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Solar Activity Control of F2-region Electron Temperature from Incoherent Scatter Measurements at Millstone Hill

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Incoherent scatter radar measurements of electron temperature (T_e) and electron concentration (N_e) at Millstone Hill (lat., 42.6°N, long., 71.5°W) are analyzed for the period 1968-74 (which covers a small part of rising and a major part of declining phase of sunspot cycle 20) to look for solar activity dependence of T_e in the F2-region of the ionosphere. As N_e is the major controlling parameter for the F2-region T_e, electron temperatures for constant values of N_e are examined for the period under study. It is observed that there is significant dependence of F2-region T_e on solar activity both during the rising and the declining phase of the solar cycle.

It is now well known that two major physical processes which control the F2-region electron temperature (T_e) are (i) the electron heating due to energy gain from hot photoelectrons and (ii) the electron cooling due to energy loss in collisions with the colder ions. With the increase in solar activity, photoelectron production rates and thus the electron heating rates increase. The increased heating should result in high electron temperature. The increase in solar activity also results in higher values of ion concentration which, on the other hand, increases the cooling rates and one would expect a decrease in T_e (Ref. 1). Therefore, solar activity increase produces a net T_e which is a balance between the above two processes.

In the topside ionosphere, at heights around 1000 km, an increase in T_e with solar activity has been observed by Brace *et al.*[2] and by Mahajan and Pandey[3]. But in the F2-region no meaningful relationship between T_e and solar activity has been observed, as the major fluctuations in T_e were found to be dominated by day-to-day, seasonal and solar activity changes in N_e (Refs 4-9). Although the earliest empirical models by Mahajan[10] gave some evidence of solar activity effect in the F2-region T_e, no definitive study of solar activity on T_e has been made, except for an ad hoc inclusion of solar activity parameter (S) in the empirical relationship[11,12].

$$T_e = A - BN_e + CS \qquad \ldots (1)$$

where A, B and C are the various coefficients linking T_e with N_e and S. In this communication we attempt to bring out clearly the effect of solar activity on T_e by filtering out the effect of N_e, caused by day-to-day seasonal and solar activity changes.

The data used in this work are the incoherent scatter measurements at Millstone Hill (lat. 42.6°N; long. 71.5°W) for the period 1968-74 which includes a small part of rising phase and a major part of declining phase of sunspot cycle 20. The data were read from the contour plots of $\log_{10}N_e$ and T_e, as given in the MIT technical reports, containing Millstone Hill data for the years 1968-1974 (Refs 13-19). The electron density was available in $\log_{10} N_e = 0.2$ steps, whereas the electron temperature was in 200 K steps. About 400 profiles of N_e and T_e during 1000-1500 hrs LT were used in the present study. For a single day the profiles at 1000, 1200 and 1400 hrs (or 1100, 1300 and 1500 hrs) were included and the average value of T_e and N_e obtained for that day. Table 1 shows the dates during different years for which average N_e and T_e values were computed.

We selected a height of 300 km as a representative of the F2-region ionosphere. All the available data of T_e at 300 km during each year were plotted against N_e at 300 km. Linear regression curve was obtained from all these pairs of N_e and T_e. This was done separately for each year from 1968 to 1974. One such plot is shown in Fig. 1. The straight line fit clearly reveals the strong negative correlation between N_e and T_e in the F2-region. This result is consistent with the earlier results obtained from several experimental measurement through incoherent scatter radars[4-8,20,21] and satellite probes[9,22-25].

To determine the extent of accuracy of this linear regression curves, we calculated the standard error in getting the electron temperature, from the electron concentration value. The standard error for each regression curve for every year was obtained. The standard error in T_e was calculated by assuming T_e as dependent variable depending on N_e (and N_e as independent variable). For each year, electron temperature values were read from the regression curves for fixed values of electron concentration. As a result, we obtained T_e values for constant values of N_e, at various levels of solar activity. Fig. 2 shows a plot of T_e against years for different ranges of available electron concentration. The top curve of Fig. 2 shows the solar activity parameter which corresponds to annual average obtained from the daily values of 10.7-cm solar radio flux averaged over 3 solar rotations for various years.

It is clear from Fig. 2 that electron temperature is directly related to solar activity. As the averaged solar radio flux starts increasing from its value of 150 units during 1968, electron temperature for all the N_e ranges shows an increasing trend. Solar activity parameter $\langle F \rangle_{81\ \mathrm{day}}$ peaks during 1970 and so does T_e for all the N_e ranges. When $\langle F \rangle_{81\ \mathrm{day}}$ starts decreasing after 1970, T_e also shows decreasing trend towards 1971. Again during 1972 as $\langle F \rangle_{81-\mathrm{d}}$ increases, T_e also increases. Thus we see that as $\langle F \rangle_{81-\mathrm{d}}$ increased, T_e also increased and vice versa. Electron density values $\geq 8.0 \times 10^5$ cm^{-3} were not observed during 1973 and 1974 and thus T_e vatiations for these N_e values cannot be shown for these years in Fig. 2. We, however, note that during 1974, for $N_e \leqslant 6 \times 10^5$ cm^{-3}, T_e increases despite the decrease in $\langle F \rangle_{81-\mathrm{d}}$. This peculiar behaviour of T_e variation may not be real and is perhaps due to the smaller sample of data available during this particular period. As a matter of fact, standard error was quite large for regression curve for the year 1974.

