PMSE and Propagation at 50 MHz
Carl Luetzelschwab K9LA

Are Polar Mesosphere Summer Echoes a factor in 6-Meter Propagation? Their occurrence pattern seems to fit the occurrence pattern of 6-Meter QSOs across the polar latitudes. In this article K9LA takes a brief look into the physics of the atmosphere in relation to Polar Mesosphere Summer Echoes.

Introduction

Polar Mesosphere Summer Echoes (PMSE) are routinely seen by VHF radars operating around 50 MHz as very strong echoes at high latitudes in the summer months. Echoes are returned from mesopause altitudes (generally 80-90 km), where the lowest temperatures in the atmosphere occur. The red line in Figure 1 shows the atmosphere in terms of temperature, with PMSE altitudes bracketed in white.

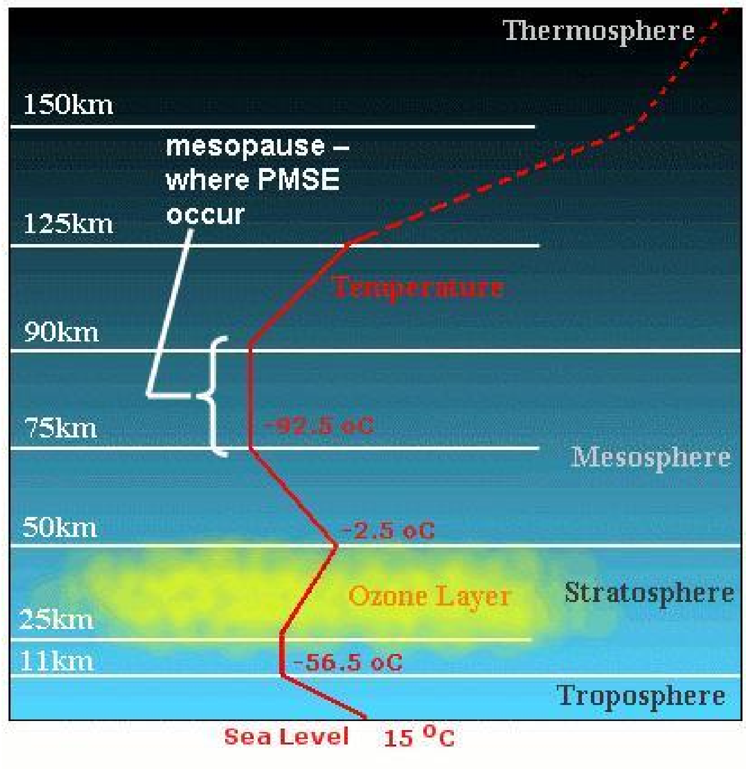

Figure 1 – Temperatures in the Atmosphere

PMSE Observations

PMSE were first observed extensively with VHF radar at Poker Flat (Alaska) in the late 1970s/early 1980s [**footnote 1**]. The extremely low mesopause temperatures allow ice particles to form and grow at mesopause altitudes. Under favorable conditions the largest of these ice particles can be visually observed in the form of noctilucent clouds (NLCs).

These ice particles are immersed in the plasma of the D region, and electrons attach to the ice surfaces such that the ice particles become charged. Turbulence at mesopause altitudes results in small-scale structures in the spatial distribution of the ice particles, and hence in the electron density. These small-scale structures, or irregularities, in the electron density cause scattering and are observed as PMSE by VHF radars.

Further research has also allowed statistical patterns of PMSE to emerge. Figure 2 summarizes the diurnal and seasonal patterns of PMSE in the northern hemisphere.

