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THERMOSPHERIC COMPOSITION CHANGES SEEN DURING A GEOMAGNETIC STORM

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ABSTRACT

The largest magnitude winds observed using the instruments on board the Dynamics Explorer 2 (DE-2) satellite were measured during the large geomagnetic storm that occurred on the 24th of November 1982. Neutral temperatures exceeded 2000 K during this storm, and these high temperatures, combined with the very large observed winds and the very full instrumental coverage available in both hemispheres, make it a unique event to study. In this paper we present results obtained using these DE-2 data and a time dependent simulation of the event made using the National Center for Atmospheric Research Thermosphere/Ionosphere General Circulation Model (NCAR-TIGCM). In general, the agreement between model calculations and the data is very good, implying that most of the important physical processes controlling the energetics and dynamics of the thermosphere are reasonably well represented in the model. The modelled summer hemisphere changes in the mass mixing ratio of N_2 (Ψ_{N2}) are in very good agreement with the DE-2 data, and the overall global pattern of Ψ_{N2} in the model is also in good agreement with the averaged data in both hemispheres. This agreement allows us to study the physical processes occurring in the model with confidence that they are the same as those occurring in the "real" thermosphere. This short paper describes model-experiment comparisons for the November 24, 1982 geomagnetic storm, but does not include the processes reponsible for these changes. A full description of them is available in the set of papers /1, 2, 3, 4/.

INTRODUCTION

The study of the changes in neutral composition that result from geomagnetic storms has continued for a relatively long time. For example, Duncan /5/ attributed the observed high-latitude decrease in electron densities during geomagnetic storms to changes in neutral composition. Satellite measurements have enabled us to gain a greater understanding of the morphology of these changes, particularly in the region above 250 km In particular, Prölss /6/ has presented a local time-latitude map of the observed neutral composition changes during geomagnetic storms. A number of theoretical studies have been made to attempt to explain these changes which have met with considerable success (e.g. /7, 8, 9, 10/). However, these studies have attempted to solve the problems associated with composition changes during geomagnetic storms in a one or two dimensional sense, whereas the problem is essentially a three-dimensional one.

The two major TGCMs (Thermospheric General Circulation Models) presently in existence, the University College London (UCL) TGCM /11 and 12/ and the NCAR-TIGCM /13, 14 and 15/, have the potential to solve some of the problems associated with geomagnetic storms, provided that they can predict thermospheric composition changes accurately. Until recently it was believed that they were not producing the required composition changes (e. g. /16, 17/), but new work has indicated that not only are reasonable predictions being made /4, 18/, but also that the two models are in quite good agreement /18/. It is clear that these models have now reached the stage where detailed comparisons should be made with data, so that a better understanding of the processes involved in producing storm time composition changes can be attained.

In this paper we discuss a study of the very large geomagnetic storm that occurred on the 24th of November 1982. Excellent data quality was available from all the instruments on board the Dynamics Explorer 2 spacecraft during this storm, including measurements of neutral composition, wind and temperatures, ion winds and ion temperatures, and electron densities and temperatures. Neutral composition variations cannot be considered in isolation from the other state variables of the thermosphere, and a greater understanding of neutral composition changes is best gained by using as many different types of data as possible, combined with the most appropriate model. Such coverage is

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provided by the DE-2 data and by the NCAR-TIGCM for this time period The geomagnetic storm studied is described in more detail in the next section, which also includes a general comparison of model results with DE-2 data, and a specific comparison between these data and the model for one orbit The results of this work are summarized in the last section.

DATA-MODEL COMPARISONS

A very large geomagnetic storm occurred at about 1100 hours universal time (UT) on day 328 of 1982 (see Figure 1a for the record of the K_p index during this period) The large event was preceded by 2 smaller storms in the previous two days, before which geomagnetic activity had been predominantly moderate for a few days. The relatively short period (10 - 11 hours) between the large event and the preceding smaller event means that long-lived thermospheric compositional perturbations induced by the earlier geomagnetic activity may have affected the data associated with the later event. In this later event, which is the storm discussed here, K_p reached values of 7^+, and very strong geomagnetic activity (K_p greater than 7^-) continued for the 15 hours after 1200 UT (the storm onset occurred at around 1100 UT). Data were also available about the interplanetary magnetic field (IMF) for this period. Bulk IMF speeds of over 800 km/s were observed during this storm and the magnitude of the IMF exceeded 30 nT at times The large values of these IMF parameters were associated with large potential drops across the polar cap, which in turn forced ion winds of more than 2000 m/s and neutral winds in excess of 1200 m/s. These strong winds also led to large temperature increases as a result of frictional heating (neutral temperatures exceeded 2000 K at times), and consequently large changes in neutral composition at high and middle latitudes

