MICROCOPY RESOLUTION TEST CHART

AD-A175 170

# A Multiple-Satellite Observation
# of the High-Latitude Auroral
# Activity on 11 January 1983

D. J. GORNEY and P. F. MIZERA
Space Sciences Laboratory
The Aerospace Corporation
El Segundo, CA 90245

D. S. EVANS
Lockheed Palo Alto Research Laboratory
Palo Alto, CA 94304
and
M. S. GUSSENHOVEN
Air Force Geophysics Laboratory
Hanscom Air Force Base, MA 01731

1 November 1986

DTIC
SELECTE
DEC 1 8 1986
D

DTIC FILE COPY

SECURITY CLASSIFICATION OF THIS PAGE *(When Data Entered)*

| REPORT DOCUMENTATION PAGE | | READ INSTRUCTIONS BEFORE COMPLETING FORM |
|---|---|---|
| 1. REPORT NUMBER<br><br>SD-TR-86-68 | 2. GOVT ACCESSION NO. | 3. RECIPIENT'S CATALOG NUMBER |
| 4. TITLE *(and Subtitle)*<br><br>A MULTIPLE-SATELLITE OBSERVATION OF THE HIGH-LATITUDE AURORAL ACTIVITY ON 11 JANUARY 1983 | | 5. TYPE OF REPORT & PERIOD COVERED |
| | | 6. PERFORMING ORG. REPORT NUMBER<br>TR-0086(6940-05)-15 |
| 7. AUTHOR*(s)*<br><br>David J. Gorney, Paul F. Mizera,<br>D. S. Evans, and M. S. Gussenhoven | | 8. CONTRACT OR GRANT NUMBER*(s)*<br><br>F04701-85-C-0086-P00016 |
| 9. PERFORMING ORGANIZATION NAME AND ADDRESS<br><br>The Aerospace Corporation<br>El Segundo, CA 90245 | | 10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS |
| 11. CONTROLLING OFFICE NAME AND ADDRESS<br><br>Space Division<br>Los Angeles Air Force Station<br>Los Angeles, CA 90009-2960 | | 12. REPORT DATE<br>1 November 1986 |
| | | 13. NUMBER OF PAGES<br>31 |
| 14. MONITORING AGENCY NAME & ADDRESS*(if different from Controlling Office)* | | 15. SECURITY CLASS. *(of this report)*<br><br>Unclassified |
| | | 15a. DECLASSIFICATION/DOWNGRADING SCHEDULE |

16. DISTRIBUTION STATEMENT *(of this Report)*

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT *(of the abstract entered in Block 20, if different from Report)*

18. SUPPLEMENTARY NOTES

19. KEY WORDS *(Continue on reverse side if necessary and identify by block number)*

aurora, polar aurora, imagery

20. ABSTRACT *(Continue on reverse side if necessary and identify by block number)*

Unusual high-latitude auroral activity occurred on 11 January 1983 during a period of persistent IMF $B_z > 0$, $B_y > 0$ and $B_x > 0$. This activity, which lasted from 06:00 - 21:00 UT, was characterized by numerous high-latitude sun-aligned arcs and a diffuse oval. Near 15:00 UT a single broad (250 km) sun-aligned arc was observed by the optical linescan system on DMSP-F6. The arc was contiguous with the dawn auroral oval and extended across the northern polar cap, similar to previously reported "theta aurora"

DD FORM 1473<br>(FACSIMILE)

SECURITY CLASSIFICATION OF THIS PAGE *(When Data Entered)*

19. KEY WORDS (Continued)

20. ABSTRACT (Continued)

configurations. The fortunate orbital locations of the DMSP-F6, NOAA-7 and NOAA-6 satellites allows a detailed analysis of the precipitating particle populations responsible for both the sun-aligned arc and oval auroras. Specifically, NOAA-7 and DMSP-F6 cross the broad sun-aligned arc almost simultaneously in the northern hemisphere, with NOAA-7 crossing the arc 1500 km farther toward the dayside. During the arc crossing, NOAA-7 observes electron fluxes, temperatures and accelerations similar to DMSP-F6, but observes ion fluxes diminished by a factor of fifty in comparison with DMSP. Almost simultaneously NOAA-6 crosses the southern polar cap and observes flux levels in an apparent high-latitude arc comparable to those observed by DMSP. The results are consistent with, but supplementary to, previous observations of high-latitude auroral observations and thus place meaningful constraints on emerging theoretical concepts of this phenomenon.

# CONTENTS

Accesion For

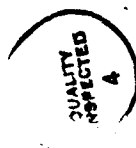| | | |
|---|---|---|
| NTIS CRA&I | ☑ | |
| DTIC TAB | ☐ | |
| Unannounced | ☐ | |
| Justification | | |

By ...........................

Distribution /

| Availability Codes | | |
|---|---|---|
| Dist | Avail and / or Special | |
| A-1 | | |

FIGURES

OBSERVATIONS

Very unusual auroral activity was observed on 10-11 January 1983 (Akasofu and Tsurutani, 1984). Akasofu and Tsurutani used visible linescan imagery from the DMSP-F6 satellite to monitor auroral activity over the northern (winter) polar region, and used magnetometer data from the ISEE-3 and IMP-8 spacecraft to monitor the interplanetary magnetic field (IMF) orientation. They noted a number of auroral features which occurred in coincidence with changes in the IMF orientation. In this report we concentrate on the specific occurrence of a broad transpolar arc late on 11 January 1983, during which the IMF $B_z$ and $B_y$ components were positive and stable in time. This auroral feature is similar in appearance to transpolar or "theta" arc configurations reported by Frank et al. (1982), for which no complete theoretical explanation is available. The purpose of this report is to use a fortunate orbital configuration of three low-altitude polar-orbiting spacecraft to probe the distribution of precipitating plasma responsible for the arc. The measurements include information on the plasma distribution both along and across the transpolar arc as well as a comparison of plasma distributions in opposite hemispheres. These measurements put meaningful constraints on theoretical concepts of transpolar aurora formation mechanisms.

