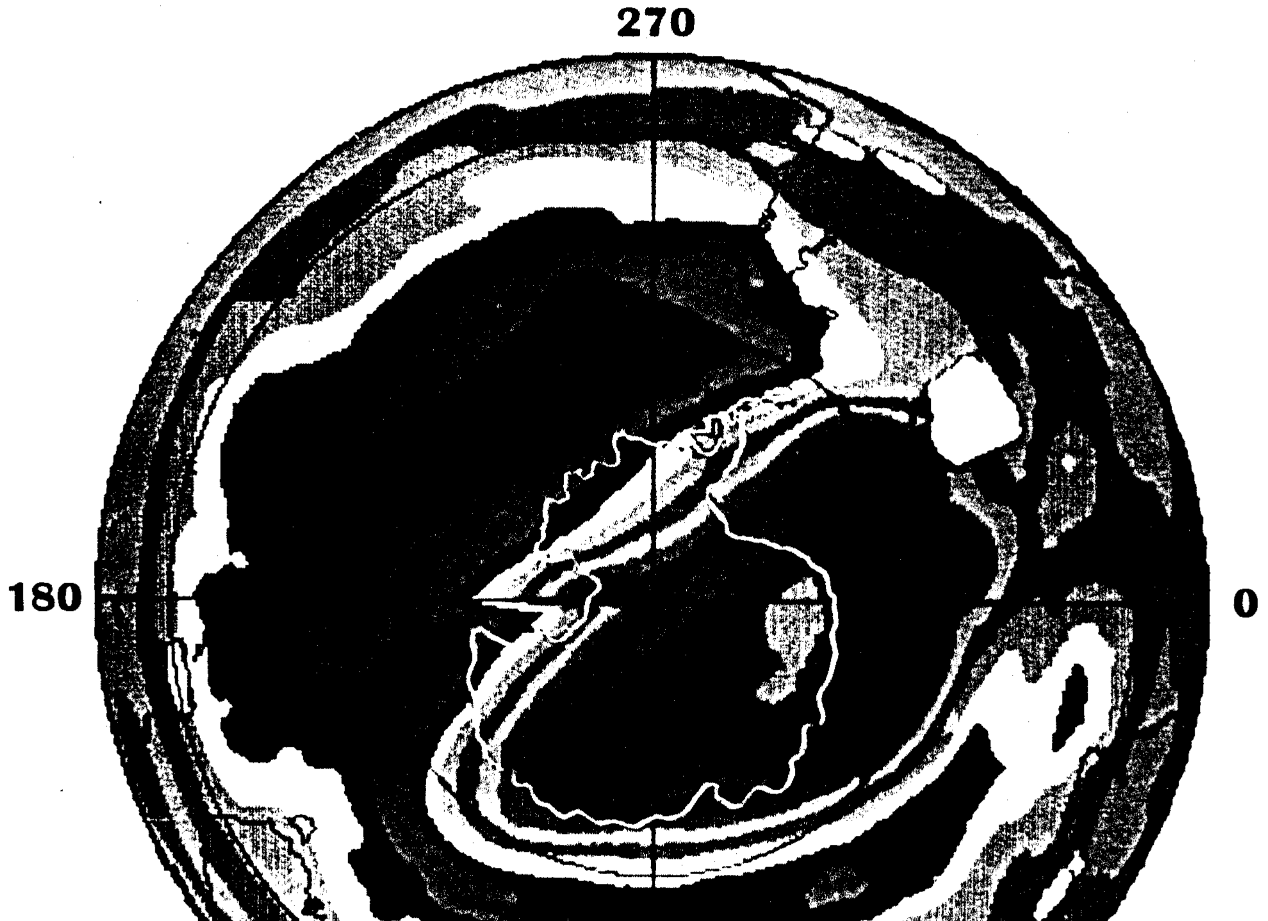
CIÊNCIAS ESPACIAIS E DA ATMOSFERA NA ANTÁRTICA

René A. Medrano-B
Enio B. Pereira
Editores



FIRST OBSERVATIONS OF PMSE IN ANTARCTICA

Ronald F. Woodman[1], Ben B. Balsley[2], Freddy Aquino[1], Luis Flores[3], Edilberto Vazquez[3], Martin Sarango[1]

[1]Jicamarca Radio Observatory, Lima, Peru

[2]Cooperative Institute for Research in Environmental Sciences, Boulder, Colorado, U.S.A.

[3]Universidad de Piura, Piura, Peru

ABSTRACT

A 50 Mhz radar, with 25 kW average power, has been installed at the Peruvian base in St. George Island, Antarctic. A search for PMSE echoes were made during its first year of operation, with negative results. These results have already been reported in the literature. Here we report our results during the summer of the second year of operation. This time the observations were made starting earlier, closer to the summer solstice. On this occasion PMSE have been observed, albeit much weaker that what one would expect based on the Poker Flat radar results at comparable latitudes in the Northern Hemisphere. The asymmetry, therefore, remains. It is explained in terms of subtle differences in temperature in the mesopause region of both polar regions. The potential of the technique to monitor global changes in temperature is discussed.

INTRODUCTION

It is unusual to find, today, recent important discoveries of upper atmospheric geophysical phenomena. Decades of intense space activities, initiated with the International Geophysical year in 1957, has left little to be discovered. One interesting exception is the discovery by Ecklund and Balsley (1981) of what, now, are known as the Polar Mesospheric Summer Echoes or PMSE's (See Cho and Kelley, 1993, and Rottger, 1994, for a review). The phenomenon manifests itself as very strong radar echoes from mesospheric altitudes at VHF frequencies, these echoes can not be explained --- as other echoes of similar nature have been --- on the basis of standard turbulent mixing theories. The existence of related radar echoes at even UHF frequencies (Rottger et al., 1990) makes them even more puzzling.

