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Investigations of the possible relationship between PMSE and tides using a VHF MST radar

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Abstract. The possible relationship between Polar Mesospheric Summer Echoes (PMSE), tidal winds and vertical wind shear associated with the tidal winds is examined. PMSE were observed by the Esrange VHF MST Radar (ESRAD) 52 MHz radar at 67°56'N, 21°04'E during May-August 1997. Three data series in the beginning, middle and the end of the PMSE season are considered. The seasonal variation of PMSE shows a steep increase in occurrence at the end of May and fade-out in mid-August. Daily variation of echo power in the middle of the season has a minimum around 20-22 UT. Wind measurements reveal terdiurnal, semidiurnal and diurnal tides. Between 82-87 km we found a strong wind shear which tends to increase through the season, but does not show significant correlation with SNR (signal-to-noise ratio). It seems likely that PMSE appearance is conditioned by small scale dynamics and tidal effects on aerosols, and not by large scale wind shear.

Introduction

Polar Mesospheric Summer Echoes (PMSE) are strong radar echoes commonly observed by VHF MST radars from thin layers in the 80-90 km altitude interval at high latitudes during summer. These radars detect echoes from refractive index fluctuations due to density, temperature, humidity, electron density variations, turbulence and air mass mixing [*Cho and Kelly*, 1993; *Cho and Röttger*, 1997]. Most turbulence in the mesosphere is believed to be produced by breaking of saturated tides and gravity waves, and the two main production mechanisms are thought to be through dynamical or convective instability [*Fritts et al.,* 1988]. Recent studies verified the relationships between waves, tidal components and PMSE, but their interpretation varies from wave-induced temperature changes [*Rüster*, 1995; *Cho and Morley*, 1995; *Chilson et al.*, 1997] to wave-induced shear instabilities [*Williams et al.*, 1989; 1995] as possible links between the dynamics and PMSE. In support of the latter explanation, *Fritts et al.* [1988] suggested that the maximum of echo power occurs preferentially in regions of small positive Richardson numbers induced by dynamical instabilities associated with the backgrounds wave field, and *Klostermeyer* [1992] has argued that turbulent structures are produced by parametric instability of long-period waves.

A study of PMSE using the SOUSY VHF radar [*Czechowsky et al.*, 1989] demonstrates that many of the weaker echoing regions are related to the background wind shear. The wind shear can be concentrated in narrow altitude regions, within which the horizontal wind speed is minimum and the gradient in vertical velocity has a relative extremum [*Widdel and von Zahn*, 1990; *Hooper and Thomas*, 1997]. Around these altitudes the Richardson number, which is a criterion for dynamical instability of the atmosphere, tends to be close to or slightly smaller than 0.25, indicating that turbulence might possibly be present there.

In this paper we present results obtained during the first complete season of PMSE observations using the Esrange MST radar. We examine the possible relationship between PMSE, tidal wind variation and vertical wind shear associated with the tidal winds.

PMSE observations with ESRAD

Observations of PMSE were carried out by the Esrange MST Radar (ESRAD) located at Esrange (67°56'N, 21°04'E), just outside Kiruna in northernmost Sweden. ESRAD operates at 52 MHz with 72 kW peak power and a maximum duty cycle of 5%. The antenna consists of a 12×12 array of 5-element Yagis with a 0.7λ spacing. The radar is designed to use the spaced antenna, Doppler beam swinging and meteor wind measurement techniques. An automated switching system enables multiple sequential measurements with predetermined radar configurations. During the PMSE measurements the radar used a 16-bit complementary code having a Baud length of 1 μS. This corresponds to height resolution of 150 m. The sampling frequency was set at 1450 Hz. For these observations ESRAD was operated in a spaced antenna mode [*Briggs*, 1984].