Although we concentrate on a specific event near 15:00 UT on 11 January 1983, it is of interest to review, for perspective, the behavior of the IMF for the entire 10-11 January period. Figure 1 is reprinted here from Akasofu and Tsurutani (1984), and shows the IMF $B_x$, $B_y$ and $B_z$ components, the IMF magnitude, and a preliminary Auroral Electrojet (AE) index. The magnetometer data were acquired by ISEE-3 at GSE coordinates X = -175 $R_e$, Y = -19 $R_e$, Z = 304 $R_e$, and although the spacecraft was probably in the equatorial dawn flank of the magnetosheath, Akasofu and Tsurutani argue that the observations are well representative of the IMF.
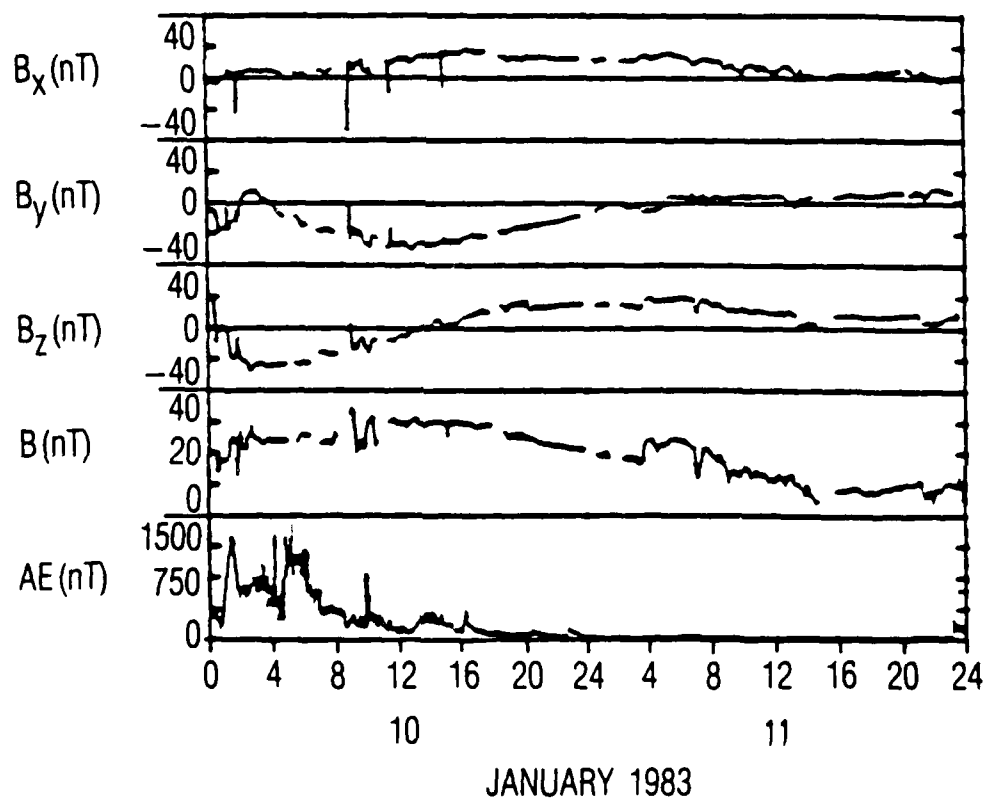
5

Figure 1. The Interplanetary Magnetic Field Components and Magnitude and a
Preliminary AE Index for 10-11 January 1983 (from Akosofu and
Tsurutani, 1984)

Figure 1 shows that the IMF magnitude was relatively large during all of 10-11 January, with magnitudes decreasing from 30 nT on the 10th to about 10 nT on the 11th. Through 10 January the IMF at ISEE-3 performed a rotation in the ($B_y$, $B_z$) plane while $B_x$ increased to near 15 nT. After about 05:00 UT on 11 January the IMF maintained its orientation with $B_x > 0$, $B_y > 0$ and $B_z > 0$. Late on 11 January $B_x$ decreased to near zero and $B_y \approx 5$ nT and $B_z \approx 10$ nT. These magnitudes persisted for several hours. The AE index was high during the period of negative IMF $B_z$ early on the 10th, but declined to near zero throughout the 11th.

Akasofu and Tsurutani observed very active auroral features, primarily in the dawn sector, throughout the latter half of 10 January. This pattern changed early on the 11th, when the polar region became covered with a large number of sun-aligned arcs. Later on the 11th, near 15:00 UT, a single broad transpolar arc dominated the visible imagery. The remainder of this report will deal exclusively with the one-hour interval surrounding 15:00 UT, during the period of occurrence of the transpolar arc and when IMF conditions were stable at $B_x \approx 0$, $B_y \approx 5$ nT and $B_z \approx 10$ nT.