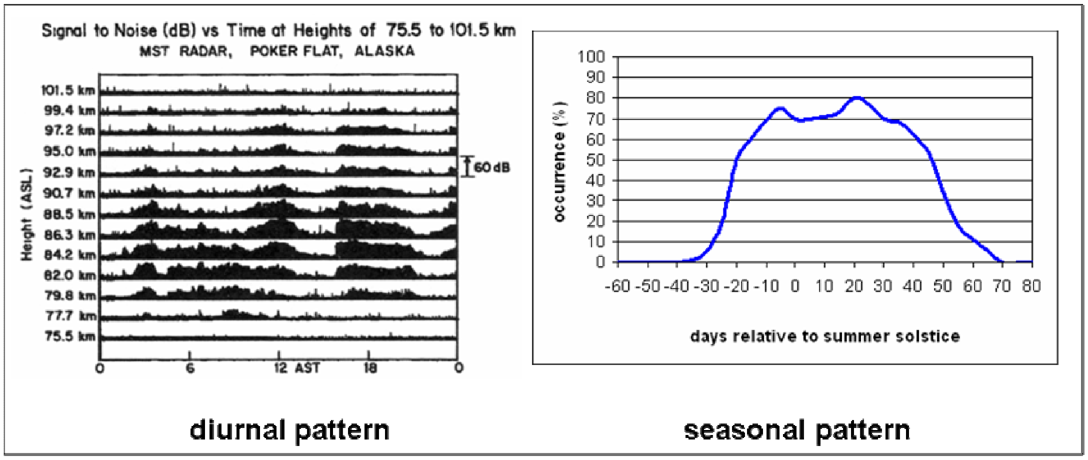

Figure 2 – Statistical Patterns of PMSE

The image on the left in Figure 2 comes from the seminal paper by W. L. Ecklund and B. B. Balsley (*Long-Term Observations of the Arctic Mesosphere With the MST Radar at Poker Flat, Alaska*; **Journal of Geophysical Research**; Volume 86; Number A9; pages 7775-7780; September 1, 1981). In addition to showing the height at which PMSE occur (the aforementioned 80 – 90 km), this image indicates that PMSE occur from roughly 2AM to 1PM local time and from 4PM to 9PM local time at the Poker Flat location in Alaska, with an obvious drop-out at most altitudes from 1PM to 4PM.

The image on the right in Figure 2 comes from data in a paper by R. Latteck, W. Singer, R. J. Morris, D. A. Holdsworth, and D. J. Murphy (*Observation of polar mesosphere summer echoes with calibrated VHF radars at 69^{o} in the Northern and Southern hemisphere*; **Geophysical Research Letters**; Volume 34; L14805; July 2007). This image shows occurrences of PMSE in the northern hemisphere referenced to the summer solstice (usually June 20 or June 21). PMSE are seen from about one month before the summer solstice to about two months after the summer solstice.

Another study of PMSE (M. Smirnova, E. Belova, and S. Kirkwood, *Polar mesosphere summer echo strength in relation to solar variability and geomagnetic activity during 1997-2009*, **Annales Geophysicae**, 29, 563-572, 2011) arrived at two conclusions. First, there is no statistically significant trend in PMSE yearly strengths from 1997 through 2009. Second, there is a correlation with the 3-hour K index – but it may be due to the additional non-PMSE precipitating electrons that get down to mesopause (D region) altitudes when the K index is elevated.

PMSE Hypothesis

In his article in the September 2006 issue of the Japanese magazine CQ Ham Radio (subsequently translated into English in the UKSMG's Six News by Chris G3WOS), Han JE1BMJ first proposed that PMSE may play a role in 50 MHz propagation across the polar latitudes (for example, from Japan to the Upper Midwest of the US). His Figure 3, reproduced herein as Figure 3, shows his hypothesis.

