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On the linear relationship between the Zurich Sunspot Numbers and the incident Solar Radio Radiation Flux at 10.7 cm

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ABSTRACT. The linear relationship between the solar radio radiation flux at 10·7 cm as measured at Ottawa and the Zurich sunspot numbers (R_z) is examined. The linear relationship between daily flux and sunspot activity has been found inadequate.

1. The decimetre radio radiation from the sun is composed of a quiet component and a slowly varying component. The slowly varying component is associated with sunspots and plages and varies in phase with solar activity (Covington 1959). Allen (1957) had segregated the slowly varying component by its regression on solar activity and determined the flux from the quiet sun. An important conclusion by Allen was that the quiet-sun background continuum had small but significant variation with solar activity. From a study of 26 radio regions of activity during relatively quiet solar period in 1952, Covington and Harvey (1960) observed that the total flux was composed of three components, the quiet-sun background, a component associated with sunspot groups and a third component from regions with no association with sunspots. The radiation from regions associated with sunspots again consisted of two components, one dependent on sunspot area, and other independent of it. Das Gupta and Basu (1964) examined the effect of the orbital eccentricity of the earth on the solar radio radiation flux at 10·7 cm as measured at Ottawa. They determined the quiet component by extrapolating to zero sunspot activity the close fitting straight line through the plot of mean monthly total solar flux values and mean monthly Zurich sunspot numbers for each of the twelve months in the year over the entire solar cycle, 1949-59. They noted that the incident solar radio radiation flux at 10·7 cm in the month of July was less than that in January by 7·6 per cent which agreed with the reduction figure of 7·5 per cent for peak electron density of the E-layer obtained by Appleton (1963). An examination of the linear relationship between the solar radio radiation flux at 10·7 cm as measured at Ottawa and the Zurich sunspot number (R_z), using the daily as well as the monthly mean data for the period 1955-65, is attempted here.

2. The data are taken from the *Quarterly Bulletins of Solar Activity* from Zurich. The flux values on days when there was no observation are interpolated. The monthly mean values of flux and sunspot numbers for 1966 are also used. Provisional values of Zurich sunspot numbers have been used for 1966.

3. The correlation coefficient (C.C.), the linear regression equation as well as the standard deviations of both the daily flux values and the sunspot numbers for each of the 132 months are computed. To average out the variation due to solar rotation, 27-day running mean daily values of the flux and the sunspot numbers are calculated and the correlation coefficient, the linear regression equation and the standard deviations are computed with these mean daily values. All the computations were carried out on the CDC-3600 computer at the Tata Institute of Fundamental Research, Bombay.

4. While correlation coefficient (C.C.) between daily values of R_z and flux has not been found negative, it varies between wide limits, *e.g.*, from 0·98 in November 1958 to 0·00 in June 1965. Even during high solar activity it can be as low as 0·17 (February 1957) and during low solar activity as high as 0·95 (May 1965). The C.C. is fairly consistent and high only for $50 > R_z > 20$. For $R_z < 20$ the C.C. falls off very rapidly and for $R_z > 50$, the scatter is very considerable.

4.1. The slope of the regression line is dependent on sunspot number for $40 > R_z > 0$. Beyond this the slope shows a heavy scatter with R_z.

4.2. The intercept or flux reduced to zero R_z shows very high scatter beyond $R_z > 50$. Thus the linear relationship between daily flux and sunspot activity $F = F_0 + KA$ (where F_0 is the total flux, F_0 the basis quiet-sun component and KA, the component dependent on sunspot

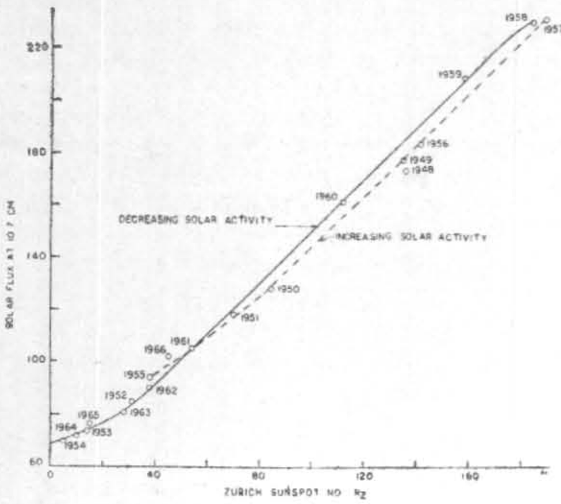

Fig. 1. Variation of the quiet-sun component of solar radio radiation flux at 10·7 cm represented by the intercept of the regression line of monthly mean Zurich sunspot numbers over the period February 1947 to August 1966