There is still no consensus on the nature of the physical processes responsible for the exceptionally stong echoes received. Fluctuations in the dielectric constant of the medium, produced by turbulence-induced fluctuations in the ionization densities, have been used as an explanation for the relatively much weaker echoes (although still strong when compared to Incoherent Scatter levels) received at comparable altitudes and lower latitudes (Woodman and Guillen, 1974). But, even this weaker echoes can only marginally be explained using turbulent processes, since the inner scale of turbulence is comparable or even larger than the unique wavelength to which the radar is sensitive. The "inner scale" is the smallest structural size that turbulence can create against the competition of molecular diffusion, an efficient mechanism for destroying structure this small. The current thinking is that turbulence must still play an important role, but with the requirement of the existence of slowly diffusing heavy and large ions or changed particles. The reader is referred to the work of Cho and Kelley (1993) for the current understanding (or lack of) the physical processes that have being put forward, to explain the strength of PMSE.

The interest in the phenomena is heightened by its possible relation to Global Change. There is relationship of this phenomena with the occurrence of Polar Noctilucent Clouds and the related Polar Mesospheric Clouds (Thomas, 1991). The possible relation of these phenomena with man industrial activity has been postulated by Thomas and Oliveira (1989). They observed that Polar Noctilucent Clouds --- spectacular as they are -- were not reported before the industrial era. According to Thomas and Oliveira (1989), the first observation of this kind was made by R. Leslie in 1885, who attributed the formation of the clouds in this occasion to the eruption of the Krakatoa, two years before. This first observation, and all the later ones since, would be due to the increase in methane in the earth atmosphere. Methane is the main source of water vapor in the mesosphere, necessary for a condensation process responsable for the particles producing the light scattering.

The occurrence of the clouds, and all the mechanisms proposed for the PMSE, also need the existence of very low temperatures (which are the lowest in the region of the earth atmosphere where they occur) capable of producing the necessary condensation. It is therefore interesting to speculate that man industrial activities could also produce temperature changes at these altitudes, and that we have an easily observable phenomena, using radar techniques, sensitive to thse changes.

In the summer of 1993 a VHF radar was installed and operated in Machu Picchu, Antarctic (not Cuzco), 62° 06' S, 58° 28' W, in the Peruvian base at King George Island. The project is an important part of the Peruvian research activities in Antarctica, and was carried out with the collaboration of the Polar Programs of NSF. The most interesting result of this first campaign was the discovery that no PMSE's were observed (Balsley et al., 1993, 1995). This was indeed surprising, since an equivalent radar, with the same sensitivity, would have observed echoes at least 30 db above the noise level, in an equivalent latitude in the Arctic, and at an equivalent time of the year. The observations in this first campaign were made in the period between the 21 of January and the 15th of February, i.e., on the later part of the Summer months, when echoes would have been observed in the Arctic.

A second campaign has been carried out during the Summer of 1994. This time, echoes have been observed, albeit much weaker than in northern latitudes. The purpose of this paper is to report these observations and discuss their significance in the context of our previous negative results reported by Balsley et al. (1993, 1995).

We also include one particular observation made during the first campaign, lasting about a few hours, where weak echoes can be appreciated. Its detection required a longer integration time than the one used before by Balsley et al. (1995), and a more sophisticated interference rejecting scheme. The existence of this one observation was added as a note in proof in this earlier, and we are here providing the evidence.

OBSERVATIONS

The instrument used in this particular occasion was, for the earlier part, until January 15, 1994, exactly the same as the one used in our previous paper (Balsley et al., 1995. See Sarango et al., 1994, for a description of the instrument). The 1993-1994 Summer campaign started much earlier than the previous one. Had it not been for antennas problems, we could had been observing as early as the first days of December. Unfortunately, the antenna did not survive well the harsh winter conditions, and it was not possible to repair it until the ice over its ground structure and foundation had melted. The North pointing antenna was back in operation on December 16, 1993, but we now suspect that the system did not have its designed sensitivity until January 11, 1994, at 19:00 L.T., when the system was switched to the vertical antenna and used a overhauled receiver and front end. Within this period, the system was down for the days between the 22nd and 24th of December.

After January 11, the system was switched to the vertical antenna and was operated in a mode that sampled continuously the mesospheric alttitudes. This is a period when mesospheric echoes were observed almost continuously. We will discuss them, in more detail, in the results section. The observations were discontinued again on January 16, 1994, due to equipment failure.

The system was back on operation with a newly developed processing system on January 29, 1994. This new system was used until the end of the campaign on February 13, 1994. No mesospheric echoes were observed during this period, except for sporadic meteor echoes. Tropospheric echoes were seen, in occasions up to 11 km, giving us confidence on the good performance of the system.

The newly developed system has three transmitters and three receivers, one for each of the three antennas, one antenna points in the vertical direction and the other two 15 degrees north and west off Zenith. The processing system is capable of processing the spectral characteristics of the three channels in paralled and in real time. Within each channel, two sampling windows can be defined, one in the troposphere-stratosphere region, and the other in the mesosphere. Any of this windows can be selected in a real time display to show the spectral information as a function of altitude and frequency, either as a shade or as a contour plot. The system, except for a later developed 8-mm tape recording media, has been described elsewhere by Sarango et al. (1995). Because of technical problems, only two transmitter-receiver channels were operated with the new system. The parameters that determine the system sensitivity are shown in Table 1.

