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First artificially induced modulation of PMSE using the EISCAT heating facility

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Abstract.
A coordinated experiment involving ionospheric heating and VHF observations of polar mesosphere summer echoes (PMSE) has recently been conducted at the EISCAT facility near Tromsø, Norway. We have demonstrated for the first time that ionospheric heating can influence VHF radar returns associated with PMSE. Artificially elevating the electron temperatures within the PMSE layer has been shown to reduce the echo power. Based on this and other results from the experiment, it is suggested that the observed reduction in PMSE power is related to an enhancement of the electron diffusivity through the heating.

1. Introduction

Polar mesosphere summer echoes (PMSE) are strong radar returns that occur during summer months near the mesopause at high latitudes. It is commonly believed that at VHF, the enhanced radar backscatter associated with PMSE is related to the presence of ions and charged aerosols [e.g. *Cho et al.*, 1992]. The central problem connected with PMSE is that structures in the electron density distribution required to produce VHF radar echoes should be quickly dissipated by turbulence or, at least, molecular diffusion. However, the diffusivity of the free electrons could be reduced via ambipolar interactions with the heavy ions/aerosols and allow the structures to persist [*Kelley et al.*, 1987]. A quantity used to parameterize this effect is the Schmidt number, Sc, which is given by the ratio of the kinematic viscosity and the molecular diffusion coefficient. For a neutral gas, $Sc \sim 1$.

We note that there are problems with invoking enhanced Schmidt numbers to explain PMSE. The Schmidt-number mechanism requires neutral turbulence. However, rocket measurements made within a PMSE layer have shown cases for which there were strong fluctuations in the electron number density without corresponding fluctuations in the neutral number density [*Lübken et al.*, 1993].

An ionospheric heating experiment was conducted in conjunction with observations of PMSE using a VHF radar in an attempt to test these and other theories. We present the first results from the experiment and offer a preliminary interpretation of them.

2. Experiment

During the period July 1 - 16, 1999, the EISCAT VHF radar (69.58°N, 19.22°E) in Tromsø, Norway was operated for a total of 87 hours as part of a multi-national campaign to observe PMSE and noctilucent clouds. Participating countries in the EISCAT radar measurements were Germany, Norway, and Sweden.

The radar parameters used for this experiment were the same as those given in *Chilson et al.* [2000]. In short, the EISCAT VHF radar was operated in a two-frequency mode using 224.0 and 224.6 MHz; however, for the present investigation the dual frequency data are not exploited. Pulses were transmitted with an inter-pulse period of 2.487 ms, and 12 samples were coherently averaged to produce a single data point (in-phase and quadrature). A total of 64 data points were stored as a single data record before writing the information to disk. This results in a dwell time of 1.88 s, but the data dump interval was 2 s. For a technical description regarding the radar see *La Hoz et al.* [1989].

The EISCAT heating facility is used for ionospheric modification experiments by transmitting powerful radio waves in the frequency range of 3.85 to 8 MHz [*Rietveld et al.*, 1993]. We have operated the heating facility in several experimental modes in conjunction with the measurements of PMSE with the EISCAT VHF radar. Prior to conducting the

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heating experiments it was not known whether it would be possible to effect an observable modification to PMSE. Indeed, earlier attempts to modify the characteristics of PMSE using ionospheric heating have failed [*Röttger, 1999, private communications*]. Therefore, several variants on the configuration of the heating parameters were tried. A total of 16 heating experiments were performed using 13 unique configurations. These were distributed over 10 hours of heating time. Here we present results from 4 of the experiments. A short summary of the heating experiments is presented in Table 1. The heating parameters for the other 12 experiments represent either slight variations of those shown in Table 1 or were designed to test more subtle effects of ionospheric effects on PMSE. In all of the experiments listed in Table 1, the polarization of the transmitted waves corresponded to the extraordinary mode.

3. Results

For the periods corresponding to the times of the heating experiments, the first three spectral moments of the EISCAT radar complex time-series data were calculated on a "dump-by-dump" basis for each of the two transmitted frequencies. That is, estimates of the backscattered power and the center and spread of the Doppler frequency spectrum were estimated for every data record. A more thorough description of the data analysis method is given in *Chilson et al.* [2000]. For the present analysis, we only consider the zeroth moment of the Doppler spectrum, that is, the backscattered power. Note that all powers are expressed in arbitrary units.

