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Geomagnetic Storms & Associated Ionospheric Effects*

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Some typical cases of ionospheric disturbances associated with geomagnetic storms in different seasons are studied for dip-conjugate low and middle latitude places located along nearly the same longitude. The results show initial changes in N_mF2 similar to those in the magnetic field at all places, but later, the changes in the F2-ionization seem to be governed by the heating of the upper atmosphere and the accompanied changes in the neutral wind pattern and the gas composition. The anomalous increase of F2 electron density in winter at midlatitude duriug the main phase and after, of the storm is traced to the change in the meridional wind system and to the neutral wind transport from the summer hemisphere to the winter hemisphere. Satellite observations of the day-to-day and disturbed F-region also confirm changes in the gas composition in good correlation with the changes in N_mF2 or total electron content. As against the instantaneous effects of the storm in the F2-ionization, there is an after-effect of the storm in the D-region at midlatitudes but practically no such storm-effects in the low-latitude D-region. It is believed that the post-storm low energy electrons precipitate into the lower ionosphere from the magnetospheric slot and cause the delayed increase in the D-region ionization at midlatitudes. The D-region effects are inferred from the absorption of hf radio waves.

1. Introduction

It is now fairly well established that, in general, the electron density or N_mF2 and the total electron content (TEC) in the F2-layer of the ionosphere are diminished at high latitudes and enhanced at equatorial latitudes. At midlatitudes, these increase in winter and decrease in summer.[1-6] These conclusions have been drawn from the statistical analysis of ground-based and satellite-borne experiments in attempts to find average D_{st} and SD variations of N_mF2 or TEC on lines similar to those adopted by the geomagneticians. However, the characteristic features of individual ionospheric disturbances differ in many ways depending on the local time of sudden commencement (SC) or main phase onset (MPO) of the geomagnetic storm, its intensity and progress of its activity, since they are eventually responsible for bringing about changes in the electromagnetic (em) fields, neutral wind, gas composition and temperature. In the past, the synoptic picture of F2-layer disturbance during magnetic storms was drawn from the study of f_0F2 (or N_mF2), h_pF2 and TEC over places widely separated in latitude and longitude and these brought in some complications difficult to explain in a plausible way. Here, three typical storms are taken and the changes in f_0F2 are studied for low and midlatitude dip-conjugate places situated along nearly the same geographic longitude. Such a grouping minimizes the extent of anomalies in the results due to geomagnetic control of F2 and probably the D-layer ionization and also those due to local time (LT) differences and asymmetric longitudinal distribution of magnetic field. The stations for which the F2-data are studied, are listed in Table 1.

The D-layer ionospheric absorption variations on disturbed days are given for Ahmedabad (23°N, 72.6°E, I=34°N).

2. Changes in f_0F2 at Dip-conjugates

The changes in f_0F2 during a storm are expressed as ratios of the disturbed-day f_0F2 to the monthly median f_0F2 at corresponding hours and are shown for about 5 hr before the SC until about 50 hr after the SC of the magnetic storm. Two of

Table 1—Details of Stations Used in this Study

Station pairs	Geographic coordinates deg	Magnetic dip deg
Wakkanai	45·4 N, 141·7 E	59·5 N
Canberra	35·3 S, 149·0 E	65·0 S
Akita	39·7 N, 140·1 E	53·7 N
Brisbane	27·5 S, 152·9 E	56·6 S
Yamagawa	31·2 N, 140·5 E	44·3 N
Townsville	19·3 S, 146·7 E	48·8 S
Baguio	16·4 N, 103·8 E	18·0 N
Singapore	1·3 N, 103·8 E	18·0 S

