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FINAL REPORT (1 OCTOBER 1997 – 30 SEPTEMBER 2000)
Solar Wind-Magnetosphere-Ionosphere Coupling
AFOSR Grant F49620-98-1-0012

Effort under this contract deals with coupling between the solar wind, magnetosphere and ionosphere. We have completed a series of studies ranging from active experiments in the auroral ionosphere to substorm triggering in the magnetosphere.

(1) Wave-Particle Interactions – Active Experiments

We have completed a series of studies of active experiments involving wave-particle interactions observed during the reflight of the Tethered Satellite System on the space shuttle, and OEDIPUS-C. Using the correlator on TSS-1R we analyzed the low-frequency waves returning to the shuttle as coherent particle bursts (Huang et al., 1998; Gough et al., 1998). High-frequency wave modulations during beam operations were studied (Rubin et al., 1998; Burke et al., 1999). We also analyzed charging of the shuttle during beam operations (Burke et al., 1998; Gentile et al., 1998).

OEDIPUS-C was a sounding rocket experiment which was launched into a quiet auroral arc from Poker Flats, Alaska. The rocket carried two payloads (forward and aft) connected by a conducting tether which deployed during flight. Both payloads carried electron detectors. The forward payload carried a radio sounder while receivers were mounted on both payloads. Three papers have been written analyzing electron plasma responses to the sounder. They have shown that (1) the sounder is capable of accelerating electrons up to the maximum detectable energy of 20 keV (Huang et al., 2001); (2) this acceleration mechanism is largely unexplained by current theories (James et al., 1999); (3) as the rocket descended through the ionosphere a wealth of plasma modes was excited (R. Benson, private communication). Oral presentations summarizing these results were made at the URSI meeting in Toronto in August 1999.

These studies are important in understanding the complex interaction between actively radiated VLF waves and the ambient ionosphere. This interaction is central to an ongoing effort to control energetic fluxes in the radiation belts.

(2) Equatorial Plasma Bubbles (EPBs)

Our study of the effects of the storm of 4-6 June 1991 at geosynchronous distances and in the ionosphere showed that at the time when a large stormtime electric field penetrated close to the Earth, equatorial bubbles were observed at DMSP altitude (800 km) (Burke et al., 1998a; 1999). It appeared that there was a coupling between the ionospheric electric field and the high-altitude field. We have surveyed the Julia coherent scatter radar data at Jicamarca when the station is located near the dusk sector and found several examples when equatorial bubbles appear to be coincident with large electric fields or high dynamic pressure in the solar wind.

We have surveyed the DMSP spacecraft which orbit in the evening sector (F9, 10, 12, 14, 15) for the entire past solar cycle, starting from 1989 and continuing to the present. Over two years of continuous coverage during 1989 and 1991 which correspond to solar maximum, we found 2806 EPBs during 15,000 overflights of the evening sector. The seasonal and longitudinal climatology of the EPBs observed on DMSP agreed well with that given by ground-based radar and scintillation studies. The results of this initial study were recently published (Huang et al., 2001). We are continuing to analyze the DMSP data for the solar cycle. Preliminary results were shown at the Spring American Geoophysical Union Meeting held in Boston. We showed that the solar cycle dependence is readily apparent in the DMSP data. We compared the satellite observations with ground-based scintillation data from Ancon in Peru (C. Valladares, private communication) and found good agreement between the two sets of data from 1994 to 2000, with an overall correlation coefficient of 88% for the 21 – 21MLT sector. These results will be submitted to the Journal of Geophysical Research shortly.

We are continuing to build a database of EPBs with current DMSP Flights, and have started to examine solar wind electric field and dynamic pressure, and the polar cap index, simultaneous with the EPB times. This ongoing study will be significant for the C/NOFS project, currently scheduled to be launched in October 2003, which has been ranked first by the Space Experiments Review Board for the past three years.

(3) Geomagnetic Storms

Forcing of the ionosphere during passage of a magnetic cloud showed the temporal relation between changes in the solar wind and the subsequent particle precipitation on the nightside (Huang et al., 1998; Burke et al., 1998).

