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STATISTICS OF AURORAL RADIO ABSORPTION AT SIPLE AND SOUTH POLE

S. KRISHNASWAMY

Institute for Physical Science and Technology, University of Maryland, College Park, Maryland 20742, U.S.A.

Abstract: Analysis of cosmic noise absorption data from South Pole ($L \approx 14$) and Siple (75.6°S, 83.6°W, $L=4.2$), Antarctica, (a pair of stations on opposite sides of the latitude of maximum auroral activity) has revealed important differences in the statistics of auroral radio absorption at the two locations. At Siple, there is a general tendency for summer absorption levels to be higher than the absorption in winter (especially around local magnetic noon), but the data (1975, 1980, 1982) show significant year-to-year variations in the diurnal patterns of absorption. The diurnal patterns at South Pole also exhibit year-to-year variations (1982–1985) but they are very different from those at Siple, and the winter/summer relationship also changes from year to year. However, the regular trend in the South Pole variations suggests that they may be subject to a form of solar-cycle control not apparent at Siple. A second difference has to do with the occurrence statistics: while at Siple the occurrence-frequency distribution departs significantly from a log-normal relation (a relation commonly adopted to characterize the cumulative amplitude-probability distribution of auroral absorption), the South Pole distributions are closer to a log-normal and the two sets of distributions can have substantially different trends above about 1 dB.

Comparison with seasonal and annual means of the geomagnetic *Ap* index suggests that auroral absorption at Siple is more strongly correlated with *Ap* than is absorption at South Pole.

In addition to their relevance for high latitude radio communication circuits, these observations may also have implications for auroral zone physics and morphology and also for magnetosphere-ionosphere interactions.

1. Introduction

Studies of auroral phenomena over the last few decades have revealed that their morphology is quite complex in space and time. Although the activity is generally confined to the so-called auroral zones, there are significant variations in location and in activity level. These variations have diurnal and seasonal components as well as long-term changes associated with the solar cycle.

A study of the patterns of auroral radio absorption at different locations can provide clues to some of the physical mechanisms governing magnetospheric phenomena. A more practical motivation lies in the fact that the occurrence of auroral absorption is of sufficient frequency and intensity in the auroral zones that the quality of HF (3–30 MHz) communications at these high latitudes can be significantly affected. Data on auroral absorption statistics at different sites can make an important contribution to models which are currently being developed to predict radio-wave propagation conditions at high latitudes (*e.g.*, FOPPIANO and BRADLEY 1983, 1984).

This report presents the results of cosmic noise absorption (CNA) measurements made by riometers at Siple, Antarctica (75.6°S, 83.6°W, L=4.2) during 1975, 1980 and 1982, and at South Pole ($L\approx 14$) during 1982–1985. Since the main part of the auroral oval passes between Siple and South Pole, the two stations may be expected to sample different regimes of magnetospheric phenomena. A comparison of the observations at the two locations can bring out some of these differences.

2. Observations and Discussion

The observations reported here were made with riometers operating at 30 MHz connected to zenith-pointing antennae with (full) beamwidths of 60°. The data were digitally sampled at 0.5 Hz (Siple, 1975 and 1980) or at 1 Hz (all other data) and one-minute average absorption values were computed using monthly 'quiet day curves' derived using the method described by KRISHNASWAMY *et al.* (1985).

2.1 *Seasonal variations*

Figure 1 shows the average diurnal variations in auroral absorption at Siple during 1975, 1980 and 1982. The data are plotted every 30 min and divided into the austral summer and winter seasons; the two curves for each year thus represent an 'average' winter day and an 'average' summer day during that year. The seasons were defined in a manner analogous to that adopted by THORNE *et al.* (1977), as appropriate for the southern hemisphere: winter covers the interval from May 1 to August 10 and summer

