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Geomagnetic perturbations in the southern polar cap

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RESUMEN

La inyección de energía a la ionosfera auroral no diurna proveniente de la región de la hoja neutra de la cola magnetosférica intensifica los electrochorros aurorales, cuyas variaciones se reflejan en el campo geomagnético en la superficie en los casquetes polares. El objetivo de este estudio es determinar el significado de los índices geomagnéticos de la zona auroral en las latitudes polares. Para este propósito se analizan las perturbaciones de los años 1967, 68 y 69. En contraste con los criterios para definir perturbaciones en otras latitudes, nosotros consideramos las variaciones en los índices de actividad geomagnética AE, AL, y AU.

PALABRAS CLAVE: Perturbaciones geomagnéticas; índices AE, AL y AU

ABSTRACT

The energy input in the non-diurnal auroral ionosphere from the surrounding of the magnetotail neutral sheet enhances the auroral electrojets, whose variations are reflected by the ground level geomagnetic field within the polar caps. The subject of the present study is to determine the significance of auroral zone geomagnetic indices in polar latitudes. For this purpose perturbations of the years 1967, 68 and 69 are analyzed. In contrast with the criteria for defining perturbations in other latitudes, we consider variations in the geomagnetic activity indices AE, AL and AU.

KEY WORDS: Geomagnetic disturbances; AE, AL and AU indices.

1. CRITERIA FOR SELECTING DISTURBED PERIODS IN THE POLAR CAP.

Included are intervals satisfying the following criteria:

i) the hourly AE index exceeds 200 nT (threshold of perturbation);

ii) an undisturbed interval of up to 7 hours occurring between two disturbed sequences constitutes one single disturbed event, since the energy loss rate in the electrojets is high as compared with the equatorial ring current;

iii) undisturbed intervals of at least 7 hours must precede and follow the perturbation;

iv) at least one hourly AE must exceed 780 nT, so as to consider intense perturbations;

v) in order to allow the analysis of correlation, the disturbed interval must be longer than 72 hours.

In the three years under study, 27 of such disturbed periods were identified.

The observatories considered were South Pole (-78.7° gm lat., 0° gm long.) and Vostok (-89.5° gm lat., 116.4° gm long.) contributing 20 and 19 suitable sequences respectively, according to the availability of data.

For the six dark months, we adopt as a reference level for the perturbations the monthly average of the daily means of Q-days containing the majority of hours comprised in the interval, i.e. considering that no Sq variation is present. The deviations from that reference level are the mean hourly variations ΔZ, ΔH and ΔD of the disturbance.

2. CORRELATIONS

Correlations were determined between the disturbed variations ΔZ and M, the absolute value of the horizontal disturbance, with $M^2=(\Delta H)^2 + (\Delta D)^2$, and the geomagnetic auroral zone indices AL, AU or AE, during the same 5-hour subinterval [T1,T2] along succesive days of each disturbed sequence.

In Figs. 1 and 2 the correlation coefficient R is plotted for the cases of $R > 0.78$ in such a way that its value corresponds to the 5-hour subinterval [T1,T2].

Fig. 1 shows the correlation R between ΔZ and AL, and Fig. 2 between M and AE, these being the significant cases. Both only comprise winter perturbations (April to September), 9 of them at Vostok and 15 at the South Pole. The coefficient R between ΔZ(PO) and AL and between M(PO) and AE exceeds 0.78 at least once in 11 of the 15 South Pole perturbations, while at Vostok it exceeds 0.78 in 5 of the 9 cases for ΔZ(VO):AL, and in all 9 cases for M(VO):AE.

In the summer months the correlations of AE with M become higher if calculated for AE > 200 nT; yet they do not turn out to be significant.