RESULTS

In Figure 1, we show a spectral profile corresponding to mesospheric heights for a particular time. As in all Middle-atmosphere radars, the spectra can be characterized by three parameters: power, Doppler shift and spectral width. In this paper we will discuss only the power of the signal. Its Doppler characteristics will be discussed in a later paper. For our purpose here, it suffices to say that the Doppler shift and the spectral width are typical of what one would expect from PMSE echoes. The vertical velocities are typical of mesospheric heights and the spectral width is what one would expect from beam broadering effects for characteristic mesospheric winds.

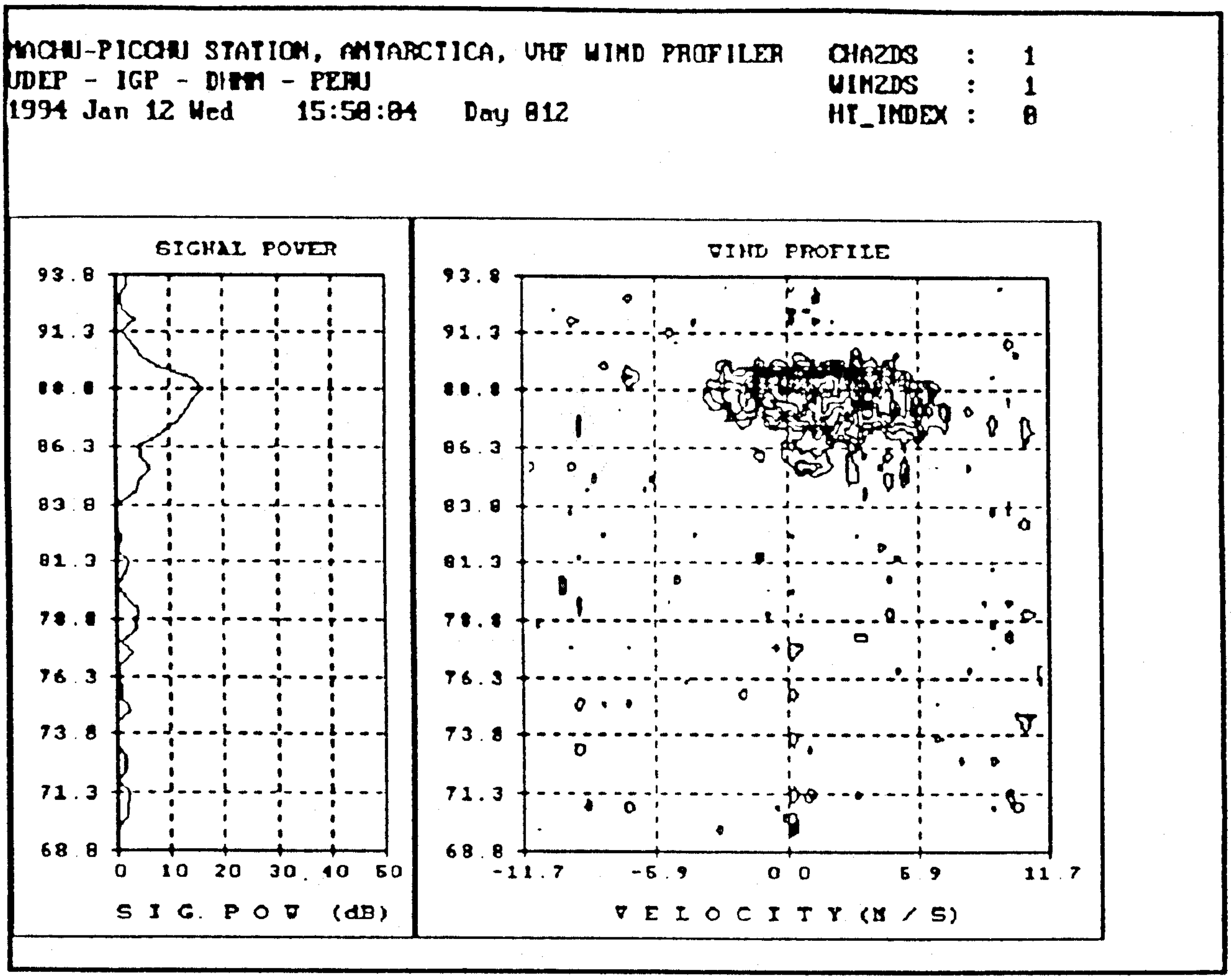


Figure 1 - Typical power profile (left) and spectarl contour plot (right) obtained by the radar.

Table 1 - Machu Picchu Radar Parameters

Coordinates	62 06'S, 58 28' W
Antena Area (m^2)	
Vertical	2500
15 al West	5000
15 al North	2500
Transmitter power (Peak)	25 w
Pulse width (microseconds)	8 (16)
Inter-pulse Period (miliseconds)	1
Coherent integration time (sec.)	0.128
Receiver bandwidth (microseconds)	8 (16)
Receiver noise-Figure	3 dB approx.

