(4)

AFGL-TR-88-0134 AD-A198 549

Incoherent Scatter Measurements of the High-Latitude Ionosphere

James F. Vickrey

SRI International
333 Ravenswood Avenue
Menlo Park, CA 94025

July 1986

Final Report
1 April 1983-1 April 1986

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED

AIR FORCE GEOPHYSICS LABORATORY
AIR FORCE SYSTEMS COMMAND
UNITED STATES AIR FORCE
HANSCOM AIR FORCE BASE, MASSACHUSETTS 01731

"This technical report has been reviewed and is approved for publication"

DAVID N. ANDERSON
Contract Manager

WILLIAM K. VICKERY
Acting Branch Chief

FOR THE COMMANDER

ROBERT A. SKRIVANEK
Division Director

This report has been reviewed by the ESD Public Affairs Office (PA) and is releasable to the National Technical Information Service (NTIS).

Qualified requestors may obtain additional copies from Defense Technical Information Center.

If your address has changed, or if you wish to be removed from the mailing list, or if the addressee is no longer employed by your organization, please notify AFGL/DAA, Hanscom AFB, MA 01731. This will assist us in maintaining current mailing list.

Do not return copies of this report unless contractual obligations or notice on a specific document requires that it be returned.

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

1a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED	1b. RESTRICTIVE MARKINGS
2a. SECURITY CLASSIFICATION AUTHORITY N/A since Unclassified	3. DISTRIBUTION/AVAILABILITY OF REPORT Approved for public release; Distribution unlimited
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE N/A since Unclassified	
4. PERFORMING ORGANIZATION REPORT NUMBER(S) SRI Project 5760	5. MONITORING ORGANIZATION REPORT NUMBER(S) AFGL-TR-88-0134
6a. NAME OF PERFORMING ORGANIZATION SRI International 6b. OFFICE SYMBOL (if applicable)	7a. NAME OF MONITORING ORGANIZATION Air Force Geophysics Laboratory Air Force Systems Command
6c. ADDRESS (City, State, and ZIP Code) 333 Ravenswood Avenue Menlo Park, California 94025	7b. ADDRESS (City, State, and ZIP Code) L. G. Hanscom Air Force Base Bedford, Massachusetts 01731
8a. NAME OF FUNDING/SPONSORING ORGANIZATION 8b. OFFICE SYMBOL (if applicable)	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER F19628-83-K-0021
8c. ADDRESS (City, State, and ZIP Code)	10. SOURCE OF FUNDING NUMBERS PROGRAM ELEMENT NO. 61102F; PROJECT NO. 2310; TASK NO. G9; WORK UNIT ACCESSION NO. BA

11. TITLE (Include Security Classification)

INCOHERENT SCATTER MEASUREMENTS OF THE HIGH-LATITUDE IONOSPHERE

12. PERSONAL AUTHOR(S)

Vickrey, James F.

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15. PAGE COUNT
Final Report	FROM 830401 TO 860401	1986 July	16

16. SUPPLEMENTARY NOTATION

17. COSATI CODES

FIELD	GROUP	SUB-GROUP
17	02	1
20	09	

18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)

Plasma diffusion;
Ionospheric plasma structure,

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

We summarize the tasks performed for the Air Force Geophysics Laboratory (AFGL) under support from this contract. These tasks included incoherent-scatter-radar data taking and analysis, as well as software transfer, theoretical modeling of ionospheric plasma diffusion processes, and simulation of the proposed CRRES barium releases. We have also published four journal articles; the principal results of these papers are summarized.

