

A 2-year climatology of polar low events over the Nordic Seas from satellite remote sensing

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[1] A new 2-year data set of polar low events over the Nordic Seas is presented. The detection of polar lows is based on the combined use of thermal infrared AVHRR imagery and SSM/I derived wind speeds from the satellite climatology HOAPS (Hamburg Ocean Atmosphere Parameters and Fluxes from Satellite Data). A total of 90 polar lows are found in 2004 and 2005 with a maximum of polar low activity during the winter months. The main polar low genesis regions lie between Iceland and Finnmark in the Norwegian Sea, in the Barents Sea and in the lee region of Cape Farewell. Interannual variability in polar low activity results mostly from more frequent cold air outbreaks in 2004. Statistics for several atmospheric parameters (e.g., wind speed, precipitation, cloud top temperatures) which describe the intensity of the cyclones are retrieved from satellite observations. The data set builds a basis for studies about polar low forcing mechanisms and for the validation of mesoscale numerical models.

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1. Introduction

[2] Polar lows are intense maritime polar mesocyclones. Knowledge about their phenomenology, origin and life cycle is limited. This is mostly due to a lack of meteorological in situ data in polar low genesis regions. Moreover, the small scale and short lifetime of these systems complicates their representation in numerical models. A large number of studies about polar lows therefore benefit from satellite observations. It was only with the general availability of satellite imagery in the 1960s that it was realized that these phenomena are quite common [Rasmussen and Turner, 2003].

[3] Only few climatologies of polar low events or at least polar mesocyclones over the Nordic Seas exist. For example, *Wilhelmsen* [1985] mainly scrutinized weather maps to document gale-producing polar lows with horizontal scales between 100 km and 500 km near the Norwegian coast for the period 1972 to 1977. She found a total of 33 cases out of which most polar lows originated in the regions around Spitsbergen and the Barents Sea where large SST-gradients occur. December and January were months of high polar low activity whereas only two polar lows occurred in February. A February minimum has also been identified in later studies [e.g., *Lystad*, 1986; *Noer and Ovhd*, 2003;

Kolstad, 2005]. Another study about polar mesocyclone activity over the North-East Atlantic and Nordic Seas is available from *Harold et al.* [1999] for the period October 1993 to September 1995. This study based completely on eye inspection of thermal infrared AVHRR (Advanced Very High Resolution Radiometer) images. All cloud systems with a cyclonic curvature and a diameter of less than 1000 km appearing on satellite images were defined as polar mesocyclones. It was mentioned that the term “polar low” should be used for a subgroup of these polar mesocyclones with surface wind speeds exceeding 15 m/s. However, the study remained limited to polar mesocyclone activity because no wind speed information was included in the detection scheme. An unexpectedly large number (4054) of polar mesocyclones were found which mainly developed during the winter months. The highest density for cyclone formation occurred over the north Norwegian Sea. Another preferred region for cyclone formation was the Greenland Sea. Only few cyclones formed in the southern part of the study area and over the Barents Sea. There was a significant difference in the amount of cyclone activity in the 2 years of the study with the first year being much more active. However, the seasonal and geographical distribution was comparable for the 2 years. *Noer and Ovhd* [2003] studied polar lows near Norway in the period 1999 to 2003 between October and May using more restrictive criteria for polar low detection. This included a horizontal extent between 100 km and 500 km and the development in cold air outbreaks from the polar ice cap. Only 41 cases fulfilled their selection criteria for polar lows.

[4] Overall, no clear conclusion about the number and characteristics of polar lows that form over the Nordic Seas can be drawn from the above references. This is mainly due to different areas and different data sets on which the studies about polar low activity are based. Moreover, a broad range of definitions for the term polar low can be found in literature [e.g., *Dannevig*, 1954; *Reed*, 1979; *Noer and Ovhd*, 2003] and confuses the reader. However, the study by *Harold et al.* [1999], though limited to polar mesocyclone activity, is probably one of the most comprehensive ones and often cited in literature regarding polar lows [e.g., *Rasmussen and Turner*, 2003; *Claud et al.*, 2007; *Kolstad*, 2005].