We recently completed a large multi-point study of a large geomagnetic storm which occurred on 8 – 9 July 1991. Using observations made in the solar wind, at geosynchronous orbit, in the inner magnetosphere and in the ionosphere we were able to provide a timeline for the growth, onset and main phase of the storm. The penetration electric field was clearly seen on CRRES, together with large plasma depletions we have identified as equatorial plasma bubbles. From an extensive network of ground-based magnetometer measurements we found that the currents extended from the high-latitude auroral zone to the equator and peaked on the dayside of the ionosphere. We concluded that the convection corresponded to a DP 2 system driven by the solar wind electric field imposed on the polar cap for many hours during which the interplanetary magnetic field was directed southwards. This investigation has just been accepted for publication in Journal of Geophysical Research (Wilson et al., 2001).

(4) Onset of Magnetospheric Substorms

We have studied 19 cases of substorm onset and 2 cases of pseudobreakup which occur within the substorm current wedge as it appeared at the CRRES satellite (Maynard et al., 1998). All but one are clearly inconsistent with the near-Earth neutral line model of substorm onset. The remaining 20 events show consistent signatures which favor drift-Alfven ballooning as the triggering mechanism for onset. These signatures appear as westward-drifting ballooning waves which are coupled to the ionosphere in pairs via Alfven waves. When such pairing does not occur, a pseudobreakup results and no substorm ensues (Burke et al., 1998; Maynard et al., 1998a; 1998b).

We continued our substorm studies with an investigation of the explosive growth phase (EGP). In their paper Ohtani et al. (J. Geophys. Res., 97, 19,311, 1992) described the EGP as the magnetic signature of an explosive increase of cross-tail current tailward of the satellite, just prior to cross-tail current disruption which occurs at substorm onset. Our interpretation of this magnetic signature is that the eastward polarization current at the head of the Alfven wavefront described above creates a magnetic perturbation.

Our results were presented at the Fifth International Conference on Substorms in St. Petersburg, Russia and were published in the Proceedings (Erickson et al., 2000; Burke and Erickson, 2000) and in the Journal of Geophysical Research (Erickson et al., 2000). At the most recent meeting of the Science Advisory Board this paper was selected as the most outstanding of all the AFRL investigations reviewed by the board.

PUBLICATIONS

Burke, W. J., C. Bonifazi, D. A. Hardy, J. S. Machuzak, L. C. Gentile, D. G. Olson, C. Y. Huang, B. E. Gilchrist, J.-P., Lebreton, and C. A. Gurgiolo, Shuttle charging by tether controlled electron beam, *Geophys. Res. Lett.*, **25**, 717, 1998.

Burke, W.J., N. C. Maynard, G. M. Erickson, M. Nakamura, S. Kokobun, B. Jacobsen, and R. W. Smith, High-latitude auroral boundaries compared with GEOTAIL measurements during two substorms, in *Encounter between Global Observations and Models in the ISTP Era*, Geophys. Monogr. Ser. 24, p. 129, American Geophysical Union, Washington, D. C., 1998.

Burke, W. J., N. C. Maynard, M. P. Hagan, R. A. Wolf, G. R. Wilson, M. S. Gussenhoven, L. C. Gentile, C. Y. Huang, T. W. Garner, and F. J. Rich, Electrodynamics of the inner magnetosphere observed in the dusk sector by CRRES and DMSP during the magnetic storm of June 4-6, 1991, *J. Geophys. Res.*, **102**, 29,399, 1998a.

Burke, W. J., M. P. Gough, L. C. Gentile, C. Y. Huang, J. S. Machuzak, and A. G. Rubin, MHz and kHz modulations of particle fluxes during beam experiments of the tethered satellite system missions, *Adv. in Space Res., COSPAR*, **24**, 8, 1047, 1999.

Burke, W. J., A. G. Rubin, N. C. Maynard, L. C. Gentile, P. J. Sultan, F. J. Rich, O. de la Beaujardiere, C. Y. Huang, and G. R. Wilson, Ionospheric disturbances observed by DMSP at mid to low latitudes during the magnetic storm of June 4-6, 1991, *J. Geophys. Res.*, **101**, 18,391, 2000.

