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Dependence of HF Radio Communication between India - Antarctica on Seasonal and Geomagnetic Conditions and Some Anomalies

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Abstract

During 13th Indian Scientific Expedition to Antarctica (ISEA) (1993-95), the dependency of high frequency (HF) radio links at 16.94 MHz, 14.45 MHz and 17.425 MHz operated between India and Antarctica, on degree of geomagnetic disturbance was studied. The data was collected from Jan. 1994 to Dec. 1994. Earlier observations carried out over 1992 (JEEVA *et al.* 1994) during the 11th ISEA, showed good correspondence between HF communication and the quietness of the electromagnetic environment of the Earth. In contrast to this during 1994, though there was in general, good correspondence between HF signal strength and level of magnetic quietness, on certain days no correlation was found. We try to explain some of these observations and anomalies in this report.

Introduction

A high frequency radio link with New Delhi (India) has been in operation at Indian Antarctic Station MAITRI (geographic coordinates 70°46'S, 11°45'E) over the past few years. The link was regularly operated by the Indian Navy (NAVY) from 1000 hrs to 1500 hr. UT at Maitri, and the quality of communication was studied during 1992 and 1994. NAVY used 5 kW power with T_x (transmitter) and R_x (receiver) frequencies of 16.941 MHz and 14.45 MHz respectively. In addition, during Jan 1994, the Defence Electronic Application Laboratory (DEAL) installed an HF link at Maitri with DEAL's Head-quarters at Dehra Dun, India. DEAL used 100 W power with T_x R_x frequency, 17.425 MHz. While NAVY operation had its HF radio link in Morse Code, DEAL had its link in voice communication mode.

With the active collaboration of NAVY and DEAL, the Indian Institute of Geomagnetism closely monitored the India-Antarctica HF radio link in terms of its signal strength, communication time, power of the system, and seasonal variations. These observations were then interpreted in terms of 1) variations in the magnetograms for the relevant days, and 2) in terms of the magnetic activity index Kp.

Instrumentation

Using a fluxgate magnetometer, daily variations of the geomagnetic elements X (north-south), Y (east-west) and Z (vertical) components were recorded, using a Rikendenshi Speedex Recorder run at a speed of 3 cm/hr. The sensitivity of the record was changed from 10 V (Volt) to 40 V full scale deflection (FSD), depending on the degree of geomagnetic disturbance.

The HF radio signal clarity of the India-Antarctica communication has been classified in the following manner:

Rank 5 - Excellent communication

Rank 4 - Very good communication

Rank 3 - Good communication

Rank 2 - Poor communication

Rank 1 - Very poor communication

Navy with its T_x - R_x system (5 kW) operated the HF radio link between MAITRI and NEW DELHI everyday over 1000-1500 hr UT. DEAL (T_x - R_x system at 100 W) operated its HF link between 1530-1730 hr UT, and 0500-0700 hr UT; in addition DEAL operated the link whenever Navy was not operating its HF system.

Though most of the time the signal strength of HF radio link between India and MAITRI was found to be well-correlated with the degree of geomagnetic activity, on occasions signal intensity did not correlate with geomagnetic activity.

Observations

Sample Magnetograms used in study

Fig. 1 shows the magnetogram recorded at MAITRI on 4 Mar 1994. This was a magnetically quiet day with $\Sigma Kp = 7$ Kp is a 3 hourly index of planetary magnetic activity published regularly by IUGG from Gottingen in Germany, and Kp represents the sum of the eight 3 hourly Kp values for any one day. A value of ΣKp less than 10 is taken as quiet condition, while a value exceeding 20 represents disturbed conditions. On 4 Mar 1994, between 1310 to 1610 hrs UT (marked by arrows), the HF radio link between Maitri and India was very good, with a constant signal strength of Rank 4 in both 5 kW and 100 W (T_x -

