Magnetospherically reflected (MR) whistlers observed in DEMETER satellite and on the ground observation of normal whistlers at low latitudes

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The DEMETER (Detection of Electromagnetic Emissions Transmitted from Earthquake Regions) satellite data have been analysed for a period of three and half months from 01 September to 16 December 2010 in search of whistlers and VLF emissions and their ground observations at low latitudes. The quick look data show intense sporadic bursts mostly in the Instrument Champ Electrique (ICE) channel of the satellite. These bursts are analysed using MATLAB software for the nighttime passes of upgoing orbits in the latitude range 20°-50°. The analysis shows records of large number of first component of magnetospherically reflected (MR) whistlers, mostly when the satellite is in low latitude ionosphere. These whistlers, together with normal whistlers observed in the satellite, are not observed on the ground as revealed by simultaneous ground observations at low latitude station Agra. This confirms them to be non-ducted whistlers which are reflected and observed in the ionosphere and magnetosphere. These MR whistlers are suggested to be the major source of slot formation between the two radiation belts.

Keywords: Ionospheric disturbance, Magnetospherically reflected (MR) whistlers, VLF emission, VLF burst
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1 Introduction

It is well known that whistlers are electromagnetic waves, which are radiated from lightning discharges and propagated from one hemisphere to the other along the geomagnetic field lines1. The propagation of such waves is controlled basically by the gradients in the magnetic field and electron number density in the ionosphere and megnetosphere. These gradients also cause the waves to be deviated away from the field lines and reflected at certain points, leading to so-called magnetospheric reflections. Such waves are called magnetospherically reflected (MR) whistlers and can be recorded by rockets and satellite only as they cannot reach the ground. The process of propagation and reflection can occur several times before MR whistlers are absorbed by superthermal electrons through Landau damping. Kimura2 presented ray paths of such whistlers for the first time by ray tracing computations. The MR whistlers were originally recorded in OGO1 and OGO3 satellites and studied thoroughly by a number of researchers4,8. Recent work involving MR whistlers in precipitation of resonant particle fluxes has been carried out by Lundin & Kraft9 and Blake et al.10. More recently, Bortnik et al.11 have modeled the propagation of MR whistlers using ray tracing and Landau damping calculations and estimated the energy distribution and life time of MR whistlers injected into the ionosphere from four different locations between 25° and 55° latitudes. An important result that they obtained shows that MR whistler energy is maximized at the location of the slot region, suggesting that such MR whistlers launched by lightning discharges may be responsible for the enhanced diffusion rates and may play a more significant role than previously assumed in the formation and maintenance of the slot region between the inner and outer radiation belts. Bortnik et al.12 have studied the temporal and global signatures of radiation belt electron precipitation induced by MR whistlers. In an experiment conducted from the Radio Plasma Imager (RPI) Instrument on the IMAGE satellite, Sonwalkar et al.13 have recorded magnetospherically reflected (MR), specularly reflected (SR), and backscattered (BS) whistler mode radio-sounder echoes on the satellite and interpreted them thoroughly.

The satellite DEMETER was launched by LPCE/CNRS, France in circular orbits at a height of 710 km on 29 June 2004 which worked successfully
till 16 December 2010. Although, the basic scientific objectives of the DEMETER satellite was detection of electromagnetic emissions transmitted from earthquake regions and confirm their origin and propagation mechanism; there were other payloads also for the measurement of electron and ion densities, temperature, detection of energetic particles, and a general study of overall electromagnetic environment in the ionosphere\textsuperscript{14-16}. The DEMETER data have been extensively utilized to study the ionospheric perturbation in relation to seismic activities and for general studies of geophysical phenomena\textsuperscript{17-20}. Since Agra station has been awarded USER-1 category for the analysis of DEMETER data in India, extensive use of the satellite data has been made for studies in the fields of seismo-electromagnetics and space science\textsuperscript{21,22}.

A study of magnetospherically reflected (MR) whistlers recorded on the DEMETER satellite has been carried out and presented in this paper. The results show that on account of non-ducted conditions existing largely in the low latitude ionosphere relative to higher latitudes, MR waves are produced, which may be a major causative source for the formation and maintenance of slot region between the radiation belts. It is also shown and confirmed that normal whistlers recorded on the DEMETER satellite are not accessible to ground because of non-ducted mode of propagation possible in this region of the ionosphere only.