PMSE have been observed with ESRAD within the 80-90 km height interval from 20 May to 24 August 1997. Echoes can be judged to be present if the SNR (signal-to-noise ratio) exceeded -5 dB at any height. This limit is somewhat conservative (compare to the -10 dB limit used by *Kirkwood et al.* [1998] for the same radar configuration), but was chosen such as to increase the confidence level of our analysis. SNR values exceeding 50 dB have been excluded, since they represent noise spikes. Figure 1 presents 3, 3-day series in the beginning, middle and the end of the PMSE season. Note that in this study we choose to investigate discrete time intervals as opposed to a more general analysis of PMSE data over the entire season. Our observations show considerable variation in the periodicities in the SNR and winds associated with the PMSE throughout the season. Consequently, we have chosen to concentrate on subsets of our data. The clearest feature in the date shown in Figure 1 is the rapid increase of PMSE in the beginning of the season, i.e. 26, 27 and 28 May. Echoes start at about 86 km, then extend successively over the height interval between 80 and 90 km. In the middle of the season the echoes are strong and continuous as shown for 23, 24 and 25 June. The echoes gain maximum values in the middle of the day, have a minimum in the evening and a less pronounced

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minimum in the morning (Figures 1, 2). The decay of PMSE is a gradual process. The echoes became more irregular and less powerful, as is shown for 12, 13 and 14 August. An analogous tendency for seasonal occurence has been previously reported by *Kirkwood et al* [1998] and *Cho and Röttger* [1997]. However, in all three cases, we observe a tendency to lower values of PMSE after 17 UT (Figure 2), with a pronounced minimum around 20 - 22 UT in the middle of the season. This pattern of daily variation has also been seen in longer time series (*Czechowsky et al.*, 1989; *Kirkwood et al.*, 1995; *Hoffmann et al.*, 1997) and variations might reasonably be thought to be related to effects of the tidally varying background winds. To investigate this hypothesis we have considered the time series of the zonal and meridional wind components. Due to unavoidable gaps in the data series, a harmonic fitting procedure has been applied.

Tidal winds and vertical wind shear

The analysis reveals the existence of the diurnal, semidiurnal and terdiurnal tides for all three cases. In Figure 3 we present the combined mean, 8-h, 12-h and 24-h wind components found using the harmonic fitting. As expected, the zonal wind field is characterised by a strong westward flow which demonstrates some seasonal variation. Maximum values reach 120 ms^{-1} primarily at 83 km. In June and August the easterly (towards the west) component falls off towards the higher altitudes. Above 85 km the mean easterly wind is minimum and the overal winds (mean plus tidal components) change to westerlies at times. The meridional component is found to be predominantly southward, consistent with that expected for the summer mesosphere [*Kirkwood et al.*, 1995; *Schminder et al.*, 1997]. However, the meridional component decreases and changes its direction to northward a few times during the day. Minimum wind speeds of the meridional component vary for different times of the season, and one possibility to be examined is whether this in combination with the minimum of the zonal component might explain the minimum in PMSE. The general feature for the both the zonal and meridional components is their height dependent variability, which might be connected with interactions between different tidal modes or to the Doppler shifting of the propagating waves in the presence of a strong background wind field [*Hansen and Hoppe*, 1996].

