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SHORT PAPER

ON THE VARIABILITY OF LYMAN-ALPHA WITH SOLAR ACTIVITY

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ABSTRACT

After taking into account the changes in the calibration, or in the sensitivity, of the instruments used to measure solar irradiance of Lyman-alpha, a critical analysis leads to the following expression for the relation between the Lyman-alpha irradiance and the solar flux at 10.7 cm:

$$I(\text{Lyman-alpha}) = 2.5 \times 10^{11} + 0.011\ (F - 65) \times 10^{11} \text{ photons cm}^{-2} \text{ sec}^{-1}$$

with a correlation coefficient $R = 0.91$ and a standard deviation $D = 0.25$. The limitations in the absolute calibration of the instruments mean that the values deduced from this expression have an accuracy of $\pm$ 25%; the irradiance for a perfectly quiet Sun is $(2.5 \pm 0.5) \times 10^{11}$ photons cm^{-2} sec^{-1}.

The role of Lyman-alpha (121.567 nm) in the chemistry of the atmosphere has been recognised for several years. In fact, this radiation is responsible for the formation of the D region of the ionosphere (Nicolet, 1945) and is important in the mesospheric photodissociation processes involving O_2, CO_2 and especially H_2O (Nicolet, 1981). The intensity of this radiation is of the same order as that of all the other solar radiation at wavelengths less than 150 nm; hence it is appropriate to examine its characteristics in detail and, in particular, its strong dependence on the level of solar activity. Since the numbers of observations of Lyman-alpha are much greater than those of other solar radiations, the data available can be subject to a more than usually critical analysis. Reference may be made to the study of the collected observations of the irradiance of Lyman-alpha made by Vidal-Madjar (1977).

This study illustrates clearly the difficulties in arriving at an absolute value for the irradiance of Lyman-alpha of better than 25% although,

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for short-term variations such as the 27-day cycle, the precision may reach ± 5%. Thus the two major problems in analyses of this kind are the determination of the absolute value of the irradiance, and of the variation with time of the sensitivity of the measuring instruments.

By making use of the various measurements made by rockets between 1955 and 1966, Weeks (1967) has already shown that the variation from about 2.5×10^{11} to 4×10^{11} photons cm^{-2} sec^{-1} could be attributed to an increase in solar activity. However, the much greater numbers of observations made using satellites (Woodgate et al., 1973 ; Vidal-Madjar, 1975 ; Vidal-Madjar and Phissamay,1980 ; Hinteregger, 1980) indicate more clearly the variations in irradiance corresponding to the 27-day and the 11-year cycles of solar activity. Quite apart from the difficulty of ensuring the absolute calibration of the instruments, there is the additional problem of trying to assess the changes in the sensitivity of the instruments over a number of years. For example, Vidal-Madjar (1975) assumed that the sensitivity of the instrument in OSO-1 decreased by 10% per year from 1969 to 1972, that there was no change during the period of 1.7 years when the instrument was not in use, and that there was a further decrease in sensitivity from 1974 to 1975.

The detailed discussion of the observations made in satellite AE-E (Hinteregger, 1980 a, b, and tables received by the authors from Hinteregger, 1981) show how important it is to make corrections in an attempt to obtain a correct estimate of the absolute value of the irradiance of Lyman-alpha. The long-term decrease in the sensitivity of the measuring instrument poses a major problem. Comparisons of such data observations made using rockets (Rottman, 1980) bring to light differences which can be explained only by systematic errors, and which cannot be neglected. The introduction into the analysis of theoretical considerations (Tousey, 1963 ; Cook et al., 1980) which take account of all the observations provides another approach to the solution of the problem.

It is important to note that the observations of ultraviolet irradiance made by Hinteregger (1979) lead to higher values for Cycle 21 than for Cycle 20. The author adds that this increase is not matched by corresponding increases in the sunspot number or in the solar flux at 10.7 cm or, in consequence, in thermospheric densities and temperatures. It is for this reason that we have decided to try bring some homogeneity into the observational data.

