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Differences in Seasonal Variation of Noon F2-ionization at Dip-conjugate Places

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A study is made of noon f_0F2 over a period of one solar cycle (1958-69) at some pairs of magnetically near-conjugate places in the eastern and central zones with dips (I) 0-60°. Seasonal dependence of the sensitivity of f_0F2 on solar activity is studied and the differences in the seasonal variation of f_0F2 are shown for low and high solar activity epochs. It is found that the seasonal variation of noon f_0F2 at dip-conjugates are significantly different, and the change-over seems to occur at the geographic equator. The midlatitude winter anomaly of f_0F2 found in north is not observed at the southern dip-conjugate till near the peak of the sunspot cycle. The results are discussed specially with reference to the neutral wind and the associated changes in the gas composition.

1. Introduction

Contrary to rather simple and regular behaviour of the E- and F1 layers of the ionosphere, the F2-layer is known for its complexities in respect of diurnal, seasonal and latitudinal variations. Of late, much interest is shown in the processes related to the electromagnetic drift forces, diffusion, neutral wind, air composition and magnetospheric coupling for the understanding of the F2-layer dynamics. Matuura[1] and Rishbeth[2] have given reviews tracing the development of new ideas on F2-dynamics and they contain a good glossary of the relevant bibliography.

The parameter f_0F2 (ordinary wave critical frequency of the F2-layer) is used in various kinds of analysis for the study of F2-ionization. For its comparison at different places, some workers selected stations at similar geographic latitude in different longitude zones, while others chose stations at same dip in the two hemispheres irrespective of longitude. Since the F2-ionization shows profound geomagnetic control and since the geomagnetic field is not symmetrically distributed over the earth, the results obtained from the study of the F2-layer data at stations grouped in a manner as stated above make their interpretation difficult. In this paper, a study is made of the variations in noon f_0F2 with solar activity and of their seasonal differences at dip-conjugates situated along nearly the same longitude. Such selection at least removes the hemispherical differences in f_0F2 that arise from the magnetic dip control, and longitudinal anomalies. Table 1 gives the particulars of the conjugate-pair stations.

2. Seasonal Dependence of Solar Activity Control of f_0F2

In order to find the seasonal influence on the solar cycle variations of F2-ionization, the noon f_0F2 is plotted against sunspot number R_z separately for each month over a sunspot cycle. This is done for all the 8 pairs, but here only the plots of one pair, viz. Maui/Rarotonga are given while the results of such plots for other pairs are given in a graphical form. Since the F2-ionization is influenced by a multiplicity of factors as stated earlier and not purely by solar control alone, it makes little difference whether we plot f_0F2 or $(f_0\mathrm{F2})^2$ against R_z. In fact, we have found a high correlation of f_0F2 with R_z and an equally high correlation of $(f_0\mathrm{F2})^2$ with R_z.

Tabels. 1—Details of the Ionospheric Stations

Station	Geographic coordinates	Magnetic dip
Eastern Zone		
Wakkanai (WK)	45·4°N, 141·7°E	59·5°N
Brisbane (BR)	27·5°S, 152·9°E	56·6°S
Kokubunji (KO)	35·7°N, 139·5°E	48·8°N
Townsville (TO)	19·3°S, 146·7°E	48·0°S
Maui (MA)	20·8°N, 200·2°E	38·5°N
Rarotonga (RA)	21·2°S, 200·2°E	39·5°S
Baguio (BA)	16·4°N, 120·6°E	19·0°N
Singapore (SN)	1·3°N, 103·8°E	18·0°S
Kodaikanal (KDK)	10·2°N, 77·5°E	3·5°N
Trivandrum (TR)	8·5°N, 77·0°E	0·6°S
Central Zone		
Sottens (SO)	46·7°N, 6·7°E	63·0°N
Johannesberg (JO)	26·2°S, 28·1°E	62·0°S
Djibouti (DJ)	11·5°N, 43·0°E	4·5°N
Ibadan (IB)	7·4°N, 3·9°E	6·0°S

Again, we have found perfect correlation between the mean values of R_z and 10·7 cm solar radio flux, the latter starting with a minimum value of 57 units at $R_z=0$. Fig. 1 shows the variation of monthly median noon f_0F2 at Maui with R_z in different months. It may be noted that the points fall fairly well along a line of least squares represented by $f_0F2=a\ (1+bR_z)$ where a gives the value of f_0F2 at zero sunspot number, b gives increase of f_0F2 relative to its quiet-sun value and the slope ab is sensitivity of f_0F2 to sunspot activity. It is seen that ab at Maui is large in winter and small in summer with a tendency to rise a little in equinoxes. In contrast, it is seen from Fig. 2 that ab at Rarotonga is high in equinoxes and low in summer and winter. Thus, the solar activity control of f_0F2 is seen to change with season and also with the hemispherical location. In other words, it is a function of the sun-earth geometrical orientation and the related atmospheric phenomena.

