The Behaviour of foF2 at Sanae

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Abstract

This paper presents a discussion of the solar cyclic, seasonal and diurnal variations as well as the day-to-day fluctuations of foF2 as observed at Sanae. The main aim is merely to describe these variations and little attempt is made to investigate their causes.

Samevatting

Hierdie referaat behels 'n bespreking van die sonsikliese, seisoens- en daaglikse wisselinge sowel as die dag-tot-dag-afwykings van foF2 soos by Sanae waargeneem. Die hoofdoel is slegs om hierdie variasies te beskryf en weinig aandag word aan hul oorsake geskenk.

Introduction

Figures 1 and 2 represent plots of the hourly values of foF2 at Sanae (70°S 2°W geographic; 63,6°S, 43,9°E geomagnetic) for each day of two complete years, June 1962 to May 1963 and June 1968 to May 1969. The former period is near solar minimum and the latter near solar maximum. ΣKp is indicated for each day as well as the Zurich mean sunspot number for each month. These two diagrams contain a great deal of information concerning foF2 at Sanae and are used here to discuss the solar cyclic, seasonal and diurnal variations as well as the well-known day-to-day fluctuations of foF2. The main aim here is merely to describe these variations as they occur at Sanae and little attempt will be made to investigate their causes. There has been a demand for this type of material by workers engaged in radio prediction services and ionospheric research.

Quality of Observations

The ionosonde used at Sanae is a Cossor with a frequency range of 1,0 to 18MHz. The sweep time is 15 sec. and the peak pulse power ~ 1kw. To ascertain the quality of the data, three months were taken near solar minimum and three near solar maximum (summer, winter and equinox) and the percentage of hourly observations that were impossible or made with reduced accuracy are listed in Table 1.

It is possible that some of the observations denoted by the symbol B (absorption in the vicinity of fmin) should be under E (less than the lower limit of the normal frequency range) or C (any non-ionospheric reason). As the observations in classes B and C usually yield no numerical value, these have been added to give a rough idea of the amount of data lost. Observations qualified by the symbol U are accurate only to within ±0,5MHz. The remainder are probably accurate to within 0,1MHz.

Fluctuations in foF2

A marked feature of Figures 1 and 2 is the very fluctuating and erratic behaviour of foF2 on the whole. This is evident at solar maximum and solar minimum, although October 1962 and February 1963 can probably be singled out as the most disturbed months.

Any analysis of foF2 fluctuations is difficult because of the problem of establishing exactly what represents the normal quiet ionosphere. For these purposes it will be assumed that the normal undisturbed ionosphere is fairly closely represented by the median of foF2 on the ten magnetically quiet days. *Rourke* (1964)

Table 1

URSI Symbol (1961)	Nov. 1962	July 1962	Apr. 1963	Nov. 1968	July 1968	Apr. 1969
A			3,0		9,4	
B	24,0	68,5	37,1	18,3	23,6	16,1
C	1,4		9,0	18,3	11,0	12,5
E					2,1	
F			6,0	1,9	4,9	1,4
J			2,2	2,6	1,9	2,9
R			8,0	24,9	9,2	
T	4,4	1,9	0,1			
U (% of observations accurate to ± 0,5MHz)	11,9	1,3	18,2	9,6	4,6	2,1
% of observations accurate to ± 0,1MHz	62,7	30,2	35,7	53,8	60,8	69,3
% of observations made impossible by C or B	25,4	68,5	46,1	36,6	34,6	28,6

has compared locally selected quiet days at 13 Antarctic stations during the IGY with the internationally selected days. He found that, on the average, 30 per cent of the locally selected days differed from the international quiet days.

