Tellus (1995), 47A, 324–330
Printed in Belgium – all rights reserved


TELLUS
ISSN 0280–6495

# TOVS retrievals obtained with the 3I-algorithm. A study of a meso-scale cyclone over the Barents Sea

By GÜNTHER HEINEMANN, *Meteorologisches Institut, Universität Bonn, Auf dem Hügel 20, D-53121 Bonn, Germany*

(Manuscript received 25 October 1993; in final form 17 June 1994)

ABSTRACT

ECMWF analyses and TOVS retrievals obtained with the Improved Initialisation Inversion (version 2) algorithm are used to study a meso-scale cyclone over the western Barents Sea during 26–27 February 1987. Due to the good spatial and temporal coverage of the polar regions by TOVS data, the development of this vortex was documented in detail. Results from TOVS retrievals are compared with results from a simulation using a limited area model. The retrievals reveal the intensification of a cold air outbreak over the period of a few hours, leading to enhanced formation of the vortex. The development of an extended warm belt over the Barents Sea is observed, but the weak warm core, shown by the numerical simulation at lower layers inside this warm belt, is not resolved.

## 1. Introduction

The investigation of meso-scale phenomena in polar regions by means of retrievals of atmospheric temperatures and humidities from measurements of the TOVS (TIROS-N Operational Vertical Sounder) sensors has become a topic of increasing interest in recent years (e.g., Claud et al., 1993; Turner et al., 1993b; Claud et al., 1992; Heinemann, 1989). Meso-scale cyclones (MC) in polar regions occur in both hemispheres (cf. Rasmussen et al., 1993; Turner et al., 1993a; Heinemann, 1990; Rasmussen, 1983). It has been documented by climatological studies that these vortices are embedded in cold air pools in the 500/1000 hPa thickness fields, which are related to cold air outbreaks (Businger, 1985; Ese et al., 1988). As TOVS retrievals yield layer-mean temperatures for relatively thick layers, they seem to be a good tool for monitoring the synoptic and subsynoptic environment associated with the meso-scale cyclogenesis of these systems.

Heinemann et al. (1994) demonstrated the potential and limitations of the TOVS sensor package to resolve meso-scale temperature disturbances for the algorithm of the Improved Initialisation Inversion (3I-version 2; Chedin et al., 1985; Chedin et al., 1986; Scott et al., 1991), which is used for the retrievals of atmospheric temperature fields in this paper. Meso-scale phenomena can be detected by the retrieval algorithm only if they have a horizontal scale exceeding 200 km and a significant radiance signal. Many of the MCs found in polar regions do not fulfil these criteria and are not resolved by TOVS retrievals. In such cases, the retrieved temperature and humidity fields yield useful information of the synoptic-scale conditions of the background field as operational analyses are often poor due to the scarcity of observations. Turner et al. (1992) showed for a mature polar low over the Norwegian Sea, that the main features of the thickness field, that were found in the meso-scale analysis from aircraft data (Shapiro et al., 1987), were reproduced by TOVS retrievals. For a quasi-stationary MC near Halley Station in the eastern Weddell Sea, Turner et al. (1993b) used TOVS retrievals as an important source of information to refine the meso-scale analysis of the vortex.

## 2. The synoptic situation

On 26 February 1987, a MC developed over the western Barents Sea, moved towards the Norwegian coast and reached its mature stage during the first hours of the next day. Fig. 1 shows the channel 4 AVHRR image (reduced resolution) for 04.10 UTC 27 February. The vortex centre was located at 72° N, 23° E, close to the Norwegian coast. West of the centre there were extended cloud streets, which covered the area between Svalbard and the 65° N latitude circle. The cloud structure of the MC showed pronounced spiral arms (lowest brightness temperatures around −43°C) and a cloud-free centre with a diameter of 30–40 km (brightness temperatures about +2°C). Shallow convective clouds on the western side (cloud top temperatures about −20°C) were separated from deeper convection cells on the eastern side (cloud top temperatures about −30°C) by a shallow meso-scale front or convergence line indicated by a pronounced spiral arm extending from the western side of the core towards the north and northeast.

