APPLICATION OF RIOMETERS IN SPACE WEATHER

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ABSTRACT

The application of riometry in HF radio communication and radio science has been reviewed in this presentation. Basic principles of riometry are discussed along with a brief description about the operation of riometers. The superiority of riometry over pulse reflection method under high absorption conditions has been established by analyzing a Polar Cap Absorption event. New applications of riometers have been suggested at the end of the presentation.

INTRODUCTION

The accuracy in the prediction of appropriate HF radio wave frequencies for communication using ionospheric reflections depends completely on our ability to accurately determine the characteristics of the different layers of the ionosphere. Various techniques have been used to study these characteristics of the ionosphere, each one having its own merits and limitations. The method of creating and analyzing ionograms is probably still the most popular technique used for this purpose, but it fails at the time of high absorption of radio waves in the ionosphere during solar and magnetospheric events, especially at high latitudes [1].

Since the characteristics of the ionosphere have a direct dependence on the absorption of RF waves in the ionosphere, and the regions of the ionosphere above the level of maximum ionization are not accessible to the normal reflection technique, a technique was proposed [2] to measure the absorption of cosmic radio waves with a view to having a better understanding of the ionosphere. Based on this technique, the Riometer (Relative Ionospheric Opacity Meter) was first designed and developed by Little and Leinbach [1] for a continuous measurement of ionospheric absorption. It can be used to determine the potential for communication disruptions due to enhanced ionospheric absorption and to measure RF absorption during solar X-ray events and during the arrival of high-energy particles [3]. A more sophisticated imaging riometer can even produce a two dimensional map of the cloud of ionization in the ionosphere. Unlike the radio wave reflection method, a riometer provides valuable information about ionospheric absorption, even during periods of high absorption, such as a Polar Cap Absorption (PCA) event.

RIOMETRY TECHNIQUE

Basic Principle

A riometer measures the absorption of cosmic radio noise as it passes through the atmosphere. Riometers are convenient instruments for investigation of the processes leading to absorption in the lower ionosphere (D and E regions) and also at higher altitudes in auroral and polar regions [1, 2, 3]. Riometers are based on the principle that, if no absorption of the cosmic radio noise occurs in the ionosphere, the pattern of noise power variation repeats every sidereal day. The galactic radio noise power received on a fixed receiving system at the earth's surface will be a function of sidereal time only, since each day the aerial beam explores the same strip of sky as the earth rotates. The absorption of the radio noise in the atmosphere at a particular instant of time is, therefore, given by the ratio of the signal strength received under conditions of little ionospheric absorption to that actually received on a particular day at the same sidereal time.

The amount of absorption of the galactic radio waves passing through the ionosphere is measured relative to the amplitude signal received under quiet ionospheric conditions, which makes it important to obtain a consistent 'Quiet Day Curve' (normally called QDC). Since the ionosphere is always present, we cannot achieve an ideal situation of zero absorption for the QDC. Also the cosmic radio noise level continuously fluctuates. Therefore, statistical techniques are employed to determine the QDC. A good analysis of these techniques has been presented by Krishnaswamy et al.[5]. The estimation of the QDC involves the examination of the diurnal variation over an extended period of time, usually several weeks. At IPS Radio and Space Services (IPS) an IDL program is used to generate the QDC, which is based on the following steps [4]:

1. A signal amplitude distribution is constructed as a function of local mean sidereal time from a statistically representative number of days centred on the selected day or, as for real-time absorption, from the preceding days (typically, a month's worth of data).

2. Points of maximum negative slope past the mode in the amplitude distribution are found and they define the QDC as a function of local mean sidereal time.

The following equation is then used to determine the actual absorption, A(dB), of the cosmic radio noise, in units of decibels.

$$A(dB) = 10 \log_{10} (A_{qdc}/A_{day}) \quad (1)$$

where A_{qdc} is the signal amplitude recorded on a quiet day and A_{day} is the signal amplitude received on the selected day at the same sidereal time [4].

Operation

A standard riometer mainly consists of a horizontal dipole (broad beam) antenna, a self-calibrating radio receiver and a data acquisition system, as shown schematically in Fig. 1. Fig. 2 shows a photograph of an actual La Jolla riometer installed at the Casey Antarctic Station.

