SUBSTORM OBSERVATIONS AT $L=4$

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Abstract: Observations of auroral absorption associated with substorms have been made at Siple Station, Antarctica ($L=4$) with a newly developed riometer system. The instrument is run in conjunction with various VLF experiments, together with magnetometer and micropulsation observations. Features of the riometer system are described with special reference to a technique which has been devised to improve the dynamic range and resolution of the absorption measurements. The initial results from a study of phenomena recorded simultaneously with the various instruments are presented. The results confirm earlier observations made at a high latitude station, but with the fast time constant of the recording system a wide variety of detailed interrelationships between the various phenomena have been revealed. In particular, although variations in the micropulsation activity and the absorption record correspond very closely once an event is underway, the micropulsation activity nearly always precedes the onset of absorption by an amount which varies significantly for event to event.

1. Introduction

During the IGY (1957–1958) a radio astronomical technique for the measurement of galactic radio noise was adapted for the measurement of radiowave absorption in the earth's ionosphere. The instrument used was named the riometer (LITTLE and LEINBACH, 1959) and a transistorized version was developed in 1962 (SHIFFMACHER, 1962). With the development of the Unmanned Geophysical Observatory for use in the Antarctica, it was necessary to develop a new riometer which would operate with the limited amount of power available in the UGO. The resulting instrument consumes only 0.8 watts at 12 volts and is contained within a box which measures 10 cm by 13 cm by 18 cm. A solid state RF noise generator was incorporated in this instrument utilizing design information made available by the Antarctic Division of the Australian Department of Science (BYRD and HUMPHREYS, 1972) and since this source has an instantaneous response to the driving current, it became possible to operate the new riometer with a time constant as fast as 0.25 sec. The other major technical advance incorporated in the new instrument was the addition of CMOS logic circuitry to arrange a calibration and timing sequence which is derived from a crystal oscil-

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lator. This feature ensures that riometer records will routinely have calibrations once each hour and timing information with an accuracy of a few seconds as long as a standard time reference is incorporated in the data at least once a month.

With the availability of the new riometer, a new mode of recording ionospheric absorption immediately became available. This approach depends on the realization that even at a manned station, the low power requirement of the riometer makes it possible to locate the instrument near the antenna rather than in a convenient observing hut. The instrument is simply placed in an insulated container and is connected to the antenna using a short length of coaxial cable. Power to the instrument is fed on a simple DC cable and the recorder signal is returned to the observing facility on another DC cable. Since the necessary cable only has to carry small currents, the cable can be extremely lightweight and lengths of 1,000 ft or more can be utilized. Two major advantages accrue with this method of operation. One is that the short length of coaxial cable used avoids the 3 dB or more loss which is encountered in the older installations when 300 feet or more of coaxial cable was used to connect the antenna to the observing hut. Thus the dynamic range of the instrument is increased by 3 dB and the resolution of small absorption events (of the order of 0.1 dB) is considerably improved because of the logarithmic response of the instrument. A second benefit is that since the antenna can now be located 1,000 ft or more from the nearest hut, there is much more freedom in the choice of location for the antenna so that it can be placed clear of structures which would affect the beam pattern. Incidentally, a third benefit of the "remote riometer" method of operation is that both the cost and shipping weight of the complete system is less than that of older systems incorporating large lengths of low-loss coaxial cable. Locating the riometer at a distance from the observing facility further enhances the quality of the records obtained because of the remoteness of the antenna from the source of interference located within the observing facility.

Since riometer systems operate over a relatively wide bandwidth, they are subject to a wide variety of interfering signals both propagated and local, wide band and narrow. Standard procedure has always been to operate with the widest possible bandwidth for a given location and to use a minimum detection system to remove interference within that band. From a scientific point of view this is a poor choice because it results in an asymmetric time constant so that absorption changes with a periodicity shorter than about 1 minute are distorted in the recording system because decreasing absorption is low pass filtered with a cutoff frequency less than that for increasing absorption. With the new riometer system, and particularly with the remote operation, we have found that superior records are obtained if one utilizes the advantage of the very fast symmetrical time constant with no minimum detection scheme. Interference typically reveals itself as very fast positive pulses in the record, but since the recorder returns to the base line immediately the interference ceases, it is very easy to distinguish the sky noise level in most cases. Computer processing of digitized data is even more effective at reducing the effects of interference in the riometer record. With this technique it is now possible to operate over a much wider bandwidth than previously thought possible and we have found that a figure of 100 kHz is practical at most locations.