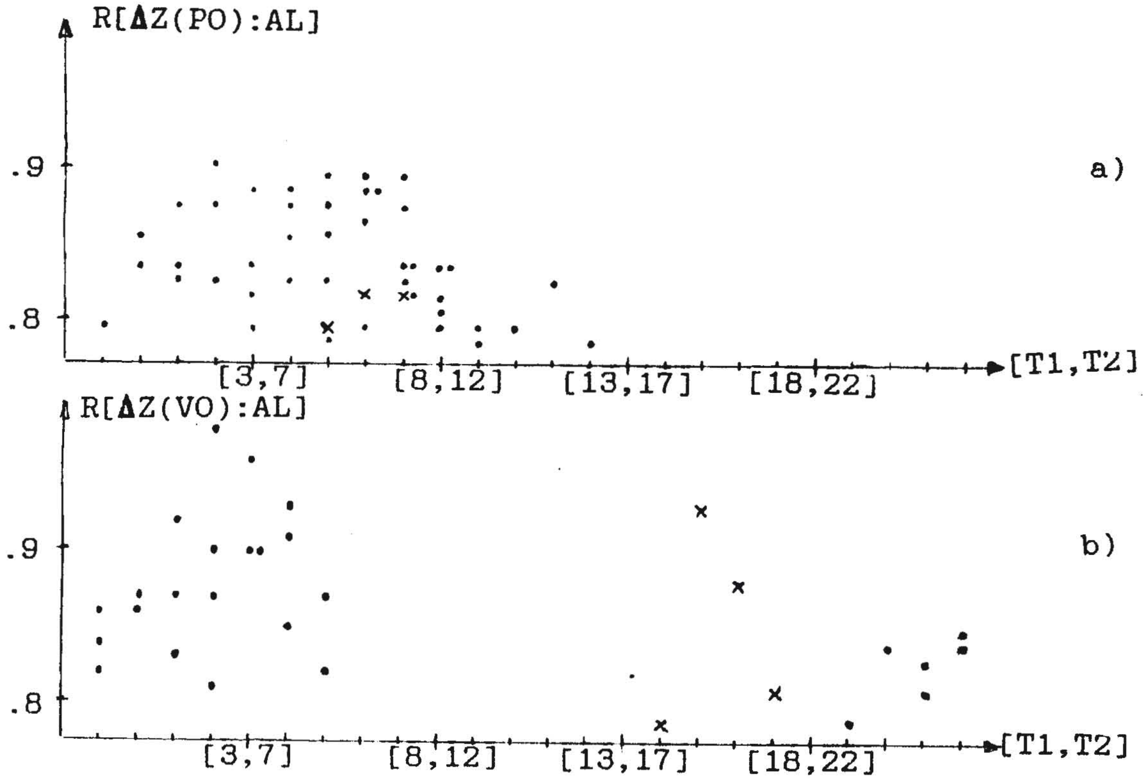

Fig.1: Coefficients of correlation R>0.78, between: a) ΔZ(PO) and AL; b)ΔZ(VO) and AL(PO: South Pole; VO: Vostok)

