A Prediction Model for Equatorial & Low Latitude HF Communication Parameters during Magnetic Disturbances

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A prediction model for equatorial and low latitude disturbed time ionosphere has been evolved using a large data base to aid in short-term forecasting of HF communication parameters. The variety of solar and geophysical data that is available on near-real time basis at the Associate Regional Warning Centre being operated from National Physical Laboratory, New Delhi, enables the prediction of magnetic activity levels with some accuracy. The present model will facilitate the HF link operators to correct their predicted circuit parameters for any short-term deviations produced by magnetic storms. This study has shown that deviations in maximum usable frequencies during magnetically disturbed days exhibit rather complex behaviour in certain latitude zones and the possible actions which a communicator can take to improve the reliability of HF circuits operating through reflections in this zone are suggested.

1 Introduction

The purpose of this paper is to present a storm-time model to HF communication users at low latitudes so that they can update their median predictions whenever active magnetic conditions are expected. Such information is available for middle and high latitudes where storm departures are more marked. At low latitudes, where these departures are less marked, excessive averaging techniques have flattened the modest storm-time changes. It is now essential to investigate and quantify these departures in maximum usable frequency (MUF) values at low latitudes partly because of increasing pressure on HF spectrum management and mainly because reliable magnetic activity forecasts are made available now on the International Ursigram and World Days Service network which can be profitably used by making appropriate changes in operational frequencies. While the data sets used belong to the Indian zone (geographic latitudes 8 N to 30 N), the conclusions should be valid for any low latitudes region with similar geomagnetic latitudes (geomagnetic latitudes from 0 N to 20 N).

There have been several excellent studies on the effects of magnetic disturbances on F-region ionization levels and the results are well documented. The most outstanding results are the negative response of F-region peak electron densities ($N_e F_2$) to magnetic disturbances at high and midlatitudes and the positive changes in $N_e F_2$ at low and equatorial latitudes. However, the peak F-region heights ($h m F_2$) are known to increase at all latitudes.

2 MUFs and Magnetic Disturbances

The ionosphere over the Indian zone covers a wide belt of geomagnetic latitudes starting from geomagnetic equator to 25 N geomagnetic latitude and its response to magnetic disturbances is rather varied because of other low latitude ionospheric features that manifest in this zone. These include the equatorial anomaly in the F-region peak electron densities, high levels of geophysical noise in F-region parameters, equatorial spread-F and sporadic-E; the focus of $Sq$ current system which is known to influence the electron distribution in the F-region is also located within this zone. The limitations set by some of these features are discussed while evaluating the disturbed ionospheric model for HF communication parameters.
indistinguishable from day-to-day variability or the geophysical noise of the quite days. Restriction of the present analysis to only severely disturbed days ($A_p > 30$) has enabled us to overcome the limitation set by the geophysical noise as the departures from medians on these severely disturbed days are found to be considerably larger than the quiet time noise in the ionospheric parameters.

Fig. 1 shows the percentage deviations in MUF(4000)F2 values from monthly median values for several disturbed days for Kodaikanal (geographic coordinates: 10.2 N, 77.5 E) during summer months. Fig. 1 clearly demonstrates the effect of ionospheric storms on circuits operating with the reflection points in the equatorial zone during summer. The MUF changes during disturbed days are positive almost all through the day, the increase being as high as 40% on certain occasions. The standard deviation in MUF(4000)F2 departures from monthly medians expressed in percentage is found to be around 20% and 18% respectively.

The present analysis indicated that the ionosphere over the latitude zone 0 to 10 N geomagnetic latitude in general responded positively to magnetic disturbances resulting in increased MUFs for the circuits operating with reflections in these latitudes.

The ionospheric responses to magnetic storms at latitudes above 10 N geomagnetic in the Indian zone show a much more complex behaviour in contrast to the distinct positive responses seen around equatorial latitudes. The responses can be both positive and negative at all the hours of the day and also show strong seasonal dependence. Fig. 2 shows such departures in MUF(4000)F2 from monthly medians for disturbed days during winter for Ahmedabad. This situation does complicate the task of modelling these responses: however, the large data base of this analysis did yield meaningful results for certain latitudes which would be of significant importance to the modelling of these responses.