Documentation of the synoptic development and a simulation with the numerical model of the Norwegian Meteorological Institute (DNMI) using a horizontal resolution of 25 km was described by Rasmussen (1989) and Nordeng and Rasmussen (1992). The latter paper will be referred to as NR92 in the following. These papers demonstrate that the genesis of the MC started near the centre of an occluded synoptic-scale cyclone (denoted "L" in the following) in the western part of the Barents Sea near 74° N, 30° E, at 12.00 UTC 26 February 1987. In the ECMWF analysis for this time (not shown), "L" was

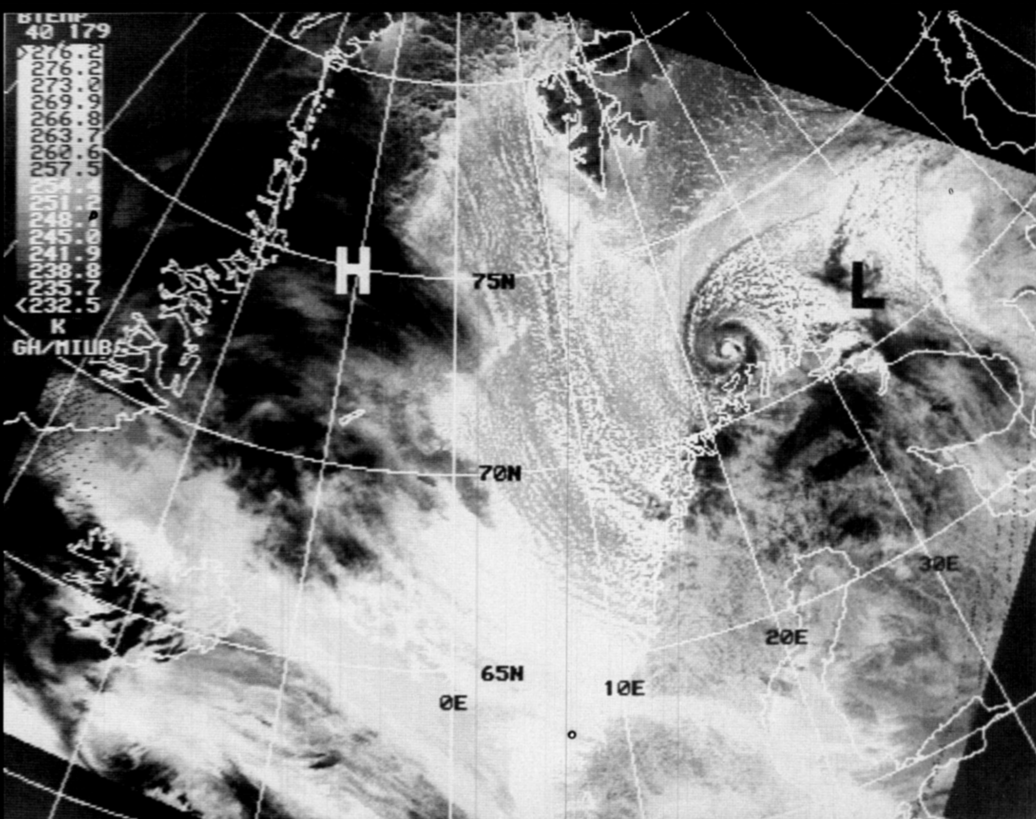


*Fig. 1.* AVHRR-channel 4 (polarstereographic projection) 04.10 UTC 27 February 1987. "H" and "L" mark positions of surface pressure centres from the ECMWF analysis 00 UTC 27 February (cf. Fig. 2).

