Bull. Astr. Soc. India (2000) **28**, 657-663

Covariation of critical frequency of F_2-layer and relative sunspot number

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Received 1 March 2000; accepted 14 September 2000

Abstract. Seasonal and overall covariation of relative sunspot number and the critical frequency of F_2-layer of the terrestrial ionosphere has been investigated and the following results have been obtained;

1) There is a strong correlation between the relative sunspot number and the critical frequency of F_2-layer of ionosphere.

2) There exist alternate similar and dissimilar zones in the seasonal variation pattern of the relative sunspot number and critical frequency of F_2-layer.

3) Critical frequency of F_2-layer increases nonlinearly with relative sunspot number reaching a maximum at sunspot maximum.

4) An empirical equation connecting critical frequency of F_2-layer with relative sunspot number has been derived by applying least square method of curve fitting which gives values of critical frequency of F_2-layer very close to the experimentally obtained values of the same.

1. Introduction

Being a variable source of electromagnetic and particle radiation the sun in general has two distinct physical states of its own; i) Quiet, ii) Disturbed. When the sunspots appear on the solar surface in a very small number the sun is said to be in its 'quiet' state while many large spots appear in a high multitude on the surface of the sun in its highly disturbed state.

The frequency and distribution of sunspots, which are so to say relatively cooler regions on solar surface evolved due to solar magnetoplasmodynamical instability, is roughly periodic. Spots individually may vary in size and in life time. Majority of sunspots may have life time of less than one day while some large sunspots may persist for as long as 70 days. Intensity of magnetic field associated with a spot may well vary from 100 gauss to 4000 gauss (1959). Although the exact mechanism of producing ionospheric variations along with the corresponding change in solar activity is still unknown all such terrestrial effects are found to increase in magnitude at sunspot maximum.

Action of solar UV rays on the rarified gases of Earth's upper atmosphere produces different ionized layers within it and as because the production of solar UV rays is closely associated with the successive appearance and disappearance of sunspots in the solar disk one would naturally expect the sunspot number to have a control over terrestrial ionosphere. The increase in UV radiation during sunspot maximum however is greater than in other wavelengths (1959).

Complicated relation exist between the intensity and spectrum of the emitted radiations and epoch in the solar cycle measured in terms of various indicators (1982). Remarkable geomagnetic disturbances occur due to various solar activities and low level ionisation is produced in the neighbourhood of polar caps by the collision of solar cosmic rays with terrestrial atmosphere there (1982).

It has been observed that ionisations of all the ionospheric regions increase or decrease as the spottedness of the sun increases or decreases in course of a solar cycle. The ionisation of the F_2 - region undergoes remarkable solar cycle variation. Bartels proved from examination of Huancayo data even that a 27 day variation in f_oF_2 can be observed along with the sunspot number (1952). Ratcliffe too mentioned that the critical frequency of F_2-layer shows marked variation with the solar cycle being greater at the sunspot maximum. He gives a relation between the f_oF_2 and the sunspot number as the following;

$$(f_oF_2)^2 \propto (1+0.02\ R)$$

where R is the mean Zurich sunspot number. With the above mentioned relation Ratcliffe (1960) suggests that attachment plays more important role than recombination in the process of loss in the F_2-region. Unlike the relationship between f_oF_2 and R given by Ratcliffe the following relation given by Smith and King (1981) describes the covariation of f_oF_2 and R more accurately along with the secular variation in their mutual relationship;

$$f_oF_2 = 4.95+0.0280R+0.000457A_F, \tag{1}$$

where A_F is the corrected area of solar faculae.

In this paper I have considered the monthly mean values of f_oF_2 for a period of twelve years which has been supplied by Prof. D. Karunakaran, Indian Institute of Astrophysics, Kodaikanal, India. The monthly mean values of sunspot number for the corresponding twelve years have been collected from NOAA Dept. of commerce, USA. In this paper the correlation between f_oF_2 and relative sunspot number (RSSN) has been studied from various statistical angle of view and an empirical equation relating f_oF_2 with RSSN has been found out, which is again different from that of Smith and King.