The newly developed riometer system is in operaton in Canada, Alaska and Antarctica. The remainder of this paper will be devoted to a presentation and discussion of results obtained at Siple Station in Antarctica.

2. Observations

A 30 MHz riometer system has been in operation at Siple Station, Antarctica since 1973. The station is located at 76°S, 84°W and has an L value of 4. A variety of sensors are operated at the station, including a major VLF transmitter system to investigate wave particle interactions in the vicinity of the plasmapause. Additional VLF equipment includes various receivers for recording the signal strength of the distant VLF transmitters, and various wide band VLF receivers to record both hiss and chorus phenomena. The station also has a three component flux gate magnetometer and a three component micropulsation detecter system. These experiments are operated by different university groups, as independent research programs, but in order to investigate the correlation between the various phenomena, many of the signals are connected to common recording systems. For instance, eight channels of data are selected for presentation on an eight-channel analog pen recorder, while other sensors are chosen for simultaneous recording on digital magnetic tape. In this paper we present some initial observations made with the eight-channel pen recorder mainly from the point of view of significant riometer absorption. Future papers will deal with the results of an analysis of the digital data and a study of events chosen from significant occurrences on the other data channels.

At a low latitude location like Siple, few substorms have sufficient magnitude to cause absorption overhead at the station. Although the riometer only operated successfully for a few months during 1973 because of antenna problems, the results for 1973 and 1974 indicate that absorption usually occurred for a few days each month. There was a tendency for activity to be more common and more intense during the months of the austral winter. Such a low occurrence rate of events has the advantage that periods of activity are well isolated and the cluttering effect of multiple events which complicates the analysis of high latitude stations is not a factor. Moreover, there is ample time between events to establish the quiet time operating conditions of the equipment. Examination of the published Kp indices for 1973 indicate that when absorption events occurred at Siple, the Kp index was always 4 or greater. Since it has been shown (CHAPPELL, 1972) that the plasmapause is over $L=4$ when $Kp=3$, we can assume that Siple was outside the plasmapause when the events occurred. Using CHAPPELL's formula for L value of the plasmapause, $L_{pp}=6-0.6\,Kp$ we see that $Kp=5$ the plasmapause should be at $L=3$.

Two general classes of events occur at Siple and these can be called the "night" events and "day" events because of their local time of occurrence. This classification is based on the work of MOROZUMI (1965) who did substantial work at Byrd Station on the correlation of riometer absorption with VLF and geomagnetic phenomena. A typical night event, as observed at Siple, is illustrated in Fig. 1 which illustrates the 8 channels recorded around 0200 Z on 13 May 1973. It can be seen that an absorption event of magnitude 1.5 dB began at

