Polar Lows and Other High Latitude Weather Systems

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1. Introduction

Polar lows are mesoscale (less than 1,000 km diameter), short-lived (lifetime usually less than 24 hours) active depressions occurring over certain ice-free, maritime areas poleward of the main polar front. Over the years they have been referred to by a bewildering variety of names, including Arctic hurricane, Arctic bomb, Arctic instability low, cold air depression, comma cloud and polar mesocyclone. An infra-red satellite image of an active polar low off the north coast of Norway is shown in Fig. 1.

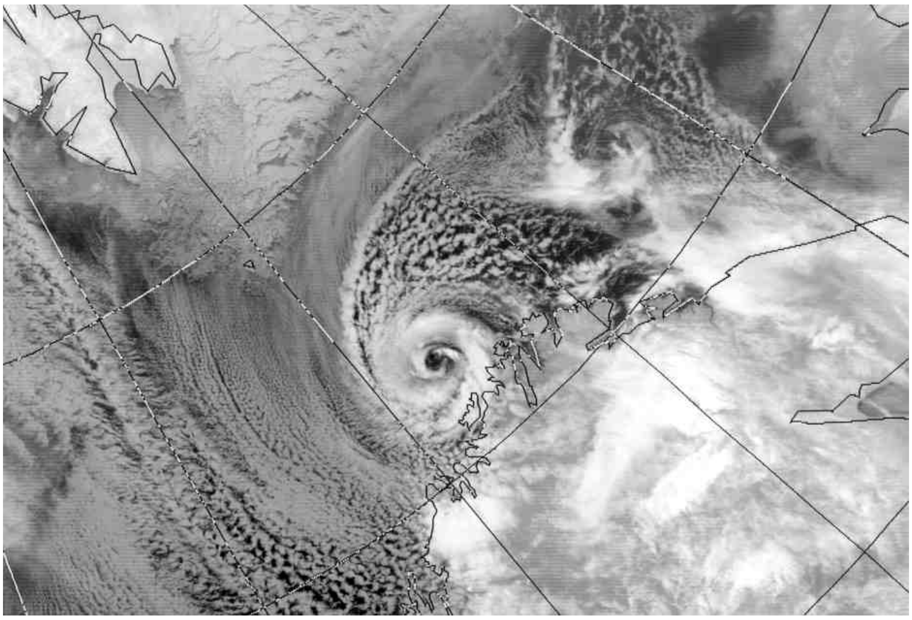

Figure 1: An infra-red satellite image at 0418 GMT 27 February 1987

Polar lows in the Arctic are primarily a winter season phenomenon with very few disturbances being found during the summer. Most of the active polar lows have a horizontal length scale of around 400-600 km, although sometimes convective systems can have smaller vortices embedded within them. Polar lows are part of the broad category of disturbances known as polar mesocyclones, which includes the many minor vortices observed on satellite imagery of the polar regions (Harold et al., 1999). The definition of a polar low is that it should have a surface wind speed of gale force (17 m/s) or stronger. They bring some of the worst weather to Arctic coastal and island locations and observations have indicated that they can have winds speeds as high as 33 m/s.

In the Antarctic the air-sea temperature differences are much less than in the Arctic and deep convection is not found close to the coast of the continent or at the latitude of the circumpolar trough over 60-70 deg S. Therefore the polar lows that occur tend to be baroclinic in nature. However, there are many minor polar mesocyclones apparent on satellite imagery.

Polar lows were first investigated in the late 1960s when the early satellite imagery became available, but studies were hampered by the lack of *in-situ* observations since the lows rarely crossed the synoptic observing stations. Early modelling studies frequently failed to represent the systems because of their small horizontal scale and the poor parameterisation of some key physical processes, such as deep convection. Recently, major advances have been made in our understanding of these systems because of dedicated aircraft campaigns flying through the lows (Douglas et al., 1991), studies with multiple sources of satellite data and experiments with high resolution, limited area models. Here we briefly review the recent advances that have been made in our understanding of polar lows and consider future research requirements.

2. The Polar Low Spectrum

In the late 1960s/ 1970s there was an active debate over whether polar lows formed and deepened as a result of baroclinic (Harrold and Browning, 1969) or convective (Conditional Instability of the Second Kind (CISK)) processes (Rasmussen, 1979). However, observational studies have now shown that there is in fact a spectrum of disturbances ranging from the rather rare (at least in the Arctic) purely baroclinic type of system with a frontal structure that resembles a small mid-latitude cyclone (Fig. 2) to the systems characterised by many deep cumulonimbus clouds (Fig. 3).