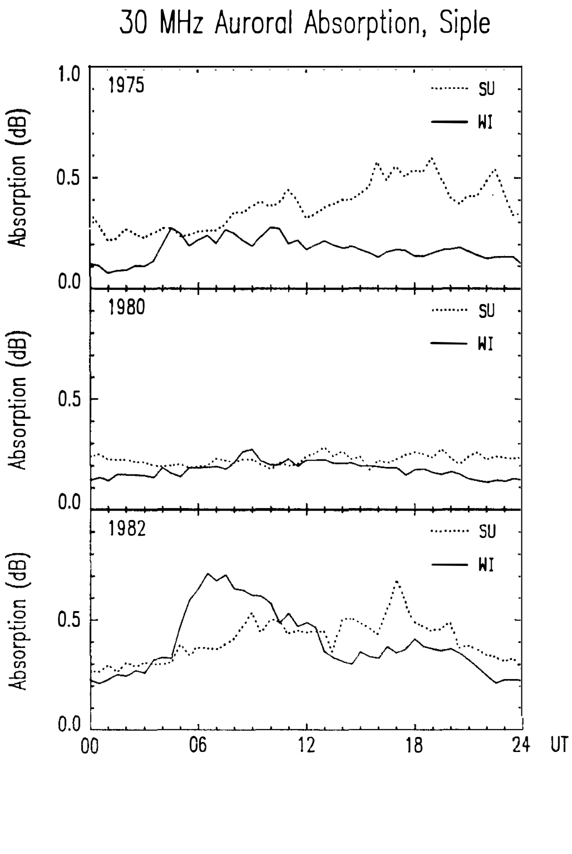

Fig. 1. The average diurnal variation of auroral absorption at Siple station for summer (SU) and winter (WI) during 1975, 1980 and 1982. The absorption tends to be greater in summer, especially near local magnetic noon (1700 UT). The austral winter and summer seasonal means of the Ap index (excluding days for which the absorption data were unavailable) were, respectively: 11 and 15 (1975); 11 and 12 (1980); 21 and 14 (1982). As a measure of the day-to-day variability of the absorption, the winter and summer means of the standard deviations of the absorption values at different times (see text) were found to be: 0.24 and 0.47 dB (1975); 0.27 and 0.23 dB (1980); 0.52 and 0.45 dB (1982).

from November 1 to February 10. Thus each season is roughly centered on the appropriate solstice and covers a total interval of 102 days. (Note, however, that the summer season as applied to this study is not continuous but consists of two separate intervals: January 1 to February 10 and November 1 to December 31 of the same year). The actual number of days used varies from year to year due to missing data.

Although the curves plotted represent average diurnal variations in summer and winter, it should be kept in mind that there can be quite large day-to-day variability in the auroral absorption at a given time of day. Since the minimum absorption value of zero dB can always occur at any given time, a higher average value implies a greater variability at that time of day. Thus the range of variation is greater when the average absorption value is higher and is different at different times of day. An estimate of the average variability during a season can be obtained by computing the standard deviations of the distributions of absorption values at each of the plotted points in Fig. 1 (30 min apart) and then taking the mean value of these standard deviations (which will be different at different times), yielding one value for each curve in Fig. 1. Calculated in this way, the mean standard deviation is a one-parameter measure of the variability of the auroral absorption during that season. For the Siple data shown in Fig. 1, the winter and summer means of the standard deviations were found to be, respectively, 0.24 and 0.47 dB (1975); 0.27 and 0.23 dB (1980); 0.52 and 0.45 dB (1982).

Two main points are apparent from Fig. 1. First, there is no consistent pattern in the diurnal structure of the absorption at Siple between different years: while the absorption during both seasons is roughly constant over the course of the day in 1980, it varies by about a factor of 2 in 1975 and 1982; on the other hand, the two seasons appear to track each other moderately well in 1980 but differ widely in 1975 and 1982. Second, there is a general tendency for summer absorption levels to be higher than the absorption in winter during much of the day in all three years but this is most evident in 1975. This summer/winter difference appears to be greatest around local magnetic noon (1700 UT). The curves for 1975 and 1982 also suggest that the diurnal absorption during the summer peaks around local magnetic noon while the winter-time absorption peaks around local magnetic midnight (0500 UT).

The variations apparent from Fig. 1 imply that there were significant differences in the level and temporal pattern of geomagnetic activity from year to year. In order to shed further light on this question, the mean value of the geomagnetic *Ap* index has been computed separately for the two seasons for each year after excluding days for which absorption data were unavailable. The winter and summer values were, respectively: 11 and 15 (1975); 11 and 12 (1980); 21 and 14 (1982). Although these values represent mean levels for the whole day, the changes in the *Ap* index appear to be reflected in the overall differences in the curves in Fig. 1. For example, in 1975, the summer value (15) was significantly higher than the winter value (11) and the curves indicate that much higher absorption values occurred in the summer; in 1980, the mean *Ap* values were essentially the same for the two seasons and so are the two seasonal curves; in 1982 the correlation was less clear but comparing 1975 and 1982 we see that the mean winter *Ap* value in 1975 (11) was half that in 1982 (21) and this difference appears to be consistent with the difference in the corresponding levels of absorption activity (winter 1975 *vs.* winter 1982) as shown in Fig. 1. Similarly, the mean summer

Ap values in 1975 and 1982 were about the same (15 and 14) and indeed the two corresponding curves look very similar.