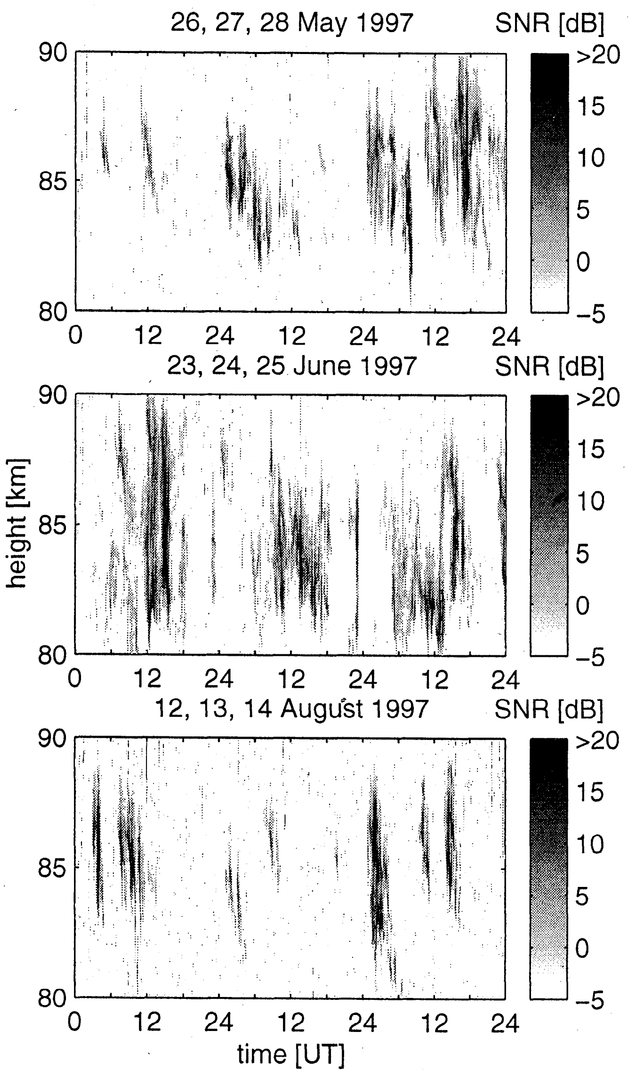

Figure 1. Plots of SNR versus altitude and time for 26, 27, 28 May, 23, 24, 25 June and 12, 13, 14 August 1997.

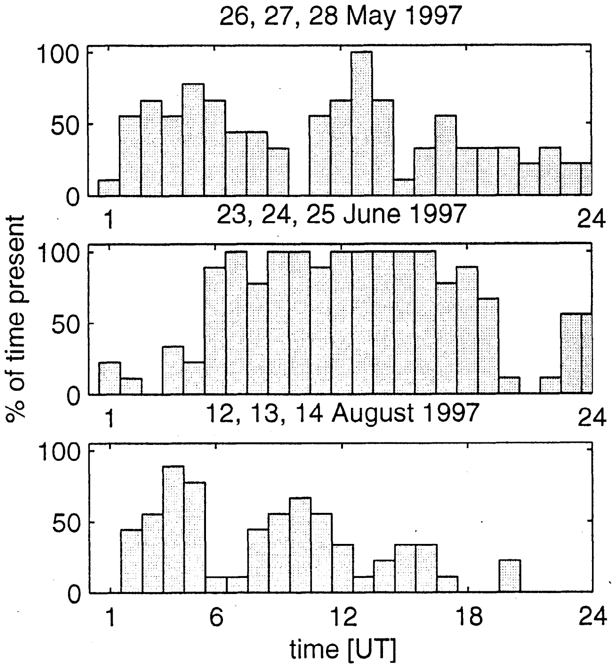

Figure 2. Occurence rates of PMSE as a function of time of day.

One possibility for strong turbulence is shear instabilities in the prevailing winds. We have examined this quantity within the height interval 82-87 km. The vertical wind shear has been calculated using

$$S_z = \sqrt{\left(\frac{\Delta u}{\Delta z}\right)^2 + \left(\frac{\Delta v}{\Delta z}\right)^2}$$

where Δu and Δv are changes in the zonal and meridional components of the tidal wind across the sampling volume, respectively, and Δz is the range resolution of the radar, here 150 m (Figure 3). The maximum values of the shear tend to increase through the season and altitude, and can reach values of 200 m s^{-1} km^{-1} for some heights above 85 km. The scatter plots for heights 84 and 86 km show a lack of correlation between the echo power and the wind shear which is typical for

