Foreword

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1. Introduction

The primary goal of the Geospace Environment Modeling (GEM) program of the National Science Foundation (NSF) is the development of one or more comprehensive, physical, first principles model(s) of Earth's geospace environment. There are many needs for such models, including the codification of our understanding of the physical processes, as a tool for the analysis of single (or a few) spacecraft observations, and in an operational setting for the forecast of space weather, to name a few. The analogy with atmospheric sciences shows that such model development takes decades and that the quality of models mostly progresses in small, incremental steps. In the course of model development it is imperative to test the models frequently in real world scenarios in order to document the progress and to expose shortcomings.

The GEM community has chosen to pose challenges to modelers to test their models against observations. Although this is not a formal model evaluation program, which would require more comprehensive data sets and well-defined metrics, it allows modelers to evaluate the realism of the modeling approach and to make, to a limited extent, comparisons among models, as well as with data. One has to realize, however, that magnetospheric and ionospheric data sets are quite limited in comparison to, for example, the data sets available in the atmospheric or oceanographic sciences. In particular, magnetospheric data are restricted to statistical average pictures, point measurements, and ionospheric synoptic maps. Even the most comprehensive data sets have limited resolution. For example, the synoptic maps of convection provided by assimilative mapping of ionospheric electrodynamics (AMIE) [*Richmond and Kamide*, 1988] are still very coarse in their spatial and temporal resolution. Thus model evaluation cannot be comprehensive but has to focus either on certain regions or on certain processes. One also needs to recognize that magnetospheric models are still in an early phase of development when compared with, for example, atmospheric models. The latter models are nowadays used for operational weather forecasting and face daily reality tests. By comparison, magnetospheric models are now at a development stage where atmospheric models were two to three decades ago. Thus expectations should not be too high, and significant differences between the models and the data are expected. In fact, it is exactly these differences that pose the most interesting questions and that drive improvements of the models. That is to say, it is not the objective of this challenge and other challenges to produce the best looking results but rather to reveal the models' shortcomings as a basis for further development.

The first GEM challenge specifically addressed ionospheric convection patterns during intervals of relatively stable interplanetary magnetic field (IMF) intervals [*Lyons*, 1998]. This challenge was quite successful, both in terms of participation and in terms of the scientific results. In particular, it showed that all models, ranging from global numerical models to field mapping models, produced consistently cross polar cap potentials larger than those observed. On the other hand, however, the polar cap potential patterns of most models were qualitatively similar to the observations.

On the basis of the success of the first challenge, the GEM community decided on a much more ambitious challenge, namely, the modeling of a substorm. Unlike the ionospheric potential patterns, the substorm is a much more complex phenomenon, and most researchers would certainly agree that key aspects of the substorm dynamics are still unresolved, despite several decades of research. While one might argue that testing the models against a phenomenon that is not yet understood from data may be pointless, one might also hope that the modeling efforts may actually reveal important aspects of a substorm that may go undetected in the data because of lack of coverage.

2. The Substorm

In choosing a suitable challenge event the emphasis was on finding an isolated substorm with well-defined features following an interval of magnetospheric quiescence. In other words, the challenge substorm should be as simple as it ever gets. However, it was also deemed important that sufficient data were available to drive the models and to compare with the model results. Specifically, continuous high-quality solar wind and IMF data needed to be available for inputs to the models, while various ground, ionospheric, and magnetospheric data sets could be used for comparison with the model results. This narrowed the choices considerably, and the November 24, 1996, 2230 UT substorm was chosen for the challenge. For this substorm the following key data sets were generously made available by the respective experimenter groups: Wind plasma and IMF; International Monitor for Auroral Geomagnetic Effects (IMAGE), Canadian Auroral Network for the OPEN Program Unified Study (CANOPUS), Magnetometer Array for Cusp and Cleft Studies (MACCS), and Greenland ground magnetometer data; IMP 8 magnetometer data from the midtail lobe; Geotail plasma and field data from the midtail; geosynchronous high- and low-energy plasma data from the Los Alamos National Laboratory (LANL) satellites; geosynchronous magnetic field data from the GOES satellites; Polar magnetic field data; Polar Visible Imaging System (VIS) auroral images; Defense Meteorological Satellite Program (DMSP) electric field data; AMIE synoptic maps of polar cap convection and field-aligned currents; Super Dual Auroral Radar Network (SuperDARN) convection data; and the empirical potential patterns from the Weimer model.

Wind observations of the solar wind [*Ogilvie et al.*, 1995] and IMF [*Lepping et al.*, 1995] are shown in Figure 1 for the period of 1800–2400 UT on November 24, 1996. Wind is during this time located at (73, -18, 8) R_E in GSE coordinates. The data in Figure 1 are not time-shifted. From the Wind location and the prevailing solar wind speed one expects a time shift of $\sim$18 min to the magnetopause. The solar wind velocity is almost constant throughout the entire interval. The solar wind number density is somewhat higher than normal ($10 - 12$ cm^{-3}) but fairly constant. There are also no major variations in the solar wind temperature. The period of interest is from 2030 to 2330 UT. Prior to 2045 UT the IMF is predominantly northward for over an hour. At that time a major rotation of the IMF occurs, and the IMF becomes predominantly southward, until $\sim$2213 UT. After that time the IMF is predominantly northward again. From these data one would expect a quiet magnetosphere prior to 2103 UT when the southward IMF reaches the magnetopause. After that a substorm growth phase should commence and eventually lead to a substorm expansion phase onset. However, from the IMF data it is impossible to predict when the expansion will occur.