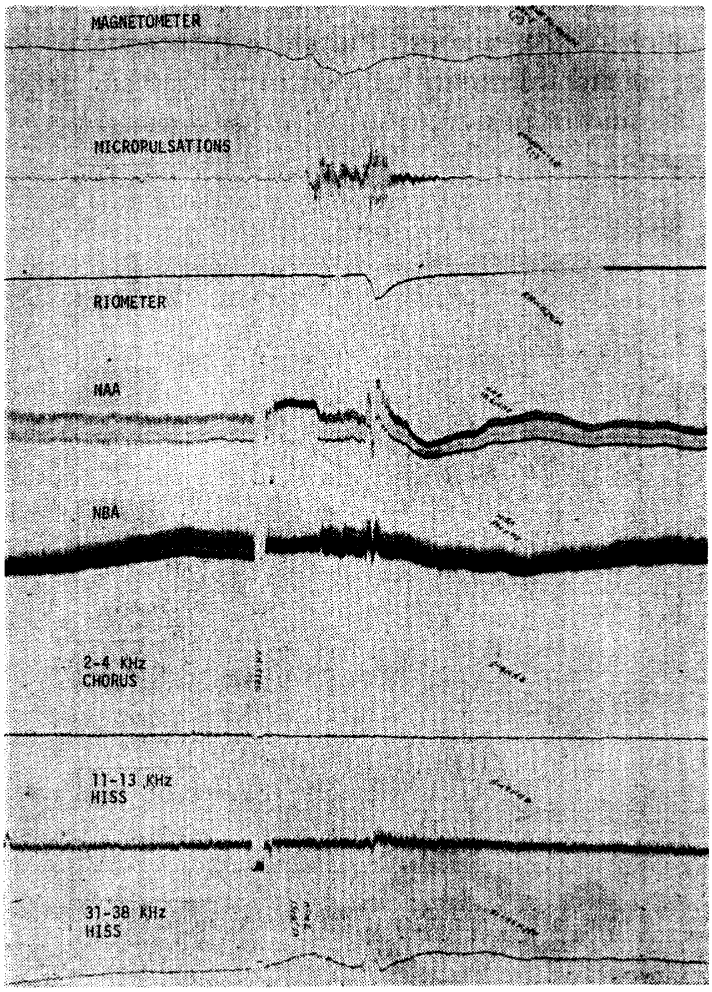

Fig. 1. 8 channels of data recorded at Siple Station, 13 May 1973 near 0200 Z.

about 0207 Z and was accompanied by a major increase in micropulsation activity, and significant deviations in the amplitudes of the various VLF recording. The event followed a general geomagnetic disturbance as shown on the magnetometer record, but at this resolution detailed correlation with the magnetometer is not evident. This event follows the classical pattern revealed by MOROZUMI in that the absorption was preceded by a burst of VLF hiss, although the generally expected burst of chorus during the event is not apparent in this record. The power of the multi-channel recording technique can be illustrated by Fig. 1 by noting that otherwise insignificant variations in the absorption pattern coincide precisely with variations in the other channels. For instance, the onset of very weak absorption (0.1 dB) at about 0158 is seen to coincide with a significant change in the micropulsation record. Minor irregularities in the otherwise smooth absorption event are found to be coincident with variations in the micropulsation and VLF record. These changes are illustrated in Fig. 2 which is a sketch made from a detailed examination of the records. Further amplification of the magnetometer record using the digital recording (LANZEROTTI, private communication) has shown that similar fluctuations occur in the magnetometer record with an amplitude of a few gamma.

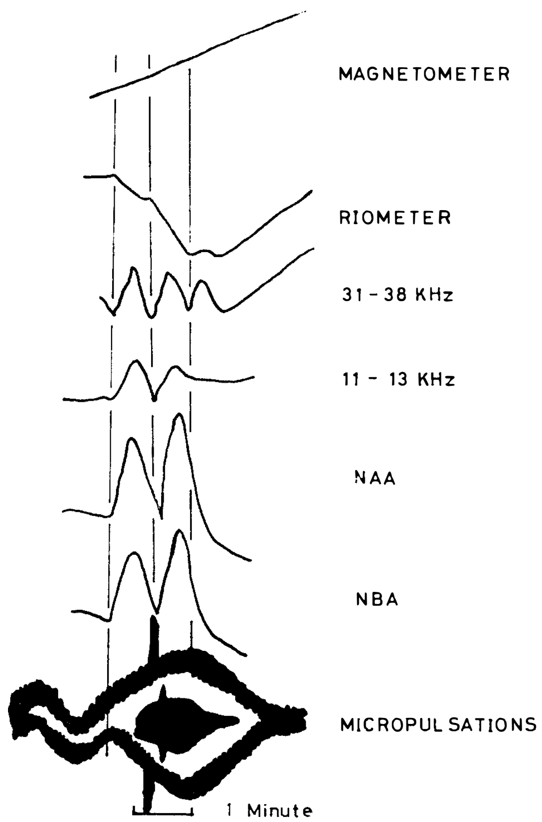

Fig. 2. Siple events, ~2000 Z, 13 May 1973.