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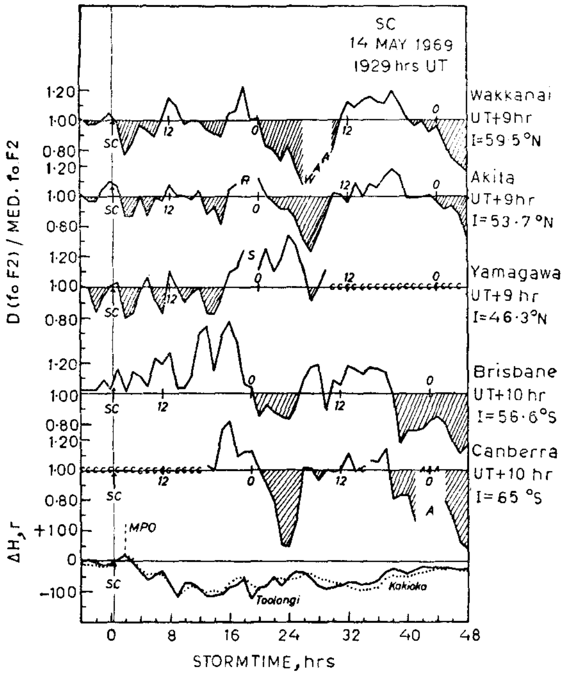

Fig. 1—Stormtime changes in f_0F2 on magnetically disturbed days after an SC at 1929 hrs UT on 14 May 1969 at dip-conjugate places in the far east (winter in south) (SC time is marked by an arrow. Local times at a place are also given.)

them are for winter and summer in either hemisphere and one is for equinox. Deviations of the H-component of the magnetic field at the appropriate places are also given.

2.1 14 May 1969

The SC time of the storm was 1929 hrs UT, i.e. early morning in the far east. As seen in Fig. 1, f_0F2 increased in the southern hemisphere (winter) for about 18 hr after the SC at dips greater than 55°. A fall was noticed after midnight. In the northern hemisphere (summer), f_0F2 remained below normal continuously for about 30 hr and then the changes were similar in both the hemispheres, although differing in magnitude. The disturbance seems to have propagated from north to south with a speed of about 150 m/sec as inferred from the onset of the negative phase in f_0F2 at different places. Similar sequence was also seen in the European-African zone, although the local time there differed by 10 hr from that in the far east. At Baguio and Singapore near the boundary of F2-equatorial zone, f_0F2 increased for most of the stormtime barring initial six hours.

2.2 7 Nov. 1970

The magnetic storm commenced at 0050 hrs UT, i.e. around noontime in the far east and sunrise along 105°E meridian. Fig. 2 shows the progress of events in the F2-ionization and the geomagnetic activity. It shows an initial increase of f_0F2 for about 10 hr at dip 65° south and then this increase spreads over longer interval towards north. It appears that the disturbance travelled from south to north with a speed of about 125 m/sec as inferred from the timings of positive peaks and onset timings of negative phase, both observed in a continuous manner. A long spell of depleted electron density prevailed in the south (summer) after the short initial increase. Similarly, in European-African zone, large increases of f_0F2 were found for nearly 24 hr after an initial decrease for 3 to 4 hr at Rome and Freiburg, whereas at the southern conjugate Johannesberg (dip 62°S), opposite conditions prevailed (Figure is not reproduced here). Variations corresponding to SD component are found to be superimposed on the overall stormtime variation shown in Fig. 2.

