NASA Technical Memorandum

NASA TM-86589

MEETING REPORT

YOSEMITE CONFERENCE ON IONOSPHERIC PLASMA IN THE MAGNETOSPHERE: SOURCES, MECHANISMS, AND CONSEQUENCES

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Science and Engineering Directorate

February 1987

(NASA-TM-86589) YOSEMITE CONFERENCE ON IONOSPHERIC PLASMA IN THE MAGNETOSPHERE: SOURCES, MECHANISMS AND CONSEQUENCES, MEETING REPORT (NASA) 11 p CSCL 04A

N87-20689

Unclas
G3/46 45329

National Aeronautics and Space Administration

George C. Marshall Space Flight Center

MSFC - Form 3190 (Rev. May 1983)

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TECHNICAL MEMORANDUM

MEETING REPORT

Chapman Conference on Ionospheric Plasma in the Magnetosphere: Sources, Mechanisms, and Consequences

A Chapman Conference on Ionospheric Plasma in the Magnetosphere was held in Yosemite, California, February 3-6, 1986. The purpose of the conference was to discuss the role of ionospheric plasma in the magnetosphere. Conference sponsors were the National Aeronautics and Space Administration, Office of Space Science and Applications, and the American Geophysical Union.

Over the last several years our understanding of the relative importance of solar versus terrestrial sources of magnetospheric plasma has changed substantially. Although the solar wind was once thought to dominate the supply of plasma in the Earth's magnetosphere, it is now thought that the Earth's ionosphere is a significant contributor. Polar wind and other large volume outflows of plasma have been seen at relatively high altitudes over the polar cap and are now being correlated with outflows found in the magnetotail. The auroral ion fountain and cleft ion fountain are examples of ionospheric sources of plasma in the magnetosphere, observed by the Dynamics Explorer 1 (DE 1) spacecraft. With these marked changes in our perception of the dynamics of the ionospheric/magnetospheric system, it was deemed timely to bring researchers together to discuss and contrast the state of our investigative efforts. This was the sixth biennial Yosemite topical conference and the first as a Chapman Conference.

The conference was organized into six sessions: four consisting of prepared oral presentations, one poster session, and one session for open forum discussion. The first three oral sessions dealt separately with the three major topics of the conference, i.e., the source, mechanisms, and consequences of ionospheric plasma in the magnetosphere. A special session of invited oral presentations was held to discuss extraterrestrial ionospheric/magnetospheric plasma processes. The poster session was extended over two evenings during which presenters discussed their papers on a one-on-one basis. The last session of the conference was reserved for open discussions of those topics or ideas that were the most interesting or controversial.

SOURCES OF IONOSPHERIC PLASMA IN THE MAGNETOSPHERE

The conference and the first session began with a talk by T. Moore of NASA Marshall Space Flight Center who reviewed the sources and transport of ionospheric plasma entering the magnetosphere. His discussion of the outflow of light ions from the polar cap and the light and heavy ion outflows from the dayside cusp/cleft set the stage for much of the discussions which followed during the conference. He concluded his presentation by stating that the ionospheric sources of magnetospheric plasma may be sufficiently robust to account for most, if not all, of the magnetospheric plasmas.

In contrast to the ion outflows generally discussed during the conference, J. Sojka of Utah State University presented new direct measurements of 0.5 to 10 eV electron outflow from the ionosphere. Of particular interest in his presentation was the discovery of thermal electrons at altitudes between 7 and 10 R_E that show no net field-aligned potential drop between the ionosphere and the satellite.

Ion outflows in association with Birkeland currents were discussed by P. Bythrow of Johns Hopkins University and W. Heikkila of the Danish Space Research Institute. Bythrow showed observations of ion outflow coincident with inverted-V events. Heikkila and co-workers found high densities and heavy ions dominating in regions of upward Birkeland currents and low densities and light ions dominating in regions of downward currents. Also discussed was the variation from light to heavy ion outflows in field-aligned current regions, in the presence of transverse heating. Wave and particle observations during an event of transverse ion acceleration were shown by B. Whalen of the Herzberg Institute of Astrophysics. The latitudinal width and relative location of ion acceleration regions were discussed by A. Ghielmetti of Lockheed Palo Alto Research Laboratories. A principal conclusion of that study is that ionospheric ions are often injected upward over latitudinally wide regions nearly always located within the (high latitude extension) plasma sheet.

