Effects of storm-time electrodynamic phenomena on the nighttime F-layer height at the magnetic equator: Analysis of ionograms data

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Abstract

In this paper, we report on a comparative study of the observed changes in the nighttime-profile of the F-layer height during the main and recovery phases of the 10-19 March 1998 storm period and the quiet night of 8-9 March preceding that period. The disturbed nights i.e. 10-11 March and 16-17 march were selected from the time variation of the *Dst* magnetic index in the main and recovery phases, respectively. The F-layer height data were collected from the quarter-hourly ionograms of an IPS 42-type vertical sounder at Korhogo (Ivory Coast; 9.2° N; 5° W; 2.4° S dip. lat.) in the West African sector. A common feature is that both time profiles show a single pulse height, peaking at about 20:15 LT. However, while the time profile in the quiet night is quite similar to the well known ExB pulse, with altitude and thickness about 330 km and 100 km respectively, the time profiles of the nights in the main and recovery phases show amplified altitudes up to 450 km. In view to understand these tendencies, the time variations of the polar magnetic disturbances *DP* of the 10-11 March and 16-17 March nights were represented as a function of the latitude varying from polar to equatorial regions conjointly to that of the polar magnetic activity indices *AU* and *AL*. A clear magnetic disturbance was detected on the polar magnetic activity indices *AU* and *AL*, in the night 10-11 March of the storm main phase, and was found to move equator-ward on the time profile of the polar magnetic disturbances *DP*, qualitatively explaining the ExB pulse reinforcement in this night. In contrast, the time profiles of the *AU* and *AL* indices and *DP* disturbances remained featureless in the 16-17 March night of the storm recovery phase. We discussed these trends in the light of the magnetospheric and ionospheric-disturbance dynamo theories.

1. Introduction

It is generally admitted that the F-layer motion in magnetic quiet conditions is controlled by three main mechanisms, i.e. the chemical recombination process at the bottom of the layer, the neutral winds and the polarization electric field [1]. Since the investigation of Fejer [2], one knows that the F-layer after sunset undergoes a rise and fall motion that peaks at about 330 km altitude nearby 20:00 LT. This motion is attributed to an enhancement of the zonal polarization electric field [3]. Very recently, an additional motion attributed to meridional neutral winds was evidenced in spring equinox period and it was observed that both electric field and neutral wind-controlled motions were influenced by the geomagnetic activity [4]. Several works devoted to the effects of geomagnetic storms on the ionospheric parameters have shown that two main mechanisms are involved in the changes of the current and electric fields patterns. The one is the magnetospheric dynamo whose effect is the direct penetration of an electric field from high to low latitudes [5]. The other, the ionospheric disturbance dynamo, is due to equator-ward neutral winds produced by high-latitude heating during geomagnetic storms. Its effect is to generate a westward electric field during the day and an eastward field in nighttime, at low latitudes. It is the purpose of this paper to study the nighttime changes of the F-layer height profile throughout a geomagnetic storm period at Korhogo/Ivory-Coast (9.2°N, 5°W, 2.4° S dip. lat.) and to verify the relevance of the magnetospheric and the ionospheric disturbance dynamo theories.

2. Data and processing

The device set up at Korhogo (Ivory Coast; 9.2° N; 5° W; 2.4° S dip. lat) is a vertical sounding IPS 42 transmitter-receiver. It explored the HF frequency range [1 MHz-22 MHz] and provided ionograms profiles in virtual coordinates every 15mn. The bottom level altitude of the F-layer, h'F2, is extrapolated from the low-frequency asymptotic value of the virtual height while the upper level one, hpF2, is read on the ordinary trace and is taken as the virtual height for the plasma frequency 0.832 foF2, foF2 being the critical frequency. The plot of h'F and hpF as a function of the time delimitates the F-layer semi-thickness and allows studying F-layer dynamics. We consider as F-layer height at any time, the altitude h'F2 of the bottom limit at that time and the comments on the layer motion are held with respect to its trace. The horizontal magnetic field data and the magnetic index Dst are collected from the Kyoto data base. The magnetic disturbance DP at any time, for a given station, is calculated using the following expression in which, θ denotes the dip latitude of the station, H and Hr

