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QUIET SOLAR GEOMAGNETIC VARIATIONS AT OBSERVATORIES IN SYMMETRICAL LATITUDES DURING A MINIMUM OF SOLAR ACTIVITY

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Abstract

Solar geomagnetic variations on quiet days (Sq), neglecting the small lunar contribution (L), are compared for Teoloyucan (geogr.lat. 19°45', long. -99°11') and La Quiaca (geogr.lat. -22°06', long.-65°36'), located in the longitudinal sector of maximum difference between geographic and geomagnetic latitudes, the latter being 29,6° and -10,6°respectively. Given the manifest asymmetry, even during the equinoxes comparable data from Pilar (geogr.lat.-31°40', long.-63°53'; geomagn.lat.-20,4°) are supplied.

Noon values of the geomagnetic north component of Sq can be represented by a plane model including an electrojet centered at the dip equator and two ionospheric current systems of greater latitudinal extent. Application of this model to the particular group of E-months (March/April-September/October) shows that the distance between the vortices of these current systems and the equator is greater in the northern hemisphere than in the southern. Merely geomagnetic causes cannot account for this discrepancy.

Resumen

El objetivo del trabajo es comparar las variaciones geomagnéticas diarias solares tranquilas (Sq), despreciando cualquier influencia lunar, de los observatorios Teoloyucan (lat.geog 19°45',long.geog.-99°11') y La Quiaca (lat.geog.-22°6', long.geog.-65°36') en los que es máxima la diferencia entre la latitud geomagnética (29,6° el primero,-10,6° el segundo) y la geográfica.

Dada la asimetría manifiesta aún durante los equinoccios, se comparan las variaciones con las obtenidas en el observatorio Pilar (lat.geog.-31°40', long.geog-63°53', lat.geom.-20,4°). Ajustando los valores de mediodía de la componente geomagnética norte de Sq a un modelo plano constituído por un electrochorro centrado en el ecuador de inclinación y dos sistemas de corrientes ionosféricas más extendidos en latitud se halla que la distancia entre el ecuador y el vórtice de esos sistemas como así también la intensidad de la corriente ionosférica total durante los meses marzo-abril-setiembre-octubre son mayores en el hemisferio norte que en el austral.

1. Introduction

The purpose of this study is to compare the quiet solar daily geomagnetic variations (Sq) at observatories of symmetrical geographical N-S position in the longitude sector of maximum difference between the geographical and geomagnetic and dip latitudes.

In an expansion of the geomagnetic field by spherical harmonic series it is found that the first term predominates; it can be conceived as representing the effect of a dipole located at the Earth's center, slightly inclined with respect to the axis of rotation, and defines the geomagnetic equator, which is the great circle of zero vertical component produced at ground level by this equivalent dipole. In turn, the line connecting the points where the vertical component of the actual field vanishes is the dip equator.

The external part of the geomagnetic variations results from the interaction of diverses causes. The quiet solar daily variation Sq, in particular, is caused by:

a)tide-like convective motions in the conductive upper atmosphere,especially the ionospheric E region (Chapman and Bartels,1940); the ionization, being produced by solar UV radiation, is therefore in the yearly average distributed symmetrically with respect to the geographic equator; b) an interaction of the ionospheric motions with the main (or quasi-permanent) geomagnetic field in the manner of a dynamo, which produces a system of electrical currents originating at ground level the external part of Sq. The participation of the main field in this process would call for a distribution of Sq symmetrical with respect to the geomagnetic equator; however, there is some evidence (Onwumechilli,1962) that the dip equator might be a better line of reference for the N-S symmetry of Sq.

The maximum distances between the geographic, geomagnetic and dip equators are found in the longitudinal sector where the observatories compared in the present study are located.

From the value of North component X of Sq at the time of vanishing Y (east component) it is possible to estimate the mean intensity of the corresponding ionospheric currents, provided that a proper separation of the internal (induced) contribution to Sq can be achieved. This requirement is reasonably fulfilled during the equinoctial months of March, April, Sptember and October, when the foci of the equivalent internal and external current systems coincide approximately. For these months we propose a model capable of accounting for the striking difference in daily range between the two observatories here considered, which are near-symmetrical in geographic latitude.

2. Selection of data.

We have compared the quiet solar daily variations Sq recorded in 1976 (low solar activity, with R 20) at Teoloyucan (TEO: geogr. lat. 19°45'; long.-99°11') and La Quiaca (LQA: geogr.lat.-22°06'; long.-65°36'); in contrast to their near-symmetrical geographical position these two stations differ considerably in geomagnetic latitude, being 29,6° at TEO and -10,8°at LQA. For comparison we also include some features of Sq at Pilar (PIL: geogr.lat.-31°40'; long.-63°53'; geomagnetic lat. -20.4°). The dip latitudes are TEO: 28.25°; LQA: -7.6°; PIL: -15.3° (see Figure 0).