[5] In the present paper polar low activity in the Nordic Seas (i.e., the North Atlantic between 60° and 80° latitude and between Greenland and Novaya Zemlya) for the years 2004 and 2005 is investigated. A useful compromise between the different definitions of polar lows is given by *Rasmussen and Turner* [2003, p. 12] and applied in this study: “A polar low is a small, but fairly intense maritime cyclone that forms poleward of the main baroclinic zone. The horizontal scale of the polar low is approximately

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between 200 and 1000 kilometers and surface winds near or above gale force.” The new detection scheme is an extension of the detection method for polar mesocyclones by *Harold et al.* [1999] to polar lows. It is based on the combined use of thermal infrared AVHRR imagery and SSM/I derived wind speeds from the satellite climatology HOAPS (Hamburg Ocean Atmosphere Parameters and Fluxes from Satellite data; *Andersson et al.*, 2007). The purpose is to build a data set of polar lows consistent with the definition given by *Rasmussen and Turner* [2003] for further studies about the dynamics that lead to polar low formation and for the validation of mesoscale numerical models.

2. Methodology

[6] The detection scheme consists of two steps. In the first step mesocyclones with horizontal scales not bigger than 1000 km are detected by eye inspection of thermal infrared AVHRR quicklook images. In the second step it is checked, whether HOAPS shows a wind speed of at least 15 m/s anywhere in the region of the mesocyclone on the AVHRR imagery. As described in section 3, HOAPS wind speeds are derived from instantaneous satellite observations. This may result in minor underestimation of the number of polar lows if the velocity criterion was not fulfilled at the time of the satellite overpass but at another point in time.

[7] In general, there is a good coverage of HOAPS data over the study area. Nonetheless, it is not always possible to check the wind speed criterion for polar lows, especially if their center is located close to land or ice. In very few cases, no HOAPS wind speed is available because heavy precipitation inhibits the calculation of wind speeds. If no HOAPS wind speed is available the mesocyclone is termed “polar low-like mesocyclone” to indicate that it has the potential to be a polar low. In contrast to the study by *Harold et al.* [1999] however, all mesoscale cyclones that are recognized on AVHRR images but do not fulfill the wind speed criterion for polar lows in the HOAPS data field are excluded from further analysis.

[8] Statistics of several atmospheric parameters for the detected polar lows are derived from HOAPS and MODIS (Moderate Resolution Imaging Spectroradiometer) data.

3. Satellite Observations

[9] The quicklook images from the thermal infrared channel 4 of the AVHRR onboard the NOAA (National Oceanic and Atmospheric Administration) polar orbiting satellites were received and processed by the NERC Satellite Receiving Station at the Dundee University in Scotland (<http://www.sat.dundee.ac.uk/>). Approximately 10 images per day are available over the study area. This is about twice as much as was available for the study by *Harold et al.* [1999]. The NERC Satellite Receiving Station receives images from a large circle centered on Dundee. The time interval between two AVHRR scenes is approximately between 1 and 4 hours. The Norwegian Sea is covered by 90 to 100 percent of the images, the Barents Sea by 30 to 60 percent and the region between East Greenland and Iceland by 30 to 40 percent. Therefore, the time intervals between two consecutive images are estimated to be 1 to 4.5 hours in

the Norwegian Sea and 3 to 13 hours in the Barents Sea and the region between East Greenland and Iceland. Consequently, the number of undetected polar lows resulting from varying coverage of AVHRR images over the study area can only be insignificant given that their lifetime is shorter than the time interval between two consecutive images.