Since 1975 was a solar minimum year and 1980 was near the time of solar maximum, some influence of the solar cycle, either direct or indirect, cannot be ruled out, but the overall level of geomagnetic activity is clearly a strong factor in determining the year-to-year changes in auroral absorption activity at Siple. The *Ap* index may thus be used as a predictor of the mean diurnal level of auroral absorption at Siple. It would be of interest to see if a higher time resolution index such as the 3-hour *Kp* index is able to predict some of the details of the diurnal behavior of this absorption and to investigate the correlation between the two quantities as a function of local time, season and solar-cycle phase. Data from Siple station for 1986, when analyzed, will be of particular importance in this kind of study since, together with the earlier data, they will provide coverage over an entire solar cycle.

The behavior of the auroral absorption activity at South Pole differs from that at Siple in a number of important respects. Figure 2 shows the results for South Pole for the period 1982–1985, again divided into summer and winter seasons. The average absorption levels are lower than those for Siple because South Pole is not as close to the auroral absorption zone maximum as Siple. Since South Pole is a higher latitude

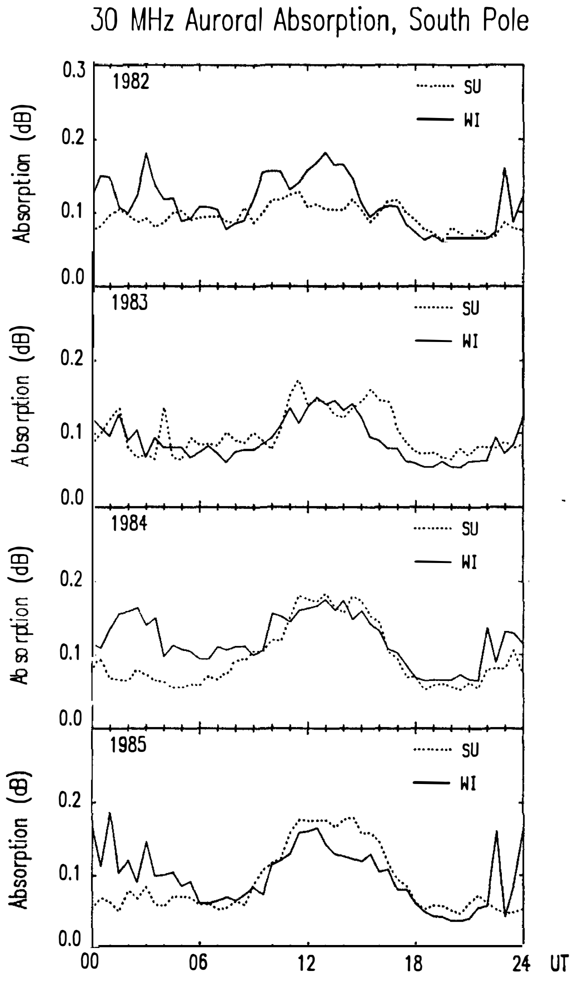

Fig. 2. The average diurnal variation of auroral absorption at South Pole for summer (SU) and winter (WI) during 1982–85. Days with PCA activity have been excluded. Note the consistent pattern, the trend over the 4-year interval and the change in the summer/winter relationship near local magnetic noon (1530 UT). The austral winter and summer seasonal Ap means (excluding PCA days and days for which the absorption data were unavailable) were, respectively: 21 and 13 (1982); 17 and 16 (1983); 16 and 17 (1984); 11 and 15 (1985). The mean of the standard deviations of the absorption values at different times (a measure of the day-to-day variability of the absorption) was about 0.1 dB for all the curves shown here.

station which is significantly affected by solar proton events in the form of polar cap absorption (PCA) activity, in order to avoid distorting the auroral absorption statistics by PCA events, data for days dominated by PCA activity were excluded from the curves in Fig. 2. (Such days were identified by generating a set of plots showing the diurnal absorption profile for each day of the year and scanning these plots for days which had signatures typical of PCA activity). There were 52 such days in 1982 (an usually active year), 4 in 1983, 13 in 1984, and 6 in 1985. The measure of variability was derived as described earlier for the Siple data by computing the mean standard deviation of the absorption values at different times for each curve in Fig. 2. These were all found to be about 0.1 dB, with individual standard deviations increasing to about 0.2 dB during times of peak absorption activity. These values are significantly lower than the corresponding values for Siple and presumably reflect the fact that South Pole is somewhat removed from the main part of the auroral zone and therefore experiences less day-to-day variability in auroral absorption activity. The numbers also suggest that, in contrast to Siple, the level of variability at South Pole remains roughly the same from year to year.