Burke, W. J., and G. M. Erickson, Bursty bulk flows: Some electrodynamic considerations, *Proceedings, 5th International Conference on Substorms*, May 16-20, 2000, St. Petersburg, Russia, p. 153, 16 – 20 May 2000.

Erickson, G. M., N. C. Maynard, G. R. Wilson, and W. J. Burke, Electromagnetics of substorm onsets in the near-geosynchronous plasma sheet, *Proceedings, 5th International Conference on Substorms*, St. Petersburg, Russia, p. 385, 16–20 May 2000.

Erickson, G. M., N. C. Maynard, W. J. Burke, G. R. Wilson, and M. Heinemann, Electromagnetics of substorm onsets in the near-geosynchronous plasma sheet, *J. Geophys. Res.*, **105**, 25,265, 2000.

Gentile, L. C., W. J. Burke, C. Y. Huang, J. S. Machuzak, D. A. Hardy, D. G. Olson, B. E. Gilchrist, J.-P. Lebreton, and C. Bonifazi, Negative shuttle charging during TSS 1R, *Geophys. Res. Lett.*, **25**, 433, 1998.

Gough, M. P., W. J. Burke, D. A. Hardy, C. Y. Huang, L. C. Gentile, A. G. Rubin, M. R. Oberhardt, A. T. Drobot, D. C. Thompson, and W. J. Raitt, Megahertz electron modulations during TSS 1R, *Geophys. Res. Lett.*, **25**, 441, 1998.

Huang, C. Y., W. J. Burke, M. S. Gussenhoven, D. A. Hardy, and L. C. Gentile, Ionospheric response to magnetic forcing: magnetic cloud passage of October 18-20, 1995, *J. Geophys. Res.*, **25**, 2581, 1998.

Huang, C. Y., W. J. Burke, D. A. Hardy, M. P. Gough, H. G. James, E. Villalon, and L. C. Gentile, Electron acceleration by MHz waves during OEDIPUS C, *J. Geophys. Res.*, **106**, 1835, 2001.

Huang, C. Y., W. J. Burke, D. A. Hardy, M. P. Gough, D. G. Olson, L. C. Gentile, B. E. Gilchrist, C. Bonifazi, W. J. Raitt, and D. C. Thompson, Cerenkov emissions of ion acoustic-like waves generated by electron beams emitted during TSS 1R, *Geophys. Res. Lett.*, **25**, 721, 1998.

Huang, C. Y., W. J. Burke, J. S. Machuzak, L. C. Gentile, and P. J. Sultan, DMSP observations of equatorial plasma bubbles in the topside ionosphere near solar maximum, *J. Geophys. Res.*, **106**, 8131, 2001.

James, H. G., V. I. Sotnikov, W. J. Burke, and C. Y. Huang, OEDIPUS-C observations of electrons accelerated by RF fields at whistler-mode frequencies, *J. Plasma Phys.*, **6**, 4058, 1999.

Maynard, N. C., G. M. Erickson, W. J. Burke, A. G. Yahnin, J. C. Samson, G. D. Reeves, M. Nakamura, and V. V. Klimenko, Substorms and the inner magnetosphere: onset and initial expansion, in *Polar Cap Boundary Phenomena*, Ed. By J. Moen, A. Egeland, and M. Lockwood, p. 381, NATO Advanced Studies Series, Kluwer Academic Publishers, Dordrecht, 1998a.

Maynard, N. C., G. M. Erickson, W. J. Burke, and G. R. Wilson, Magnetospheric electric fields during substorm onset and expansion phases, in *Substorms-4*, Ed., by S. Kokobun and Y. Kamide, p. 605, Terra Scientific Publishing Company, Kluwer Academic Publishers, Dordrecht, 1998b.

Rubin, A. G., W. J. Burke, M. P. Gough, J. S. Machuzak, L. C. Gentile, C. Y. Huang, D. A. Hardy, D. C. Thompson, and W. J. Raitt, Beam induced electron modulations observed during TSS 1R, *J. Geophys. Res.*, **104**, 17,251, 1999.

Wilson, G. R. , W. J. Burke, N. C. Maynard, C. Y. Huang, and H. J. Singer, Global electrodynamics observed during the initial and main phases of the July 1991 magnetic storm, *J. Geophys. Res.*, accepted, 2001.