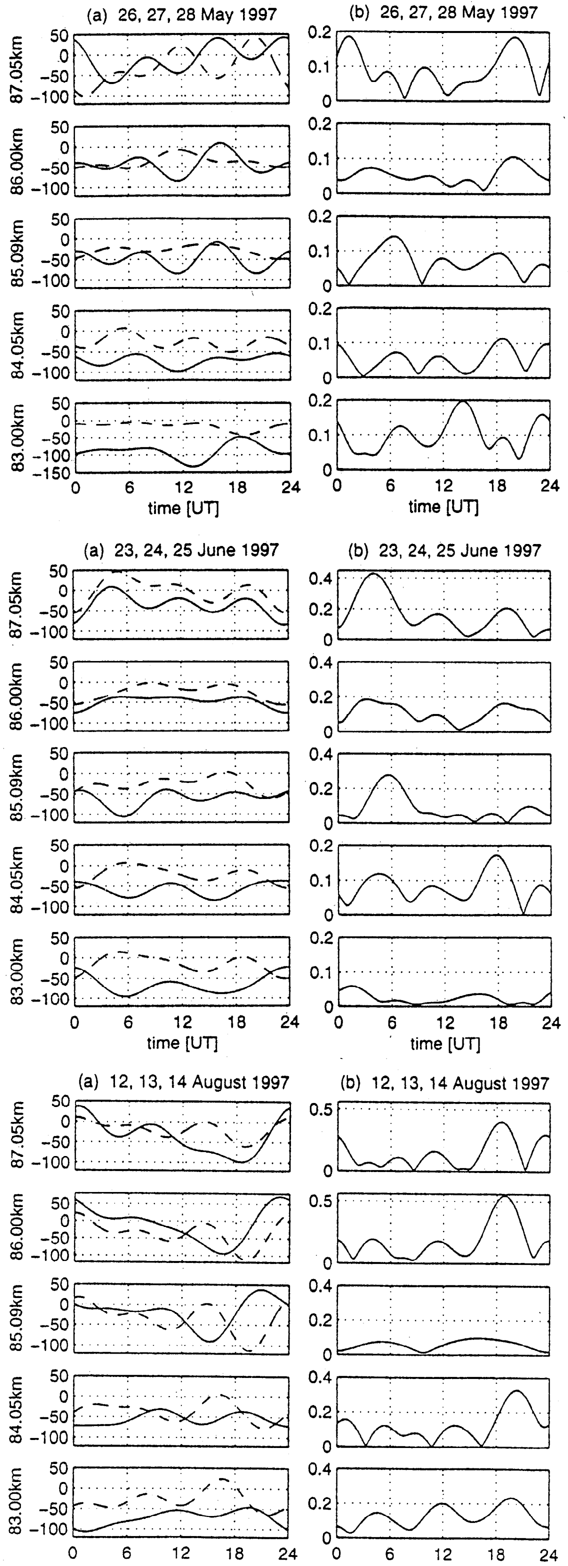

Figure 3. Tidally varying zonal wind (solid line) (a), meridional (dashed line) wind (a), and vertical wind shear (b) for 26, 27, 28 May, 23, 24, 25 June and 12, 13, 14 August 1997. Wind values are given in ms^{-1}. Positive and negative values of zonal wind correspond to eastward and westward components, respectively. Positive and negative values of meridional wind correspond to northward and southward components, respectively. The vertical wind shear is expressed in s^{-1}.

all heights (Figure 4). The lag time of the autocorrelation function calculated from the radar series data, which is proportional to the inverse of the spectral width, varies for these cases between 0.19 and 0.45 s, typical of regions of turbulence. However, as it seen there is no evidence for correlation between the vertical wind shear and SNR. The PMSE (high SNR) is equally likely to occur for high shear as well as for low shear.

Discussion

VHF MST Radar observations during May-August 1997 reveal the seasonal occurrence of PMSE, characterised by a rapid increase in the beginning and gradual decay at the end of the season. Daily variations of PMSE have lower values after 17 UT during the whole season and a pronounced minimum between 20-22 UT in the middle of the season. Horizontal wind components demonstrate terdiurnal, semidiurnal and diurnal tidal variations.