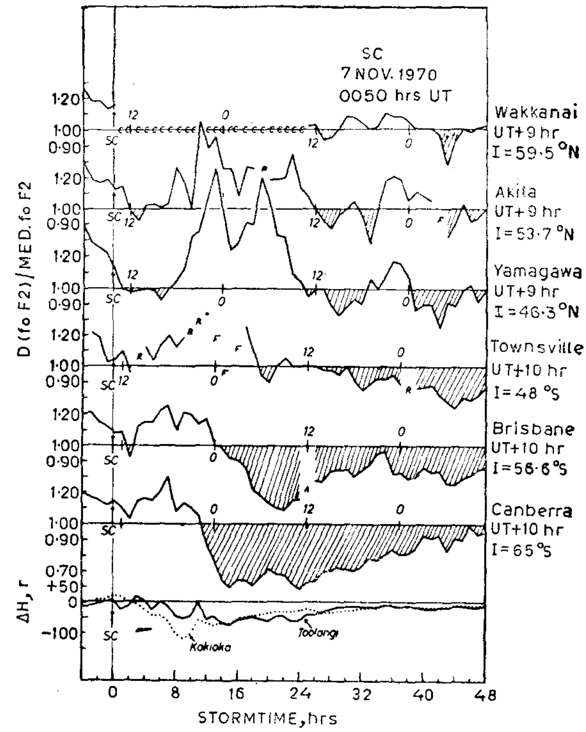

Fig. 2—Same as Fig. 1, but for a storm with SC at 0050 hrs UT on 7 Nov. 1970 at dip-conjugate place in the far east (winter in north)

2.3 8 Mar. 1970

This magnetic storm commenced at 1418 hrs UT with MPO within 2 hr of the SC. The magnetograms showed a maximum depression in the H-field of more than 200 gammas below normal at 8 hr after the SC, whereas the two described above had maximum depressions in the H-field of 100 to 150 gammas occurring at 20 hr after the SC. Almost everywhere (barring low latitude places) N_mF2 decreased appreciably during daytime as well as nighttime for two consecutive days (Fig. 3). At equatorial latitudes in the east, after the initial ups and downs of f_0F2, there was increase for nearly 24 hr, maximum occurring after 32 hr from the SC time.

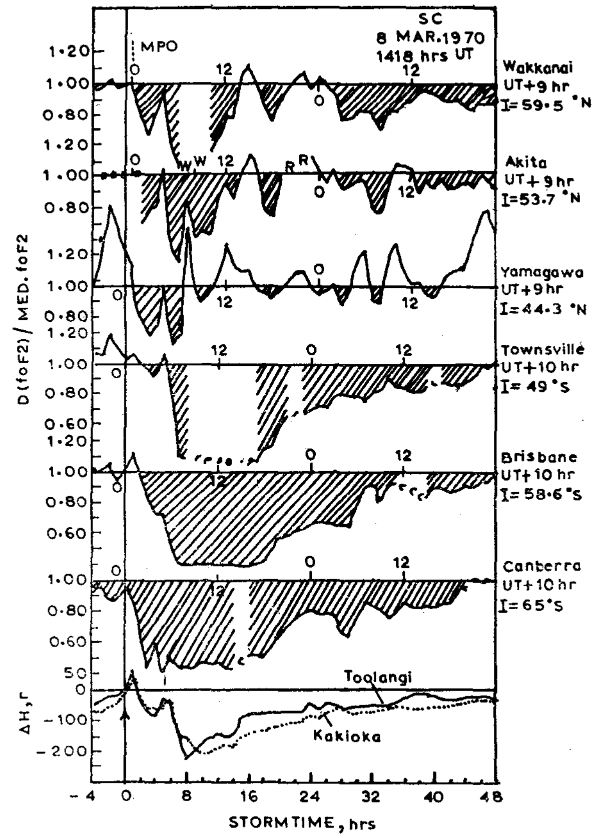

Fig. 3—Same as Fig. 1, but for a storm with SC at 1418 hrs UT on 8 Mar. 1970 at dip-conjugate places in the far east (equinox)

In spite of large deviations during the storms, there is a tendency for N_mF2 to come to its normal value around noontime. At low latitudes up to that of Yamagawa, the variations in f_0F2 were irregular.

3. D-region Absorption of Radio Waves

Lauter *et al.*[7] have extensively studied the post-storm events of increased radio wave absorption in in the D-region. An example of the variation of Al-ionospheric absorption on 2·5 MHz at Ahmedabad during a sequence of solar-geomagnetic disturbances in Aug. 1972 is shown in Fig. 4. It is seen that the absorption markedly increases during the solar flare (X-ray) events, but no significant change takes place in the absorption on or after the magnetically disturbed days.