In view of this, the ten local magnetically quiet days are used here. Figure 3 shows hourly values of foF2 at Sanae for a summer month (November, 1962). The circles represent the values of foF2 on the magnetically quiet days and the crosses are the values on the remaining days of the month. An analysis of these data reveals that if the standard quiet day is represented by the median of the magnetically quiet days, then 30 per cent of the observations lie above the standard and 62 per cent lie below it. Therefore, for this station, for this period, the majority of the fluctuations or disturbances are decreases in electron density. The average positive deviation of foF2 from

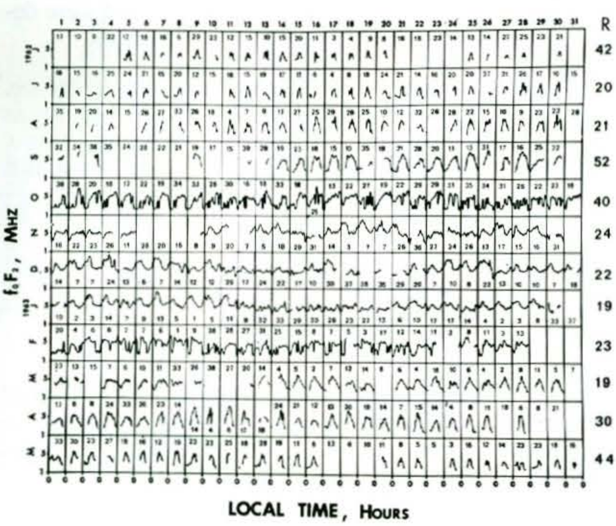

Fig. 1. Hourly values of foF2 for the period June 1962 to May 1963 for Sanae. Upper scale indicates the day of the month; lower scale indicates the position of local midnight. ΣK_p is shown for each day and the mean Zurich sunspot number for each month (R)

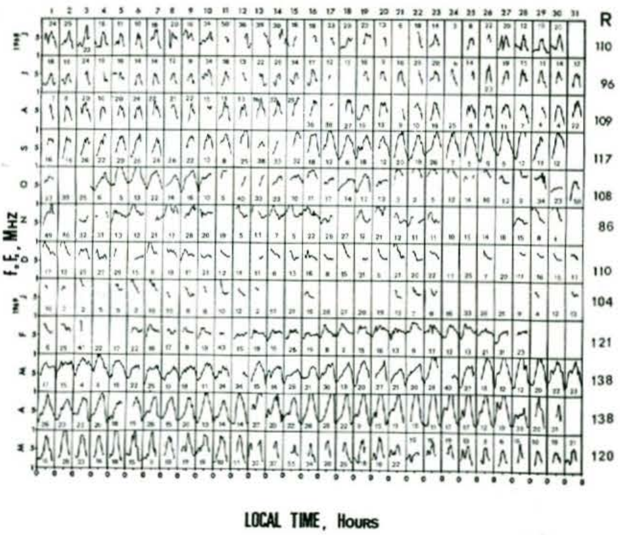

Fig. 2. Hourly values of foF2 for the period June 1968 to May 1969 for Sanae. See caption to Figure 1 for further explanation.