New measurements of thermal ion upwellings were presented by R. Tsunoda of SRI International. He and co-workers found these events closely associated with the source of the cleft ion fountain. Upwelling ion events were also found to be latitudinally confined and co-located with electron precipitation, upward field-aligned currents, and velocity gradients in magnetospheric convection. The injection of stormtime ions into the plasmasphere was described by R. Newell of Johns Hopkins University. These ions are thought to result in latitudinally narrow precipitation regions at low latitudes. Multi-spacecraft observations of ion outflows in the auroral zone and plasmasphere were presented by R. Robinson of Lockheed Palo Alto Research Laboratories and J. Horwitz of The University of Alabama in Huntsville, respectively. The mass and solar cycle dependence of upflowing ion beams on auroral field lines was presented by H. Collin, also of Lockheed Palo Alto Research Laboratories.

MECHANISMS FOR IONOSPHERIC OUTFLOW INTO THE MAGNETOSPHERE

The dominant theme of this session was the phenomenon of conical ion distributions and the various proposed mechanisms of transverse ion energization which may produce these distributions. M. Temerin of the University of California at Berkeley began the session with a review of candidate acceleration processes, including heating by lower hybrid waves, coherent and incoherent electrostatic ion cyclotron waves, and electrostatic shocks. He described in some detail a relatively new model involving obliquely propagating ion cyclotron waves with frequencies below the ion gyrofrequency, which may be particularly effective in producing the commonly observed O^+ ion conics.

In the first contributed paper, Temerin proposed a new model for the size of the ion conic heating region. Previous models have assumed a heating region of a rather restricted altitudinal extent which, from observational data, almost always was located well below the point of observation. In his paper Temerin showed results of a Monte Carlo calculation of ions in a perpendicular heating region extending from the ionosphere all the way up to the point of observation, with the heating rate an increasing function of altitude. This model also produced results consistent with typical spacecraft measurements.

The possibility of ion conic production at altitudes of a few hundred kilometers in the bottomside ionosphere was presented by P. Satyanarayana and co-workers of the Science Applications International Corporation. The proposed mechanism is the collisional ion cyclotron instability driven by electron collisions.

A new explanation of the apparent preferential heating of heavy ions was proposed by R. M. Winglee and co-workers of the University of California at Los Angeles (UCLA). Their model involves the generation of Alfvén waves by field-aligned currents and/or a temperature anisotropy of H^+ ions that have been heated by ion cyclotron waves.

Experimental results were presented in three papers by J. H. Waite, Jr., of NASA Marshall Space Flight Center, W. K. Peterson of Lockheed Palo Alto Research Laboratories, and J. L. Burch of Southwest Research Institute, along with their co-workers. Waite's paper reviewed Dynamics Explorer measurements of upwelling ionospheric oxygen ions in the polar cusp. Peterson presented evidence for upward acceleration of positive ions by a parallel electric field along with the preferential transverse energization of O^+ ions, particularly during solar minimum. Burch and co-workers used DE data and a linear stability analysis to identify beams of injected magnetosheath ions as a likely free energy source for ion conics observed by DE near the cusp equatorward boundary.

J. L. Roeder and D. J. Gorney of Aerospace Corporation described a newly developed technique which uses a maximum entropy algorithm to derive distribution functions with higher angular resolution than that possessed by the detector itself.

High-latitude convection and ion trajectory models were discussed in papers by J. L. Horwitz and T. R. Reyes, both of The University of Alabama in Huntsville. Horwitz showed how the cleft ion fountain can populate the magnetotail lobes with O^+ ion distributions that are reasonably consistent with observed lobe ion streams.

