Anatomy of High Wind Events along Alaska's North Slope

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Introduction

Wind events along the arctic coast of Alaska (i.e.-North Slope) are a common occurrence throughout the year. There are two basic weather regimes that produce these wind events. The most common regime occurs when high pressure is located over the Beaufort Sea with lower pressure over Alaska, producing easterly winds. Westerly wind events typically occur when lower pressure is situated over the Beaufort Sea with higher pressure to the south. The most damaging wind related events occur during the open water season (approximately mid-June through early October), when waves generated in the Beaufort Sea erode the coast near Barrow and other communities.

Furthermore, if the Arctic Basin continues to experience a reduction in sea ice coverage and thickness, trans-polar marine traffic may become a viable form of commerce. A better understanding of arctic weather systems is needed before such projects are initiated because of the dangers imposed by powerful arctic storms. The main threat to marine traffic will be the potential for superstructure icing, even during the 'warmer' months of the year. Icing is a function of wind speed, duration of the wind as well as water temperature. Since arctic storms frequently produce moderate to high wind speeds for extended periods of time, combined with the fact that sea surface temperatures (SST) in the Arctic Ocean are rarely above 40^o F (5^o C), icing is a major concern. Although this current study focuses on winds observed at or near Barrow Alaska and the southern Beaufort Sea, the fundamental results will apply to a considerably larger region.

Barrow wind events have been previously studied by Lynch *et al* (2003) and Lynch *et al* (2004). In the former paper the authors studied two of the most powerful and damaging storms (October 1963 and August 2000) that have been recorded in recent decades. One of the underlying results of that paper was that most arctic storms do not track along the ice edge. In addition, a reduction of sea ice along the Siberian coast might help storms intensify as open water provides an increased heat flux. In a study of the climatology of these events (Lynch *et al* 2004), found that the intensity of arctic storms increased during the summer months, with little change throughout the remainder of the year.

Data Sources

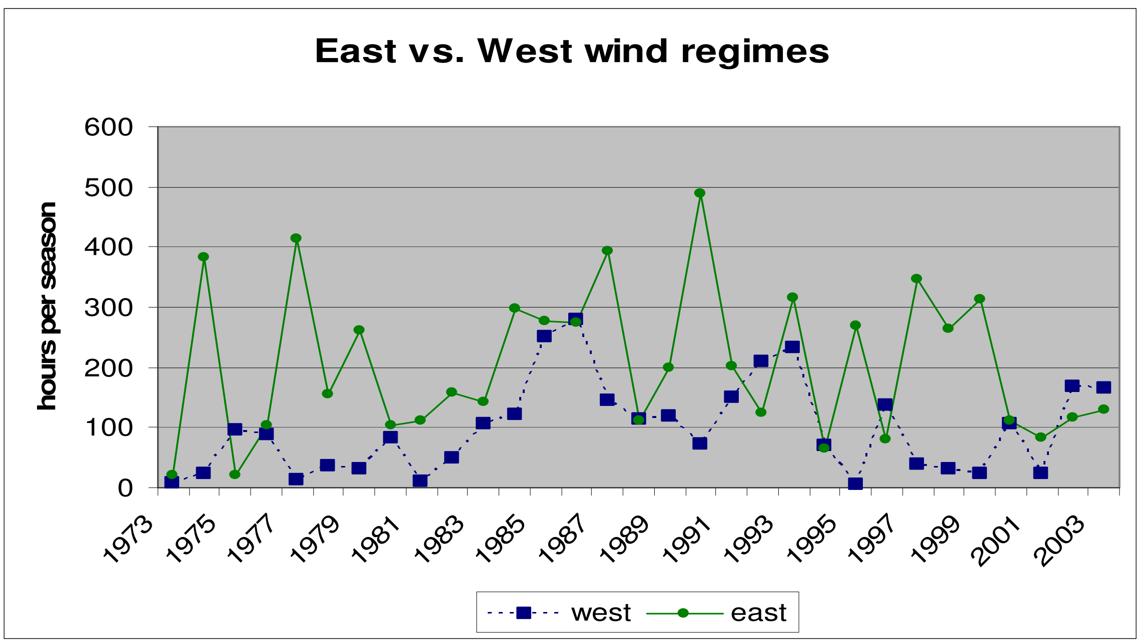
The data used in this study was obtained from the Climate Monitoring and Diagnostic Laboratory (CMDL), which is located 5 miles east of Barrow. This facility has been in operation since 1973, and makes routine meteorological measurements as well as twice daily upper air soundings. The National Weather Service operates it's standard suite of instrumentation at Wiley-Post airport, located on the edge of town. However, in December 1986 the wind sensor was moved from the village to the airport and placed on the standard 10 m tower. The net result has been a sharp increase in measured winds in the post-move period than in the previous period. Therefore climatology of winds at Barrow using the NWS observations would need to factor in this shift in the data. Additional data was obtained from the Minerals Management Service, which since 2001 had operated five meteorological sites along the arctic coast in the vicinity of Prudhoe Bay. For the study of specific events, fields of mean sea-level pressure and geopotential heights, as well as air temperature were obtained from the NCEP-NCAR reanalysis data.