Figure 2 depicts the auroral luminosity observed by the DMSP-F6 visible linescan system over the northern polar region. The image was acquired between 15:12 and 15:26 UT on 11 January 1983 and has been projected into invariant latitude and magnetic local time coordinates in the figure. A very weak diffuse oval extends from pre-midnight to morning local time. (The equatorward edge of the midnight portion of the oval was not quite visible in the original image.) Two auroral arcs appear at very high latitudes. One is a narrow hook-shaped arc in the pre-midnight region, and the other is a broad, linear, sun-aligned transpolar arc which is contiguous with the post-midnight diffuse oval. The transpolar arc is the brightest auroral feature observed,
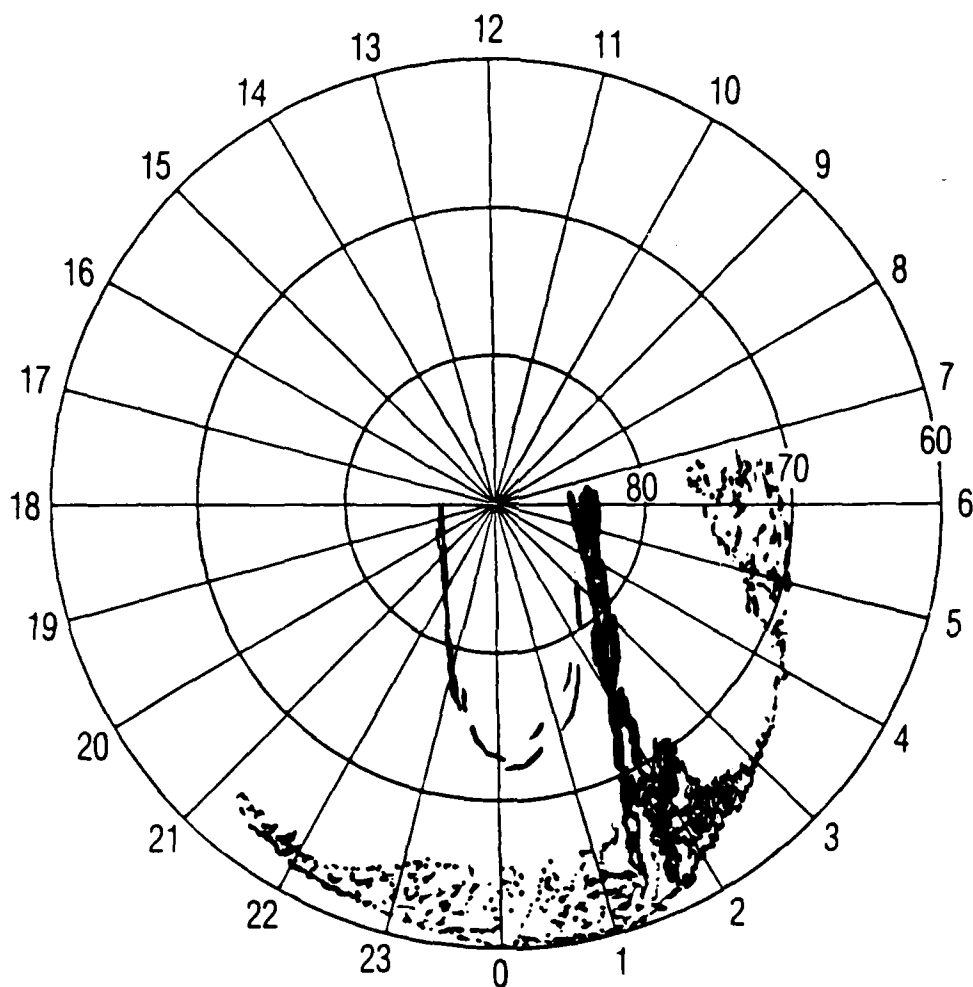
7

Figure 2.   A Depiction of the Auroral Luminosity Observed by the DMSP-F6
            Visible Linescan System over the Northern Polar Region Between
            15:12 and 15:26 UT on 11 January 1983.   Here, the auroral
            luminosity has been projected into invariant latitude and magnetic
            local time coordinates.

and it is approximately 250 km in width, although it is composed of finer-scale structures. A fairly isolated brightening of the diffuse oval occurs where the oval and transpolar arcs meet.

DMSP-F6 acquired this visible image while traversing the northern polar cap from dawn toward dusk. The trajectory of DMSP-F6 in invariant latitude and local time coordinates is shown in Figure 3. Also plotted in Figure 3 are the polar trajectories of NOAA-6 and NOAA-7 which occur within an hour of the DMSP-F6 observations. The notation on the trajectories indicates whether the polar pass occurred over the northern (N) or southern (S) pole. The relative timing of the trajectories is NOAA-6 (N) at 14:36 - 14:56, DMSP-F6 (N) at 15:12 - 15:26, NOAA-7 (N) at 15:15 - 15:32 and NOAA-6 (S) at 15:25 - 15:42. Note that all three satellites are in circular orbits at approximately the same altitude and therefore travel at about the same speed.

*The auroral particle instrument* on the NOAA-6 and 7 satellites measures ions and electrons over the energy range 300 eV to 20,000 eV at two pitch angles which, at auroral and polar latitudes, are always within the atmospheric loss cone. Rather than measuring a detailed energy spectrum, this instrument performs an on-board integration to obtain the directional energy flux carried by ions and electrons (separately) within this energy range at each of the two pitch angles. A transformation of pitch angles to the top of the atmosphere followed by an integration over angle yields the energy flux carried into the atmosphere by these particles. In addition to the energy flux moments, the peak in the energy flux spectrum is identified, and this energy, together with the particle intensity at that energy, is transmitted. A full set of these measurements is made every 2 seconds or 14 km of spacecraft travel. At a lower duty cycle, measurements of particle intensities at a selected set of energies are also made. When available, this
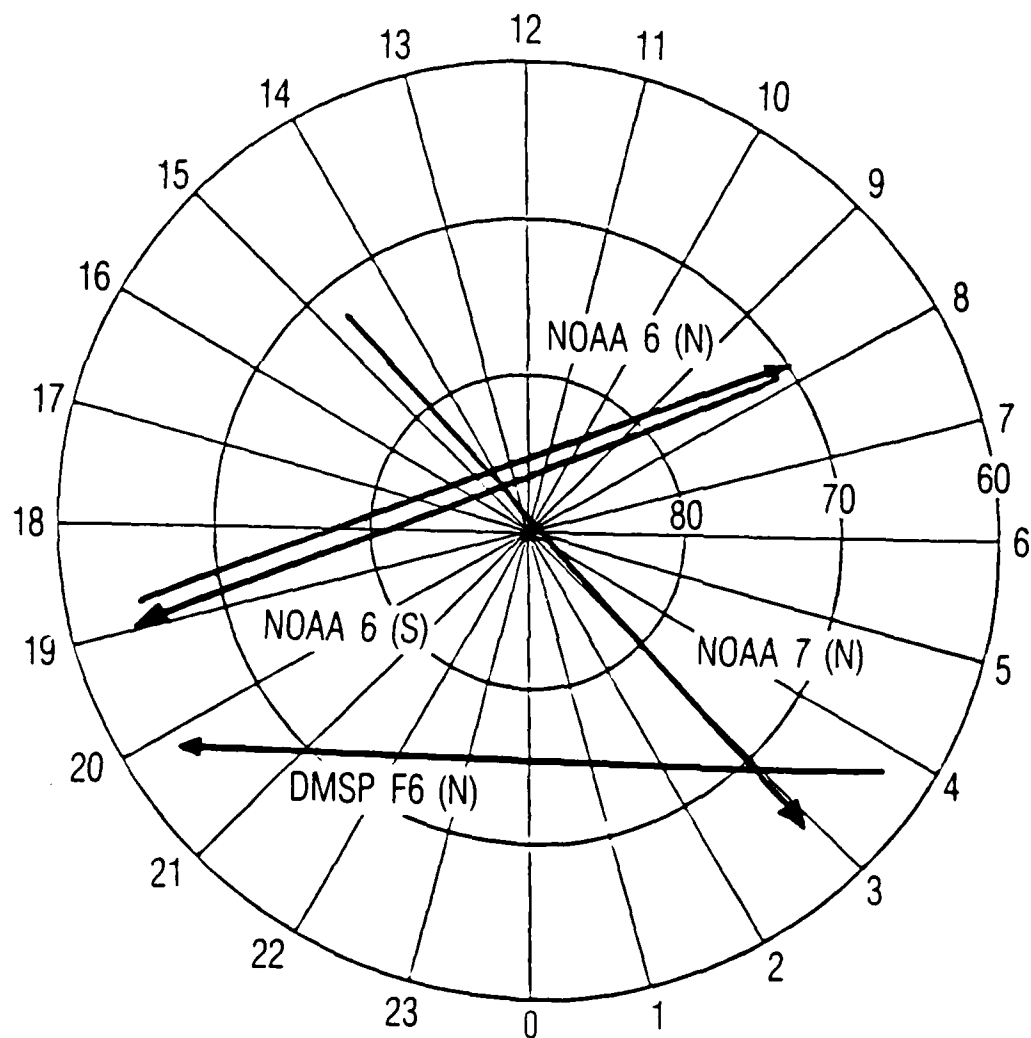
9