[10] HOAPS is a completely satellite based climatology of precipitation, evaporation and all basic state variables needed for the derivation of these fluxes over the global ice free oceans [*Andersson et al.*, 2007]. Except for SST, all variables are derived from SSM/I passive microwave radiometers. Pixels containing substantial atmospheric contamination due to heavy precipitation are filtered in HOAPS-3 to avoid misdetection of wind speeds. For this study a multi-satellite composite data set with a spatial grid separation of 0.5° has been produced. Due to the remapping, each grid-point represents a mean value over about one to three instantaneous SSM/I observations, which have a footprint size of approximately 50 km. The data is available twice-daily with at least 50 km distance to the coast. Each grid-cell contains data from one of the three DMSP (Defence Meteorological Satellite Programm) satellites (F13, F14, F15), there is no average from two or more satellites. Early passes are overwritten by later passes. The composited data is much better suited for polar low detection than a data set derived from averaging data of several DMSP satellites because the latter can lead to artificial effects like repeated wind speed maxima or double fronts.

[11] MODIS is a key instrument aboard the Terra and Aqua satellites. In this study the operational Level-2 cloud product is used, which has a spatial resolution of 5 km.

4. Results

[12] After the detection of the polar lows, their tracks, genesis regions, diameters and observed lifetimes have been estimated from AVHRR imagery. Diameters correspond to the visually derived horizontal scale at the mature stage of the system. The mature stage is the time when the polar low appears fully developed on the AVHRR image. The time between the first and last AVHRR observation of the polar low is termed “observed lifetime”. The shape of the polar low (comma or spiral) is also specified. Groups of polar lows or groups of polar low-like mesocyclones which form close to each other and in the same atmospheric current (e.g., the same outbreak of cold air) visible on the AVHRR image are treated as one event in this study.

4.1. Cyclogenesis and Movement

[13] A total of 90 polar lows and 109 polar low-like mesocyclones have been detected in the 2-year period. The resulting frequency distributions are shown in Figure 1. While in 2005 only 39 polar lows and 40 polar low-like mesocyclones developed, 51 polar lows and 69 polar low-like mesocyclones have been detected in 2004. In general, there is a minimum in polar low activity during the warm season and a maximum during the cold season. This agrees with the climatological study by *Wilhelmsen* [1985]. The February minimum of polar low activity detected in previous studies is not confirmed by the present results. This might be due to different detection schemes, to different study areas in the Nordic Seas and to interannual variability.

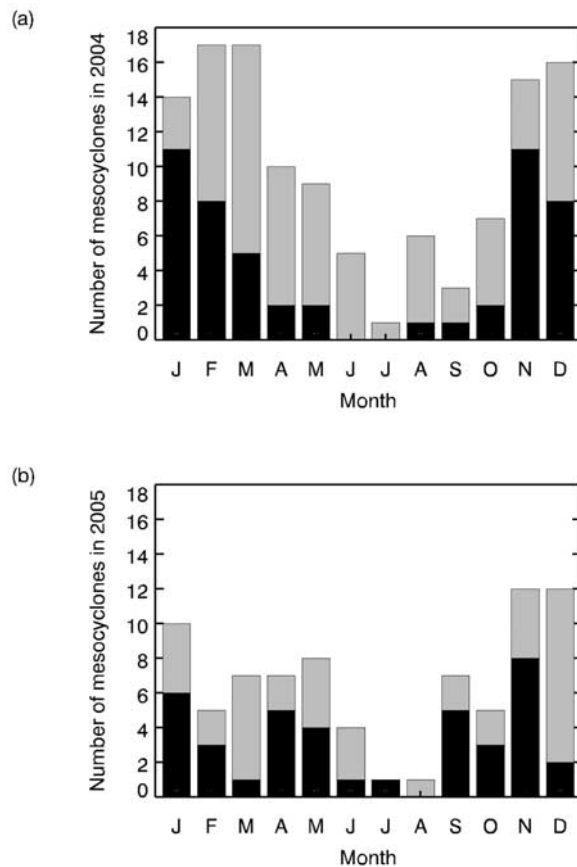


Figure 1. Frequency distribution of detected polar lows (black bars) and polar lows plus polar low-like mesocyclones (grey bars) in (a) 2004 and (b) 2005.

