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Polar mesosphere summer echoes with ESRAD, Kiruna, Sweden: Variations and trends over 1997–2008

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ABSTRACT

Measurements of Polar Mesosphere Summer Echoes (PMSE) with the MST radar ESRAD, in northern Sweden, from 1997 to 2008, were used to study diurnal, day-to-day and year-to-year variations of PMSE. The PMSE occurrence rate and volume reflectivity on a daily scale show predominantly semidiurnal variations with small interannual variability in the shape of the diurnal curves. Day-to-day and interannual variations of PMSE are found to correlate with geomagnetic activity while they do not correlate with mesopause temperature or solar activity. No statistically significant trends in PMSE occurrence rate and length of PMSE season were detected over the observation interval.

1. Introduction

Polar Mesosphere Summer Echoes (PMSE) are strong radar echoes observed from mesopause altitudes at polar latitudes during summer time. A radio wave is scattered at irregularities in the radio refractive index when it reveals structures at the radar half wavelength (Tatarskii, 1961). At mesopause altitudes the radio refractive index is mainly determined by the free electron number density. It is now generally accepted that both charged ice particles and atmospheric turbulence play major roles in the creation of the electron number density structures that lead to PMSE in the mesopause region (Rapp and Lübken, 2004). From May to August in the northern hemisphere, temperatures of 130 K and lower are commonly found at altitudes 80–90 km. This allows particles to form from water vapor and to grow at mesopause altitudes (~85–88 km). Measured radii of these aerosols are typically between ~5 and 50 nm (Rapp and Lübken, 2004). The largest charged ice particles (larger than ~20 nm) are observed visually from the ground in the form of noctilucent clouds (NLC). Gravity waves propagating from the troposphere grow unstable in the mesosphere and create turbulence which produces irregularities in the radio refractive index, thus leading to radar echoes. More detailed reviews on PMSE have been published by Cho and Röttger (1997) and Rapp and Lübken (2004).

In recent years, NLCs have attracted considerable scientific interest because it has been suspected that these mesospheric clouds could be possible indicators of global change in the mesosphere (Thomas and Olivero, 2001). In practice, it is difficult to test this hypothesis because the long-term measurements of NLC are based mainly on visual and lidar observations which depend on human and weather factors. Recent statistics of the NLC occurrence rate (for NLC observations made by eye from the ground) show that there is no statistically confident overall long-term trend during the last 43 years (Kirkwood et al., 2007a). However, the authors commented that the observational limitations and high year-to-year variability in NLC makes it impossible to determine any trend less than 1% per year. PMSE observations with radar, unlike NLC observations, have the advantage of being continuous, and independent of observers and weather conditions. Thus PMSE observations over a long interval, at least over one solar cycle, are very attractive for studying variations and long-term trends in the atmospheric parameters at the polar mesopause.

PMSE were detected for the first time with the 50 MHz MST radar at the Poker Flat Research Range (65°N; 147°W), in Alaska, USA, in 1979 (Ecklund and Balsley, 1981). Since this first observation, PMSE measurements have been carried out by many radars, among others in the Northern Hemisphere—in Kiruna, Sweden (68°N; 21°E), Hankasalmi, Finland (62.3°N; 26.6°E), Andenes, Norway (69°N; 16°E), Svalbard, Norway (78°N; 16°E), Tromsø, Norway (69°N; 19°E), Resolute Bay, Canada (75°N, 95°W)—and in the Southern Hemisphere—in Antarctica at the Davis (69°S, 78°E), Wasa (73°S, 13°W) stations (e.g. Kirkwood et al., 1998; Ogawa et al., 2003; Bremer et al., 2009; Zecha and Röttger, 2009; Rapp et al., 2008; Huaman et al., 2001; Morris et al., 2007; Kirkwood et al., 2007b).

This paper presents the results of PMSE observations over the period 1997–2008 from the ESRAD 52 MHz radar located near Kiruna in Sweden. This is the world's longest data set of PMSE

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observations made by the same radar at the same site with the same operating mode. We have analyzed the characteristics of the polar mesosphere summer echoes in terms of diurnal, day-to-day and year-by-year variations of occurrence rate and diurnal variations of the volume reflectivity. We have examined the possible relationship between day-to-day variations of PMSE occurrence rate, mesopause temperature, meridional wind and geomagnetic activity. Observations of winds and temperature, starting from 2003, were obtained with the collocated SKiYMET meteor radar. We have investigated the changes in meridional wind and zonal wind shear associated with the start of the PMSE season. The influence of solar and geomagnetic activity on year-to-year variations in PMSE occurrence rate and the length of the PMSE season have been investigated, and the trends over whole 12-year interval have been studied.