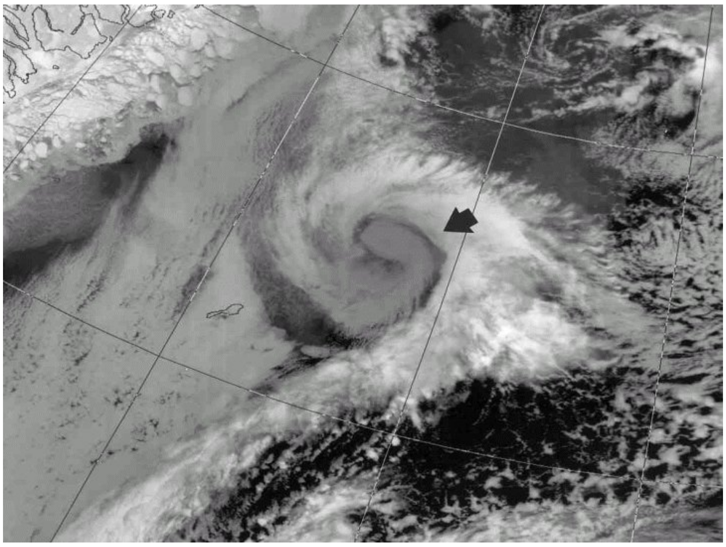

Figure 2. A baroclinic polar low off NE Greenland.

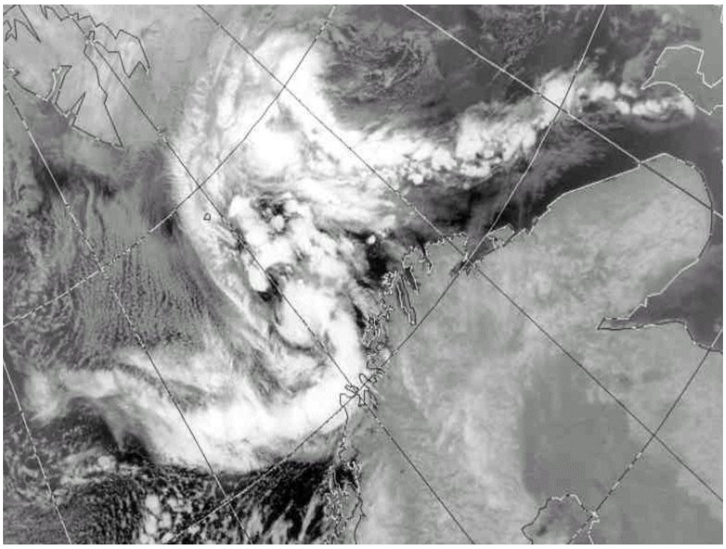

Figure 3: A convective polar low off northern Norway

Many polar lows form initially as minor baroclinic disturbances and then deepen as convective processes come into play.

We now know that there are many different types of polar low, plus various hybrid types of system, but in Rasmussen and Turner (2003) they identified seven categories of low that are found in the Arctic:

1. Reverse shear-systems. These are a baroclinic type of development that often forms between Iceland and Spitsbergen when the surface winds are from the north or north-east and the mid-tropospheric winds from the southwest.

2. Trough systems. Developing in trailing troughs in the cold Arctic air masses to the west of major synoptic-scale lows.

3. Lows forming on boundary layer fronts separating Arctic air masses of different characteristics. This type of polar low is often found around Svalbard or near the edge of the sea ice.

4. Cold lows (including merry-go-round systems). Such systems can be observed as spiral cloud patterns in the centre of old, barotropic synoptic-scale lows. The term merry-go-round system refers to a number of polar lows rotating together within an old synoptic-scale low. A cold low system is shown in Fig. 4.

5. Comma clouds. Such systems were first identified in the Pacific where comma-shaped cloud bands were observed close to the main polar front. Interactions between comma clouds and the polar front can result in 'instant occlusion' developments where the polar low and front merge to produce a system with the appearance of a frontal cyclone. Here the polar low provides the 'occlusion' and the polar front the warm and cold fronts.

6. Baroclinic wave-forward shear. These are the polar lows that have the appearance of small-scale frontal cyclones, such as illustrated in Fig. 2. They develop on minor baroclinic zones, such as those found near the edge of the sea ice.