Instead of a well defined February minimum, there is a continuous decrease in polar low activity from January to March especially in 2004. In 2005 the monthly variability throughout the year is much stronger than in 2004.

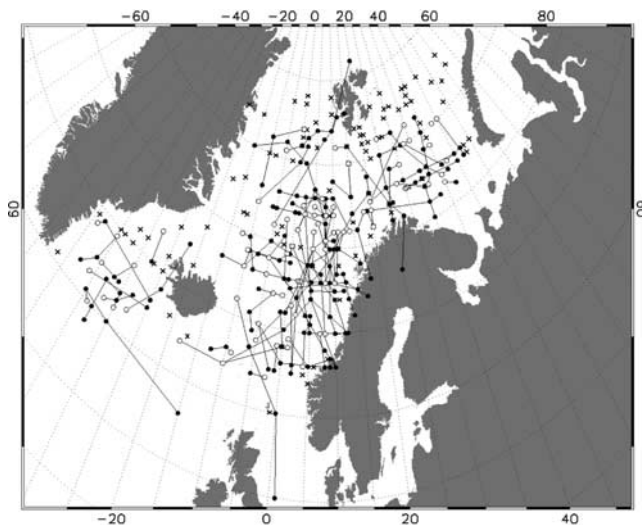


Figure 2. Tracks of the polar lows detected in 2004 and 2005. The white circles represent the genesis regions of the polar lows. The crosses indicate the locations where polar low-like mesocyclones occurred.

[14] Regarding the shape of the cyclones, the number of comma shaped polar lows (75) is five times larger than the number of spiral shaped polar lows (15).

[15] Figure 2 shows the tracks of the polar lows and the locations where polar low-like mesocyclones occurred. Overall, there is no preferred direction of movement recognizable. However, there is a tendency to a southward progression for polar lows that affect the Norwegian coast. This agrees with the study by *Wilhelmsen* [1985], finding that most polar lows that passed Norwegian meteorological stations or weather ships near the Norwegian coast moved southwards. The majority of polar lows in the present study (67 percent) originated in the Norwegian Sea between Iceland and Finnmark which is located at the northeastern most part of Norway. A maximum in polar low activity in the Norwegian Sea was also found by *Lystad* [1986] and *Noer and Ovhed* [2003]. There is a secondary maximum in polar low activity in the Barents Sea (22 percent developed here). Large SST gradients favour the development of polar lows in these areas. Fewer polar lows (11 percent) formed between southern Greenland and Iceland. This region is also known as a main cyclogenesis area for synoptic scale cyclones [*Whittaker and Horn*, 1984]. Polar lows in this region form in a synoptic scale westerly or northwesterly flow as the air is forced to flow around or over the southernmost part of the Greenland ice cap [*Rasmussen and Turner*, 2003].

[16] The spatial distribution agrees well with the results of *Kolstad* [2005] who estimated the potential for polar low formation in reverse-shear by identifying favourable con-