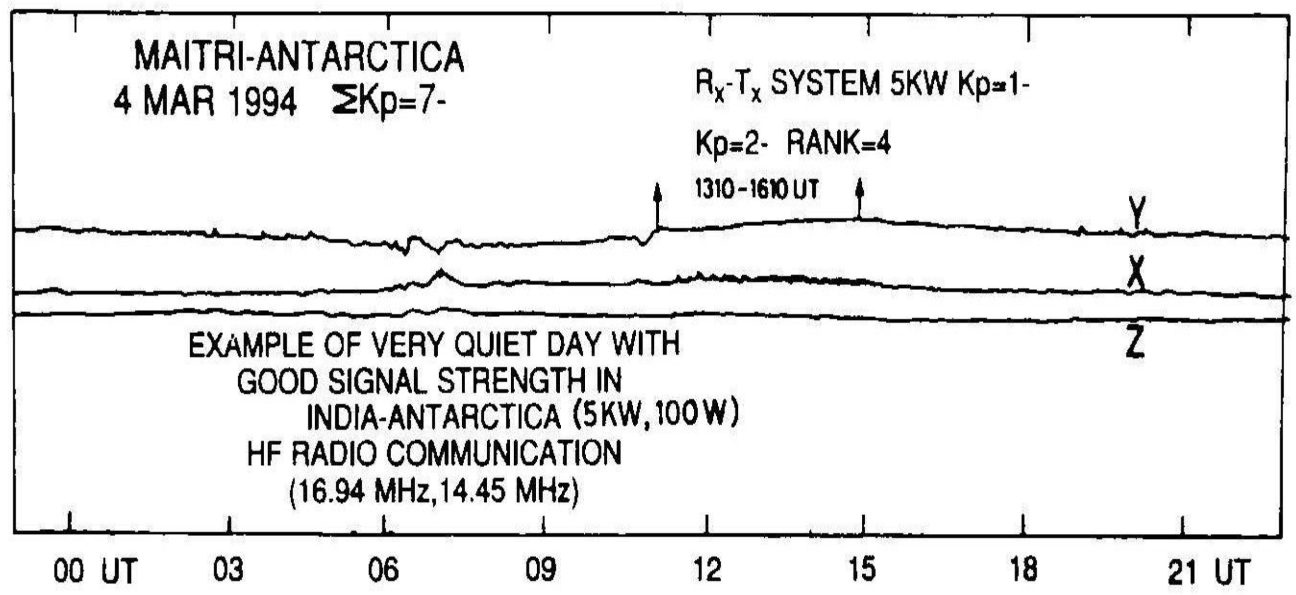

Fig. 1: Magnetogram recorded at MAITRI on 4 Mar 1994, showing variations in the X, Y, Z components on a magnetically quiet day (ΣKp = 7-). On this quiet day, as expected HF radio communication between India- Antarctica was very good on both 5 kW and 100W Tx - Rx systems

R_x) systems of Navy and DEAL respectively. The overlapping Kp values for this interval were 1_0 and 2_0.

Fig. 2 on 20 May 1994 shows another magnetically quiet day with ΣKp = 12 . During the period 1300 - 1600 hrs, HF radio communication was very poor (Rank 1) and NAVY could not establish its HF link with India, even using its 5 kW power. In contrast to the quiet conditions discussed above.

Fig. 3 on 7 Mar 1994, shows highly disturbed X, Y and Z traces indicating that a geomagnetic storm is in progress. The geomagnetic index on that day is ΣKp = 43, and the magnetogram points to a very disturbed state of electromagnetic environment of Earth. On 7 Mar 1994 between 1400 - 1600 hrs UT (Kp = 5_0 during this interval) however, despite very disturbed geomagnetic conditions, NAVY succeeded in establishing HF link with India, and messages (300 groups of 5 letters each) were received at Maitri from Naval Head Quarters at Delhi with a good signal strength of Rank 3.

Fig. 4 for 9 Mar 1994 shows another magnetically disturbed day with ΣKp = 44-. Unlike the previous example of 7 Mar 1994, on this day 9 Mar 1994, there was total lack of HF radio link between India and Maitri on both 5 kW and 100 W power systems of NAVY and DEAL.

Bar diagrams showing relationship between Kp and HF signal strength

For a clearer understanding of the relationship between magnetic activity and the rank of the HF signal, the electromagnetic state of Earth in terms of ΣKp was plotted for each of the 12 months of 1994 and it was compared with daily rank of HF signal strength. A few months are depicted here in order to indicate the typical pattern. It may be mentioned here that in the figures which follow, the symbols ND or NO DATA include occasions when the HF radio operator at MAITRI tried to send or receive messages, across India-Antarctica, and found no response either way.

Fig. 5 and Fig. 6 for the months of Mar 1994 and Apr 1994 indicate that during magnetically disturbed days when the value of ΣKp was large, there was a simultaneous decrease in HF signal strength in both 5 kW and 100 W, T_x R_x systems. This is the general trend for the dependence of signal strength on the level of geomagnetic activity for all other months of 1994 as well. Fig 5 and Fig 6 that when the Kp value exceeds 30 there is no HF link in either 5 kW (NAVY) or DEAL (100 W) T_x R_x systems. It would suggest that the daily sum magnetic index value ΣKp = 30 can be taken as a "cut-off" for satisfactory HF radio communication, between India - Antarctica.

Fig. 7 and Fig. 8 for Nov 1994 and Dec 1994 demonstrate that at quiet times when ΣKp was less than 30, HF radio communication between India and