2. Symbols and notation

f_oF_2 - Critical frequency of F_2-layer of ionosphere

RSSN - Relative sunspot number

3. Results and discussion

Correlation coefficient for the covariation between yearly values of RSSN and f_0F_2 respectively has been calculated and it is found to have a value approximately equal to 0.98. This certainly indicates that extremely strong correlation does exist between RSSN and f_0F_2 which was ofcourse mentioned earlier by several authors (1952, 1960 & 1981, 1982). A scatter diagram between RSSN and f_0F_2 is drawn (Fig. 1) very carefully with the monthly mean values of the corresponding parameter for years starting 1980 to 1991. The diagram resembles exactly to the pattern of covariation between yearly average values of the same two parameters. Then an empirical equation has been found out by means of least square method of curve fitting and the least square curve is drawn over the scatter diagram for the covariation of RSSN and f_0F_2. The empirical formula thus obtained is given below;

$$f_0F_2 = 10.62 - 1.084 \times 10^{-4} (\mathrm{RSSN} - 200.65)^2 \qquad (2)$$

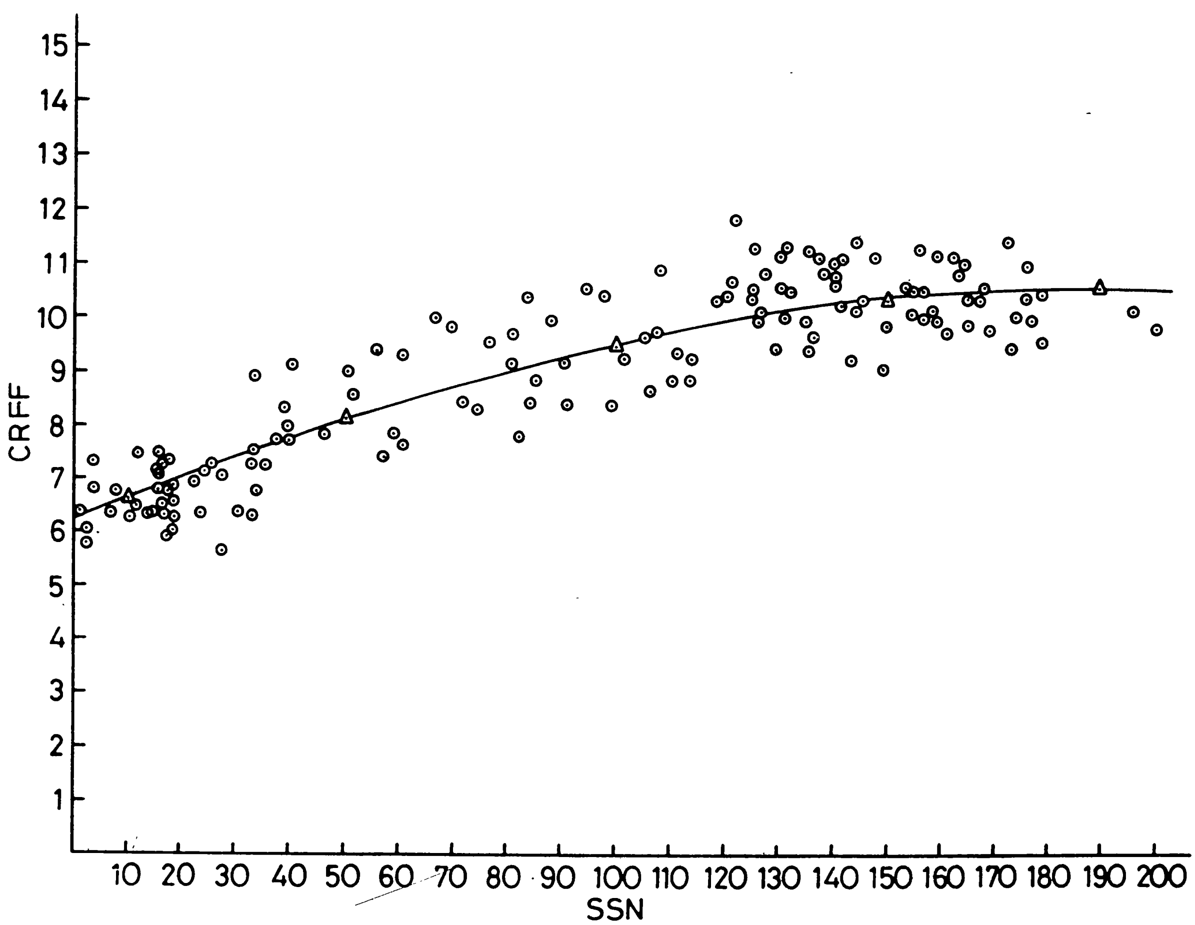

Figure 1 Scatter diagram for monthly mean values of SSN and f_0F_2 respectively for a period of twelve years (1980-1991).