Wind Events

In order to determine the frequency (total number of hours) that observed winds were 20 kts or greater (>10 m/s), CMDL's hourly wind data was analyzed for the period from June 1 to October 31 spanning the years 1973 to 2003 (31 seasons). The results indicate that easterlies (68%) have twice the frequency as westerlies (32%):

West: 3004 hrs East: 6325 hrs

Figure 1 shows a plot of east and west winds by year. It is readily apparent that the frequency of each mode of winds is highly variable from one year to the next year. There is no discernable frequency trend in either the westerlies or easterlies. The period from 1984-1993 shows a higher frequency of westerlies compared to the long-term average, this could be related to the observed reduction in MSLP during the 1987-1994 period as noted by Walsh *et a*l (1996) In addition, there is no significant correlation between east and west winds, in other words, the frequency of east (west) winds is independent of the frequency of west (east) winds (although some periods of modest negative correlation). The current decrease in the frequency of east winds is not without precedent, a similar four year 'lull' occurred in the early 1980's as well.



In order to explore the possible relationship between wind frequencies and weather and climate modes, the frequency of each wind regime was correlated with several climate indices. The first correlation was constructed between west winds and the summer (5 month average) Southern Oscillation Index (SOI). The results indicate that there is no significant correlation (-0.17) when all 31 seasons are used. It should be noted that El Nino's occurred in 10 of the 31 seasons used in this analysis. Of these 10 seasons, five corresponded with a higher than normal frequency of west winds. The correlation between the frequency of *east* winds and the SOI is -0.32 (negative SOI corresponds with a higher frequency of east winds). Closer inspection of the data however, indicates that many of the *weak* negative SOI values correspond to the *highest* seasonal frequency of east winds. Overall, there is a very weak correlation between ENSO events and the frequency of either east or west winds along Alaska's North Slope and the southern Beaufort Sea.

We also correlated the seasonal Arctic Oscillation Index (AO) with each wind regime. There was no correlation between west winds and the AO (+0.09), however a modest correlation can be found for the east regime (-0.44). Month-to-month correlations for east winds and the AO are moderately significant for June and August. Overall, the negative phase of the AO (weaker polar vortex with higher pressure in the Arctic Basin) appears from this analysis to favor a higher frequency of east winds.

Seasonal correlation between the east (+0.13) and west (-0.15) modes and the PNA is not significant. Month-to-month correlations are not significant except for September where r=-0.65 for west winds. Whether this moderate correlation represents a real physical connection or is only a statistical artifact is not known at this time.

Modest correlation was found between the seasonal PDO index and west (+0.37) and east (+0.33) regimes. Finding meaningful relationships between these climate indices and wind regimes is difficult but is certainly an avenue for future research.