CONSEQUENCES OF IONOSPHERIC PLASMA IN THE MAGNETOSPHERE

The session on consequences of ionospheric plasma in the magnetosphere dealt with the presence of ionospheric plasma in the magnetosphere and on its interaction with the magnetospheric particles and fields. The session started with an invited paper by R. J. Strangeway of UCLA which discussed the effects of ionospheric plasma in the magnetosphere with respect to the generation of waves and the subsequent nonlinear interaction of the waves back on the plasma. Three particular examples were described: the formation of ion conics, the heating of equatorially trapped helium, and the generation of broadband electrostatic noise. In the case of ion conics, it was shown that waves can supply the necessary energization to the ionospheric plasma so that the ions can escape from the ionosphere and flow into the magnetosphere. The heating of helium ions by ULF waves showed that ionospheric ions can modify the dispersive properties of the plasma. Consequently, these ions are heated by nonlinear interactions with the waves. The last example, the generation of broadband electrostatic noise, emphasized that cold ionospheric ions in the boundary layer may play an important role in allowing additional instabilities to be present, such as the electron acoustic mode. Other papers in this session that concerned waves were given by B. J. Fraser also of UCLA and M. J. Engebretson of Augsberg College. Fraser described ion cyclotron waves near the oxygen cyclotron frequency observed from ISEE-1 and -2 in the plasmapause and the outer plasmasphere. The results are considered an example of wave-particle interactions occurring during the outer plasmasphere refilling process at the time of substorm recovery. Engebretson described first results of a study of Pc 3-5 pulsations observed by instruments on the AMPTE/CCE satellite. Enhancements of warm plasma dominated by H^+ ions were often observed on the dayside in conjunction with radially polarized transverse oscillations at or very close to the magnetic equator. It appears likely that the latitudinal structure associated with these light, warm plasmas is trapping some of the wave energy near the equator.

Three other papers in the session described direct measurements of ions in the magnetosphere. D. M. Klumpar of Lockheed Palo Alto Research Laboratories discussed AMPTE/CCE observations of a heated plasma population confined to within a few degrees of latitude near the magnetic equatorial plane and lying just outside of the plasmapause. Dominance of H^+ over He^+ suggests the heating mechanism for creating these warm trapped light ions near the equator may be more complicated than the recently suggested mechanism involving preferential heating of He^+ by electromagnetic ion cyclotron waves. W. Lennartsson of Lockheed reported on a statistical analysis of ISEE ion composition measurements in the plasmasheet which showed that O^+ ions are a significant but highly variable component out to the ISEE-1 apogee at 23 R_E. He reported concentrations varying from less than 0.1 percent to more than 50 percent with the highest concentrations observed during periods of high geomagnetic disturbance and near the midnight meridian. J. M. Quinn, also of Lockheed, reported on variations in the ionospheric component of stormtime magnetospheric plasmas within several groups of closely spaced storms. The data, from three spacecraft, addressed the storm-to-storm composition variation that occurs in the absence of solar cycle and seasonal effects.

This session only touched on a few aspects of the broad range of important consequences that heavy ions upwelling out of the topside ionosphere have on dynamic processes in the magnetosphere. It seems clear that our present understanding of the consequences of ionospheric plasmas in the magnetosphere leaves much room for further progress.

EXTRATERRESTRIAL IONOSPHERIC PLASMA

The planetary session of the conference dealt mainly with the supply of plasma from the ionosphere into the extended planetary environment for the case of a non-magnetic (Venus) and the case of a magnetic (Jupiter) planet. The session was comprised of three invited talks, the first of which was given by L. Brace of NASA Goddard Space Flight Center and entitled "Planetary Coupling Processes." Brace gave a review of our current state of knowledge on the solar wind/ionosphere interaction at Venus including the structure of the ionopause and bow shock and emphasized the formation of ionospheric holes in the nightside magnetosphere. These ionospheric holes seem to be related to the passage of solar wind magnetic field through the Venus system, but they appear to have a strange latitudinal location that is independent of the interplanetary magnetic field orientation.

R. Thorne of UCLA presented a review of the Jovian ionosphere as a source of magnetospheric plasma. His presentation covered the early work of Ionnidis and Brice on ionospheric outflow in a gravitational/rotational-dominated magnetosphere system. More recent work on ion escape as the result of electron heating and back-scattered secondary electrons from ion precipitation was also discussed in detail. The conclusion was that the Jovian ionosphere supplies roughly the same amount of plasma to the magnetosphere as does Io outgassing. The difference is that Jovian ion outflow consists of H^+, H_2^+, and H_3^+ and I_O processes lead to the formation of Na^+, S^+, S^{++}, O^+, and O^{++} ions.