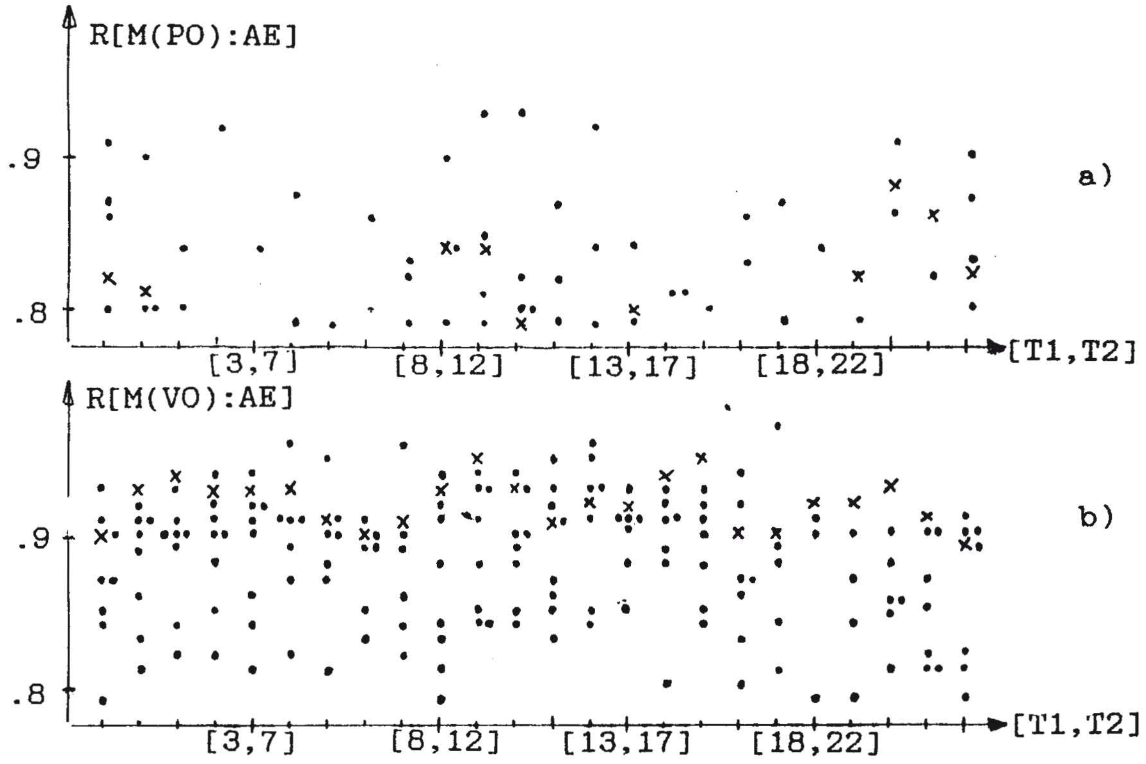

Fig. 2: Same as Fig. 1, between: a) M(PO) and AE; b) M(VO) and AE. The case marked by x represents a perturbation of 150 hs duration starting at 04 UT of May 1, 1967.

3. CURRENT SYSTEMS

3.1 Vertical fields

The vertical geomagnetic field perturbation ΔZ is caused by horizontal ionospheric currrents: the westward auroral electrojet (IL) and two transpolar current threads (I1 and I2). A geomagnetic latitude of 65° is appropriate for the disturbed period electrojets and is a fair approximation to a current thread, in view of the position of the observatories.

The westward (eastward) auroral electrojet generates right below itself a horizontal field, whose value is expressed by the index AL(AU), and assuming it to be an infinite thread, its intensity is

$$IL = \frac{AL.h}{2\mu o} \qquad \left(IU = \frac{AU.h}{2\mu o}\right) \tag{1}$$

The electrojet can be considered as a circular arc centered at the observatories, causing field effects ZL (negative if the current flows westward, and positive otherwise), such that

$$ZL = \mu o IL \frac{r^2}{(h^2 + r^2)^{3/2}} (\varepsilon_2 - \varepsilon_1) \tag{2}$$

$$ML = 2\mu o IL \frac{r\,h}{(h^2 + r^2)^{3/2}} \sin\left(\frac{\varepsilon_2 - \varepsilon_1}{2}\right) \tag{3}$$

where i is the radius of the arc, h is the height of the electrojet, ε_1 and ε_2 are the ends of the arc and ML is the horizontal component towards $(\varepsilon_1 + \varepsilon_2)/2$. The three idealized currents IL, I1 and I2 do not cause significant horizontal field variations at the South Pole or at Vostok.

In a system fixed at the Sun, and assuming the electrojets to be fixed within this system, the geomagnetic effects at a polar cap observatory arising from the rotation of its site are due to: (i) the relative position observatory/electrojet; and (ii) the instantaneous intensity of the electrojet.

For studying the dependence, at such an observatory, between the field and the electrojet intensity, the effect of the relative position must be eliminated. Except for a station at the geomagnetic pole, the hypothesis of system-fixed electrojet implies that the relative position depends on the longitude. We analyze 5-hourly subintervals, each day at the same UT, along a disturbed period: thus the field variations during the subinterval can be related to the corresponding current intensities. It is reasonable to suppose that the subinterval of best correlation corresponds to the closest approach between the observatory site and the electrojet.

3.2. Horizontal components.

When the correlation R between the horizontal component M and the index AE approaches unity during the disturbed period for the same proportionality factor p (M = p.AE+MV), the vertical currents can be assumed to be stable. The following hypotheses are then made for calculating the density of the field-aligned currents:

i) The variation M at the point (ρ,ϕ), measured from the center of the cap is caused by a horizontal current thread of intensity i at the height of 110 km, and by the induced internal current:

$$(5/7)\, M(\rho,\phi,T) = \frac{2\mu o \,.\, i(\rho,\phi,T)}{h} \tag{4}$$

ii) In the center of the cap (near the geomagnetic pole) the field lines are vertical. Vostok rotates around the geomagnetic pole, the distance being 0.5° (ρ=55 km). In consequence, the curvature is neglected and a system of cylindrical coordinates centered at the geomagnetic pole is adopted.