Table 1: Total hours > 20 kts		
	WEST	EAST
June	174	344
July	498	286
Aug.	770	1186
Sep.	770	1734
Oct.	792	2778

The total number of hours from the 31 year data set where the wind speed was >20 kts (10 m/s) for each regime, listed by month, can be found in Table 1. The west mode increases in frequency from June to August, then remains steady through the autumn. The east mode in contrast, continues to increase from early summer through autumn, in large part due to the re-development of the Beaufort Sea High. The increased frequency in high pressure over the Beaufort limits the number of lows that can track across the Beaufort Sea. [Hence although there is a general increase in the frequency of cyclogenesis in the *sub-arctic* in the autumn, the movement of these systems into the *arctic* is limited by more frequent episodes of high pressure that form a block.]

Strong winds over southern Beaufort Sea are generated by a broad spectrum of synoptic weather patterns. Periods of strong west winds (summer or winter) tend to be associated with low pressure systems positioned in the Chukchi or northern Beaufort Seas, with higher pressure over the Bering Sea and Alaska. The lows that produce these winds originate as: a pre-existing (mature) low, a developing secondary low, or a developing primary system. Careful study of reanalysis mslp fields shows that mature lows can move around the Arctic Basin for a week or longer. These systems form in the Arctic or at lower latitudes and subsequently move into the Arctic. Two preferred areas for these storms to transit are the Bering Strait and Greenland/Norwegian Seas.

The spin-up of secondary lows on the southern flanks of a mature low is also common over the Arctic Ocean. These systems are influenced to some degree by the strong baroclinic zone that exists between the open water and the edge of the sea ice or between open water and the warmer land masses. The degree of influence that these lower tropospheric baroclinc zones have on developing systems is a matter of considerable research (Lynch *et al* 2003). The majority of lows that develop within the Arctic Basin do so along the northern margins of the continents, with the extensive coastline of Eurasia being a prime area for cyclogenesis according to the work of Serreze *et al* (2001), and Lynch *et al* (2004).

It is important to make a clear distinction between warm season east and west regimes: the majority of east winds are a result of high pressure over the arctic while the majority of west events are a product of low pressure systems. On occasions, high pressure over Alaska will generate west winds over the North Slope and Beaufort Sea, but these events are usually confined to the cooler months of the year when strong highs (>1030 mb) are capable of forming over the sub-arctic.

Westerly Wind Events

In order to study the types of synoptic patterns that produce wind events and to trace the origin of these patterns, we identified west wind events in which the CMDL hourly averaged wind speeds were greater than or equal to 20 kts (10 m/s) for at least 12 continuous hours. These specific criteria were selected in order to isolate significant events. Using the entire 31 years of data, 68 'episodes' were identified. It should be noted that several episodes were composed of multiple Barrow wind events. They were grouped as one episode in this particular scheme because the same synoptic forcing was responsible for producing each event.

Of the total 68 episodes, 11 are associated with high pressure over Alaska, Far East Siberia and the Chukchi Sea. There is a tendency for these episodes to occur in the September and October period, rather than earlier in the summer. This corresponds with the gradual cooling of the lower troposphere in the autumn. Of the remaining 57 episodes that are 'forced' predominately by low pressure systems, three distinct geographical regions over which these systems either develop or track is evident. Thirty-one episodes are linked with Siberia and the offshore arctic islands of Eurasia. Some systems develop over the Siberian landmass before moving into the Arctic Ocean, while other systems intensify while over the land-ocean margin. It should be noted that lows that form in this large region typically move east-to-northeast. There are cases where a low moved out of the Laptev or East Siberian Seas to the northeast (high arctic) for several days, before moving south into the Beaufort Sea at which time they produced a high wind event at Barrow. However, most of the systems that originate over the Eurasian coast move into the Beaufort Sea within 48 hours.

The second geographical source region comprises the Arctic Ocean north of 75°N, in which 14 episodes occurred. The lows that form in this region are for the most part secondary systems that spin-up and subsequently move from west-to-east (rotate around the parent low). As alluded to earlier, the influence that low-level baroclinicity may or may-not have on these systems is not explored in this current paper, however, it is probably important for their development.

