Unclassified

SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

AD-A208 794

1a.	1b. RESTRICTIVE MARKINGS
2a.	3. DISTRIBUTION/AVAILABILITY OF REPORT Approved for public release; Distribution unlimited.
4. PERFORMING ORGANIZATION REPORT NUMBER(S) GL-TR-89-0134	5. MONITORING ORGANIZATION REPORT NUMBER(S)
6a. NAME OF PERFORMING ORGANIZATION: Geophysics Laboratory — 6b. OFFICE SYMBOL (If applicable): PHP	7a. NAME OF MONITORING ORGANIZATION
6c. ADDRESS (City, State, and ZIP Code) Hanscom AFB Massachusetts 01731-5000	7b. ADDRESS (City, State, and ZIP Code)
8a. NAME OF FUNDING/SPONSORING ORGANIZATION — 8b. OFFICE SYMBOL (If applicable)	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
8c. ADDRESS (City, State, and ZIP Code)	10. SOURCE OF FUNDING NUMBERS

PROGRAM ELEMENT NO.	PROJECT NO.	TASK NO.	WORK UNIT ACCESSION NO.
62101F	7601	22	01

11. TITLE (Include Security Classification)
Precipitating Polar Cap Particles During Northward IMF

12. PERSONAL AUTHOR(S)
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13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15. PAGE COUNT
Reprint	FROM ____ TO ____	1989 May 22	10

16. SUPPLEMENTARY NOTATION *Physics Department, Boston College, Chestnut Hill, MA 02167
Reprinted from Physics of Space Plasmas (1987) SPI Conference Proceedings and Reprint Series, Vol. 7

17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB-GROUP	Polar cap arcs, Boundary Plasma, Northward Bz, Electron Precipitation, Ion precipitation, DMSP

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

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20. DISTRIBUTION/AVAILABILITY OF ABSTRACT ☐ UNCLASSIFIED/UNLIMITED ☒ SAME AS RPT. ☐ DTIC USERS	21. ABSTRACT SECURITY CLASSIFICATION Unclassified
22a. NAME OF RESPONSIBLE INDIVIDUAL M.S. Gussenhoven	22b. TELEPHONE (Include Area Code): (617) 377-3212 — 22c. OFFICE SYMBOL: PHP

DD FORM 1473, 84 MAR — 83 APR edition may be used until exhausted. All other editions are obsolete.

SECURITY CLASSIFICATION OF THIS PAGE

Unclassified

GL-TR-89-0134

SPI CONFERENCE PROCEEDINGS AND REPRINT SERIES

Series Editor: T. S. Chang

Number 7

Physics of Space Plasmas (1987)

Proceedings of the
1987 Cambridge Workshop in Geoplasma Physics
Ionosphere–Magnetosphere–Solar Wind Coupling Processes

EDITORS

T. Chang, G. B. Crew and J. R. Jasperse

Scientific Publishers, Inc.

Box 6, MIT Branch Post Office
Cambridge, Massachusetts 02139

Library of Congress Catalog Card Number: 82-062441

Printed in the United States of America

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PRECIPITATING POLAR CAP PARTICLES DURING NORTHWARD IMF

H.-C. Yeh, N.C. Heinemann
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ABSTRACT

We have studied the global features of high-latitude precipitating particles during a fifteen hour period of stably northward, toward sector interplanetary magnetic field (IMF). Thirty passes of DMSP precipitating electron and ion measurements enabled us to examine the average polar cap particle intensity, morphology and characteristic spectra. Large scale regions of ion enhancement, with energy spectra similar to those for boundary plasma sheet ions, are associated with polar cap arcs. The high latitude precipitation patterns for each hemisphere are nearly mirror images, thereby showing an IMF sector (or By) dependence.

I. INTRODUCTION

When the IMF has a strongly northward component (+Bz), enhanced particle precipitation into the polar cap occurs and characteristic precipitation patterns can be recognized. It is important to our understanding of polar cap dynamics to relate the source region and global features of the precipitating particles to aspects of the solar wind-magnetosphere-ionosphere coupling process. In this report we describe the DMSP observed particle characteristics during a period of strongly positive IMF Bz and negative IMF By. Asymmetrical features between the polar hemispheres that indicate an IMF effect are examined.

