POLAR LOWS

AND

THEIR ATMOSPHERIC ENVIRONMENTS

by

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A DISSERTATION

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Polar Lows and Their Atmospheric Environments

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University of Nebraska, 2003

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Conditions for polar low development are not clearly understood. Polar lows were identified using high and low resolution satellite imagery over the Gulf of Alaska region for an eight year period between 1992 and 2000. In addition, NCEP Reanalysis 6-hourly gridded (2.5° x 2.5°) data were utilized for thermodynamic and kinematic analysis of spiraliform polar low case studies between 1997 and 2000. Compositing was also done to create a physical model of the large scale conditions that are needed for polar low genesis and growth (-24 hr, genesis and +24 hr).

The analysis focuses on low and upper level meteorological parameters like specific humidity differences, equivalent potential temperature, and potential vorticity at the time

of spiraliform polar low cyclogenesis. The analysis shows that favorable specific humidity difference fields greater than 2.0 g/kg and equivalent potential temperature ridges at both the 925 and 850 hPa levels are important for cyclogenesis. The 850-500 hPa thickness using the threshold height of 3960 m also proved useful in determining spiraliform polar low development. Polar lows favor development when there is an upper level trough and associated cold air advection over the warmer Pacific Ocean. An upper level ridge over the central Pacific Ocean basin helps to increase the winds advecting cold air over the cyclogenesis area.

Finally, polar low frequency and various indices related to atmospheric and oceanographic changes were investigated through statistical analysis to determine linkages between polar lows and atmospheric and oceanographic conditions. Polar low frequency was strongly linked to the Atmospheric Forcing Index (AFI). The AFI is represented by warm sea surface temperatures, an intense Aleutian Low and strong westerly winds which favor polar low genesis. A link between the Pacific-North American Index (PNAI) and polar low frequency was also found. A positive PNAI represents a favorable long wave trough over the region where polar lows form. There was a negative correlation between polar low frequency and positive Arctic Oscillation Index (AOI) values. This suggests when the AO is in a negative phase, Arctic air is able to move over warmer oceanic waters and encourages polar low genesis because of the release of latent and sensible heat that aids in their development. The weakening of the circumpolar vortex also allows more potential vorticity in the upper levels to promote polar low genesis.

The results of this study enhance our ability to understand the dynamics and development of polar lows. This research will provide an avenue for more research on polar lows and the environment in which they form.

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Chapter 1

Introduction

Intense mesoscale winter storms over water, polar lows, are non-frontal weather systems that occur in very cold air masses. Meteorologists have studied polar lows over the extreme North Atlantic and nearby Nordic seas since the 1960s (Harley 1960; Pedgley 1968; Harold and Browning 1969) and later over the Pacific Ocean (Reed 1979; Locatelli et al. 1982; Mullen 1982; Reed and Blier 1986a, b; Businger 1987). Scientific understanding of these small (<1000 km) weather systems, however, is still not complete. Surface and upper air observations are usually unavailable, because polar lows occur in remote Arctic areas. Polar lows have short life spans, varying from 3 to 48 hours. Polar lows can generate gale to hurricane force winds, high deep-sea waves, heavy and blowing snow and thunderstorm activity. Although small in size, polar lows can produce hazards for shipping and coastal boating and raise environmental concerns because of their rapid development and intensification. Polar lows have been known to cause extensive damage at military installations located in the Arctic regions (Horn 2001, personal communication).

There are two types of polar lows, comma cloud and spiraliform. The comma cloud polar low is the more frequently occurring type of polar low in the North Pacific Ocean (Yarnal and Henderson 1989). Comma cloud polar lows are considered deep baroclinic systems and are found directly in the rear of synoptic scale low pressure centers or frontal boundaries (Carleton 1996).

Spiraliform polar lows are considered to be true polar lows, because they form in areas of less tropospheric baroclinicity (i.e., more barotropic), away from major frontal boundaries and poleward of the jet stream (Rasmussen 1981; Carleton 1987; Twitchell et al. 1989; Barry and Carleton 2001). The spiraliform polar lows have been studied extensively over the North Atlantic Ocean near the ice-sea boundary during the winter months (Carleton 1996; Barry and Carleton 2001).