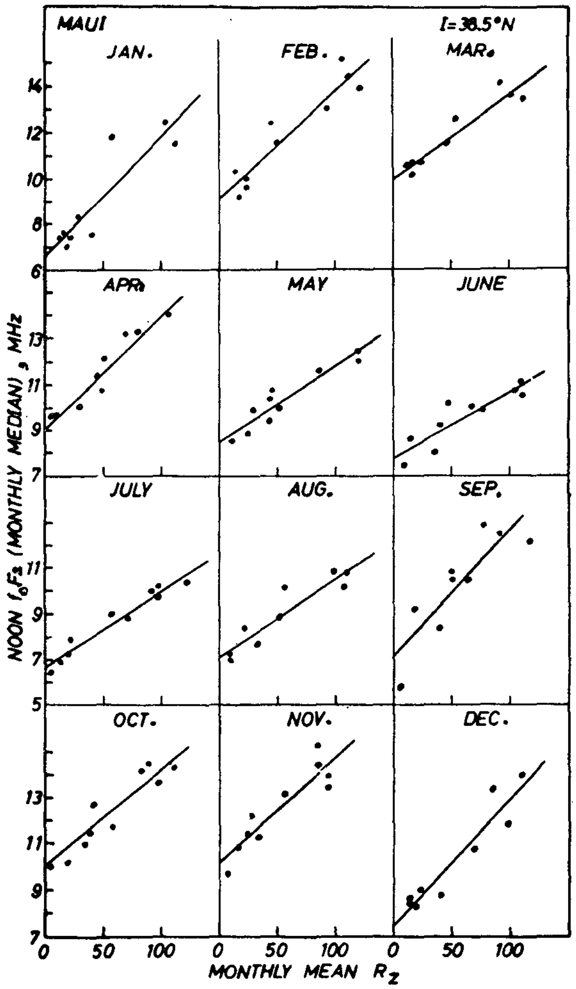

Fig. 1—Changes in noon f_0F2 at Maui with sunspot number for different months

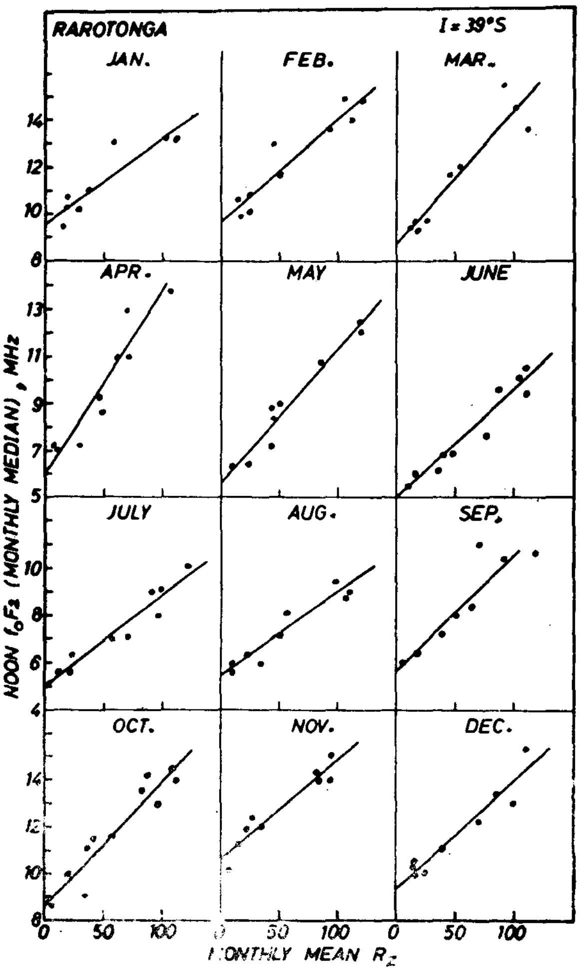

Fig. 2—Same as in Fig. 1 for Rarotonga

The variation with season of the sensitivity ab is shown in Fig. 3. It is to be noticed that f_0F2 responds greatly to R_z in April and October in low latitudes and such response shifts towards D-solstices at northern midlatitudes, whereas in south, the spring-maximum is more prominent at low latitudes and the autumn-maximum tends to equalize with the spring one at 60°S dip.