It is clear from Fig. 2 that the diurnal pattern of absorption at South Pole is very different from that at Siple. In the one common year (1982) for which data are shown at both sites, the absorption at South Pole is generally higher in winter than in summer, which is consistent with previous results from South Pole measurements (HARGREAVES and CHIVERS, 1965), but is the opposite of the results for Siple. A detailed study and discussion of the seasonal behavior of auroral absorption and VLF emission intensity at sub-auroral latitudes in 1975 is given by ROSENBERG and DUDENEY (1986). The diurnal absorption variation at South Pole is generally similar for all the years shown in Fig. 2: there is a broad maximum before local magnetic noon (1530 UT) in both winter and summer and a rather 'spikey' maximum just before local magnetic midnight (0330 UT) essentially only in winter. However, the amplitude of the diurnal variation, especially in summer, progressively increases from 1982 to 1985 as solar minimum approaches. In addition, the summer absorption around local noon is less than the winter absorption at the same time of day in 1982 but gradually increases until, by 1985, it exceeds the winter absorption. On the other hand, the summer absorption around local midnight appears to be consistently below the winter absorption. (The curve for the summer of 1983 is less certain because data were unavailable for a significant fraction of this period.) Thus, in contrast to Siple, the diurnal pattern of absorption at South Pole not only maintains its general behavior from year to year but also appears to show a gradual and fairly well-defined trend in the summer/winter relationship from one year to the next. Since the 4-year period covered in Fig. 2 is a substantial part of a solar cycle, this strongly suggests that the seasonal and diurnal pattern of auroral absorption at South Pole is a function of the level of solar activity. In order to investigate the influence of geomagnetic activity on auroral absorption at South Pole, the mean *Ap* index values have been calculated by season for each year. For consistency with the absorption data, PCA days (as well as days without absorption data) were excluded this time. The winter and summer values were, respectively: 21 and 13 (1982); 17 and 16 (1983); 16 and 17 (1984); 11 and 15 (1985). These numbers suggest that auroral absorption at South Pole is less well correlated with the *Ap* index than is auroral absorption at Siple. For example, the 1985 mean winter *Ap* index value (11) was roughly half that of the 1982 winter value (21) but the winter absorption curve is not significantly lower in 1985 compared to 1982. Similarly, the mean summer *Ap* values in 1982 and 1985 were roughly equal (13 and 15 respectively) and yet the summer absorption curve appears to be much higher (around 1000–1600 UT) in 1985 than in 1982.

2.2. *Occurrence statistics*

In recent years, considerable effort has been expended in developing models of auroral absorption which can be incorporated into radiowave propagation models appropriate for the high latitude regions (*e.g.*, FOPPIANO and BRADLEY, 1983, 1984). One of the aspects of auroral absorption that is of interest in relation to communication problems is the question of the statistical distribution of absorption amplitudes. A log-normal relation has generally been adopted for the cumulative amplitude-probability distribution of auroral absorption. Figures 3a–3c show plots, derived from 1-min averages of the Siple riometer data, of the probability of occurrence of auroral absorption above a given threshold as a function of the threshold value. In each figure, the vertical axis is nn a probability scale and the horizontal axis is on a logarithmic scale so that a log-normal relation would be represented by a straight line on this graph. It is evident that a log-normal distribution does not characterize well the observed distributions over the entire range. Moreover, for all three years (1975, 1980 and 1982) at Siple, the occurrence probability of high absorption values (greater than about 1 dB) is less than that predicted by a straight-line extrapolation of the distribution of lower absorption values, implying that the distribution falls off faster than log-normal (or at a faster log-normal rate) at values above about 1 dB.

