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Ionospheric Influence on Substorm Development

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ABSTRACT: Our understanding of the geogenic component (i.e. the component of ionospheric or Earth origin) of the plasma sheet and its importance in substorm development is incomplete. Empirical and numerical models of plasma sheet composition disagree. Thirty years after the detection of significant fluxes of geogenic ions in the magnetosphere, we are still unable to unambiguously affirm or refute the assertion that substorm onset is causally related to heavy ion outflow. Here we review observations relating to the ionospheric contribution to the plasma sheet and the various approaches used to investigate the relationship between heavy ion outflow and substorms. We suggest that the only practical way to investigate the long term feedback effects thought to be associated with changes in ion outflow and mass composition in the plasma sheet is to self-consistently include ion outflow in large scale magnetospheric models and to test these models with the best available data sets and theories of plasma instabilities.

Introduction

Our current understanding of the dynamics of the geogenic (i.e. of Earth or ionospheric origin) portion of the plasma sheet is incomplete. Initial energetic mass composition observations led to several reasonable speculations about the role of geogenic plasma in the magnetosphere which we are still not able to affirm or refute. In particular, episodic reports as well as empirical and numerical models of plasma sheet mass energy and angular composition disagree in major ways.

After reviewing the relevant observations, we look at the controversy surrounding two of the unresolved questions about the plasma sheet. Does O^+ concentration in the plasma sheet lead to initiation of plasma instabilities that are the trigger of substorms? Is there a hidden cold ion population in the plasma sheet that was missed by the early instruments reporting plasma sheet composition? We then go on to explain why the key to advancing our understanding of the influence of geogenic plasmas on substorm development is to identify and parameterize coherent features in existing ion outflow data sets in such a way that they can be easily included in all magnetospheric models.

Early Observations

Shelley et al. [1972] were the first to report observations of energetic ions of geogenic (Earth) origin in the magnetosphere. Prior to this report, the magnetosphere was thought to be primarily of heliogenic (i.e. from the solar wind) origin. The intent of Shelley and his colleagues was to verify the consensus hypothesis of early magnetospheric modelers that the He^{++}/H^+ ratio observed in the magnetosphere was the same as in the solar wind. The first reported observations were made during a large geomagnetic storm (Kp max ~7) in December, 1971. Instead of confirming the consensus hypothesis, the observations revealed extremely large fluxes of geogenic plasma in the magnetosphere. The observations were made with a low mass resolution instrument ($M/\Delta M > 2$ at $m/q=16$) from a low altitude (800 km) satellite at magnetic local times of 0300 and 1500. We now know energetic geogenic ions are least often observed under these constraints. Most magnetospheric workers accepted these observations as valid almost immediately after the second, confirming, report appeared [*Sharp et al.*, 1974].

The European GEOS -1 and -2 satellites carried mass spectrometers that obtained data first used to document the solar cycle variation of magnetospheric composition.. Young et al. [1982] reported that the *monthly average* O^+ composition in the 1-16 keV range in *near geosynchronous* orbit increased significantly with solar activity as measured by the solar radio flux index ($F_{10.7}$) and the Zurich sunspot number, Rz, but *not with geomagnetic activity* measured by the monthly average AP index. Subsequently, data from a long series of satellites, (S3-3, ISEE -1, SCATHA, PROGNOZ, DE -1, AMPTE/CCE, Akebono, CRRES, Geotail, Viking, Freja, The InterBall series, Polar, Fast, and most recently the Cluster satellites) have steadily improved our understanding of magnetospheric ion