3. Hemispherical Differences in the Seasonal Variation of f_0F2

The seasonal variation of f_0F2 in a particular year is somewhat distorted due to the solar activity changing from month to month. From the plots such as shown in Figs. 1 and 2, one can read out f_0F2 at some fixed value of R_z for each month. Seasonal variation of f_0F2 then obtained will be free from the influence of the changing solar activity. In Fig. 4, curves are drawn showing seasonal variations of f_0F2 at conjugate stations of the eastern zone for two epochs of sunspot cycle, viz. $R_z=0$ and $R_z=100$ plotted side by side preserving the continuity of the

f_0 F2 scale for a given station. It is seen that the transition of the behaviour of f_0F2 from northern to southern hemisphere type takes place somewhere near Singapore, probably at the geographic equator. The single annual wave of noon f_0F2 at Rarotonga is distinct from the semi-annual wave at Maui during sunspot minimum. The winter and summer minima of f_0F2 in the north have nearly same magnitudes at $R_z=0$, in contrast to one prominent J-solstice minimum in the south. The semi-annual component in f_0F2 in south develops with increase in solar activity and that too more clearly at geographic latitude beyond 30°S (King and Smith[3]) as against the annual component getting stronger in the north. The winter anomaly of high f_0F2 at the midlatitude stations like Wakkanai and Kokubunji is not found at their southern dip-conjugates Townsville and Brisbane. The equatorial transition in the seasonal variation and the midlatitude winter anomaly in noon f_0F2 thus bring out the control of the F2-layer by geographic latitude.

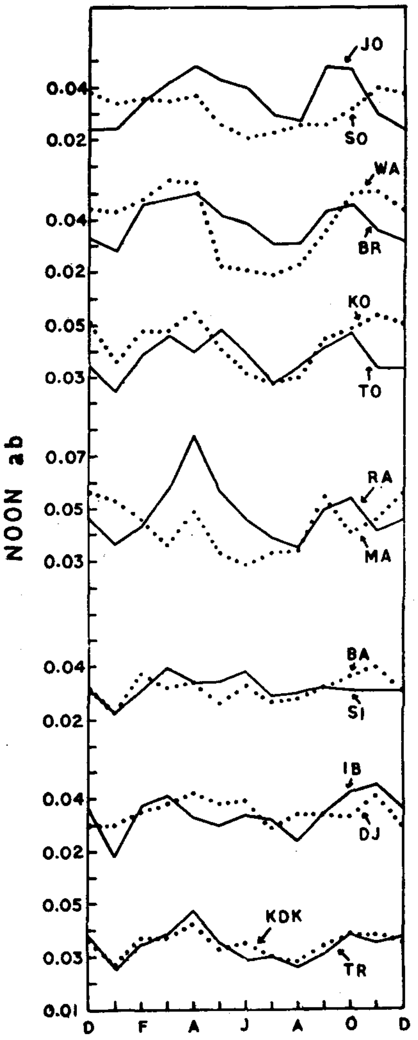

Fig. 3—Seasonal dependence of the sensitivity of f_0F2 with solar activity

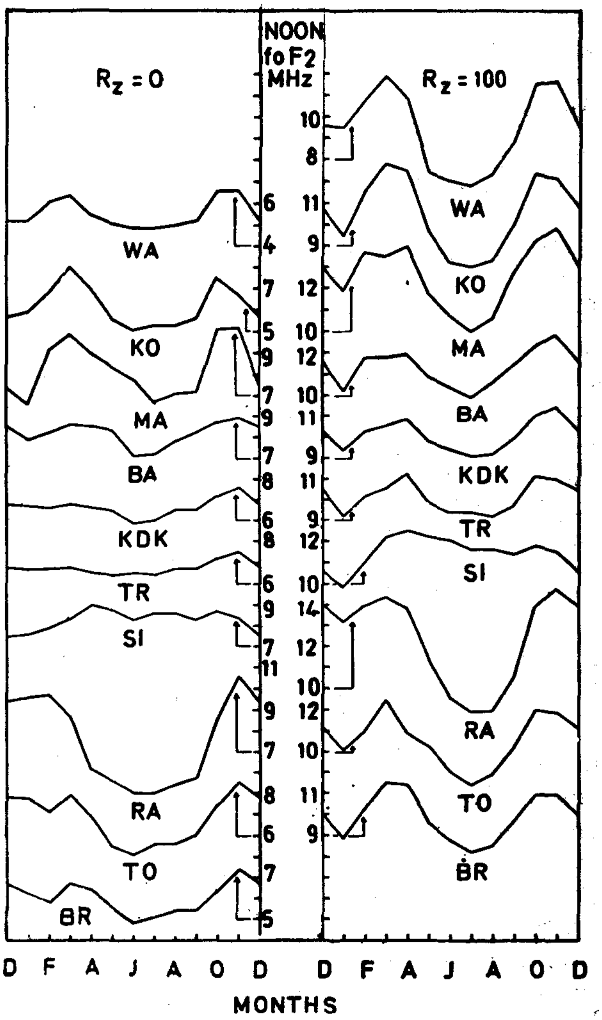

Fig. 4—Seasonal variation of noon f_0F2 at various stations in the eastern zone for $R_z=0$ and $R_z=100$ [f_0F2 for $R_z=0$ is also the value of a in the linear relation $f_0F2=a\ (1+bR_z)$]