Again, in order to compare these results with the geomagnetic index, the mean value of *Ap* for the whole year (excluding days without absorption data) has been calculated for each of the three years and found to be 14, 11 and 20 respectively for 1975, 1980 and 1982. Comparison of the *Ap* means with Figs. 3a–3c shows that the differences in the occurrence distribution curves for Siple are, on the whole, generally consistent with the differences in the values of the mean annual *Ap* index, *i.e.*, the entire distribution is shifted upward or downward as the *Ap* index goes up or down. For example, the curve is highest in 1982 when the mean *Ap* also has a large value (20) and the distribution is lowest (1980) when the mean *Ap* index has a low value (11). This implies that, at Siple, the probability of having auroral absorption above some specified intensity increases as the mean *Ap* value increases. Thus, the *Ap* index appears to have a significant influence on the occurrence statistics of auroral absorption at Siple. Similar analyses can be performed for summer and winter seasons separately.

Figures 4a–4d show the occurrence probability curves for South Pole, 1982–1985 respectively. Again, the days with PCA activity have been excluded from these statistics. The occurrence probability of absorption amplitude above any given threshold is significantly lower at South Pole than at Siple, reflecting the much higher latitude location of South Pole relative to the auroral zone. The distribution for 1982 (Fig. 4a) deviates from a log-normal relation above about 1 dB, but the deviation is in the direction opposite to that for the Siple data: the occurrence probability at high absorp-

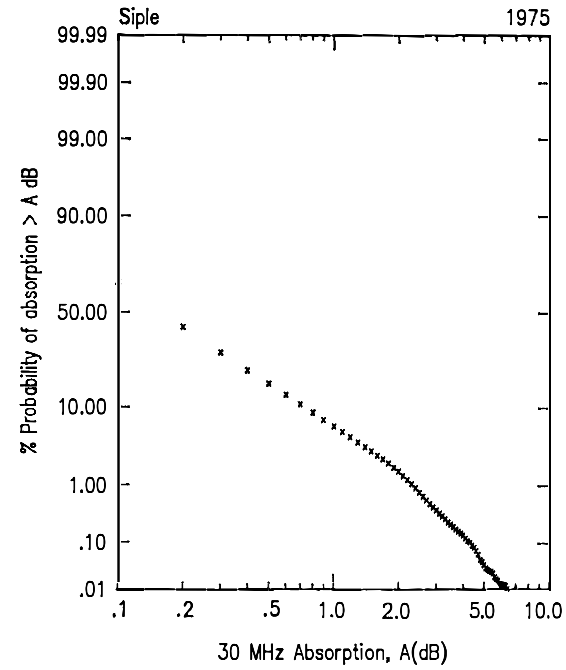

Fig. 3a.

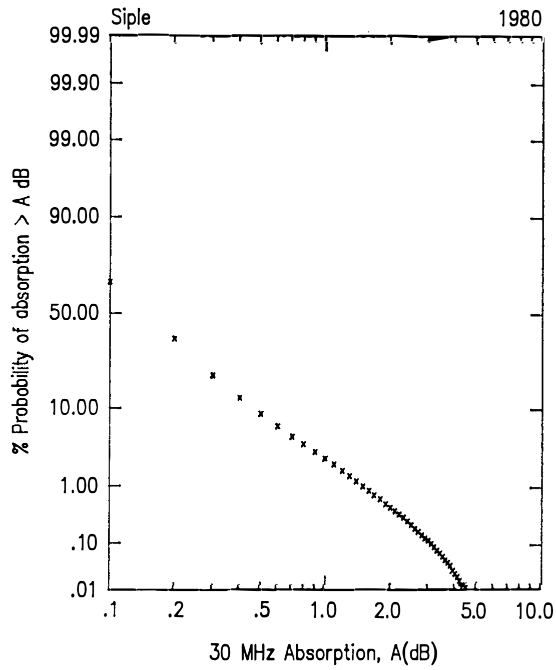

Fig. 3b.

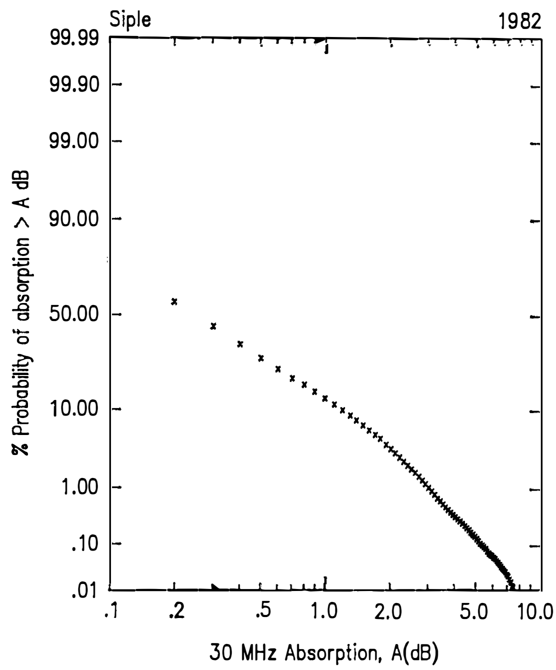

Fig. 3c.