Figure 3.  A Plot of the Trajectories of DMSP-F6, NOAA-7 and NOAA-6 in the
Same Coordinates as Figure 2.  The notations (N) and (S) refer to
northern and southern polar passes, respectively.

10

additional information, together with observations of particle intensities at energies above 30 keV that are also made on board the satellites, permits the construction of the detailed particle energy spectra that appear in this report. The SSJ/4 electrostatic analyzer on DMSP-F6 obtains complete precipitating ion and electron spectra once per second over the energy range 30 eV-30 keV. For comparison with the NOAA data, only the DMSP measurements from greater than 300 eV are used, while all the DMSP energy channels are used to determine plasma characteristics such as temperature.

Figures 4a-d show the precipitating ion (thin line) and electron (dots) energy flux for the four satellite trajectories shown in Figure 3. The ion and electron energy fluxes are integrals over energies from 300 eV to 30 keV. The energy flux is plotted versus invariant latitude, with the maximum latitude appearing in the middle of each plot. Note, for example, in Figure 4b, DMSP-F6 only reaches 75° invariant latitude, while NOAA-7 in Figure 4c reaches almost 90° latitude. Also, note that the data are plotted in order of increasing time, so two of the plots (a and c) proceed from dusk to dawn while plots b and d proceed from dawn to dusk. On each plot an arrow marks the position in invariant latitude and local time at which each satellite is expected to cross the transpolar arc based on the DMSP image. (The projection into the southern hemisphere is done simply on the basis of invariant latitude and local time coordinates.)

It is most instructive to examine the DMSP-F6 data in Figure 4b first, since these data correspond directly in space and time to the auroral image shown in Figure 2. The DMSP-F6 trajectory is from dawn to dusk over the nightside portion of the polar cap. The satellite encounters the equatorward boundary of the dawn diffuse oval at about 67° invariant latitude. The dawn oval extends up to about 71.5°, where both the ion and electron fluxes drop to
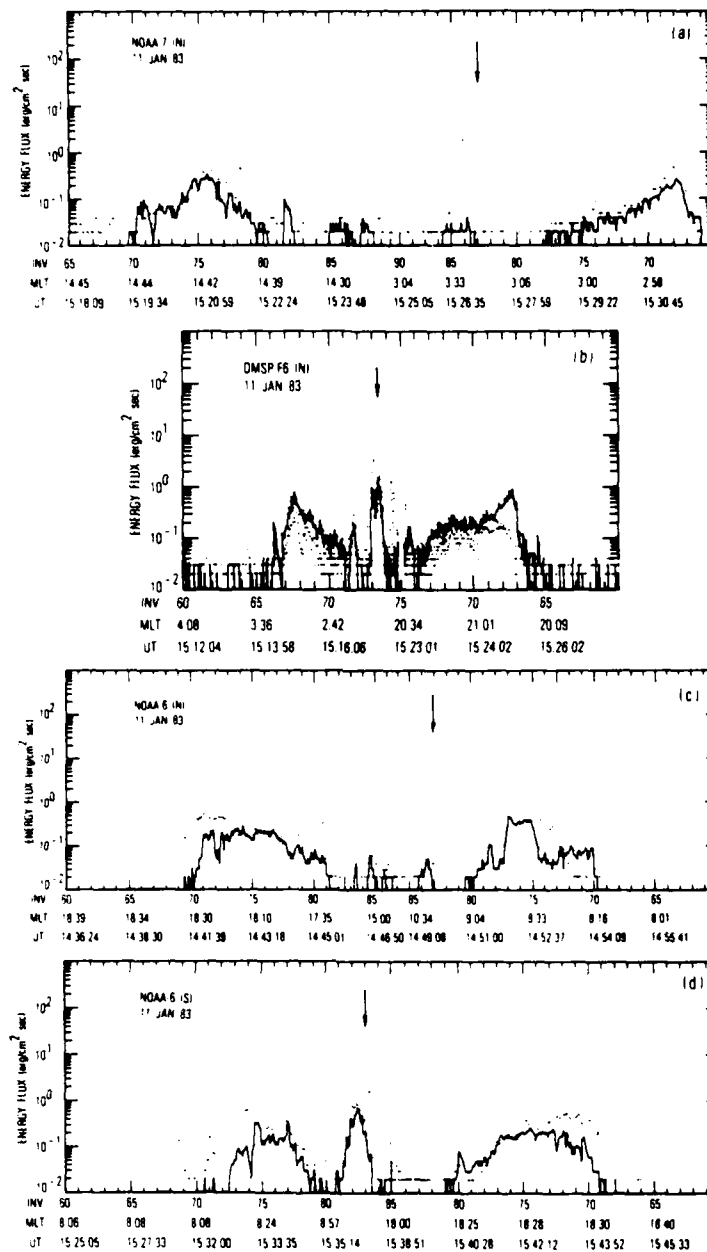
11

Figure 4.  Plots of the Ion (Solid Line) and Electron (dots) Precipitating
Energy Flux Versus Invariant Latitude from the Polar Traverses of
a) NOAA-6(N), b) DMSP-F6(N), c) NOAA-7(N) and d) NOAA-6(S).  Note
that the  maximum invariant latitude for each satellite trajectory
appears in the middle of each plot.