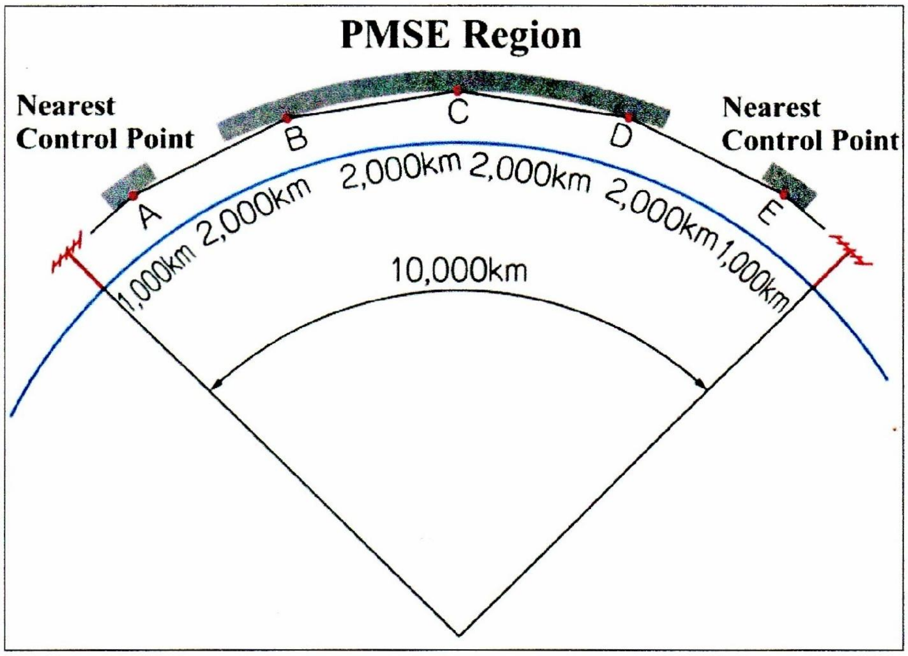

Figure 3 – The JE1BMJ Hypothesis

JE1BMJ hypothesizes that an electromagnetic wave out of Japan encounters the ionosphere at the Nearest Control Point A, and is refracted by this control point such that it then goes into successive chordal hops in the PMSE region until it similarly encounters the Nearest Control Point E on the other end of the path, where it comes back to Earth. JE1BMJ believes the E region is involved in the Nearest Control Points (A and E) based on elevation angle observations, although he suggests that it could be the F1 region [**footnote 2**].

The critical issue in this hypothesis is that the wave must initially encounter the PMSE region (point B in Figure 3) at a very low grazing angle. Why is this? It's due to the extremely low electron density at PMSE altitudes, and the frequencies that this electron density could refract.

PMSE Electron Density

From the earlier explanation of why VHF radars "see" these echoes, PMSE are tied to the number of electrons in the D region of the ionosphere. At a mesopause altitude of 85 km (halfway between 80 and 90 km) at polar latitudes, the electron density during the daytime from our model of the ionosphere is around 2000 electrons per cubic centimeter [**footnote 3**]. This compares favorably with actual PMSE measurements of electron densities in the paper *Polar* *mesosphere summer echoes (PMSE): review of observations and current understanding* by M. Rapp and F.-J. Lübken (**Atmospheric Chemistry and Physics**, 4, 2601-2633, 2004). The right panel of Figure 4 shows this measured electron density data.