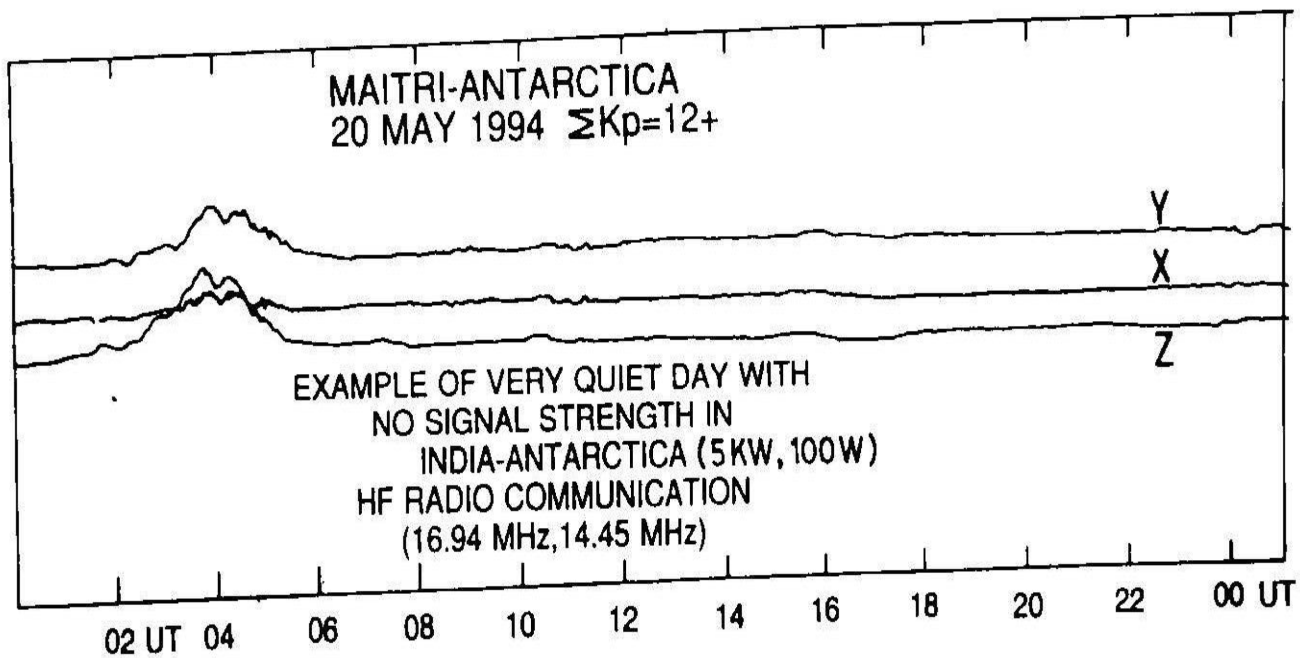

Fig. 2: Magnetogram recorded at MAITRI on 20 May 1994, another magnetically quiet day with $\Sigma Kp = 12$. On this day despite quiet conditions, no HF radio communication was possible between India-Antarctica. This is a deviation from expected conditions

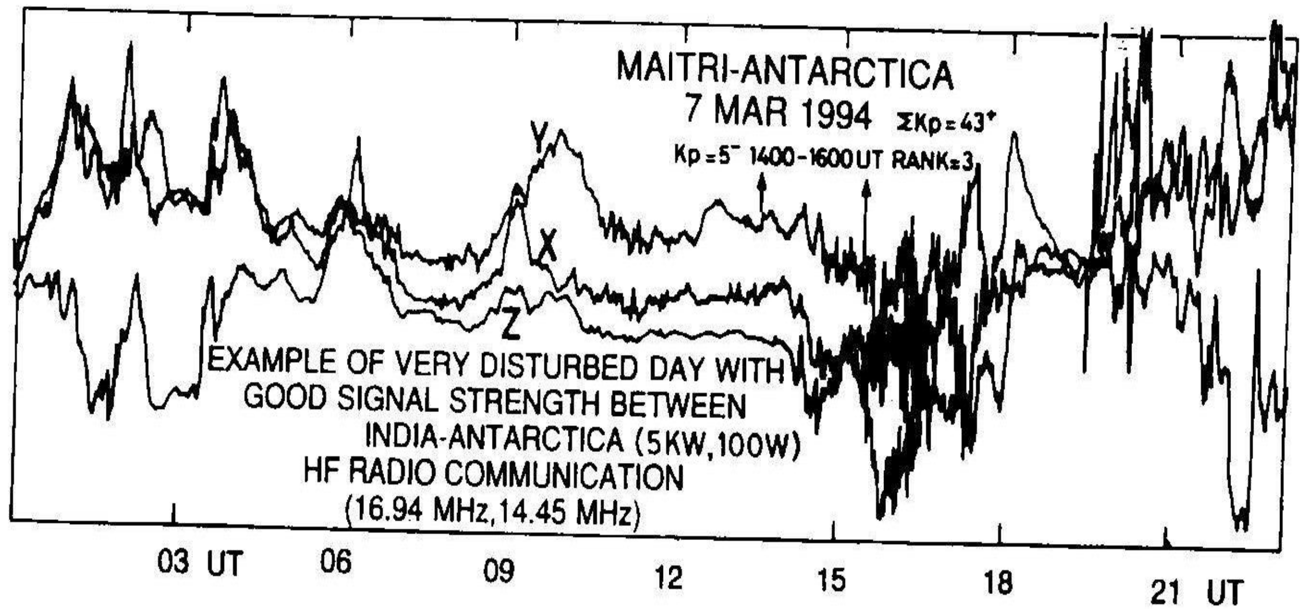

Fig. 3: Magnetogram recorded at MAITRI on 7 Mar 1994 on a very Disturbed day ($\Sigma Kp = 43+$). Surprisingly on this day, a reasonably good (Rank = 3) India-Antarctica HF radio link was established during 14-16UT. This constitutes an anomaly in expected behaviour

