PREDICTION OF SUDDEN COMMENCEMENT ABSORPTION

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Abstract

The HF bands covering the range 2 – 30 MHz are utilised by a variety of services and the use of these bands at high latitudes requires careful design to include the effects unique to this area, including enhanced non-deviate absorption. The increase in non deviate absorption classified for example as, sudden cosmic noise absorption, auroral absorption and polar cap absorption can last from minutes to days, often causing severe disruption to communications.

Ionospheric absorption at high latitudes that occurs coincidently with storm sudden commencement (SSC) events is categorised as sudden commencement absorption (SCA). This paper exams the step change in the interplanetary magnetic field (IMF) (which initiates the SSC), as a method to predict the median of the expected SCA amplitude.

Introduction

Radiowave Absorption

The basic transmission loss formula given in equation 1 defines the loss between two isotropic antennas. It is used to determine the reduction in power density as a function of frequency and distance, and incorporates functions for a number of loss mechanisms.

$$L_{Total} = 32.45 + 20\log f_{(MHz)} + 20\log d_{(km)} + L_i + L_g + L_x \qquad \text{Eq.1}$$

Where: f = Frequency of operation; d = distance; L_x = System Loss; L_i = Absorption loss; L_g = Ground Reflection Loss

L_i in Eq.1, the absorption loss, must include both deviative and non deviative forms of absorption. Deviative absorption arises at any point in the ray path where significant ray bending occurs, primarily near the apogee of a ray trajectory, usually in the F-layer. Non deviative absorption occurs when propagation is essentially rectilinear, but where collision rates are high and the electron densities are sufficient for non deviative absorption to occur, usually in the D-layer. Different types of non deviative absorption occur at medium and high geomagnetic latitudes and includes sudden cosmic noise absorption, auroral absorption and polar cap absorption (see [1]). Caused by enhanced electron densities in the D-layer, this absorption plays a significant role in the calculation of transmission loss.

This paper is concerned with the analysis of a type of absorption that differs in some respects from the three mentioned above. This type occurs simultaneously with the sudden commencement of a world-wide geomagnetic storm and is called sudden commencement absorption – SCA.

The Cause of SCA

The dynamics of the earth's magnetosphere are a product of the plasma and field streaming from the sun, coupling with the earth's magnetic field. Coronal mass ejections from the Sun give rise to shock waves in the solar wind. The related pressure pulses, when impinging on the Earth's magnetosphere, both compress it and increase the magnetopause current. This leads into a few tens of nano Tesla (nT) change in the low-latitude ground-based magnetic field intensity, lasting typically for some tens of minutes. These signatures are called Sudden Storm Commencements (SSC) or Sudden Impulses (SI), depending whether a magnetospheric storm is initiated or not.

Previous studies [e.g. 2] have shown that on occasion, brief ionospheric absorption events occur promptly with the onset of sudden commencements of geomagnetic storms. This is confirmed as a particle precipitation event, observed as ionospheric absorption, which occurs simultaneously with a SSC [3]. The particle precipitation causing increased ionisation at the height of the D-layer increases the non-deviative absorption on the radio link.

The effect of SCA at high latitudes

Particle precipitation is measured indirectly by measuring the absorption of cosmic noise through the atmosphere. The standard instrument measuring this absorption is the riometer, the development and explanation of its operation is given in reference [4] and [8]. The effect of SCA is to increase the non-deviative absorption on the link path, degrading the link, often to the point of extinction. Bear in mind that for ground-to-ground links the ray must pass through the D-layer twice, once on the upward path and once on the downward path. It has been observed that when the vertical absorption (caused by particle precipitation) measured on the riometer exceeds typically 6-7 dB (scaled to 5 MHz), links passing through the immediate area of the riometer view (200 km by 200 km) degrade and when the vertical absorption exceeds 10 dB (scaled to 5MHz) the link becomes unusable. It is possible to calibrate riometer measurements against each link's performance and determine if outages are due to ionospheric absorption or due to other factors such as MUF changes or equipment failure. SCA events can easily exceed this 6-7 dB threshold and for short periods of time (10 – 30 minutes) cause severe degradation of high latitude radio paths.

The Prediction of the Amplitude of SCA events

The prediction of SCA is of some value to operators and planners of HF links at high-latitudes. If the magnitude of the SCA can be predicated, then at best remedial action can be taken to reroute links and at worse to understand the non-functioning of a link. Our starting point, as is the case with many ionospheric problems, must be the Sun. The sun is a continuous source of supersonic, hot, ionized gas that streams past the earth and into interstellar space. The interaction of this plasma and field with the earth's magnetic field shapes the form of the earth's magnetosphere. Perturbations in the flow of the solar wind past the earth – changes in velocity of flow, particle density or particle composition – affect the shape and also the content of the radiation belts. Imbedded in this plasma is the solar magnetic field [5]. IMF data for this study was sourced from measurements taken by magnetometers onboard the WIND and the ACE spacecraft. Details of these spacecraft and their instrumentation can be found in [6] and [7]. Data was sourced for 150 SSC events in the period 1995 to May 2005 and figure 1 is an example of the IMF data collected for each SSC event. The event in figure 1 occurs at 09:37 UT and corresponds to a SSC observed at the Earth's surface at 10:37 UT which matches approximately a simple calculation of the time for a shock wave front travelling at 335 km/s to reach the earth from the

L1 point. The L1 point lies 1.5 million kilometers inside the Earth's orbit, partway between the Sun and the Earth. At this point the gravitational forces acting between the sun and the earth cancel each other out and therefore can be used by spacecraft to 'hover'. The area of interest is marked in the figure.