The receiver captures cosmic radio noise through a fixed antenna system and quantifies it by comparing its intensity with a known stable noise source. The calibration noise source facilitates this comparison by providing the known stable noise signal. Calibration is performed by periodically switching the radio receiver between the antenna input and the calibration noise source, using the Radio Frequency (RF) switch. The 30 MHz La Jolla riometer used by IPS automatically switches to a calibration signal every hour for 56.25 seconds. A timing unit controls synchronization of signals in various stages of operation. The output of the receiver is then fed to the data acquisition system.

ANARE uses a PC-based data-logging program ADAS (Analogue Data Acquisition System) for data acquisition. Real-time ADAS data files, containing raw data of 5 minutes duration are communicated regularly to IPS computers from the four Australian Antarctic Stations of Macquarie Island, Casey, Davis and Mawson. These files are concatenated and cleaned up at IPS to make daily data files. The data are used for space weather monitoring and forecasting and then are archived for any future use. Real-time data are also displayed on the IPS web site in graphical form for public inspection.

OBSERVATION OF A POLAR CAP ABSORPTION EVENT

An M7 X-ray flare was observed on day 313 (8 November, 2000). It started at 2242 UT and reached its peak at 2328 UT the same day. The event was accompanied by a halo CME (Coronal Mass Ejection) and a Type IV radio sweep. Three other optical flares were observed also during this M7. Two proton events, as shown in Table 1, were also observed the same day and were associated with the M7 flare. Table 1 shows a sequence of major events observed between day 313 and 318 (Nov. 8-13, 2000). A PCA event occurred because of these proton events. All these factors resulted in an enhanced ionization of the lower ionosphere and hence a considerable increase in the absorption of the radio waves in these regions. Fig. 3 shows this sudden increase in the absorption of cosmic radio waves in the late hours of 8 November, 2000, as recorded by the riometers installed at the four Antarctic stations. The bottom part of Fig. 3 shows the flux variation of solar protons of various energies, as recorded by GOES-10. This figure also shows a sudden rise in the proton flux in the late hours of 8 November and corresponds to the rise in the galactic radio noise absorption that day.

Table 1: Sequence of major events observed between 8 and 13 November, 2000

Event	**Started at** Day/Time (UT)	**Peaked at** Day/Time (UT)	**Ended at** Day/Time (UT)
M7.4 X-ray flare	08/2242	08/2328	09/0005
>100 MeV Proton event	08/2355	09/0350	11/0240
>10 MeV Proton event	08/2350	09/1600	13/0745 (very low on 12 Nov.)

Fig. 4 presents a sequence of gradually disappearing ionograms recorded at Mawson at the time of these events. Before the events started, the ionosphere had well-defined layers in it. Both the low and high frequencies were reflected by the ionosphere, thus forming clear ionograms. As the events progressed, an increase in the ionization level of ionospheric layers caused a greater absorption of sounding radio waves, resulting in a gradual loss of reflected radio waves- the lower frequencies disappearing first (Fig. 4 a, b, c). As the M7 flare reached its peak (2328 UT), the ionogram completely disappeared, showing a complete absorption of all the sounding radio frequencies (Fig. 4 d). No ionogram traces were recorded on subsequent ionograms until the greater than 100 MeV PCA event ended on 11 November, 2000. During this period of about 56 hours, the method of studying the ionosphere by using the radio wave reflection technique proved less useful.

Even after a failure of the radio wave reflection method, the riometers continuously provided useful information about space weather, in particular the absorption of radio waves by the ionosphere and the likelihood of conditions returning to normal. The gradual decrease in the absorption during the late hours of 10 November and early hours of 11 November (Fig. 3) indicated that the ionosphere was returning to normal and communication would soon be possible again. The reflection method, however, provided minimal useful information until the ionosphere actually recovered from the effect of the events. The greater than 100 MeV proton event ended at 0240 UT on 11 November. However, since the slower protons were still arriving, absorption remained high for more than 4 hours longer before the recovery of the ionosphere could start around 0710 UT. Fig. 5 shows the gradual recovery of ionograms at the end of the event and corresponds to observations of low absorption recorded by the riometer. The 10 MeV proton event continued to decrease slowly in magnitude on 11 November and remained steady at 22 PFU (proton flux units) for several hours before falling down very close to the event threshold (12.4 PFU) at 2100 UT on 12 November.