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT ☐ UNCLASSIFIED/UNLIMITED ☒ SAME AS RPT. ☐ DTIC USERS	21. ABSTRACT SECURITY CLASSIFICATION UNCLASSIFIED
22a. NAME OF RESPONSIBLE INDIVIDUAL David Anderson	22b. TELEPHONE (Include Area Code) 22c. OFFICE SYMBOL AFGL/LIS

DD FORM 1473, 84 MAR

83 APR edition may be used until exhausted.
All other editions are obsolete.

SECURITY CLASSIFICATION OF THIS PAGE

UNCLASSIFIED

Contents

I SUMMARY OF RESEARCH

A. Introduction

A wide variety of research activities have been conducted under this contract. Much of the work was oriented toward incoherent scatter radar--experiment design, data collection, support of Air Force Geophysics Laboratory (AFGL) rocket launches, data analysis, and software transfer. In addition, we have refined a model of F-region cross-field diffusion [Vickrey and Kelley, 1982; Vickrey et al., 1984; and Heelis et al., 1985].* This model has shown qualitative agreement with in situ rocket observations at the equator. On the basis of that success, we have attempted to make preliminary predictions of the effects of the proposed CRRES satellite barium releases over Arecibo. The results of this modeling effort are summarized in Section B.

In Section C, we discuss recent HILAT satellite measurements of the current/voltage relationship of the magnetosphere at small spatial scales. We find that the magnetosphere tends to behave as a constant current generator. In Sections D and E, we describe satellite observations of localized high-speed ion upwellings in the dayside auroral zone, and EISCAT radar measurements of hydromagnetic waves.

---

*References are listed at the end of this report.

B. Scale-Size Dependent Plasma Diffusion Processes

Under partial support from this contract, we have constructed a model of the temporal evolution of a decaying spectrum of F-region irregularities, which includes electrical coupling along magnetic-field lines to a compressible E-region, plasma and accommodates a "classical" cross-field diffusion process [see Heelis et al., 1985]. The existence of F-region structure induces irregularities in an initially uniform E layer. Because E-region images form at the expense of F-layer plasma, the scale-size dependence of the F-region structure loss rate is strongly influenced by coupling to the E layer.

Once an image is formed, the image amplitude and the driving F-region structure amplitude decay at the same rate. At large scale sizes, λ ($\lambda = 2\pi/k$), this rate is proportional to k^2 and the ratio of the temperatures in each region. At small scale sizes, it depends on the E-region recombination rate and on the temperatures of the two regions, but it is only very weakly dependent on k. The density gradients associated with image structure impact the driving electrostatic field and parallel current that couple the two layers. The net result is that images prolong the lifetime of F-layer structure in a way that depends on scale size.

We have shown that the amplitude of the E-region-image irregularity is related to the driving F-region irregularity in a way that allows the image spectral amplitude to be a constant multiple of the F-region spectral amplitude for all wave numbers beyond a particular value. This condition may be routinely achieved where the E-region density is low (i.e., in the winter polar cap, in equatorial spread F, or in barium clouds). Under this condition, the E- and F-layer spectra decay with a common spectral shape at a rate determined by E-region chemistry.

There are two fundamental weaknesses in this model: (1) the electric field is assumed to map unattenuated between the E and F layers, and (2) the E and F layers themselves are assumed to be coarse single slabs. In future work, we hope to relax these assumptions by constructing an altitude-dependent model.

C. Magnetospheric Generator Properties

A fundamental property of the coupling between the magnetosphere and ionosphere is the current-voltage relationship of the magnetospheric "circuit." Our understanding of large-scale electrodynamics at high latitudes has increased significantly in recent years as a result of the availability of more sophisticated in situ and ground-based diagnostics. For example, satellite and radar observations of the large-scale electrostatic potential pattern at high latitudes generally show two cells when the interplanetary magnetic field (IMF) is southward. The size and shape of the two cells, however, depend on the detailed orientation of the IMF, the solar-wind speed, and the like.

