

Solar Control of the Annual Variation of the Quiet-day Horizontal Component of Geomagnetic Force

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ABSTRACT. The predominant component of the mean annual variation of H_q for Alibag for the period 1904 to 1958 is the 12-monthly component. For Huancayo, for the period 1923—1946 it is the 6-monthly component which is found to be predominant. This difference is accounted for by considering the annual variation of H_q as a consequence of the superposition of S_q on H_q . Huancayo being much closer to the geomagnetic as well as the geographic equators than Alibag, the variation in the course of a year of the intensity of the ionospheric S_q current circuits will largely be a semi-annual feature for Huancayo, while for Alibag this variation will largely be an annual feature.

While the amplitudes of the 12-monthly components of individual years show very little correspondence with sunspot numbers, the amplitudes of the 6-monthly components show appreciable correspondence with sunspot numbers. To explain this feature the variation in the heliographic latitude of the earth, in the course of the year, coupled with the emanation of short-wave radiation of high ionization potential from solar active regions, which are known to form two average belts 10° — 15° N and S of the solar equator, is suggested in the preference to the incidence of disturbance on H_q , since the dates of maxima of the 6-monthly component for years of high sunspot numbers are found to be closer to the equinoctial months.

1. Solar control of many of the geomagnetic variations is well known. The precise control by the sun of the annual variation of the quiet-day geomagnetic force has, however, remained vague (van Wijk 1953, Lewis *et al.* 1955). The present investigation is an attempt to examine the nature of the solar influence in the annual variation of the geomagnetic force.

2. The annual variation of the quiet-day horizontal component H_q of the geomagnetic force at Alibag (Lat. 19° N, Long. 73° E) for the period 1904 to 1958 is derived, after correcting for the secular change, and harmonically analysed (1) for each of the years, (2) for the period as a whole, (3) for years of high sunspot number and (4) for years of low sunspot number. The quiet days selected are the five international quiet days of each month. The analysis is also done for the annual variation of H_q for Huancayo (Lat. 12° S, Long. 75° W) for the period 1923—1946 (limited by the availability of data) for a comparative study.

3. In Fig. 1 are shown the harmonic dials for the 12-monthly I_a and the 6-monthly I_b components of the annual variation of H_q at Alibag for each year, wherein are indicated the amplitude and the date of maximum of the respective component. Though there is some concentration of the points about the summer months, a good deal of scatter is in evidence. The reason for this is twofold; firstly because of irregularities in the secular change in H_q and secondly because the mean monthly values of H_q (used for the derivation of the annual variation) being based on the five I_q days, are not exactly centred in the middle of the months. To settle whether there is any systematic annual variation of H_q , the ratio $\sigma_m : \sigma/\sqrt{N}$ (N , here is equal to 55) is computed, where σ_m is the standard deviation derived from the average monthly mean H_q (averaged over the 55 years) and σ is the standard deviation derived from each individual year by computing the departures of the 12-monthly mean H_q from their respective mean of the year (*i.e.*, σ is derived

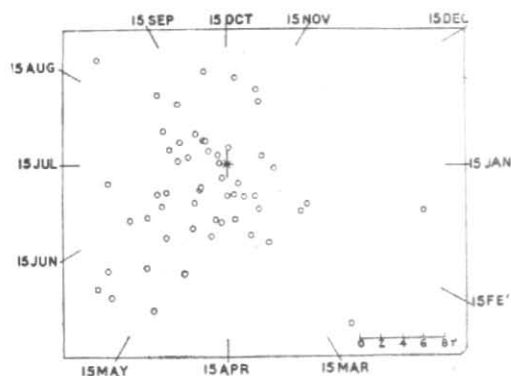


Fig. 1 (a). Harmonic-dial of the 12-monthly components for Alibag during 1904-1958