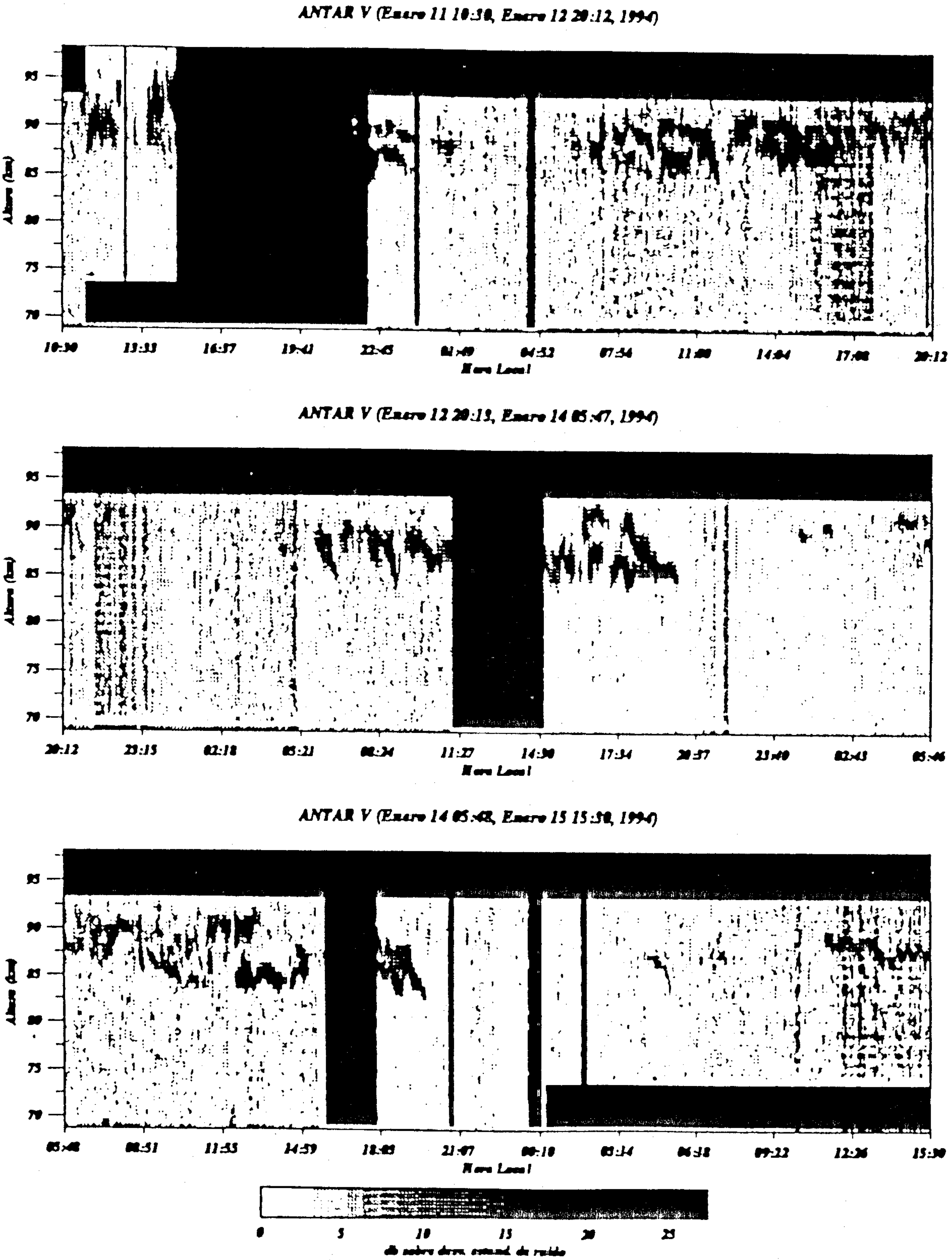


Figure 2 - Range-time-intensity plot covering the period between late January 11 to mid day Jan. 15, 1994, when continuous observations at mesospheric heigths were made and PMSE were observed.