12

extremely low values. The transpolar arc is encountered near 73° - 74°, where ion flux increases to values similar to those observed in the low-latitude portion of the dawn oval ($\sim$ 1 erg/cm$^2$ sec), and electron flux increases to 2-15 erg/cm$^2$ sec, the highest values observed over the entire trajectory. Another high-latitude auroral arc is observed near 75° invariant, with peak electron flux near 2 erg/cm$^2$ sec but ion fluxes hardly above background values of $\sim$ 0.02 erg/cm$^2$ sec. The dusk oval extends from about 73° down to 67° invariant latitude.

The region near the transpolar arc crossing is displayed on an expanded time scale on the left portion of Figure 5. Note that the arc is about 250 km in width, with extremely sharp gradients in ion flux near its edges. Ion flux increases by about two orders of magnitude over about 10 km at the satellite altitude. Electron enhancements seem to occur primarily at both edges of the broad structure, and the electron spectra responsible for these enhancements show evidence of downward acceleration similar to that seen in inverted-V's. Figures 6, 7 and 8 show some of the relevant ion and electron spectra observed by DMSP-F6.

The electron distribution function within the dawn oval is shown in Figure 6. Two observations are plotted, one taken by DMSP-F6 (squared and dashed line) and the other by NOAA-7 (circles and solid line). Both spectra are approximately Maxwellian, as indicated by the dashed and solid lines, with temperatures between 225 and 240 eV. This spectral shape is repeated as the dashed line in Figure 7, which compares the electron spectral shape in the oval (i.e., plasma sheet) to precipitating electron spectra within the trans-polar arc. Note that the two spectra displayed are from the enhanced region near the edge of the arc (15:18:11 UT) and nearer the center of the transpolar arc (15:18:03 UT). The spectrum acquired near the edge of the arc is charac-

13

ELECTRON ENERGY FLUX (erg/cm²sec)

11 JAN 83

DMSP F6
TRANS POLAR ARC

NOAA /
TRANS-POLAR ARC

ELECTRONS

IONS

ELECTRONS

IONS

100

10

0.1

0.01

15 17    15 17 30    15 18    15 18 30
U T                              15 26

15 26 30    15 27    15 27 30
U T
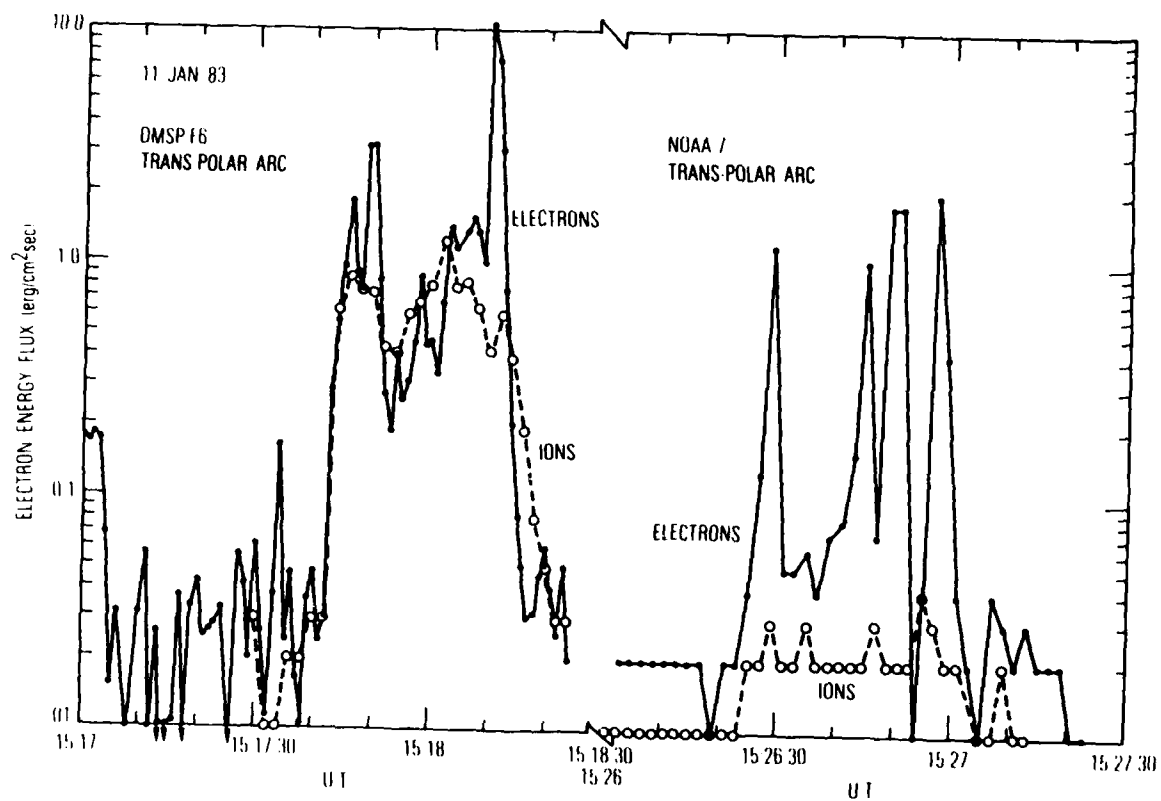
Figure 5.    A Plot of the Ion and Electron Energy Flux Versus Time Observed
Within the Transpolar Arc by DMSP-F6 (Left) and NOAA-7 (Right)