Fig. 5 gives the result of a superposed-epoch analysis of ionospheric absorption and K_p-sum geomagnetic activity index, taking zero day as that on which K_p-sum exceeded 30. It is evident from Fig. 5 that there is no indication of any post-storm increase of absorption at a low-latitude (23°N) station like Ahmedabad. Incidentally, it is recalled that Ahmedabad falls outside the winter anomaly zone of enhanced absorption. It is interesting to note that while there may be some connection between the F-region and the D-region regarding the geomagnetic control and the winter anomaly at midlatitudes of their ionizations, such a connection is apparently not seen in their geomagnetic storm-effects. Whereas in the F-region the storm-effect is almost instantaneous, it is delayed in the D-region. The mechanisms for this non-agreement between the uppermost and the lower regions of the ionosphere should, therefore, be distinctly different.

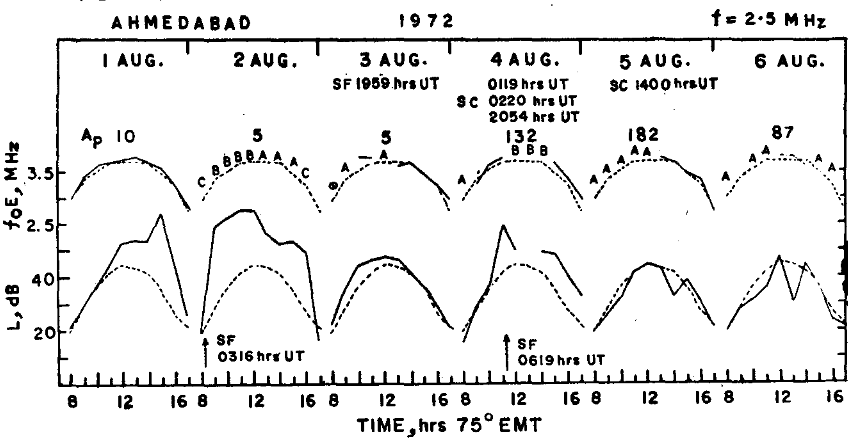

Fig. 4—Diurnal variation of ionospheric absorption on 2·5 MHz at Ahmedabad on a sequence of six days in Aug. 1972 when several solar flares and geomagnetic storms occurred (The arrows indicate the occurrence times of SF and SC. B means complete fade-out and A means presence of blanketing Es. Dashed line curves give monthly median values of f_0E and L.)

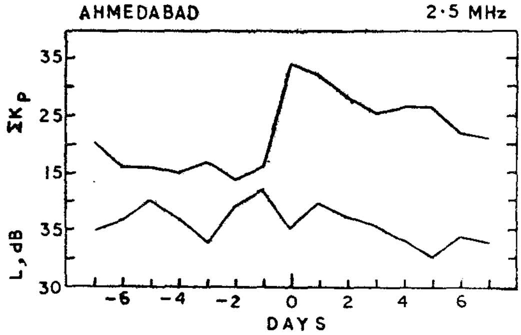

Fig 5 – Superposed-epoch comparison of geomagnetic activity K_p-sum and ionospheric absorption on 2·5 MHz at Ahmedabad (62 epochs of K_p-sum greater than or equal to 30)

4. Salient Features Deduced from the Observations

(i) Whatever may be the time of SC or MPO of the geomagnetic storm, there is greater probability of positive F2-storm at midlatitudes in the winter hemisphere. The evening rise of f_0F2 is particularly seen for storms commencing in the morning and afternoon and this rise may continue during the nighttime also in the winter hemisphere at midlatitudes.

(ii) From the well-planned set-up of the ionospheric stations in the east, it has been possible to estimate the speed of a travelling disturbance, probably of neutral wind, caused by the hemispherical energy imbalance. The speed turns out to be 125 to 150 m/sec, and this is directed from the summer hemisphere to the winter hemisphere. The changes in f_0F2 during the equinox are similar in both the hemispheres.

