Simulation of electric field and current during the June 11, 1993, disturbance dynamo event: comparison with the observations

K. Z. Zaka[1], O. K. Obrou[2] and N. M. Mene[3]*

Laboratoire de Physique de l'Atmosphère, UFR SSMT, Université Félix Houphouët Boigny Abidjan-Cocody, 22 BP 582 Abidjan 22, Cote D'ivoire

[1] komzach@yahoo.fr ; [2] olivier.obrou@fulbrightmail.org ; [3] medardmene@yahoo.fr

Abstract

The ionospheric disturbance dynamo signature in geomagnetic variations is investigated using the National Center for Atmospheric Research Thermosphere-Ionosphere-Electrodynamics General Circulation Model. The model results are tested against reference magnetically quiet time observations on June 21, 1993, and disturbance dynamo effects observed on June 11, 1993. The model qualitatively reproduces the observed diurnal and latitude variations of the geomagnetic horizontal intensity and declination for the reference quiet day in middle and low latitude regions, but underestimates their amplitudes. The patterns of the disturbance dynamo signature and its source "anti-Sq" current system are well reproduced in the northern hemisphere. However, the model significantly underestimates the amplitude of disturbance dynamo effects when compared with observations. Furthermore the amplitude maxima occur at different local times than the observations. The discrepancies suggest that the assumed high-latitude storm-time energy inputs in the model were underestimated.

1. Introduction

During high geomagnetic activity periods, disturbance winds from high latitude regions may influence the low latitude ionosphere. These dynamo effects have been associated with mid-latitude winds driven by the high latitude Joule heating and with fossil winds accelerated by strong ion convection in the auroral regions. [1] proposed the ionospheric disturbance dynamo mechanism to explain electric field disturbances observed at the end of magnetic storms. The influence of geomagnetic activity on mid and low latitude thermospheric winds and ionospheric electric field has been investigated using the National Center for Atmospheric Research Thermosphere-Ionosphere-Electrodynamics General Circulation Model (NCAR TIE-GCM) by [2]. The model results showed that when the geomagnetic activity ceases, zonal disturbance winds can last for many days in the post recovery period, while the meridional disturbance winds vanish more rapidly, in accordance with the changes in the thermospheric circulation, which lead to disturbances of electric fields and currents at mid and low latitudes. However, the ionospheric disturbance dynamo effects observed at mid and low latitudes through measurements of electric fields and currents have not yet been fully reproduced by models. In the present study, we use the NCAR TIE-GCM to investigate the effects of disturbance winds on the electric field and current in the mid and low latitude ionosphere during the disturbance dynamo (*Ddyn*) event on June 11, 1993 [3]. To that end, the observed magnetic variations are compared with the model results. In fact, electric current simulations at mid latitudes and low latitudes with the TIE-GCM have not yet been presented for disturbed conditions. Using the TIE-GCM to simulate the equatorial electrojet (EEJ) magnetic perturbations, [4] focused their study on magnetically quiet periods only. Furthermore, the previous simulations performed by [2] did not assess the capability of the model to reproduce the current circulation associated with the ionospheric disturbance dynamo mechanism at mid and low latitudes.

2. Model Description and Input Parameters

As described by [5], the NCAR TIE-GCM is a three-dimensional, time-dependent model which solves the full dynamical equations of the coupled thermosphere and ionosphere self-consistently. It is designed to calculate the coupled dynamics, chemistry, energetic, and electrodynamics of the global thermosphere-ionosphere system between about 97 km and 500 km altitude. In particular, the TIE-GCM calculates the ionospheric electric fields and currents and their associated magnetic perturbations. With a specified day number of the year, *F10.7* solar flux, high-latitude hemispheric power of precipitating auroral particles, cross-polar-cap electric potential and tides specified at the lower boundary, the model calculates global electric fields and currents, ion and neutral densities, temperatures, compositions, and velocities.