7. Orographic polar lows. These are lee lows that develop into active mesoscale vortices in locations such as south of Iceland (during a northerly outbreak) and to the east of Greenland.

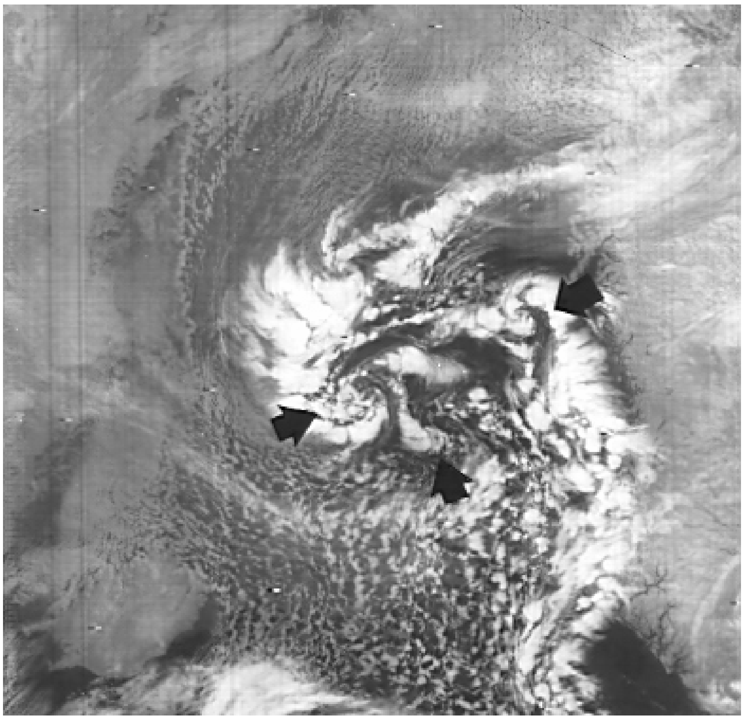

Figure 4. A 'merry-go-round' cloud signature associated with a cold core old symoptic-scale low.

3. Climatological Distribution

Polar lows were first investigated in the Norwegian and Barents Seas area where the systems affected the coastal communities of Norway and gave some of the most significant snowfalls over the United Kingdom. However, as satellite imagery became more readily available polar lows were identified in several other parts of the Arctic where there are large air-sea temperature differences, including:

1. The Davis Strait/Labrador Sea. Research into systems in this area only began in the 1990 but papers such as Moore et al. (1996) showed that very active lows could develop when strong northerly flow occurred to the west of Greenland.
2. The Gulf of Alaska and the Bering Sea. Polar lows tend to occur in this area during the winter months of November to March, particularly when there are negative height anomalies at the mid-troposphere level. Systems in this area have been investigated by Douglas et al. (1991) using a research aircraft.
3. The Beaufort Sea. Polar lows can develop here when there is limited sea ice present during the summer and early autumn. At that time of the year strong storms have been observed, although there are few documented cases in the literature.
4. North of Russia. There are reports of polar lows occurring in the Laptev and East Siberia Seas but there are no papers published on these systems in the English language literature. However, these areas have ice-free conditions during the summer and early autumn seasons so conditions are probably rather similar to those in the Beaufort Sea.
5. The northwest Pacific, Sea of Japan and surrounding areas. During the winter, cold continental air masses stream off the Asian continent and cross relatively warm waters triggering mesoscale developments. Some of these systems forming in the Sea of Japan can bring heavy snowfall to the Japanese Islands, especially Hokkaido.

While some polar lows are found in the Antarctic, these are primarily baroclinic in nature as there is no deep convection at high southern latitudes. This situation arises because the oceanic circulation of the Southern Hemisphere is much more zonal than north of the Equator and warm water masses do not reach the Antarctic coast line. Large air-sea temperature differences can exist in the coastal polynyas (ice-free areas), but the track of air across these areas is quite short so polar lows do not develop.

Minor polar mesocyclones are a common feature over the Southern Ocean and climatological studies based on satellite imagery suggest that they occur year-round, especially over the areas that are free of sea ice.

Satellite studies have suggested that polar lows with the characteristics of their Arctic counterparts can be found further north in the Southern Ocean in areas such as New Zealand.