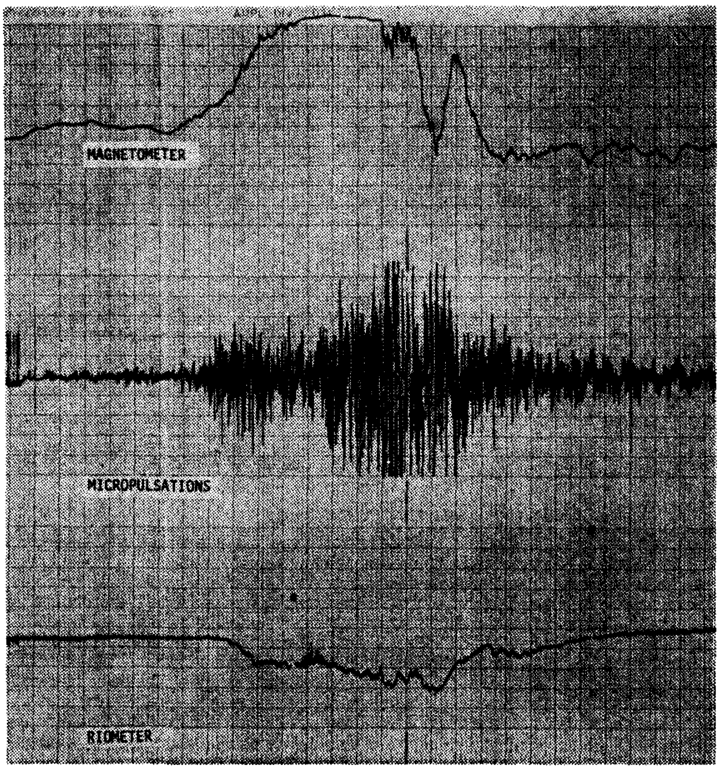

Fig. 3. Magnetometer, micropulsation and riometer data recorded at Siple, 3 April 1973 near 0500 Z.

Another typical night event is illustrated in Fig. 3 which is restricted to show only the magnetometer, micropulsation and the riometer recordings. This recording was made near 0500 Z on the 3rd of April 1973 and illustrates a typical night event in that the envelope of the micropulsation even follows quite closely the magnetic disturbance and the riometer absorption event. This record indicates that the precipitation process causing the absorption results in ionospheric currents which cause the geomagnetic changes observed. In contrast to this, events observed during the day tend to show much less geomagnetic disturbance for a given absorption event. An example is illustrated in Fig. 4 which was recorded on 14 May 1974 at 1800 Z. The small (0.7 dB) absorption pulsations shown on the riometer record are accompanied by small ($<50\,\gamma$) and uncorrelated magnetic field fluctuations, and essentially continuous, small and uncorrelated micropulsations. On the other hand examination of the chorus record of channel 6 shows a strong correlation between bursts of chorus and the individual absorption pulsations. Thus the chorus emission is created by the streams of particles which cause the absorption pulsations, but the ionospheric conductivity at the time restricts the geomagnetic phenomena.

Examination of the remaining records has shown that at Siple the multi-

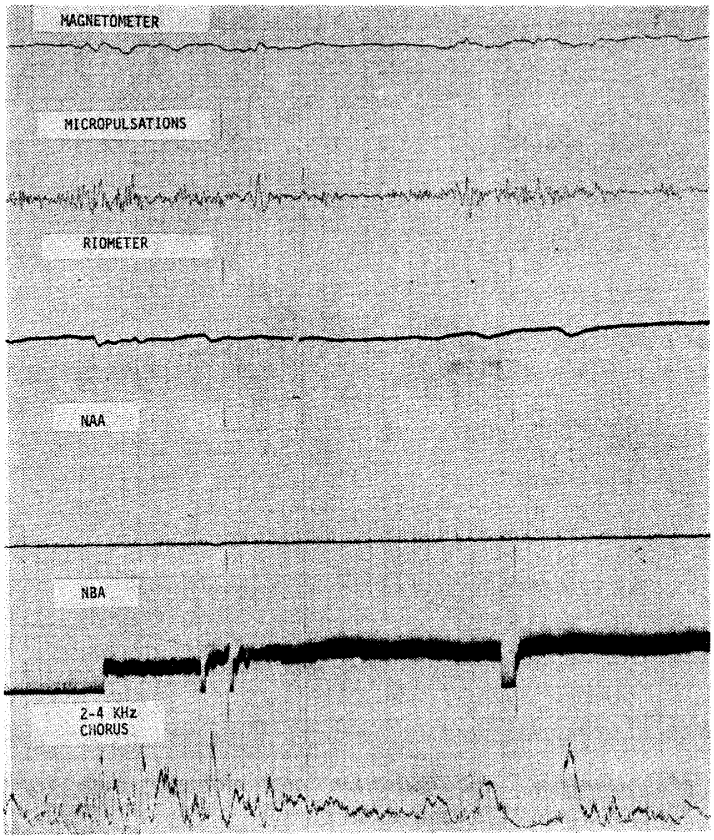

Fig. 4. Chorus bursts observed at Siple, 14 May 1974 near 1800 Z.

