Day-to-day variability of ionospheric electron content over Waltair

Indian Journal of Radio & Space Physics
Vol. 22, December 1993, pp. 391-396

Polarization rotation data (136 MHz) recorded from the geostationary satellites ETS-II and SIRIO at a low latitude station, Waltair (17.7°N, 83.3°E) during high (1978-79) and low (1984-85) sunspot number years have been used to study the day-to-day variability of the ionospheric electron content (IEC). The ratio of the standard deviation of daily IEC values to the mean IEC values has been used as a measure of the variability. The daytime ratios are reasonably constant and independent of season during both the sunspot number years. The nighttime ratios are higher (20-80%) during high solar activity period compared to those (15-30%) of low solar activity period. A correlative study is made on the day-to-day variability in IEC with possible causative factors, such as solar 10.7 cm flux, electrojet strength (ΔH) and magnetic index (Ap) during the low solar activity period. The IEC at Waltair shows a linearly increasing trend with 10.7 cm flux during three different seasons and with the electrojet strength only in summer, while it does not seem to depend on the magnetic index. However, the percentage variations in the diurnal IEC, when considered separately for magnetically quiet and disturbed days during three different seasons of low solar activity period, show a clear ‘mirror-image’ behaviour only during summer.

1 Introduction

The study of day-to-day variability of ionospheric parameters is of scientific interest in view of the causative mechanisms and is of great importance in assessing prediction capabilities. It expresses the expected accuracy of the daily predictions if the monthly average could be predicted. To optimize the frequency usage in a HF communication link, it is imperative to know the morphology of this day-to-day variability of the maximum usable frequency (MUF), since (i) all the users have to choose frequencies much less than the predicted MUF values, (ii) the available frequency spectrum is reduced and (iii) at frequencies far less than the MUF values, the power requirements steeply go up demanding an expensive equipment. The variability in ionospheric electron content (IEC), which is of practical importance in communication systems, navigation, etc. is best described by the ratio of the standard deviation (SD) of daily IEC values from the monthly mean to the mean IEC values. The extent of this variability is dependent on geographic location of the station, local time, season and solar activity.

At middle and high latitude stations, Soicher and Gorman observed that the day-to-day variability of IEC during daytime is less than 25% irrespective of location, season and solar activity, while at night, it is significantly higher especially in the equinoctial season. At high latitudes, during moderate solar activity period, Vijay et al. found that the day-to-day variability of IEC during daytime is around 30-40% and during nighttime 50-60%. It has been suggested that these variabilities are due to some geophysical phenomena. Kane suggested that at midlatitudes, the day-to-day variability in IEC is due to the erratic equatorward neutral winds that originate in polar regions intermittently even under quiet conditions, creating convective cells that result in ionospheric irregularities of scale length about 3000 km. At temperate latitudes, Ramana Rao et al. interpreted the day-to-day changes in the F-region as due to the changes in thermospheric conditions. In recent times, using the FM data at a number of stations extending from equatorial to midlatitudes in Indian and American sectors for high and low solar activity years, Aravindakshan and Iyer reported that the day-to-day variability of IEC is larger at night than during day, highest in February and November (D months) and lowest in equinox (E months).

Waltair (17.7°N, 83.3°E) being a station situated in the sub-tropical latitudes of the northern hemisphere, it is expected that IEC over Waltair is subjected to a large day-to-day variability as a
consequence of the variability in the solar and geomagnetic activities. It is further expected that IEC over such latitudes is affected by the equatorial plasma transport which, in turn, is subjected to wide variability due to the changes in the equatorial electrojet strength. In this paper, using IEC data at Waltair during high and low solar activity periods, the characteristics of day-to-day variability of IEC are examined and their correlation with possible causative sources such as solar flux, electrojet, and magnetic activity is studied.

2 Data and method of analysis

The Faraday rotation (FR) data of 136 MHz signals of ETS-II and SIRIO satellites recorded at the low latitude station, Waltair (17.7°N, 83.3°E), for the high solar activity period from March 1978 to February 1979 and for the low solar activity period from September 1984 to August 1985 are used to study the characteristics of day-to-day variability in IEC.

The standard deviation (SD) of hourly IEC values from monthly mean values is determined, and the ratio, SD/Mean, in percentage is derived for each hour of each month of observation. This forms the basic parameter representing the day-to-day variability of IEC. Other geophysical parameters such as 10.7 cm flux and magnetic activity index are obtained from Solar Geophysical Data Bulletins. The electrojet strength parameter is derived from the published Indian Magnetic Data Bulletins as suggested by Kane. According to this method, the electrojet strength (unaffected by ring current contribution) is obtained by the simple difference of the horizontal geomagnetic intensity between the equatorial station Trivandrum (magn. lat., 0.3°N) and a low latitude station Alibag (magn. lat., 9.5°N) outside the equatorial electrojet region.

