Latitudinal variation of the ionospheric disturbance dynamo magnetic signature

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Abstract

During magnetic storms, the auroral electrojets intensification affects the thermospheric circulation on a global scale. This process which leads to electric field and current disturbance at middle and low latitudes, on the quiet day after the end of a storm, has been attributed to the ionospheric disturbance dynamo (Ddyn). The latitudinal variation of the Ddyn disturbance dynamo magnetic signature exhibits an eastward current at mid latitudes and a westward one at low latitudes with a substantial amplification at the magnetic equator. Such current flow reveals an "anti-Sq" system established between the mid latitudes and the equatorial region and opposes the normal Sq current vortex. However, the localization of the eastward current and consequently the position and the extent of the "anti-Sq" current vortex change from one storm to another. Indeed, for a strong magnetic storm, the eastward current is well established at mid latitudes about 45°N and for a weak magnetic storm, the eastward current is eastward current is established toward the high latitudes (about 60°N), near the joule heating region, resulting in a large "anti-Sq" current cell.

1. Introduction

During magnetic storms, two main physical mechanism of disturbance take place in the ionosphere, at the planetary scale: the direct penetration of magnetospheric convection electric field [1] and the ionospheric disturbance dynamo [2]. These mechanisms generate significant disturbances of electric fields and currents responsible for the terrestrial magnetic field disturbance in equatorial ionosphere, with different timescales, during and after the magnetic storms. During the active phases of storms, the auroral electrojets currents transfer thermal energy to the neutral gas via Joule heating and impulses through the ion-neutral momentum transfer. This process sets up gravity waves and equatorward thermospheric winds at F-region altitudes. These winds extend from auroral zone to mid and low latitudes with a small return flow at the E-region altitudes around the equator. At mid latitudes, through the Coriolis force action due to the Earth rotational movement, the equatorward thermospheric meridional flow gives rise to a westward zonal flow which drives a part of the ionized fluid. The westward zonal movement of ionized particles, in combination with the downward component of the Earth's magnetic field, produces a complex system of electric fields and currents. This physical process is called "ionospheric disturbance dynamo" [2] and denoted by the symbol Ddyn [3]. At mid latitude, the result eastward currents flow located at 45° magnetic latitude in a 20° wide strip within which the largest densities are produced. These currents are interrupted at the dawn and dusk terminators where the ionospheric conductivities have large longitudinal gradients. The interrupted currents set up polarization charges at the terminators and give rise to an electric field directed from dusk-to-dawn. There is consequently a large divergence of the east-west currents at dawn and dusk which requires a closure of these currents on the highly conducting dayside through the adjacent latitudinal regions. These currents achieve closure through two separate vortices: the polar vortex realized via the higher latitudes and the equatorial vortex realized via the lower latitudes where it constitutes a striking feature of the currents maps: a sort of "reversed Sq" current vortex flowing clockwise on the dayside with a focus close to noon at about 25° magnetic latitude. Both vortices have westward currents associated with them in polar and equatorial region respectively. Hence, at the equatorial region, the westward currents flow is opposed to the normal eastward equatorial electrojet currents.

2. Criteria of selection and data reduction

The selection criteria of observation periods were defined by Le Huy and Amory-Mazaudier [3]. These periods mainly correspond to the daytime in order to determine the dynamo action in the conducting E-region. These periods are subsequent to a magnetic storm related to a Joule heating in the auroral zone. The periods of observation show a weak auroral activity (intense generally in the main phase of the storm), thus there is no penetration of magnetospheric convection electric field from high latitude to the equator. To investigate the Ddyn event, we first analyze the variation of the solar wind speed component, V_x, following the Sun Earth axis, the B_z component of the interplanetary magnetic field, the *Dst*, *AU*, *AL* indices and the horizontal component of the terrestrial magnetic field *H*. V_x gives an estimate of the amplitude of the solar wind disturbance. When B_z is southward, there is a transfer of energy, particles and impulses from solar wind towards the magnetosphere. This process is at origin of the auroral electrojet intensification. *Dst* index illustrates the development of the magnetic storm and the influence of various magnetospheric current systems while the auroral *AU* and *AL* indices are used to evaluate the auroral electrojets. The *H* component is used to estimate the intensity of the equatorial electrojet current. Under the conditions of periods of observation, only the ring current is in action in the magnetosphere involving the magnetic disturbance evaluated from *Dst* index which gives a good approximation of the symmetric ring current during the observation periods. Then for each period of observation, the magnetic disturbance called *DP* is evaluated by following equation:

$$DP = H - Dst \times \cos(L) - S_R \tag{1}$$

where L represents the dipole latitude of the station and S_R the daily magnetic quiet variation of the H component. The H component variations during these periods of observation, in the equatorial zone, are compared with those of quiet reference days in order to highlight the influence of the disturbance dynamo mechanism. Indeed, the main characteristic associated with disturbance dynamo observed on the magnetic data [3] is the reduction of the H component amplitude at the magnetic equator due to the circulation of a disturbed westward electric current opposing the regular equatorial electrojet eastward flow. We analyze one selected event: 10, 11 June 1993. Tables 1 and 2 gives respectively the geophysical context of the period and the coordinates of the magnetometers used.

Table 1: The geophysical context of the period

Days	ΣKp (nT)	Remarks
10 June 1993	21-	Disturbed day
11 June 1993	17	Quiet day
21 June 1993	2+	Reference quiet day

Table 2: Position of the magnetic stations

		Geographic coordinates		Magnetic coordinates		
Code	Name	Latitude	Longitude	Latitude	longitude	LT
	Europe-Africa sector					UT
BJN	Bjornoya	74.50	19.20	71.00	109.10	+1
LER	Lerwick	60.13	358.82	62.37	89.19	+0
ESK	Eskdalemuir	55.32	356.80	58.30	83.56	+0
CLF	Chambon-La-Forêt	48.03	2.26	49.84	85.06	+1
TAM	Tamanrasset	22.79	5.53	24.66	80.31	+1
TOM	Tombouctou	16.73	357.00	6.36	71.15	+0
MOP	Mopti	14.51	355.91	3.85	69.90	+0
SAN	San	13.24	355.12	2.45	68.98	+0
KOU	Koutiala	12.36	354.55	1.49	68.32	+0
SIK	Sikasso	11.34	354.30	0.37	67.96	+0
NIE	Niellé	10.20	354.36	−0.89	67.88	+0
KOR	Korhogo	9.34	354.57	−1.84	67.98	+0
TSU	Tsmeb	−19.20	17.58	−18.77	83.51	+2
HBK	Hartebeesthoek	−25.88	−27.13	-26.82	91.86	+2
HER	Hermanus	−34.42	19.23	−33.98	81.35	+2

3. Cases studies: observations

Figure 1 shows the plots of the speed component V_x, the component B_z, the indices *AU*, *AL* and the *Dst* index for the period. The *Dst* variations characterize the beginning of the magnetic storms in the first day of this period. The subsequent days are magnetically quiet and coincided with the recovery phase of the storms. During the night from 10 to 11 June 1993, in the time interval 20:00-03:00 UT, the variations of the V_x component and the B_z component show an increase of the solar wind speed towards the Earth associated with a southward B_z component. The auroral activity becomes weak thereafter in time interval 04:00-16:00 UT on June, during the recovery phase of the storm. Figure 2 shows the plot of the H component on 10 and 11 June 1993 (solid line) compared with those of the reference quiet day levels (dashed line), over the African sector (UT=LT). On 11 June 1993, during the time interval 06:00-16:00 UT, we clearly observe an attenuation of the *H* component amplitude in all the station the stations as an evidence of the decrease of the auroral activity. The attenuation is more significant in Sikasso station (MLAT: 0.37°N), the nearest station to the magnetic equator. The variations of the DP disturbance exhibit a southward disturbance in all station (more noticeable in Sikasso), in the same time interval. The period of observation extends over the time interval 06:00-16:00 UT on 11 June 1993. During the main phase of the storm the disturbed days prior to this period of observation the AU and AL indices increase in response to the Joule heating in the auroral zone generated by the auroral electrojets which became very intense. The period of observation corresponds to the subsequent quiet day, when the recovery process sets up and the auroral activity becomes weak. Thus, only the mechanism of the ionospheric disturbance dynamo is in action in the ionosphere [3]. The southward variation of the DP disturbance in all the equatorial stations consistently with the attenuation of the equatorial electrojet constitutes an evidence of a westward electric current which superimposes the regular eastward equatorial electrojet currents. The attenuation of the equatorial electrojet concurrently with the decrease of the auroral activity, the quiet day after the magnetic storm, illustrates the signature of the Ddyn disturbance process at the equator according to the predictions of Blanc and Richmond [2]. Hence the DP disturbance depicts the magnetic signature of the Ddyn disturbance.