4. Modelling Investigations

While the first experiments concerned with modelling polar lows had little success, there have been great advances in recent years as the horizontal and vertical resolution of the models has increased and better parameterisation schemes have been included for convection. Cases such as that examined by Woetman Nielsen (Nielsen, 1997), of a very vigorous polar low in the North Sea, have shown that the current generation of models can give valuable predictions of how polar lows may develop over the next 48-72 hours so that such systems can be forecast operationally. This study was carried out using the Danish HIRLAM model, which has a horizontal resolution of about 45 km and 31 levels in the vertical.

Work has recently been undertaken to assess whether polar lows are represented in the re-analysis data sets and the current operational NWP analyses. The UK Meteorological Office cyclone data base has been created to objectively identify cyclones in their global model output via their signal of enhanced vorticity. The data base covers the period from January 2000 to April 2004 and has been described by Hewson in internal Met Office publications. The data base contains a range of information on each low and is suitable for investigating even weak vortices.

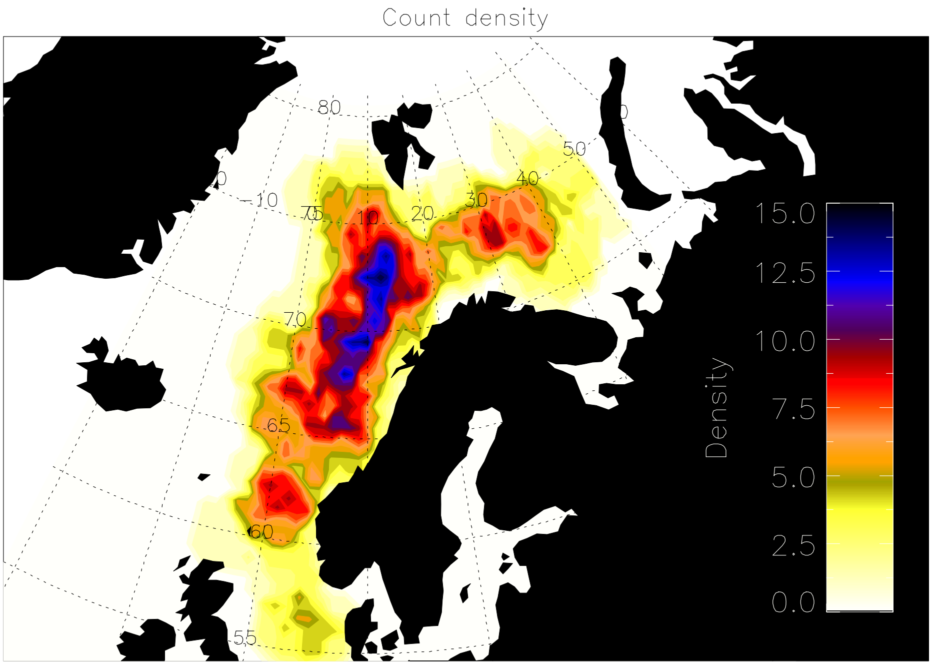

Figure 5. The polar low count density from January 2000 to April 2004 as derived from the UK Met Office cyclone data base.

This study showed the potential of using operational analyses for investigating polar lows and other high latitude mesoscale vortices. Over the 3 month period December 2001 to February 2002 100% of the polar lows were found to be represented in the UK Met Office analyses, when satellite imagery was used to verify the occurrence of the systems. In addition, 76% of the mesoscale vortices (i.e. polar lows and weaker vortices) were represented in the vortex data base. The great strength of using the data base is that the processes involved in the formation and development of the systems can be investigated.

Recently Condron and Bigg (2006) have compared polar mesocyclones in the ECMWF 40 year reanalysis (ERA-40) with vortices observed in AVHRR satellite imagery. Vortices were again identified automatically in ERA-40 using MSLP and centres tracked with the 500 hPa winds. The study area was the northeast Atlantic and the time period October 1993 to September 1995. It was found that up to 80% of cyclones larger than 500 km were detected in the ERA fields, but this decreased roughly linearly to around 40% for 250 km diameter lows and around 20% for 100 km systems. Fig. 6 shows polar mesocyclones observed in AVHRR imagery and identified automatically in an ERA-40 PMSL field.

5. Theoretical Studies

We now have a reasonable understanding of the mechanisms responsible for the development of baroclinic polar lows, but the situation is much less clear with systems dominated by convection. CISK was first put forward as one mechanism for polar low deepening in the late 1970. Emanuel and Rotunno (1989) then proposed that polar lows could intensify through air-sea interaction instability (ASII, later called WISHE (wind induced surface heat exchange)). However, the question of which is the dominant process, or if other processes play a role is still not answered because of the lack of observations at sufficiently high resolution within developing lows. The polar lows observed in the Arctic have a very wide range of forms, and even change radically during their lifetime, suggesting that a range of mechanisms are responsible for their formation and deepening.