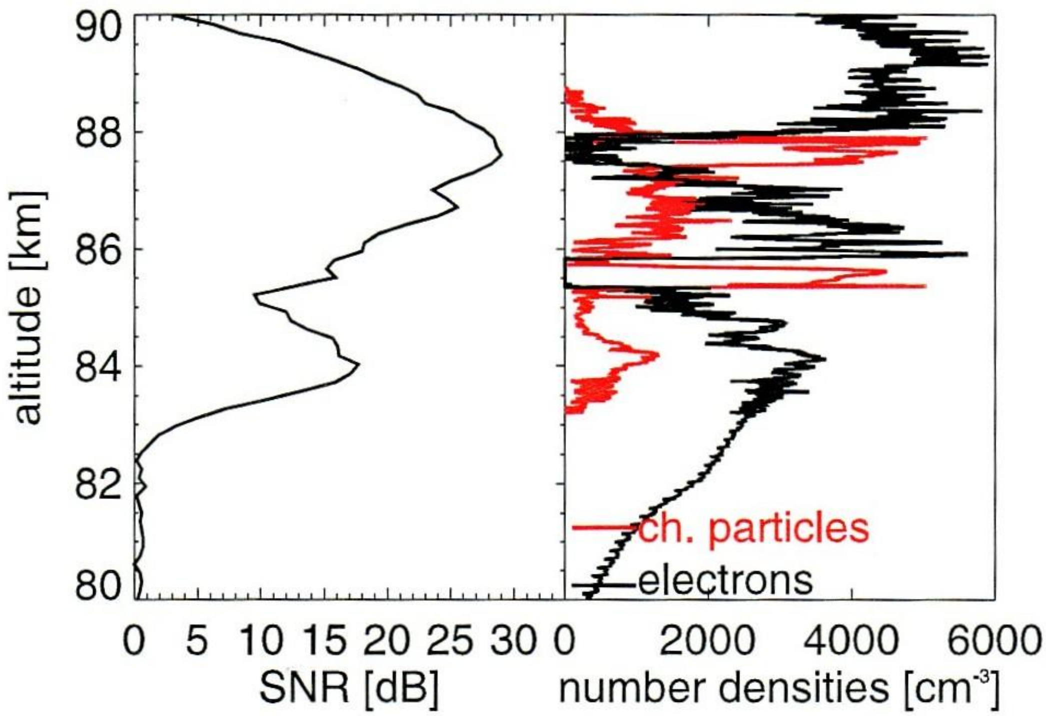

Figure 4 – PMSE Electron Density Measurements

Let's be optimistic and assume from Figure 4 that there are 5000 electrons per cubic centimeter. Translating this electron density to a plasma frequency gives 640 KHz. For this extremely low plasma frequency to refract an electromagnetic wave at 50 MHz requires an M-Factor of 78 (from 50 MHz divided by 640 KHz). This then says an electromagnetic wave must encounter the PMSE electron density at an angle no greater than about 0.7 degrees (a very low grazing angle indeed) per the secant law [**footnote 4**].

Thus for JE1BMJ's hypothesis to work, or for that matter any hypothesis that includes PMSE, the wave arriving at the PMSE region must be at an extremely low grazing angle to allow refraction of an electromagnetic wave at 50 MHz. What mechanisms could allow this condition to be met?

Possible Mechanisms

The most obvious mechanism could be a sporadic E cloud. A sporadic E cloud can have electron densities on the order of (and even greater than) 1,235,000 electrons per cubic centimeter (a plasma frequency of 10 MHz). This is more than enough to bend a ground-reflected upcoming wave enough to encounter the PMSE region at a very low grazing angle.

Since electron density (more appropriately, a gradient in the electron density) is not the only mechanism by which the index of refraction can change to bend a wave, a second mechanism could be what happens down lower in the troposphere – something akin to a temperature inversion. The factors affecting the index of refraction in the troposphere are atmospheric pressure (P), absolute temperature (T), and water vapor pressure (e) per the equation

$$\text{index of refraction} = 1 + [77.6 \times P/T + 373200 \times e/T^2] \times 10^{-6}$$

For typical values of P, T, and e at ground level, the index of refraction is around 1.000315. Because this is such a small amount above 1, the term in brackets is defined as N and the index of refraction of the atmosphere is defined in terms of N-units. In this ground-level example, N = 315. Furthermore, N decreases by about 0.04 N-units per meter of altitude, which is the standard lapse rate.

In a temperature inversion, the amount of N-units is slightly lower than 315 (mostly due to the higher altitude), but the lapse rate can increase to tenths of N-units per meter, which causes more bending and long distance QSOs on 2-Meters and up [**footnote 5**].

Plugging in values of P, T, and e from the World Meteorological Organization standard reference atmosphere (Adolph S. Jursa, Scientific Editor, **Handbook of Geophysics and the Space Environment**, Air Force Geophysics Laboratory, 1985) indicates an extremely low value of N due primarily to the extreme reduction in pressure at mesopause altitudes. Even if there was a significant gradient in N-units in the mesopause (and there could be due to gradients seen in Figure 4 of the aforementioned Rapp and Lübken paper), I seriously doubt that it could generate enough bending to turn a ground-reflected wave enough.

A third mechanism could be scatter. The ground-reflected wave could be forward scattered when it encounters the PMSE region, resulting in a scattered portion of the wave encountering the PMSE region at low grazing angles.

To assess this, we can reverse-engineer the 10,000 km path in Figure 4 to estimate how much loss from scatter could be tolerated. Assuming antenna gains of 14 dBi, calculating a free space path loss of 147 dB, assuming on average 4 dB per ground reflection (from personal reflection coefficient data versus frequency and polarization), and assuming 1 dB of absorption per hop (from Figures 7.5 and 7.6 in Ionospheric Radio Propagation, K. Davies, 1965) says 41 dB of scatter could be tolerated to put a 100 Watt transmitted signal right at the noise floor of a typical Amateur Radio receiver (around -130 dBm in a 500 Hz bandwidth – this assumes man-made noise is not a limiting factor). This value of 41 dB is probably a bit optimistic, as polarization mismatch loss and other small losses were not taken into account.

From Figure 1 of the Latteck, Singer, Morris, Holdsworth, and Murphy paper, the radar volume reflectivity of PMSE is at best 1E-11, which is a loss of 110 dB (now you know why those VHF radars need to run such high ERP). Thus this back-of-the-napkin estimate suggests that scatter, at least in terms of Amateur Radio power levels and antenna gains, is many orders of magnitude away from supporting any hypothesis involving PMSE.