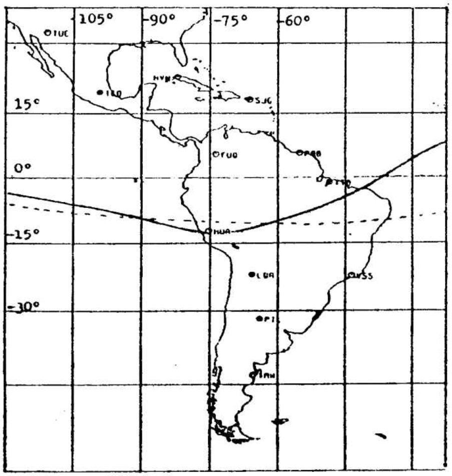

Fig. 0: Map showing the mentioned observatories, geographic latitudes and longitudes, and geomagnetic (- - -) and dip(---) equators.

Local time (LT) at La Quiaca and Pilar is some 2 hours ahead of Teoloyucan; so for the first value (Oh...1h LT) of the daily sequences we have taken the interval 4h...5h UT at La Quiaca and Pilar, and 6h...7h UT at Teoloyucan. Mean hourly values of the field components H(t), D(t) and Z(t) (t=1...24) were used throughout (Universidad Autónoma de México, 1986; Servicio Meteorológico Nacional (Argentina)).

The selection of quiet days was based on the Km indices (Berthelier et al.,1991), stipulating that during sequences of 9 succesive three-hourly intervals (eighths) beginning with the 2nd eighth of a UT day Km must be 2-. Days with incomplete records were discarded, except for the following cases where interpolation of single hourly values was considered legitimate: a) TEO, 24-03-76, 24h UT, in H, D and Z; b) TEO, 21-06-76, 21h UT,in D; c) PIL, 19-07-76, 24h UT, in D and Z.

This led to the selection of 10 quiet days for the southern solstice months November through February (winter at TEO, summer at LQA and PIL), 6 days for the equinoctial (E) months April, May, September and October; and 16 days for the remainder (summer at TEO, winter al LQA and PIL), though only 10 days for Z at PIL, where records for June are lacking. As a consequence of this grouping, the dates of the individual "summer" and "winter" days included at TEO and LQA/PIL, respectively, are not the same, nor is the statistical volume of these sets identical. However, they can be considered comparable in view of the identical criterion adopted for their selection, as regards a low geomagnetic activity.

3. Procedures

The mean declination (Do) at the three observatories is small or nil (Do 8° at TEO; 0° at LQA and PIL), and so is the angle between the respective geographic and geomagnetic meridians (5° at TEO; 0° at LQA and PIL). We have therefore neglected the difference between the geographic (and geomagnetic) north component X and the observed horizontal component H, considering the latter, for simplicity, as representing X.

Our Sq was obtained after eliminating on each individual day, hour by hour, the contribution due to drift currents in the plasmasphere and magnetopause, as well as the internal currents induced by these in the Earth. These contributions were determined by means of Dst indices as Dst(t).cos and Dst(t).sin for the north and vertical components, respectively, where is the geomagnetic latitude of each observatory. Sq was considered as being the departure from near-midnight levels (Xo,Yo,Zo) expressed by the average of the hourly values at t = 23,24,1,2 LT. Thus the component of Sq turns out to be:

i) north: Xq(t) = H(t) - Dst(t).cos - Xo;

ii) east: Yq(t) = D(t).Ho - Yo, where D is expressed in radians and Ho the annual mean value of the horizontal component at each observatory, and

iii)vertical Zq(t) = Z(t) + Dst(t).sin - Zo.

Contamination by lunar variation L (visibly significant on individual days only in the close neighbourhood of the equator) was neglected. Finally, seasonal mean of Xq(t), Yq(t) and Zq(t) were determined according to the grouping described in section 2.

4. Results

We represent the variation Bq(Sq) by its projections $Yq.e_x + Xq.e_y$ on the horizontal plane, and $Xq.e_x + Zq.e_y$ on the meridional vertical plane, respectively; here e_x and e_y are the usual unit vectors.