Table 1 summarizes the results of the present analysis and gives the details of departures in MUF(4000)F2 values from the monthly medians during disturbed periods for various latitude zones during different seasons and local time intervals. The percentage standard deviations in MUF(4000)F2 departures are in parenthesis in Table 1. The standard deviations have been computed using data of 60 to 75
disturbed days for each of the seasons. The disturbed time data belongs to medium and high solar activity periods during the years 1958-1980. Table I also shows the complex behaviour in 10-14° N geomagnetic latitude zone where the departures can be either positive or negative for most of the time. More important is the fact that these departures are significantly high reaching as much as 50% on certain occasions and they need to be taken into account by HF communicators. Section 5 discusses the various measures a HF communicator can take to improve the efficiency of circuits operating in the Indian zone. Advance warnings on likely occurrence of a magnetic storm should be of a value to operators in anticipating these unpredictable situations.

3 Relative Effects of \( f_{0}F2 \) and \( h_{m}F2 \) Variations on Maximum Usable Frequencies

It is well known that the responses in \( f_{0}F2 \) to magnetic disturbances can be both positive and negative depending mainly on the latitude and season and are generally accompanied by positive \( h_{m}F2 \) responses. However, negative responses in \( h_{m}F2 \) to magnetic disturbances are also not uncommon at equatorial and low latitudes. Fig. 3 shows departures of the median \( f_{0}F2 \) and \( h_{m}F2 \) values for a group of disturbed days in Oct. 1967 from the monthly median values for three stations in the Indian zone. It can be noticed from Fig. 3 that the responses in \( h_{m}F2 \) during disturbed days are in general positive at all latitudes unlike \( f_{0}F2 \) responses which are latitude-dependent. It can be also seen that the deviations in \( h_{m}F2 \) are of lesser extent in comparison to those \( f_{0}F2 \).

The MUF variations are dependent on the simultaneous variations of \( f_{0}F2 \) and \( h_{m}F2 \). MUF of a circuit is related to \( f_{0}F2 \) and \( h_{m}F2 \) as

\[
\text{MUF}(3000)F2 = f_{0}F2 \times M(3000)F2
\]

where MUF(3000)F2 is the maximum usable frequency for a path length of 3000 km and M(3000)F2 is a factor scaled directly from the ionogram, which contains information on the height of the layer (\( h_{m}F2 \)). It is also known that \( f_{0}F2 \) variations prevail over \( h_{m}F2 \) variations in controlling MUF values. This is particularly true for circuits shorter than 1000 km. The height variations assume greater significance for
circuits with path lengths longer than 1500 km. The increases or decreases in $f_0F_2$ will affect the MUFs in the same sense while the variations in peak heights ($h_mF_2$) affect the MUFs in the opposite sense. In a situation, when both $f_0F_2$ and $h_mF_2$ are increasing simultaneously their effects on MUFs will be compensating in nature, especially for longer circuits. In case of $f_0F_2$ decreases with accompanying increases in height also, the height variations assume importance only for long circuits (> 1000 km), the main difference here being that simultaneous negative $f_0F_2$ and positive $h_mF_2$ variations act in the same way as to reduce the MUFs. These effects can be clearly appreciated from Table 2 which gives the details of effective MUFs for various path lengths due to varying percentage changes in $f_0F_2$ and $h_mF_2$. The $f_0F_2$ and $h_mF_2$ range of values chosen to compute the effective MUF changes shown in Table 2, cover the values that are normal in the Indian zone.