The third region extends from the Bering Strait across Alaska into western Canada, in which 12 systems were identified. The majority of these systems formed over the North Pacific and moved north into the arctic via the Bering Strait or from the Gulf of Alaska and then across Alaska into the Beaufort Sea. The majority of these cases involve systems that are in the decaying stage, but are still deep enough to generate a potent pressure gradient. On occasions cyclogenesis will occur over Alaska with the low moving into the Beaufort Sea a day or two later, but these cases are limited in number. There are also a few cases where a formerly deep mid-latitude low weakens before moving into the arctic, only to re-intensify as it moves northward.

Note that the June-October timeframe approximately corresponds to the open water season along Alaska's North Slope. Approximately because the actual period of open water is a function of seasonal air temperature, advection of multiyear ice by ocean currents as well as synoptic-scale winds to name a few. The leading summer time ice edge varies considerably not only from month-to-month, but from one year to the next. Autumn corresponds to the time of year when sea ice extent is at its minimum, increasing the fetch along the margins of the Arctic Ocean.

In order to facilitate the analysis of a sub-set of the 68 wind episodes noted above, a list of ten events that have the highest observed westerly wind speeds is presented in Table 2. The values listed in the speed column were derived by averaging any 12 continuous hours of observations during the life of the event

Table 2: Ten highest west wind events at Barrow (1973-2003)

Date	Speed+ (kts)	Origin--Track
Sep 21-24, 1986	42.0*	N. Pacific – Bering Strait – Beaufort Sea
Aug 10-11, 2000	40.2	Siberia – East Siberian Sea – Beaufort Sea
Oct 11-12, 1993	38.4	E. Bering Sea – W. Alaska – S. Beaufort Sea
Sep 12, 1986	35.0	High pr. over Ak (1028mb): 1000mb low Bering Sea -- Beaufort
Jul 29-30, 1993	34.2	E. Siberian Sea – S. Beaufort Sea
Sep 16-17, 1985	33.0	High pr. over Bering Sea/E. Siberia: 980mb low over western Arctic
Aug 5-6, 1991	32.8	Arctic Ocean – Beaufort Sea
Jul 29, 2003	32.6	Siberia – E. Siberian Sea – Beaufort Sea
Oct 8-9, 1989	32.4	Gulf of Alaska – Alaska – S. Beaufort Sea
Sep 18-19, 1993	32.2	Bering Strait – N. Alaska – Beaufort Sea

+ 12 hour average of CMDL hourly mean speeds

* 7 hours of missing data during a 90 hr event

Although these powerful wind storms can occur any month, there is however a preference for late summer and autumn, a point noted by Lynch *et a*l (2003) in their list of wind events dating back to 1945 (they used a different data set and criteria). This list does not necessarily represent the storms that have produced the largest amount of flooding or beach erosion at Barrow (BRW). Damage caused by waves is of course to a large degree a function of fetch and duration of the winds. It is clear from this Table 2 that the origin and track of these ten events represent a broad sample of the much larger set discussed earlier. In order to gain a better understanding of the evolution of these events, several are analyzed in the following section.

<u>Sep 21-24, 1986</u>

The low that produced this particular wind event originated in the Bering Sea (982 mb) more than a week prior to the BRW wind event. This system went through several deepening/filling stages before moving over the Bering Strait late on the 19th with a central pressure of 1004 mb. On the 20th as this system moved N/NE across the Chukchi Sea it began to deepen reaching 990 mb by 20th 18Z. There was little change in pressure until the 23rd 12Z when it slowly began to fill. However, with high pressure rapidly building over Far East Siberia and the Bering Strait, the pressure gradient across the Chukchi and Beaufort Seas continued to be significant through late on the 24th. From the 21st-25th the center only moved several hundred miles to the NE during this period. The Barrow wind event concluded as high pressure that had been previously over Far East Siberia and the Bering Strait moved into northwest Alaska.