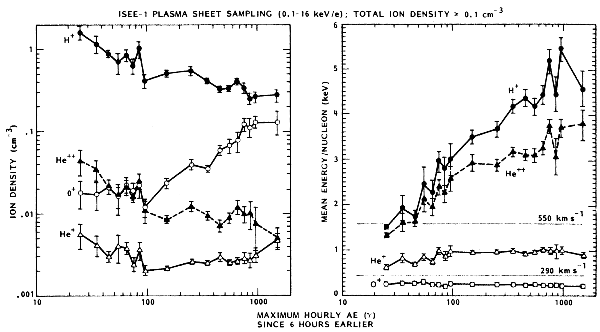

Figure 1. Densities (left) and mean energy per nucleon (right) of the for major ions obtained in the energy range $0.1 < E/q < 16$ keV/e, in the plasma sheet (GSM $X < 0$, and $10\ R_E < R < 23\ R_E$. The data were obtained during successive tail seasons, January through April, in 1978 and 1979. Reproduced from Lennartsson [1987].

composition and its variability. The short term (i.e. minutes to hours compared to the GEOS monthly average) variability of the O^+ with magnetic activity in most regions of the magnetosphere is now well established. Johnson [1983] and Hultqvist et al. [1999] have assembled two excellent books summarizing what has been learned in the past 30 years about magnetospheric composition. Yau and André [1997] have also compiled a comprehensive review of geogenic ion outflow observations.

Here we focus on the limited number of high-quality, quantitative, long-term, statistical studies of average magnetospheric composition and energetic ion outflow. These include reports by Young et al. [1982], Yau et al. [1995, 1988], Lennartsson [1987, 1989], Peterson et al. [2001], and Cully [2002]. Peterson et al. [1981] first showed that during large geomagnetic storms the plasma in the plasma sheet is occasionally dominated by O^+. Lennartsson [1987, 1989] examined several years of data obtained on the ISEE -1 spacecraft in the near ($-10< X < -20\ R/R_E$) plasma sheet. He quantified the variation in average composition with geomagnetic and solar activity indices A_E and $F_{10.7}$. Figure 1, reproduced from Lennartsson [1987], shows the systematic increase of O^+ density (open circles, left panel), but constant energy (ie. temperature, open circles, right panel) as a function of the maximum A_E index obtained in the six hours prior to the ISEE -1 observations. Surprisingly the heliogenic component (He^{++} and a fraction of H^+) temperature increases with geomagnetic activity in the Lennartsson data set from ISEE -1, but not the geogenic component (O^+ and He^+). This observation shows that the quantity of O^+ entering the plasma sheet increases dramatically with geomagnetic activity. The data also suggest that processes energizing O^+ into the energy range sampled by the ISEE instrument do not add additional energy at the highest levels of geomagnetic activity.

Yau et al. [1985, 1988] obtained complementary information on the average strength of the ionospheric source from an energetic ion mass spectrometer on DE -1. Figure 2, reproduced from Yau et al. [1988], shows the variation in the H^+ and O^+ outflow rates for two levels of the solar activity $F_{10.7}$ index as a function of the hourly average geomagnetic activity index A_E. Yau et al. derived and explicitly stated empirical relations between average H^+ and O^+ ion outflow and the geomagnetic and solar indices, $F_{10.7}$, A_E, K_P, and D_{ST}.

Shelley [1986], and Shelley et al. [1986] used the data and empirical relations developed by Yau, Lennartsson and their colleagues to make an estimate of the variability of plasma sheet composition as a function of solar and geomagnetic activity. The calculation involved several assumptions. First, Shelley assumed a constant plasma sheet volume. To account for the fact that H^+ in the plasma sheet could come from both the ionosphere and solar wind, he assumed that the fraction of geogenic H^+ in the plasma sheet was determined from the ratio of escaping H^+ and O^+ fluxes and the concentration of O^+ in the plasma sheet. With these assumptions, and the empirical relations between composition and the $F_{10.7}$ and A_E indices from the work of Lennartsson, Yau and their colleagues, Shelley produced the data appearing in Figure 3 using straightforward algebraic manipulation. Figure 3 shows that Shelley's estimate of the geogenic fraction of the plasma sheet is less than 10% during geomagnetically quiet intervals and significantly over half during disturbed intervals.