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the values of the horizontal magnetic field, at that time, for the studied disturbed night and the reference quiet night, respectively [6]:

$$DP = H - Hr - Dst \times Cos\theta$$

The disturbed nights investigated, March 10-11, 1998 and March 16-17, 1998 are selected from the time dependence of the Dst magnetic index over the whole March 10-19, 1998 storm period (fig. 1b). In this figure, the compression phase takes the Dst index up to 15 nT at 06:00 LT. Then the Dst index drastically decreases to -115 nT at about 20:00 LT. This is the storm main phase. Beyond 20:00 LT, it slowly increases up to the asymptotic value of 0 nT. This phase is the recovery one. Figure 1b shows that the March 10-11 night is spread over the peak of the Dst profile, including partly the main phase, and the March 16-17 one is far in the recovery phase. In all the paper, in order to characterize the magnetic activity, we use the daily magnetic index Am. The reference quiet night March 08-09, 1998 is selected in the period preceding the storm. In this night Am=3

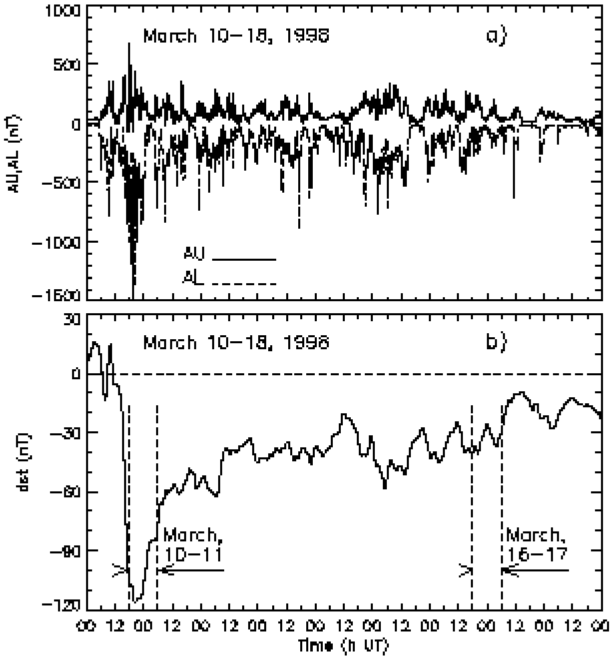

Figure 1: Time variations of a) the auroral magnetic activity indices AU and AL, and b) the magnetic activity index Dst over the whole disturbed period of March, 10-18, 1998.

3. Results and discussion

Figure 2a depicts the time variations of the F-layer height in the magnetic quiet night of March 08-09, 1998 (Am=3). The height time-profile can be subdivided into three main phases. In phase (1) laying between 18:00 LT and about 23:00 LT, the layer exhibits a single narrow pulse peaking at 330 km, at about 20:15 LT, with an elevation of 90 km that compares well with that found in other works, ~100 km [4]. This phase is well known and generally interpreted as the ExB plasma drift consecutively to the pre-reversal enhancement of the polarisation electrical field after sunset [2]. During phase (2), the layer remains featureless at about 210 km altitude until 04:30 LT. This phase is often associated to chemical processes that control the altitude at the bottom part of the F-layer. Beyond 04:30 LT, phase (3) is observed with a slight increase in the layer height, possibly due to pre-sunrise phenomena. We consider now, the F-layer height time-variations in the disturbed nights of, March 10-11, 1998 (Am=72) in the main phase (fig. 2b) and, March 16-17, 1998 (Am=24) in the recovery phase (fig. 2c), of the storm. As did the time profile in the quiet night (fig. 2a), both height-profiles exhibit three phases i.e., a single-pulse phase, ExB-like as it peaks at about 20:15 LT, between 18:00 LT and 22:30 LT, a steady phase at about 225 km altitude between 22:30 LT and 04:00 LT and a pre-sunrise ascent phase beyond 04:00 LT. The main difference with the quiet night profile lies in the ExB-like pulse altitude that is strongly amplified in the disturbed nights. As a comparison, we find the values of 450 km and 420 km for the nights in the main and recovery phases of the storm respectively, against 330 km that was measured for the quiet night. This suggests, at least, an intensification of the post-sunset electric field in the disturbed nights. Two mechanisms, possibly involved, are the magnetospheric and the ionospheric disturbance dynamos [7]. In figure 1b, the time dependence of the magnetic index Dst, throughout the overall disturbed period, strongly decreases and reaches its peak value of -115 nT in the night March 10-11, 1998, i.e. around the moment of the amplified ExB height-pulse peak (fig. 2b). This is correlated to the highest auroral activity indices AU and AL (fig. 1a), meaning that an intense westward disturbance ring-current, associated to a high auroral activity, flow in the equatorial plan in the night March 10-11, 1998. To analyse its implications on the F-layer height amplification in this night, we represent in figure 3a, the time dependence of the magnetic-field DP associated to polar-origin disturbances, as a function of the geographic latitude varying from auroral to equatorial regions, conjointly to that of the auroral activity indices AU and AL (top panel), during the storm main-phase.