(iii) No conclusive evidence is discernible for the increase in N_mF2 with the SC increase of the H-field, but generally their changes are found to be similar in nature during the initial 3 to 4 hr of the storm. Of particular interest to note is that even the great storm of 8 March 1970 did not cause decrease in f_0F2 at low and equatorial latitudes in the east except for some ups and downs during the first ten hours. However, there were large decreases in N_mF2 and TEC and increase in h_mF2 at Huancayo in the west.

(iv) No post-storm or stormtime increase is found in the daytime absorption of radio waves in the lower ionosphere at a low latitude station as against those found at middle latitudes.

5. Discussion

The initial increase in N_mF2 observed sometimes or similar changes in f_0F2 and the H-field after the SC are explained as due to electrodynamic drift of electrons ; the sign of drift as compared to that under normal conditions depends on the direction of the electric field conveyed from the magnetosphere.[8-11] The evening increase of f_0F2, observed particularly for storms commencing in the morning or afternoon is also due to the e.m. drift.[10,11] However, the extension of such increase further in the nighttime is attributed to the upward drift of electrons associated with the equatorward meridional neutral wind triggered by the penetration of energetic particles from the magnetosphere and the consequent joule-heating in the auroral zone. The heat is conducted to lower latitudes by way of gravity waves and the electron collisions with the neutrals.

Under quiet conditions, the neutral wind is poleward during daytime and equatorward during nighttime. Any opposition or reinforcement of such a wind system during the storm will cause likewise changes in the F2-ionization. The vertical e.m. drift of electrons carried by the neutral wind is downward for the poleward wind and upward for the equatorward wind. Following the e.m. drift effects coupled with the changes in the fields and wind, there is an additional major effect of change in the gas composition produced as a result of the change in the neutral wind pattern. Increase of [O/N_2] or [O/O_2] will reflect as increase in the electron density and vice versa. The large decrease found in N_mF2 after the initial e.m. drift effects is due to decrease in [O/N_2]. Accentuation of positive F2-storm may result from the increase of [O/N_2] or decrease of [N_2/O] gas ratios at heights below a certain transition level from the peak-height.[12-17]

The seasonal anomaly, i.e. increase of f_0F2 at midlatitudes during storms and in the average SD variation of N_mF2 or TEC[17] may be explained as due to the increase of [O/N_2] caused by the transport of relatively more atomic oxygen in the augmented neutral wind from the summer hemisphere to the winter hemisphere. The augmentation of the neutral wind occurs due to the heating of the atmosphere by the storm-induced electric current.

The equatorial positive storms are explained by the upward drift of electrons associated with the equatorward neutral wind, decrease in the loss-rate of ionization, near-inhibition of upward transport of electrons due to reversal or reduction in the normal eastward electric field[18] and opposition to the ambipolar diffusion away from the equator. Most of the cases of prolonged decrease in F2-ionization at all places are probably caused by the violent changes in the neutral gas composition (abundance of molecular gas species and/or fall in atomic gas species) resulting in decreased production and increased loss-rate of ionization. Speeds of gravity wave disturbances and neutral winds ranging from 120 to 500 $msec^{-1}$ have been observed and theoretically predicted.[19,20] Some of the electrons from F2-region may also be peeled out into the plasmasphere causing the latter to contract to a lower latitude.[21-23]

As regards the storm-effects in the D-region, the post-storm increase of ionization or radio wave absorption at midlatitudes has been attributed to the precipitation of low energy electrons from the magnetospheric radiation belt slot to the lower ionosphere during the recovery phase of the storm[7,24,25] and this explanation is supported by the satellite observations of ELF whistler noise his produced in the magnetospheric plasma.[26-29] Such penetration of electrons and ionization by them is not possible at low latitudes which fact explains no post-storm increase of radio wave absorption at Ahmedabad.

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