Chappell et al. [1987] performed a complementary analysis of the relative contribution of ionospheric plasma to the plasma sheet. Chappell and his colleagues scaled data from Yau et al. [11985], and

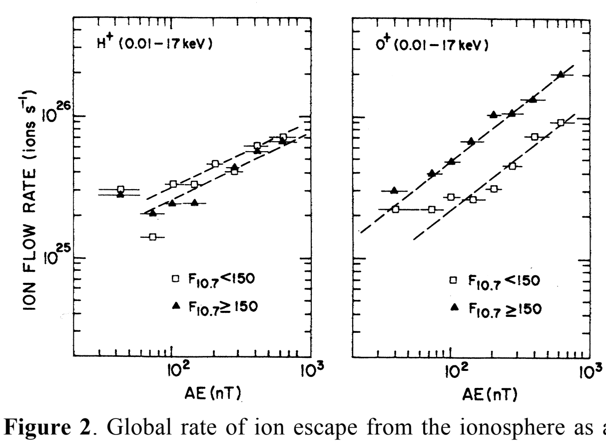

Figure 2. Global rate of ion escape from the ionosphere as a function of the geomagnetic activity index, A_E. The data were obtained between 1981 and 1987 from Dynamics Explorer -1. Reproduced from Yau et al., [1988]

supplemented them with episodic measurements from the DE -1 low energy mass spectrometer obtained in the cusp region [Moore et al., 1986]. Chappell et al. [1987] also used a more sophisticated model of the plasma sheet volume. They concluded that the ionospheric source could account for all of the plasma in the plasma sheet under all geomagnetic and solar activity conditions. That is, they suggested that solar wind plasma plays a minor role in plasma sheet dynamics.

In addition to all of the other assumptions, both the Chappell and Shelley analyses implicitly assumed that all of the escaping ionospheric flux would be trapped in the plasma sheet. Recent results from Geotail [e.g. Seki et al., 2001] showing intense streams of cold (~100eV) O^+ steaming 100's of Earth radii down tail show that this implicit assumption is not valid. Early models of the plasma sheet source clearly identified the energization and transport of relatively cold O^+ from the cusp region as one of the major uncertainties in understanding the role of ionospheric plasma in the plasma sheet. (See, for example, Delcourt et al., [1989]).

Our current understanding of the composition of the plasma sheet is obviously incomplete. Empirical and numerical models of plasma sheet composition disagree

Conflicting impressions about plasma sheet composition also came from investigations of plasma sheet dynamics using multiple platforms. For example, during the February 21-22 1979 magnetic storm, six satellites monitoring energetic ionospheric composition were operating (Prognoz -7, ISEE -1, GEOS -1 and -2, and SCATHA). Balsiger[1981] noted that O^+ was the dominant ion in the <~20 keV/e energy range sampled at the three times of D_{ST} minima during the weak (D_{ST} = -107 nT) storm, except for one ISEE -1 location near

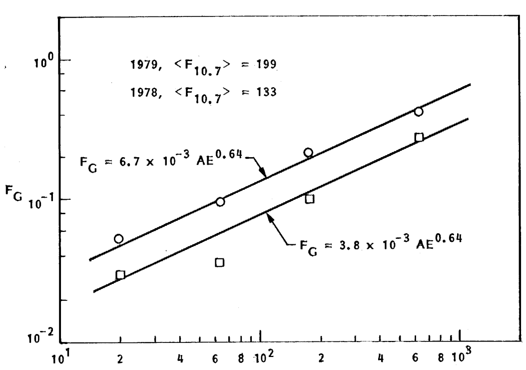

Figure 3. Estimate of the geogenic (of ionospheric origin) fraction F_G of the plasma sheet as a function of the geomagnetic activity index A_E for two levels of the solar activity index $F_{10.7}$ from Shelley et al. [1986]. The open circles correspond to the observations made in 1979 and the open boxes to those made in 1978.