On the 20th 0Z a 500mb trough (5250 m) extended from the Bering Strait to the northwest. This trough had been moving toward the Bering Strait for the previous two days. By the 23rd 0Z a 5160 m cut-off low had formed over the Beaufort Sea, with a broader trough extending down towards the Gulf of Alaska. At the onset of the deepening phase of this system, 850 mb temperatures indicate a very strong temperature gradient (26^{o} F between Wrangel Is. and Barrow), with cold air over the Chukchi Sea and warmer air over Alaska and the southern Beaufort Sea (arctic front). It should be noted that also during this deepening phase, the low center started to deepen well south of the ice edge which was located near 73^{o}N. However, by the time the center reached 990 mb, the system was close to the ice edge (~72^{o}N). There was also strong upper-level support for this system, as indicated by lower stratospheric temperature patterns, and the presence of tropopause undulations (Hirschberg and Fritsch 1993). Prior to the redevelopment phase, an upper-level trough was positioned between Franz Josef Land and the North Pole. As the low deepened on the 20th, the trough elongated toward the southeast, eventually encompassing all of the Chukchi and Beaufort Seas.

It appears that this particular low redeveloped because as it moved north into the Chukchi Sea it entered a region with strong low-level baroclinic zone, in addition it 'merged' with a mid-tropospheric (500 mb) trough that was moving towards the southeast from the high arctic.

Aug 10-11, 2000

Forming over central Siberia west of the Lena River, the low that eventually produced this wind event subsequently moved into the East Siberian Sea early on the 9th. At the same time, a low in the northern Beaufort Sea was all ready producing moderate westerly winds along Alaska's North Slope, the winds at Barrow for example, were >20 kts for 9 consecutive hours, with a peak of 26 kts. By late on the 9th the low in the Beaufort Sea moved into the Canadian Archipelago while the system over the East Siberian Sea moved near Wrangel Island. This eastward shift in the synoptic pattern continued through the 12th.

Minimum sea level pressure as shown in reanalysis was ~994 mb which occurred on the 11th around 6Z. Wind speeds at CDML were >25 kts for a period of 22 hours (10th 18Z-11th 16Z), with a peak hourly wind of 44 kts. The peak gust measured at Barrow Airport was 64 kts. An important component of this storm was the cold air advection which occurred in the lower troposphere. Surface air temperature at Barrow decreased from 50^{o} F to 33^{o} F in an 8 hour period at the beginning of the event. Sounding data and reanalysis indicate that this cold air advection was confined to the lowest mile of the troposphere. This cooler air originated over the Arctic Ocean, moved south near Wrangel Island on the west side of the low, and then due east across southern Beaufort Sea. The net affect of this cold air advection was to increase the thickness gradient across northern Alaska and the southern Beaufort Sea, generating 45 to 55 kts of wind between the surface and one mile.