Now this empirical equation is used to determine the values of f_0F_2 from known monthly mean values of RSSN for several months of the year 1992 and those calculated values of f_0F_2 are compared with the monthly mean of the experimentally obtained values of f_0F_2 (Table 1).

Table 1. Comparison between values of f_0F_2 calculated from empirical equation (2) and experimentally obtained values of the same for different months of the year 1992.

Months	Mean value of RSSN (Expt.)	Corresponding values of f_0F_2 (Theo).	Mean value of f_0F_2 (Expt.)	Percentage deviation
January	150.00	10.34	09.942	-04.0%
February	161.10	10.45	11.083	+05.7%
March	106.70	09.66	11.296	+14.5%
April	102.20	09.57	10.173	+05.9%
May	073.50	08.87	09.729	+08.8%
June	065.30	08.63	07.800	-10.6%
July	084.50	09.16	07.862	-16.5%
August	064.40	08.61	08.042	-07.0%
September	062.90	08.56	09.096	+05.9%
October	088.30	09.25	09.475	+02.4%
November	–	–	–	–
December	–	–	–	–

It is observed that the percentage deviation lies below plus minus 10% in most of the cases and the average percentage deviation becomes approximately equal to 5%. This result evidently confirms that the empirical equation, given in the above, tallies very well with the real situation. Then a study about an approximate average seasonal variation of f_0F_2 and RSSN has been made by plotting 12 yearly average values of both f_0F_2 and RSSN for each month against the months only (Fig. 2). It is therefrom observed that alternate zones of similar and dissimilar variations of f_0F_2 and RSSN against months do exist and period of similarity or dissimilarity repeats themselves each after a particular interval of time periodically. The empirical equation (Eq. 1) mentioned above, although signify the relative importance of attachment than recombination in the process of loss in F_2-layer, need being theoretically investigated for a better understanding about the process of energy loss in F_2-layer. Moreover the successive similar and dissimilar modes of seasonal variation of f_0F_2 and RSSN between themselves is little understood.

As because the atom-ion interchange becomes dominant over dissociative recombination within F_2-layer, which is usually optically thin too to the most of ionizing radiation, ambipolar diffusion is to be considered along with chemical processes (1978).

Massey (1982) has mentioned that the resonant charge exchange cross section Q_E of the relative impact energies of importance can be put down to a good approximation in the following form.

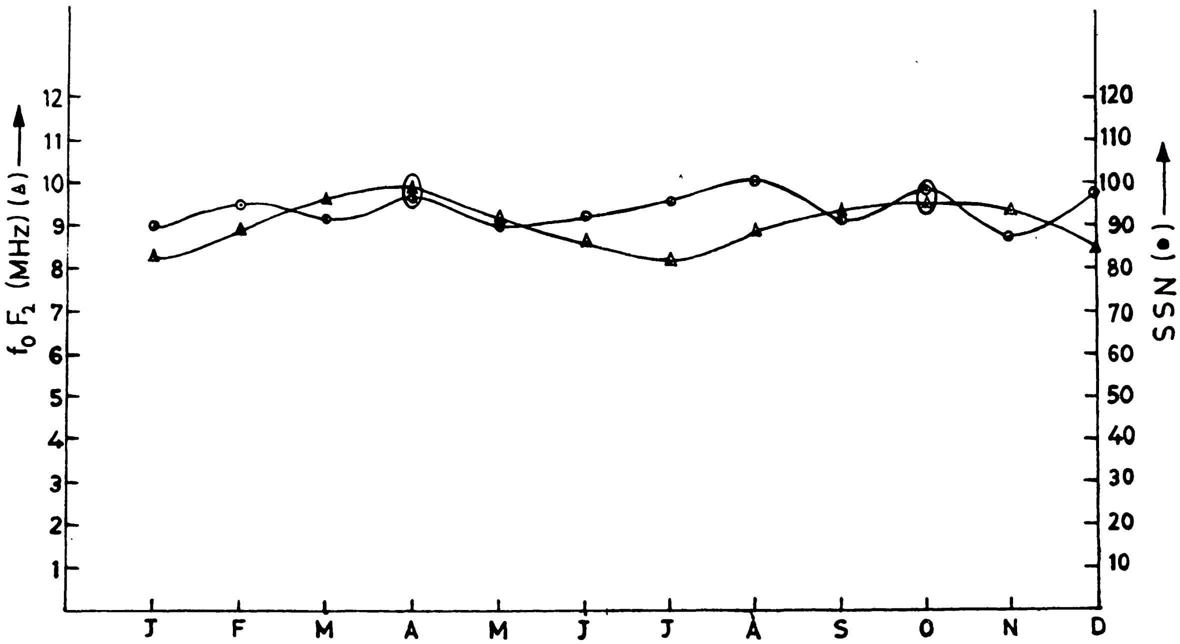

Figure 2 Seasonal variations of SSN and f_0F_2 as found out from 12 yearly average values of the parameters concerned for each month of year.

$$Q_E = (A - B \log_{10} E)^2 \quad (3)$$

where E' is the relative kinetic energy.