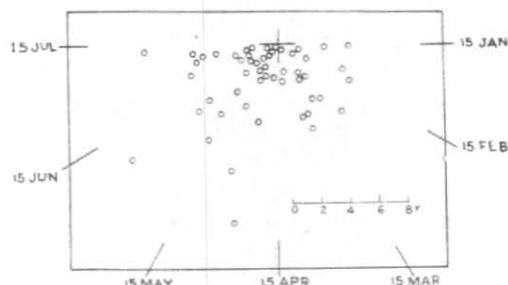


Fig. 1(b). Harmonic-dial of the 6-monthly components for Alibag during 1904-1958

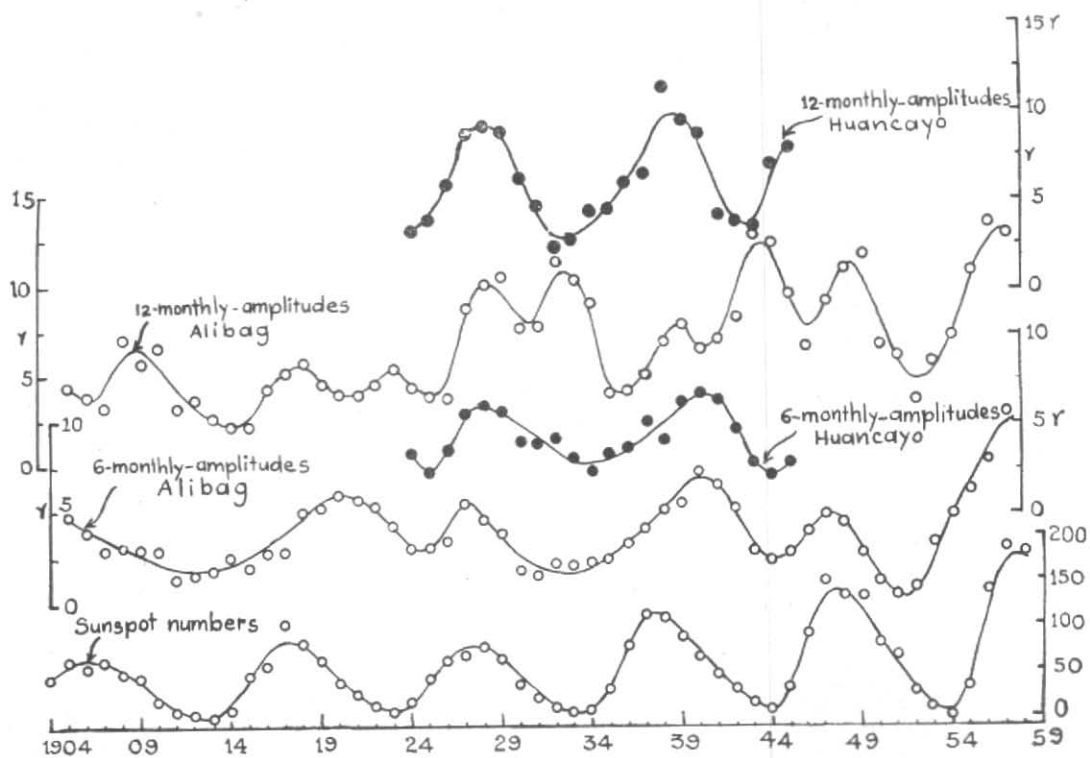


Fig. 2. Mean relative sunspot numbers and amplitudes of 12-monthly and 6-monthly components of annual variation of H_g for Alibag (1904-58) and Huancayo (1923-46)

The amplitude have been smoothed by taking running 3-year mean

from 12×55 departures). Physical reality of the annual variation is indicated if the ratio is greater than 1. In this case for the 55-year period considered, the ratio $\sigma_m : \sigma/\sqrt{55}$ works out to $1.76 : 1$ and hence it may be concluded that, in spite of the scatter seen in Fig. 1, the annual variation of H_q is a significant physical reality.

4. The results of harmonic analysis of the mean annual variation of H_q for the period 1904 to 1958 as well as those for years of high sunspot numbers and for years of low sunspot numbers are given in Table 1. Results for Huancayo for the period 1923-1946 are also given in the table. The following may be noted from the table—

- (a) For Alibag the most predominant component is the 12-monthly component;
- (b) For Huancayo predominance of the 6-monthly component is indicated, as seen from the results of all years;
- (c) For both Alibag and Huancayo a small increase in the amplitude of the 12-monthly component from years of low sunspots to years of high sunspots is seen. But this increase is too small to be of any significance; and
- (d) For both Alibag and Huancayo the amplitude of the 6-monthly component for years of high sunspots is double the amplitude of the same component for years of minimum sunspots.

