550.38 : 523. 746

Solar control of the Quiet-Day range in *H* at Alibag for the period 1905-1960

A. YACOB

Colaba Observatory, Bombay

(*Received 17 May 1965*)

ABSTRACT. The degree of direct relationship between the quiet-day range in H at Alibag and solar activity as depicted by sunspot number is examined for the period 1905 to 1960. Coefficients of correlation and linear regression equations for the two parameters are given for the monthly mean values as well as the yearly mean values. The coefficients of correlation obtained for the monthly mean values range from $+0\cdot79$ to $+0\cdot91$, while that for the annual mean values is $+0\cdot98$. The linear regression equation for the annual mean values is $YH_q r = 31\cdot5\,(1+0\cdot007\ YR)$ in γ, where $YH_q r$ is the annual mean quiet-day range in H and YR is the annual mean sunspot number. The coefficient of YR obtained for Alibag for the period 1905 to 1960 is comparable with earlier results of other workers.

The annual variation of the coefficients a, b and their product ab in the linear relation $MH_q r = a\ (1+bMR)$, where $MH_q r$ is the monthly mean quiet-day range in H and MR the monthly mean sunspot number, are examined and discussed.

1. Introduction

Several studies have been made on the sun-spot cycle variation of the quiet geomagnetic diurnal ranges. A summary of the earlier work is given by Chapman and Bartels (1940). However, most of the relationships derived between solar activity and diurnal ranges of magnetic elements H, Z or D are based on records of about 10 years. Even Allen (1946), in his detailed study of the subject, has used data of only seven years. An exception to this is the recent study by Appleton (1964), where a series of monthly values of the quiet-day range in the geomagnetic Y component over the years 1938—1959, relating to SE England have been used. So far as the data for the Indian region is concerned there have been only two studies so far. The first is by Chree using Bombay data over the years 1894 to 1901 and the second by Moos (1910) who studied Bombay data and obtained the linear equation connecting the annual mean smoothed summed ranges (sum of the 24-hourly inequalities without regard to sign) in H and sunspot number :

$$\text{Summed range} = 205\ (1+2\cdot22\,R)$$

As most of the studies have been based on data for short periods, often less than a sunspot cycle, it is considered interesting and valuable to examine the relation between the long and homogeneous series of H at Alibag (Geog. Lat. 18° 38′N, Long. 72°52′E, Geomag. Lat. 9·5°N, Long. 143·6°) and sunspot number over a period of five sunspot cycles (1905—1960). The extent of the monthly and annual relationships has been examined and compared with the results of earlier similar studies. Incidentally the annual variations of the average monthly quiet-day range in H and of the monthly coefficients in the linear relation between diurnal range in H and sunspot number are also examined and discussed.

2. Data and Results

The geomagnetic horizontal component H has a large quiet-day range at Alibag and hence this element has been selected for the present study. The period of data used is 1905 to 1960. The monthly mean quiet-day range in H, ($MH_q r$), is obtained by averaging the hourly values of the five international quiet days during the particular month, correcting the average hourly values for non-cyclic change and then taking the difference between the highest and lowest average hourly values. The annual mean range, ($YH_q r$) is obtained similarly by averaging all the international quiet days during the particular year. The monthly and annual mean relative sunspot numbers, (MR and YR) have mostly been taken from the compilation by Chernosky and Hagan (1958).

The correlation coefficient (C. C.) between $MH_q r$ and MR for each month of the year is shown in Table 1. In the same table, the C. C. between $YH_q r$ and YR is also shown. The C.Cs. are positive and very highly significant statistically. For the annual values the regression is

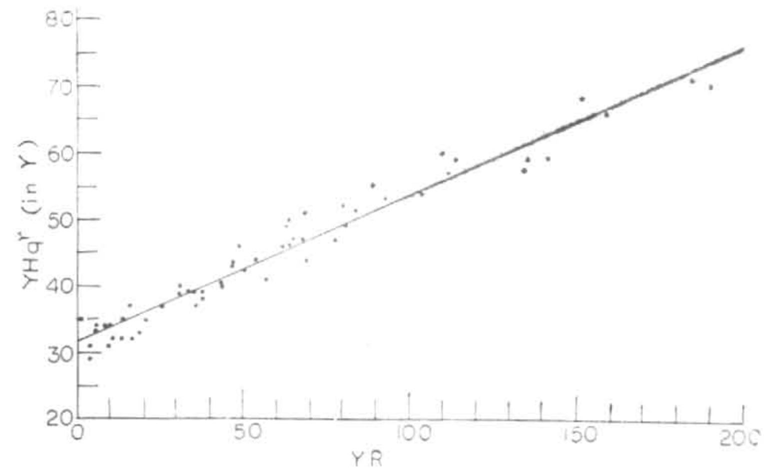

Fig. 1. Plot of yearly mean quiet-day in H, ($YH_q r$), at Alibag against yearly mean relative sunspot number (YR), for the years 1905 to 1960. The straight line fitting the data is $YH_q r = 31.5\,(1+0{\cdot}007\,YR)$