analysed as a warm core system at the 1000 hPa level with weak warm air advection on its eastern side and strong cold air advection on the western side. At the 500 hPa level, "L" was analysed as a cold core system with lowest temperatures of −46°C and with the surface centre lying downstream of a trough in the geopotential field. The ECMWF analyses show that the MC developed near the centre of this trough in a region of weak upper air cyclonic vorticity advection and weak temperature gradients at the 500 hPa level. However, in the simulation of NR92 the genesis of the MC was triggered by a small-scale maximum of isentropic potential vorticity in the middle troposphere (Fig. 12 in NR92). At 17.00 UTC 26 February, the first signs of shallow convective spiral arms with a circulation around a cloud-free centre can be detected at 74° N, 28° E. During the following hours, the onset of strong convection was observed, and the MC moved westward while it intensified (cf. Fig. 1). Windspeeds up to 20 m/s were recorded at Norwegian coastal stations at that time and a pressure disturbance associated with the MC of about 5 hPa was estimated in NR92.

The ECMWF analysis of the thickness fields 850/1000 and 500/1000 hPa at 00 UTC 27 February (Fig. 2), close to the mature stage of the MC, displayed a warm belt over the Barents Sea for both fields (resulting from a warming of 2–4 K along the Norwegian coast in the previous 12 h), which covered the areas of "L" and of the MC. In NR92, the MC was analysed as a warm core system in its mature stage and "L" was observed during the whole development of the MC, playing the role of a "parent low".

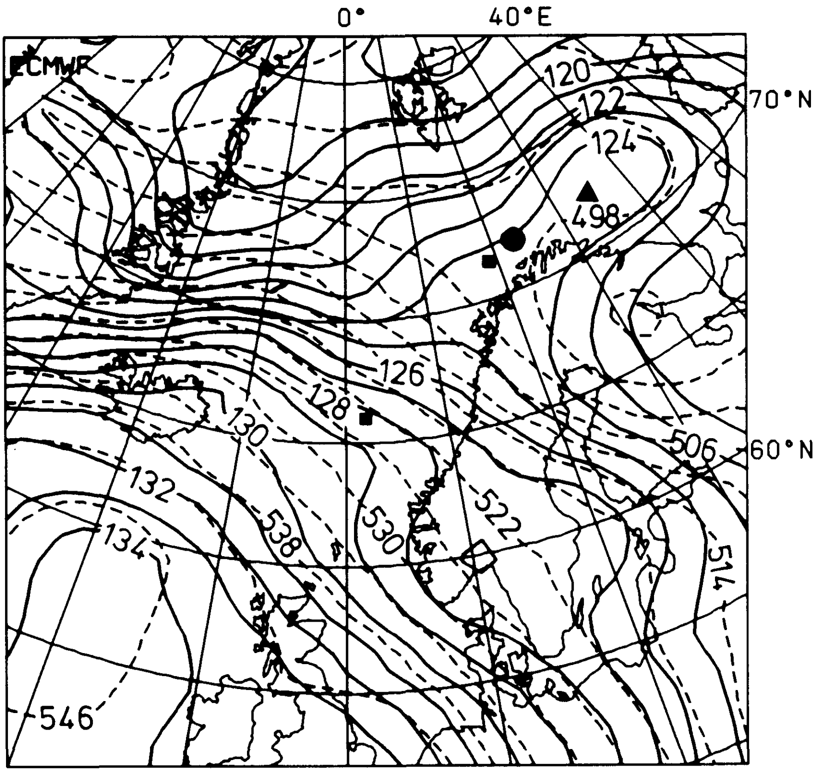


*Fig. 2.* ECMWF analysis for 00 UTC 27 February 1987, for the geopotential thickness 850/1000 hPa (full lines, isolines every 1 dam) and 500/1000 hPa (dashed line, isolines every 4 dam). The full circle marks the position of the MC, the triangle indicates the location of the synoptic-scale cyclone "L", the squares indicate positions of weatherships.