3. Models Results

3.1. Model Simulation Context

The primary goal of this study is emphasizing the disturbance dynamo effects in mid and low latitude regions on the basis of the TIE-GCM simulations. The model simulations are performed in the geophysical contexts of the quiet

day 21 June 1993 ($\sum Kp = 2+$) and of the storm recovery day 11 June 1993 ($\sum Kp = 17$). Figure 1 shows variations of the *Dst* index (Figure 1a) and the *AE* index (Figure 1b) for 20–21 June (dashed lines) and 10–11 June (solid lines). On 21 June, the *Dst* index varies very slowly. The amplitude of the AE index is relatively weak as well (less than 100 nT). On 10–11 June, the Dst index exhibits the different phases of a magnetic storm. During the main phase of the storm, the AE index is strongly enhanced. During the recovery period, the values of the AE index strongly decrease. The strong enhancement of the AE index indicates that the auroral activity was intensified during the main phase of the storm. Although it strongly decreases after the main phase of the storm, during the recovery the auroral activity is still important. This study focuses on the disturbance dynamo effect by examining the diurnal variations of the simulated horizontal northward H and eastward D components of the geomagnetic field. The model includes the effects of disturbance dynamo and direct penetration of the imposed high latitude electric fields to low latitude. The diurnal variations of H and D simulated by TIE-GCM include these two effects, and these runs are referred to as case 2. To isolate the effect of the disturbance dynamo a second set of H and D calculations was performed without penetrating electric fields, which we refer to as case 1.

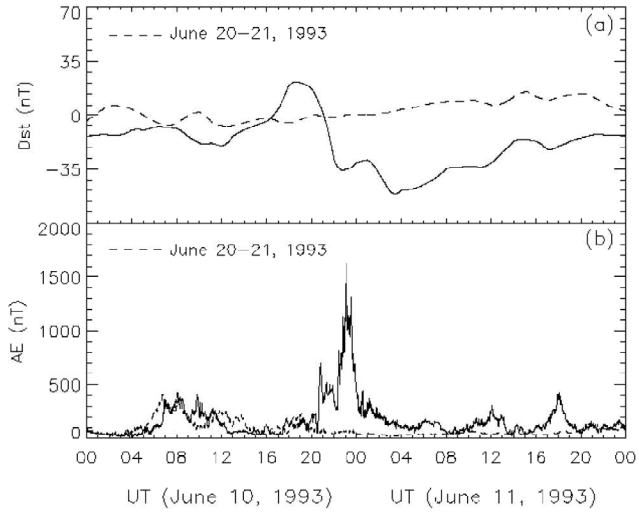

Figure 1: Variations of the (a) Dst and (b) AE indices on 10–11 June (solid lines) and 20–21 June 1993 (dashed lines)