The NCAR-TGCM is a three-dimensional, time-dependent model of the Earth's neutral upper atmosphere that is run on the CRAY-XMP and YMP computers at NCAR. The model uses a finite-differencing technique to obtain time-dependent solutions for the coupled, non-linear equations of hydrodynamics, thermodynamics and continuity of the neutral gas /13, 14/ and for the coupling between the dynamics and the composition /14/. The new TIGCM with a coupled ionosphere and a self-consistent aeronomic scheme has been developed recently by /15/. The simulation used in this study was a time-dependent study, appropriate for the geophysical conditions that existed on November 24, 1982, which was made by specifying the cross-cap potential and hemispheric power using algorithms developed by Drs. P Reiff and B Emery, B_y data from NSSDC and F 10.7 data from Ottawa.

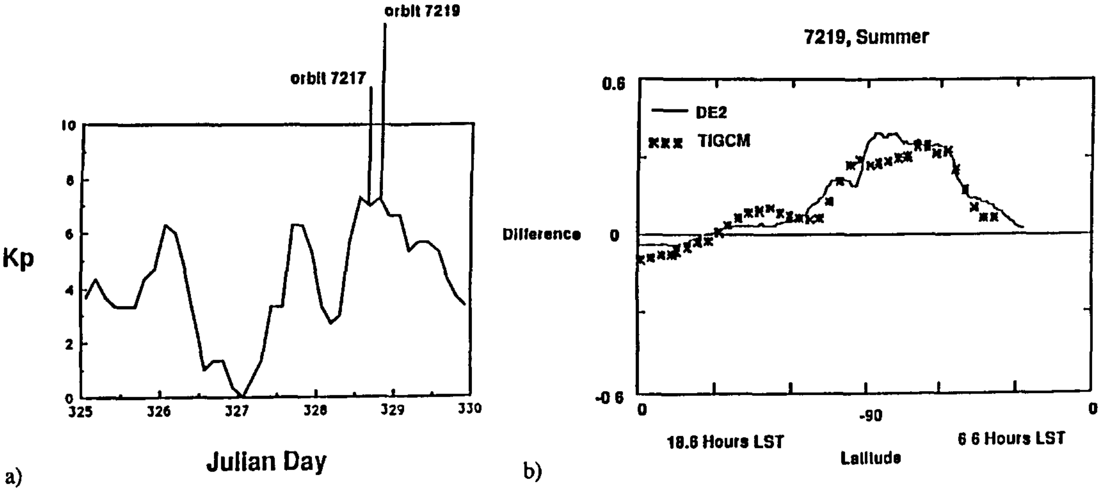

Fig. 1. a) K_p values for the period prior to and including the storm on the 24th of November b) A comparison of Ψ_{N2} changes for DE-2 storm time data compared with the quiet time MSIS case and for the equivalent orbit through the NCAR-TIGCM simulation in storm and quiet times. The data and the model simulations are for DE-2 orbit 7219, which occurred at about 1900 hours on the 24th of November. The magnetic pole projection is located about 10 degrees from the geographical pole on the dawn side.

A comparison has been made between the Ψ_{N2} changes from storm to quiet times predicted by the NCAR-TIGCM and those observed by the DE-2 satellite (the satellite data are compared with quiet time MSIS - 86 /19/ values) during orbit 7219, at about 1900 hours on the 24th of November (Figure 1b). This figure is for the summer (southern) hemisphere and the altitude of the satellite is between about 270 km and about 530 km (the latter occurs at low latitudes on the morning side of the auroral oval). An equivalent satellite trajectory has been run through the gridded model output fields, allowing a point by point comparison to be made with the DE-2 data. The agreement between the model and the data is excellent at this time, with the peak in Ψ_{N2} perturbations occurring in the region between about 70 degrees geographic latitude on the evening side of the auroral and 50 degrees on the morning side. The magnetic pole projection is displaced some 10 degrees to the morning side of the geographic pole at this universal time and this will influence the distribution of changes in Ψ_{N2}. Agreement is not perfect at these high latitude regions, primarily because of the difficulties of parameterizing the ion convection pattern and the auroral precipitation. The NCAR-