## 3. Results of TOVS retrievals

For the period 26 to 27 February 1987, TOVS data covering the area of the Barents and the Norwegian Seas were available for the following NOAA overpasses: 26 February: 02.40, 06.00, 11.00, 12.40 (NOAA9), 17.00, 18.40 (NOAA10); and 27 February: 04.10 (NOAA9). In the morning of 26 February (not shown), the synoptic-scale low "L" at 73°N, 27°E was accompanied by a cold trough on its western and a warm ridge on its eastern side. Around noon, at the time of the genesis of the MC, the centre of "L" moved to 74°N, 30°E and began to dissipate. Its major cloud band extended southwards across Finland and merged with the nearly stationary zonal frontal zone near 63°N. The 500/1000 hPa retrievals for this stage (11.00–12.40 UTC) reveal similar gross structures as the ECMWF analysis (values being about 6 dam higher near "L", not shown), but show a

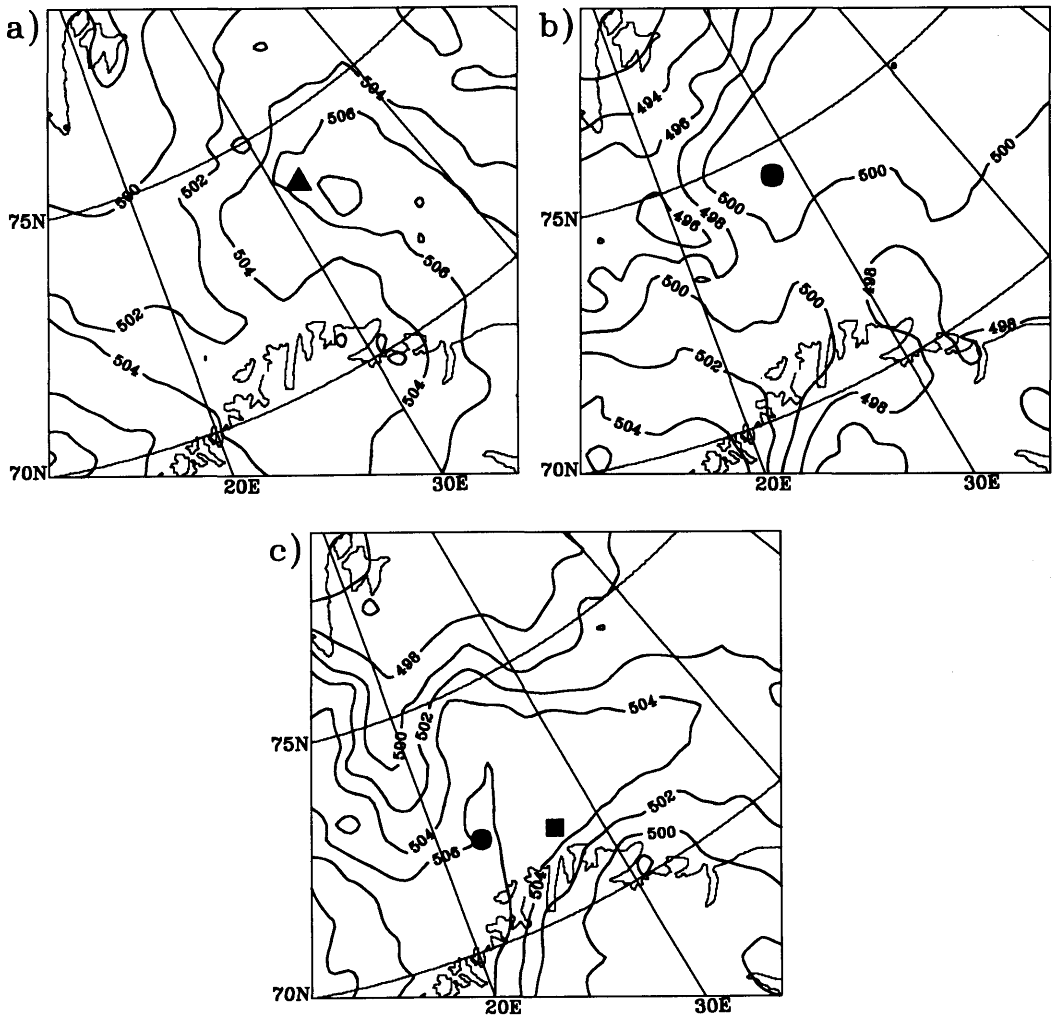


*Fig. 3.* Retrievals of the 500/1000 hPa thickness field for the Barents Sea (isolines every 2 dam); the triangle indicates the location of the occluded synoptic-scale cyclone "L", the full circle and the full square indicate the positions of the mesocyclone according to satellite images and limited area model results, respectively. Part a: 26 February 1987, 11.00/12.40 UTC; part b: 26 February 1987, 17.00/18.40 UTC; part c: 27 February 1987, 04.10 UTC.

