SRI International

NASA/CR-1998- 207796

7N-46-CR
119123

Annual Report • 30 April 1998

TESTS OF SUBSTORM MODELS' PREDICTIONS USING ISTP OBSERVATIONS

SRI Project 1877

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Grant NAG5-4602

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1 INTRODUCTION

This report provides progress to date on grant NAG5-4602 to test the predictions of substorm models using ISTP observations. During the first year, two investigations were initiated in collaboration with a number of ISTP researchers. Both investigations use a combination of simultaneous measurements from high-, low-, and ground-altitude instruments to (1) explore the role of MHD resonances in the onset and evolution of substorms, and (2) establish the timing of events in the magnetosphere and ionosphere during the substorm evolution beginning with the growth phase and ending with the recovery phase.

2 INSTRUMENTS AND COLLABORATORS

Data from the following ISTP instruments are included in the analysis of the two investigations. Names of the collaborators for each effort are included in parentheses.

Groundbased

- CANOPUS magnetometers (J. Samson and T. Hughes)
- SuperDARN radars (K.B. Baker and R.M. Ruohoniemi)
- Sondrestrom incoherent scatter radar (J.D. Kelly)

Spacecraft

- LANL synchronous orbit particle analyzers (G. Reeves)
- LANL magnetospheric plasma analyzers (M. Thomsen)
- GOES 8 and 9 magnetometers (H. Singer)
- POLAR UVI (M. Brittnahcer)
- POLAR VIS (J. Sigwarth)
- Geotail low energy particle (T. Mukai and Y. Saito)
- Geotail magnetic field measurement (S. Kokubun)
- Geotail electric field detector (V. Angelopoulos)
- Interball tail magnetic field (S. Romanov)
- IMP 8 magnetic field investigation (R. Lepping)
- Wind magnetic field investigation (R. Lepping)
- Wind solar wind experiment (K. Ogilvie)

Other data sets included in the analysis are

Ground based

- IMAGE magnetometer network (A. Viljanen)
- DMI magnetometer network (T. Moretto)
- MACCS magnetomster network (W. J. Hughes)

Spacecraft

- DMSP (P. T. Newell and M. Hairston)

3 STUDY 1

In the first investigation, a combination of simultaneous measurements from high-, low-, and ground-altitude instruments was used to explore the role of MHD resonances in the onset and evolution of substorms. Two intervals were selected for which ISTP spacecraft were appropriately positioned in conjugate positions to ground-based magnetometer and radar chains. These intervals are 7–8 February 1996 and 19–20 May 1996. A spectral analysis of the observations for the first time establishes a direct relationship between Pc-5 resonances measured on the ground and the periodicity of stepwise dipolarizations and particle injections at geosynchronous altitude, discrete westward electrojet intensifications, plasma and magnetic field oscillations of the plasma sheet and lobes, and plasma and magnetic field oscillations in the magnetosheath. These observations strongly suggest that a coupling of magnetic field line resonances in different regions of the magnetosphere–ionosphere (M-I) system dictate a coherent substorm response.

A comparison of the power spectra of measurements taken at different magnetospheric regions during the mentioned substorm periods revealed that there are spectral peaks during expansion that are common to magnetic field pulsations at geosyncronous altitude (measured by GOES 8 and 9 spacecraft). The comparison also revealed geosynchronous energetic particle injections (LANL spacecraft); plasma density, convection, and magnetic field pulsations in the plasma sheet near –25 R_e (Geotail); and pulsations in the magnetosheath (IMP 8 and Interball Tail). Some observed frequencies coincided with the frequencies characteristic of the near-Earth cavity mode resonances, namely at or near 1.3, 1.5, and 1.9 mHz. However, there were peaks at frequencies that did not fit the resonant cavity picture. Two of these peaks, at around 0.8 mHz and 1.1 mHz, have been previously reported in spectral analyses of ground-based magnetometer data and it has been suggested that these peaks correspond to resonances of the magnetotail waveguide. Our investigation shows for the first time that the 0.8 and 1.5 mHz oscillations registered on the ground also occur in the afternoon and dusk geosynchronous regions, in the magnetosheath, and in the plasma sheet near the region where the onset of the substorm X-line is believed to occur.

This result, therefore, strongly supports the paradigm of a coherent response of the M–I system to substorm onset. It also suggests that the coherence may be effected through a coupling of resonant cavity modes, which involves energy transfer from compressional oscillations propagating from the outer magnetosphere into the near-Earth closed field lines, with other oscillation modes in different parts of the magnetosphere. Those modes include waveguide modes originated in the high-latitude open field line regions of the magnetosphere, and waveguide modes in the low-latitude closed field line regions of the magnetosphere encompassed by the low-latitude boundary layers and the plasma sheet. In the paradigm proposed, the coherent response can be a consequence of either of two properties of the M–I system, as presented in the following paragraph.