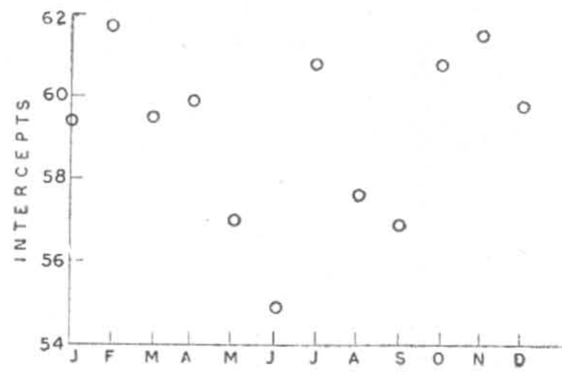

Fig. 2. The relation between the yearly mean solar radio radiation flux at 10·7 cm and the yearly mean Zurich sunspot numbers

areas or number) has been found inadequate as noted by Covington and Harvey (1960).

5. Considering the years 1955 to 1957 and 1966 as years of increasing solar activity and the years 1950, 1951, 1960 to 1962 as years of decreasing solar activity, the regression equations of the monthly mean values of flux on the monthly mean values of R_z are derived separately for the two periods. It is observed that the spot-free solar radiation at 10·7 cm is lower for the period of declining solar activity, *viz.*, 55 units as compared to that for the period of increasing solar activity, *viz.*, 61 units. But the rate of increase of flux with R_z is slightly higher for the period of declining solar activity than for the period of increasing solar activity, the slope being 0·918 and 0·882 respectively.

6. Regression equations between monthly mean values of flux and corresponding monthly mean sunspot numbers for each of the twelve months over the period February 1947 to August 1966 are devived. The data from February 1947 to June 1958 are taken from Appendix IV of the paper by Minnis and Buzzard (1959). Considering the intercept of flux by the regression line as the quiet-sun component of flux, Das Gupta and Basu (1964) had shown the existence of the effect of earth's orbital eccentricity on flux. However, from more precise computed values shown in Fig. 1, it is seen that there is an unexpectedly large increase in the intercept for the month of July and a reduction in December-January, indicating that the effect of earth's orbital eccentricity is not very definite.

7. Yearly mean values of solar flux are plotted against yearly mean sunspot numbers in Fig. 2. It is readily seen that for R_z greater than 100, the solar flux at 10·7 cm is greater by about 6 to 7 units during the declining part of the solar cycle than during the ascending part of the cycle. During the beginning of new solar cycles, *viz.*, 1955 and 1966 the flux is about 5 units more than the average for the sunspot number at that part of the cycle. In other words the emissive regions, both associated with sunspots and those not associated with sunspots, are brighter or larger

during the period of declining activity and during a period about a year at the beginning of a new cycle. For $50 < R_z < 100$, the difference is progressively less and for R_z less than 50 the flux is same during the two parts of the solar cycle. The assumption of constancy of quiet-sun background underlies this explanation. However, a plot of intercept against R_z shows considerable scatter, using the daily values of flux and R_z. This leads to a doubt about the constancy of the quiet-sun background.

8. Using the 27-day running means of daily values of solar flux and Zurich sunspot numbers, the scatter in the daily values of both is considerably reduced as observed by Nicolet (1963) and the correlation is improved. However, negative correlations have been observed during some months : the negative C.C. for April 1965 is as high as 0·85. The method of separation of the quiet-sun component by the linear regression method has again been observed to be inadequate with the 27-day running mean daily values of solar flux and sunspot number.

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