Figure 2 shows this substorm from a ground magnetometer perspective. Figure 2 shows the north-south component

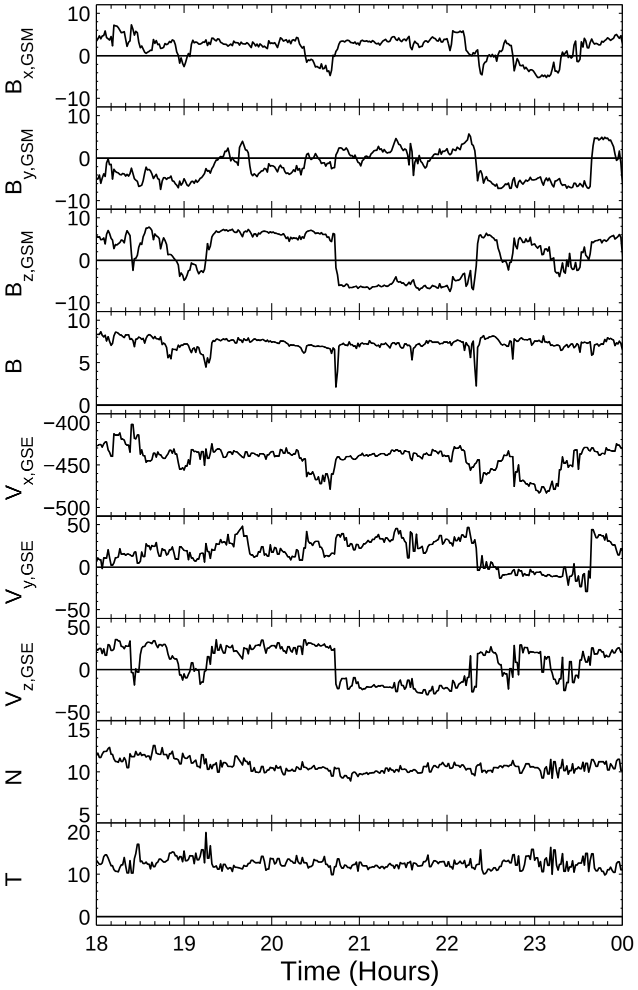

Figure 1. Wind interplanetary magnetic field (IMF) and solar wind data from (73, -18, 8) R_E GSE on November 24, 1996. From top to bottom are shown the magnetic field components B_x, B_y, and B_z; the total magnetic field (all in nanoteslas, GSE); the flow velocity components V_x, V_y, and V_z (in km s^{-1}, GSE); the number density (in cm^{-3}); and the temperature (in eV).

of the ground perturbation measured by the IMAGE magnetometer chain [*Viljanen and Häkkinen*, 1997] in Scandinavia. The stations are ordered from north to south in Figure 2. From 1800 UT until ∼2230 UT the magnetosphere is quiet. At ∼2230 UT there is a well-defined substorm onset, which begins about at the stations KIR (Kiruna), MUO (Muonio), SOD (Sodankylä), and PEL (Pello), all located between 63° and 65° magnetic latitude, and then expands both northward and southward. The exact onset timing is discussed in the following papers and by *Petrukovich et al.*, [1999]. The sharp features in the IMF and the isolated sharp onset make this event well suited for model comparisons.

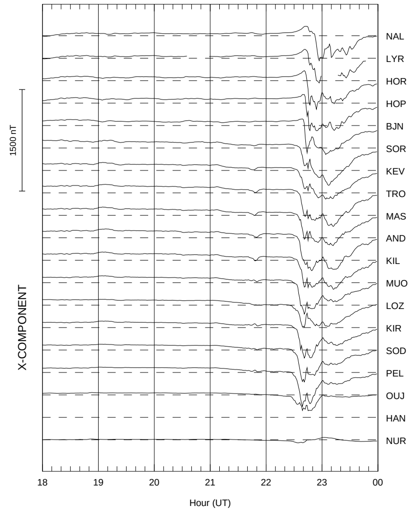

Figure 2. Ground magnetometer traces (1-min averages) from the International Monitor for Auroral Geomagnetic Effects (IMAGE) magnetometer chain on November 24, 1996. Shown is the north-south (X) component in units of nanoteslas. The stations are ordered in latitude from north to south: NAL (New Aalesund); LYR (Longyearbyen); HOR (Hornsund); HOP (Hopen Island); BJN (Bear Island); SOR (Sørøya); KEV (Kevo); TRO (Tromsø); MAS (Masi); AND (Andenes); KIL (Kilpisjärvi); MUO (Muonio); LOZ (Lovozero); KIR (Kiruna); SOD (Sodankylä); PEL (Pello); OUJ (Oulujärvi); HAN (Hankasalmi); NUR (Nurmijärvi).

3. Methodology

With the event selection and the data available the stage was set for detailed model comparison. After selection of the event in 1998 a mini-GEM workshop was held at the Fall American Geophysical Union (AGU) Meeting in December 1998, and full workshop sessions were held at the GEM meeting in June 1999. Owing to the fact that substorm dynamics is still a controversial issue, the event also attracted substantial interest from the experimental community, which helped considerably to interpret its features and aided in the discussion of the model results at the workshops. Models were fine-tuned, on the basis of discussions and data comparisons. The following papers present both experimental and modeling perspectives of this event and represent the current state of the art.

4. Conclusions

Clearly, predicting the onset time, location, and magnitude of the substorm electrojet, along with the plasmadynamic processes in the tail, poses a significant challenge for any model. The papers in this collection show that while some substorm features can be modeled with considerable fidelity, there is still much room for improvement. The important point is that a basis for such comparisons is established on which future model development can be built. In particular, one might expect that this event will be revisited with refined models in the future to document their progress.

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