14
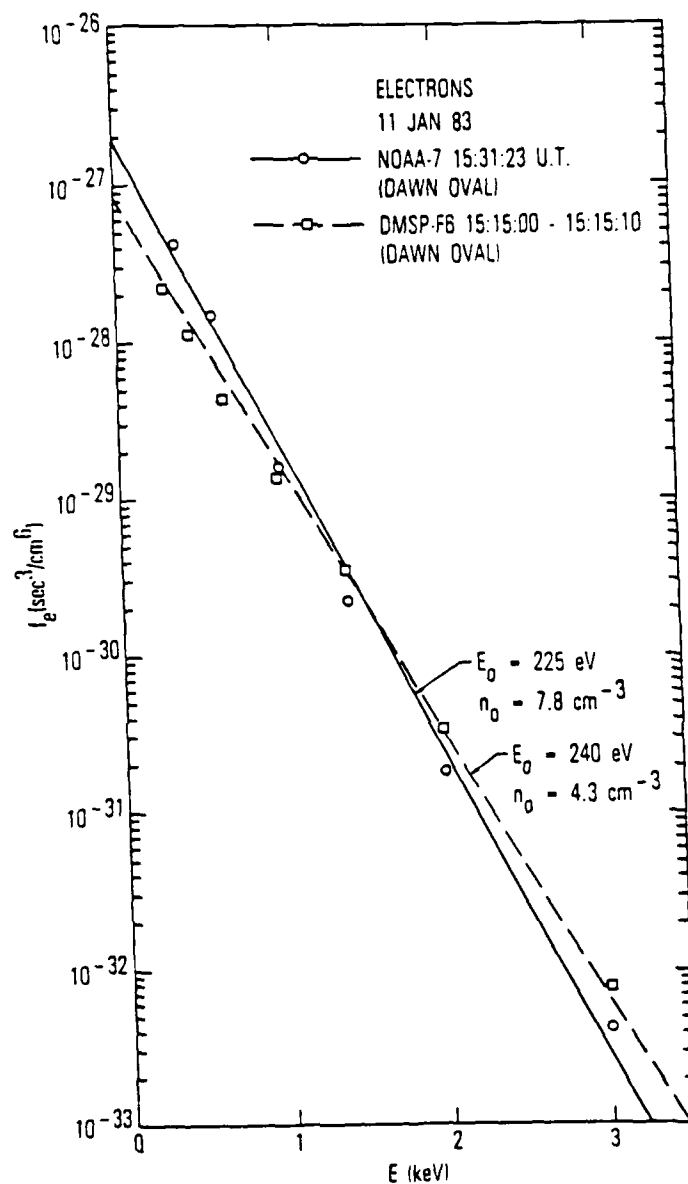
Figure 6. A Plot of the Electron Distribution Function Versus Energy for DMSP-F6 (Squares) and NOAA-7 (Circles). Both spectra were acquired within the dawn auroral oval. The spectral parameters noted on the plot are based on Maxwellian fits to the data (dashed and solid lines).

15
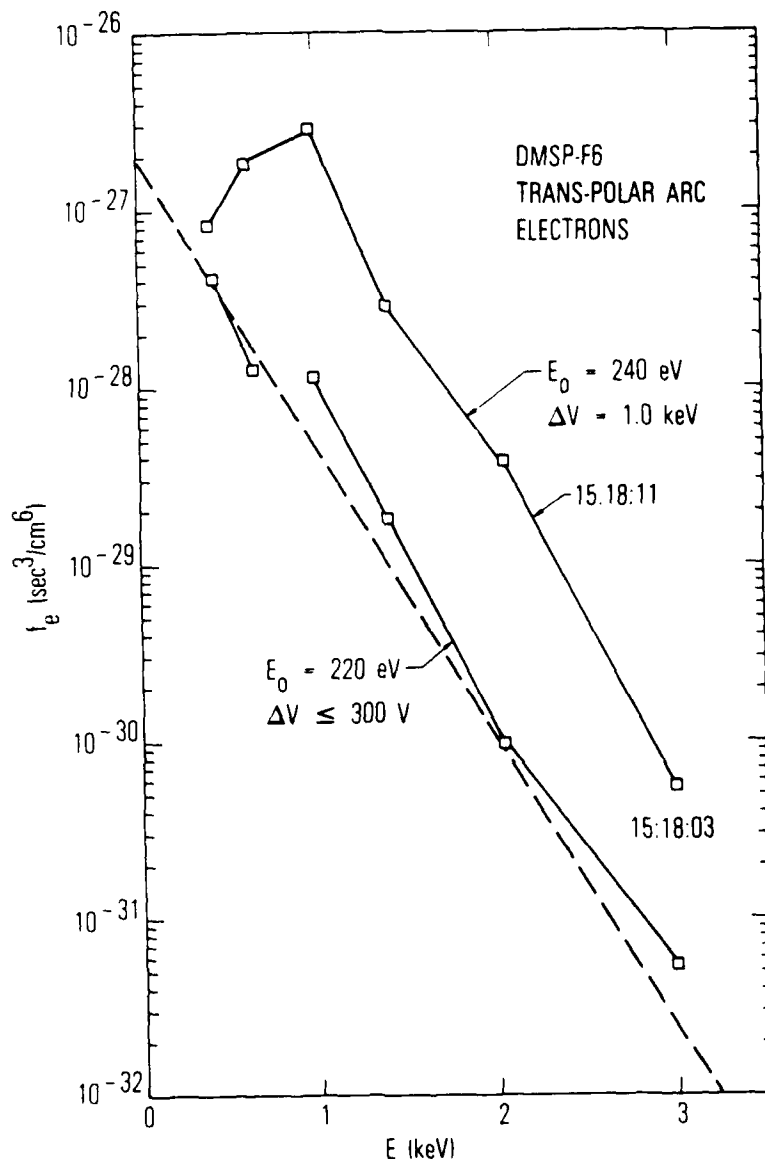
Figure 7.  A Plot of the Electron Distribution Functions Versus Energy
Observed by DMSP-F6 Within the Transpolar Arc.  The dashed line
represents the Maxwellian fit to data acquired within the dawn
auroral oval.  Two observed electron distribution functions are
plotted, one acquired near the edge of the transpolar arc at
15:18:11 UT and the second from the interior of the arc at 15:18:03
UT.