DISCUSSION AND CONCLUSIONS

These observations suggest that riometers provide us with useful information about the ionosphere, even during a high absorption event at any location on the earth when other methods show up their limitations. They offer the ease of operation and calibration, good stability and no need for a transmitter. No multiple echoes are required for the studies and the linear response to the variation in the input noise speeds up the data analysis. However, they do have their limitations of being relatively insensitive to small ionospheric changes, susceptible to local radio interference, and providing data only on fixed frequencies[6].

If appropriate models are developed and riometers are designed to work on more than one frequency, they can be used for many more scientific purposes. They can be used to study ionosphere-magnetosphere-solar wind interaction, estimate ionospheric production and loss rates, characterize and study precipitation of energetic particles, determine potential hazard of radio noise to microelectronic components, measure the local RF noise for radio science and communication studies, and determine the potential for communication disruptions due to enhanced ionospheric ionization for any reason.

From all this discussion we can conclude that riometers have very important applications in HF radio communications and space weather studies. With appropriate modifications in their design and development of mathematical models, they can provide very rich science returns to the scientific world.

ACKNOWLEDGEMENTS

The authors are grateful to Michael Hyde of Australian Antarctic Division for providing the picture of the Casey riometer site. We also acknowledge Lloyd Symons of AAD with the development and maintenance of ADAS software. Support from Richard Marshall, Patrick Phelan and Ammu Premkumar of IPS in the presentation of data is also thankfully acknowledged.