The analysis begins with the bringing together of the observations of Lyman-alpha irradiance made by satellites OSO-1 and AE-E between 1969 and 1980 (Figure 1). This figure illustrates the relation between the variations in the observed values of Lyman-alpha and of 10.7 cm flux. The data represent four series of observations :

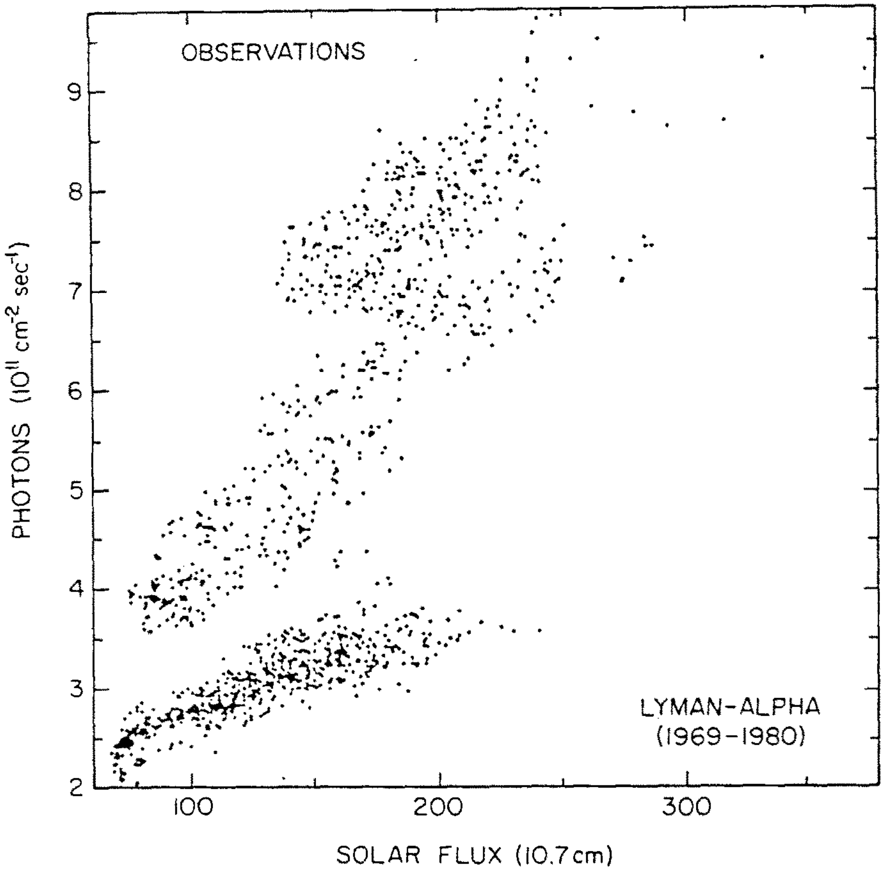

FIGURE 1.- Irradiance of Lyman-alpha between 1969 and 1980 (uncorrected) plotted as a function of solar flux at 10.7 cm.

(a) Vidal-Madjar (1975): 496 observations between 25 Januari 1969 and 18 December 1972;

(b) Vidal-Madjar and Phissamay (1980): 121 observations between 9 October 1974 and 11 August 1975;

(c) Hinteregger (1980a, b): 260 observations between 3 June 1977 and 21 December 1978;

(d) Hinteregger (1980a, b): 529 observations between 3 Januari 1979 and 31 December 1980.

As can be seen, the values of irradiance can be divided into three main groups: a lower including series (a) and (b), an intermediate group for series (c) and an upper group for series (d).