Between 82-87 km we found strong vertical wind shears associated with the tidal winds. Our data show that values of wind shear tend to increase through the season, but there is no significant correlation between SNR values and the vertical wind shear. This is somewhat in disparity with *Czechowsky et al.* [1989], who found that weak echo power observed by the SOUSY VHF Radar is related to the wind shear. This discrepancy might be partially explained by differences in power-aperture products of ESRAD and the SOUSY radar,

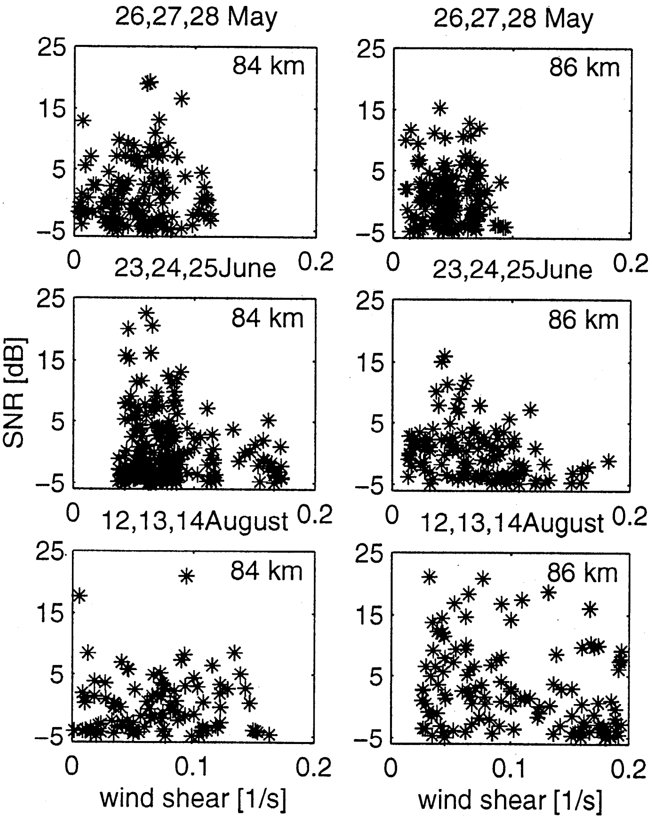

Figure 4. Scatter plots of the correlation between the SNR and the vertical wind shear at 84 and 86 km for 26, 27, 28 May, 23, 24, 25 June and 12, 13, 14 August 1997.

making detection of low SNR by ESRAD difficult. We might also be seeing a quasi-specular type of PMSE observed by *Thomas et al.* [1992]. They showed different correlations between SNR and spectral width, and had different aspect sensitivities [*Thomas et al.*, 1992]. We note that *Czechowsky et al.* [1989] also showed that regions in their PMSE data with strong power tended to be associated with the narrowest spectral width and show no clear relation to shear produced by long-period wave motions or the background wind. Since ESRAD was operated in a spaced antenna mode, we hope to conduct an analysis similar to that reported by *Leiscar and Hocking* [1992] to try and parameterize the degree of specularity in our data

The possibility remains that tidal effects on aerosols and/or small scale dynamics, i.e. Kelvin -Helmholtz instability, may be involved in the variability of the echoes. The presence of large charged species, such as ice aerosols and extremely large cluster ions, that lower the electron diffusivity, has been found to be a necessary (but not sufficient) factor for PMSE production [*Lübken et al.,* 1993; *Cho and Röttger*, 1997]. Subvisible ice particles with low charge number and number densities of the order of the electron density are assumed to be the main participants, including meteoric dust and embryonic ice-cloud particles [*Cho and Kelley*, 1993]. The potential influences on the aerosols of temperature fluctuations associated with tides and gravity waves, are not fully understood. Furthermore, studies by *Czechowsky and Rüster* [1997] have demonstrated cloud-like structures of enhanced turbulence in the upper layer of PMSE. The lifetime of these cells are of order of 20 to 30 min., the horizontal extent less than 40 km, and they move with the same phase trace velocity as simultaneously observed gravity waves. It has been suggested that these turbulent cells are generated by a Kelvin - Helmholtz mechanism. Hence, they are expected to be observed in the regions of strong wind shear.

There remains much work to be done in this area, and we are investigating some of the above mentioned effects on the temporal variability of our data. Nevertheless we can already conclude from our observations that the daily variation of the echoes for these days is not determined by large scale wind shear producing turbulence, and wind shear seems not to be a necessary precondition for PMSE.

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