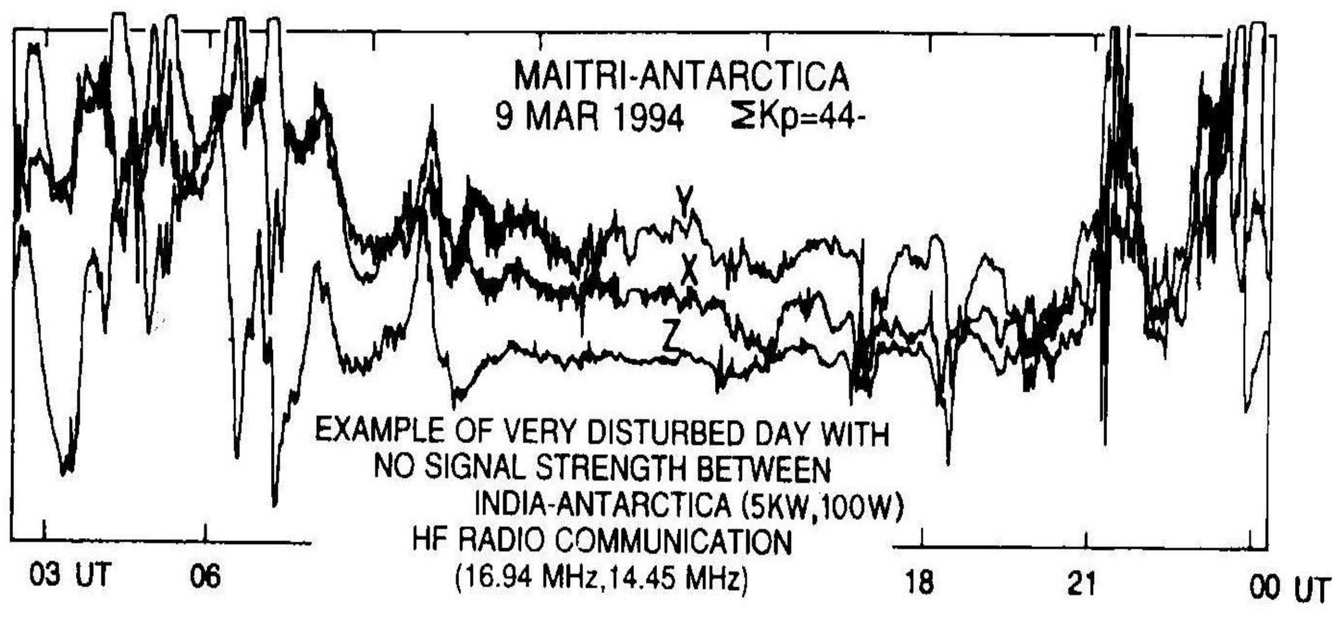

Fig. 4: Magnetograms recorded at MAITRI on a very Disturbed day ($\Sigma Kp = 44^-$), indicated by the wild variations in the X, Y, Z components. On this day as normally expected, no HF radio communication link could be established between India-Antarctica

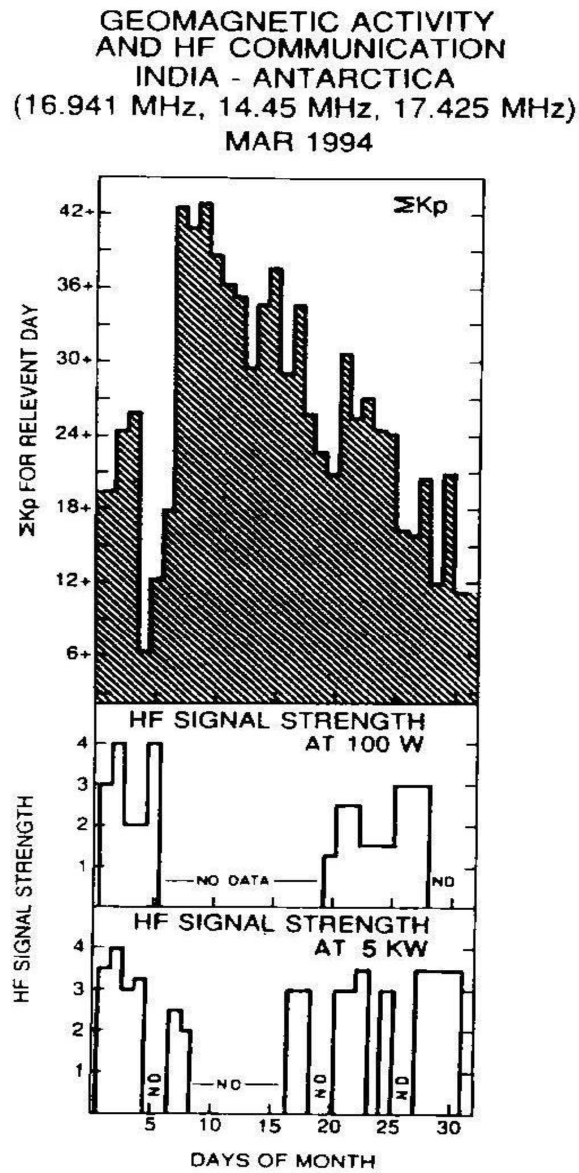

Fig. 5: Bar diagram for equinoctial March 1994 showing the day-by-day variation of the HF signal strength on both 100W and 5 kW T_x - R_x systems, as a function of the variation of the Kp index for the day. Both systems show a lack of HF radio communication on the India-Antarctica route when the ΣKp value rises; ΣKp = 30 seems to be the cut-off level