The DMSP F6 and F7 satellites measure both precipitating electrons and ions in the energy range 30 eV to 30 keV. Polar cap precipitating electrons in the energy range of 50 eV to 20 keV for similar IMF conditions have been discussed by Hardy et al. [1]. Here we focus on the precipitating ion structures and the characteristics of simultaneously measured electrons over the larger energy range.

We describe the environmental conditions under which observations were made in Section II. In section III we identify large-scale features from the integral number flux, integral energy flux and average spectral characteristics of the precipitating ions and electrons for two consecutive passes over the south pole and the north pole. In section IV we make northern-southern hemisphere comparisons of the large-scale features in the average precipitation patterns for various magnetic local time sectors.

II. GEOMAGNETIC, IMF, AND SOLAR WIND CONDITIONS

Prevailing conditions from 19 UT, 1 November to 10 UT, 2 November 1984 are as follows: For the 15 hours of interest (with a data gap at 03-05 UT) each IMF component had a fixed polarity (+Bz, -By, +Bx). The magnitude of Bz is persistently large (>10 nT). The ratio of Bz to By, except for the first hour, varies from 1.5 to 5. The solar wind density is <15 ions/cm^3 and temperature is >10^5 °K. The solar wind speed ranges from 400 to 500 km/s [2]. The Kp index is stable at 2- to 3-. The Dst index shows that the period of interest occurs during the late recovery phase of a storm.

We assume that the similar IMF conditions which are seen before and after the data gap from 03 to 05 UT on 2 November, persist during the gap. This is reasonable since Kp is stable, Dst is stable and 3 consecutive F6 images (not shown) from before, during and after the gap are similar.

III. LARGE SCALE FEATURES OF PRECIPITATING PARTICLES

The observed particle precipitation is used to determine large scale features and patterns, particularly, 1) the equatorward boundaries of auroral electrons and ions; 2) the boundaries between diffuse and discrete auroras; and 3) the boundaries between discrete auroral electron precipitation and low-intensity electron precipitation at the highest latitudes. The boundaries are determined from the profiles of the integral number flux (JTOT in electron/cm^2-s-sr) and energy flux (JETOT in keV/cm^2-s-sr) of precipitating electrons.

We illustrate the large-scale features found with the electron and ion data from two consecutive south and north polar passes of the F6 satellite on 2 November 1984 between 2:59 and 4:06 hours UT. Fig. 1 is a plot of electron (top) and ion (bottom) JTOT and JETOT profiles for these passes. From left to right the F6 satellite travelled over the south pole (SP) from dusk to dawn and continued over the north pole (NP) from dawn to dusk. Arrow bars shown between electron and ion panels in Fig. 1 indicate the approximate locations of various boundaries that separate the electron JTOT pattern into 5 regions: (A) the evening diffuse aurora characterized by a uniform flux level of ~ 6×10^7 (electron /cm^2-s-sr); (B) the evening discrete aurora with an average (though non-uniform) flux level of ~ 10^8; (C) the polar cap characterized by a low flux level of < 10^7; (D) the morning discrete aurora with an average flux level of ~ 10^8; and (E) the morning diffuse aurora with a constant flux level of ~ 1.5×10^8. These boundaries also serve to characterize regions in the electron-JETOT and the ion-JTOT and -JETOT patterns.

Comparing the north pole electron JETOT pattern to the north pole DMSP image, intense polar cap arcs occur on the morning side (Region D), which coincide with the second intensification of JTOT in the electron and ion precipitation patterns at the high latitude portion of Region D. We also associate the second high latitude block of electron and ion precipitation in the south pole with polar cap arcs. The polar cap arcs of the south pole, however, are most intense on the evening side (Region B). The intensity level of both electron and ion fluxes in the polar cap (Region C) in the north pole is considerably lower (about an order of magnitude for the electrons) than it is in the south pole. The preferred enhancement in the south polar cap for -By is the same as the hemisphere-selective enhancement of the polar rain flux found by Gussenhoven et al. [3]. Additionally, we note in Fig. 1 that the strongest ion precipitation is located in the equatorward section of the morning discrete aurora (Region D), independent of hemisphere.