L~8 and 0500 MLT where it accounted for only 40% of the plasma sheet density. The Balsiger observations were obtained during solar maximum conditions. They contrast sharply with H^+ dominance observed during a slightly stronger (D_{ST} = -125 nT) magnetic storm made during solar minimum obtained from AMPTE/CCE by Krimigis et al. [1985]. The Krimigis et al. observations also included ring current (100 keV/e) energies, but were limited to within ~ 9 R_E. The Cluster spacecraft are now returning high time resolution, energetic (~ > 100 keV/e) ion composition from the magnetotail beyond the CRRES and AMPTE/CCE orbits so we should be able, in the near term, to more precisely sort out the solar cycle dependence of the geogenic (H^+ , He^+, and O^+) and the more energetic heliogenic (H^+ and He^{++}) plasmas in the magnetotail in the important 10-20 R_E region during geomagnetically active times.

Reasonable Conjectures

The initial series of energetic mass composition observations led to many reasonable speculations about the role of geogenic plasma in the magnetosphere. Here we look at the subsequent analysis and controversy about two of the conjectures: 1) O^+ initiation of plasma instabilities that are the trigger of substorms; 2) The existence of a hidden cold ion population in the plasma sheet.

Baker et al. [1982] noted that two dimensional plasma theory [e.g. *Schindler*, 1974] predicts that regions of the plasma sheet dominated by O^+ are significantly more susceptible to the "linear tearing mode" instability. The analysis presented in the Baker et al. paper was consistent with an O^+ initiated tearing mode instability initiating substorms. In a subsequent paper Baker et al. [1985] examined two substorms on March 22, 1979 and concluded that in the second substorm the observations were consistent with "the possible important role O^+ plays in the initiation of plasma sheet instabilities during substorms".

Other investigators have noted that the time of flight of low energy ionospheric plasma to the plasma sheet is of the same order of magnitude as the average interval between substorms. They, too, have suggested that changes in mass composition in the plasma sheet could be responsible for substorm onset (e.g., *Daglis et al.,* [1990], and *Cladis and Francis*, [1992]). Several hundred dispersionless injections were identified from energetic particle data obtained within the 9 R_E apogee of AMPTE/CCE by Lopez et al. [1988]. Daglis et al. [1990] examined the composition from these events in the energy per charge range from 1 to 300 keV/e.

They identified a significant enhancement of O^+ in the data at the beginning of the substorm growth phase. The evidence presented by Daglis et al., while consistent with increased O^+ appearing above the energy threshold of the detector before substorm onset, was not sufficient to unambiguously demonstrate that enhanced O^+ was the substorm "trigger."

Cladis and Francis [1992] modeled the transport of cusp/cleft plasma, including O^+, using existing electric field models. They showed that enhanced convection, associated with southward turning of the IMF energizes and convects O^+ into the central plasma sheet at X~ -10 R_E *after about 1.7 hours*. They argued that the increased O^+ pressure associated with this event modifies the local electric and magnetic field configuration that in turn leads to velocity shears in the plasma that become unstable and trigger a substorm.

Lennartsson [1987] and Lennartsson et al. [1993] approached the cause/effect relationship between increased O^+ in the plasma sheet and substorms using statistical studies of O^+ densities in the energy range between 0.1 and 16 keV/e, obtained on the AMPTE and ISEE -1 spacecraft. They looked for a significant increase in O^+ shortly before substorm onset and found none in their extensive data bases. They found a consistent increase in O^+ after substorms and concluded that increased O^+ is most probably a consequence of substorms, not a trigger of them.

Grande et al. [1998] looked at the relative composition of energetic ions (70 < keV/e < 400) from the CRRES spacecraft from a large number of substorms. They performed a superposed epoch analysis and looked at the relative change in the geogenic/heliogenic composition as a function of time from substorm onset. Specifically they reported that the O^+/He^{++} energy density ratio decreased before and increased after substorm onset.

Daglis and Sarris [1998] disagreed with the conclusions of Lennartsson et al [1993]. They argued that the statistical approach used by Lennartsson and his coworkers could not adequately account for small scale spatial and temporal variations in the plasma sheet composition. In their formal reply, Lennartsson et al. [1998] agreed that some O^+ concentration increases could have been missed in any finite set of random single-point measurements. However, they noted that the question then becomes: Is it probable that the O^+ concentration at the point of substorm initiation is systematically different from what has been sampled elsewhere in the near-Earth plasma sheet?