TABLE 1

Coefficients of correlation between the average quiet-day range in H at Alibag and the average sunspot number for the period 1905 to 1960

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
+0·79	+0·86	+0·87	+0·87	−0·85	−0·88	−0·82	−0·91	+0·88	+0·82	+0·81	+0·81	+0·98

TABLE 2

Coefficients a and b in the linear relationship, Range$=a\,(1+bR)$, between the average quiet-day range in H at Alibag and the average sunspot number for the period 1905 to 1960. The average monthly quiet-day range in H and the average sunspot number for the period are also shown

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
a in gamma	24·2	30·4	40·6	43·1	34·6	36·3	38·3	30·8	30·5	38·7	35·5	25·6	31·5
$b\times10^4$	80	72	58	55	72	62	49	71	75	52	51	58	70
Average quiet-day range in H, ($MH_q r$)	25·3	43·0	54·1	56·9	49·7	50·0	50·0	44·9	44·8	50·6	46·1	24·3	
Average sunspot number	57	57	7	59	60	61	62	64	62	59	59	59	

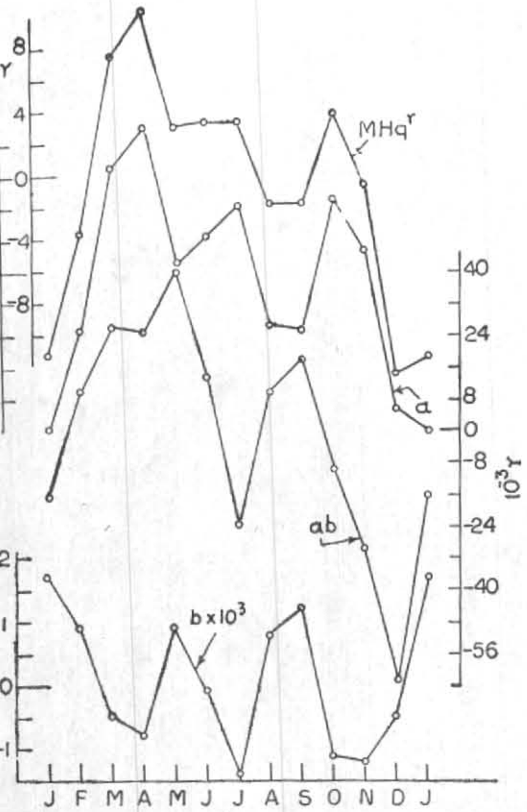

Fig. 2. Annual variations of (1) the average monthly mean quiet-day range in H, ($MH_q\ r$), at Alibag and (2) the coefficients, a, b and their product ab in the linear regression equation between $MH_q\ r$ and monthly mean relative sunspot number (MR)

about linear with a high C.C. of $+0 \cdot 98$. This high degree of direct correspondence between the two parameters may also be noticed in Fig. 1, where plot of $YH_q\ r$ against YR is exhibited.

Linear regression equations of the form $MH_q\ r = a\ (1+bMR)$ are obtained for each month of the year and the values of the coefficients a and b arrived at are shown in Table 2. The relation $YH_q\ r = a\ (1+bYR)$ is also derived and the respective values of the constants are given in Table 2. In the same table are also shown the average values of $MH_q\ r$ and MR (average of 56 values).

Annual variations depicted by the monthly coefficients a, b and their product, ab, as well as the average values of $MH_q\ r$ are shown in Fig. 2.

3. Discussion

Examination of the monthly mean and yearly mean quiet-day ranges of the element, H, of Alibag for the continuous series of years 1905 to 1960 has clearly shown a very good measure of dependence of the parameter on the level of solar activity, as measured by the relative sunspot number. The C.Cs. for the different months of the year range from $+0 \cdot 79$ to $+0 \cdot 91$ while that for the year is $+\ 0 \cdot 98$. The solar-cycle control of the quiet-day range in H is necessarily through the medium of the ionosphere, the intensity of ionization and, therefore, also the conductivity of which are known to have a systematic direct correspondence with solar activity (Allen 1946, Scott 1952, Saha 1953, Ratcliffe and Weekes 1960, Appleton 1964 and Noonkester 1964), signifying an increase in the intensity of solar ultra-violet radiation with increase in solar activity. The linear relationship arrived at between solar activity and the quiet-day range in H indicates that for Alibag the value of $YH_q\ r$ for an ideal year of no sunspots is $31 \cdot 5\ \gamma$ and the additional contribution to this range with increasing sunspots is of the order of $2 \cdot 2\ \gamma$ for an increase of 10 in the number of sunspots. The rate of increase in $YH_q\ r$ for the lower range of solar activity is, however, slightly greater than that for the upper range of solar activity. Thus for the range of annual mean sunspot numbers 0 to 50 the increment to $YH_q\ r$ works out as $2 \cdot 4\gamma$ for an increase of 10 in sunspot number, while for the ranges of sunspot number 50 to 200 and 100 to 200 the corresponding increments are respectively $2 \cdot 0\gamma$ and $1 \cdot 8\ \gamma$ for the same increase of 10 in sunspot number.