more pronounced cold air outbreak south of Svalbard and a tongue of warm air south of the occluded cyclone (Fig. 3a). About 6 h later, the geopotential thickness retrievals display again the almost stationary frontal zone between Greenland and Norway (values being about 0–4 dam lower compared to the retrievals 11.00–12.40 UTC; not shown). Over the Barents Sea, a significantly intensified structure of the cold air outbreak on the western side of the developing MC is visible, whereas an almost homogeneous temperature field can be found on the eastern and southern side (Fig. 3b).

The vortex matured about ten hours later at 4.00 UTC 27 February (Fig. 1). The large-scale structures in the retrievals of the 500/1000 hPa field (Fig. 4) remain unchanged for the major part of the Norwegian Sea (reflecting the broad frontal zone between Greenland and Norway), but over the Barents Sea the cold air outbreak mentioned above is even more distinct. This structure represents also the main difference to the ECMWF analysis (Fig. 2), whereas for other regions a close similarity between the structures of the retrievals and synoptic analysis can be found. The absolute values of the thicknesses in the area of Svalbard are higher compared to 17.00–18.40 UTC 26 February (Fig. 3b), but the horizontal temperature difference has increased in the vicinity of the MC and the centre is now found on a thermal ridge embedded between two cold air pools (Fig. 3c). In their numerical simulation, NR92 explain the warming in the cold air mainly by large surface energy fluxes and the release of latent heat.

The modelled centre of the MC was analysed as a warm, dry core from the surface up to 600 hPa in NR92. The largest horizontal temperature gradients were found below 850 hPa (about 4 K/200 km

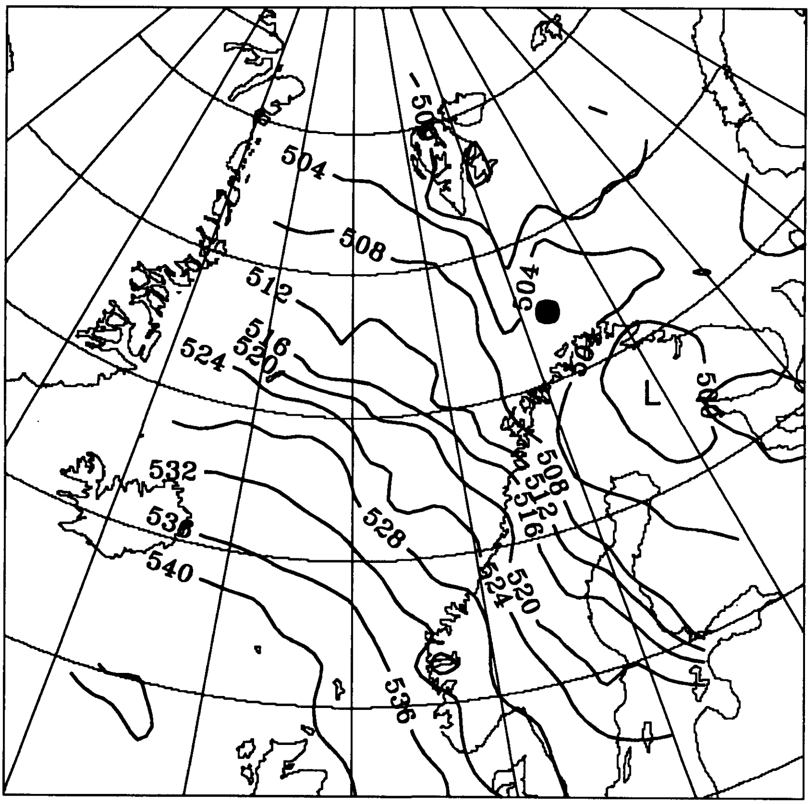


*Fig. 4.* Retrievals of the 500/1000 hPa thickness field for the Norwegian and Barents Sea at 27 February 1987, 04.10 UTC (isolines every 4 dam); the full circle indicates the position of the mesocyclone.