We note here that recent Geotail observations (e.g. *Nishida et al*. [1998] and references therein) have clearly identified the most likely region of substorm initiation to be between -15 R_E and -30 R_E.. This region has only been partially investigated using data obtained between 1978 and 1981 from the energetic ion composition instrument on the ISEE -1 spacecraft. There are no mass composition data available from Geotail, and the mass composition information from the Interball Tail Probe in this region has not yet been systematically examined for O^+ blobs associated with substorm onset (Ingrid Sandel, private communication, 2002).

Chappell et al. [1987] argued that the most important constituent of the deep magnetotail is the less than 100 eV/e O^+ population and that this population was systematically excluded (ie. hidden) from Lennartsson's data base. The ISEE -1 data base has limited temporal (~ 10 minutes) and energy (0.1 < e/q < 16 keV/e) resolution. Chappell and his colleagues based their argument on the existence of a hidden plasma sheet ion population on episodic reports of composition derived from the low energy (E/q < 100 eV/e) channels of the ISEE -1 energetic ion composition instrument (e.g. *Horwitz* et al., [1983]), models such as Delcourt [1989], and the analysis in their paper [*Chappell et al*., 1987]. Lennartsson (private communication) argues that if there was significant <100 eV/e O^+ population in the plasma sheet, it would appear above 100 eV (and add to the data bases he has assembled) every time the **E**x**B** plasma drift rate exceeded 35 km/s. Sharp et al. [1981] and others have demonstrated that O^+ drift velocies above 35 km/s are commonly observed.

Chappell et al. [1987], however, raised an important question: Has the less than 100 eV O^+ ion population in the plasma sheet between -10 and -30 R_E been significantly underestimated? Lennartsson and his colleagues argue it has been adequately accounted for. Daglis, Chappell and their colleagues argue that it has not. Episodic data from two intervals, one from Polar and one from Cluster, presented and discussed below, suggest that the less than 100 eV O^+ ion population has been adequately accounted for and does not play a significant role in the initiation of substorms. It must be noted, however, that Polar and the Cluster satellites have just recently begun to explore the equatorial plasma sheet composition tailward of 9 R_E and we can expect further reports from them and perhaps the Interball Probes on this important topic.

The Polar satellite began sampling composition of the near Earth (X < -9.6 R_E), equatorial plasma sheet in the summer of 2001. Figure 4 shows the observations from the magnetometer [Russell et al., 1995], and two plasma instruments that respond to particles in the range from thermal to 25 keV/e. The interval displayed in Figure 4 was very active; the A_E index was above 300 throughout the interval and reached values over 2000 at ~15:20. The magnetometer data (top panel) show that from ~14:00 to ~15:00 UT Polar was in the so called neutral sheet, where the magnetic field is dominated by a small (~50 nT) Bz component. Measurable quantities of energetic (i.e. E/q > 1keV/e) H^+ and O^+ were observed in the neutral sheet and northern plasma sheet between about 13:40 and 15:20 (second and third panels, respectively). The energetic H^+ ions