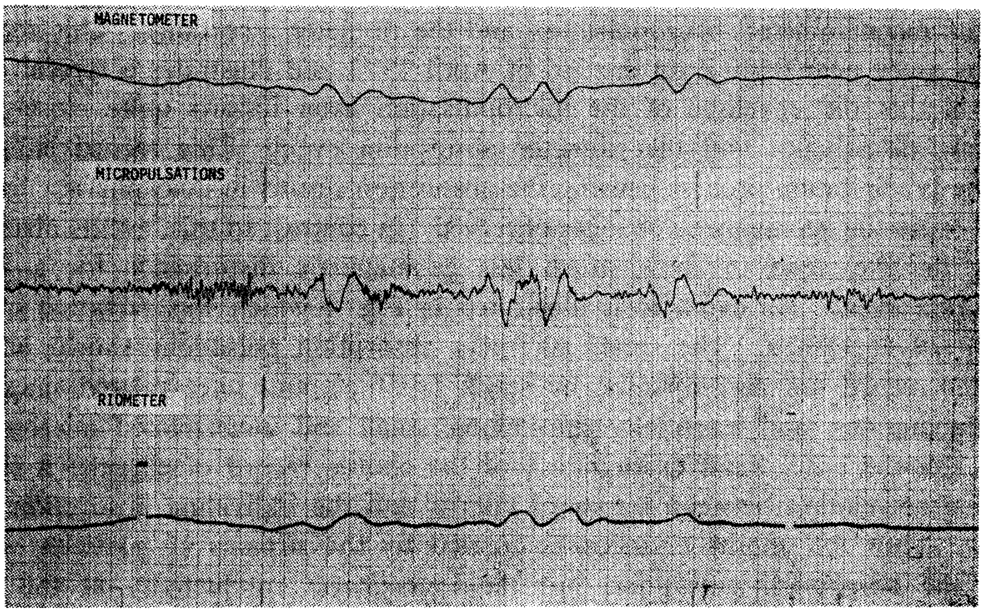

Fig. 5. Magnetometer, micropulsations and riometer data recorded at Siple, 20 April 1973 near 2000 Z.

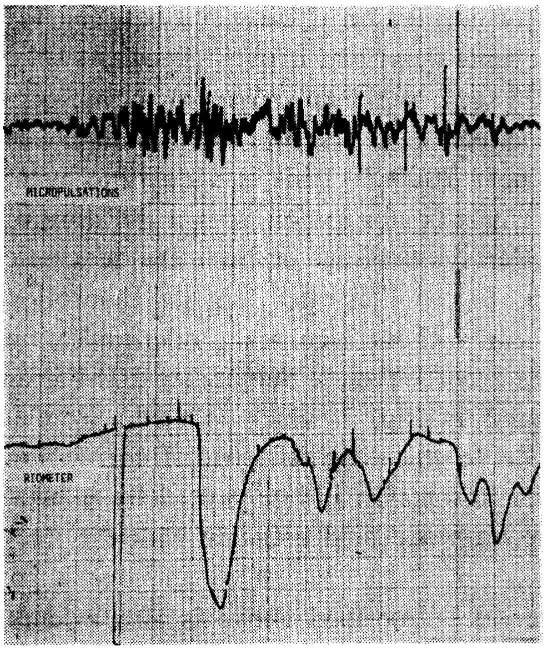

Fig. 6. *Micropulsation and absorption data recorded at Siple, 2 September 1974 near 2056 Z.*