2 Scientific payloads in DEMETER satellite

The basic purpose of the DEMETER satellite is to study the ionospheric disturbances related to seismic activities. However, there are other payloads, which give global information on the earth’s electromagnetic environment. For these purposes, the satellite payload consisted of Instrument Champ Electrique (ICE): three electric sensors for measurement from direct current (DC) to 3.5 MHz, and Instrument Magnetometer Search Coil (IMSC): three magnetic sensors for measurement from a few Hz to 18 kHz, besides an ion analyzer, an energetic particle detector, and a Langmuir probe. Since the present study is concerned with the study of electromagnetic waves in extremely low frequency/very low frequency (ELF/VLF) range, only the electric and magnetic field data provided by the satellite in this range are considered.

3 Ground observations at Agra

The whistler observations at Agra station (geomagnetic latitude 18.09°N, longitude 152.21°E) were conducted for a period of three months from 01 October to 31 December 2010 using the experimental setup developed at Agra\textsuperscript{23}. The basic objective for conducting short period observations was to examine whether the whistlers recorded in the DEMETER satellite are observed on the ground or not. This is a digital recording set up which consists of a vertical antenna, amplifier, band pass filter, sound card and a PC (with sound recording software). This experimental setup is different from those used at other Indian stations\textsuperscript{24-28} where Stanford University designed AWESOME (Atmospheric Weather Electromagnetic System for Observation, Modeling and Education) receiver is being extensively used. The signal induced in the antenna is fed to the amplifier, which has a gain of 40 dB with flat frequency response in audible range. The amplified signal is passed through a band pass filter (02-10 kHz) and recorded on the PC through the sound card. The sampling rate used for the present study is 20 kHz. The observations are taken during nighttime (1800-0600 hrs LT) at Bichpuri which is located in rural area about 12 km west of Agra city, a location with very low electric and electromagnetic disturbances. The digital data stored on the computer hard disk is analysed using offline DSP technique available in MATLAB software.

4 Results and Discussions

The DEMETER data are accessed through the website \texttt{http://demeter.cnrs-orleans.fr} by assigned user ID and password. Initially, quick-look data for the ICE and IMSC channels was downloaded for nighttime orbits between 01 September and 16 December 2010 (last active day of the satellite). One of the orbits of the satellite passing through Indian longitudes on 21 October 2010 is shown in Fig. 1. The orbit (no. 33746_1 upgoing) passes through a grid bounded by latitude range 25°-35°N and longitude range 60°-80°E. Similar grids have been chosen at mid and high latitude also. The solid rectangle blocks shown on the map are of website origin.

Then VLF bursts existing during nighttime between 20° and 50° geomagnetic latitudes were examined. Pandey \textit{et al.}\textsuperscript{22} have shown that these bursts are due to clusters of whistlers and VLF emissions occurred in short periods of time (1-2 h) and recorded in the satellite. Four examples of short and long duration bursts which occurred along the upgoing orbits of the satellite during nighttime at low and
middle latitudes below 60° are show in Figs (2–5). The top panels in these figures indicate the quick look electric and magnetic channel data containing the bursts (intense electric than magnetic). The date and orbit number are given on the top and other orbit parameters (universal and local time, UT/LT, latitude and longitude) are given at the bottom of the magnetic channel. The middle panels of the figures show examples of 01 second of frequency-time data out of numerous of such types analysed by using MATLAB. The details of such data (time and location of observation) are indicated on the respective spectrograms themselves. The bottom panels show the frequency-time records of the data observed at Agra station corresponding to approximately the same times at which the satellite data in the middle panels were recorded. The Agra data are shown in Figs (2 and 3)

Fig. 1 — An upgoing orbit of DEMETER satellite passing over Indian longitudes through a grid of open rectangle formed by latitude range 25°–35° and longitude range 60°–80°; [solid squares and rectangles are of website origin]

Fig. 2 — (top): Quick-look electric and magnetic field data presented in the ICE and IMSC channels; (middle): Frequency-time spectrograms of 01 second data recorded in burst of ICE channel; and (bottom): corresponding frequency-time spectrograms of data recorded at Agra station
only because they correspond to low latitude observations of the satellite data presented in the middle panels. It is assumed that whistlers recorded at the satellite at low latitudes might leak through the ionosphere to reach the ground and recorded at Agra station, while those at middle and high latitudes (presented in Figs (4 and 5)) may not be observed at Agra station.