Now Q_E plays an important role in controlling the rate of production of electrons in F_2-layer while E' is appreciabley influenced by solar energy flux and therfore also by sunspot number. Therefore one can use the equation given above as the fundamental one for a theoretical derivation of the empirical equation (Eq. 2) given in this paper.

Didebulidze and Pataraya (1999) have shown that in addition to ambipolar diffusion one should consider also the evolution of atmospheric acoustic gravity waves and horizontal shear flow for explaining some changes in the F_2-layer electron density and hence f_0F_2. Regarding the relative importance of equation (2) over equation (1) it can be observed that both the equations have same nature over a long range of values of RSSN upto a certain maximum and within that range of values of RSSN upto a certain maximum and within that range the average slope calculated from Eq. (2) is almost of the same order of magnitude as that calculated from Eq. (1). But the nature of variation obtained from Eq. (2) is different from that obtained from Eq. (1) in respect that Eq. (2) gives an upper cut off value of RSSN for which the f_0F_2 has a maximum. As many authors demand today that ionospheric variations which are mostly though not completely controlled by corresponding solar event, are related to their indirect solar cause in a very complex manner. Rastogi (1996) has concluded that the amplitude of any solar flare effect, which of course always coupled directly with change in solar magnetodynamic potential energy and therefore indirectly connected to the sunspot number variation would depend on both the intensity of the solar flare itself and on the intensity of the ionospheric current at that instant. Therefore it is very hard to extract a true local time variation of the amplitude of a solar event-coupled ionospheric phenomenon and a phase lag will always exist between the two. Chaman Lal (1996) has established a striking similarity between the long-term semiannual variation of geomagnetic activity as represented by the planetary geomagnetic activity index A_p and that of the planetary ion-density of the F_2-layer of the ionosphere in terms of their normalised seasonal enhancement factors (SEF). The assessment accuracy of planetary index ion-density of F_2-layer, a layer which happens to be a region of transition between the magnetosphere and ionosphere is based on the measurement of f_0F_2. Hence seasonal variation of f_0F_2 has to be coupled with geomagnetic activity index. Moreover Chaman Lal (1996) has shown that his proposition of active involvement of UV/EUV and solar wind energy in creation of the F_2-layer of ionosphere is realistic and that the planetary index, planetary ion density of F_2-layer of the ionosphere (F_2 pd-value) calculated by combining the geomagnetic activity index with EUV-index becomes very close to the experimentally obtained value of F_2 pd. From the above discussion then it can be concluded that relative sunspot number which is a solar plasmodynamical instability phenomenon have some influence on the geomagnetic activity through magnetic field stretching which again is related to f_0F_2. Moreover sunspots' successive appearances and disappearances are also related to the breaking of and forming of old and new solar magnetic field lines respectively and thereby are related to solar flare event. Among the emission lines coproduced with such solar flare event, as per Chaman Lal's view EUV index is the most important one which have a correlation with f_0F_2. Sahai et al (1988) have shown that OI 6300 A intensity is approximately in phase with the sunspot cycle, showing much larger intensities during years of maximum solar activity. OI 6300 A intensity is approximately proportional to, as the well known Barbier's equation gives, the square of f_0F_2. Hence it is once more confirmed that f_0F_2 has a very good correlation with the RSSN.

Acknowledgement

The author wishes to offer his grateful thanks to D. Karunakaran, of the Indian Institute of Astrophysics, Kodaikanal for supplying ionospheric data, to Prof. B. Ghosh, Solid State Division and Mr. Swapan Mukherjee both of Saha Institute of Nuclear Physics, Calcutta for providing me with library and other facilities and to Dr. S.K. Midya, Dept. of Physics, Serampore College, WB, India for his willful inspiration. The author acknowledges also the cooperation of Smt. Jhuma Chattopadhyay in preparing the manuscript. Thanks are also due to an unknown referee for his valuable comments on the paper and also to the editor of the journal for his kind cooperation.

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