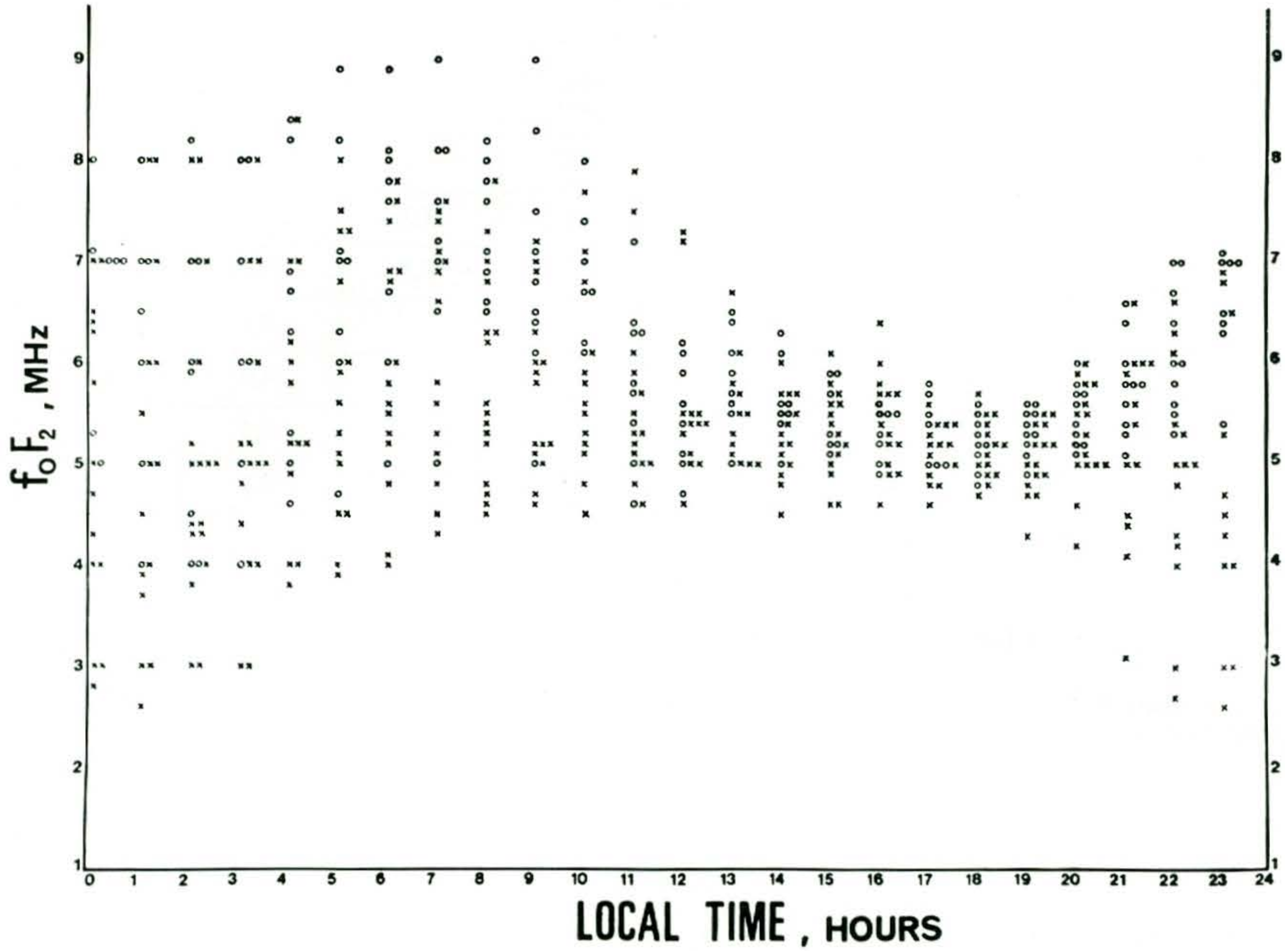

Fig. 3. Hourly values of foF2 for Sanae, November 1962. The quiet day values are represented by open circles.

the quiet day standard is 1,2MHz (with a maximum of 1,9MHz) and the average negative deviation is 1,6MHz (with a maximum of 4,2 MHz).

A rough estimate shows that ~13 per cent of the days agree with the quiet profile i.e. lie within 0.5MHz of it, ~26 per cent lie outside this range for 6 to 10 hours and ~60 per cent lie outside this range for the whole day.

A similar analysis has been done for a typical mid-latitude station (Johannesburg) for November 1962 (*Torr and Torr*, 1969). The average fluctuation in foF2 from a quiet day standard is ~0,5MHz.

The deviations are slightly more often (i.e. 49 per cent as opposed to 42 per cent) decreases in electron density than increases. In this case 30 per cent of the days correspond closely to the quiet profile (i.e. within 0,5MHz), 33 per cent are disturbed for 6 to 10 hours and 37 per cent are disturbed for the whole day. A feature of the Sanae foF2 is that the quiet day values are spread throughout most of the range of monthly values, whereas at Johannesburg (26°S, 28°E) or Campbell Is (75°S, 27°W), the quiet day values tend to group together. (See figures 5 and 9 of *Torr and Torr*, 1969). Table 2 summarizes the results of such an analysis for summer, winter and equinox at Sanae at solar minimum and maximum.