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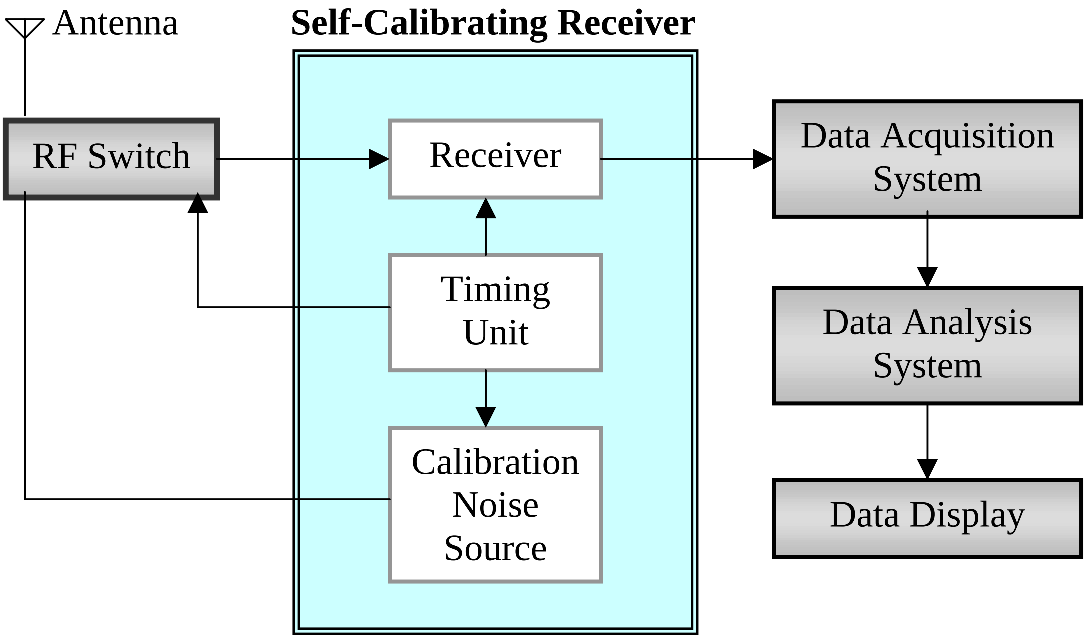
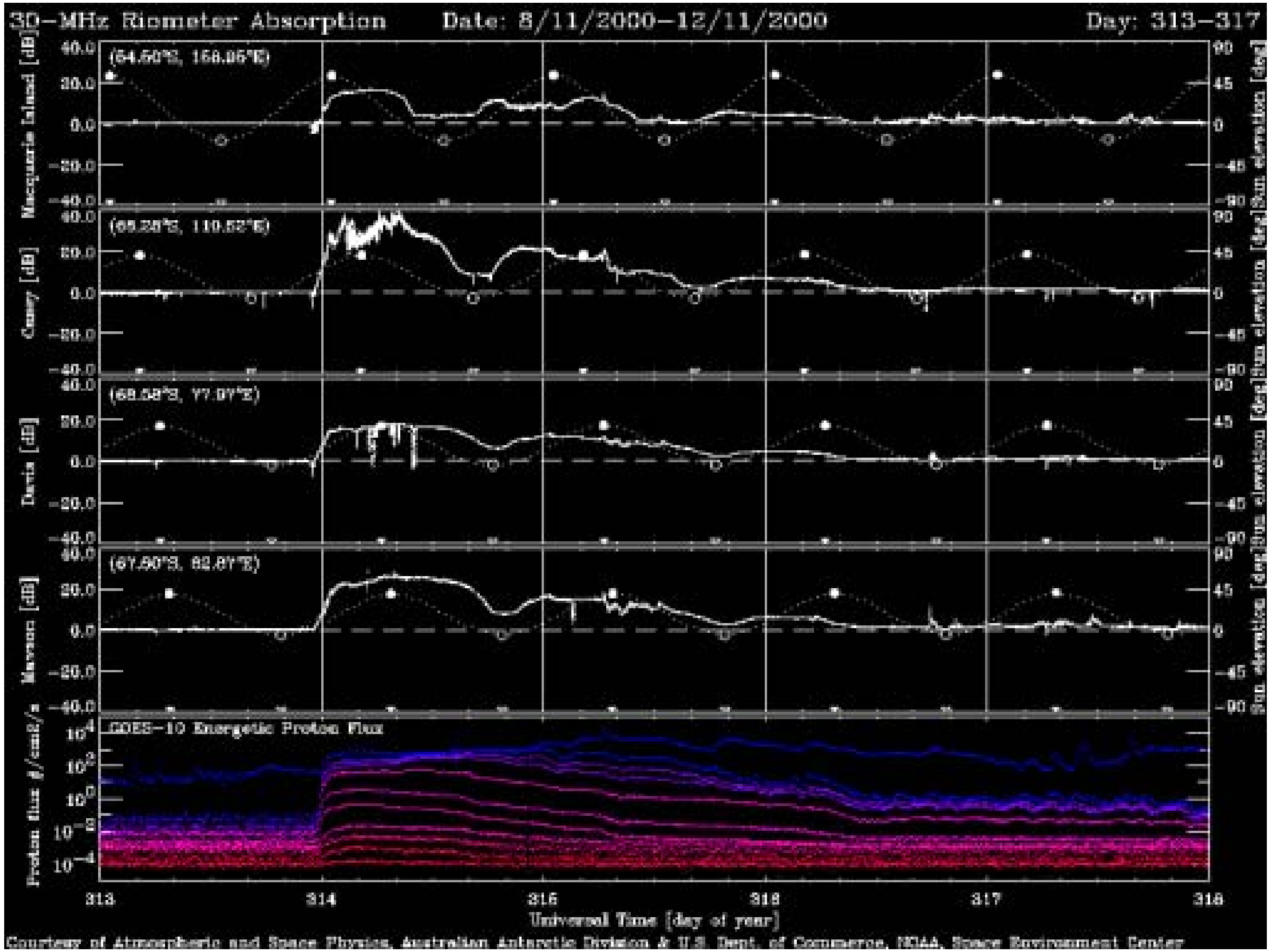


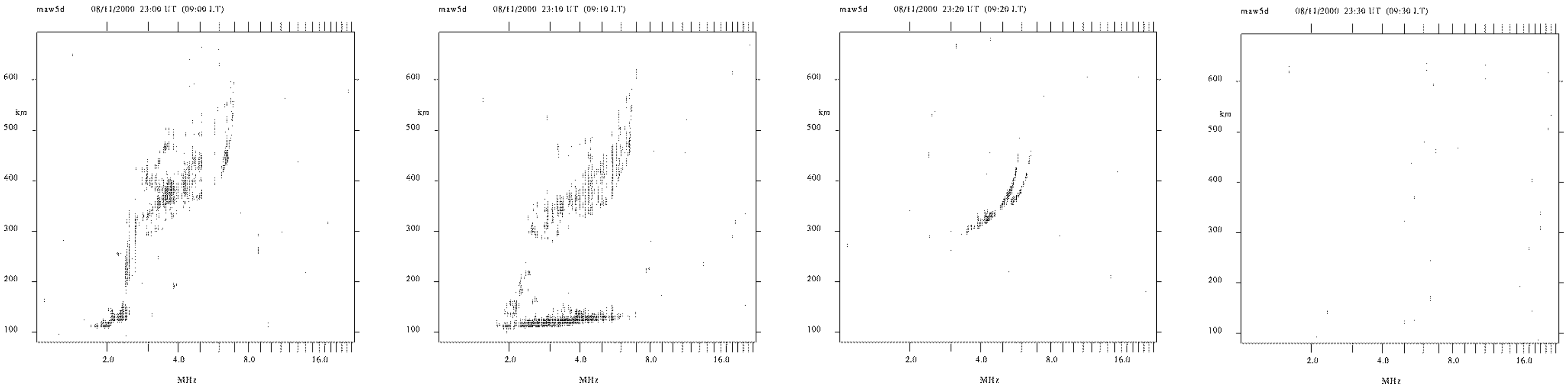
Fig. 1: Simplified schematic diagram of a basic riometer.