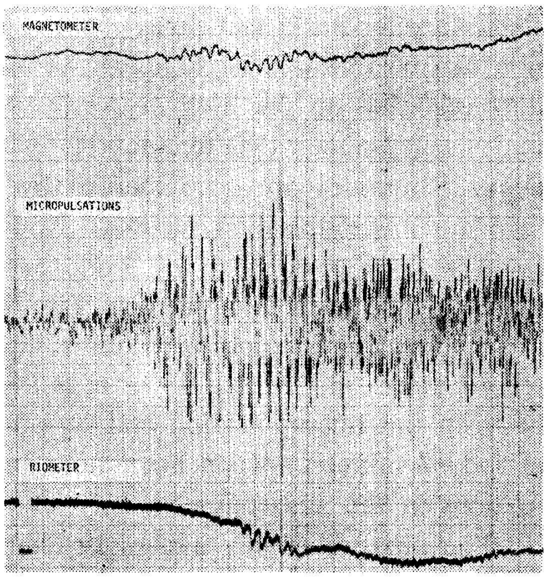

Fig. 7. *Magnetometer, micropulsations and riometer data recorded at Siple, 13 May 1973 near 0800 Z.*

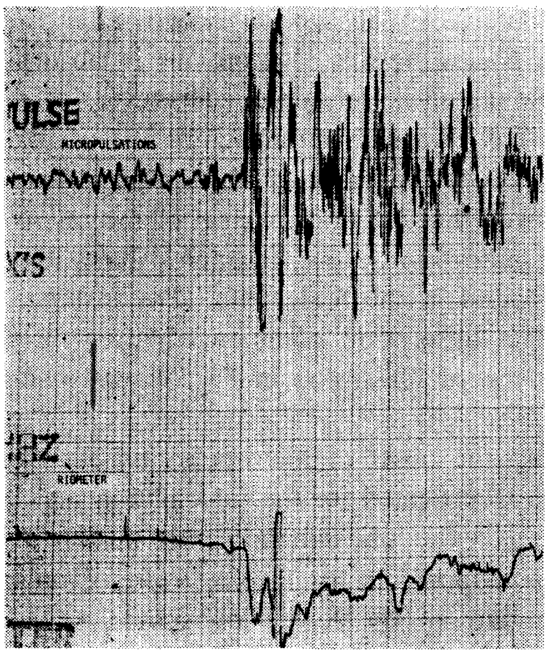

Fig. 8. *Micropulsations and riometer data recorded at Siple, 28 June 1974 near 0110 Z.*

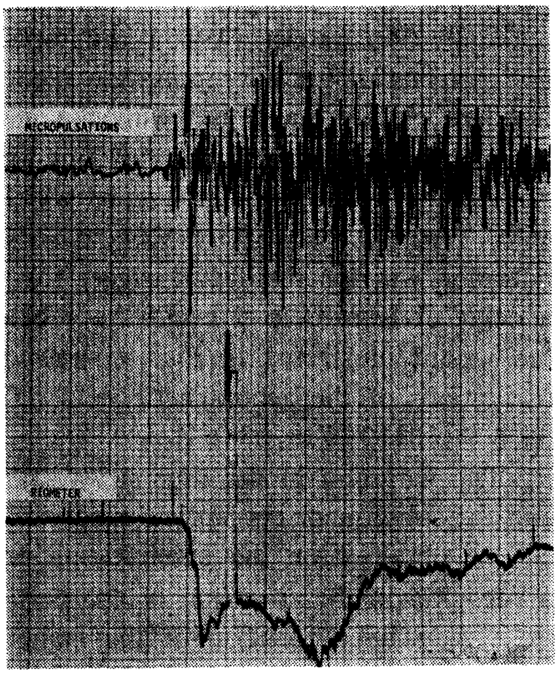

Fig. 9. *Micropulsations and riometer data recorded at Siple, 6 April 1974 near 0316 Z.*

channel recordings illustrate a wide variety of correlation phenomena between the extremes of the generalized night and day events described above. Since the solid state riometer has a fast time response (0.25 sec), rapid pulsations in the absorption can be followed accurately. As an example, Fig. 5 shows three channels of data recorded on the 20th of April 1973 near 2000 Z. This is a daytime event and it can be seen that fluctuations in the riometer absorption with a duration of about 3 minutes are accompanied by similar fluctuations in both the magnetic field and micropulsation records. However, Fig. 6 illustrates that an absorption event with a peak value of 7 dB, can occur without significant micropulsation activity. The event illustrated in Fig. 6 was recorded on 2 September 1974 near 2056 Z. A further complication is illustrated in Fig. 7 which is taken from a record made on 13 May 1973 near 0800 Z. In this case the general correlation between the micropulsation activity and the absorption is interrupted by a brief period (3 minutes) when fluctuatons in the magnetic field coincide with the fluctuations in the absorption.