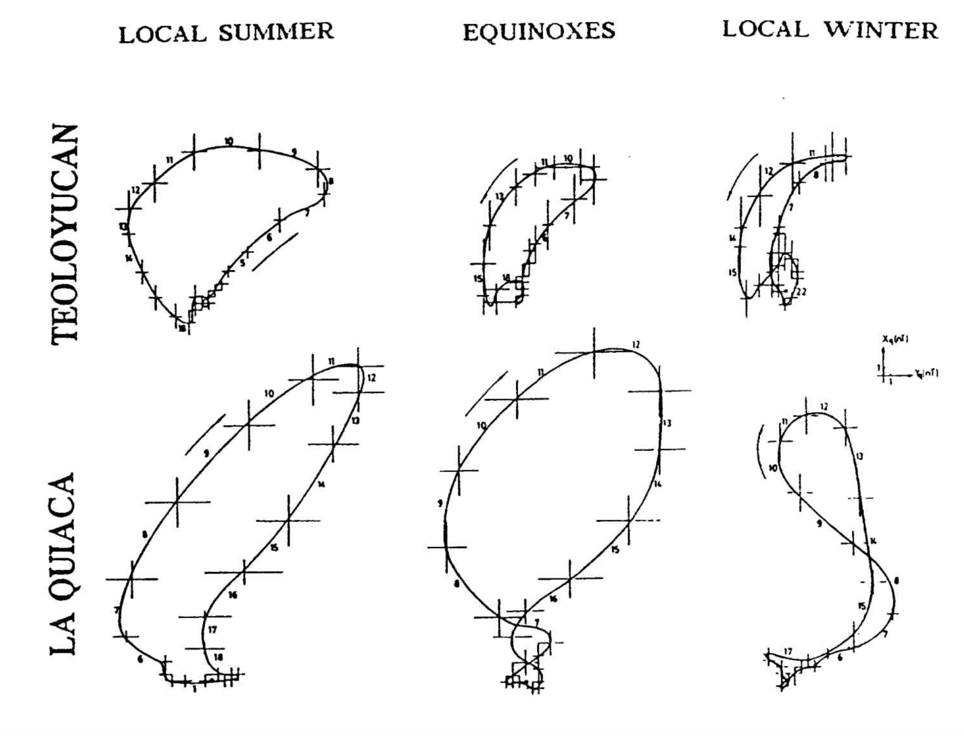

Fig. 1: Projection on the horizontal plane of the mean quiet solar daily variation (Sq) at the two observatories located at symmetrical geographic latitudes, for three local seasonal groups (1976). Numbers: full hours in local time; crosses: scatter of the hourly values centered between each pair of successive full hours.

Figure 1 shows the horizontal vectograms and the scatter of each hourly mean at TEO and LQA (nearly symmetrical in geographic latitude), for the three seasonal four-monthly groups as defined in section 2; Figure 2, in turn, gives analogous vectograms in the vertical meridional plane. In Figure 2 the sign of Zq is in accordance with the generally upward field direction in the southern hemisphere; so the maximum of Zq al LQA means that around noon the upward field inclination is least. A different possible representation as adopted, e.g, by Vecchi et al. (1985) shows the hourly departures of the vertical component in space, i.e., negative downwards. Figure 3 shows the mean daily variations Xq during the E-months of 1976 for the same observatories, along with PIL.

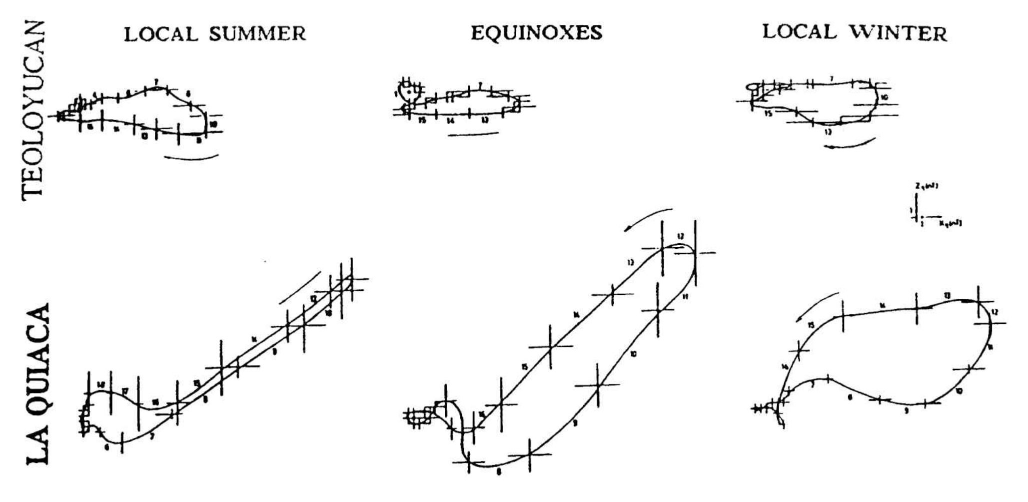

Fig. 2: Analogous to Figure 1, in the vertical meridian plane.