Overview plots showing the results from experiment 01 are presented in Figure 1, where the full range of heights and time for the heating experiment are shown. Range-time-intensity (RTI) plots of the backscattered power corresponding to times when the heater was transmitting (P_{on}) and when the heater was not transmitting (P_{off}) are shown separately. From the RTI plots it is already quite obvious that the backscattering cross-section of the PMSE has been dramatically reduced through the introduction of the ionospheric heating.

We next present the data shown in Figure 1 in more detail by producing time histories of the PMSE backscatter power for two different heights. These are shown in Figure 2. The differences in the logarithm of P_{on} and P_{off} are roughly constant in time for both heights, provided P_{on} remains above the level of the background noise. We note, however, that cases have been found during the other heating experiments (not shown here) for which the differences *do* vary with time. We furthermore note, that the differences between P_{on} and P_{off} exhibit a height dependence. This could be due to the fact that electrons are not heated equally in height [*Belova et al.*, 1995]; however, the difference may reflect inherent differences in the backscattering mechanisms of the PMSE. Differences in PMSE with height have been observed in earlier studies [e.g., *Ulwick et al.*, 1993].

The most striking ionospheric heating effect was obtained during experiment 04, during which the ERP was 629 MW. Results of experiment 04 are shown in Figure 3, where it can be seen that the PMSE were dramatically modified by the heating. Further noteworthy features in Figure 3 are the very abrupt transitions in the power levels, P_{off} to P_{on} and P_{on} to P_{off} and that the values of P_{on} are quite similar before and after each heating pulse. That is, the conditions of the plasma associated with the PMSE layer do not exhibit lasting effects from the heating.

The operation of both the VHF radar and the ionospheric heater places a substantial drain on the available supply of electrical power to the EISCAT site. Consequently, the transmitted radar power, P_{tx}, is slightly reduced during times when the heater is on. It is therefore necessary to consider whether or not the heating effects on PMSE that have been observed are instrumental in nature. In that spirit, Figure 4 has been created. The received echo power is directly proportional to the transmitted power, irrespective of the nature of the scattering mechanism. Since the transmitted power of the VHF radar is continuously monitored and stored with every data record, it is possible to calculate the ratio of the received and transmitted powers, $P_{on/off}/P_{tx}$. For the data shown, P_{on}/P_{tx} is reduced by 80% compared to P_{off}/P_{tx}! By comparison, peak transmitted powers for the radar are only reduced by about 10% when the heater is on.

The data in Figure 4 additionally confirm a feature of the heating experiment that was already observed in Figure 3. It appears that the response time of the heating on the PMSE is less than the 2-second dump time. Otherwise, the ratio of received and transmitted powers would exhibit a pattern of ramping up and down, similar to that found in the peak transmit powers.

Lastly, we present a summary of the data from all 4 heating experiments in Figure 5. The height dependence mentioned earlier is also apparent in these plots. Experiments 05 and 08 provide additional evidence that the observed ef-

Table 1. Partial Listing of the EISCAT PMSE Heating Experiments for 1999

Exp[a]	Date	Time (UT)	Freq (MHz)	ERP[b] (MW)	Modulation Type	Beam Direction
01	July 09	22:06 - 22:55	4.040	194	10 s on / 10 s off	Vert.
04	July 10	01:04 - 01:58	5.423	629	20 s on / 20 s off	Vert.
05	July 10	20:18 - 23:00	4.040	183	20 s on / 20 s off	16° South
08	July 11	00:00 - 00:45	4.040	183	10 s Vert. / 10 s Off-Vert.	Vert. & 16° South

[a] Here the numbering sequence of the original experimental series is maintained
[b] Effective Radiated Power