First, it is noted that the oscillations in the 0.8–1.1 mHz range have a period 15–20 min., which happens to be the inherent nonlinear response time of the magnetotail [e.g., Klimas et al., 1991]. Alternatively or cooperatively, the lobe-plasma sheet waveguide can develop compressional and flapping modes with resonances in the frequency range that contains the cavity mode frequencies and the 0.8 mHz component [Siscoe, 1969; Walker et al., 1992]. In either case, a 15–20 min. recurrence of the formation of an X-line in the tail is expected, and, consequently, a similar recurrence in the magnetic flux buildup in the near-Earth region and waves radiated outward into the magnetosheath.

Results from this investigation were presented in an invited poster at the Fall AGU Meeting. The poster was entitled "Multi-point observations of resonances near substorm onset," by E.R. Sánchez and J.D. Kelly. Results were also presented in a contributed talk at the IAGA Symposium in Uppsala, Sweden. The talk was entitled "Resonant cavity modulation of substorms," by E.R. Sánchez, J.D. Kelly, V. Angelopoulos, T. Mukai, Y. Saito, G.E. Parks, H.E. Singer, G. Rostoker, R.P. Lepping, and S. Kokubun. A manuscript to be submitted to the *Journal of Geophysical Research* has been distributed to all co-authors for comments. Submission is expected in May of 1998 The manuscript title is "Resonant modulation of mass and magnetic field circulation: The magnetosphere as a coherent system," by E.R. Sánchez, J.D. Kelly, V. Angelopoulos, T. Mukai ,and Y. Saito.

4 STUDY 2

The second effort initiated during the first year of this effort consisted of establishing the timing of events in the magnetosphere and ionosphere during the substorm evolution beginning with the growth phase and ending with the recovery phase.

Establishing a framework that describes the coupling between the ionosphere and the magnetosphere is paramount to this effort. Events are needed where it is possible to relate electric field and conductivity in the ionosphere to the electric field, magnetic field, and plasma pressure in the magnetosphere.

To date there have been very few measurements of nightside ionospheric convection during substorm expansion and recovery. Two substorm periods were chosen that provided high-resolution electromagnetic measurements in the midnight region and electric field, magnetic field, and plasma measurements in multiple regions of the magnetosphere. These substorm periods are 9–10 September 1996 and 9–10 December 1996.

Data analysis thus far has shown that (1) convection in the ionosphere very often does not conform to the expected 2-D electrostatic potential in the polar cap and auroral oval. Instead, strong sunward convection in the dawn and dusk flank regions of the oval coincides with very weak antisunward convection in the nightside polar cap and "throat." Combined ground-based radar spacecraft measurements show that at times this can be explained by the presence of large magnetic field-aligned potential drops; for instance, at the height of an expression phase. At other times, however, it appears that weak antisunward ionospheric convection coincides with weak earthward, or even tailward, convection in the plasma sheet. This is particularly evident during the growth phase. (2) Rapid enhancement of the antisunward convection at the nightside ionospheric throat is observed during the last stages of the growth phase without an apparent enhancement of earthward convection in the tail. Accompanying that enhancement there is an intensification of a train of large-scale vortices in the nightside oval that greatly alters the total ionospheric potential distribution. Several of the observed solar wind disturbances involve superdense plasmas that penetrate deep into the plasma sheet, since they are observed at X~ -10Re and at geosynchronous altitude. (3) The mass loading of the plasma sheet facilitates expansion onset over an unusually wide local time without necessarily enhancing earthward convection in the tail or tailward ejection of plasma and magnetic flux. This suggests that the formation of an X-line in the tail may not always be the dominant mechanism for the release of energy characteristic of the substorm expansion phase.

The results described here will be presented at the 1998 Spring AGU Meeting in Boston, Massachusetts; at the 1998 GEM Workshop in Snowmass, Colorado; and at the 1998 Fall ISTP Workshop. A manuscript is in preparation and will be distributed soon to all co-authors. Submission to the *Journal of Geophysical Research* is expected June of 1998.

5 PLAN FOR THE SECOND YEAR

With all the events properly identified and the relevant data assembled and currently being analyzed, efforts in the second year will address the following questions as posed in the original proposal:

- Relationship of the magnetosphere resonances to the substorm energy budget —that is, how does the electromagnetic energy flow in the different regions of the magnetosphere as the system evolves from a quiet state into a disturbed state.
- Relationship of the directly driven component of the substorm to an electric field-dominant westward electrojet and relationship of the unloading component of the substorm to a conductivity-dominant electrojet.
- Contribution of BBFs to the overall energy budget of the magnetosphere at growth, expansion, and recovery.

6 REFERENCES

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