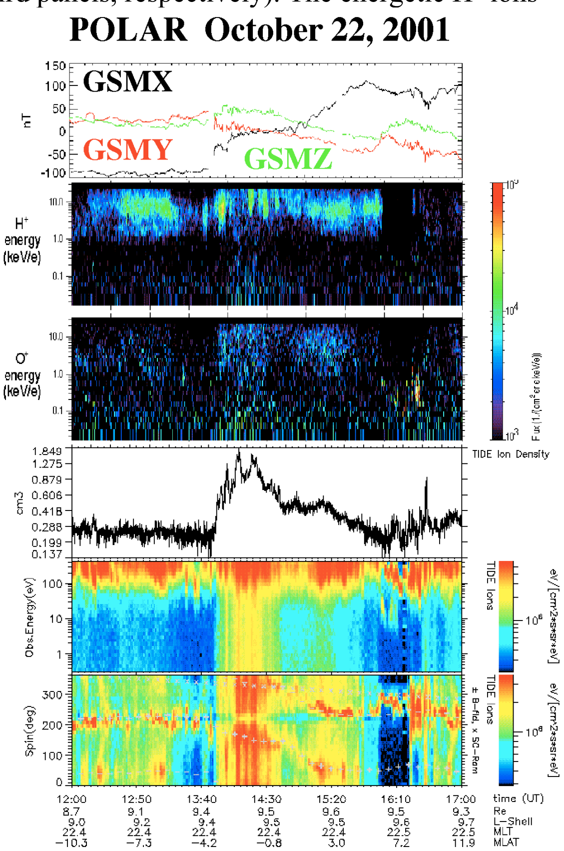

Figure 4. Observations of magnetic field and plasma composition in the near Earth, equatorial plasma sheet from the Polar spacecraft on October 22, 2001. Top panel: Measured magnetic field components in GSM coordinates as indicated. Second and Third panels: H^+ and O^+ energy-time spectrograms from the TIMAS instrument [Shelley et al., 1995], over the energy range 0.015 < E/q < 25 keV/e. The observed number flux in the range 10^3 to 10^5 ions/cm^2-s-sr-keV/e is encoded using the color bar on the right. The fourth panel and below are from the TIDE [Moore et al., 1995] instrument that is responsive to all ions in the energy range from spacecraft potential to 300 eV/e. The fourth panel reports the estimated plasma density in units of cm^{-3} assuming all ions are H^+. The next to bottom panel reports the observed energy flux of ions observed by TIDE in units of eV/cm^2-s-sr-eV encoded by the color bar on the right. The bottom panel is an angle-time spectrogram of the TIDE data for the same interval.

observed before and during this interval showed considerable spatial or temporal structure. Presumably this structure is also in the energetic O^+ population but not visible because of the low signal level. Data describing the thermal (i.e. less than 300 eV/e) ions are displayed in the bottom three panels. The thermal plasma is significantly more dense and isotropic in the neutral sheet. The TIMAS and TIDE instruments indicate that the thermal plasma has a significant O^+ component in the neutral sheet. This means that the densities reported in the fourth panel are underestimates of the plasma density because they are calculated assuming that the plasma is all H^+. We note that these data were acquired during the first Polar "equatorial tail sampling season" and that the most intense energetic and thermal O^+ fluxes during this season were observed during the interval on October 22, 2001, presented in Figure 4. The A_E index records indicate that there was at least one substorm during this interval. However, the dense thermal plasma with a significant O^+ component in the neutral sheet observed by Polar between ~1400 to ~1500 UT obviously did not become unstable and therefore was not the trigger for a substorm. Of course a single observation, especially one made so close to the Earth, does not prove that O^+ initiated tearing mode instabilities do not exist and are not associated with substorm onset.

A report of simultaneous Cluster and Polar observations was made at this confence by Baker et al., [2002]. Some of their observations are reproduced here in Figure 5. Baker et al. examined Cluster and Polar data obtained during the first season both spacecraft were observing the plasma sheet. They identified several substorms where Cluster obtained data near X = -20 R_E and Polar near X= -9 R_E at the time of substorm onset. For the interval presented in Figure 5, they also obtained data from a wide variety of other spacecraft and ground arrays. They determined that the substorm began ~04:01 UT between the positions of Polar and Cluster. They identified the first indication of a substorm on the ground at ~04:08 UT. Baker and his colleages are currently preparing these observations for publication so they will not be discussed in detail here. We note only that at 04:20 on August 27, 2001, Polar was at [-7.7, -4.9, 3.5] and Cluster 1 was located at [-18.9, -2.1, -.3] in GSM coordinates. Cluster 1 and Polar both observed energetic O^+ plasma. Neither spacecraft detected a significant component of O^+ below ~100 eV. So, for this case also, O^+ blobs can not be associated with substorm onset at or near the spacecraft locations.

