Study of long path VLF signal propagation characteristics as observed from Indian Antarctic station, Maitri

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Abstract

To examine the quality and propagation characteristics of the radio waves in a very long propagation path, Indian Centre for Space Physics, Kolkata, participated in the 27th Indian scientific expedition to Antarctica during 2007-2008. One Stanford University made AWESOME Very Low Frequency (VLF) receiving system was installed at the Indian Antarctic station Maitri and about five weeks of data was recorded successfully from the Indian transmitter VTX and several other transmitting stations worldwide. The signal quality of VTX was found to be very good and the signal was highly stable. The signal shows the evidences of the presence of the 24 hours solar radiation in the Antarctic region during local summer. We compute the elevation angle of the Sun theoretically during this period and the spatial distribution of the signal by using the LWPC model. We compute the attenuation coefficient of the different propagation modes and observe that different modes are dominating in different propagation conditions. We also observe effects of the Antarctic polar ice in the propagation modes.

1 Introduction

Indian Centre for Space Physics, Kolkata (ICSP) participated in the 27th Indian Antarctica expedition in the summer period during 2007-2008 to observe the long distance propagation characteristics of Very Low Frequency (VLF) radio wave signal. The data was recorded at the Indian permanent station Maitri (Lat. 70°45′, Long. 11°44′E) from 10 January to 15 February 2008. Our main observing transmitter was the Indian Navy's VLF VTX station transmitting at 18.2KHz. This station is located at Vijayanarayanam (Lat. 08°23′, Lon. 77°45′). The Maitri station is located at the Schirmacher Oasis region which is a rocky patch surrounded by polar ice at the east Antarctic region with a height of 100 meter above the sea level. During the summer period of the southern hemisphere, most of the time we received uninterrupted solar flux for the entire twenty-four hours. We were able to record the signal in the "full day and no night" (no true sunset) condition at the Maitri station. For the long path propagation it is expected to observe the modal conversion in the propagation path which reflects in the signal variation. To understand the 'normal' signal characteristics for a very long path (specifically, VTX-Maitri path) under the interesting and uninterrupted solar flux variation, Antarctica is most certainly a perfect location. As the receiver is close to the pole, charged particles from solar coronal mass ejections can interact with the geomagnetic field and our recorded signal should also carry the information of this strong interaction.

2 The Instruments

In the left panel of Figure 1, we show the locations of the transmitters (signals from which we expected to receive), the receivers at Maitri, and the propagation paths. To compare the results with short propagation paths, we kept a similar AWESOME setup at ICSP, Kolkata. Though we tuned our receiving system for several transmitting frequencies, the data from VTX (18.2 kHz) is found to be clean enough at both the receiving stations for a viable comparison.

We used crossed loop magnetic field antenna of dimension 30ft × 30ft at the base, and 15ft in height (right panel of Figure 1). Both the broadband (0 to 50 kHz) and the narrow-band data were recorded

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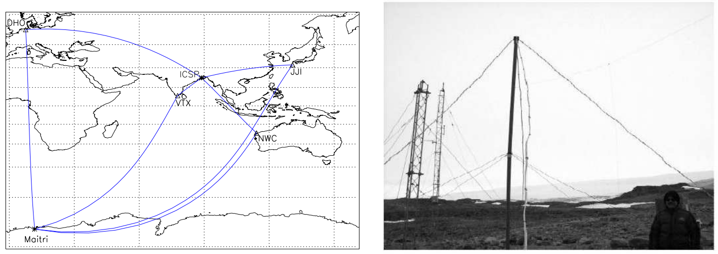

Figure 1: [Left]The positions of the transmitters we expected to receive. [Right]The cross loop VLF antenna at the Indian Antarctic station Maitri.

separately from different transmitters in the form of amplitude and phase from both the north-south and east-west aligned antennas.

3 The Observations and Interpretations

The receiving system at Maitri worked satisfactory. In the left panel of Figure 2, we present an example of the broad-band data we received at Maitri. The top is for the north-south aligned antenna and the bottom is same for east-west. This spectrum gives an idea of the signal status in the entire received frequency band (0-50 kHz). The color code gives the signal strength in dB. The horizontal lines represent the signals from fixed-frequency transmitters.