4. Discussion and Conclusions

(i) At stations with magnetic dip 0-60°, a striking feature common to both the hemispheres is that of pronounced *J*-solstice minimum of f_0F2 despite the fact that summer conditions prevail in the north and winter conditions in the south. Equinoxial maxima are prominently seen at low latitudes in the north during low solar activity, but in the south they become prominent during high solar activity. These features could be explained by the effects of neutral wind. The high poleward noontime neutral wind velocity of 70-80 m/sec in *J*-solstices as given in the model by Anderson and Matsushita[4] probably brings in large amounts of molecular gas (O_2 and N_2) which readjusts diffusion equilibrium and causes increased loss rate of F2-ionization by attachment process.

This may be the reason for the pronounced *J*-solstice minimum of noon f_0F2 in both the hemispheres. Another type of wind, viz the transequatorial summer-to-winter hemisphere wind blowing away atomic oxygen near the F2-peak level is not much effective in low sunspot years, but it seems to be significantly effective during high sunspot years in increasing the ionization or filling up the winter minimum of f_0F2 (winter anomaly) at northern midlatitudes in the *D*-solstices with a development of its depression in the south (summer). Such transequatorial wind would also aggravate the *J*-solstice f_0F2 minimum in north (summer) and shallow the said minimum in south (winter). The above reasoning is in conformity with the recent satellite measurements[5-8] of O and O_2 gases in the thermosphere which show relative abundance of O_2 in summer at midlatitudes. Even the day to day changes in O^+ ion density and the ratio $[O]/[N_2]$ as recorded in the satellite ESRO[4] show good correlation (Prölss and Zahn[9]). Thus, the two types of meridional neutral wind causing changes in the relative amounts of molecular gas which affect the loss-rate of ionization and of atomic oxygen which affect the production of ionization could explain the major observed features of the seasonal variation of f_0F2 and their N-S differences. In addition, there is also the downward drift $U \cos I \sin I$ of electrons associated with the poleward neutral wind which further favours the loss-rate. This effect is larger in *J*-solstices than in *D*-solstices.

(ii) The variation of f_0F2 at Singapore with a maximum in April-May gives a feeling of its being in a transition region for the N-S asymmetry in the seasonal variation of noon f_0F2. This revelation of transition region is very significant because Singapore happens to be almost at the geographic equator where the neutral wind is practically zero. Also, the southern dip-conjugates of the northern midlatitude stations considered here have geographic latitude less than 30°. So the hemispherical differences in the seasonal variation of f_0F2 at *dip-conjugates* are essentially due to the geographically symmetric neutral wind and the associated changes in the air composition. The factor $\cos I \sin I$ in the vertical drift is same at the dip-conjugates, while U is supposed to be maximum at 45° latitude and minimum at poles and equator (all geographic).

(iii) In the Pacific region, the seasonal variation of noon f_0F2 at Maui and Rarotonga which have same magnetic dip, same geographic latitude and longitude, presents a curiously anomalous situation. Earlier, the authors[10] had reported on the differences in the diurnal variation of f_0F2 at these places. At Rarotonga, the seasonal variation apparently seems to be solar-controlled with a maximum in summer and a minimum in winter as compared to equinoxial maxima at Maui. However, purely a solar control and attachment-loss process of electrons would give a *D*-to-*J* solstice f_0F2 ratio of 1·18 at Rarotonga, while actually it is found to be 1·5 or more. This difference could be attributed to the effect of the meridional neutral wind. In *D*-solstices, the poleward wind at these places is only about 20m/sec and is not much effective in changing the normal solar-controlled f_0F2 for the local summer there. However, the large influence of *J*-solstice poleward wind decreases f_0F2 considerably as a result of which the summer (*D*)/winter (*J*) ratio of f_0F2 at Rarotonga becomes larger than normally expected. A depression of f_0F2 in *D*-solstices at Rarotonga in high sunspot years is probably due to the decrease of the ratio $[O]/[N_2]$ caused by the summer-to-winter hemisphere neutral wind.

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