It appears from this table that at Sanae more perturbations are negative in summer than in winter and more are negative at solar maximum than at solar minimum.

Table 3 shows the direction (i.e. increase or decrease) of the majority of perturbations from the quiet day standard over four six-hour periods.

In Table 3, the dashes indicate insufficient data from which to draw a conclusion and two arrows indicate that the number of disturbances that were increases did not differ from the number that were decreases by more than 10 per cent of the total.

Figure 4 is similar to Figure 3 but for winter i.e. July 1962. The spread of points in Figure 4 is not as great as that in Figure 3 but it is interesting to note that the time of maximum spread moves from just after midnight in summer to midday in winter.

Solar Cyclic Variations

Figures 1 and 2 show clearly that there is a marked increase in foF2 generally from solar minimum to maximum. Table 4 shows the values of the parameters a and b in the expression

$$\overline{(\mathrm{foF2})}^2 = a(1 + bR)$$

for certain hours of the day. $\overline{\mathrm{foF2}}$ is the monthly median at a particular hour for the years 1962 to 1969. (No usable data were available for the months examined for 1965). R is the Zurich mean sunspot number.

Table 2

	Percentage of hourly observations lying—		Average deviations (in MHz) from standard day	
	above standard day	below standard day	positive	negative
November 1962	30	62	1,2	1,6
July 1962	53	35	0,6	0,5
April 1963	47	47	0,9	0,7
November 1968	32	59	0,8	1,4
July 1968	47	43	0,7	0,6
April 1969	40	51	1,0	1,1

Table 3

	Solar Minimum				Solar Maximum			
	0–6	6–12	12–18	18–23	0–6	6–12	12–18	18–23
Summer (November)	↓	↓	↓	↓	↓	↓	↓ ↑	↓
Winter (July)	↑	↑	↑	—	↓	↓ ↑	↑	—
Equinox (April)	—	↓	↑	↑	↓	↓	↓	↑