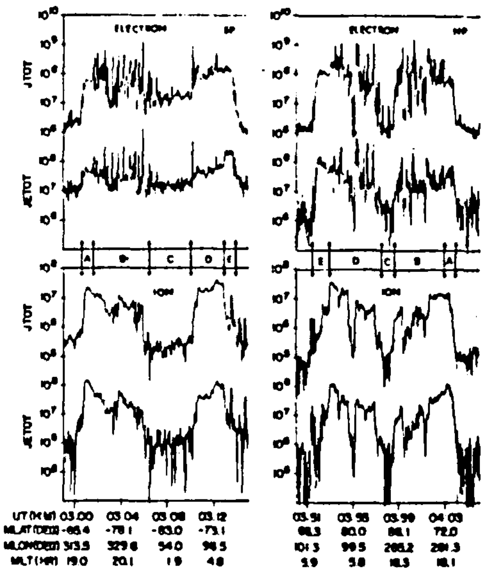

Figure 1. Examples of the integral number flux (JTOT) and energy flux (JETOT) of precipitating particles in the south pole (SP) and north pole (NP). JTOT, in $(cm^2\text{-}s\text{-}sr)^{-1}$, and JETOT, in $(keV/cm^2\text{-}s\text{-}sr)$ are plotted as functions of universal time (UT) in (hours:minutes), corrected geomagnetic latitude (MLAT), longitude (MLON) and magnetic local time (MLT) all projected to an altitude of 110 km. Arrows mark large-scale regions of characteristic precipitation.

We also examine the spectral characteristics in the high latitude precipitation regions which show north-south pole asymmetry. Sample spectra from the north pole pass (right panel) in Fig. 1 are shown in Fig. 2 where we plot the electron (left) and ion (right) distribution function ($cm^{-6}\ sec^{3}$) as a function of energy (eV). The solid lines represent spectra from the poleward portion of the polar cap arc region (Region D). The dashed lines represent spectra from the central Region C. Clearly the spectra in the two regions differ.

The electron energy spectrum associated with polar cap arc can be described approximately as an accelerated-Maxwellian distribution with a parallel electrostatic potential drop ($\phi_{\parallel}$) of ~ 0.5 kV. The ion energy spectrum from the polar cap arc region can be described as a drifting-Maxwellian distribution with bulk energy (E_b) of ~2 keV.

The sample polar cap arc region spectra are typical of spectra measured throughout the poleward portion of Region D (dawn side) in the north pole, and the poleward portion of Region B (dusk side) in the south pole. The $\phi_{\parallel}$ of electron spectrum across the polar cap arc region varies form 0.3 to 1 kV, while the E_b of ion spectrum ranges from 0.4 to 2 keV. The ion spectra in the polar cap arc regions resemble the earthward streaming ion spectra observed in the distant plasma sheet boundary layer [4]. The small electron acceleration ($\phi_{\parallel}$) and the ion bulk motion (E_b) seen in the distribution functions would suggest plasma sheet boundary layer as the possible source region of the precipitating particles.

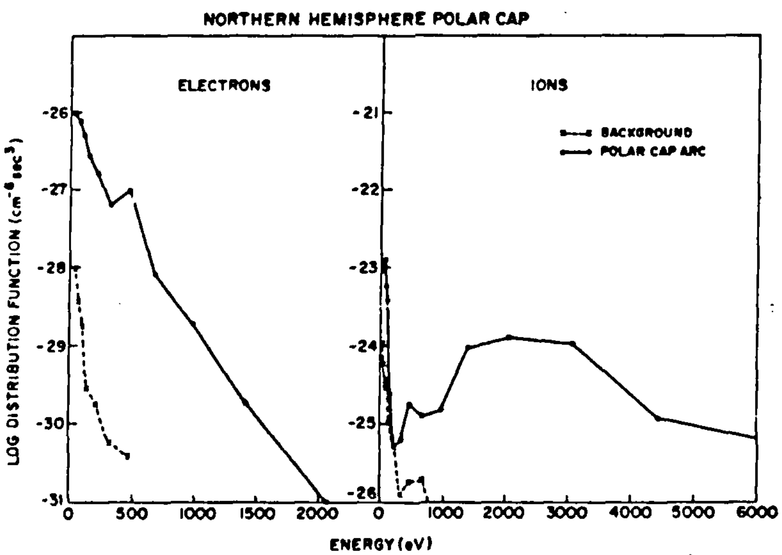

Figure 2. Sample energy spectra at the highest latitudes in the northern hemisphere during stable, northward IMF Bz.