iii) The field-aligned currents are calculated from the horizontal currents:

$$j_{//} = \bar{\nabla} . \bar{i}$$

iv) Throughout the perturbation the horizontal variation M contains a term p.AE(T) depending on the time variation of the current, and another term MV depending on the position with respect to the geomagnetic pole:

$$M(\rho,\phi,T) = p.AE(T) + MV(\rho,\phi).$$

From (4):

$$i = \frac{5}{14} \frac{M(\rho,\phi,T).h}{\mu o} \quad ;$$

but

$$j_{//} = \bar{\nabla}.\bar{i} = \frac{1}{\rho}\frac{\partial i\phi}{\partial \phi} \quad \text{,hence } i\phi = -\,i.\cos\phi = \frac{1}{\rho}\frac{5}{14}\frac{h}{\mu o}$$

$$\left[p\,.\,AE(T)\frac{\Delta(\cos\phi)}{\Delta\phi} + \frac{\Delta[MV(\rho,\phi).\cos\phi]}{\Delta\phi}\right]$$

4. RESULTS

The perturbations of May 1, 1967 (commencement at 4 UT, duration 150 h) and June 25, 1967 (commencement at 17 UT, duration 75 h) were examined. In both there is a factor p for which R(M(VO):AE)>0.8 throughout the period.

For the first example, we find:
in (7,11)UT: R(ΔZ(PO:AL)= 0.82 and ΔZ(PO)= 0.46.AL-17 nT= -80 nT, R(ΔZ(VO):AL)= 0,64 and ΔZ(VO)= 0,11.AL-15 nT= -30nT, with AL= -140 nT and AE= 270 nT; R(M(VO):AE)>0.8, for all 5-hour intervals considered; the correlation between M(VO) and AE when AE>200 nT turns out to be R(M(VO):AE)=0.83, whit P=0.19 (101 hours).

If the electrojet is at a height of h=110 km and a latitude 65°, we find IL=77 KA (from Eq 1). Then,

At South Pole:	at Vostok:
ZL = -8nT	ZL = -2nT from (2)
ML $\approx$ 0 nT	ML $\approx$ 0 nT from (3), and
Z' = ΔZ-ZL+17 nT= -55 nT	Z' =ΔZ-ZL+15 nT= -13nT

It remains to justify the vertical components of intensity Z'(PO)= -55 nT and Z'(VO)= -13 nT, proportional to AL. Suppose two parallel infinite current threads I1 and I2, perpendicular to the direction toward $(\varepsilon_1+\varepsilon_2)/2$, near geomagnetic morning, representing gravity centers of horizontal transpolar ionospheric currents, at distances d1 and d2 from the geomagnetic pole (with d1 measured toward the South Pole). These currents must satisfy:

$$Z'(PO)/Z'(VO) = 4.2 \; ; \qquad (5)$$

Since in (7,11) UT AL = -140 nT and AU= 130 nT, it follows from (1) that IL = 77kA and IU = 71.5 kA, so that I $\approx$ IL $\approx$ IU. In particular, if I1 = IL and I2 = IU, some pairs d1, d2 satisfying equation (5) are:

d1(h)	4	5	6	7	8	9	10
d2(h)	2.9	3.5	3.9	4.2	4.2	4	3.7

which shows that the "gravity center currents" can represent the (real) transpolar closing currents of the electrojets.

The horizontal components M1 and M2 are negligible.

During the 150 hours duration of the perturbation, one finds from the horizontal component M at Vostok that at a distance of 55 km from the geomagnetic pole:

(a) in (2,7)UT, $j_{//}<0$: in the geomagnetic forenoon the field-aligned currents flow upwards;
(b) in (12,14)UT and (15,24)UT, $j_{//}>0$: around geomagnetic midnight the field-aligned currents flow earthwards;
(c) in both cases they run to some hundreds of mA/m.

For the second case study the results are similar.

5. CONCLUSIONS

Disturbed sequences defined on the basis of geomagnetic auroral zone activity indices AE where analyzed. Though originating from the northern hemisphere, our results show them to be appropiate for the study of events observed in the southern polar cap.

During geomagnetic post-midnight or morning intervals, the high correlation between the auroral zone indices AL and the variations of the vertical component (ΔZ) of the geomagnetic field at the South Pole determines the position of the electrojet in a system centered at the geomagnetic pole; the westward electrojet and two (real) horizontal transpolar currents threads account for the field variations observed at South Pole and at Vostok.

The high correlation (0.83) found at Vostok, during two typical southern winter perturbations, between the AE index and the horizontal field component $((\Delta H)^2+(\Delta D)^2)^{1/2}$ suggests that the field aligned current systems are stable, and that their density can be calculated. Near the geomagnetic pole during geomagnetic forenoon these currents flow outwards and around midnight earthwards. During other winter intervals the correlation is also high, but there is no proportionality between the index and the horizontal field component independently from the interval considered.

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