Fig. 3a. Cumulative amplitude-probability distributions of 30 MHz auroral absorption values (1-minute averages) at Siple for 1975. A log-normal relationship would be represented by a straight line on this graph. Note the deviation from a straight line, in the direction of lower occurrence probabilities, above about 1 dB. The annual mean value of the Ap index (for the days for which absorption data were available) was 14.

Fig. 3b. The same as Fig. 3a for Siple, 1980. The annual mean Ap value was 11.

Fig. 3c. The same as Fig. 3a for Siple, 1982. The annual mean Ap value was 20.

tion values is higher than would be predicted by linearly extrapolating the distribution at lower absorption values. For the other years (1983–1985), the distribution appears to be well represented by a log-normal over almost the entire range (0.1–3 dB). Note, however, that at South Pole, the occurrence statistics are such that the distribution cannot be meaningfully explored to the same absorption intensities as is possible at Siple.

The yearly mean *Ap* values, excluding PCA days, for 1982–1985 were found to be

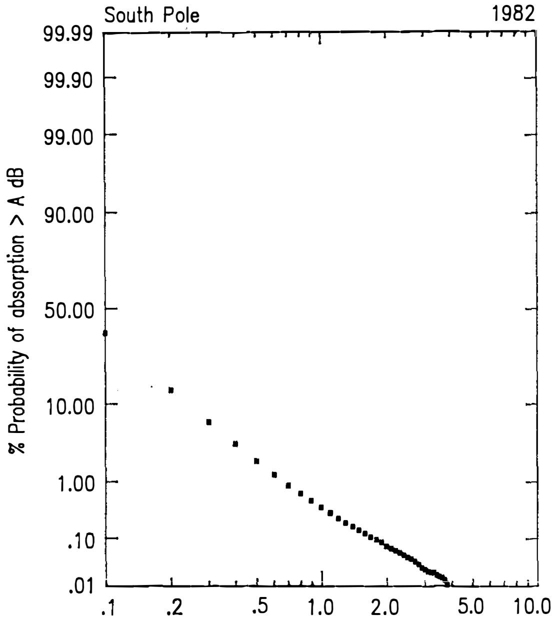

Fig. 4a.

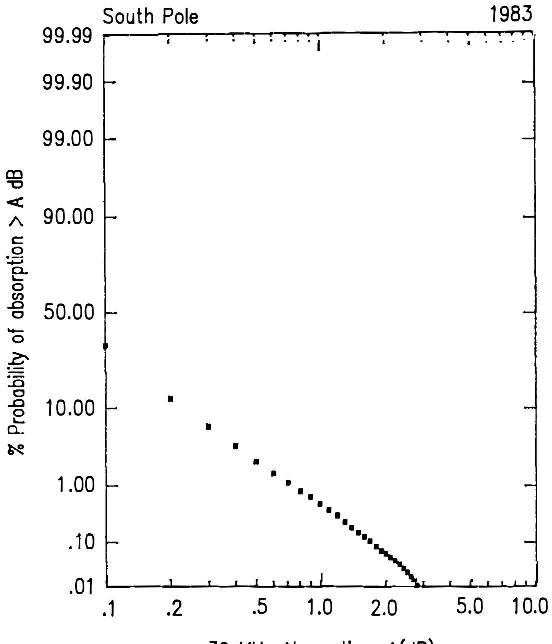

Fig. 4b.