3 Results

3.1 Diurnal variation

The monthly mean diurnal variation of IEC at Waltair during the high and low solar activity periods are shown in Fig.1. The spread of the curves due to the day-to-day variability of electron content in the minimum sunspot number years is comparable to that observed for high solar activity period. This

![Fig. 1—Monthly mean diurnal variation of IEC at Waltair for the high (1978-79) and low (1984-85) solar activity periods](image-url)
day-to-day variability is best described by the ratio, SD/Mean. Such ratios in percentage for different months of observation during high and low solar activity periods are computed and presented in Fig. 2. It is observed that the daytime (0800-1800 hrs LT) ratio is independent of season and attains a constant value of about ≈ 20% during both the sunspot number maximum and minimum years. Recently, Aravindakshan and Iyer have shown that the variability is higher during high sunspot years than during low sunspot years for midlatitudes, while for low latitudes this trend is reversed from 0800 to 2300 hrs LT. On the contrary, the nighttime ratio during high solar activity period ($R_z$ varying from 76 to 166) is higher (ranging between 20 and 80%) than those (ranging between 15 and 30%) of low solar activity period ($R_z$ in the range 11-31). It can also be seen that the variability during high solar activity period is greatest around the ionospheric sunrise and drops slowly in the morning hours. This suggests that the rate of production of electrons in the ionosphere varies from day to day. The range of variation for the loss processes which govern the nighttime densities is relatively small. Similar SD/Mean ratios for IEC, ranging from 25 to 50%, were reported at midlatitudes by Soicher and Gorman, at equatorial and low latitudes by Rastogi and Alex, Jayachandran and Nair, and at low-midlatitudes by Aravindan and Iyer.

3.2 Effect of 10.7 cm flux

The amount of ionization produced in the ionosphere and hence the IEC is mainly dependent on the ionizing radiation, if the transport processes are not significant. Solar flux at 10.7 cm has now, more or less, become the universally accepted surrogate index for EUV radiation from the sun which ionizes the upper atmosphere. To examine the day-to-day changes in IEC at Waltair, the maximum values of IEC diurnal variation during low solar activity period (mean $R_z = 20$) are plotted against the corresponding values of 10.7 cm solar flux for three different seasons [Fig.3(a)]. Using the least square method, the correlation coefficients are calculated and best fit lines are drawn. It is observed that the electron content shows a linearly increasing trend with 10.7 cm solar flux. The slopes of the best fit lines shown in Fig.3(a) are found to be more during winter months than those of equinoctial and summer months during low solar activity period, while it was reported that the slopes are more during summer months followed by equinoctial and winter months during high solar activity period. The correlation coefficients between IEC and 10.7 cm flux are found to range between 0.4 and 0.25 for low solar activity period, 1984-85. On the other hand, Koparkar reported that IEC at Bombay increased with the increase in 10.7 cm flux and the correlation coefficient between IEC at 1.7 cm flux was found to be maximum (0.62) during equinoctial months and least in summer months during low solar activity period.

3.3 Effect of equatorial electrojet

At low latitudes, the electrodynamic $E \times B$ drift is very effective in transporting the ionization in the ionosphere. The electric field $E$ is derived from the equatorial electrojet and the measure of electrojet strength, $\Delta H$, may be obtained from the difference in the horizontal intensity recorded at Trivandrum (equator) and Alibag (24° latitude; outside the equatorial electrojet).

The effect of electrojet strength in controlling the day-to-day variability of IEC near the crest of the equatorial anomaly is well established. The dependence of IEC on the electrojet strength at Waltair is presented in a scatter plot of diurnal IEC max values against the electrojet strength in Fig.3(b). The correlation coefficients between these two parameters are found to be low during equinoctial and winter months, whereas in summer (correlation

![Fig. 2—Diurnal variation of the ratio (%) of the monthly standard deviation of IEC to the mean IEC at Waltair during high (1978-79) and low (1984-85) solar activity periods](image-url)
Fig. 3—Correlation of IEC with (a) 10.7 cm solar flux, (b) electrojet strength ($|\Delta H|$) and (c) magnetic index ($A_p$) during low solar activity period (1984-85) [r represents the correlation coefficient]

3.4 Effect of magnetic index

To study the influence of the magnetic index ($A_p$) on the observed day-to-day variability of IEC, the diurnal maximum values are plotted against the corresponding values of the magnetic index, $A_p$, for the three different seasons as shown in Fig. 3(c). It is observed that IEC did not show any clear dependence on $A_p$. The correlation coefficients were also found to be low (0.1) for all the seasons. Similar results were also reported by Koparkar 12 from Bombay.