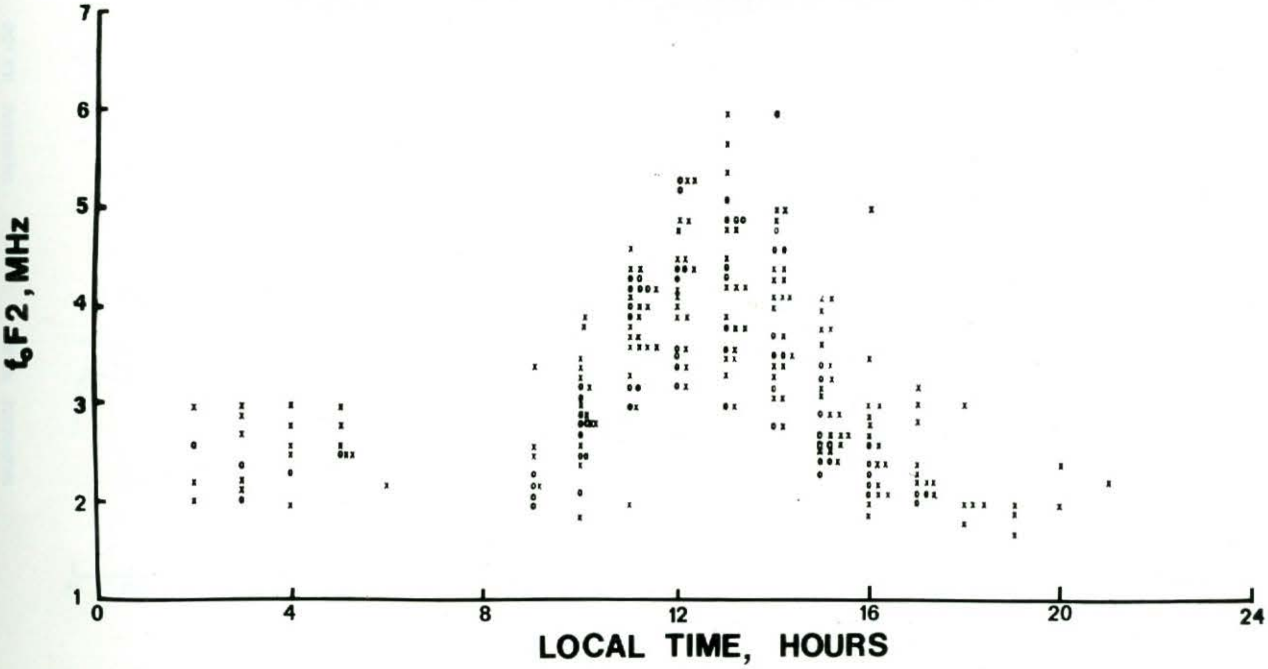

Fig. 4. Hourly values of foF2 for Sanae, July 1962. The quiet day values are represented by open circles.

Table 4

Hour	November	July	April
06	26(1+0,01R)	(1+0,17R)	(1+0,20R)
12	23(1+0,01R)	8(1+0,02R)	19(1+0,01R)
18	16(1+0,02R)	4(1+0,005R)	4(1+0,08R)

accuracy: (a ± 5; b ± 0,01)

This confirms the conclusions of *Scott* (1953) that in polar regions the variation with solar cycle is markedly different at different hours and seasons.

Further solar cyclic variations are evident in the seasonal and diurnal variations discussed below.

Seasonal and Diurnal Variations

Figures 1 and 2 show the well-known summer-winter difference in diurnal behaviour (*Bellchambers et al.*, 1962; *Baker and Gledhill*, 1964; *Sato and Rourke*, 1964). In summer there is relatively little diurnal variation with a maximum usually at about 06LT. This early morning maximum appears to be more evident at solar maximum. In winter there is a peak at midday in most cases. *Torr and Torr* (1969, 1970) have suggested that this summer-winter behaviour is due to a combination of three effects:

(1) vertical drift of ionization due to the global wind system of *Kohl and King* (1967);

(2) time variations in chemical processes which arise mainly from:

  (*a*) the effect of the temperature dependence of the linear recombination coefficient on the diurnal variation of the number densities of N_2 and O_2 and

  (*b*) the fact that the sun does not set on the F2 layer in summer and only illuminates it for ~6 hours in winter;

(3) the influx of low-energy electrons.

The semi-annual variation is also apparent in the data shown at solar maximum. Largest values of foF2 are obtained at the equinoxes. This variation is fairly common at middle-latitude stations especially in the southern hemisphere. *Rishbeth* (1968) has reviewed the possible causes of such a seasonal anomaly and has concluded that winds and composition changes are possibilities. Winds might be the cause if the heated region of the atmosphere, the diurnal bulge, is centred in the winter hemisphere (*King*, 1967). However, it still has to be shown whether winds can overcome the effect of the seasonal change of solar radiation which could produce greater electron densities in summer. Similarly, theories involving composition changes in the neutral atmosphere have yet to be confirmed. *Rishbeth* (1968) points out that although there is no conclusive evidence that energetic particles cause the seasonal anomaly, they may be a possibility in view of the geomagnetic dependence shown by the phenomenon.

Figure 5 shows the monthly medians (instead of the quiet day medians which were used before) and the quartile ranges for summer, equinox and winter, at solar maximum and minimum. This summarizes many of the features discussed.

Table 5 presents a least squares fit of the relation

$$foF2 = a + b\ \Sigma Kp$$

where foF2 is the hourly value of foF2 over four three-hourly periods centred on the times 00, 06, 12 and 18. The results, however, vary so much from hour to hour and season to season as well as over the solar cycle that it is difficult to see a trend.