outside the warm core). The temperature field structure relative to the centre obtained from the retrievals fits well to the results of the numerical simulation, but the simulated centre is found approximately 100 km east of the centre observed in the AVHRR image (Fig. 1). A distinct warm core of the MC was reproduced neither in the ECMWF analyses nor in the TOVS retrievals. Instead, both show the development of a long belt of warm air over the Barents Sea. At lower levels, this structure is largely determined by the preexisting temperature maximum near the centre of "L" (Fig. 2), which is likely to be a result of either the occlusion or a warm seclusion process (Shapiro and Keyser, 1990). An inspection of the horizontal temperature field structure of the numerical simulation (Nordeng, 1993, personal communication) confirms the analysis obtained by the TOVS retrievals, as the warm core found in the simulation is very weak (anomaly of about 2 K at levels close to the ground) and lies in a belt of increased temperatures.

## 4. Summary and conclusions

The development of an intense meso-scale vortex with spiral arms and a cloud-free centre over the Barents Sea during 26–27 February 1987 has been described using ECMWF analyses and geopotential thickness structures obtained from TOVS retrievals with the 3I-version 2 retrieval algorithm. Results of a simulation with a limited area model (Nordeng and Rasmussen, 1992) are also used for comparison.

The TOVS retrievals show the largest development of the geopotential thickness field structure in the area of a cold air outbreak on the western side of the MC, with almost stationary fields in other regions. It should to be mentioned that problems with the Microwave Sounding Unit (MSU) of the TOVS packages of NOAA9 and NOAA10 are known to have occasionally occurred during the beginning of 1987, which sometimes yielded degraded radiance measurements and even jumps in the calibration (Flobert et al., 1991). In the case study presented here, however, the consistency of the retrievals from seven different overpasses from both satellites is a strong indicator that correct radiance measurements were obtained from the MSU sensors, on which the retrievals rely to a great part (especially in cloudy areas).

The TOVS retrievals reveal the intensification of the cold air outbreak over the period of a few hours during the formation stage of the MC. This is not documented by the numerical simulation of NR92 and may even be undetected by their simulations. This strong advection of cold air seems to be an enhancement mechanism for rapid development of the vortex, which was simulated as a warm core by the limited area model. The development of an extended warm belt over the Barents Sea is also observed, but the weak warm core at lower layers inside this warm belt, found in the numerical simulation of NR92, is not resolved.

## 5. Acknowledgements

This research was supported by the "Deutsche Forschungsgemeinschaft" under grant Kr228/16. The author is thankful to the members of the Laboratoire de Météorologie Dynamique for their support. Digital data have been made available by the University of Dundee, NOAA/SDSD and by the ECMWF, Reading.

## REFERENCES

Businger, S. 1985. The synoptic climatology of polar low outbreaks. *Tellus* **37A**, 419–432.

Chedin, A., Scott, N. A., Wahiche, C. and Moulinier, P. 1985. The Improved Initialisation Inversion method: A high resolution physical method for temperature retrievals from satellites of the TIROS-N series. *J. Clim. Appl. Meteor.* **24**, 128–143.

Chedin, A., Scott, N. A., Wahiche, C., Moulinier, P., Husson, N. and Sitbon, P. 1986. The "3I" procedure applied to the retrieval of meteorological and climate parameters from NOAA-7. *Ocean-Air Interactions* **1**, 29–42.

Claud, C., Scott, N. A. and Chedin, A. 1992. Use of TOVS observations for the study of polar and arctic lows. *Int. J. Remote Sensing* **13**, 129–139.