The two examples given here are most consistent with the view of Lennartsson and his colleagues that O^+ in the plasma sheet is a consequence of, not a driver of, substorms. However, these and other reports from Polar and Cluster are still not adequate to affirm or refute the assertion that “blobs” of O^+ in the plasma sheet initiate instabilities that trigger substorms.

Testing the assertion that O^+ driven instabilities in the plasma sheet initiate substorms.

The only practical way to investigate the long term feedback effects thought to be associated with changes in ion outflow and mass composition in the plasma sheet is to self-consistently include ion outflow in large scale magnetospheric models and to test these models with the best available data sets and theories of plasma instabilities.

We have shown above how observation and modeling of plasma sheet plasmas have not been able to unambiguously determine the relative importance of geogenic (of Earth or ionospheric origin) plasma in the plasma sheet or to affirm or refute the reasonable conjecture that “blobs” of O^+ in the plasma sheet initiate instabilities that subsequently trigger substorms. The main reason for this incomplete understanding is the large size of the plasma sheet and

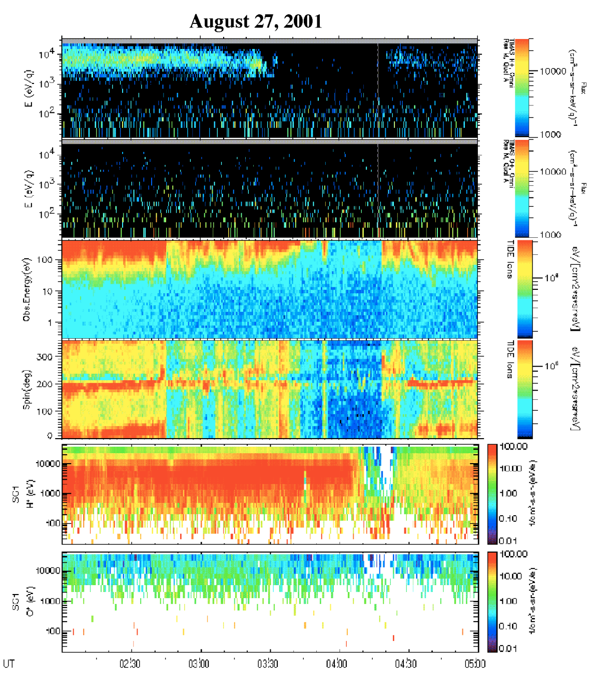

Figure 5. Plasma measurements from Cluster 1 and Polar obtained on August 27, 2001. Top two panels, H^+ and O^+ energy-time spectrograms from Polar/TIMAS similar to that in Figure 4. The middle two spectrogram panels are from Polar/TIDE similar to the data presented in Figure 4. The bottom two panels are H^+ and O^+ energy time spectrograms from the Cluster 1 spacecraft. [Réme, et al., 2001]. Adapted from Baker et al. [2002].

the relatively small temporal and spatial scales of its dynamic plasma structures. In addition, existing global models and fundamental plasma theory are too rudimentary to provide observers with well posed criteria to distinguish between postulated states of the plasma sheet or its dynamics during intervals of geomagnetic activity. For example, basic plasma theory provides little guidance on the relative volumes or densities of O^+ “blobs” capable of initiating instabilities. Existing theory does not treat the three dimensional nature of the plasma and stabilizing role of electrons. As a result it is not possible to make quantitative predictions on which plasma instability can initiate a substorm. These difficult questions are being addressed (e.g. *Büchner and Zelenyi*, [1989]).

Adequate observational data now exists to validate large scale models and test plasma theory. Since the launch of the ISAS Geotail, NASA Wind and Polar, IKI Interball Probes, and the more recent ESA Cluster satellites, there have been several intervals where the plasma sheet composition and dynamics have been monitored at multiple points for extended periods with supplemental data available from extensive ground arrays and geosynchronous satellites. The data and spatial coverage available from these satellites and ground arrays is significantly better than that previously available.

Large scale models, even the multifluid model of Winglee [1998], however, are limited in their ability to fully utilize the existing data sets because they have not been able to translate the extensive knowledge of ion outflow into boundary conditions that can be self-consistently incorporated into the codes.