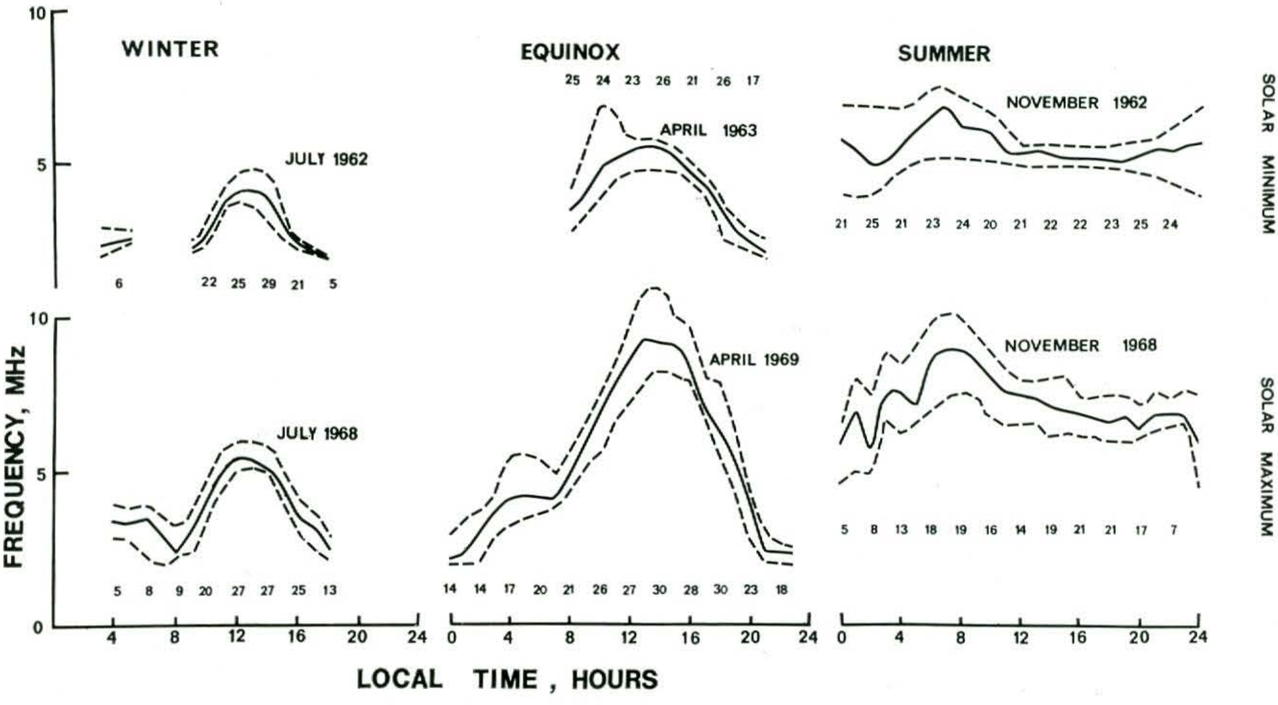

Fig. 5. Monthly medians and quartile ranges of foF2 at Sanae for summer, winter and equinox at solar maximum and minimum. The numbers on the diagram indicate the count at two-hourly intervals.

Table 5

	SOLAR MINIMUM				SOLAR MAXIMUM			
Hour	00	06	12	18	00	06	12	18
Nov.	$34,4-3,4\Sigma K_p$	$42,5-3,9\Sigma K_p$	$12,2+1,6\Sigma K_p$	$75,2-11,1\Sigma K_p$	$21,6-1,1\Sigma K_p$	$47,1-3,7\Sigma K_p$	$-6,9+3,1\Sigma K_p$	$42,2-3,4\Sigma K_p$
July	—	$21,5-2,4\Sigma K_p$	$16,4+0,2\Sigma K_p$	$22,3-1,2\Sigma K_p$	—	$9,4+3,2\Sigma K_p$	$20,5-0,6\Sigma K_p$	$13,1+1,1\Sigma K_p$
April	—	$25,6-3,4\Sigma K_p$	$30,4-2,9\Sigma K_p$	$3,0+3,4\Sigma K_p$	$27,8-3,3\Sigma K_p$	$16,6+0,5\Sigma K_p$	$37,7-2,1\Sigma K_p$	$11,3+1,2\Sigma K_p$

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