The mixture of day and night characteristics described above is also evident in another class of events which have been observed in the Siple record. These are events which have a sudden onset of both the absorption and the micropulsation activity and usually occur at night. An example is illustrated in Fig. 8 which is copied from a recording made on 28 June 1974 near 0110 Z. Large micropulsations begin abruptly at about the same time as absorption commences. As noted by MOROZUMI (1965) the rapid increase in absorption occurs after the first reversal of the micropulsation record. Following this, fluctuations in absorption are closely correlated with the individual micropulsations. However, close examination of several events of this kind has shown that the number of oscillations of the micropulsation record which precede the onset of absorption is variable. Whereas the work of MOROZUMI showed that the first reversal of the micropulsation was the significant trigger for the absorption event, examples illustrating a delay of from 0 to 5 cycles have been found in the Siple data. For instance, the record illustrated in Fig. 9 showed that absorption commenced after three oscillations of the geomagnetic field. The record illustrated in Fig. 9 was made on 6 April 1974 at 0316 Z.

The variation in the time delay between the onset of micropulsation activity and the subsequent absorption event will be investigated for the information which can be obtained on the precipitation process. The phenomenon may be due to a variation in the spectrum of the particles responsible for the fast onset events, or it may be a function of the response time of the lower ionosphere to the precipitating flux of electrons. The installation of a riometer of a frequency such as 50 MHz would help to resolve this problem. Certainly for very short duration precipitation events, the riometer record can be used to determine the response

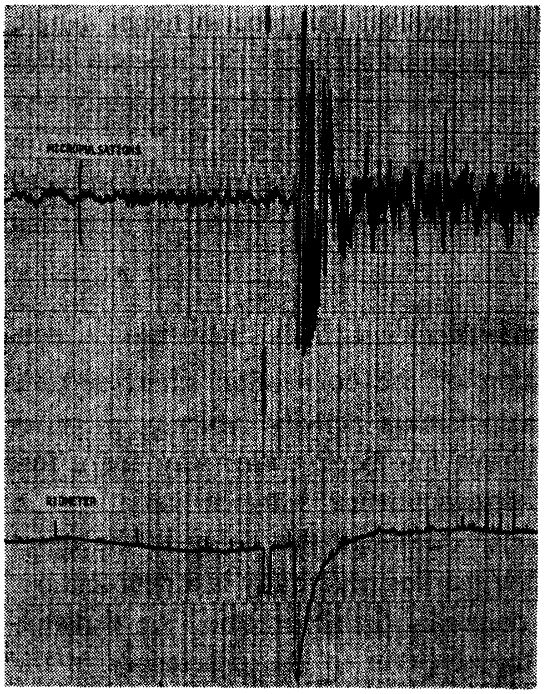

Fig. 10. Micropulsations and riometer data recorded at Siple, 15 September 1974 near 1345 Z.

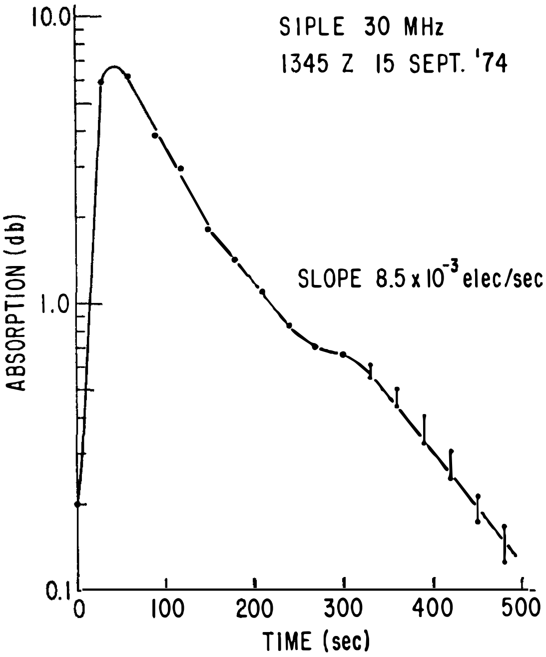

Fig. 11. Absorption profile of riometer event recorded 15 September 1974 at Siple.