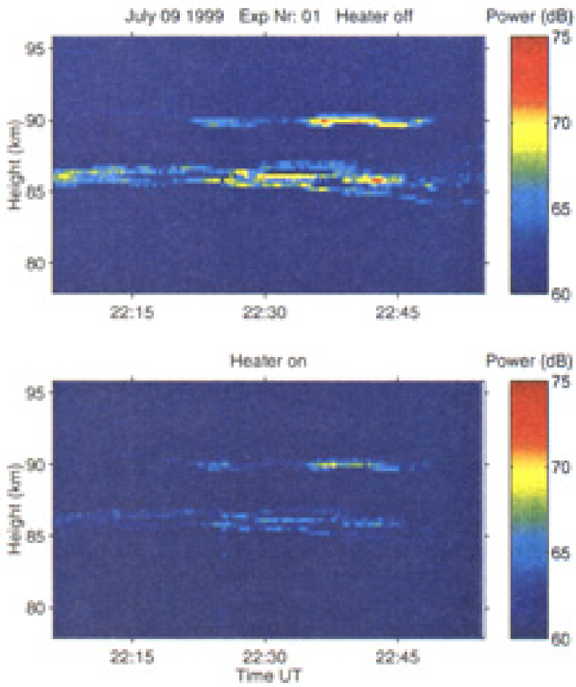

Figure 1. PMSE signal strength during the time of heating experiment 01. The upper panel shows the echo power during the times the heater was off. The lower panel shows the echo power during the times the heater was on

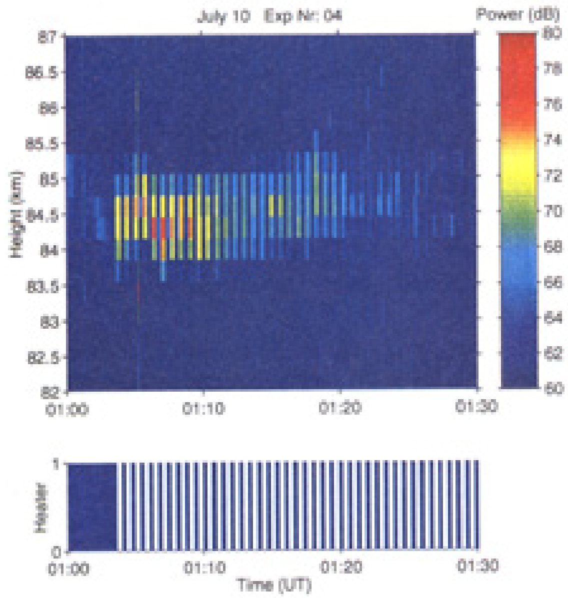

Figure 3. PMSE echo powers recorded during heating experiment 04 for a selected range of times and heights are shown in the upper panel. Data for both the heater on and off states are presented. The lower panel shows the state of the heater, where blue represents "heater on". During the beginning of the experiment the heater was operated continuously while the transmitters were adjusted to their final phases and power.

fects of ionospheric heating on PMSE are not instrumental. During experiment 05, the beam for the heater was directed 16° off zenith and was therefore not illuminating the same volume as observed by the radar. The heater was, however, modulated (on/off), but no effects are observed in the radar echo power. As a final test for instrumental effects, the heater was left on, and the modulation was accomplished by steering the heater beam. As can be seen in the data for experiment 08, the PMSE power is reduced when the heater beam is directed vertically.

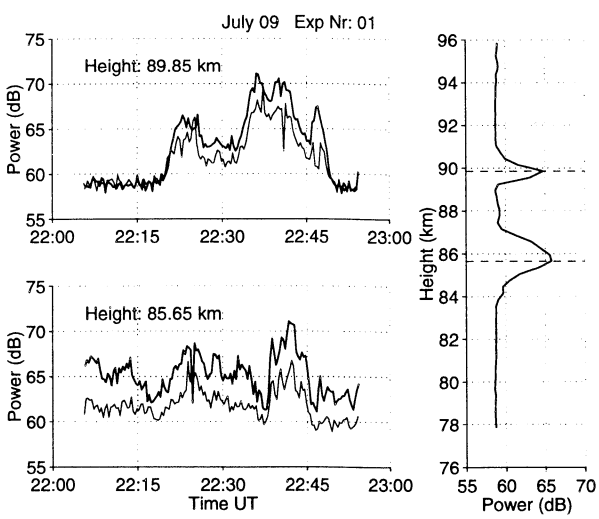

Figure 2. Time histories of the PMSE echo powers recorded during heating experiment 01 while the heater was off (heavy solid line) and on (light solid line) for two different heights. Also shown is the height profile of the echo power (heater off) averaged over the duration of the heating experiment. Dashed lines indicate the heights corresponding to the time histories of the echo powers.

