on the effects of stratosphere-troposphere coupling during the wintertime season.

Acknowledgements

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Comments?

Comments or questions concerning the material in this document are encouraged, and may be sent to Christian.Cassell@noaa.gov.

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