Robinson [1984] examined the global current-voltage relationship of the magnetospheric generator using a large body of data from the Chatanika radar. He presented statistical evidence that the total (large-scale) ionospheric Pedersen current is linearly related to the polar cap-potential drop. Under partial support from this contract, we have examined the current-voltage relationship of the magnetosphere in the scale-size region, 3 km $< \lambda <$ 80 km [Vickrey et al., 1986]. Using data from the drift meter and magnetometer on board the HILAT satellite, we have examined fluctuations in high-latitude electric and magnetic fields. A comparison of data from summer and winter allowed us to assess the impact of changing ionospheric conductivity on the magnetospheric generator. We found that, at these scale sizes, the magnetosphere tends to behave like a constant current source that is independent of ionospheric conductivity. By this we mean that the same "level" of current structure is observed for high (summer) and low (winter) ionospheric conductivity. The electric-field pattern, on the other hand, is much more highly structured in winter than in summer. This characteristic was noted on both open and closed field lines.

There seems to be little doubt that in the open-field-line region, the current generator must reside in the flowing magnetosheath plasma itself. The data at the highest latitudes show very little variation in the intensity of the currents from day to night in the same season.

Thus, we conclude that in this scale-size regime, the energy dissipated in the ionosphere by these currents is small compared with that available in the magnetosheath. Moreover, the source of the currents is distributed more or less uniformly across the magnetopause boundary.

Within the closed-field-line region, plasma need not have the relatively constant-flow characteristics that we expect of the magnetosheath. In such a case, we can only establish the self consistency of the system as a current generator. We note, however, that, on closed field lines, the differences in electrostatic structure between hemispheres (but presumably not in the largest scale dc electric field) imply a scale-size-dependent potential drop somewhere along the magnetic-field lines. To our knowledge, such subtleties are not addressed in present global models of the magnetosphere.

D. Thermal-Ion Upwellings

There is a growing body of evidence that energetic heavy ions observed at one or more earth radii over the polar cap originate from the dayside ionosphere in the vicinity of the dayside cleft. The ions, consisting mostly of O^+, are often characterized by conic pitch-angle distributions--suggesting that they have undergone acceleration transverse to geomagnetic-field lines. This process of ion injection from a latitudinally localized source region in the dayside auroral oval, followed by dispersal throughout the entire polar cap, has been called the "cleft-ion fountain." Except for placement of the ion injection source somewhere in the vicinity of the dayside auroral oval, however, very little is known about the altitude regime in which the source operates nor the nature of the process that transports ionospheric ions into the magnetosphere. Under partial support from this contract, Tsunoda et al. [1986a] have examined upward thermal-ion flows measured by the HILAT satellite at 800-km altitude in the dayside polar ionosphere.

These upward flows, which we have called thermal-ion upwellings (TIU) are collocated with intense soft-electron precipitation, upward field-aligned currents, and often with a convection pattern characterized by $\nabla \cdot \mathbf{E} < 0$, when $\mathbf{E}$ is the electric field. These relationships were found to occur in the vicinity of avelocity-reversal (polar-cap) boundary in the post-noon sector, and perhaps near the equatorward edge of the westward electrojet in the prenoon sector. We have further shown that these low-altitude TIU events are likely to be associated with the low-energy upward-flowing ion (UFI) events observed at much higher altitudes in the polar cap [e.g., Lockwood et al., 1985]. As evidence, we showed that TIUs have a similar latitudinal distribution as the UFIs have a similar magnetic K_p dependence, and similar ion fluxes.

Small latitudinal differences found between low-altitude TIU events and high-altitude UFI events can be explained in terms of poleward displacement by the antisunward convection of ionospheric ions during their upward transport along geomagnetic-field lines. We found that TIU events tended to occur about 2° lower in latitude than UFI events. If we choose 2500 km as the lowest altitude of observed UFIs [Lockwood et al., 1985], ions at 800-km altitude would have to travel 1700 km along geomagnetic-field lines while being convected poleward 2° in latitude. For example, an upward velocity of 1 km/s would require a corresponding antisunward convection velocity of 130 m/s. The time required for ions to reach higher altitudes is, of course, longer, and would require even smaller antisunward convection velocities. (Upward velocities, however, are expected to increase with altitude.)