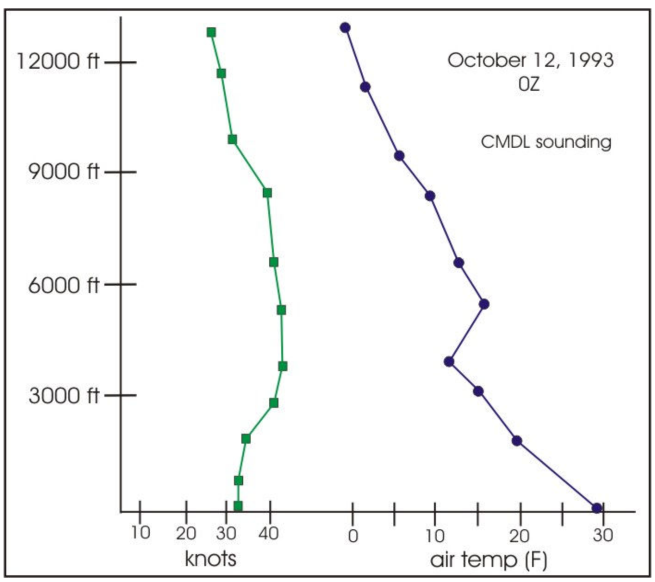
August 5-6, 1991

A number of days prior to the Barrow wind event a ~998 mb low had been moving around the high Arctic, in the vicinity of the North Pole. The low began to intensify on the 4th as the upper-level disturbance came in alignment with the surface low. By the 6th 12Z the mslp was 978 mb. It should be noted that this deepening phase occurred will north of the ice edge which was located about 73°N at that time. This system is also noteworthy because it's mslp remained between 980 mb and 990 mb for the next four days as it slowly moved eastward, entering the Canadian Archipelago on the 10th.

The maximum sustained wind speed was 36 kts on the 6th at 0z. There some interesting thermal properties during this event. 850 mb temperature gradients oriented north-south through the low center were on the order of 3°F per hundred miles. During the period of maximum winds, temperatures at 850 over BRW (from CMDL raob) decreased 24°F with only a slight change in wind direction, from west to northwest.

October 11-12, 1993

This storm produced some of the strongest resultant winds (daily mean of 32.5 kts) ever observed at Barrow Airport (1987-2003). The low center originated in the North Pacific and tracked over Bristol Bay (986 mb) and then into western Alaska. The low then moved directly over Barrow on the 10th 20Z with a mslp of ~997 mb. As the system moved into the central Beaufort Sea, pressure at Barrow continued to rise with minimal cold air advection. The strongest winds occurred around 17Z on the 11th, where the CMDL anemometer measured a hourly mean of 41.2 kts. The highest peak gust at the airport for this event was measured at 54 kts.



The local soundings taken during the event indicate that six or more hours prior to the development of strong surface winds, a band of modest west winds (20-24 kts) located 250-1000 m above the surface (surface winds at this time were on the order of 10 kts). Twelve hours later as the winds at the surface were ramping up to their maximum speed, the sounding clearly shows that the strongest winds are confined to the lowest 1500 m of the troposphere. The wind speed and direction at the 500 mb for example was18 kts at 275°. The low center in the middle and upper troposphere was located further south of the center in the lower troposphere. The low becomes vertically aligned once it enters the central Beaufort Sea.

An important aspect of this event is that surface high pressure quickly builds over Alaska as the low moves into the Beaufort Sea. For example, during the period of strongest winds the pressure in the low center was on the order of 1000 mb, but over central Alaska the surface pressure has increased to 1024 mb. Without the rapid increase in pressure over Alaska as the low moves into the Beaufort Sea, this would not have been a significant Barrow wind event. Additionally, the region of high pressure to the south of the low moved onshore from the North Pacific in conjunction with the low. Vertical cross-sections of height tendencies from the Beaufort Sea to Bristol Bay indicate that the lowest layers of troposphere had significantly larger height changes when compared to the middle and upper troposphere.

July 29, 2003

The low that generate this wind event was the second in a series of systems that formed in northern Siberia near the upper Lena River and subsequently moved E-NE across the East Siberian Sea and then into the central Beaufort Sea. Re-analysis indicates that this low intensified as it moved eastward, reaching 976 mb early on the 30th. As the winds began to increase there was minimal warm advection with south-southwest winds, but once the flow became westerly, modest cold advection occurred. The CMDL winds were 25 kts or greater from the 29th 7Z through the 30th 0Z, with a peak gusts of 59 kts at the airport. Wind speeds measured further east at the MMS sites were consistent as well. For example, peak hourly winds were 29 kts at Badami and 38.2 kts at Northstar, with the remaining three stations falling within this range.

It should be noted that the wave damage and sea water intrusion that occurred in Barrow was in part due to the fact that prior to the event of the 29th, strong west winds had occurred on the 27th. For example, the winds at CMDL were 20 kts or greater for 17 straight hours on the 27th. The MMS observations indicate peak hourly winds were on the order of 26-32 kts (28th 0Z). Hence there would have been a swell of considerable size extending from the East Siberian Sea across to the Beaufort Sea.