6. Possible Climatological Importance

Individual polar lows are obviously important in weather forecasting for the two polar regions, but it is still unclear whether they are important climatologically. With the large air-sea temperature differences associated with polar lows, coupled with the high near-surface wind speeds, surface heat fluxes of up to 1,000 W m^{-2} have been recorded in association with active systems. However, there are relatively few such systems each season at a particular location. Nevertheless, the question has been posed as to whether the many minor vortices at high latitude can together generate sufficient heat loss from the surface of the ocean to trigger downward convection, which may affect the thermohaline circulation. This question can only be answered using modelling experiment, and work along these lines is taking place at the moment. Work such as that on Condron and Bigg (2006) will hopefully advance our understanding of the importance of these systems to the ocean circulation.

7. Forecasting of polar lows

In the Arctic, polar lows can have a severe impact on island and coastal communities, marine operations and oil and gas operations. In the Antarctic, they affect research and logistical operations being carried out by both ships and aircraft through the strong winds, extensive cloud and precipitation that the systems can bring.

In the early years, a nowcasting approach was used for the forecast period of up to about 12 hours ahead. Here a variety of satellite tools were used to identify vortices and the development and movement of the systems was predicted using a knowledge of the wind field and the climatological development of the lows in a particular area.

Gradually, the output from NWP forecast model predictions began to be used to try and infer when mesocyclone development might take place in a particular region. Such techniques were used in the period up to 12–48 hours ahead. Then, on the day that a forecast was issued, extensive use was made of satellite imagery to try and predict the movement and development of an existing mesoscale vortex.

Today the global NWP models have such a high horizontal resolution that, as described above, they can explicitly represent most polar lows in their analyses. They also clearly have skill in predicting the development and movement of such systems, although there have been no studies to quantify this skill.

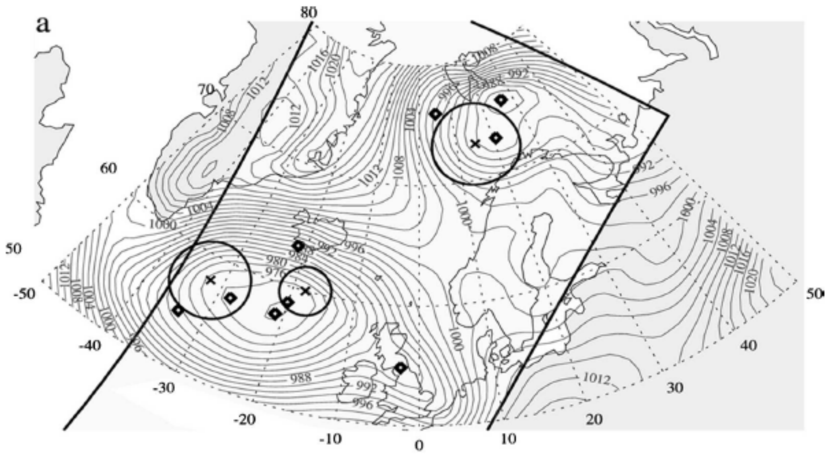

Figure 6 (a) MSLP from ERA-40 at 0600 2 January 1994 with model cyclones indicated as diamonds and the mesocyclones observed in the AVHRR imagery marked as crosses.