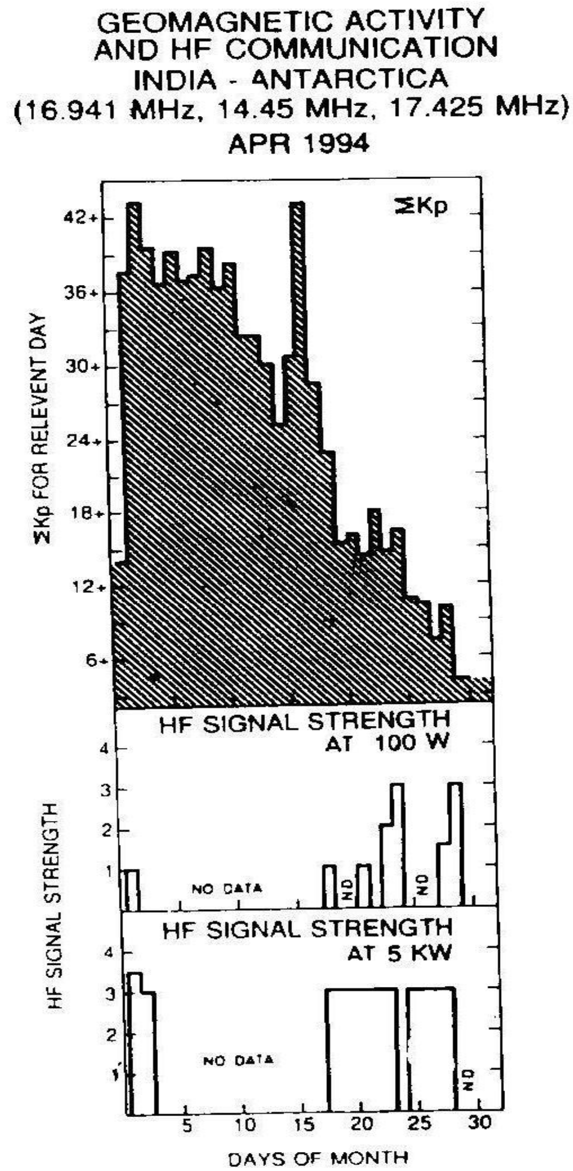

Fig. 6: Shows the same as Fig.5 for the equinoctial of Apr 1994. This figure also indicates the value of $\Sigma Kp = 30$ to be cut-off level above which India-Antarctic HF communication ceases

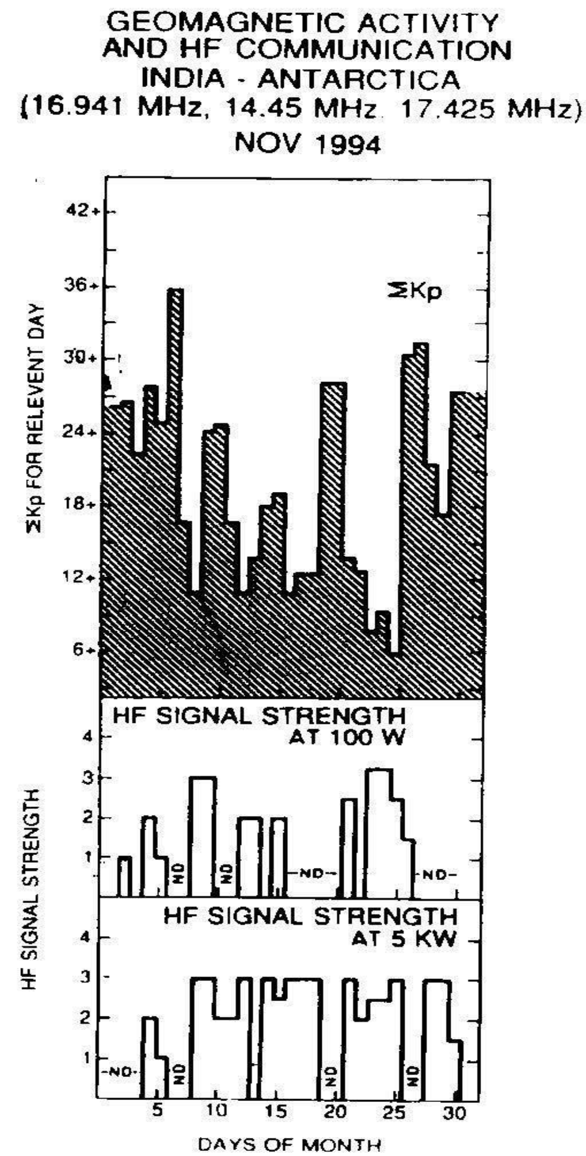

Fig. 7: Shows that same as Fig.6 for the Antarctica summer month of Nov 1994. Since magnetic activity over the entire month was low (ΣKp values less than 24), radio commuincation between India-Antarctica was not seriously disrupted. Fig.7 shows too that the 5 kW T_x - R_x system was able to pick up the signal on more days than the 100 Watt system