Fig. 2: A complete riometer system installed at Casey Antarctic station showing riometer, dipoles and the elevated ground plane



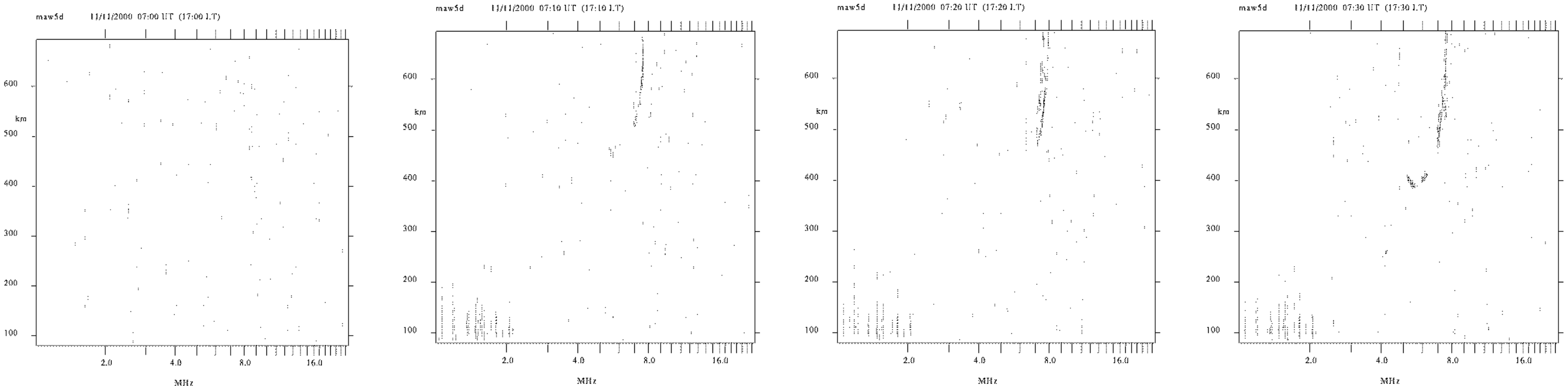
Courtesy of Atmospheric and Space Physics, Australian Antarctic Division & U.S. Dept. of Commerce, NOAA, Space Environment Center

Fig. 3: A sudden increase in cosmic radio noise absorption in the ionosphere observed on 8 Nov., 2000. The absorption fell back to the normal level on 11 Nov. and remained very close to QDC on 11 and 12 November. The data were recorded at the following four Antarctic stations whose geo-magnetic coordinates are shown in brackets: Macquarie Island (60.12°S, 115.65°W), Casey (76.66°S, 176.25°W), Davis (76.54°S, 127.62°E), Mawson (73.25°S, 109.56°E). The dotted lines indicate the diurnal variation of the solar elevation angle at each site, with ○ and ● representing local sidereal noon and mid-night respectively.



(a) 23:00 UT (b) 23:10 UT (c) 23:20 UT (d) 23:30 UT

Fig. 4: Gradual disappearance of ionograms with an increase in cosmic radio noise absorption recorded at Mawson Antarctic station on 8 Nov., 2000.



(a) 07:00 UT (b) 07:10 UT (c) 07:20 UT (d) 07:30 UT

Fig. 5: Gradual reappearance of ionograms with a decrease in cosmic radio noise absorption recorded at Mawson Antarctic station on 11 Nov., 2000.