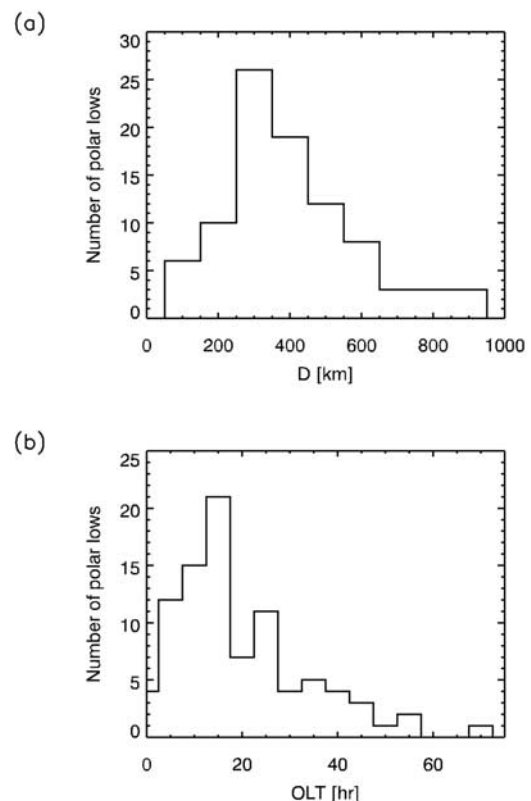


Figure 3. Frequency distribution of (a) diameter and (b) observed lifetime of the polar lows detected in 2004 and 2005.

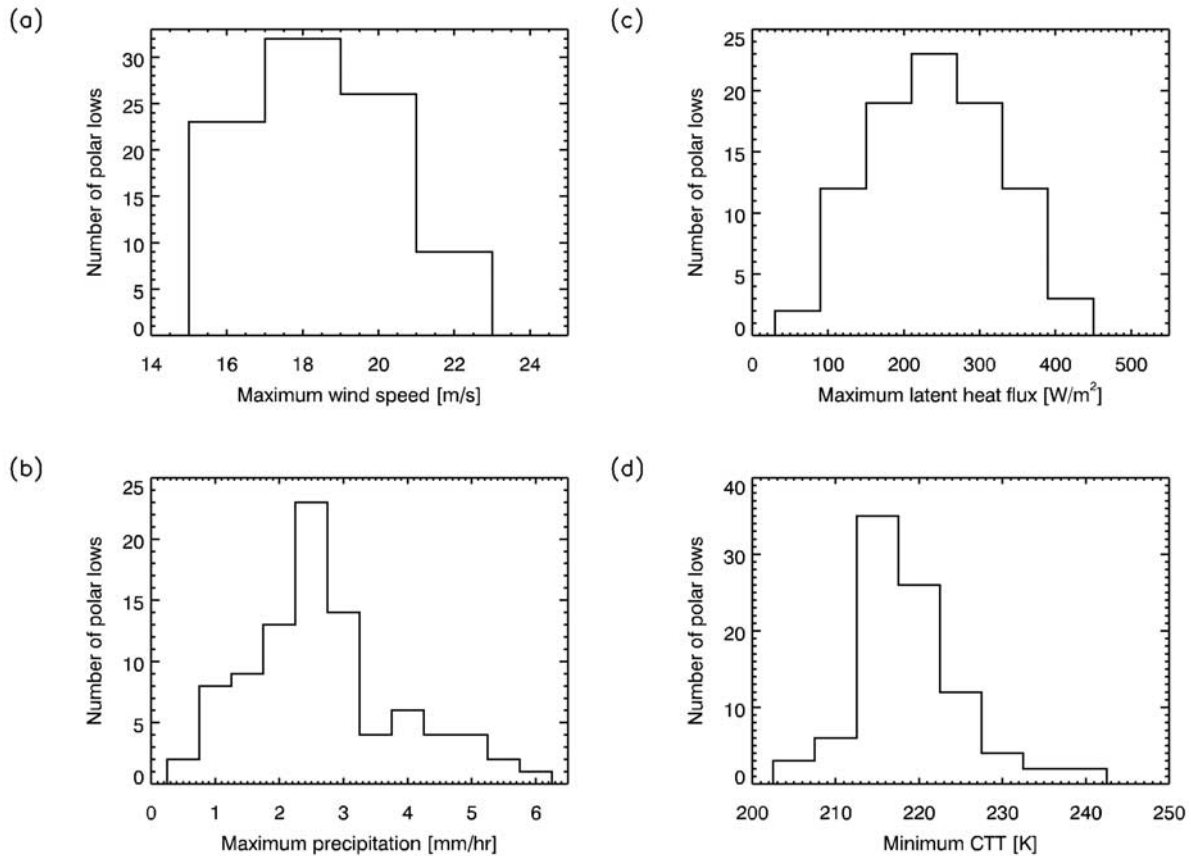


Figure 4. Frequency distribution of (a) maximum wind speed, (b) maximum precipitation, (c) maximum latent heat flux and (d) minimum cloud top temperature for the polar lows detected in 2004 and 2005.