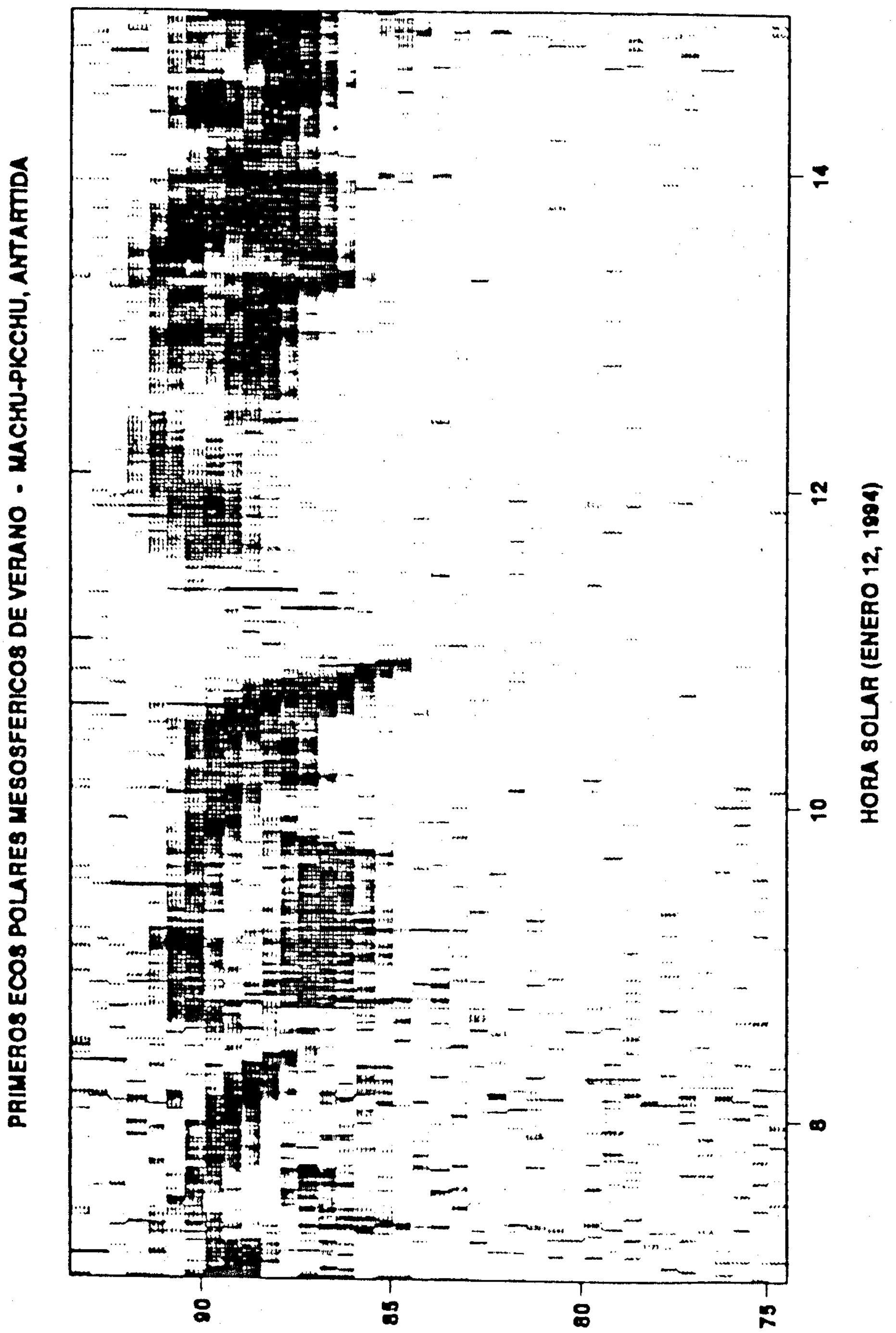


Figure 3 - Same as in Fig. 2 but for a shorter period between 7:30 and 14:20, Jan. 12, 1994.

Previous to January 11, 19:00 L.T., the north pointing antenna was used. During this period, only in two occasions, weak mesospheric echoes (-4db signal-to-noise ratio) were observed: once, on January 9, for a short time around 20:56 L.T., and again on January 11, between 13:00 and 14:53. The altitudes corresponded to a range of 84 km and 94 km respectively. The signals did not exceed 10-12 db over the detectable level, corresponding to a signal-to--noise ratio of -2 to -4 db. No mesospheric echoes were observed during the rest of the period, even though a time window of around two hour duration, starting after midday, was daily dedicated to mesospheric observations, except for the down period between December 22 and 29. The rest of the day was used for tropospheric and lower stratospheric observations. Observational parameters, which influence the system sensitivity, are shown in Table 1.

Figure 2 shows a Range-Time-Intensity (RTI) plot corresponding to the period between the 11th and 16th of January. This is the only period when PMSE's were observed almost continuosly. Figure 3 shows a blowup of an interesting sub-period showing the same information, but at full observing temporal resolution. The on line incoherent integration time for both plots is 1.5 minutes, but further integration has been performed in the longer record, to match the pixel resolution of the display. The plots show the signal strength in a logarithmic scale, after having subtracted noise and altitude independent interferences. We had interference problems, with interference power levels comparable to the noise. It was originated mainly in the processing and control electronics. The noise and the interference is estimated from the first ten altitudes, and subtracted from the other. Here we are taking advantage of the fact that these altitudes never had any echoes.

Although it is difficult to separate the noise from the interference, we need to do so, in order to use the noise level as a reference for comparison with other radar results. We have estimated the noise level indirectly. The standard deviation of the noise power estimate was evaluated using the same ten altitudes, assuming that the interference was range independent. From the level of the standard deviation, the noise power level can be obtained assuming a Student distribution for its deviation statistics. The only additional parameter needed is the corresponding number of degrees of freedom in the averaging process, which is equal to twice the number of coherently integrated samples taken. The factor of two comes about because two values, the real and the imaginary part of the phase detected signals, are used for each sample. The assumption of range independence for the interference can be checked post facto, by observing the resultant RTI plot. And indeed, except for the time at around 16:00 and 21:00 on January 12th, we notice that there are no power fluctuations in range which can be attributed to interference. Even at the time of the exception, the range dependent fluctuations are only a few db, 10 db below the noise level.

It is clear from Figures 2 and 3, that the echo observed during the times displayed, correspond to PMSE. They have the same morphology as other similar plots taken at other northern latitude stations. The activity is centered at 87 km, within a km of what has been reported for Poker Flat (Ecklund and Balsley, 1981). Furtheremore, if we scale down the Poker Flat results, consdering the difference in power and sensitivity, the altitude range of the affected zone is within the same range we observe. In addition, their velocity and spectral width correspond to expected PMSE values. Their velocity correspond to expected vertical mesospheric velocities and their spectral width to antenna beam broadened spectra consistent with expected horizontal mesospheric velocities.

Another conspicuous feature that is evident from the RTI plots is the existence of quasi-periodic down-coming structures with periods of about 30 to 60 minutes. See for instance the almost identical features between 17:40 to 19:00 on January 12. The form of these two features is very similar to other isolated features which can be seen at 11:30 and 16:20 on the same day, and at 6:00, 8:30 and 10:00 on January 13. They all progress downward, slowly at the beginning and precipitating at the end. The downward phase progression, and its periodicity, indicate a close relationship with gravity waves. Such a relationship has also been observed at the northern polar latitudes.

Both days show minimum activity between midnight and 04:00 hours, indicating strong solar control. We don't have a long enough series as to derive a climatology, but this behavior in time is also similar to its northern latitude counterpart. The only and important difference is the echoe strength and the seasonal duration of the phenomena, at least with the sensitivity of our instrument. The January 11th to 15th reduce the difference in power from our previously reported figure, for the two hemispheres, from three orders of magnitude to two. This is still a very large asynmetry which needs to be explained.