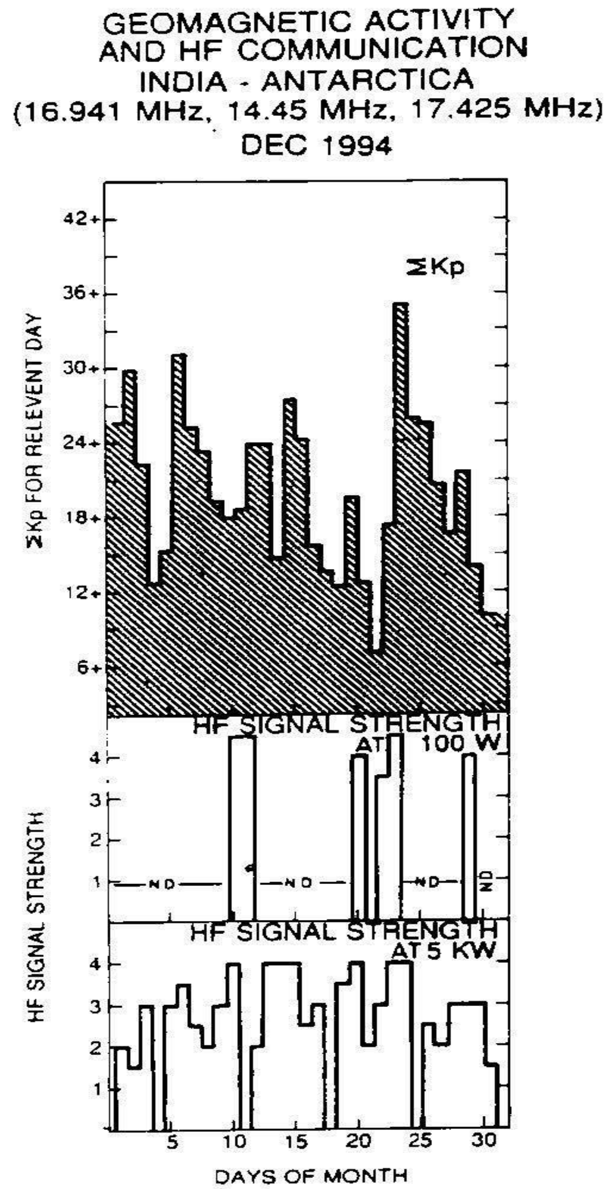

Fig. 8: Same as Fig.5 but for the Antarctic summer month of Dec 1994. It also shows that the 5 kW T_x - R_x system succeeded in picking up the India-Antarctica radio link on many more days than the 100 Watt system

Antarctica was possible on the 5 kW system but not on the 100 W T_x - R_x system. This observation would suggest that higher T_x - R_x power definitely contributes to good HF communication.

Mass plots of correlation between signal strength and Kp

Fig. 9 shows a mass plot for all months of 1994, of the rank of the HF signal versus Kp value for the same period as the HF observation (referred to in figure as SIMULTANEOUS Kp) and Kp value for the period 3 hr before the HF observation. This was done to check whether there is a delayed magnetic activity effect on HF radio communication. Concentric circles in Fig. 9 indicate more than one observation (see key in figure). Fig. 9 brings out three features, namely:

(1) there is no major difference between the mass plots for simultaneous Kp and previous Kp

(2) both mass plots show a general trend of lower values of HF rank (i.e. poor communication) with increasing values of Kp

(3) there are very few points beyond Kp = 4, and large clusters of points are concentrated at values less than 4. This indicates absence of transmission and reception of radio signals on the India - Antarctica link, during periods of marked magnetic disturbance (Kp >4)

(4) even for low values of Kp (less than 4 showing magnetic quiet), there are a few points with rank of HF signal having values of 1 and 2 (i.e. poor communication). Similarly for high values of Kp (more than 4 showing magnetic disturbance) there are a few isolated points with HF rank values of 3 and 4 (i.e. good communication). These are clearly anomalies in the general trend which we try to interpret in Section 4 of this work.

Seasonal dependence

Finally Fig. 10 shows mass plots of the HF signal rank of the versus simultaneous Kp for the different seasons of 1994. It depicts clearly that season does affect long distance India- Antarctica HF communication. The number of days on which the communication link is established is largest in Summer, less in Equinox, and least in Winter. A similar result was obtained by Jeeva *et al.* (1994).