Figure 8.    A Plot of the Ion Distribution Function Versus Energy Observed by
             DMSP-F6 Within the Dawn Auroral Oval (Squares and Solid Line) and
             Within the Transpolar Arc (Circles and Dashed Line).  The spectral
             parameters are based on Maxwellian fits to the data.

teristic of a cool (~ 240 eV) electron population of intensity comparable to that observed within the dawn oval, which has been accelerated downward through a ~ 1 kV electrical potential. This spectrum is also represent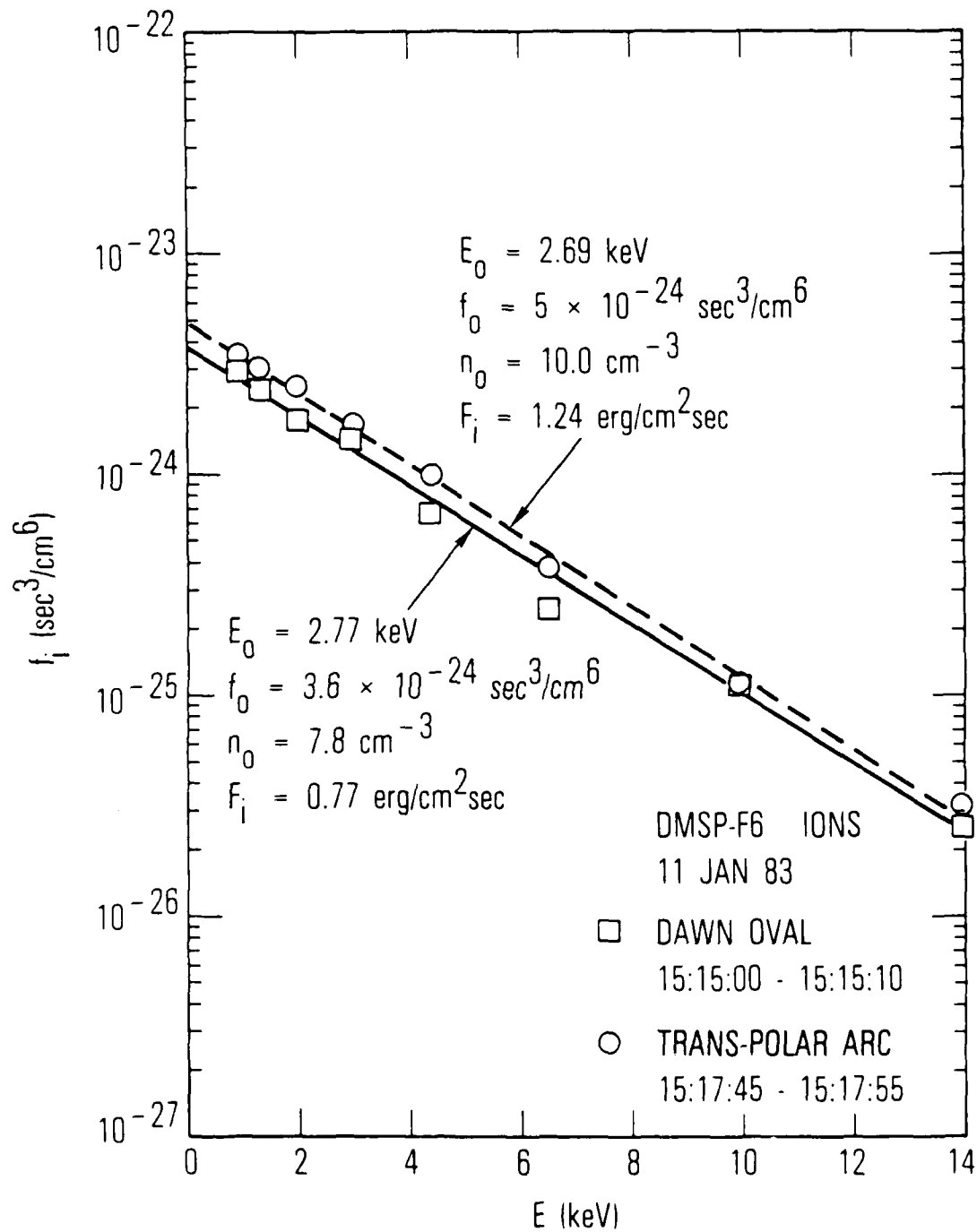ative of those observed within the enhancement at the opposite edge of the arc. The spectrum acquired nearer the center of the arc also has a temperature near 220 eV, but apparently has not been accelerated significantly ($\Delta V \leq 300$ V).

Figure 8 shows characteristic ion distribution functions observed by DMSP-F6 within the dawn oval (squares and solid line) and within the center of the transpolar arc (circles and dashed lines). Both spectra have character-istic energies of about 2.7 keV, and the intensities are virtually identical. Variations of about a factor of three in ion flux were observed across the transpolar arc. The variations in ion flux had no clear relationship to the regions of electron acceleration. Only small variations in ion flux would be expected from these weak potential drops because of the relatively high ion temperatures. It is clear from these observations that the plasma within the transpolar arc has characteristics identical to that within the plasma sheet (observed within the dawn auroral oval) and that the electrons experienced downward acceleration near the edges of the transpolar arc.

The DMSP-F6 observations describe the distribution of plasma across the transpolar arc and provide a comparison of ion and electron populations within the arc and within the dawn oval. The other available observations from the NOAA-6 and NOAA-7 satellites, shown in Figures 4a-d, provide a comparison of plasma distributions along the arc in the northern hemisphere and in the opposite hemisphere.

18

Figure 4a shows the ion and electron energy flux observed by NOAA-6 as it traversed the dayside portion of the northern polar cap from dusk toward dawn. These observations were acquired about one-half hour previous to the DMSP-F6 observations. Flux levels within the dusk and dawn auroral oval are similar to those observed by DMSP-F6, although the latitudinal distribution of plasma is rather different than that observed on the nightside. More importantly, NOAA-6 observes a number of very high latitude arcs, including a weak arc in a position comparable to the dayside extension of the transpolar arc seen in the DMSP image. The electron flux in this arc has a peak intensity of about 3 erg/cm$^2$ sec, and the peak ion flux is 0.05 erg/cm$^2$ sec. The electron and ion characteristic energies are comparable to those observed by DMSP-F6 within the arc. Similar to DMSP, NOAA-6 observes a number of narrow high-latitude arcs farther toward the dusk. Although these dayside observations are interesting in themselves, a more significant observation of the dayside extension of the transpolar arc is available from the more time-coincident observations of NOAA-7.