J. H. Waite, Jr., of NASA Marshall Space Flight Center iterated the role of ionospheric outflow as a source of magnetospheric plasma from a slightly different point of view, scaled from terrestrial auroral ion outflow. The resulting ion outflow magnitude was, however, similar to Thorne's result at Jupiter. Waite also discussed the role of clustered water ion inflow from the inner Saturn magnetosphere (i.e., the ring system) to the ionosphere. Water ions appear to play a major role in determining the diurnally varying structure of the Saturnian ionosphere.

J. Richardson completed the session by discussing the recent Voyager/Uranus thermal plasma measurements. The extended hydrogen atmosphere and the large dipole tilt make the Uranian system an extremely interesting new planetary system to study. The convolution of pole on planetary spin with a 60-degree magnetic axis offset leads to a "wobbling," yet Earth-like, plasmasheet and interesting corotational convection patterns in the inner magnetosphere.

POSTER PAPERS

Ten poster papers were presented during an informal setting on the second and third days of the conference. Papers included topics from all three of the primary subjects of the conference, i.e., source, mechanisms, and consequences of ionospheric plasma in the magnetosphere. P. Craven and associates of NASA Marshall Space Flight Center presented evidence of molecular ion outflow at high latitudes and in a separate paper detailed the sudden acceleration and later convection of light and heavy ions out of the auroral zone. In the latter paper, one acceleration event was coincident with the passage of a western traveling surge.

Ion heating was addressed in separate posters by T. Moore of NASA Marshall Space Flight Center, I. Roth of the University of California at Berkeley, and R. Bergmann and co-workers of Rice University. T. Moore presented rocket observations in the midnight polar cap and equatorward into the auroral oval. Heating of the O^+ ions and not H^+ and He^+ was found in association with both lower hybrid and cyclotron frequency waves. Heating was also found in association with auroral electron precipitation bursts at 300 to 350 km altitude. I. Roth presented the results of modeling large amplitude, transversely propagating electrostatic wave packets on ions. The modeled waves are like those found in association with ion conics between 1000 and 8000 km with S3-3. R. Bergmann presented a study of ion acoustic models produced by an H^+-O^+ two-stream instability. The ion-ion instability is found to have larger growth rates than the electron-ion drift instability. In this study, growth rates were examined for oblique ion acoustic and ion cyclotron waves, which will produce ion heating in ionospheric plasma outflows accelerated by strong parallel electric fields.

The characteristics and transport of ionospheric plasma in the magnetosphere were discussed by the remaining poster authors. K. Swinney and J. Horwitz, both of The University of Alabama in Huntsville, presented the results of modeling the three-dimensional trajectories of ions flowing out of the high-latitude ionosphere. In a second paper, J. Horwitz computed bulk plasma parameters, such as density and parallel flux, in the polar magnetosphere based upon a model ionospheric source in the cleft region and a kinetic model of particle trajectories. Using whistler emissions,

D. Carpenter and R. Helliwell, both of Stanford University, have determined that there is an annual variation in plasmaspheric electron density. The effect is seen over 180-deg in longitude. Although the 2:1 variation in plasmaspheric density has no current explanation, it may be caused indirectly by a northern and southern hemisphere land mass asymmetry. R. Comfort of The University of Alabama in Huntsville and C. Chappell of NASA Marshall Space Flight Center presented statistical measurements of temperatures and densities for H^+, He^+, O^+, and O^{++} in the plasmasphere. These parameters and their spatial distribution were examined for variations with local time and magnetic activity. Observations of sharply defined regions of significant plasma depletion at polar and auroral latitudes were presented by A. Persoon and co-workers of the University of Iowa. The plasma depletions were found to be correlated with ion beams and field-aligned currents. Field-aligned density structures with scale lengths of tens of kilometers were found within density cavities, which may be produced by shear-driven turbulence, instabilities associated with steep density gradients, and electric fields associated with auroral acceleration processes.

OPEN FORUM SESSION

A final open forum session provided opportunities for unstructured discussion of the topics raised during the course of this conference. The greatest level of interest was in the mechanism(s) of transverse ion energization and conic formation.

Evidence for transverse heating by current-driven ion cyclotron waves was reviewed, including the presence of field-aligned currents in the heating region, but so far not including actual observations of the waves. Particular stress was placed on the distribution of ion heating in altitude. Monte Carlo calculations and ion observations were cited as evidence that the heating must be distributed over a very large altitude range. This would certainly support contentions that part of the observed heating must occur at very low altitudes observable by sounding rockets, but contrasts with very localized heating regions inferred from some observations.