Conclusions and Discussion

Conclusions

The above-mentioned observations clearly suggest that the quality of HF radio communication between India-Antarctica is dependent on:

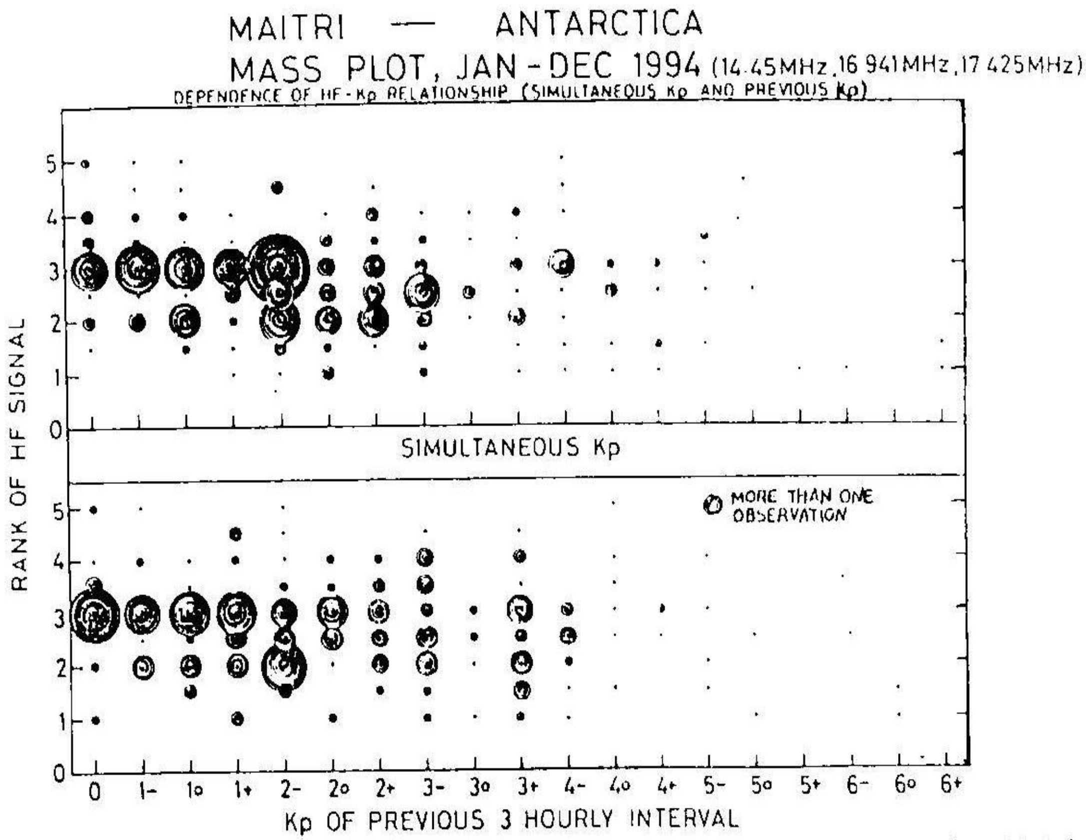

Fig. 9: Mass plot of the Rank (Signal quality) of the India- Antarctica HF radio communication link with the magnetic activity index Kp. The two figures are for simultaneous Kp, and Kp of the previous 3 hourly interval. This figure brings out the anomalies that 1) on some occasions, for quiet conditions with low Kp, the Rank of the signal is rather low (poor HF communication), and 2) on other occasions for Disturbed conditions of high Kp, the Rank of the HF signal is rather high. This is contrary to what is expected