A statistical analysis of the data in Figure 1 leads to the following relations for Lyman-alpha irradiance (I) as a function of 10.7 cm flux (F): for series (a) and (b):

$$I = 2.44\ (1 + 0.0037\ (F - 65)) \times 10^{11} \text{ photons cm}^{-2} \text{ sec}^{-1} \qquad (1)$$

with a correlation coefficient $R = 0.86$, standard deviation $D = 0.19$, number of observations $N = 617$, and maximum flux $F = 220$;
for series (c), for values of F not exceeding 220:

$$I = 3.61\ (1 + 0.0045\ (F - 65)) \times 10^{11} \text{ photons cm}^{-2} \text{ sec}^{-1} \qquad (2)$$

with $R = 0.79$, $D = 0.39$, $N = 260$;
for series (c) and (d), with F maximum = 375:

$$I = 3.79\ (1 + 0.0063\ (F - 65)) \times 10^{11} \text{ photons cm}^{-2} \text{ sec}^{-1} \qquad (3)$$

with $R = 0.78$, $D = 0.93$, $N = 789$, and
for all four series:

$$I = 2.2\ (1 + 0.0141\ (F - 65)) \times 10^{11} \text{ photons cm}^{-2} \text{ sec}^{-1} \qquad (4)$$

with $R = 0.75$, $D = 1.34$, $N = 1406$.

In series (a), Vidal-Madjar (1975) introduced an instrumental drift of 10% per year; this reduces D to 0.19 in Equation (1), as compared with $D = 1.34$ in Equation (4), and illustrates the importance of effects other than solar activity.

Since the period of about 4400 days covered by the observations includes a sufficiently large number of values (1406), it is possible to group them according to several levels of solar activity. In Figure 2, they have been separated into seven classes corresponding to the following levels of solar flux at 10.7 cm: 65 - 80, 80 - 100, 100 - 120, 120 - 140, 140 - 160, and more than 180 units (1 unit = 10^{-22} W m^{-2} Hz^{-1}, National Research Council, Canada).

For each class c, the irradiance has been expressed in a modified form $I_c(t)$ defined in terms of the solar flux at 10.7 cm at time t:

$$I_c(t) = I(t) - 20 + 50 \left\lfloor \frac{F(t) - 60}{20} \right\rfloor \qquad (5)$$

where the irradiance is expressed in units of 10^{10} photons cm^{-2} sec^{-1}, $I_c(t) = 0$ at $I(t) = 2 \times 10^{11}$ photons cm^{-2} sec^{-1}, and $\left\lfloor \frac{F(t) - 60}{20} \right\rfloor$ is the greatest integer lower or equal to $\frac{F(t) - 60}{20}$.

The results of this analysis are shown in Figure 2, and it can be seen that for $t < 2000$, i.e. the results of Vidal-Madjar (1975) corrected for a 10% instrumental drift, almost horizontal straight lines are obtained.