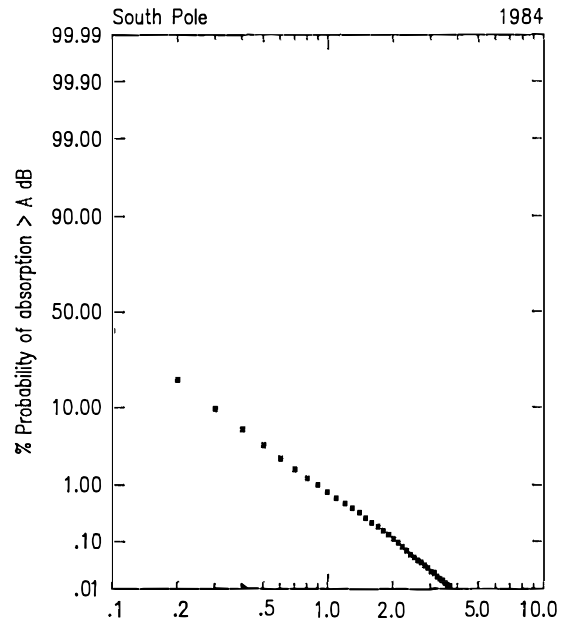

Fig. 4c.

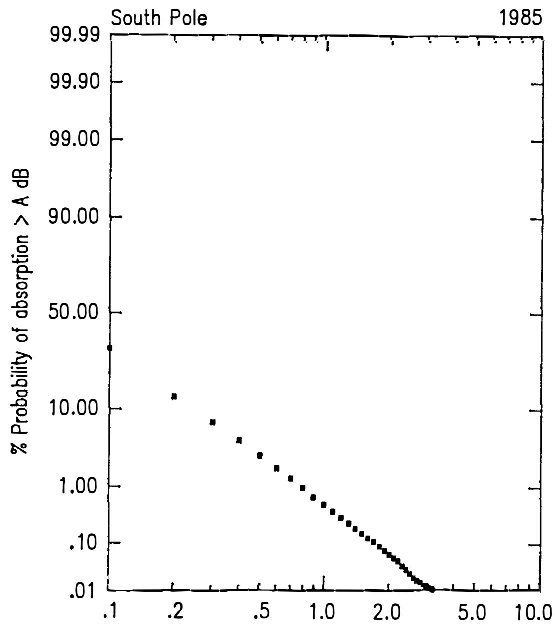

Fig. 4d.

Fig. 4a. Cumulative amplitude-probability distributions of 30 MHz auroral absorption (1-minute averages) at South Pole for 1982. The days with PCA activity have been excluded from the statistics. Note the deviation from a straight line, in the direction of higher occurrence probabilities, above about 1 dB. The annual mean Ap value (excluding PCA days and days with no absorption data) was 22.

Fig. 4b. The same as Fig. 4a for South Pole, 1983. The distribution appears to fit a log-normal relation fairly well. (The sudden downward turn of the distribution at the high absorption values is probably due to a 40-day gap in the data which would tend to affect most the statistics of high

20, 17, 19 and 14 respectively. However, the occurrence probability distributions for South Pole during this period are essentially the same in three of the four years (1983–1985), both in terms of the slope and the overall level of the curves. This observation suggests yet again that the influence of the *Ap* index on auroral absorption is much weaker at South Pole than at Siple. The consistency of the distributions also indicates that the occurrence statistics of auroral absorption at South Pole were not significantly affected by the level of solar activity during this period. This is perhaps not too surprising, despite the fact that the yearly mean sunspot number decreased from about 116 in 1982 to 18 in 1985, since auroral absorption is apparently not directly related to the usual solar activity indices and probably lags sunspot numbers by a year or two (HARGREAVES, 1969). Thus, the occurrence statistics at South Pole appear to be relatively insensitive to both the mean *Ap* index and the solar activity level. What is perhaps more surprising is that the occurrence statistics do not change much while at the same time the diurnal pattern of auroral absorption shows definite changes during the four-year period as is shown in Fig. 2. This appears to imply that the precipitation pattern fixed with respect to the sun must change in a regular manner from year to year (so as to produce the results shown in Fig. 2) while at the same time allowing the occurrence probability statistics to remain more or less unaffected. Investigating these occurrence statistics separately by season and/or local time may shed further light on this question.

3. Summary and Conclusions

Riometer observations of cosmic noise absorption at South Pole and Siple have produced evidence of significant differences between the two sites in the occurrence statistics and seasonal variation of auroral radio absorption.

