Ann. Geophys., 24, 1245–1255, 2006
www.ann-geophys.net/24/1245/2006/

Annales Geophysicae

Polar mesosphere winter echoes during MaCWAVE

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Received: 12 April 2005 – Revised: 7 November 2005 – Accepted: 21 December 2005 – Published: 3 July 2006

Part of Special Issue "MaCWAVE: a rocket-lidar-radar program to study the polar mesosphere during summer and winter"

Abstract. During the MaCWAVE winter campaign in January 2003, layers of enhanced echo power known as PMWE (Polar Mesosphere Winter Echoes) were detected by the ESRAD 52 MHz radar on several occasions. The cause of these echoes is unclear and here we use observations by meteorological and sounding rockets and by lidar to test whether neutral turbulence or aerosol layers might be responsible. PMWE were detected within 30 min of meteorological rocket soundings (falling spheres) on 5 separate days. The observations from the meteorological rockets show that, in most cases, conditions likely to be associated with neutral atmospheric turbulence are not observed at the heights of the PMWE. Observations by instrumented sounding rockets confirm low levels of turbulence and indicate considerable small-scale structure in charge density profiles. Comparison of falling sphere and lidar data, on the other hand, show that any contribution of aerosol scatter to the lidar signal at PMWE heights is less than the detection threshold of about 10%.

Keywords. Meteorology and atmospheric dynamics (Turbulence; Middle atmosphere dynamics) Ionosphere (Polar ionosphere)

1 Introduction

Polar mesosphere winter echoes (PMWE) are thin layers of strongly enhanced radar echo occasionally seen by high-latitude VHF radars such as the ESRAD (52 MHz) and EISCAT (224 MHz) radars in northern Scandinavia (Kirkwood et al., 2002a, 2002b; Stebel et al., 2004; Belova et al., 2005). It has long been known that layers of relatively weakly enhanced radar echo can be seen in the mesosphere at many latitudes, and strongly enhanced echoes are also known to occur at high-latitudes in summer. For example Ecklund and Balsley (1981) and Balsley et al. (1983), using the 50 MHz Poker Flat radar, Alaska, and Czechowsky et al. (1989), using the mobile 53.5 MHz SOUSY radar at Andenes, Norway, reported climatologies of radar echoes at high-latitudes. Strong echoes were seen in summertime at heights roughly 80–90 km (typically with signal-to-noise ratio, SNR, 30–60 dB at Andenes), and much weaker echoes were seen between 55-80 km heights in winter (SNR 5–25 dB at Andenes). It was realised early on that the strong summer echoes, later named PMSE – Polar Mesosphere Summer Echoes, could not be explained simply by the action of neutral turbulence and it was proposed that charged ice particles could play a role in their formation (Kelley et al., 1987). This theory has been largely substantiated by later studies (see e.g. reviews by Cho and Kelley, 1993, Cho and Röttger, 1997, Rapp and Lübken, 2004). The much weaker wintertime-high-latitude and lower-latitude echoes, on the other hand, were clearly correlated with dynamic processes (winds and wave motions) and it was considered that layers of neutral turbulence could provide an adequate explanation. Indeed, in-situ observations of small scale structure made by a sounding-rocket through a typical, weak mesospheric layer, seen by the 50 MHz Jicamarca radar in Peru (Røyrvik and Smith, 1984), were found to be in good quantitative agreement with a turbulent production mechanism (radar volume reflectivity was $2\times10^{-18}\,\mathrm{m}^{-1}$, turbulent energy dissipation rate 50 mW/kg).

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Published by Copernicus GmbH on behalf of the European Geosciences Union.