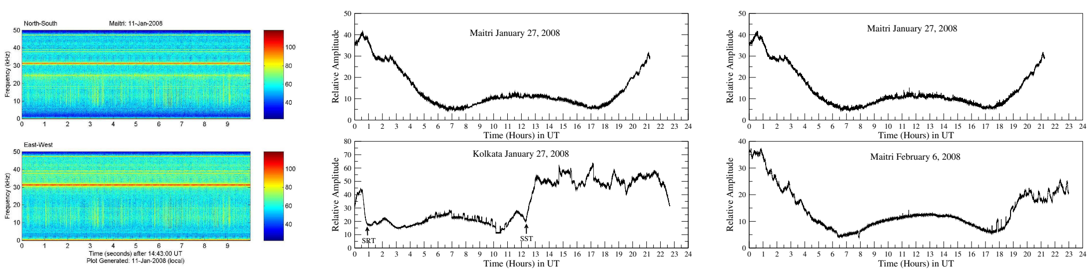

Figure 2: [Left:] The broadband data received from Maitri stations for 11th January 2008. [Middle:] The variation of signal amplitude as observed from Maitri and Kolkata station. [Right:] The signal amplitude for two different solar condition. (see text for details).

In middle panel of Figure 2, we present a typical diurnal variation of the signal amplitude of VTX at 18.2 kHz on 27th January, 2008. The VTX signal amplitude as received from Kolkata is presented in the the bottom. The data received at Maitri is qualitatively different from that received at Kolkata. In Kolkata, there are night-time signal fluctuations and a sharp rise and fall of the signal amplitude during the sunrise and sunset terminators respectively. The sunrise and sunset terminator times are quite distinct and the signal shows the clean signature of the D-layer appearance and disappearance. In Maitri data, on the contrary, the terminator like shallow but smooth deep occurred at two places. The entire signal is smooth because the ionization due to the sun is dominant in the entire 24 hour period. It took very long time for signals to fall from the 'nighttime' value of 40dB to the 'terminator' value of about 5dB, indicating that the D region is neither very well defined nor does it 'form' and 'disappear' properly. In the initial days of our observation, the true sunset did not occur. The changes of the incident solar flux changed the effective height and the ion-density profile of the D-region of the ionosphere very slowly. That is why the signatures of the formation of the D-layer or its disappearance is comparatively flatter and there is no sign of the true terminators. In the right panel of Figure 2, we present the data received from two different solar conditions. The top is during the time where there was no true sunset (27th January, 2008) and the bottom is during the time when there was true sunset (6th February, 2008) for a few minutes. Clearly the data for 6th February shows the night time signal amplitude fluctuations for a short time period.

We obtained a very stable diurnal variation with less interference among the waveguide modes. Generally in long paths, a series of minima are expected around the time of sunrise along the transmission path (Clilverd, 1999; Thomson, 2007), which are associated with modal conversion effects during the sunrise and sunset terminator. But the VTX (18.2 kHz) data received at Maitri does not show any strong modal conversion effects. In the present case for VTX-Maitri propagation path, short great circle path is over the sea water with lesser attenuation, while the long great circle path is over the land mass and the signal has to pass over the Antarctic ice mass to arrive at the receiver, hence will suffer very high attenuation. So the VTX signal received at Maitri propagated along the short great circle path.

We compute the signal amplitude along the VTX-Maitri VLF path using the more general Long Wavelength Propagation Capability (LWPC) code (Ferguson, 1998) corresponding to two propagation conditions. These are the propagation condition corresponding to 00:00 UT when the total path was under darkness and the second second is the propagation condition corresponding to 12:00 UT on the same day when the total path w

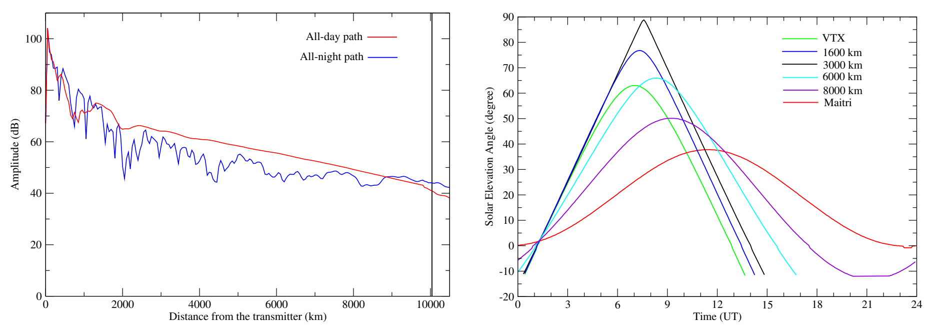

Figure 3: [Left]LWPC computation of signal amplitude of the VTX (18.2 kHz) transmitter along the propagation path as a function of distance from the transmitter. [Right] Variation of solar elevation angle at various distances along the VTX-Maitri propagation path (See text for details).