2. Radars and data description

PMSE measurements have been carried out during the years 1997–2008 with the ESRAD MST (Mesosphere–Stratosphere–Troposphere) radar in northern Scandinavia. (The year 1999 is not considered because of a radar malfunction.) ESRAD is a 52 MHz atmospheric radar located at the rocket range Esrange near Kiruna in Sweden (67.88°N; 21.10°E). The ESRAD antenna consists of an 18×16 (12×12 up to 2003) array of 5-element Yagis placed at 4.4 m (0.7 times the radar wavelength) from each other. This array is divided into 6 sub-arrays. Each sub-array is connected to a separate receiver. The main parameters of the ESRAD radar are shown in Table 1. A more detailed description of the ESRAD radar is given by Chilson et al. (1999). The radar is capable of operation in many different modes. The main radar modes usually used for long-term PMSE measurement are 'fca_4500' and 'fca_150'. The first mode, 'fca_4500'; uses an 8-bit complementary coded, 600 m resolution pulse train and a narrower receiver bandwidth, giving higher sensitivity. The second mode, 'fca_150', provides 150 m height resolution but has relatively poor signal-to-noise characteristics. The mode 'fca_4500' should be able to detect at least ten times weaker echoes than the mode 'fca_150'. Therefore in our investigation we used only the mode 'fca_4500'. The corresponding parameters are presented in Table 2. The height range of PMSE measurements was 80–90 km. Fig. 1 shows a typical example of PMSE observed by the ESRAD radar during one of the days in 2008.

Observations of winds and temperatures were obtained from the SKiYMET (All-Sky Interferometric Meteor Radar) radar located less than 1 km from the ESRAD radar, at Esrange. SKiYMET is a 32.5 MHz, multi-channel, coherent-receiver, pulsed radar. The receiving antenna consists of five separate crossed-element Yagi aerials, configured to act as an interferometer. A single aerial is used as the transmitter. The main parameters of the SKiYMET radar are collected in Table 3. The radar has provided continuous data collection since August 5, 1999. For our investigation we selected data for hourly averaged winds from heights 80.8, 84.6, and 87.5 km because the mean PMSE altitude is about 85–86 km. The temperature measurements are evaluated from meteor decay time (Hocking, 1999). These temperatures are daily mean values at altitude range 87–90 km. The radar and the wind observations are described in more detail by Hocking et al. (2001) and Mitchell et al. (2002), respectively.

We calculated the volume reflectivity which provides us with information about the characteristics of the scatterers, independent of the characteristics of the radar used. Following Kirkwood et al. (2007b) we defined the volume reflectivity as

$$\eta=\frac{P_r}{P_t}\frac{64(2\ln 2)r^2}{\pi L A_e F\Delta r}, \qquad (1)$$

where P_t is power delivered to the radar, P_r is power received by the radar, r is the distance to the scattering volume, Δr is the range resolution along the radar beam, L is loss in the antenna feed (L=0.39 was set), F is the fraction of the scattering volume which is filled with scatterers (F=1 was assumed) and A_e is effective area of the receiving antenna ($A_e=(\lambda^2 G/4\pi)$ where G is the antenna gain).

The power received by the radar can be estimated using the formula:

$$P_r=\frac{k_b B\Delta T_{sky}(S_{tot}-(S_{sys}+S_{sky}))}{C_{filt}n_{coh}n_{code}\Delta S_{sky}}, \qquad (2)$$

where k_b is Boltzman's constant, B is the receiver bandwidth, ΔT_{sky} is the daily variation of the sky noise, S_{tot} is the total detected power, S_{sys} is the power due to internal system noise, S_{sky} is the power due to sky noise, ΔS_{sky} is the range of the daily variation in sky noise, C_{filt} is a receiver filter efficiency, n_{coh} the number of coherent integrations and n_{code} is twice for the number of bits in the code. The range for ΔT_{sky} is evaluated from assimilated maps of calibrated surveys of the radio-sky, scaled to 52 MHz (Oliveira Costa et al., 2008) and is given in Table 1. The sum of (S_{sys}+S_{sky}) was calculated by averaging the power detected at the range gates where scattered signal was not expected (30–50 km). Note that all of the parameters S were used in the same arbitrary units.

PMSE occurrence rates (OR) are calculated for every hour. OR is 1 if the volume reflectivity averaged over 1 h exceeds the

Table 1
ESRAD radar characteristics.

Radar	ESRAD
Location	
Geographic coord./ height	67.88°N; 21.10°E; 295 m
Geomag. latitude/ geomag. midnight	64.82°N; 22:50 LT
Transmitter system	
Peak power	72 kW
Pulse repetition frequency	100 Hz–16 kHz
Max. duty cycle	5%
Pulse length	1–50 μs
Height range	1–110 km
Codes	Barker (2, 3, 4, 5, 6, 7, 11, 13 bits) Complimentary (2, 4, 8, 10, 16, 32, and 64 bits)
Antenna	12×12 array 5-element yagis separated by 0.7 λ 16×18 array since April 2004
Receiving system	
Sampling interval	1–20 ms
Filters	250, 500, 1000, 2000 kHz
Other information	
Galactic noise T_{sky}	1680–4500 K
Operational dates	July 1996—present

Table 2
ESRAD operating modes used in this study.

Radar modes	fca_4500
Pulse length (3 dB)	2.1 μs
Sampling resolution	600 m
Coherent integrations	128 (98.4 ms) per code up to 2004 32 (24.6 ms) per code
Filter bandwidth	250 kHz
Pulse repetition frequency	1300 Hz
Duty cycle	2.7%
Start altitude	4.8 km
End altitude	105 km
Receiver filter efficiency C_{filt}	0.72
Mean altitudes for (S_{sys}+S_{sky})	30–50 km