5. To examine further the relationship between sunspots and the amplitudes of the 12-monthly component and the 6-monthly component, the amplitudes for each of the 55 years for Alibag are plotted together with mean relative sunspot numbers in Fig. 2. The amplitudes of the 12-monthly component show very little correspondence with sunspots. On the other hand, there appears to be a greater measure of correspondence between

the amplitudes of the 6-monthly component and sunspots. The statistical correlation coefficient between the amplitudes of the 12-monthly component and sunspot numbers is only $+0.27$. In the case of the 6-monthly component the coefficient of correlation is $+0.53$.

6. In the case of Huancayo the plot of the amplitudes of the 12-monthly and the 6-monthly components (Fig. 2) show that both the components have some measure of correspondence with sunspot numbers. Since, as seen in 4(c), the average 12-monthly component does not show appreciable difference in amplitude for the high and low sunspot years, it has to be concluded that this component has a large phase variation and therefore the correspondence shown with sunspot numbers is not significant. Significance can be attached only to the correspondence between the amplitudes of the 6-monthly component and sunspot numbers, as seen in the case of Alibag.

7. From the foregoing analysis the following results emerge—

- (a) For Alibag the mean annual variation of H_q is predominantly a 12-monthly feature while for Huancayo it is predominantly a 6-monthly feature.
- (b) Solar activity has almost no influence on the 12-monthly component of the annual variation of H_q .
- (c) Some measure of influence by solar activity on the 6-monthly component of the annual variation of H_q is in evidence.

8. The finding in 7(a), is understandable when the cause of the annual variation of H_q is considered to be the superposition of $S_q(H)$ on the horizontal component of the geomagnetic force. The current flow in the ionospheric current circuits, which are responsible for the geomagnetic S_q variations, is known to fluctuate with the declination

TABLE 1
Results of harmonic analysis of the annual variation of H_q (for the first two harmonics)
for Alibag and Huancayo

	12-monthly Comp.		6-monthly Comp.	
	Amplitude (γ)	Phase ($^{\circ}$)	Amplitude (γ)	Phase ($^{\circ}$)
ALIBAG				
Mean for the period 1904-1958	3.0	314	0.8	176
Date of 1st Max.		Jun 1		Jun 2
Mean for years (17) of high sunspot numbers (mean No.=99)	3.4	311	2.3	260
Date of 1st Max.		Jun 4		Apr 20
Mean for years (15) of low sunspot numbers (mean No.=13)	3.2	300	1.2	212
Date of 1st Max.		Jun 15		May 14
Mean for the period 1923-1946 (for comparison with Huancayo)	2.7	336	0.4	152
Date of 1st Max.		May 9		Jun 14
HUANCAYO				
Mean for the period 1923-1946	1.1	161	2.5	352
Date of 1st Max.		Nov 4		Mar 4
Mean for years (8) of high sunspot numbers (mean No.=95)	4.2	78	4.0	349
Date of 1st Max.		Jan 27		Mar 6
Mean for years (8) for low sunspot numbers (mean No.=13)	3.7	246	2.0	323
Date of 1st Max.		Aug 9		Mar 18

of the sun (Chapman and Bartels 1940, Chapman 1961), so that for the northern hemisphere the current flow is maximum for the northern summer and minimum for the northern winter. It is easily seen that for a place remote from the geomagnetic as well as the geographic equators the fluctuation in the intensity of current flow, in the course of a year, will be an annual feature, while for a place closer to the equators coming under the influence of current circuits of both hemispheres, it will be largely a semi-annual feature. Huancayo is almost on the geomagnetic equator and 12° south of the geographic equator, while Alibag is about 9° north of the geomagnetic equator and 19° north of the geographic equator. The ionospheric current variation in the course of

a year will largely be an annual feature for Alibag while for Huancayo it will be a semi-annual feature, thus accounting for the finding in 7(a).