For purposes of comparison the coefficient, b, in the linear regression equation between sunspot number and quiet-day range in H obtained by different workers are given below—

Investigator	Period	Station	Coefficient $b \times 10^4$
Chree (as reported by Chapman and Bartels 1940)	1890-1900 1889-1899 1894-1901	Povlosk Kew Bombay	94 104 89
Allen (1946) (relative Sq amplitude based on H, D and Z)	1937-1943	Apia, Watheroo and Cape Town	78
Yacob	1905-1960	Alibag	70

Appleton (1964) gives the value of 39×10^{-4} for b in the linear equation in respect of sunspots and the quiet-day range in the magnetic element Y at Abinger and Hartland, while Moos (1910), using annual mean smoothed summed ranges (sum of the 24 hourly inequalities without regard to sign) in H gives it the value $2 \cdot 22$. The parameters chosen for study by these two investigators are different from that used in the present study and therefore, their results are not directly comparable with those listed above. It may be seen that except for the value given for Kew the coefficient, b, for the other stations compare reasonably well with each other, even though the periods of investigation and the stations are different. The value for Alibag has been arrived at with a fairly long series of years. It should, therefore, be considered a typical index of the solar-cycle control of the quiet-day range in H.

It may be seen in Fig. 2 that the annual variations of the coefficient, a, and the average $MH_q\ r$ are strikingly similar with equinoctial maxima. This similarity has to be expected, since both represent practically the same parameter: $MH_q\ r$ represents average monthly quiet-day range for solar activity corresponding to mean monthly sunspot of about 60, while the coefficient, a represents the same range for a level of solar activity appropriate to zero sunspot number. The product of the coefficients, ab, gives the specific increment in the average quiet-day range with increase in solar activity. The annual variation of ab is somewhat different from those of $MH_q\ r$ and a. Clear predominance of a six-monthly variation with equinoctial maxima is depicted. The annual variation of the coefficient, b, however, does not indicate equinoctial maxima. In fact the tendency is to depict equinoctial minima.

The equinoctial maxima seen in the annual variation of $MH_q\ r$ and the coefficient, a are usually accounted for by the assumption that some residual magnetic disturbance effects are still present in the quiet-day ranges of H. The magnitude of disturbance is known to exhibit equinoctial maxima and, therefore, its presence in the mean quiet-day values tends to produce equinoctial maxima in $MH_q\ r$ as well as in the coefficient, a. The prominent semi-annual variation of the product, ab, with clear equinoctial maxima does indeed support this explanation. The coefficient, b, which is the relative contribution to the quiet-day range by solar activity, *i. e.*, the increment due to solar activity when the range is unity, however, depicts an entirely different type of annual variation. Equinoctial maxima are not observed. Geomagnetic disturbance being known to have direct correspondence with solar activity, and to have equinoctial maxima, the absence of equinoctial maxima in the annual variation of b signifies that contamination by disturbance may not be the entire explanation to the phenomenon of equinoctial maxima in $MH_q\ r$. The cause could well be inherent in the pure Sq itself. According to the atmospheric dynamo theory the magnitude of the quiet-day geomagnetic variation is dependent on the product of the conductivity of the appropriate ionospheric layer and the prevailing dynamo electric field. This product may attain maximum magnitudes during the equinoxes if as suggested by Appleton (1964), the two contributing factors, namely ionization of the conducting layer and atmospheric tidal oscillations are more nearly in phase at the equinoxes than at the solstices. The phenomenon of equinoctial maxima in $MH_q\ r$ or the coefficient, a, is probably the combined result of a cause inherent in the pure Sq itself and the effect of its contamination by geomagnetic disturbance.

4. Acknowledgement

The author thanks Shri K. N. Rao and also his colleagues at Colaba for useful comments.

REFERENCES

Allen, C. W. 1946 *Terr. Magn. atmos. Elect.*, **51**, 1.

Appleton, E. V. 1964 *J. atmosph. terr. Phys.*, 26, 633.

Chapman, S. and Bartels, J. 1940 *Geomagnetism*, **1**, Clarendon Press, Oxford.

Chernosky, E. J. and Hagan, M. P. 1958 *J. geophys. Res.*, **63**, 775.

Moos, N. A. F. 1910 Magnetic Observations made at the Government Observatory, Bombay for the period 1846 to 1905 and their Discussion, Part II, The Phenomenon and its Discussion.

Noonkester, V. R. 1964 *J. atmosph. terr. Phys.*, **26**, 965.

Ratcliffe, J. A. and Weekes, K. 1960 *Physics of the Upper Atmosphere*, Ed. J. A. Ratcliffe, Academic Press, New York and London.

Saha, A. K. 1953 *Indian J. Phys.*, **27**, 431.

Scott, J. C. W. 1952 *J. geophys. Res.*, **57**, 369.