TIGCM also predicts a region of slight enhancements in Ψ_{N2} in the middle latitudes in the evening hours. These enhancements represent remnants from the previous storm but they can not be seen in the DE-2 data. Two explanations are apparent for this discrepancy: firstly, the auroral inputs used for the previous storm may have been too large and the composition changes may have been over predicted, or, secondly, the compositional recovery rate in the TIGCM may be too slow, leaving a larger "fossil" remnant Ψ_{N2} remnant than that which really occurs. We are currently studying this problem as part of a larger effort to understand post-storm compositional and thermal recovery

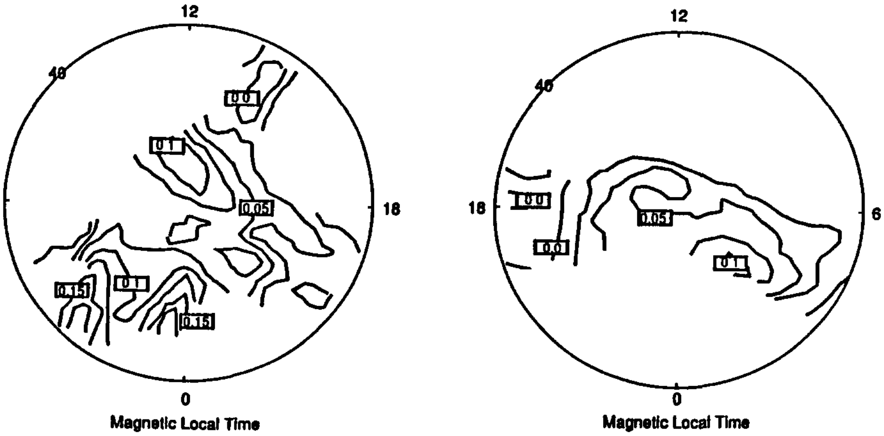

Fig. 3. Differences between the averages of DE-2 Ψ_{N2} when $K_p > 4^+$ and when $K_p < 4^o$ during the northern hemisphere winters of 1981/82 and 1982/83. The projections are in geomagnetic coordinates and extend from 40 degrees to the pole. The angular axis is in magnetic local time, and the altitude is 300 km. The left hand polar diagram represents the southern hemisphere changes at this time and the right hand polar diagram represents the winter hemisphere changes.

A more complete understanding of the storm time compositional response to geomagnetic forcing can be gained by comparing the averaged DE-2 compositional structure at times of high geomagnetic activity with the modelled compositional structure at similar times. Figure 3 shows the DE-2 measured differences between the averaged Ψ_{N2} at high geomagnetic activity ($K_p > 4^+$) and the averaged Ψ_{N2} at low geomagnetic activity ($K_p < 4^o$) for both the summer and winter hemispheres at solar maximum. One major feature that is seen in both hemispheres is that there is little enhancement in Ψ_{N2} on the dayside and evening side of the auroral oval. In fact, there is a decrease in Ψ_{N2} on the evening side of the auroral oval /4/ in the northern (winter) hemisphere at middle latitudes. Also, the area of storm-time enhanced Ψ_{N2} perturbation is very much offset towards the morning side of the auroral oval. Of particular note is the very distinctive pattern of enhancement in the summer hemisphere, whereby one tongue of strong enhancement extends towards lower latitudes at magnetic local midnight and another towards lower latitudes at a magnetic local time of about 300 hours. These averaged patterns should be treated with a little caution, however, as they are an amalgamation of data from a number of storms with very different intensities. They tend to be more representative of smaller storms rather than larger ones, as these occur more frequently. Another feature of interest is that storm-related Ψ_{N2} enhancements extend to lower latitudes in the summer hemisphere than in the winter hemisphere (also see /21/), and that Ψ_{N2} does not show larger changes in the winter hemisphere than in the summer hemisphere, unlike the N_2/O ratio /20/.