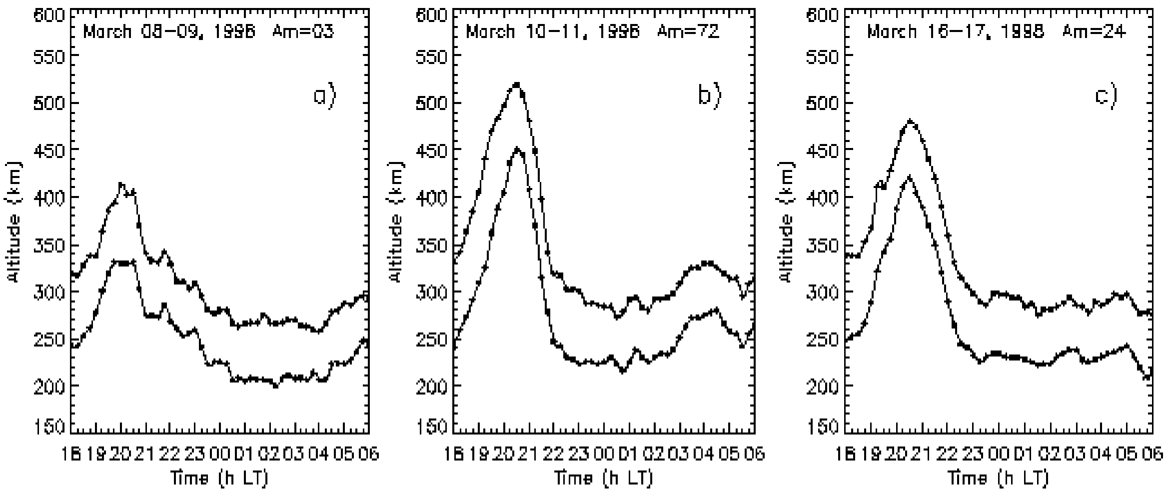

Figure 2: Time variations of the F-layer height in a) the March 08-09, 1998 magnetic quiet night, b) the March 10-11, 1998 night in the main phase and c) the March 16-17, 1998 night in the recovery phase of the storm. Note that the peak altitude of the F-layer is highly amplified in the nights of the main and recovery phases of the storm with respect to that in the quiet night.