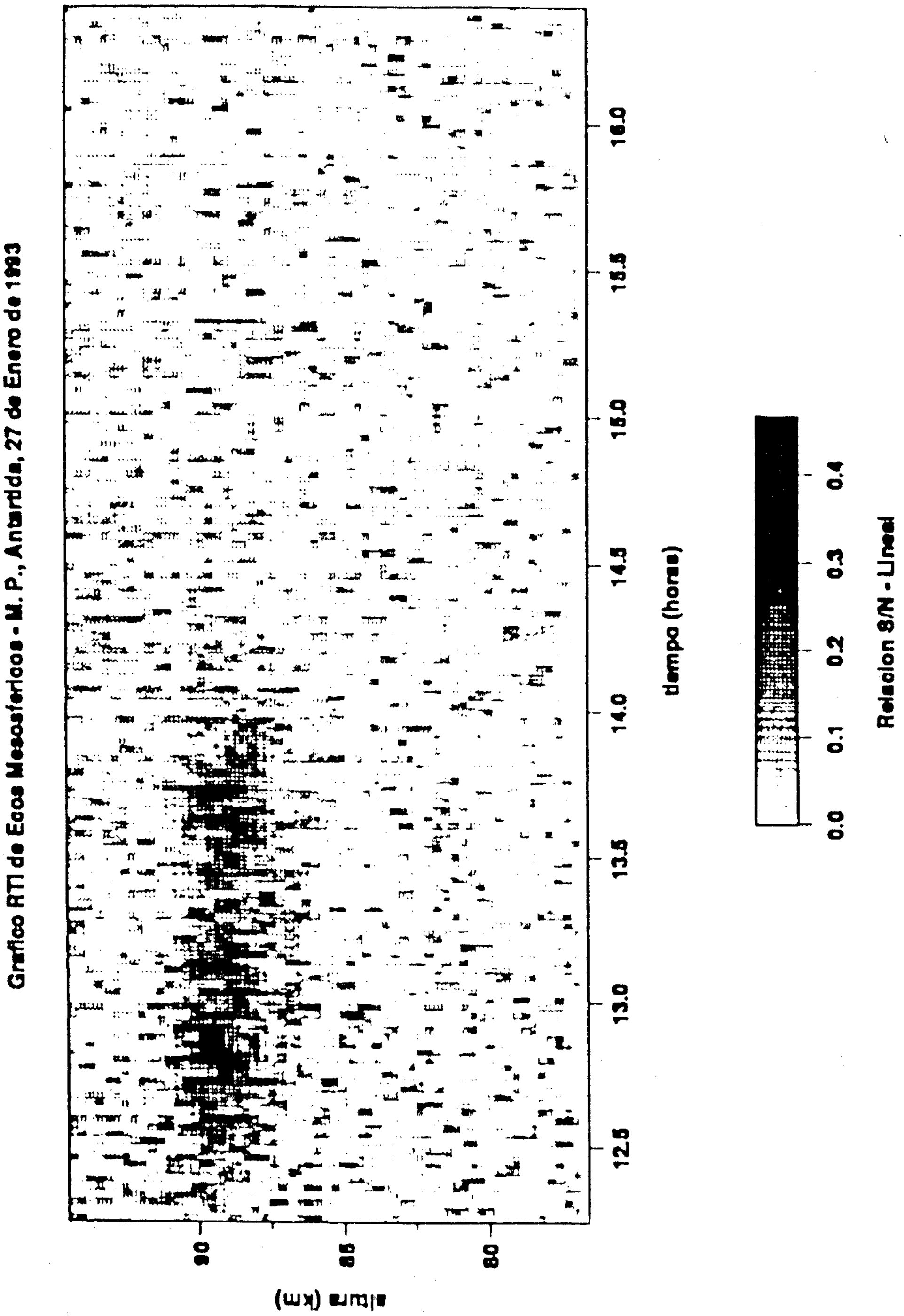


Figure 4 - Range-time-intensity plot showing the only PMSE seen in the 1993 campaign.