9. The finding in 7(b) is remarkable. Though it is known that $S_q(H)$ amplitude is very much greater during years of high sunspot numbers than during years of low sunspot numbers, yet the 12-monthly component of annual variation of H_q apparently shows almost no correspondence with solar activity. This feature may be due to the fact that in the course of the year solar activity (as manifested by sunspot numbers) is more or less linear and therefore when the monthly inequalities of H_q are corrected for the secular change, the effect of solar activity, if any, gets eliminated

and thus the effect of solar activity is not manifested in the 12-monthly component.

10. The finding in 7(c), *viz.*, the correspondence between solar activity and the amplitude of the 6-monthly component is very interesting. A plausible explanation of this feature may be based on the existence of the average belts of high solar activity about the heliographic latitudes 10° – 15° N and S. This fact coupled with the inclination of the solar axis of rotation at 7.2° to the plane of the ecliptic can account for the dependence of the 6-monthly component on solar activity, if the solar active regions are also the source of short wave radiation of high ionizing potential. Thus the same well known axial hypothesis (Cortie 1912, Gnevishev and Ol 1946) put forward to account for the semi-annual variation of magnetic activity, appears also to account for the dependence of the 6-monthly component of the annual variation of H_q on solar activity.

11. That the intensity of the solar ultra-violet and x-radiation varies in accordance with solar activity is well established. All the ionospheric layers show a direct linear relationship, in respect of their intensity of ionization, with sunspots (Ratcliffe and Weekes 1960). The fact that this ionizing radiation, especially radiation of greater ionizing potential does not emanate uniformly from the whole surface of the Sun, but originate from localised active regions of the Sun can be inferred from the 27-day recurrence tendency noticed in the critical frequency of the F-layer (Bartels 1951) as well as from the 27-day periodicity seen in the total ionizing radiation from the Sun (Beynon and Brown 1957). Recent Lyman α -photographs of the Sun (I.G.Y. Bull. 1959) have also shown that this radiation and perhaps, also the shorter wave radiation, do not emanate uniformly from the whole surface of the sun but from localised patches and spots scattered over the solar surface. It is reasonable to expect these patches and spots to coincide with solar active regions.

12. Thus, the cause of the correspondence of the amplitudes of the 6-monthly component with sunspot numbers appears to be the short wave radiation emanating from solar active regions coupled with the variation in the heliographic latitude of the earth in the course of a year. If this is true then one should expect the dates of maxima of the 6-monthly component of the annual variation of H_q for years of high sunspot numbers to be in reasonable agreement with the dates when the earth attains maximum southerly heliographic latitude and maximum northerly heliographic latitude (7.2°), which are 5 March and 7 September. For Alibag the dates when the 6-monthly component, for years of high sunspot numbers, is maximum, are 20 April and 20 October. In the case of Huancayo they are 6 March and 6 September. The good agreement for Huancayo is perhaps contributed by the predominance of the 6-monthly component of its annual variation of H_q seen in 4(b). In the case of Alibag the lag is a little too much even if the known lag of 10 to 15 days in the response of the E-layer to solar spot activity (Allen 1948) is allowed for. But, considering the fact that irregularities in the secular change of H_q play a large part in bringing about fluctuations in amplitude and phase of the annual variation, this lag cannot be considered unreasonable.

13. A plausible alternative to the axial hypothesis, coupled with the emanation of short-wave radiation from solar active regions, for explaining the correspondence between solar activity and the amplitudes of the 6-monthly component of the annual variation of H_q , is the incidence of geomagnetic disturbance, the magnitude of which is known to vary semi-annually with maxima in March and September (Chapman and Bartels 1940). But the effect of geomagnetic disturbance is to reduce the magnitude of H_q and therefore, if the correspondence seen between the amplitudes of the 6-monthly component and sunspots, is to be the result of incidence of geomagnetic disturbance, which has a well established correspondence

with solar activity, the minima of the 6-monthly component of the annual variation of H_q should occur in March and September, and the maxima in December and June. The dates of maxima of the 6-monthly component for years of high sunspot numbers for the two stations examined are closer to the equinoctial months (considering the lag in the response of the E -layer to solar activity in the case of Alibag). Thus it appears that

the axial hypothesis, coupled with the emanation of short wave radiation from solar active regions, is more favourable for accounting for the correspondence seen between the amplitudes of the 6-monthly component and solar activity.

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