Although only measurements of dayside TIU events were presented by Tsunoda et al. [1986a], we have observed these events at other local times--in particular, with auroral arcs in the night sector. Heelis et al. [1984] have reported DE-2 observations of upward-flowing ions in both day and night sectors. The occurrence pattern of TIUs, therefore, is likely to be distinctly different from the prenoon occurrence maximum associated with the cleft ion fountain [Lockwood et al., 1985; Waite et al., 1985].

Although firm conclusions cannot yet be drawn, a common thread associated with all TIU events seems to be velocity shear characterized by $\nabla \cdot \mathbf{E} < 0$. Discrete electron precipitation is closely related to this condition [Lyons, 1980]. It is, therefore, conceivable that velocity shear in magnetospheric convection is the source of free energy that drives the process of ionospheric ion injection into the magnetosphere.

E. Radar Observations of a Pc4 Event

Tsunoda et al. [1986b] measured large, irregular electric fields in the midnight sector on 25 February 1984, using the European incoherent-scatter (EISCAT) radar facility. This radar has the unique ability to determine the local, vector electric fields from the F-region ion velocity measurements so that time-varying electric fields could be detected during extremely quiet geomagnetic conditions. Peak electric-field intensities approaching 45 mV/m were observed to commence under these conditions and to persist through a negative bay event. The electric fields were characterized by a near-linear polarization (northwest-southeast orientation) and an oscillation period that was correlated with the mean oscillation amplitude. The characteristics of the time-varying electric field were similar to those of a relatively rare type of Pc4 pulsation event found in the midnight sector. Tsunoda et al. [1986b] argued that (1) the large pulsation electric fields measured in the ionosphere during quiet conditions were likely produced by hydromagnetic wave energy reflected from a poorly conducting ionosphere, (2) wave energy was probably provided by the westward component of the convection electric field, and (3) variations in the oscillation period were also associated with the westward electric field through changes in the length of geomagnetic field lines.

The finding that the pulsation amplitude appears to grow with the development of a westward electric field is intriguing, because it may represent evidence for identifying the underlying source of free energy. A westward electric field moves magnetospheric plasma earthward in the midnight sector [e.g., Mozer, 1973]. Perturbations in this earthward convection are likely to produce radial oscillations of geomagnetic-field lines (and accompanying east-west oscillations in electric field). Perturbations in this earthward flow may be magnetospheric or ionospheric in origin. For example, Maltsev et al. [1974] showed that Pi2 pulsations can be set up by the brightening of an auroral arc; the brightening corresponds to an interruption in earthward convection by a change in ionospheric conductivity.

The fact that the oscillation period appeared to be related to pulsation amplitude may be qualitatively explained as follows. Southward turning of the plasma drift vector corresponds to the development of a westward electric field. The presence of a westward electric field is often an indicator that the geomagnetic field configuration is becoming more "taillike." The effect is to lengthen geomagnetic field lines in the midnight sector and, hence, the pulsation period. When the westward electric field disappears (or weakens), the geomagnetic field returns to a more dipolar configuration. The effect is to shorten geomagnetic field lines, and hence, the pulsation period. We thus conclude that the westward electric field could contribute to hydromagnetic-wave energy in the midnight sector.

II PUBLICATIONS PRODUCED UNDER SUPPORT FROM THIS CONTRACT

The following papers have been published or have been submitted for publication in the referred scientific journals.

"Electrical Coupling Effects on the Temporal Evolution of F-Layer Plasma Structure," by R. A. Heelis, J. F. Vickrey, and N. B. Walker, J. Geophys. Res., 90, 437-445, 1985.

"On the Current-Voltage Relationship of the Magnetospheric Generator at Small Spatial Scales," by J. F. Vickrey, R. C. Livingston, N. B. Walker, T. A. Potemra, R. A. Heelis, M. C. Kelley, and F. J. Rich, in press, Geophys. Res. Letts, 1986.