The study of both types of polar lows has been limited to case studies, synoptic climatologies and satellite analyses (Carleton 1996). Case studies usually confine the analyses to sea level pressure, heights, temperatures and 1000-500 hPa thicknesses (Wilhelmsen 1985; Businger 1985, 1987; Ese et al. 1988). Synoptic climatology and satellite analyses are usually done in tandem to identify and count the types of polar lows during different seasons (Yarnal and Henderson 1989). However, previous studies have not investigated parameters such as absolute or potential vorticity, equivalent potential temperature or lifting index values, which could provide information for the understanding of the mechanisms that contribute to the formation of polar lows. Identifying environmental conditions conducive to polar low formation would prove useful for forecasting or modeling polar lows.

Favorable conditions for spiraliform polar low genesis and development over the North Pacific Ocean are not well understood especially away from any significant sea-ice boundary. In the past 20 years, there has been only one known case study (Businger 1987) using a limited number of synoptic and upper air reports to show favorable meteorological conditions for spiraliform polar low formation over open water. Businger (1987) used sea level pressures, 500 hPa heights/temperatures and 1000-500 hPa thicknesses in an attempt to show the development of a favorable synoptic environment for spiraliform polar lows over the Gulf of Alaska. However, Businger inferred these fields without actually calculating the vorticity and instability fields themselves. Calculating the fields would be a better indicator of instability, but Businger's data were limited at the time.

Today there are better data sets and methods available to calculate meteorological fields that are useful in understanding spiraliform polar low genesis and development. Not only can standardized meteorological fields (e.g., heights, 1000-500 hPa thickness, vorticity) be computed, but other thermodynamic and kinematic parameters (e.g., equivalent potential temperature, potential vorticity) can be utilized, as well. Modern spiraliform polar low analysis requires the use of alternative meteorological fields that may shed light on polar low genesis and dynamics.

The first objective of this polar low study is to identify and count both types of polar lows over the Gulf of Alaska, using geosynchronous satellite imagery, for a eight winter season period from 1992 to 2000. The actual area of study is north of 48°N to the North

American coast and east of 160°W to the North American coast, as outlined in red in Fig. 1.1. The region covers most of the Gulf of Alaska.

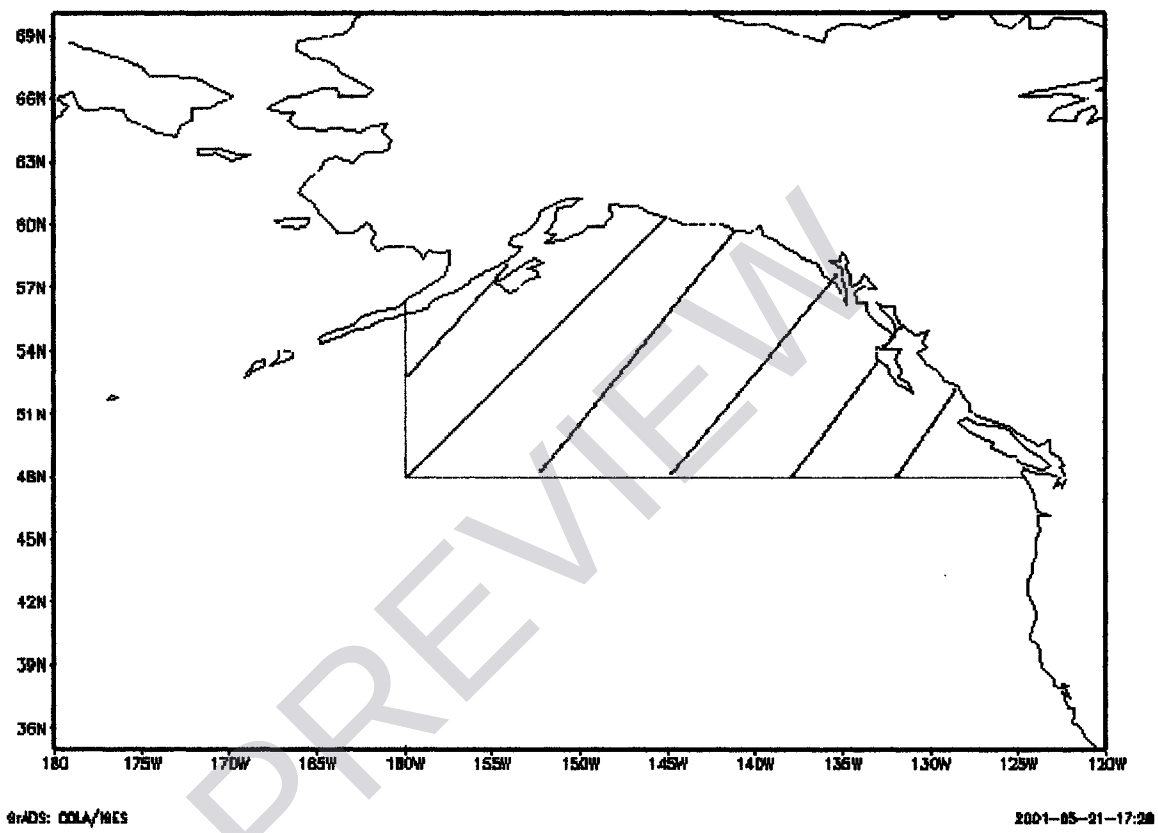

Fig. 1.1. Map of study area; the red hatched box is the polar low study area over the Pacific Ocean.