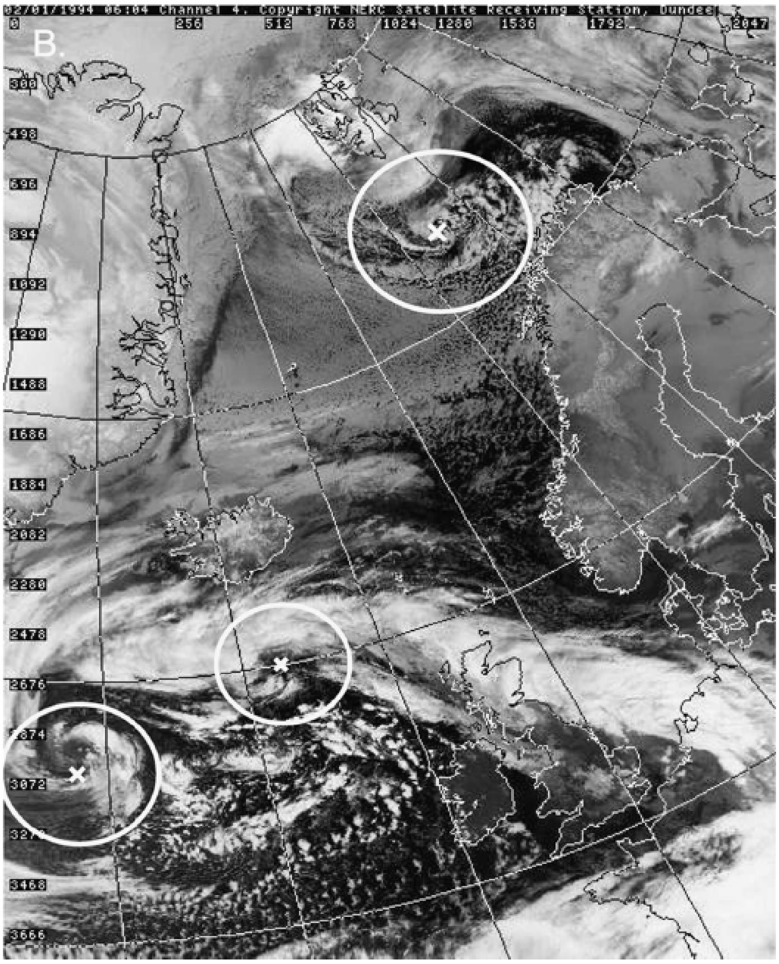

Figure 6 (b) AVHRR imagery for 0604 2 January 1994. Three multi-sighted mesocyclones are indicated. From Condron and Bigg (2006).

8. Future Research Needs

Although great advances have been made in recent years regarding our understanding of polar lows, there are still a number of outstanding questions:

1. What is the climatological distribution and frequency of polar lows? There have been a number of studies based on satellite imagery that have examined the spatial and temporal distribution of polar lows in particular parts of the polar regions. However, studies based on visual interpretation of imagery are very subjective and there is a need for a consistent analysis based on cyclone identification applied to high resolution model fields. It is unlikely that significant numbers of polar lows will be found in any new areas, but the results will be valuable in the forecasting process as well as for climatological studies.

2. How does convection act to deepen polar lows? As discussed above, this can only be answered when we have sufficiently high resolution data from within developing polar lows, coupled with greater insight from high resolution numerical models.

3. Can we provide better forecasting advice on polar lows? Operational, global forecast models now have horizontal resolutions as high as 40 km so they should be able to provide general guidance on where polar lows may form. However, higher resolution limited area models are probably required in order to predict the detailed development of many of the systems. As a priority, studies should be carried out to quantify the skill of current NWP systems to predict the development of polar lows.

References and further reading

Condron,A. & Bigg,G.R., 2006: Polar mesoscale cyclones in the Northeast Atlantic: Comparing climatologies from ERA-40 and satellite imagery. *Mon. Wea. Rev.*, **134**, 1518-1533.

Douglas, M. W., L. S. Fedor, and M. A. Shapiro, 1991: Polar low structure over the northern Gulf of Alaska based on research aircraft observations. *Mon. Wea. Rev.*, **119**, 32-54, 1991.

Emanuel, K. A. and R. Rotunno, 1989: Polar lows as arctic hurricanes. *Tellus,* **41A**, 1-17.

Harold,J.M., Bigg,G.R. & Turner,J., 1999: Mesocyclone activity over the North-East Atlantic. Part 1: Vortex distribution and variability. *Internat. J. Climatol*., **19**, 1187-1204.

Harrold, T. W., and K. A. Browning, 1969: The polar low as a baroclinic disturbance. *Quart. J. Roy. Met. Soc., 95*,710-723.

Moore, G. W., M. C. Reader, J. York, and S. Sathiyamoorthy, 1996: Polar lows in the Labrador Sea - A case study. *Tellus Series A*, **48**, 17-40.

Nielsen, N. W. An early-autumn polar low formation over the Norwegian Sea, 1997: *J.Geophys.Res.-Atmospheres*, **102**, 13955-13973.

Rasmussen, E. A. and J. Turner (Eds), 2003: *Polar Lows: Mesoscale Weather Systems in the Polar Regions*. Cambridge University Press, 602 pp.

Rasmussen, E. The polar low as an extratropical CISK disturbance, 1979: *Quart. J. Roy. Met. Soc.*, **105**, 531-549.