3.2. Comparison Between Model Simulations and Observation

Figure 2 compares the simulated diurnal variations of the H component in case 1 (solid lines) and case 2 (dashed lines) with the observations (dotted lines) on 11 June (left) as well as on 21 June 1993 (right). The magnitude of the observations is larger than that of the simulations in the two cases. During the disturbed day (11 June) the case 2 simulations are closer to the observations at the low latitude stations than are the case 1 simulations. At high-latitude and mid latitude stations, the observed diurnal variation of H exhibits a strong negative depression in the morning. Then it increases in the afternoon and gets closer to the case 2 simulation. On 21 June the morning depression is also observed at those stations, but is weaker. The morning depression in the observed diurnal variations of H is not reproduced by the simulations. The amplitude of the observed diurnal variation of H near the dip equator is remarkably higher than the simulations. On 11 June 1993 (Figure 2, left), both simulation cases reproduce the observations reasonably well at the low latitude stations. The difference between the observations and simulations is smaller for case 2 than for case 1 at those stations, because the effects of the direct penetration electric field increase the simulated amplitude. In contrast, on June 21 (Figure 2, right) both simulations significantly underestimate the observation amplitudes. On this quiet day, the amplitudes of the simulations are quite similar at low latitude, which means that the simulated effect of electric field penetration is very weak there. This result suggests that the magnetospheric convection electric fields might not affect significantly the mid latitude and the low latitude current systems during quiet days in the TIE-GCM. However, as we mentioned earlier, the limitations of the TIE-GCM for calculating direct penetration electric fields prevents a definitive conclusion on this question. Furthermore, regarding the big difference between the amplitudes of the simulations and observations at the dip equator, it could be possible that the penetration eastward electric field contributes to increase the eastward current intensity near the dip equator even during quiet days. Another major contributor to the underestimation of the magnetic perturbation at the dip equator in TIE-GCM results is the underestimation of E region electrical conductivity. The reasons for this are not well understood, but one possible reason could be an underestimation of the solar X-ray fluxes used by the model. In section 3.3, we compare the simulated and observed disturbance dynamo effects in case 1 as well as in case 2, in order to show how important are the disturbance thermospheric wind dynamo effects at mid latitudes and low latitudes.

3.3. Latitudinal Variation of Simulated and Observed Disturbance Dynamo Effects

The disturbance effects are estimated for the case 1 and case 2 simulations and for observations on 11 June by subtracting the corresponding diurnal variations of the H component on 21 June 1993. In Figure 3, the resulting disturbance dynamo (Ddyn) effects alone (case 1) and with direct penetration electric field effects (case 2) that are associated with the 11 June disturbance simulations are compared with observations from the ground based data. The observations represent a combination of Ddyn and direct penetration electric field effects. The dotted lines are the zero reference level. The latitudinal trend of Ddyn is consistent with the observations, in that the daytime horizontal Ddyn variations are southward at the low-latitude stations and northward at high-latitude stations. The structure of the horizontal Ddyn variations is associated with an equivalent current system, which flows westward at low latitudes and eastward at high latitudes. Such a current system corresponds well to the structure of an "anti-Sq" current system that had been set forth by diverse workers through observations. However, the TIE-GCM model seems to underestimate the magnetic effects of this current. Indeed, the simulated disturbance in the two cases is far weaker than the observations. It is possible that the simulated disturbance winds are too weak and may not have the correct longitudinal variation to produce the observed Ddyn variations. We noted earlier that the TIE-GCM winds at northern mid latitudes around midday have greatly diminished by 12 UT. The relatively weak disturbance winds over much of the summer hemisphere help explain the relatively weak disturbance dynamo effects predicted by the TIE-GCM. Since the disturbance winds depend on the intensity and distribution of high-latitude energy inputs during the preceding storm, it is entirely possible that the assumed distribution of the energy inputs does not adequately represent the true inputs for this storm and that the simulated winds therefore underestimate the true winds in the dynamo region. Such information can be useful to improve future modeling of thermospheric storms.