The second objective of this study is to create a physical model of the conditions that are needed for spiraliform polar low genesis and growth. Examining different time periods (e.g., -24hr, genesis, +24hr) and meteorological parameters not only give further insight on spiraliform polar low genesis, but will help identify important components of

spiraliform polar low development, which has been difficult to forecast using operational and research models. The results will examine the details of the synoptic conditions involved in spiraliform polar lows.

Finally, statistical analyses are conducted on polar low frequency and changes in the larger hemispheric, sea surface temperatures and atmospheric and oceanographic circulation patterns. Changes in atmospheric patterns and SST fields can be represented by indices. Year to year increases or decreases in polar low frequency can be related with each index value representing an atmospheric and oceanographic change. Research between polar low frequency and large-scale atmospheric and oceanographic changes is limited. The results of the statistical analyses can be useful for long term polar low forecasts over the entire Pacific Ocean.

The research objectives of this study provide insight into many aspects of spiraliform polar low genesis and polar low occurrences. The research focuses on the mesoscale and synoptic-scale environment of spiraliform polar lows, different meteorological parameters for detection and prediction of polar lows and further regional-scale conditions that may aid in the understanding of polar low frequency. This study enhances the meteorologist's ability to understand the dynamics and development of polar lows and provides an avenue for more research on polar lows and the environment in which they form.

Chapter 2

Background

2.0 History of Polar Low Research

Meteorological conditions during polar lows over the North Atlantic and Nordic Seas have been studied by meteorologists since the 1960s (Harley 1960; Pedgley 1968; Harold and Browning 1969). Several programs were undertaken during the 1980s to study the sea-ice boundary and polar lows. These included the US Navy's Marginal Ice Zone Experiment (MIZEX) study (Johannessen 1987; Davidson et al. 1988), NOAA's Arctic Cyclone Expedition (ACE) (Shapiro et al. 1987) and Norway's Polar Low Project (Lystad 1986). Studies of this type continued into the 1990s with the Coordinated Eastern Arctic Research Experiment (CEAREX) (Douglas et al. 1995) and the Labrador Sea Deep Convection Experiment (Renfrew et al. 1999).

Research has been conducted on polar low activity has also been researched over the North Pacific Ocean (e.g., Reed 1979; Locatelli et al. 1982; Businger 1985, 1987; Reed

and Blier 1986a, b; Yarnal and Henderson 1989; Bond and Shapiro 1991) and the seas around Antarctica (e.g., Streten and Troup 1973; Bromwich 1987; Turner and Warren 1988; Carleton and Carpenter 1990; Carleton and Fitch 1993; Leider and Heinemann 1999; Turner et al. 1999). Some studies even suggested that a special type of polar low occurs over land (e.g., Mullen 1982; Mills and Walsh 1988). Past polar low investigations usually concentrated on examining the atmospheric dynamics through case studies or generating a polar low climatology using satellite imagery over the region of interest. However, Businger (1987) was the first to relate polar low development over the North Pacific Ocean to large-scale atmospheric pressure and thickness changes over time. Businger's (1987) study indicated negative anomalies in the height fields with a strong northerly flow aloft over the region. Thickness analysis also revealed baroclinicity, especially in the lower levels of the atmosphere.

Improvements in satellite technology in the 1980s enabled meteorologists to actually observe the polar low phenomenon first hand, using either real time or near real time polar orbiter imagery (Carleton 1996; Joseph 1996; Renfrew 2002). Imagery of polar lows has enabled researchers to model and produce computer simulations of these systems (Renfrew 2002). In recent years, the combination of satellite imagery, derived satellite parameters (e.g., Special Sensor Microwave Imager (SSM/I) wind fields and TIROS Operational Vertical Sounder (TOVS) data), in situ balloon launches and aircraft reconnaissance information have been used to understand better the wind and precipitation patterns of these mesoscale low pressure systems (e.g., Shapiro et al. 1987; Businger and Walter 1988; Joseph 1996; Leider and Heinemann 1999).