time of the ionosphere for both the growth and decay phases of the absorption. An example of such an event is illustrated in Fig. 10 which is a copy of a record made on 15 September 1974 near 1345 Z. This event has remarkably simple structure in that there is an exceedingly rapid onset followed by a pure exponential decay. Note that a calibration immediately precedes the absorption event and this serves to illustrate the response time and resolution of the record. The pulsation event has been scaled as accurately as possible and is replotted in Fig. 11 using semi-logarithmic form. This event is similar to two small events recorded by WILLIAMSON (private communication) at Byrd using both riometers and balloon-borne scintillators. The balloon observations indicated that the event was due to rapid high energy precipitation event which had terminated even before the absorption reached its peak. Therefore the diminuation in absorption can be used to measure the response time of the ionosphere. Hence, the various models of the ionospheric process responsible for the net loss rate of electrons following the removal of the ionization source can be tested. For instance, if the dominant process is attachment, charge exchange and recombination with ambient positive ions, the semi-logarithmic plot of Fig. 11 should show a straight line since the net electron loss rate would be directly proportional to electron density. The average value for the slope of the curve plotted leads to a value of 8.5×10^{-3}

electrons per second for the electron loss rate. However the process is not simple because there is a break in the slope of the curve approximately five minutes after the event started. This could be due either to a change in the loss mechanism as the absorption decreases, or a change in the height which marks the absorption observed. Analysis of this event and others which reveal the presence of non-equilibrium disturbances in the ionosphere will be continued as a method of testing ionospheric models.

3. Conclusions

The results of a preliminary investigation of the correlation chart records obtained at Siple have shown that the micropulsation activity typically precedes the onset of absorption although once the event has been under way for a few minutes, there appears to be a detailed correspondence between variations in absorption and the micropulsation fluctuations. Although this delay in the onset of absorption has been reported previously, the marked variability is a new feature. It appears as if the micropulsations act as a precursor for absorption. An explanation of the differing onset times is to be found either in the differences in the spatial coverage of the two instruments or in the sensitivity of the instruments to variations in the energy spectrum of the incident particles. The riometer is used with an antenna that has a beam width of 60° to the half power points so that an area of sky approximately 90 km in diameter is examined. The ULF waves responsible for the micropulsation activity may be propagated over large distances so that a time delay between the onset of micropulsations and the onset of absorption simply indicates that the precipitation event commences at a distance from the station and gradually moves overhead. When the two instruments respond together at the beginning of an event, then using this hypothesis the event commences overhead at the station. An alternative explanation to the difference in beginning time seen by the two instruments is that the spectrum of the incident electrons changes as the event progresses. The micropulsations are observed when soft particles enter the atmosphere while the onset of absorption is delayed until particles of sufficient hardness to reach an altitude of 90 km or less arrive. Since our observations indicate that the micropulsations always precede the onset of absorption, this implies that the particle spectrum always hardens as the event progresses. This is in contrast to an established view that the particle spectrum softens during an event since the hardest particles arrive first.

The two tentative explanations of the time separation of the beginning of micropulsation and absorption events which have been given are based on the fragmentary evidence obtained from the correlation chart recorder. In order to investigate the cause of this effect further, it is planned to extend the observational system in several ways. A 50 MHz riometer will be added to Siple Station in order to indicate the changing spectrum of electron precipitation during absorption events. Additional riometers have already been placed at the conjugate location near Roberval, Canada, in order to investigate the detailed relationships of the precipitation in the two hemispheres. To investigate the question of the size and motion of the absorbing regions, a narrow beam antenna system has been erected at Roberval. The antenna has an elliptical beam pattern with nominal dimensions 6° by 60° to the half power points. The antenna is aligned so that the narrow dimension is in the north-south direction and this makes the antenna most sensitive to north-south movements of absorption. A future antenna is planned which will restrict the beam width to a circular pattern measuring 6° to half power. Additional analysis of the existing Siple records will be made using the digital tape recording which has a time resolution and sensitivity superior to that of the chart recorder.

Acknowledgments

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