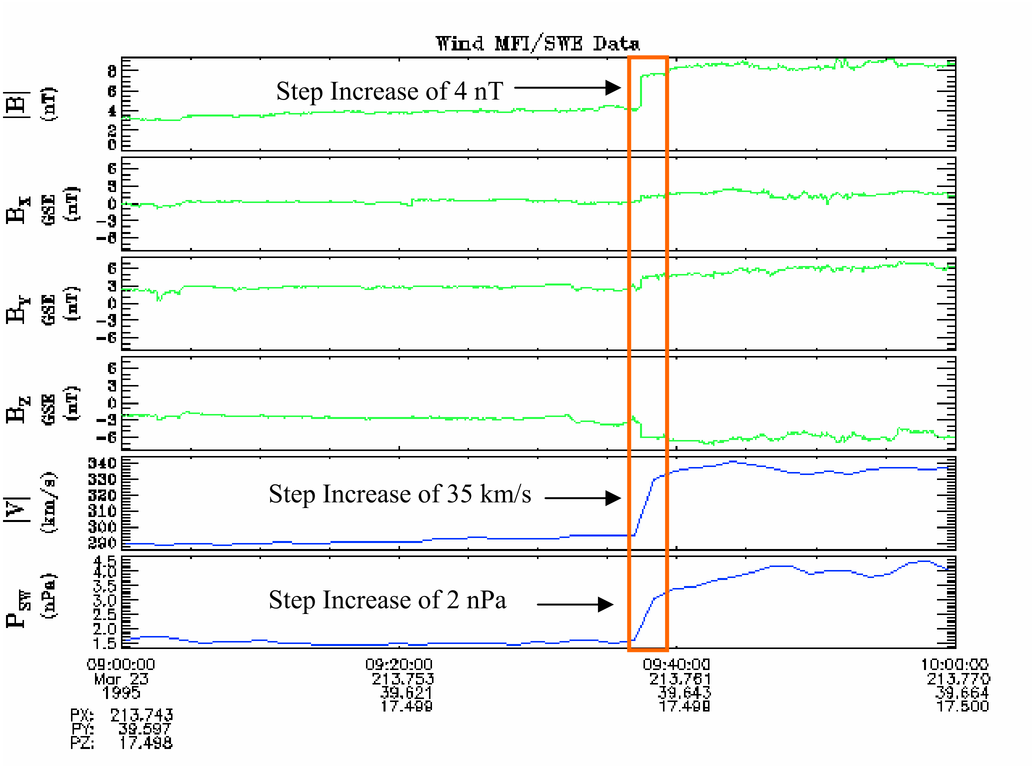

Figure 1. Example of IMF data collected showing the sudden increase in the solar wind pressure, corresponding increase in plasma speed and changes the magnetic components of the plasma.

For each SSC event the occurrence of the step change in the IMF was identified and the change in B_t (shown as $|B|$ in the top panel of fig.1) calculated. The median values of the absorption measured by the riometer at the time of the SSC events and the value of the step change in B_t is presented as a scatter plot in figure 2. The use of median absorption values is of particularly interest to ionospheric radio communications engineering where propagation prediction values are given in terms of hourly median values.

As the number of values for $B_t > 20$ nT become scarce only a simple regression analysis attempt was made to fit a first order equation to the data. The equation is of the form:

$$A = (0.126X) - 0.368 \qquad \text{Eq. 2}$$

Where: A = Absorption measured in IRIS riometer at 38.2 MHz
X = Value of IMF B_t in nT

The correlation coefficient is 0.756 and the standard deviation of the residuals of this fit is 0.62 dB – a fairly strong fit.

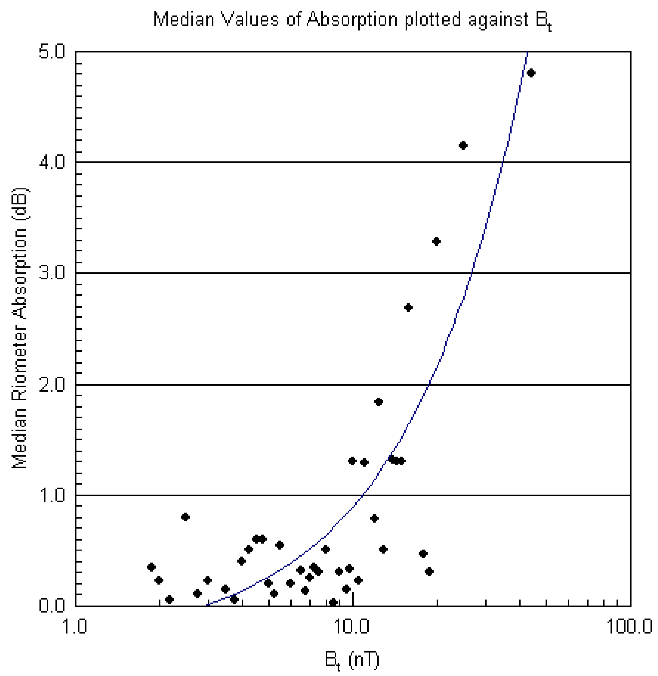

Figure 2. Scatter plot and simple curve fit for median values of riometer absorption plotted against change in IMF magnetic field, B_t.

Conclusion

The effect of enhanced absorption in high latitudes, such as that which occurs during SCA events is discussed. A method to predict the amplitude of the SCA expected, in terms of median value, is developed based on knowledge of the total step change in the IMF magnetic field. This provides useful information for HF link operators and planners working at high-latitudes.

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[8] See 'IRIS - Imaging Riometer for Ionospheric Studies' at http://www.dcs.lancs.ac.uk/iono/iris/ for information on riometers and to download data.