The ionosphere in the LWPC code has been defined by the so called Wait's exponential profiles (Cummer, 1972; Pal, 2012) with the sharpness parameter β and VLF reflection height parameter h' controlling the electron density profile at the D-region. For the all-night propagation conditions, we use β=0.59 km^{-1} and h'=85.0 km (Thomson, 2007). We use the solar zenith angle depended model for ionospheric parameters as described in (McRae, 2000) corrsponding to all-day propagation condition with $\beta = 0.5\ km^{-1}$ and h'=74.0 km. The variations of solar elevation angle (elevation angle=90-zenith angle) at various distances as a function of time along the propagation path are shown right panel of figure 3. The red curve represents the solar elevation angle with time of the day at Maitri and it is evident that the Sun was above the horizon almost for the who

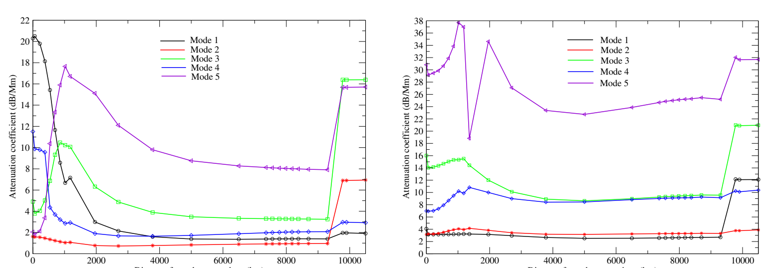

Figure 4: [Left] Attenuation coefficient (in dB/Mm) of the first five modes are plotted as a function of distance along the propagation path corresponding to all-night and [Right] all-day propagation conditions respectively (see text for details).

In left panel of Figure 3, we show the LWPC computation of signal amplitude of the VTX (18.2 kHz) transmitter along the propagation path as a function of distance from the transmitter. The blue curve is for the all-night propagation condition along the path corresponding to the and the red curve is for the all-day propagation condition along the path. The position of the receiver is indicated by the black vertical line. There are increased number of fluctuations (minima and maxima) in the night-time signal amplitude which arises due to the interference between the night-time modes up to a distance of $\sim$ 3000 km corresponding to $\sim$ 15°S latitude with 8-10 significant night-time modes. While in the day time path, only 3-4 significant modes, with second mode as the dominant one, contribute to the resultant signal. Note that the signal in the all-nighttime path is stronger than the signal in the all-daytime path. The data at 0.0 UT is stronger than that at 12:00 UT when the distance is larger than $\sim$ 9000km, giving the diurnal signal a shape similar to that of Kolkata (westerly propagation), even if the propagation here is easterly (Chakrabarti et al., 2012)). This is a unique feature that we discovered in the Antarctica signal.

The Figure 4, shows the attenuation coefficient (in dB/Mm) of the first five modes as a function of distance along the VLF path corresponding to all-night (left) and all-day (right) propagation conditions respectively. It can be seen that the mode 1, mode 2 and mode 4 are dominating modes (i.e., these have highest attenuation rate) contributing to the signal in all-night propagation while only the mode 2 is significant in all-day propagation condition at Maitri. Also it can be seen that all the modes in both conditions suffer maximum attenuation near the equatorial region and at the Antarctic ice mass at a distance $\sim$1000 km and $\sim$9300 km in the propagation path respectively.

4 Conclusion

The observation of the VLF signal (VTX) in Antarctica was very successful. Almost five weeks of data have been obtained from the VTX transmitter operating at 18.2 kHz. The data was of extremely good quality even if the propagation path was very long. There are no signature of nighttime fluctuation in the signal which has been proved by the variation of solar elevation angle. Effect of the antarctic polar ice on the signal attenuation has been observed. Also the LWPC simulations did corroborate our observation.

The authors acknowledge Ministry of Earth Science for Financial support.

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