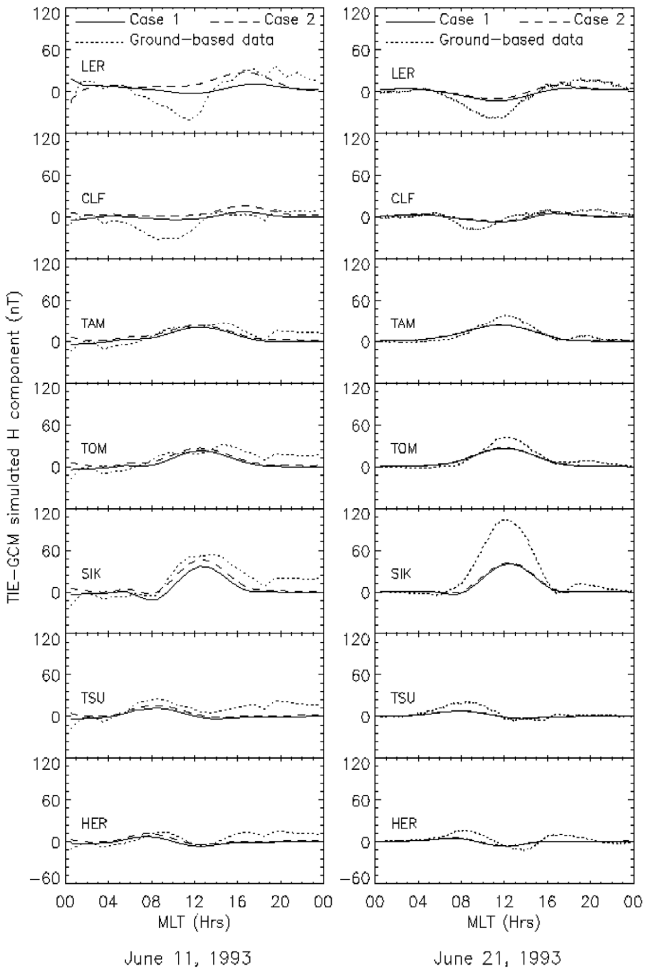

Figure 2: Comparison of the diurnal variations of the simulated H component in case 1 simulations (solid lines) and in case 2 simulations (dashed lines) with the observations (dotted lines) on (left) 11 June 1993 and (right) 21 June 1993.

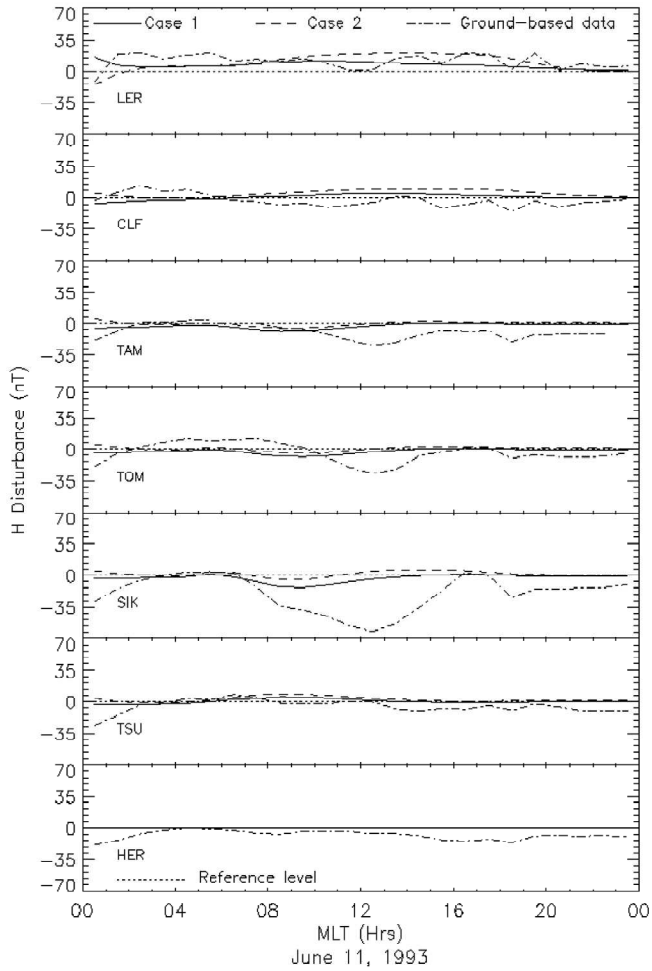

Figure 3: Comparison with observations (dash-dotted lines) of the latitudinal variations of the simulated H disturbances associated with the disturbance wind dynamo alone (Ddyn, case 1; solid lines) and of the disturbance dynamo with penetration electric field effects (case 2; dashed lines). All values represent the difference between the disturbance dynamo day (11 June 1993) and the reference quiet day (21 June 1993). The dotted line is the zero reference level.