Observations of ion velocity distributions having a ring shape in velocity space were cited as evidence for a coherent acceleration process in contrast to a stochastic heating mechanism. Such observations are apparently rare, but suggestive in view of the tendency of ring distributions to decay into bi-Maxwellians via the lower hybrid instability.

The use of Monte Carlo calculations was criticized on the grounds that velocity increments are given to individual particles on an ad hoc basis. It was suggested that a more detailed description of the acceleration physics is needed to fully understand the process.

Analysis of current-driven instabilities in the presence of Coulomb collisions was discussed, showing that ion cyclotron waves could be unstable in the low-altitude regions within the F-layer of the ionosphere. These arguments lend further support to the contention that the heating region is very extended in altitude.

The heating of heavier ions by shear Alfvén waves was discussed as a possible resolution of the problem of slow heavy ion heating by ion cyclotron waves. Such waves are likely to be present on auroral field lines. The dependence of ion heating on mass appears to be a promising observational means of distinguishing among the various proposed mechanisms.

SUMMARY

Overall, the conference was highly successful at exploring various aspects of our new appreciation for ionospheric sources of magnetospheric plasmas. Each of the topics chosen for discussion received excellent participation. The sources of ionospheric plasma in the magnetosphere were discussed in the context of the cleft ion fountain and the polar cap. Ion outflow of the polar wind and that coincident with inverted-V events, Birkeland currents, electron precipitation, and velocity gradients were discussed. The mechanisms for ion outflow were largely discussed in the context of conic formation due to ion heating by lower hybrid, ion cyclotron, and Alfvén waves.

APPROVAL

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The information in this report has been reviewed for technical content. Review of any information concerning Department of Defense or nuclear energy activities or programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

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Deputy Director,
Space Science Laboratory

☆U.S. GOVERNMENT PRINTING OFFICE 1987—730-067/40096

TECHNICAL REPORT STANDARD TITLE PAGE

1. REPORT NO.	2. GOVERNMENT ACCESSION NO.	3. RECIPIENT'S CATALOG NO.
NASA TM -86589		

4. TITLE AND SUBTITLE	5. REPORT DATE
Meeting Report – Yosemite Conference on Ionospheric Plasma in the Magnetosphere: Sources, Mechanisms, and Consequences	February 1987
	6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) D. L. Gallagher, J. L. Burch,* D. M. Klumpar,** T. E. Moore, and J. H. Waite, Jr.	8. PERFORMING ORGANIZATION REPORT #
9. PERFORMING ORGANIZATION NAME AND ADDRESS George C. Marshall Space Flight Center Marshall Space Flight Center, Alabama 35812	10. WORK UNIT NO. 11. CONTRACT OR GRANT NO.
12. SPONSORING AGENCY NAME AND ADDRESS National Aeronautics and Space Administration Washington, D.C. 20546	13. TYPE OF REPORT & PERIOD COVERED Technical Memorandum
	14. SPONSORING AGENCY CODE

15. SUPPLEMENTARY NOTES

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16. ABSTRACT

The sixth biennial Yosemite topical conference and the first as a Chapman Conference was held on February 3 to 6, 1986. Due to the recent changes in our perception of the dynamics of the ionospheric/magnetospheric system, it was deemed timely to bring researchers together to discuss and contrast the relative importance of solar versus terrestrial sources of magnetospheric plasma. Although the solar wind was once thought to dominate the supply of plasma in the Earth's magnetosphere, it is now thought that the Earth's ionosphere is a significant contributor. Polar wind and other large volume outflows of plasma have been seen at relatively high altitudes over the polar cap and are now being correlated with outflows found in the magnetotail. The auroral ion fountain and cleft ion fountain are examples of ionospheric sources of plasma in the magnetosphere, observed by the Dynamics Explorer 1 (DE 1) spacecraft.

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17. KEY WORDS	18. DISTRIBUTION STATEMENT
Plasmasphere Polar Wind Wave-Particle Interactions	Unclassified – Unlimited

19. SECURITY CLASSIF. (of this report)	20. SECURITY CLASSIF. (of this page)	21. NO. OF PAGES	22. PRICE
Unclassified	Unclassified	10	NTIS

MSFC - Form 3292 (May 1969)

For sale by National Technical Information Service, Springfield, Virginia 22151