Comments from K6MIO/KH6, WB2AMU, and N0JK

I forwarded a draft of this article to Jim K6MIO/KH6, Ken WB2AMU, and Jon N0JK. I thank them for their comments, which helped me in writing this article. I'd also like to pass along their pertinent comments.

Jim states that, statistically speaking, the path midpoint of an all E layer mode is not in a very good position for propagation, unless either the MUF is simply really high throughout or there is some sort of chordal process helping in the middle. He opines that if chordal hops are involved, then E-layer chordal hops are significantly more likely than anything involving the D layer and PMSE.

Ken comments that the polar region gets almost 20 hours of sunlight during the summer months, and this is one of the factors for increased sporadic E in the area. He also is curious why these paths appear to only show up on 6-Meters, and not on 10-Meters. This may provide an important clue as to what's going on.

Jon points out that my earlier analysis (in the March/April 2007 issue of NCJ) of probability versus time for multiple sporadic E hops on long distance QSOs tends to line up with observations. Jon says this tells him sporadic E is either the total mechanism, or at least a significant part of the mechanism. It very well could be that we're dealing with the 'control point' concept of HF propagation, which says it has empirically been found that if control points on each end of a path (2000 km from each end for the F_2 region) could support propagation, then the entire path could be supported.

Conclusion

We've looked at some fundamental atmospheric physics to determine that PMSE could play a role in propagation at 50 MHz. But it would have to be in conjunction with a sporadic E cloud to provide the necessary very low grazing angle to support 50 MHz propagation through a PMSE region due to the PMSE region's extremely low electron density.

In my opinion, I agree with K6MIO/KH6 that a chordal hop mechanism involving the E region, without any PMSE involvement, could be the most likely mechanism.

Footnotes:

1. These VHF radars run extremely high ERP (effective radiated power). Interestingly, these mesopause summer echoes can be so strong (the left image of Figure 2 shows signal-to-noise ratios up to 60 dB) that ionosondes in a quiet RF location and in a quiet noise location can see them. For example, Hai-Long Li, Jian Wu, Rui-Yuan liu, and Ji-Ying Huang noted PMSE on an ionosonde in their paper titled *Study on mesosphere summer echoes observed by digital*

ionosonde at Zhongshan Station, Antarctica in **Earth Planet Space**, 59, 1135-1139, 2007. They distinguished PMSE from normal E and sporadic E echoes through the virtual height data.

2. JE1BMJ's explanation of why the F1 region could be involved is in error as he assumed a planar Earth-ionosphere system to show that a high enough M-factor (11.5 to support 50 MHz with an F1 region critical frequency of 4 to 5 MHz) could exist. In the actual spherical Earth-ionosphere system, the M-Factor would be limited to a value of about 4 at F1 region altitudes. For more on the M-Factor, visit *mysite.ncnetwork.net/k9la,* click on the Basic Concepts link on the left, and download the pdf titled "The M-Factor".

3. JE1BMJ's statement that a high electron density is covering the JA – EU path on July 19, 2006 based on the auroral map in his Figure 4 is also in error. The map shown does not directly show electron density – all it shows is statistically where visible aurora could occur from the measured flux and energy of the precipitating electrons for that specific satellite pass. From the data on the original map (obtained from the Space Weather Prediction Center in Boulder, CO), the highest electron density for that pass translates to a plasma frequency of around 2.5 MHz and those electrons only precipitated down to 125 km or so. For more on these auroral maps, visit *mysite.ncnetwork.net/k9la*, click on the General link on the left, and download the pdf titled "A Look Inside the Auroral Zone".

4. The caption for Figure 28 in the Rapp and Lübken paper comments that there could be 10,000 ice particles per cubic centimeter of radius 5 nanometer in the mesopause. If ice particles alone were somehow the refracting mechanism, this would equate to an equivalent "plasma" frequency of 900 KHz – which still requires an extremely low grazing angle (less than 1^{o}) to refract waves at 50 MHz.

5. We have to watch it here. Down at troposphere altitudes the Earth-troposphere system is essentially planar because we're only talking a couple km of altitude. In other words, the curvature of the Earth is not seen by the wave as it travels up to the troposphere because it has so little distance to travel. Thus a wave launched at 1 degree from the ground will encounter the troposphere at close to 1 degree, which is a very low grazing angle to start with and means a lot more refraction is not needed – at least not like higher up in the ionosphere.