One the most important aspects of westerly wind events is the fact that they frequently occur in series, with a couple of days separation between events. Successive low pressure systems in the Chukchi and Beaufort Seas have the potential to produce a large swell train across the areas of these seas which do not contain any ice. A large east or southeast traveling swell in either the Chukchi or Beaufort Seas will produce substantial waves at points along Alaska's North Slope.

Easterly Wind Events

The generic synoptic pattern for easterly wind events is high pressure over the Beaufort Sea and low pressure over Alaska or the Bering Sea. The dominate feature can be either the high (August 28-29,2000) or the low (August 14-15, 2003), in some cases both are well developed (October 5-6, 2003).

One question that needs answering regarding easterly winds is: what role does multi-year sea ice play in the development or maintenance of high pressure over the Beaufort Sea? In other words, since the boundary layer over an extended area of sea ice will be cooled by the underlying surface, can this cooling be of sufficient magnitude and depth too develop or enhance the observed surface highs?

The October 15-17, 1998 event was significant because of its duration (~72 hours of >20 kts at Barrow) and the 1040 mb mslp over the northern Beaufort Sea. This high builds on the 13th and 14th as a layer of cool air between 850-700 mb becomes superimposed with an area of cold air in the lower stratosphere (250 mb).

Sounding data indicates that during easterly wind events often there is an inversion or isothermal layer in the layer from 500-1500m above the surface, in which the strongest winds are located. The October 24-25, 1998 case is a good example of an event where the lower tropospheric heights are significantly larger than those at 700 mb and above. This would imply that a low-level forcing played a significant role in the evolution of this particular event.

Summary of Important Findings:

- West wind events are produced primarily by low pressure systems that originate or track through the arctic coast of Eurasia including the Bering Strait. These systems can be old weakening systems that still produce a tight pressure gradient once they reach the Arctic, they can be new systems that form on the southern border of the arctic (northern Eurasia), or old systems that are rejuvenated as they move into a strong baroclinic zone.
- West winds increase in frequency from June to August, remaining stable through the Autumn.
- For transpolar marine traffic a major concern due to the longevity of moderate to high winds is the accompanying potential for superstructure icing.
- The importance of boundary layer heat fluxes during the open water season to the development of low pressure systems in the arctic is unknown. What is clear however is that these systems have strong lower stratospheric temperature gradients (tropopause undulations). Although in the realm of speculation, cyclones that form over the ice in the high Arctic, once they move south over the ice edge, they may maintain or decrease surface pressure as warmer more unstable air is advected into the storm center (Hirschberg and Fritsch 1991 part II). The interaction of upper-level dynamics with low-level baroclinicity is complex, and as a result, produces storms that display a broad spectrum of characteristics. In other words, storm evolution can take a number of slightly different paths- which makes forecasting a challenge since there is no 'cookie cutter template' that has universal application.
- Multiple storms with short time interval between events are fairly common across the Chukchi and Beaufort Seas. These multi-systems generally produce large 'storm surge' (waves) along the northern coasts of Alaska if wind direction remains similar from one event to the next (July 27-30, 2003). East winds: 1) strongest winds in the lower 4000 ft of the troposphere. 2) temperature advection during these events covers the full spectrum of possibilities. Not all events generate cold air advection over the southern Beaufort Sea.

Hazards to Commerce

If warm season transpolar shipping becomes a reality in future decades, careful attention will need to be paid to superstructure icing. Since warm season SST's in the Arctic Ocean will never be more than a few degrees above the freezing point of sea water, and due to the high frequency of moderate to strong winds, icing will be a major concern. The long duration of wind events will compound the problem. Since the polar pack ice is expected to continue to diminish in future decades, the period that significant swells are produced will be extended. In addition, with an increase in fetch as the ice retreats, significant wave heights should increase as well. Icing and enhanced wave heights will make forecasting for transpolar shipping a challenging venture.

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