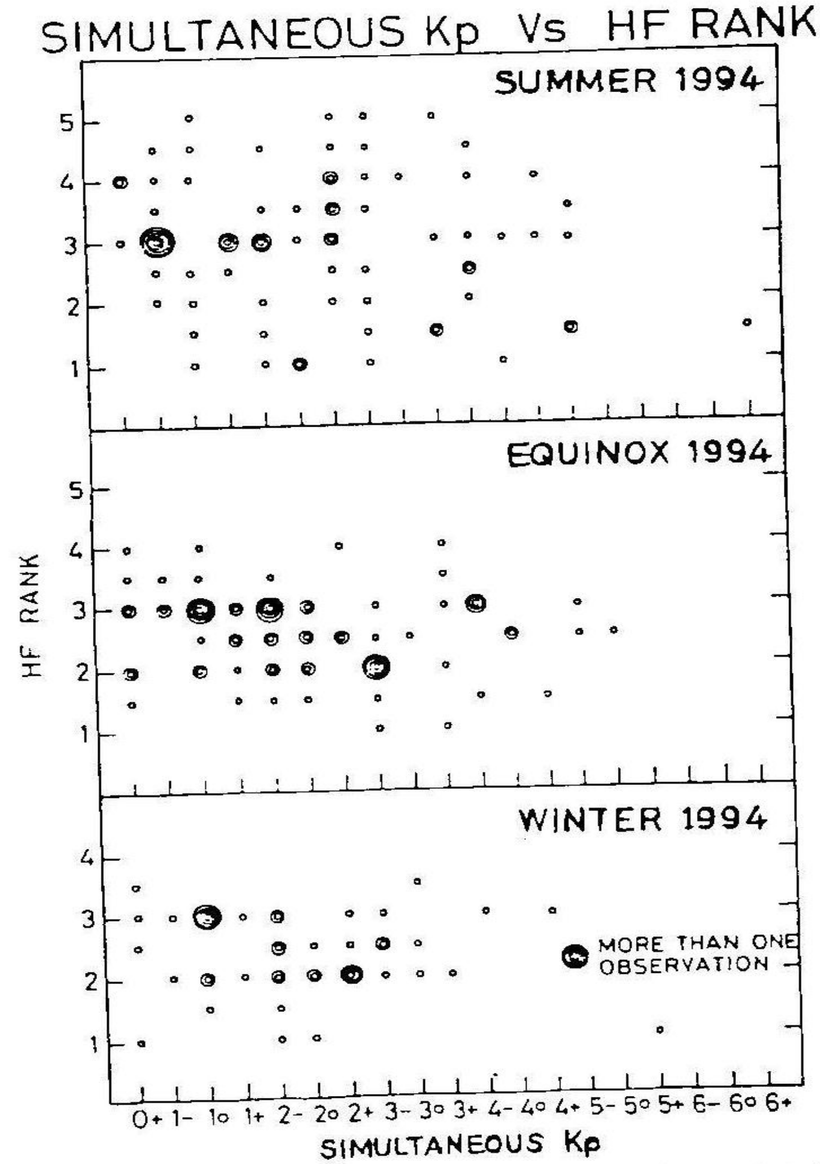

Fig.10: Mass plot of rank of India-Antarctica HF radio signal, versus Kp index for the same period, shown separately for the different seasons of 1994, summer, equinox and winter. The distribution of points clearly shows that the radio communication link is most frequent in summer, less so during Equinox, and least in Winter

a) the magnetic activity prevailing on that day; satisfactory communication seems to cease above a threshold of $\Sigma Kp = 30$, at least in the equinoctial months of March 1994 and April 1994 (Fig. 5 and Fig. 6)

b) on the power of the T_x - R_x system (Fig. 7 and Fig. 8)

c) on the prevailing season, with best communication during Summer, less effective during Equinox and least during Winter (Fig. 10)

d) the anomalous observations in Sec 3.1 and in Fig. 9 suggest that the level of geomagnetic activity is not the only parameter governing the quality of India-Antarctica HF communication. There also seems to be a role played by ionospheric conditions at the reflection points, as well as by the number of hops taken by the radio wave, in traversing the India-Antarctica distance. These would depend on the phase of the solar cycle during the period of observation, and hence would differ between 1992 and 1994.

Discussion

The matter of the HF radio signal intensity being inversely correlated with the degree of geomagnetic activity can be easily explained in terms of varying D and E ionospheric region absorption in the auroral regions. It is expected that at MAITRI, during periods of increased geomagnetic activity, the magnetosphere-ionosphere electrical coupling will be increased by the presence of field-aligned currents. This in turn implies increased precipitation of energetic electrons which cause secondary ionisation in the auroral lower ionosphere. These secondary electrons absorb energy from the traversing HF radio wave, and hence weaken the signal [Ratcliffe 1960].

The dependence of the HF signal transmitted from and received at MAITRI, on the power of the T_x - R_x system was indicated in Fig. 7 and Fig. 8. This aspect seems reasonable if understood in terms of Sensitivity of the system.

The seasonal variation in the HF radio signal received at MAITRI (Fig. 10) indicates that the conditions of electron density and electron temperature at the ionospheric reflection points in the India-Antarctica propagation path clearly play a role in this.

What is more difficult to explain are the anomalous observations in Fig. 2, Fig. 3 and Fig. 9 that on some magnetically quiet days the HF signal at MAITRI is poor, or that on some disturbed days, the HF signal is received well at MAITRI. This again shows that ionospheric conditions at the ionospheric reflection points enter the picture. The formation of ionised clouds in the E-region of the ionosphere called Sporadic E (Smith 1954) at the reflection points is one phenomenon which can affect HF propagation. Sporadic E manifests itself in several forms and can be of the blanketing or scattering types.

If it is of the blanketing type, it will absorb energy from the reflected radio wave, and weaken the HF signal. If it is of the scattering type, then HF radio propagation will be assisted.

All these factors at the reflection points of the India- Antarctica HF radio wave, namely electron density, electron temperature, electron-ion collision frequency, and formation of ionospheric irregularities, are a function of geomagnetic activity, season and solar cycle, and need careful evaluation [Alpert 1978]. Finally it must be remembered that in the absence of Auroral Electrojet (AE) indices, we are using the Kp indices of magnetic activity. Kp is really an index of mid-latitude geomagnetic activity, and a day which is classified as quiet by the Kp index may not be quiet in terms of the AE index (Hanchinal *et al.* 1996 in Press). Sudden radio blackouts in the auroral regions can for example result from secondary ionisation in the lower ionosphere caused by X-rays (generated by incoming high energy electrons from the magnetosphere). Such ionisation is created in the lower D-region for below the E-region which normally carries the dynamo currents which in turn leave signatures on geomagnetic records. Under such circumstances, only radio wave absorption and no geomagnetic variation will result (Smith 1954).

Acknowledgements

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