The main features evidenced by these graphs are:

i) Xq behave in a similar fashion at the three observatories, with only a small annual modulation; its daily range at LQA, however, largely exceeds that observed at the two other stations. This is accounted for by its proximity to the dip equator and the ionospheric current distribution (see section 5);

ii) Yq exhibits a N-S symmetry; in the northern hemisphere it reaches a maximum in the morning and minimum in the afternoon. At TEO the daily range during the E-months is similar to the winter range, whereas at LQA (and PIL) it resembles that of the summer months, a feature already stated elsewhere (Vecchi et al.,1985);

iii) Zq shows likewise the N-S symmetry, with a morning maximum around 7h to 8h LT and a minimum near noon (11h to 14h LT) in the northern hemisphere, the latter slightly receding from winter to summer. At LQA the Zq range is maximum during the E-months. At TEO, E-months, a relative maximum appears before midnight, immediately followed by a minimum. This we think might be a spurious feature introduced by the ring-current correction Dst.sin .

5. Tentative interpretation of the results

The remarkable difference in the ranges of the north component Xq between the two observatories at near-symmetrical sites in geographic latitude can be accounted for by the model of equivalent ionospheric currents, here illustrated for a special case of the E-months under the following assumptions:

i) the system of equivalent ionospheric currents is located at the height of h = 110 km;

ii) the planetary average ratio of 2/7 between the ground level Sq contributions of internal and external origin (Matsushita and Maeda, 1965) can be admitted to hold in the particular region under consideration;

iii) at the instant when Yq 0, the currents over each observatory flow along circles of latitude, generating a contribution $X_M = (5/7)\ Xq_N$ (see Fig 3); this implies considering that in this particular longitude sector the geomagnetic and dip equators are parallel to the geographic equator, which is reasonably realistic. It is important to note that the instant of Yq 0 is not the one of maximum Xq; in fact, the latter precedes the former by 1 hour at TEO, while lagging behind it by 1 hour at LQA (and PIL); the maximum Xq near local noon, with Yq 0, would call for equivalent equatorial currents deviating by more than 10 from the direction of the geographic equator;

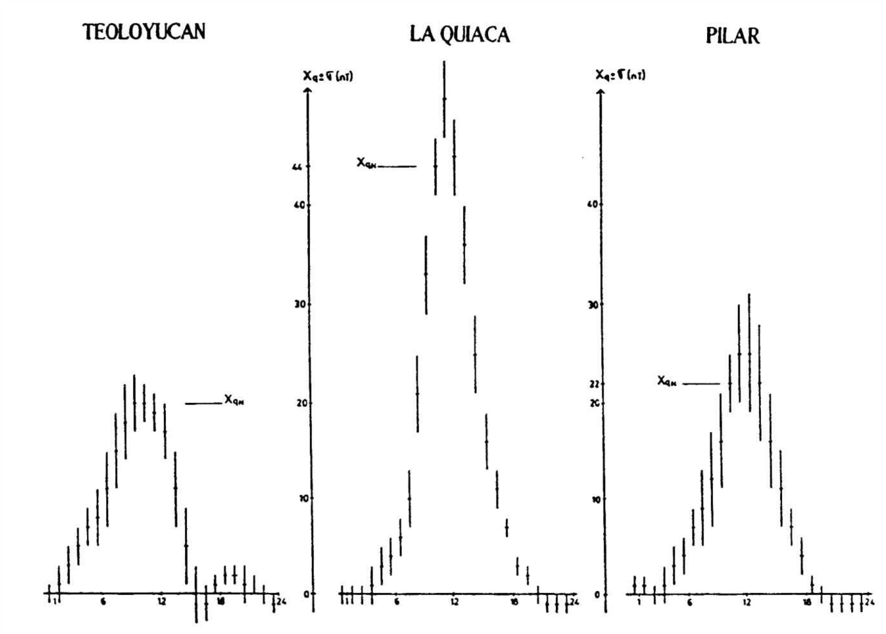

Fig.3: Mean quiet solar daily variation of the north component, Xq, for the equinoctial months March, April, September, October, 1976; same observatories as Figs. 1 and 2, and Pilar for comparison. Local time. Vertical bars: scatter of hourly values. XqN indicates the approximate level of Xq at the instant of Yq 0.