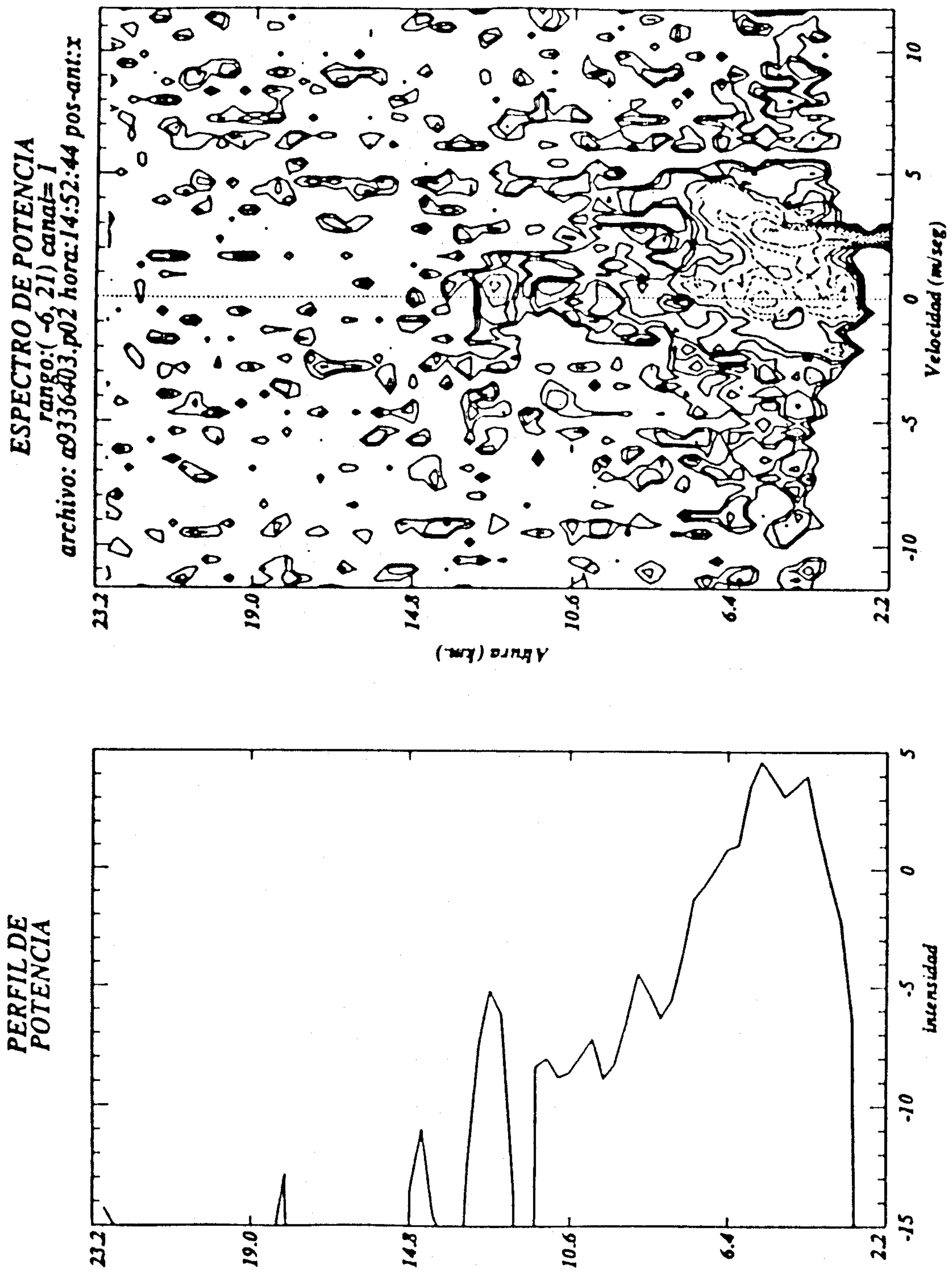


Figure 5 - Spectral contour plot corresponding to tropospheric heights, for December 30, 1993, showing good system sensitivity. Despite the sensitivity no PMSE were seen at noon time.