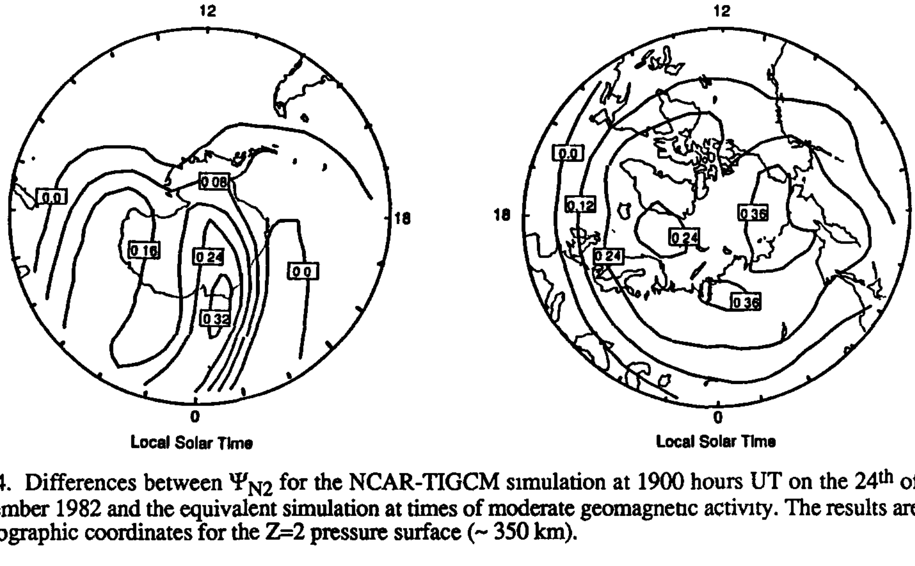

Fig. 4. Differences between Ψ_{N2} for the NCAR-TIGCM simulation at 1900 hours UT on the 24th of November 1982 and the equivalent simulation at times of moderate geomagnetic activity. The results are in geographic coordinates for the Z=2 pressure surface (~ 350 km).

Figure 4 shows the NCAR-TIGCM predictions of changes in Ψ_{N2} for the very large storm that was described earlier. The modelled enhancements in Ψ_{N2} are larger than those seen in the data considered in the previous paragraph, primarily because of the large magnitude of this storm. The overall pattern of Ψ_{N2} changes is very similar to that of the data. for example, the southern (summer) hemisphere has the two tongues of enhancement at local midnight and 300 hours local solar time, with an area of smaller enhancement in between. It is harder to make comparisons in winter because the data are more sparse, but the overall pattern seems very similar, with the largest enhancements being seen in the early morning hours near the auroral oval. It is unclear from this diagram whether the model is predicting a larger area of enhancement in the summer hemisphere than in the winter hemisphere as is seen in the data, but this feature does become apparent when global plots of mixing ratio change are considered. Even within the area of enhancement there are striking differences between the two hemispheres, with the large enhancements tending to be restricted to the area near the auroral oval in the winter hemisphere, but extending far equatorward in the summer hemisphere on the early morning side of the auroral oval The dayside enhancements equatorward of the auroral oval in the winter hemisphere represent remnants of the previous storm, rather than effects due to this period of enhanced activity.

CONCLUSIONS

We have conducted an investigation into the compositional changes associated with the very large geomagnetic storm that occurred on the 24th of November 1982 using DE-2 data and a simulation of the event that was made using the NCAR-TIGCM The large changes in the thermosphere and ionosphere that occurred during this storm make it a very interesting event to study. A point by point comparison was made by running a simulated satellite trajectory through the model, and the agreement between the model and the data was found to be excellent at times. A morphological comparison has also been made between this model simulation and the averaged DE-2 values of the changes that occur during geomagnetic storms The major features seen in the data are also reproduced by the model: the differences between the summer and winter patterns are well represented, including the smaller size of the area of enhancement in the winter hemisphere, the curious twin tongues of enhancement extending from the auroral oval towards local midnight and 300 hours local time in the summer hemisphere appearin both; the general tendency for the enhancements to occur in the early morning hours is seen and the lack of enhancements and possible reductions of Ψ_{N2} on the dayside and evening side of the auroral oval appear in both the model and the data. These results give us confidence that we can investigate the physical processes responsible for composition changes during a geomagnetic storm using the NCAR-TIGCM and the diagnostic processor discussed in /1, 2, 3 and 4/, with reasonable confidence that these processes are reasonably representative of those that are occurring in the real thermosphere. The other major conclusion that can be drawn from this study is that more physical insight can be gained when data are used in conjunction with modelling efforts than is available when either is used separately.

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