4 Disturbed and Quiet Time Ionospheric Parameters

In this section an attempt is made to study the disturbed-time variations in $f_0F_2$ and $h_mF_2$ from the quiet time situation under conditions when day-to-day variability in quiet-time reference values is restricted to a minimum. Quiet day median values have been arrived by computing the median values for a group of 4 or 5 quiet days which fall consecutively in a calendar month. The group of quiet days itself is chosen from the 5 to 7 most quiet days of the month. Care has also been taken while choosing the group of quiet days so that the 10.7-cm flux variations are marginal during that period. This process eliminates the variability in ionospheric parameters attributable to obvious solar activity variations in the quiet-day group and any remnant variability should be due to geophysical noise of F-regio 1. The data so analyzed for Kodaikanal are shown in Fig. 4. Fig. 4 shows the range of $f_0F_2$ values for the quiet days chosen for the month of June 1965 along with range of values for the disturbed days of the month. The median $f_0F_2$ values for these quiet and disturbed days are also shown separately in Fig. 4. The spread of $f_0F_2$ values that is seen in Fig. 4 for quiet days is essentially due to geophysical noise in $f_0F_2$ parameter as the solar and magnetic levels for all the quiet days are nearly same. The 10.7-cm flux is around 76 ($10^{-22}$ W/m$^2$/Hz) and $A_p$ is as low as 2 to 3 for all the quiet days chosen for June 1965. The geophysical noise is defined as a weighted mean of random variations in $f_0F_2$ and $h_mF_2$ values which do not show any correlation with any of the known solar and magnetic indices. However, the most important point to be noticed here is that the range of $f_0F_2$ values for disturbed days of the month is markedly above the quiet-day range of values. The 10.7-cm flux values for the disturbed days was also around the same level as those for quiet days, which ensures that the increased disturbed time $f_0F_2$ values are free from effects due to changes in solar activity levels and are mainly due to variations in magnetic activity.

Monthly ionospheric data for several Indian stations were also analyzed in a similar way. Fig. 5 shows quiet and disturbed day median values of $f_0F_2$ for May 1969.

5 Discussion

Because of the more definite and rather remarkable changes in the F2-layer electron densities following magnetic storms at middle and high latitudes, there are some specific models available at these latitudes, which
can be used for HF communication purposes in short-term forecasts\(^1\)\(^-\)\(^9\). However, because of not-so-marked changes at equatorial latitudes and an admixture of positive and negative changes at low latitudes, it was not possible to evolve such a model to aid in the prediction of magnetic storm effects on HF communication parameters. Some preliminary studies using a limited amount of data earlier have shown that it is indeed difficult to distinguish clearly stormtime changes in the F-region from the day-to-day variability at low latitudes\(^1\)\(^8\).

However, systematic analysis of a large volume of data by treating the quiet days and the disturbed days exclusively has shown that the trends are clear, though the variabilities due to local time, season and latitude are difficult to account for in the predictions. While it is impossible to establish any general relationship between departures in low-latitude F2-layer parameters and any magnetic activity index, a gross pattern can be arrived at, so that whenever magnetic activity of considerable intensity is forecast, the consequent changes in MUF can be estimated and included in the HF communication predictions.

6 Conclusions

(i) MUFs for circuits operating with reflections in the region 8-20 N geographic latitude are invariably increased during disturbed periods in all the seasons and this situation can be advantageously used to operate the circuits of path lengths less than 1000 km at higher frequencies and with lower transmitter powers. A higher operational frequency improves the reception partly because of reduced ionospheric losses and partly due to reduced atmospheric radio noise, which is an important parameter at low latitudes.

(ii) The circuits operating with reflections in the zone 20-23 N should have the flexibility to alter the terminal parameters (frequencies and transmitter powers) especially when high circuit reliability is desired. Since this zone is manifested by rather unpredictable positive and negative changes during magnetic storms, it is advised that for high reliability circuits, the operating frequencies should be reduced by 15 to 20\(^o\) with an appropriate increase in power whenever 'magalert' forecasts are issued.

(iii) The MUFs for circuits operating with reflections in the regions beyond 28 should be reduced by 15 to 30\(^o\) depending on the severity of predicted magnetic activity in summer and equinoctial months especially when the circuits are operated close to the predicted monthly median values.

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