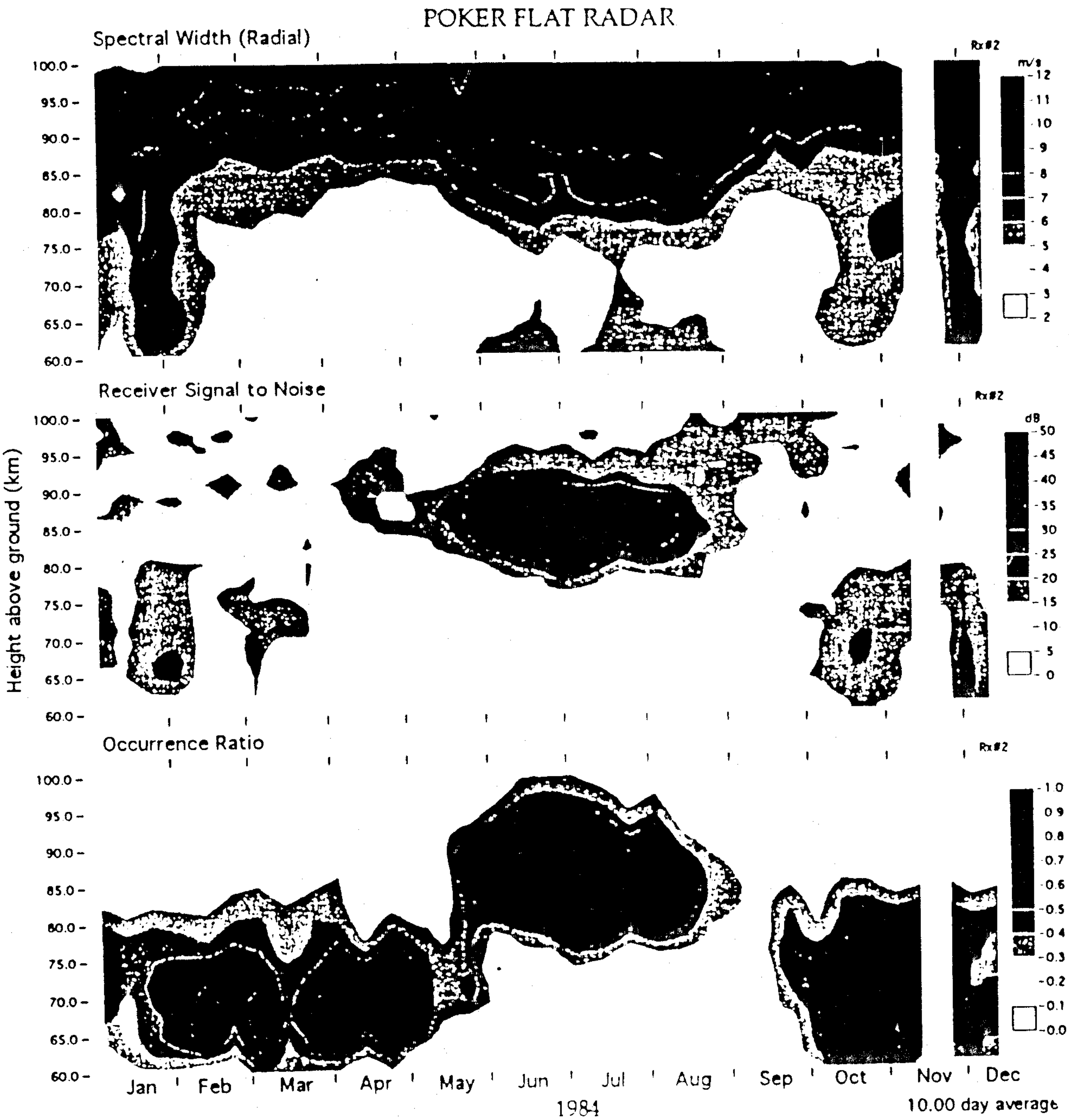


Figure 6 - Climatology of important PMSE parameters as observed with the Poker Flat radar in 1994, a) spectral width, b) signal to noise and c) occurrence ratio, B. Balsley personal communication.

Figure 4 shows the only event in which the strength of the echoes exceeded the sensitivity of the system during the previous campaign of 1993. As mentioned in the introduction, by changing our processing scheme, we have been able to "pull" this one event from the noise. We can no longer claim, as stated in Balsley et al. (1993, 1995), complete absence of echoes for the period of observations in 1993, January 27 to February 15, 1993. The event shown in figure 4 change our previously reported asymmetry by 3 or 4 db for the last days of January, but stays the same for the last 15 days of observation, were no echoes are evident, even after its improved reprocessing.

Even though we suspect the equipment was not up to specifications during the period prior to January 11, it did have sufficient sensitivity to observe tropospheric echoes to about 5 km altitude. It is not possible for us to discern now, retroactively, with certainty, if the maximum altitude was low because of lack in the system sensitivity or if the atmosphere did not present turbulent regions above this altitude from which the radar could backscatter some echoes. But at least in one occassion, on the afternoon and evening of December 30, we did see tropospheric echoes up to 10 km altitude, and yet we did not see any mesospheric echoes during the two hours of mesospheric echoes at noon time. A spectral contour plot and a power profile, corresponding to tropospheric altitudes, is shown in Figure 5, for this particular date.

As stated in the observations section, we can state with confidence that no mesospheric echoes were seen in the period January 29th to February 13th, confirming our previous negative results obtained in February 1993.

DISCUSSION

The observations made in the summer of 1994 complement the previous one made one year before, in the sense that earlier days, closer to the Austral Summer Equinox, are included. Although, the period of the newer observations reported here were not made as early as desirable, they seem to cover an important period of transition, from actual PMSE occurrence to their absence, at least for radars with sensitivities comparable to ours. If we scale down the echo power levels of the Poker Flat radar shown in Figure 6, taking into account the difference in sensitivity, we can predict positive results for the period May 15th to August 15th. The season of occurrence of PMSE, as observed by the Poker Flat radar, is so sharply defined that one can claim only a few days of error for this period of activity. May and August in the North Hemisphere map into November and February in the South.

The picture that emerges from our 1994 observations and the one day in January 27, 1993, is that the transition, marking the end of the PMSE season, occurs in the Antarctic during the last days of January, instead of February 15th, as one would expect from the Arctic observations. More importantly, the expected power levels within the active period are two orders of magnitude lower than their northern latitude counterpart. And although, we don' t have much confidence in the system for the last days of December and first days of January. There is the possibility that they disappear for more than one day at a time, even at the center of the season. We have at least one day to show, December 30, 1993, a day when the system did see tropospheric echoes at high altitudes. In any case, there was sufficient sensitivity, during the other questionable days, to claim that the echoes would be at the most 20 db below the strength of the Arctic ones at the peak of the season.

It should be mentioned that a shorter Antarctic season is also seen in the observations of Polar Mesospheric Clouds. If one looks carefully at the ocurrence frequency reported by Thomas (1991), one sees that not only the latitude extend of PMC's are wider at the Arctic, but that for a latitude of 64° the season of non-zero ocurrence is larger in the Arctic than in the Antarctic (See Fig. 4 in Thomas, 1991).

It is interesting to notice that the PMSE seen in Poker Flat at both extremes of the season, are not only weaker, but become more sporadic (Ecklund and Balsley, 1981). This can be appreciated in panels b) and c) from Figure 6 (After, Balsley, Personal communication). It appears then, that what we see at the Antarctic is only comparable with the weak and sporadic echoes at the extremes of the Arctic season.

As discussed in the literature (Balsley et al., 1995, Thomas 1991), PMSE, Noctilucent clouds and Polar Mesospheric Clouds must be related, because their confined seasonal and latitudinal extend, to the very low temperatures that occur at the polar summer mesosphere. There is apparently a temperature threshold, very possibly a condensation temperature threshold around 150 K (Thomas, 1991), that the mesosphere must go under for all of these related phenomena to take place. If such a temperature threshold exist, all what we need to postulate to explain the difference in behavior of the PMSE at the two hemispheres is a difference in temperature comparable to the one that exist between the coldest time, near the Summer Solstice, to the temperature at the end of the PMSE in the Arctic, i.e. about 180° K.

Considering the large difference in behaviour for such small difference in temperature, we can claim that a polar mesospheric VHF radar provides us with a very sensitive tool to monitor the changes in temperature that could exist at these altitude due to anthropogenetic or natural reasons. If we add to this that mesospheric temperatures are more prone to change than tropospheric ones, because of their very weak coupling to the earth surface, PMSE radars provides us with an additional advantage for monitoring global changes in temperature.

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