> *To understand the influence of geogenic plasmas on substorm development we need to identify and parameterize coherent features in ion outflow in such a way that they can be easily included in all magnetospheric models.*

Magnetospheric models are dynamic; they model the motion and evolution of plasma boundaries such as the magnetopause and geopause [see, Winglee, [1998]). Comprehensive, quantitative information on ion outflow is available from a variety of platforms only in static coordinate systems (i.e. in invariant latitude and magnetic local time. These include DE -1 [Yau et al., 1988], Polar [Peterson et al., 2001], and Akebono [Cully, 2002]. For a recent review see Yau and André [1997]. The temporal resolution of these long term static data sets is limited by the time it takes each satellite to fully sample all invariant latitudes and local times. For Polar the time scale is 6 months; for DE -1 it is 18 months; and for Akebono it is much longer.

Investigators are now reporting ion outflow in spatially related coordinates. These reports are promising but not yet comprehensive. Tung et al. [2001] investigated ion outflow in the midnight local time sector and its relationship to magnetospheric substorms. Strangeway et al. [2000] used the particles and fields data on FAST to investigate the relationship between the Poynting flux and ion outflow for a magnetic storm interval in September, 1998. Cully [2001, 2002] used a sophisticated statistical technique to examine geogenic outflow from 9 selected magnetospheric regions. Peterson et al. [2002] looked for large scale coherence in the FAST, Akebono, and Polar data sets for the storm period January 9-12, 1997. The Peterson et al. analysis revealed no obvious large scale coherence in the outflow measurements as a function of the 5 minute resolution of geomagnetic activity in the A_E index. They do however clearly show that the dependence of ion outflow on geomagnetic activity derived by Yau et al. [1988] does not extend to storm time scales. The Peterson et al. analysis, however, looked at the ion outflow in static invariant latitude and magnetic local time.

We have a very good understanding of the motion and spatial and temporal coherence of magnetospheric boundaries from global images. In addition automated routines to identify magnetospheric boundaries in particle data sets have been shown to be robust. (See for example, Sotirelis and Newell [2000].) To improve our understanding of the spatial and temporal variations of ion outflow, the author and his colleages are in the process of constructing a self-organized, boundary-based, coordinate system in which to view mass-resolved ion outflow data obtained from instruments on the NASA/FAST and Japanese/Akebono satellites. The data set we are assembling will provide new understanding about the global properties of ion outflow. In addition, the data base will be in a format that can be incorporated into large scale magnetospheric models. Our data will provide a means to improve models which can be used to systematically explore possible mechanisms which relate ionospheric outflow and long time scale magnetospheric processes such as storms and substorms.

Conclusions

Episodic reports, empirical and numerical models of plasma sheet mass energy and angular composition of geogenic plasmas in the plasma sheet disagree in major ways. The pioneering series of energetic mass composition observations led to many reasonable speculations about the role of geogenic plasma in the magnetosphere. We reviewed the controversy about the conjecture that O^+ (or other heavy ion) concentrations in the plasma sheet could lead to initiation of plasma instabilities that are the trigger of substorms. We concluded that existing data and models could not affirm or refute this hypothesis.

We noted that the only practical way to investigate the long term feedback effects thought to be associated with changes in ion outflow and mass composition in the plasma sheet is to self-consistently include ion outflow in large scale magnetospheric models and to test these models with the best available data sets and theories of plasma instabilities. We then briefly reviewed recent attempts to identify coherent spatial and /or temporal features in ion outflow and described the work we have recently undertaken.

We conclude that there is only one practical way to investigate the ionospheric influence on substorm development. That is to use the very good plasma sheet data sets that have recently been assembled in conjunction with large scale magnetospheric models and basic plasma theory to systematically explore many possible substorm development scenarios. There are two current impediments to progress on this path. 1) We need quantitative predictions based on basic plasma theory of the spatial and temporal extent as well as the density and temperature and other parameters of unstable plasma sheet populations. 2) We need to find a way to self-consistently include the geogenic source plasma in large scale codes.

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