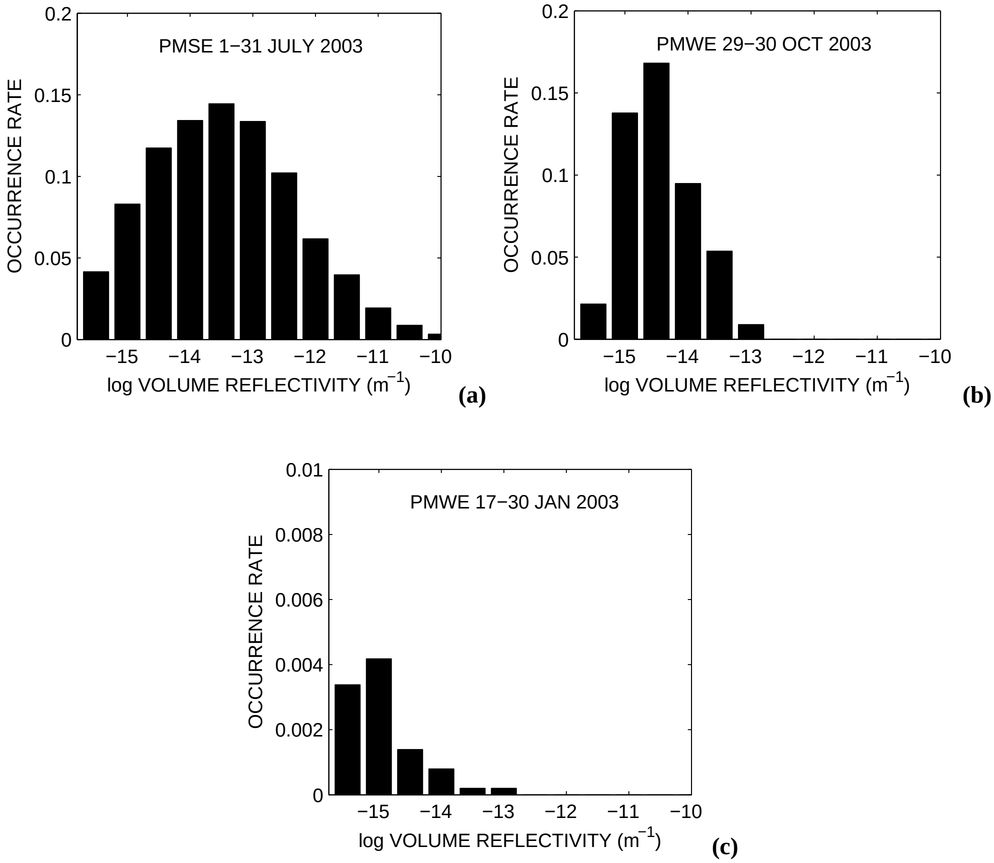

Fig. 1. Statistical analysis of the maximum volume reflectivity associated with radar echoes from the mesosphere observed by the ESRAD 52 MHz radar during different conditions. Maximum volume reflectivity is the maximum observed in each 2-min averaged height profile between the heights specified below. Occurrence rate is the fraction of total time when profiles with maximum volume reflectivity in the relevant interval were observed. Top panel shows the results for summer, heights 80–90 km, for the whole of July 2003. Middle panel shows the results for winter, heights 50–75 km, during a major solar proton event in October 2003 (Belova et al., 2005). Lowest panel shows the results for winter, heights 50–75 km, during the MacWAVE campaign in January 2003. All measurements were made with the same radar operating parameters. The derivation of volume reflectivity is as described in Stebel et al. (2004).

6 Conclusions

Measurements made at Esrange during the MaCWAVE sounding-rocket campaign in January 2003 have been used to test whether layers of enhanced radar echo in the winter mesosphere (PMWE) are likely to be caused by turbulence or by charged aerosol.

Close to simultaneous, co-located measurements of atmospheric static stability and wind shear from the MaCWAVE falling spheres, and PMWE from the ESRAD radar have not provided any evidence of background conditions favouring turbulence associated with most PMWE. The majority of PMWE were seen in conditions that would not be expected to be associated with turbulence, at least on the vertical scale resolved by falling spheres (about a kilometre or more). Observed PMWE volume reflectivities are also found to be too high to be explained on the basis of previously published theory relating turbulence to radar echoes (Hocking, 1985) and published measurements of maximum turbulent intensity (Lübken et al., 1993; Lübken, 1997), unless some other process in addition to the turbulence creates small-scale gradients in electron density. A preliminary comparison of falling-sphere densities with lidar backscatter shows no distinct signal of any contribution of aerosol particles to the lidar scatter. However, a contribution of less than 10–20% would not be detectable in the data available. Night-time Langmuir probe measurements show charge density structures in the height region where PMWE are seen during daytime. These suggest that underlying layers of aerosol particles or other minor constituents in the background atmosphere may be present. No direct evidence of aerosol particle presence can be found in the blunt-probe measurements, however these measurements are insensitive to small aerosol particles.

In conclusion, the action of neutral turbulence alone does not appear to give a good explanation for PMWE. At the same time, the possible role of aerosol particles remains uncertain.