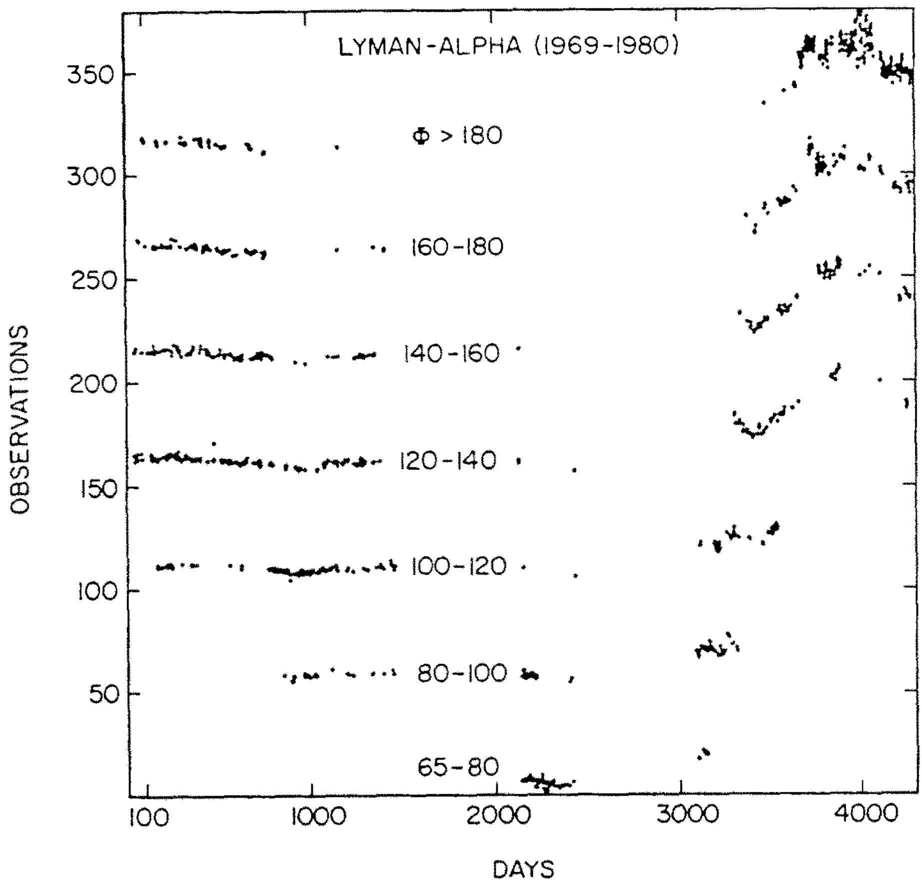

FIGURE 2.- The irradiance values of Figure 1 regrouped into seven classes defined by the levels of 10.7 cm flux, and plotted as a function of days from 1 Januari 1969 (1) to 31 December 1980 (4383).

On the other hand, for $t > 3000$, i.e. for Hinteregger's data, there are various departures from the horizontal during periods of several hundred days.

The ideal objective would be to transform the various "curves" in Figure 2 into horizontal straight lines. In practice, a method based on periods of about 150 days, containing at least 50 observations, leads to an almost ideal result. As can be seen from Figure 3, the departures from the horizontal that were visible in Figure 2 have almost disappeared; the few that remain could probably be reduced if shorter time intervals were used. The results of this procedure for increasing the coherence of the measurements of Lyman-alpha over a period of 11 years can, therefore, be regarded as satisfactory.

The final result is shown in Figure 4, which is the counterpart of Figure 1. The relation between I and F is:

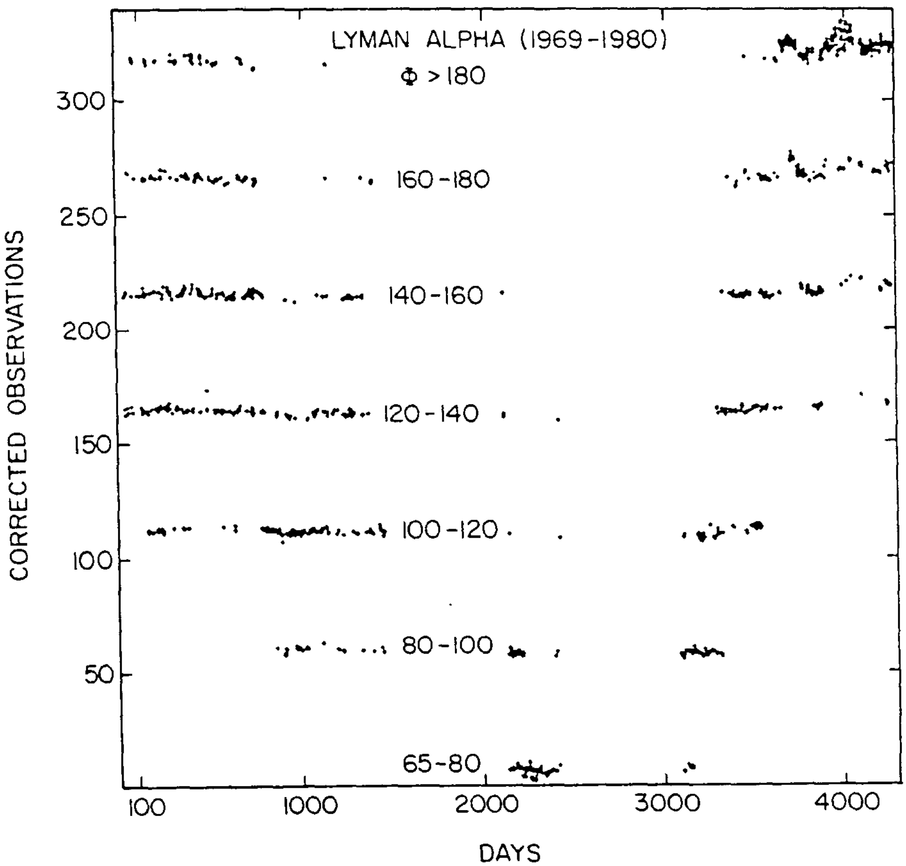

FIGURE 3.- The irradiance values of Figure 2 after modification to increase their homogeneity.

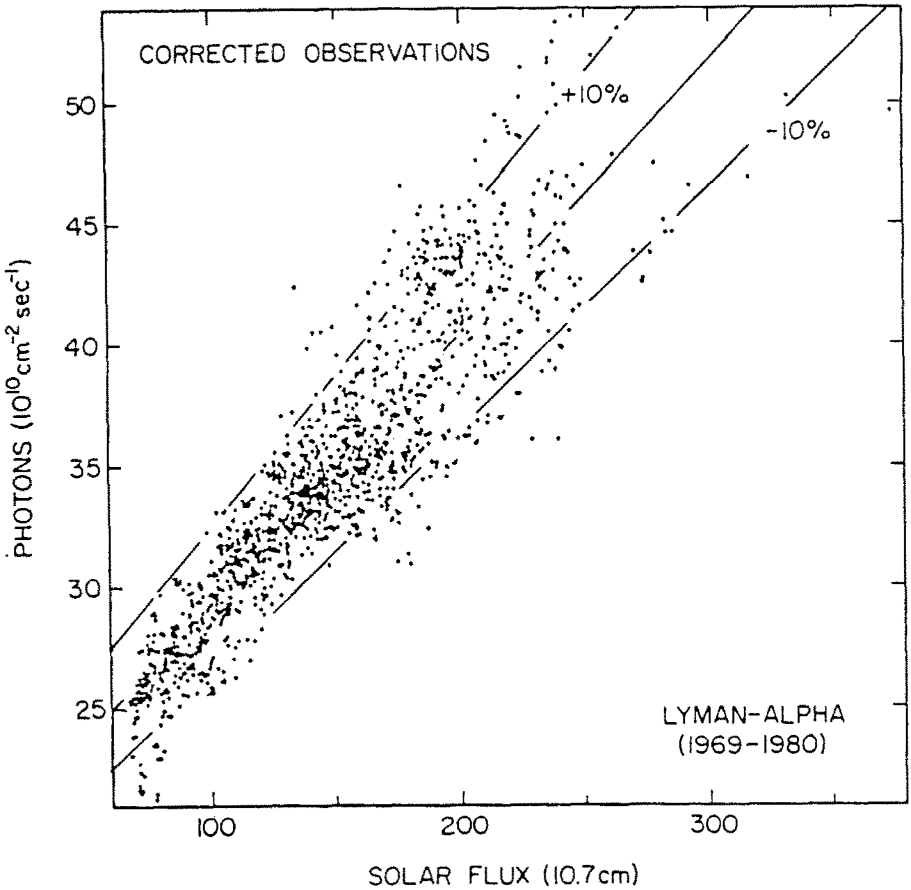

FIGURE 4.- Irradiance of Lyman-alpha plotted as a function of solar flux at 10.7 cm as in Figure 1, but after correction for changes in the sensitivity of the measuring instruments.

$$I = 2.55 \times 10^{11} + 0.011\ (F - 65) \times 10^{11}\ \text{photons cm}^{-2}\ \text{sec}^{-1}$$

with R = 0.91, D = 0.25, N = 1406. Because of the uncertainty about the absolute calibration, it is important to remember that the absolute values of irradiance cannot be expressed with an accuracy better than 25%, even though the lines in Figure 4 indicating departures of $\pm$ 10% show that the correlation between Lyman-alpha and 10.7 cm flux is good.

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