IV. NORTHERN HEMISPHERE-SOUTHERN HEMISPHERE COMPARISONS

Asymmetrical features of the polar region precipitating electrons which strongly correlate with the polarity of the IMF sector have previously been observed [5, 6]. To examine the IMF sector dependence of the high latitude precipitation we compare (Fig. 3) the average pattern of particle energy flux (JETOT) over the northern hemisphere with that over the southern hemisphere. We assume that the hemisphere-dependence mainly results from the reversal of the IMF By control and that the seasonal effect on this dependence is insignificant. Combining the F6 and F7 measurements, there are 16 northern hemisphere passes and 14 southern hemisphere passes.

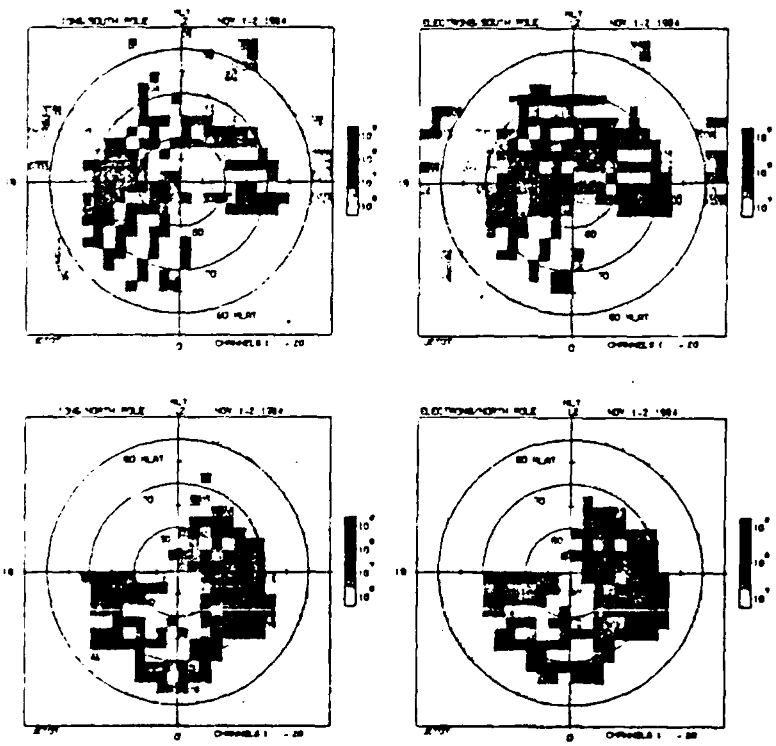

Figure 3. Global distributions of the precipitating particle energy flux (JETOT, in keV/cm^2-s-sr) in MLAT versus MLT coordinates from 19 UT 1 November to 09 UT 2 November 1984. The global patterns of JETOT are separated by pole. Hemisphere-dependent asymmetry is apparent in the JETOT patterns for MLAT > 75°.

Fig. 3 is a gray-scale plot of the levels of JETOT in MLAT versus MLT coordinates for each pole (south at top; north at bottom) and for each particle species (ions on the left; electrons on the right). The 2.5° by 2.5° bin size accommodates the small data set and reduces fine scale effects possibly resulting from the slight variations of the IMF orientation, but unfortunately also reduces the resolution of discrete particle features and underestimates the magnitude of the peak flux levels.

The equatorward boundaries of the precipitating particles shown in Fig. 3 all fit fairly well a circle of 23° radius with the center offset 3° toward midnight. There is no large difference between the electron and ion equatorward boundaries. In the diffuse aurora, just poleward of the equatorward boundary, the northern hemisphere and southern hemisphere precipitation is very similar. However, the electron energy flux is about a factor of 20 higher than the ion energy flux.