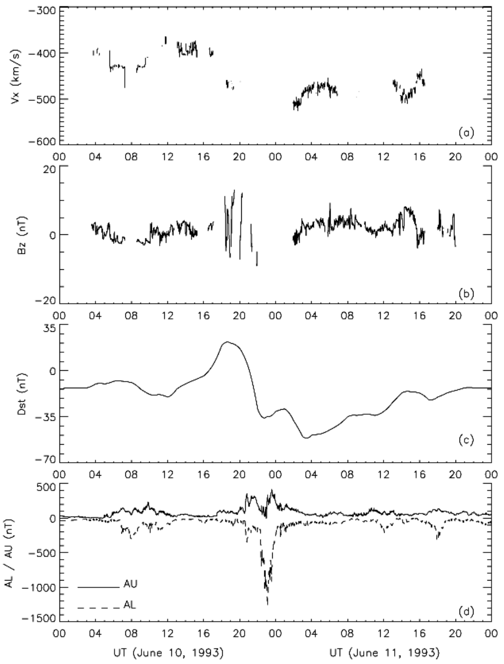

Figure 1: Variation of the interplanetary parameters and the magnetic indices on 10, 11 June 1993. From top to bottom: **(a)** component V_x of the solar wind speed, **(b)** the B_z component of the interplanetary magnetic field, **(c)** the *Dst* index and **(d)** the *AU* and *AL* indices.

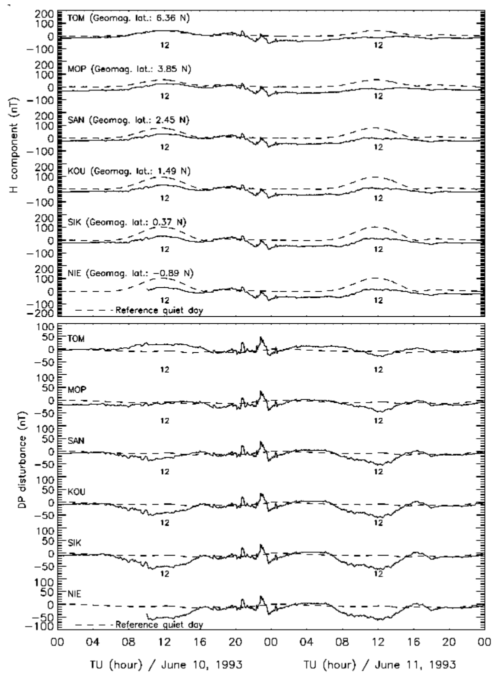

Figure 2: Variation of H component of the Earth's magnetic field observed in the African equatorial stations (top panel) and the corresponding disturbance DP (bottom panel), on 10, 11 June 1993 (solid line). The plots in dashed line indicate the variations of the reference quiet day. The local noon is indicated.

4. Latitudinal variations of the Ddyn disturbance

Figure 3 shows the latitudinal variations of the Ddyn disturbance over Europe-Africa sector, from high to low latitudes, in both hemispheres, on 11 June 1993. The latitudinal profile exhibits southward increasing Ddyn from MOP to NIE during daytime (09:00-16:00 UT) with maximum amplitude at local noon. This southward increase is due to disturbed westward flow at the equator. The Ddyn deviation is quasi inexistent in mid latitude stations CLF (46.84°N MLAT) and HER (-33.98°N MLAT). However, the Ddyn deviation increases northward notably at BJN (71°N MLAT) in the Northern Hemisphere denoting eastward equivalent current flow which closes via the equator through the previously observed westward current. As a result, the absence of the Ddyn deviation at mid latitude during daytime is indicative of the focus of a large "anti-Sq" current cell established over the African sector in Northern Hemisphere. In the Southern Hemisphere, from the magnetic equator (SIK station) toward the high latitudes, the disturbance is not observed anymore; this is an illustration of the dissymmetry of the Ddyn disturbance relative to the magnetic equator. A Ddyn disturbance case is identified by Le Huy and Amory-Mazaudier [3] during the following period of storm: 5, 6 October 2000. The variations of the Ddyn disturbance on 6 October 2000 (Fig. 4), over the Asian sector, clearly show the equatorial signature of the Ddyn disturbance in the equatorial region and at mid latitudes in the Southern Hemisphere. It is clear that the zone of influence of the westward disturbed currents differs from one storm to another. To be accurate, this latitude strip may widen or narrow, it may also shift a bit northward or southward.