The absence of any significant correlation between the IEC and $A_p$ may partly attributed to the averaging effect of quiet and disturbed day indices. Hence, the influence of magnetic ordering on IEC variations seen by Mendillo et al. 15 at midlatitudes has been examined for the IEC data of low latitude station during low solar activity period. In the present study, two extreme cases, namely, very quiet days (QQ) and very disturbed days (DD) are considered. Hourly values of IEC data are taken to obtain the percentage variations from the monthly mean values for the 5 QQ and 5 DD days of each month. The average diurnal behaviour of these percentage variations for summer, winter and equinoctial months are shown in Fig. 4. It is noted that during summer, the QQ and DD curves appear to be the 'mirror-images' of each other excepting at around 0700 hrs LT, whereas during winter and equinoxes, although a similar behaviour is observed, the times of maximum and minimum deviations are not the same. Dabas et al. 16 reported the QQ and DD curves to be the mirror-images of each other during winter for all
local times at Delhi which is situated north of the equatorial anomaly crest.

4 Discussion

Many authors\(^{17 \text{--} 22}\) have reported large variabilities in the values of IEC from different locations and have tried to correlate the same with magnetic activity, solar flux and the effect of neutral winds. At low latitudes, Tyagi and Mitra\(^{23}\) observed that there are days of unusually high or low electron content apparently unconnected with any observed geophysical events. The possible causes of day-to-day variability at low latitudes are: (i) solar ionizing flux, (ii) sunspot activity, (iii) equatorial electrojet strength which, in turn, represents the electric field, (iv) magnetic activity, and (v) neutral winds. Comparing the gross variability of some of these parameters with that of IEC, it is observed in the present study that solar flux is the main contributing factor at equatorial and low latitude stations during the equinoctial and winter months of low solar activity period. Sethia et al.\(^{24}\) and many others\(^{25 \text{--} 27}\) have shown that the electrojet has a strong influence on IEC at latitudes, extending from the equator to as high as 25°N dip latitude, which essentially correspond to the equatorial anomaly. The present study at Waltair also shows the day-to-day changes in IEC, particularly, during the summer months of low solar activity period which are mainly controlled by the strength of the equatorial electrojet.

The present study shows that the variability of IEC during daytime is independent of season and is, more or less, the same (\(\leq 20\%\)) during the maximum/minimum solar activity conditions, whereas Aravindakshan and Iyer\(^5\) and Soicher et al.\(^{28}\) reported that the daytime variability is comparatively less during high sunspot years and there is also a month-to-month variation; the variability being higher in winter as compared to that in summer months. Although no direct correlation with magnetic activity is apparent (as also observed by Mendillo and Lynch\(^{29}\)), a systematically higher variability on QQ than DD days in the daytime hours of summer and equinoctial months of low solar activity period is noticed at Waltair. The difference between the QQ and DD values is not so significant at Tokyo (35.7°N). There may be an additional contribution by the magnetospheric electric fields to the variability at low and midlatitudes under disturbed conditions.

The above results of the control of ionospheric variability at a low latitude station by the equatorial electrojet may be viewed in the context of the coupling between the equatorial and low latitudes ionization as a consequence of the electrodynamic drift and diffusion. The F-region ionization between ± 15° dip latitude is dominantly controlled by the well known ‘fountain effect’. A strong electrojet implies a larger \(\mathbf{E} \times \mathbf{B}\) upward drift at the magnetic equator and development of a pronounced equatorial anomaly. Hence, the observed day-to-day variability of IEC at low latitudes and its correlation with \(\Delta H\) variability is a manifestation of the electrodynamic coupling between equatorial and low latitude ionosphere\(^{25}\).

Thus the present study of day-to-day variability based on IEC data and other geophysical parameters from a low latitude station, Waltair, for varying levels of solar activity supports the conclusions of previous studies and highlights the importance of electrodynamic coupling between the equatorial and low latitude ionosphere.

The significant difference in the behaviour of nighttime electron content, particularly, under disturbed conditions, may be related to the coupling of high latitude/magnetospheric electric field with that of lower, even equatorial latitudes. With the Japanese chain of ionosonde stations and \(\mu\)-radar, the coupling between the high and low latitudes has been established. Theoretical models\(^{30 \text{--} 31}\) also show the importance of its coupling and its dependence on local time. The effect of coupling between high and low latitudes has been suggested to be more pronounced in the local night, particularly, in the post-midnight sector, because of the peculiar asymmetrical distribution of conductivity with local time on a global scale.

References