Poleward of the diffuse aurora at >70° MLAT two hemisphere-selective features are clearly demonstrated in Fig. 3. The first is the morphology of the low intensity (polar cap) precipitation region best seen in the ion plots. A U-shaped region which has a larger latitudinal extent on the night side than on the dayside is seen in both hemispheres. In the north pole, the low-intensity ion precipitation region is approximately symmetrical with respect to the noon-midnight MLT meridian and occurs mostly on the night side. The central location of the southern low-intensity ion precipitation region, however, shifts about 5° off the noon-midnight MLT meridian toward dawn and extends further into the dayside.

The second hemisphere-dependent feature is most readily seen in the electron plots (right panels of Fig. 3). Intense electron energy flux (>10^8 keV/cm^2-s-sr) extends to latitudes as high as > 85° in both hemispheres and is indicative of persistent arc structures. The energy flux is generally stronger in the southern hemisphere than in the northern hemisphere.

In the northern hemisphere, the location of the intense electron energy flux is in the dawn to prenoon MLT sector. The strongest, high latitude energy flux is between 80° to 85°, and ~ 05 to 10 MLT. Though somewhat smeared by the large bin size, this structure is connected to the post-midnight aurora, because the 11 DMSP images for the same time interval show continuous arc structures emerging from the early MLT hours. Also the brightest arc structure is skewed toward the dawn hemisphere, and little arc structure is seen in the dusk hemisphere.

The intense energy flux pattern is very different in the southern hemisphere. The strongest high latitude electron energy flux is now in the dusk to midnight sector and essentially reaches the pole (~ 90°). A second intense energy flux population is located in the 10-14 MLT sector between 75° and

85° MLAT, a typical location of the dayside cusp. There is no pronounced connection between the two regions of intense energy flux. Unfortunately, we do not have DMSP images from the southern hemisphere (because it is sunlit) to see whether the polar cap arcs in the dusk sector connect to the premidnight discrete aurora.

Heelis et al. [7] have examined the high-latitude ionospheric convection patterns (mostly on the dayside) in the northern hemisphere during periods of prolonged northward IMF. They found a two-cell convection pattern with the dominant cell displaced toward dusk and with an anticlockwise circulation for IMF -By. The dominant cell is displaced towards dawn and has clockwise circulation for +By; we assume that this would be the polar convection pattern in the southern hemisphere for -By. With the latter assumption, the intense polar cap precipitation found for -By essentially occurs at the highest latitude sunward convection regions in both hemispheres. This association suggests that the location of the polar cap arcs would exhibit the same dependence on IMF By as found by Heelis et al. of the convection pattern.

V. CONCLUSIONS

Examination of particle measurements from two DMSP satellites during a prolonged period of strongly northward (+Bz) and a stably toward sector (+Bx, -By) of the IMF has shown that coherent precipitation patterns exist over wide MLAT-MLT spatial range. Two hemisphere-dependent, large-scale structures are found at high latitudes, which are consistent with the features known to have an IMF By dependence. These structures are as follows: First, the polar cap low-energy population (Region C) shows the same hemispheric asymmetry as found for the polar rain for -By. In the northern hemisphere, Region C is distributed symmetrically with respect to the noon midnight meridian and confined mostly to the nightside. Region C in the southern hemisphere, however, is displaced toward dawn and has a larger dayside extension. The intensity level of energy flux is higher in the south pole.

Second, the strongest high latitude particle precipitation associated with polar cap arcs is seen preferentially in the dawn half of the northern hemisphere and in the dusk half of the southern hemisphere. Again, the average energy fluxes of electrons and ions associated with the polar cap arcs are generally stronger in the southern hemisphere than in the northern hemisphere. Furthermore, the consistent features found of field-aligned acceleration associated with precipitating electrons and bulk motion associated with precipitating ions suggest the connection of the polar cap arc region with the nightside plasma sheet boundary layer.

ACKNOWLEDGMENTS

We are grateful to R.L. Carovillano for providing valuable comments on this manuscript. We thank D. Madden for programming assistance, particularly the development of software for graphical displays, and Mira Wieraszko for her assistance in preparing the manuscript. The work of H.-C. Yeh and N.C. Heinemann was supported by the Air Force Geophysics Laboratory under contract AF19628-86-C-0029.

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