"Dayside Observations of Thermal-Ion Upwellings at 800-km Altitude: An Ionospheric Signature of the Cleft Ion Fountain," by R. T. Tsunoda, R. C. Livingston, J. F. Vickrey, C. L. Rino, R. A. Heelis, W. B. Hanson, D. A. Hardy, F. J. Rich, and P. F. Bythrow, submitted to J. Geophys. Res., 1986a.

"EISCAT Observations of Large, Fluctuating Electric Fields During a Pc4 Pulsation Event in the Midnight Sector," by R. T. Tsunoda, I. Haggstrom, A. Pellinen-Wannberg, A. Steen, G. Wannberg, and J. F. Vickrey, submitted to J. Atmos. and Terrest. Phys., 1986b.

III REFERENCES

Heelis, R. A., J. F. Vickrey, and N. B. Walker, "Electrical Coupling Effects on the Temporal Evolution of F Layer Plasma Structure," J. Geophys. Res., 90, 437-445, 1985.

Heelis, R. A., J. D. Winningham, M. Sugiura, and N. C. Maynard, "Particle Acceleration Parallel and Perpendicular to the Magnetic Field Observed by DE-2," J. Geophys. Res., 89 3893-3902, 1984.

Lockwood, M., J. H. Waite, Jr., T. E. Moore, J. F. E. Johnson, and C. R. Chappell, "A New Source of Suprathermal O^+ Ions near the Dayside Polar Cap Boundary," J. Geophys. Res., 90, 4099-4116, 1985.

Lyons, L. R., "Generation of Large-Scale Regions of Auroral Currents, Electric Potentials, and Precipitation by the Divergence of the Convection Electric Field," J. Geophys. Res., 85, 17-24, 1980.

Maltsev, Yu. P., S. V. Leontyev, and W. B. Lyatsky, "Pi2 Pulsations as a Result of Evolution of an Alfven Impulse Originating in the Ionosphere During a Brightening of Aurora," Planet. Space Sci., 22, 1519-1533, 1974.

Mozer, F. S., "On the Relationship Between the Growth and Expansion Phases of Substorms and Magnetospheric Convection,"J. Geophys. Res., 78, 1719-1722, 1973.

Robinson, R. M., "K_p Dependence of Auroral Zone Field-Aligned Current Intensity," J. Geophys. Res., 89, 1743-1748, 1984.

Tsunoda, R. T., R. C. Livingston, J. F. Vickrey, and C. L. Rino, "Day-side Observations of Thermal-Ion Upwellings at 800-km Altitude: An Ionospheric Signature of the Cleft Ion Fountain," submitted to J. Geophys. Res., 1986a.

Tsunoda, R. T., I. Haggstrom, A. Pellinen-Wannberg, A. Steen, G. Wannberg, and J. F. Vickrey, "EISCAT Observations of Large, Fluctuating Electric Fields During a Pc4 Pulsation Event in the Midnight Sector," submitted to J. Atmos. and Terrest. Phys., 1986b.

Vickrey, J. F., R. C. Livingston, N. B. Walker, T. A. Potemra, R. A. Heelis, M. C. Kelley, and F. J. Rich, "On the Current-Voltage Relationship of the Magnetospheric Generator at Small Spatial Scales," Submitted to Geophys. Res. Letts., 1986.

Vickrey, J. F., M. C. Kelley, R. Pfaff, and S. R. Goldman, "Low-Altitude Image Striations Associated with Bottomside Equatorial Spread F--Observations and Theory," J. Geophys. Res., 89, 2955-2961, 1984.

Vickrey, J. F., and M. C. Kelley, "The Effects of a Conducting E layer on Classical F Region Cross-Field Plasma Diffusion," J. Geophys. Res., 87, 4461-4468, 1982.

Waite, J. H., T. Nagai, J. F. E. Johnson, C. R. Chappell, J . L. Burch, T. L. Killeen, P. B. Hays, G. R. Carignan, W. K. Peterson, and E. G. Shelley, "Escape of Suprathermal O^+ Ions in the Polar Cap," J. Geophys. Res., 90, 1619-1630, 1985.