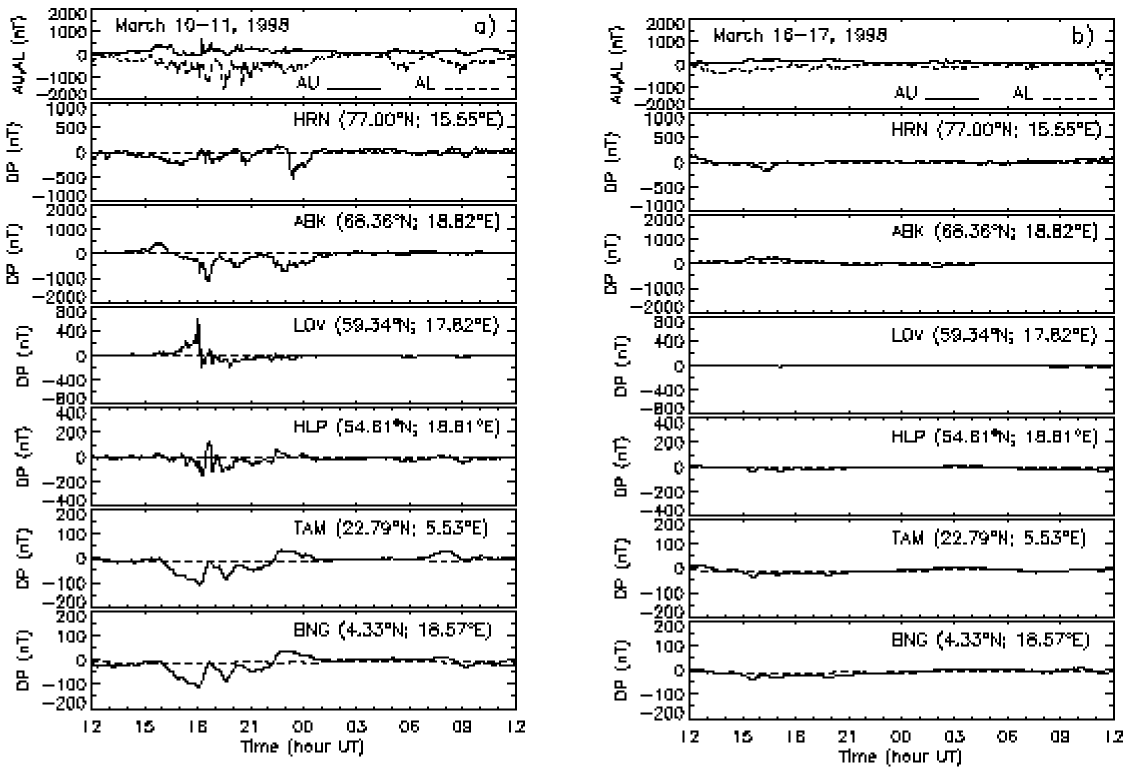

Figure 3: Time variations of the auroral magnetic activity indices AU and AL (top panels) and the polar-origin magnetic disturbance DP at different latitudes from auroral to equatorial zones in a) the March 10-11, 1998 night in the main phase and b) the March 16-17, 1998 night in the recovery phase of the storm.

One clearly notices in this figure that, in March 10-11, within the period [16:00 LT - 00:00 LT] of intense auroral activity, strong southward disturbances of the magnetic field take place in auroral regions, with a maximum magnitude of about 1000 nT near 18:00 LT at Abisko (ABK, 68.36°N). Similar disturbances are observed at lower latitudes, however with weaker maximum magnitude. In equatorial regions (fig. 3a), particularly at Bangui (BNG, 4.33°N), the maximum magnitude is about 120 nT near 18:00 LT, suggesting some intensity losses as the disturbances approach the equator. This is reminiscent of the effect of direct penetration of fields and currents from high to low latitudes [8]. One consequence of such disturbances on the night-time ionospheric parameters is the enhancement of the plasma upward-drift (additional eastward electric field), that can explain the strong intensification of the ExB height-pulse observed in figure 2b. In figure 1a, the time dependence of the indices AU and AL exhibits a weak auroral activity in the night March 16-17, 1998 as was expected for nights in the recovery phase of the storm (fig. 1b). As a consequence of this low auroral magnetic activity, no significant polar-origin disturbance DP is observed, as its time pattern is superimposed on the zero baseline whatever the geographic latitude (fig. 3b). Thus, the mechanism of direct penetration of the electric field is likely not involved in the height-pulse enhancement in the March 16-17, 1998 night. Several hours after the beginning of a storm or intense magnetic activity, auroral Joule heating drives equator-ward neutral winds. The ionospheric response to these winds at mid-latitude is a westward wind due to Coriolis force actions and a pole-ward dynamo electric field [9]. In equatorial regions, this results in a westward electric field during the day and an eastward electric field in night-time [7] that superimpose upon the regular ones. The ionospheric disturbance dynamo mechanism is a good candidate to explain the amplified ExB height pulse observed in the March 16-17 night.

4. Conclusion

The mechanisms of night-time changes of the F-layer height during the main and recovery phases of the March 10-19, 1998 storm period were investigated by comparison to that of the March 8-9, 1998 magnetic quiet night preceding that storm taken as reference. We found that the ExB mechanism is the main driver of the F-layer motion in both quiet and storm nights and that the effect of the storm is to amplify the layer height (by 27-36%) whatever the phase. The mechanism of this amplification differs according to the storm phase. In the main phase, the amplification is likely occasioned by a disturbance electric field penetrating from high to low latitude regions as revealed by a clear progression of the magnetic field disturbance DP associated to an intense auroral activity detected in the AU and AL indices. The mechanism involved in the recovery phase was discussed. Low latitude eastward electric fields consecutive to ionospheric winds produced by auroral heating are likely the driver of the layer height amplification.

This work will be continued with several storm periods in view of a quantitative comparison of the F-layer height amplification and the magnetospheric/ionospheric dynamo model.

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