4. Discussion

We have demonstrated for the first time that ionospheric heating can effect a change on VHF radar returns associated

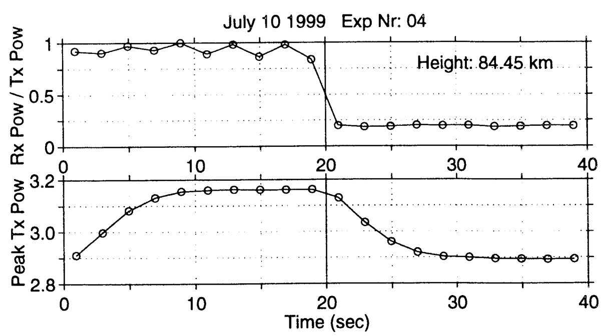

Figure 4. Cyclically averaged plots of the self normalized echo power divided by the transmit power (upper panel) and the transmitted power in MW (lower panel). The first point represents the averaged data from the first 2 seconds in the heating cycle, the second point represents the averaged data from the second 2 seconds in the heating cycle, and so on. The height corresponds to where the PMSE layer had the largest echo power.

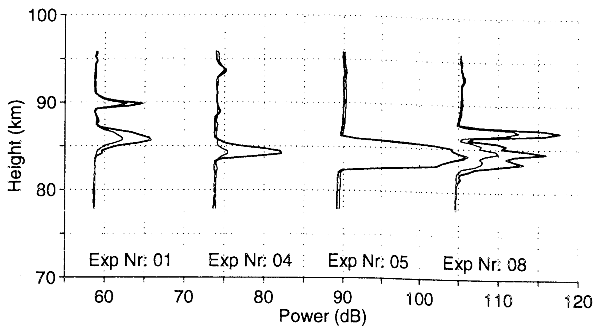

Figure 5. Height profiles of P_{on} and P_{off} averaged over the duration of heating experiments for all 4 heater configurations. Light and heavy lines indicate P_{off} and P_{on}, respectively. The profiles are separated by the addition of a 15 dB offset for the sake of display. See the text for additional information.

with PMSE in such a way that the echo power is reduced. The time required for the transition from P_{off} to P_{on} and P_{on} to P_{off} is less than 2 seconds. Furthermore, the level of reduction of PMSE power through the ionospheric heating demonstrates a height dependence. We must consider a mechanism (or mechanisms) that could account for these results.

One might imagine it to be possible to affect PMSE through heating by modifying the attachment/recombination rates of electrons to the ions/aerosols and thus change the plasma density. However, the recombination time at PMSE heights is several minutes. Therefore, a heating period of 10-20 seconds cannot noticeably change electron concentration. The attachment rate of electrons to aerosols is increased through the effect of electron heating within a few seconds [*Rapp and Lübken*, 2000], which consequently results in a reduction of free electrons. *Cho et al.* [1992] has demonstrated that $|Z_A|N_A/n_e$ must be greater than 1.2 for PMSE to exist, where Z_A and N_A are the charge number and the number density of the aerosols, respectively, and n_e is the number density of the electrons. Therefore we do not expect a reduction of PMSE power through changes in the attachment rates.

Alternatively, a modification of the electron diffusivity may have been responsible for the PMSE power reduction. One expects an increase in the diffusivity of electrons due to heating, which would lead to a reduction of the Schmidt number. So, we suggest that the observed reduction in PMSE power resulting from ionospheric heating is related to the enhanced electron diffusivity, such that structures in the electron density fluctuations responsible for the PMSE are quickly dissipated. Surely, our interpretation is preliminary and qualitative and needs further confirmation using model calculations.

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