The middle panels of Figs (2 and 3) show two kinds of whistlers: one sferics type with minor dispersion at low frequencies (ionospheric sferics), and the other full-fledge normal whistlers. The main focus of attention in the present study has been on the sferics type of whistlers. In fact, as it is known, sferics and tweeks are mainly propagated to long distances between the earth and ionosphere space, but here they penetrate the ionosphere and propagate in whistler mode along the field lines to be observed in the satellite. Since the ionosphere causes a very small dispersion of such waves (< $5^{1/2}$), they appear mostly like sferics (tweeks) with minor dispersion at low frequencies. From the ground data recorded at Agra station around the same time and presented in the bottom panels, it is seen that there are no such data as in the middle panels. This indicates that the ionospheric sferics and whistlers recorded in the

![Fig. 3](image-url) — Another example of (top): Quick-look electric and magnetic field data presented in the ICE and IMSC channels; (middle): Frequency-time spectrograms of 01 second data recorded in burst of ICE channel; and (bottom): corresponding frequency-time spectrograms of data recorded at Agra station
satellite are propagated in non-ducted mode, get reflected, and subsequently lost in the ionosphere and magnetosphere. In fact, the so-called ionospheric sferics are those which are recorded in the satellite before reflections and appear as the first component of unreflected MR whistlers. They are recorded in the satellite in the same hemisphere in which they are originated. The first and other components of MR whistlers have also been recorded in POLAR satellite as reported by Bortnik et al.\textsuperscript{12}. The full-fledged normal whistlers are those which have propagated from one hemisphere to the other in non-ducted mode so that they also could not reach the ground. There may also be hybrid whistlers of higher latitude origin which re-penetrated the ionosphere at low latitudes to be observed in the satellite\textsuperscript{1}.

The frequency-time spectrograms presented in Fig. 4 show MR whistlers recorded at middle latitudes around 36° and 41°. They contain both the first components and reflected components of MR whistlers. Obviously, the reflected components show larger dispersions than the first components. Figure 5 shows a bit higher latitudes (46° and 47°) data. Here, more normal whistlers and less number of MR whistlers are found. The first component of MR whistlers (ionospheric sferics) appear mostly as sferics recorded on the ground due to very small dispersion produced by ionosphere below the satellite height in this region.

From the quantitative analysis of MR whistlers, it is seen that the average number of MR whistlers reduces as the latitude increases. This is quite obvious because at low latitudes, the magnetic dipole field lines are more inclined, the wave normal angles (angles between the penetrating wave normals and field line) are large, and hence whistlers are deviated considerably away from the field lines to be propagated in non-ducted modes so that they are reflected in the upper ionosphere and magnetosphere as MR whistlers. In contrast, the magnetic field lines

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure4.png}
\caption{(upper): Quick-look electric and magnetic field data showing a long duration burst; (lower): One second each of data showing first and second components of MR whistlers recorded at two different locations of lat 41°N, long 91°E and lat 36°N, long 80°E}
\end{figure}
at higher latitudes are less inclined so that the penetrating whistler mode signals remain aligned with them and propagate to the opposite hemisphere without reflection in the mid-way. There are also evidences of field-aligned ducts to trap them and guide to the ground in the opposite hemisphere. Bortnik et al. have shown that the slot region between the two radiation belts is mostly due to diffusion and precipitation caused by MR whistlers. Since MR whistlers are generated and propagated relatively largely in the ionosphere at low L-shells as shown by the analysis of DEMETER data, it may be concluded that the contribution to the formation of slot region is more by MR whistlers originated at low latitudes than those at middle and high latitudes. A convincing support to this result is obtained from a glance at global distribution of intense lightning activities which are located in the equatorial regions of Asia, Africa and America.

5 Conclusion

The satellite DEMETER data has been analysed for a period of three and half months between 01 September and 16 December 2010 in search of low latitude whistlers and VLF emissions. The ground observations have also been conducted at low latitude station Agra to verify ground propagation of such waves. The quick-look data shows intense sporadic bursts mostly in the ICE channel of the satellite, which on extensive analysis, using MATLAB, show large number of magnetospherically reflected whistlers whose number decrease as the latitude increases. Non-observation of such whistlers and also of normal whistlers on the ground at Agra confirm...
that these are non-ducted whistlers, which were reflected in the ionosphere itself. It is suggested that a major source of slot region between the two radiation belts is the intense generation of magnetospherically reflected whistlers in the low latitude ionosphere.

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References


Angerami J J, Whistler duct properties deduced from VLF observations made with the OGO 3 satellite near the magnetic equator, *J Geophy Res (USA)*, 75 (1970) pp 6115.