The diurnal patterns of absorption exhibit significant variations from year to year at both locations. The patterns at Siple show no consistent structure but appear to correlate well with the geomagnetic *Ap* index. In contrast, the diurnal patterns of absorption at South Pole show a regular trend that suggests some form of solar-cycle influence but the correlation with the *Ap* index seems to be weaker. At Siple, the absorption in general tends to be greater in summer than in winter, especially near local magnetic noon (1700 UT). In fact, winter-time absorption appears to peak near local magnetic midnight while summer-time absorption peaks near local magnetic noon. At South Pole, the diurnal absorption pattern in all four years has a broad maximum around local magnetic noon (1530 UT) in both summer and winter. The winter absorption pattern has in addition to the broad daytime peak, a much more 'spikey' maximum near local magnetic midnight (0330 UT) made up of the sudden onset, shorter duration events occurring at night. This night-time peak appears to be much less

absorption amplitudes since they are relatively rare to begin with). The annual mean Ap value was 17.

Fig. 4c. The same as Fig. 4a for South Pole, 1984. The distribution appears to fit a log-normal relation fairly well. The annual mean Ap value was 19.

Fig. 4d. The same as Fig. 4a for South Pole, 1985. The distribution appears to fit a log-normal relation fairly well. The annual mean Ap value was 14.

evident during the summer. In addition, the relative amplitudes of seasonal absorption appear to change from year to year in a somewhat predictable manner. For example, near local magnetic noon at South Pole, the summer absorption gradually overtakes and eventually exceeds the winter absorption at the same time of day as solar minimum approaches.

In 1982, when data were available from both Siple and South Pole, the winter absorption was greater than summer absorption at South Pole while at Siple the situation was reversed, *i.e.*, summer absorption was greater than winter absorption.

The occurrence-frequency distribution of auroral absorption at Siple deviates significantly from a single log-normal relation above about 1 dB, falling off at a faster rate at the higher absorption values, while at South Pole, it either falls off at a slower rate at the higher absorption values (1982) or obeys the log-normal relation fairly well over almost the entire range from 0.1 to 3 dB (1983–1985). The distributions at Siple shift up and down in concert with the annual mean value of the *Ap* index, while those at South Pole remain more or less the same regardless of the mean value of *Ap* or the annual mean of the sunspot number. This last observation in conjunction with the regular trend in the diurnal pattern of absorption at South Pole implies that a precipitation pattern fixed relative to the sun changes in a regular fashion from year to year while maintaining the same distribution of absorption amplitudes at South Pole.

These statistical, seasonal and year-to-year variations imply that there are seasonal and solar-cycle related changes in the factors which determine the manifestations of magnetospheric disturbances seen from the ground. Such factors include particle acceleration and precipitation precesses, ionospheric current systems and upper atmospheric composition and chemistry. Some or all of these factors may change across magnetospheric boundaries such as the auroral zone. Conclusions reached from observations at one site during one year may not necessarily apply to other stations or even at the same station in other years. These considerations highlight the importance of making simultaneous and continuous observations at a number of sites over a number of years. Radio-wave propagation models which adopt a seasonal variation characteristic of one site during one year and assume the same variation to apply to other locations and other times may require some modification.

Finally, the details of the occurrence-frequency distribution are, one presumes, ultimately determined in some fashion by the physics of the particle acceleration and precipitation processes. Statistical data of this kind may therefore be able to provide clues to the underlying physics in addition to their practical application in developing radio propagation models for predicting the performance of high-latitude radio communication circuits.

Acknowledgments

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References

FOPPIANO, A. J. and BRADLEY, P. A. (1983): Prediction of auroral absorption of high-frequency waves at oblique incidence. Telecommun. J., **50**, 547–560.

FOPPIANO, A. J. and BRADLEY, P. A. (1984): Day-to-day variability of riometer absorption. J. Atmos. Terr. Phys., **46**, 689–696.

HARGREAVES, J. K. (1969): Auroral absorption of HF radio waves in the ionosphere; A review of results from the first decade of riometry. Proc. IEEE, **57**, 1348–1372.

HARGREAVES, J. K. and CHIVERS, H. J. A. (1965): A study of auroral absorption events at the South Pole. 2. Conjugate properties. J. Geophys. Res., **70**, 1093–1102.

KRISHNASWAMY, S., DETRICK, D. L. and ROSENBERG, T. J. (1985): The inflection point method of determining riometer quiet day curves. Radio Sci., **20**, 123–136.

ROSENBERG, T. J. and DUDENEY, J. R. (1986): The local time, substorm, and seasonal dependence of electron precipitation at $L=4$ inferred from riometer measurements. J. Geophys. Res., **91**, 12032–12040.

THORNE, R. M., CHURCH, S. R., MALLOY, W. J. and TSURUTANI, B. T. (1977): The local time variation of ELF emissions during periods of substorm activity. J. Geophys. Res., **82**, 1585–1590.

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