4. Conclusion

In the present study, we have examined the magnetic field variations associated with the ionospheric disturbance dynamo event on 11 June 1993. This event has been simulated by the TIE-GCM and compared with observations in the Europe-Africa longitude sector. The TIE-GCM simulations were performed first by ignoring the penetration of the magnetospheric convection electric field to mid latitudes and low latitudes and then by including it. In addition the geophysical conditions of 21 June 1993, selected as the reference magnetically quiet day, were used to simulate the quiet time diurnal variations of the geomagnetic field. The analysis of the simulated diurnal variations of the H and D components of the geomagnetic field showed that the TIEGCM qualitatively reproduces the features of quiet day magnetic variations associated with the mid latitude and low-latitude ionospheric current systems, although it underestimates the amplitudes. At the dip equator, our results are in accordance with the equatorial electrojet magnetic signature analyzed by [4]. The analysis of the geomagnetic field variations during the disturbance period showed that the contributions of the regular ionospheric wind dynamo, of the disturbance dynamo, and of the magnetospheric convection electric field penetrations overlap at mid latitudes and low latitudes. On the one hand, the effects of the disturbance dynamo tends to reduce the magnetic effects of the regular ionospheric wind dynamo, while on the other hand the effects of magnetospheric convection eastward electric field penetrations tend to increase the effects of the regular ionospheric wind dynamo currents at low latitudes. The patterns of the disturbance dynamo signature and its source "anti-Sq" current system are well reproduced in the Northern Hemisphere. However, the model significantly underestimates the amplitude of disturbance dynamo effects when compared with observations. Furthermore, the H disturbance minima occur at different local times than the observations. The discrepancies suggest that the assumed high-latitude storm time energy inputs in the model do not adequately represent the true inputs for this storm. The magnitudes of the penetration electric field and disturbance dynamo effects are strongly enhanced at the dip equator. The mechanism of this enhancement is related to the enhanced Cowling east-west electrical conductivity associated with the equatorial electrojet along the magnetic dip equator. During magnetically quiet days, the thermospheric wind disturbance effects do not exist or are very weak, but the effects of the convection electric field can be significant according to the level of the cross polar electric potential drop. Thus, the day to day, seasonal, and solar activity changes might have nonnegligible influences on the variability of the equatorial electrojet. At the equator, the electric field penetrations should be realistically taken into account in evaluating the disturbance as well as in analyzing the magnetic signature of the equatorial electrojet.

References

1. M. Blanc, and A. D. Richmond, "The ionospheric disturbance dynamo", *J. Geophys. Res., 85*, 1980, pp. 1669-1686.

2. C. M. Huang, A. D. Richmond, and M.,-Q. Chen, "Theoretical effects of geomagnetic activity in low-latitude ionospheric electric fields", *J. Geophys. Res., 110, A05312*, 2005, doi: 10.1029/2004JA010994.

3. K. Z. Zaka, A. T. Kobea, P. Assamoi, K. O. Obrou, V. Doumbia, K. Boka, B. J.-P. Adohi, and N. M. Mene: "Latitudinal profile of the ionospheric disturbance dynamo magnetic signature: comparison with the DP2 magnetic disturbance", *Ann. Geophys., 27,* 2009 pp. 3523-3536.

4. V. Doumbia, A. Maute, and A. D. Richmond, "Simulation of equatorial electrojet magnetic effects with the thermosphere-ionosphere-electrodynamics general circulation model", *J. Geophys. Res., 112, A09309*, 2007, doi: 10.1029/2007JA012308.

5. T. W. Fang, A. D. Richmond, J. Y. Liu, A. Maute, C. H. Lin, C. H. Chen, and B. Harper, "Model simulation of the equatorial electrojet in the Peruvian and Philippine sectors", *J. Atmos. Sol. Terr. Phys., 70*, 2008, pp. 2203–2211.