iv) during the E-months the vortices of the external and internal equivalent current systems coincide approximately (Matsushita and Maeda,1965);
v) the curvature of the Earth is neglected; and
vi) the noon system of currents is centred at the dip equator, comprising:

a) an electrojet whose current density is given by

$$j_1(x) = \begin{array}{ll} j_{1max}\ 1 - \frac{x - x_1}{D_1}^2 & \text{if } x - x_1 < D_1 \\ 0 & \text{if } x - x_1 \quad D_1 \end{array} \qquad (1)$$

where j_{1max} = 93 A/km (Duhau and Osella,1984) is the maximum current density, $D_1 = 4h$ is the half-width of the electrojet, with h = 110 km, and x_1 the position of the electrojet center (i.e. the dip equator); this is observatory on the basis of the mean annual Ho and Zo, as follows:

$$\text{tg } I = Zo/Ho;\ \text{tg} \quad = (\text{tg } I)/2,$$

where is the dip latitude of the observatory, so that x_1 = - (with the geog. latitude).
Thus, the geographic latitude of the dip equator turns out to be :

x_1(TEO) = -8.5 -8.5 h,
x_1(LQA) = -14.5 -14,5 h, and
x_1(PIL) = -16.3 -16.3 h.

The discrepancy between TEO and the southern hemisphere stations is due to their different longitudes.

The mean current intensity at 11 LT is given by

$$I_1 = \overset{x_1+D_1}{\underset{x_1-D_1}{}} j_1(x).dx = j_1 D_1 \quad 55 \text{ kA},$$

b) a current system of density

$$j_2(x) = \begin{array}{ll} j_{2max}\ 1 - \frac{x - x_2}{D_2}^2 & \text{if } x - x_2 < D_2 \\ 0 & \text{if } x - x_2 \quad D_2 \end{array} \qquad (2)$$

where j_{2max} is the maximum current density,
$x_2 = x_1$ the position of the dip equator with respect to each observatory, and
D_2 the distance from the dip equator to the foci of the equivalent current systems.

Adopting the following values of X_M defined in 5.-iii)

X_M(TEO) = 14 nT; X_M(LQA) = 31 nT; X_M(PIL) = 15 nT,

the parameters of best fit in equation (2) turn out to be

$j_{2max} = 58$ A/km; $D_{2S} = 20{,}1$ h; $D_{2N} = 36.1$ h,

where S and N refer to the southern and northern vortices, respectively.

The contribution of each external current system to X_M is

	system a) (equation (1))	system b) S (equation (2))	system b) N (equation(2))
TEO	0	1 nT	13 nT
LQA	1.5 nT	28.5 nT	1 nT
PIL	0.5 nT	14 nT	0.5 nT

The total equivalent ionospheric current flowing between the dip equator and the vortex of each hemisphere is

$$I_{2S} = \int_{x_2-D_{2S}}^{x_2} j_2(x).dx = (2/3)\, j_2\, D_2 \approx 78 \text{ kA}$$

$$I_{2N} = 140 \text{ kA}.$$

6. Discussion of the E-month results

During the equinoctial months both the distance D_{2N} from the dip equator to the focus of the current system, and the total ionospheric current I_{2N} are larger in the northern than in the southern hemisphere ($D_{2N} > D_{2S}$ and $I_{2N} > I_{2S}$). The remarkable difference between the noon range X_M of the north component at LQA and at the two other observatories is due to the close neighbourhood of LQA to the region of maximum current density.

Our ranges are smaller than those found by Matsushita and Maeda (1965) by fitting the coefficients of a spherical harmonic analysis, although the distances from the equator to the current foci are similar; our ratio I_{2N}/I_{2S} is somewhat greater than the one found by these authors in the case of vanishing night-time currents (which is also our approach).

The actual system of ionospheric currents (Chapman and Bartels, 1940; Matsushita and Maeda,1965) is more complex than ours, which neglects the effect of non-alignment of the currents with respect to the parallels before and after 11 LT; otherwise the I_2 currents would turn out to be smaller than those here calculated.

The asymmetry between the north and south hemispheres cannot be accounted for by merely geomagnetic causes; to understand it, the hybrid nature of the physical causes of the variations here considered must be kept in mind. In fact, these variations are the compound response to diverse causes (Schneider,1979), viz.:(I) the systems of equivalent ionospheric currents (atmospheric dynamo); (II) the induction caused by these in the Earth's interior; and (III) the systems of electric currents in the oceans caused by the tidal movements (oceanic dynamo). Contribution (I) implies the regime of pressure and winds of the neutral atmosphere at ionospheric levels, which shows a north-south asymmetry (Chapman and Lindzen,1970); part (II) contains regional effects due to anomalies of composition, structure and electric conductivity in the Earth's interior, while contribution (III) is affected by the distance between the observation point and the coast, obviously also a local feature.

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