Claud, C., Mognard, N. M., Katsaros, K. B., Chedin, A. and Scott, N. A. 1993. Satellite observations of a polar low over the Norwegian Sea by the Special

Sensor Microwave Imager, Geosat, and the TIROS-N Operational Vertical Sounder. *J. Geophys. Res.* **98**, 14487–14506.

Ese, T., Kanestrøm, I. and Pedersen, K. 1988. Climatology of polar lows over the Norwegian and Barents Seas. *Tellus* **40A**, 248–255.

Flobert, J.-F., Andersson, E., Chedin, A., Hollingsworth, A., Kelly, G., Pailleux, J. and Scott, N. A. 1991. Global data assimilation and forecast experiments using the Improved Initialisation Inversion Method for satellite soundings. *Mon. Wea. Rev.* **119**, 1881–1914.

Heinemann, G. 1989. On the use of TOVS data for studies of mesoscale vortices in the Weddell Sea (Antarctica). *Technical Proceedings, 5th International TOVS Study Conference*, Toulouse, France, 184–200.

Heinemann, G. 1990. Meso-scale vortices in the Weddell Sea region. *Mon. Wea. Rev.* **118**, 779–793.

Heinemann, G., Noël, S., Chedin, A., Scott, N. A. and Claud, C. 1994. Sensitivity studies of TOVS retrievals with 3I and ITPP retrieval algorithms. Application to the resolution of meso-scale phenomena in the Antarctic. *Meteor. Atmosph. Phys.*, in print.

Nordeng, T. E. and Rasmussen, E. A. 1992. A most beautiful polar low. A case study of a polar low development in the Bear Island region. *Tellus* **44A**, 81–99.

Rasmussen, E. A., Turner, J. and Twitchell, P. F. 1993. Report of a workshop on applications of new forms of satellite data in polar low research, held at Hvanneyri, Iceland, 23–26 June 1992. *Bull. Amer. Meteorol. Soc.* **74**, 1057–1073.

Rasmussen, E. A. 1989. A comparative study of tropical cyclones and polar lows. In: *Polar and arctic lows* (eds. P. F. Twitchell, E. A. Rasmussen and K. L. Davidson). A. Deepak Publishing, 421 pp.

Rasmussen, E. 1983. A review of meso-scale disturbances in cold air masses. In: *Mesoscale meteorology theories, observations and models*, 247–283 (eds. Lilly, D. K., Gal-Chen, T.). D. Reidel Publishing Company Co., Dordrecht, Holland.

Scott, N. A., Chedin, A., Achard, V., Bonnet, B., Cheruy, F., Claud, C., Escobar, J., Husson, N., Rieu, H., Tahani, Y. and Tournier, B. 1991. Recent advances in the thermodynamic analysis of the earth system through the 3I algorithm. *Technical Proceedings, 6th International TOVS Study Conference*, Airlie, Virginia, 425–467.

Shapiro, M. A., Fedor, L. S. and Hampel, T. 1987. Research aircraft measurements of a polar low over the Norwegian Sea. *Tellus* **39A**, 272–306.

Shapiro, M. A. and Keyser, D. 1990. Fronts, jet streams and the tropopause. In: *Extratropical cyclones* (eds. C. Newton and E. O. Holopainen). Amer. Meteor. Soc., Boston, 262 pp.

Turner, J., Lachlan-Cope, T. A. and Moore, J. C. 1992. A comparison of satellite sounding data and aircraft measurements within a mature polar low. *Tellus* **44A**, 119–132.

Turner, J., Lachlan-Cope, T. A. and Thomas, J. P. 1993a. A comparison of arctic and antarctic mesoscale vortices. *J. Geophys. Res.* **98**, 13019–13034.

Turner, J., Lachlan-Cope, T. A. and Warren, D. E. 1993b. A mesoscale vortex over Halley Station, Antarctica. *Mon. Wea. Rev.* **121**, 1317–1336.