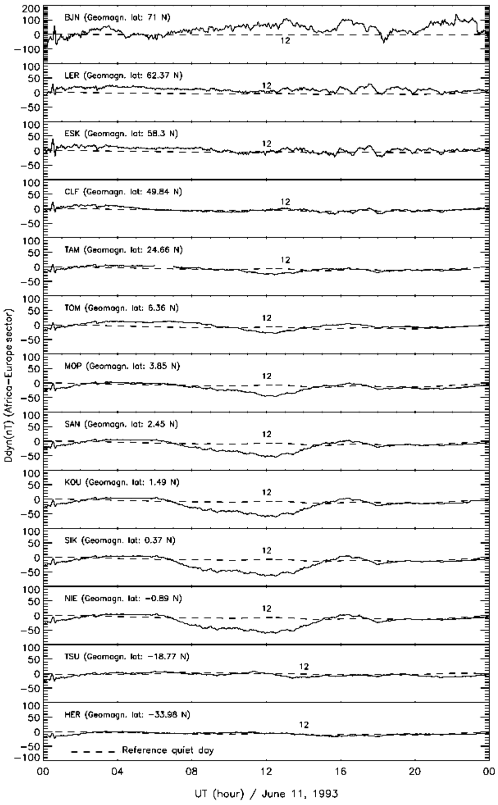

Figure 3: Latitudinal variation of Ddyn disturbance in the Africa-Europe sector, on 11 June 1993.

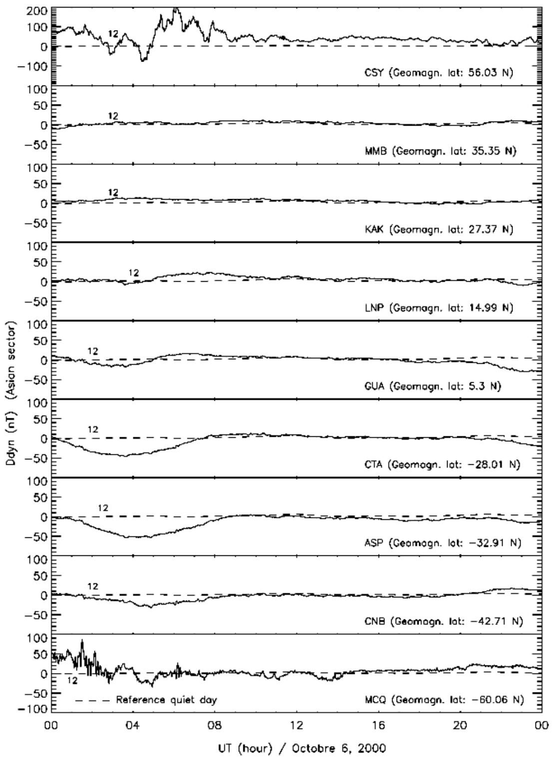

Figure 4: Idem as Figure 3, on 6 October 2000.

5. Summary and conclusion

From the analysis of the main features of the disturbance dynamo, the various results can be summed up as follow. At low latitudes and the magnetic equator, the Ddyn disturbance is southward associated with a westward disturbance of the equatorial electrojet current in agreement with recent simulations of the TIEGCM model [4]. The Ddyn disturbance is maximum at the magnetic equator, probably due to the daytime significant Cowling conductivity effect at the equatorial electrojet altitude. At mid latitudes in the Northern Hemisphere, the latitudinal variation of Ddyn disturbance shows the circulation of an eastward current at 45°N for a severe magnetic storm in agreement with the model of Blanc Richmond [2] whereas it is established around 60°N (near the heating zone) for a moderate magnetic storm. Both currents close via the low latitude and the equator through an "anti-Sq" cell. The Ddyn signature exhibits a dissymmetry with respect to the magnetic equator.

7. References

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