The correlation between the F2-region T_e and the solar activity at fixed levels of N_e is very much consistent with theory. With increase in solar activity (i.e. solar ionizing flux) the photoelectron production rate and thus the heating rate increases, thereby increasing T_e. The electron temperature here is

Table 1 — Dates for using N_e and T_e data in Different Years during 1968-74

Month	1968	1969	1970	1971	1972	1973	1974
Jan.	16-17,23-24	16	6,20-21	12,20-21	26-27	2-3,17	—
Feb.	14,27-28	5,12,26-27	17,24	19	23-24	13-14	12-13
Mar.	26-27	26	17,24	9,31	9,24	19-20	—
Apr.	16-17,25-26	9,24	14,28	28	27	25	3,16
May	23	6,30	13,19	28	9-10,25-26,30	22-23	14
June	20-21	5,23	10,24	18	8-9,13-14,28,30	—	12
July	—	1,9,30	7,8,18	15,20,28-29	1,12-13,26-27	18-19	—
Aug.	15,27-29	14,27	18,24-25,31	20	7-8	7-8,14	—
Sep.	3-4,11-12,13,26	9,23,30	1,16,29	1,3,8,10,23	6-7,12-13	19-20	—
Oct.	4,8-9,22,29	15	6,14,31	26	3-4	16-17	2
Nov.	19,25,29	4,20	1,7-8	3	15-16	13-14	26
Dec.	12-13,17,30-31	8-9	22,29	23	6-7	—	20,27

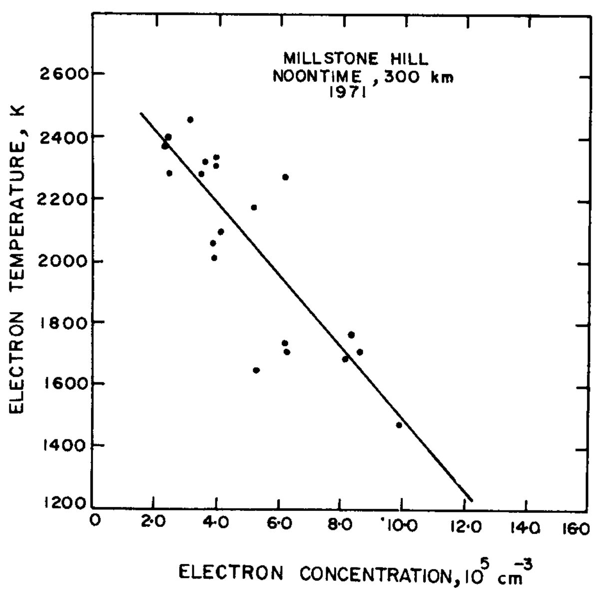

Fig. 1 — Scatter plot of noontime T_e against N_e at 300 km for the year 1971 showing strong negative correlation between N_e and T_e

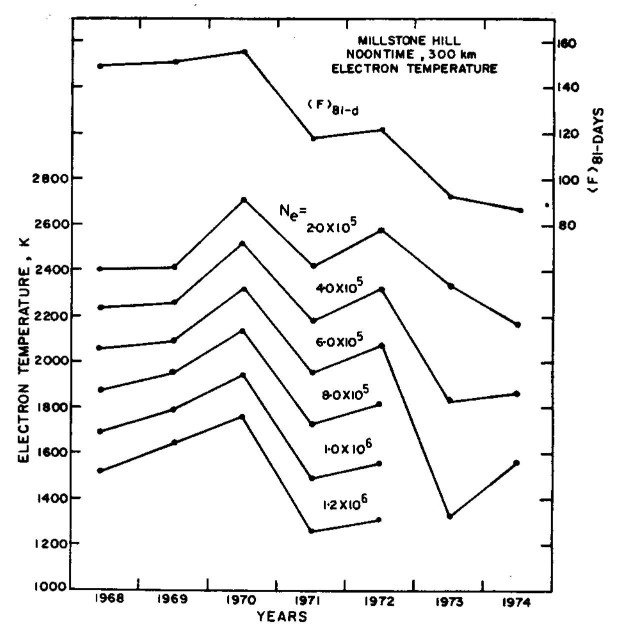

Fig. 2 — Plot of T_e against years for fixed values of N_e showing solar activity dependence of T_e

basically dependent upon the *local* heating rate. This is quite distinct from the topside T_e which is governed by *non-local* heating, i.e. by the heat flux conducted down from the protonosphere. This heat flux, however, has also been seen to increase with solar activity, thereby explaining the solar activity increase in T_e (Ref. 3).

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