ditions in ERA-40 reanalysis data rather than counting actual polar lows. According to this study reverse-shear polar lows build an important group of polar lows in the Nordic Seas. While most large, baroclinic waves develop when the surface wind, the thermal wind and the progression of the systems are in the same direction, reverse-shear polar lows form when the surface and thermal wind are in opposite directions, and the magnitude of horizontal winds decreases with height [Rasmussen and Turner, 2003]. The large scale atmospheric environment in which the polar lows of the present study formed has been investigated for reverse shear conditions by applying mostly similar criteria as Kolstad [2005] to NCEP (National Centers for Environmental Prediction) Reanalysis data. These criteria for reverse shear were fulfilled for approximately 22 percent of the polar low events.

[17] There is a noticeable difference in the geographical distribution of polar lows between the 2 years. Eleven polar lows developed between Iceland and southern Norway (0° to 20° West, 60° to 67° North) in the year 2004. However, in 2005 no polar lows developed in this area. This is due to more frequent outbreaks of cold air into this region as can be seen on the AVHRR images in the year 2004. This also explains most of the difference in polar low frequency between the 2 studied years.

4.2. Polar Low Parameters

[18] Frequency distributions of the diameter and observed lifetime of the detected polar lows are given in Figure 3. Most polar lows are small scale systems with diameters of

about 300 km. The smallest system has a diameter of 141 km, the largest a diameter of 981 km. The majority of polar lows only live for about 15 hr. Only few polar lows live longer than two days. The maximum observed lifetime was 72 hours and the minimum 4 hours.

[19] Frequency distributions of maximum wind speeds, precipitation rates and latent heat fluxes derived from HOAPS as well as minimum cloud top temperature from MODIS are presented in Figure 4. Wind speeds around 18 m/s are most common. The number of polar lows decreases strongly for wind speeds larger than 21 m/s. Precipitation rates of 2.5 mm/hr and latent heat fluxes of 250 W/m^2 are most frequently observed. It must be kept in mind that the HOAPS wind speeds represent a mean value over one to three individual SSM/I observations. It is therefore most likely that even stronger wind gusts occur during the passage of a polar low. The investigated systems therefore pose a substantial threat to ships and coastal areas.

[20] The minimum cloud top temperatures from MODIS are given for the overflight passes of Terra and Aqua closest to the mature stages of the polar lows. The temperature distribution shows a large peak at 215 K. For cloud top pressure (not shown), a value of 300 hPa is most common. The polar lows are hence associated with high clouds and it is most likely that precipitation is in a solid phase.

5. Summary and Final Remarks

[21] A 2-year data set of polar low events over the Nordic Seas resulting from a new satellite based detection scheme

has been presented. This is the first data set consistent with the widely used definition of polar lows by *Rasmussen and Turner* [2003] for the Nordic Seas. About 90 polar lows developed in the 2 years of the study with a maximum of polar low activity during the cold season. The main polar low genesis regions lie between Iceland and Finnmark in the Norwegian Sea, in the Barents Sea and in the lee region of Cape Farewell. Polar low activity was higher in the year 2004 than in 2005, mainly due to more frequent outbreaks of cold air into the study area in 2004. Statistics of polar low related atmospheric parameters show that these systems are short lived, small in size but very intense. The presented polar low data set builds a basis for future studies about the dynamics leading to polar low formation and for the validation of mesoscale numerical models.

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