The NOAA-7 observations appear in Figure 4c. NOAA-7 crosses the northern pole from 15:00 MLT to 3:00 MLT, and reaches the expected position of the transpolar arc at about 85° invariant latitude at 3:30 MLT. The arc observed by NOAA-7 has a width of about 250 km, with maximum electron fluxes of 2 erg/cm$^2$ sec and peak ion fluxes of 0.04 erg/cm$^2$ sec. The region surrounding the transpolar arc is plotted on an expanded scale in the right half of Figure 5. Note that the spatial scale of the arc and the finer spatial scale of the electron flux enhancements within the arc are similar to the DMSP observation. The peak electron fluxes are somewhat comparable to those observed by DMSP, and the enhanced regions show evidence of acceleration. The ions ob-

served by NOAA-7 have characteristic energies of 2-4 keV, similar to the DMSP observations, but diminished in intensity by about a factor of fifty.

The difference in the ion intensities observed by the two satellites cannot be an artifact of the instrumentation (e.g., a low efficiency for detecting ions by the NOAA-7 instrument relative to the DMSP F-6 instrument), because both instruments observe comparable electron and ion intensities during their nearly simultaneous transits of the dawn auroral oval (Figure 6). These observations, along with those of NOAA-6 on the dayside, seem to imply that although electron precipitation spikes of several erg/cm$^2$ sec are maintained along the polar and dayside portion of the transpolar arc, the ion flux observed at these low altitudes is diminished by a large factor. The average electron flux within the arc appears to be diminished as well, but not quite in the same proportion as the ions.

Even more intriguing observations are provided by the southern hemisphere polar cap crossing of NOAA-6, which occurs within about 20 minutes of the original DMSP observations. In the south, NOAA-6 crosses the polar cap from dawn toward dusk over almost exactly the same dayside trajectory as the earlier northern pole trajectory. Again NOAA-6 observed ion and electron fluxes within the dawn and dusk auroral oval comparable to the northern hemisphere observations. Most notable, however, is the observation of a broad enhancement in both ion and electron flux in the same latitude and local time position as that of the transpolar arc in the northern hemisphere. Note also the occurrence of narrow electron enhancements with virtually no ion flux farther toward the dusk.

The region surrounding the broad high-latitude flux enhancement is shown on an expanded scale in Figure 9. The similarity between this NOAA-6 flux
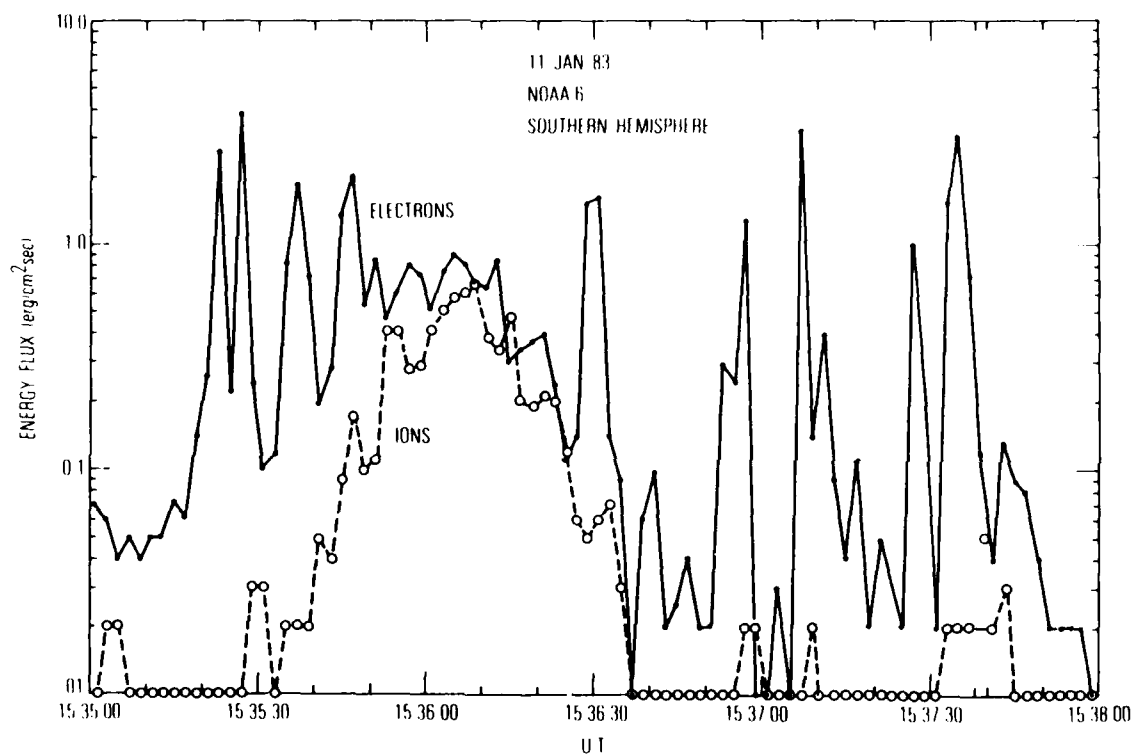
Figure 9. A Plot of the Ion and Electron Energy Flux Versus Time Observed Near the Expected Position of the Transpolar Arc in the Southern Hemisphere by NOAA-6

profile and that of DMSP-F6 crossing the nightside portion of the transpolar arc in the northern hemisphere (Figure 5) is quite apparent. NOAA-6 observed a factor of 100 increase in ion flux to several tenths of an erg/cm$^2$ sec over a spatial scale of about 300 km, and electron enhancements to 4 erg/cm$^2$ sec. Here too the smaller scale electron enhancements appear near the edges of the broad ion enhancement. The electron and ion characteristic energies within this region are almost identical to those observed in the north. Note also the occurrence of electron enhancements somewhat later in the trajectory (farther toward the dusk) which are associated with relatively low ion flux. All in all, the data from NOAA-6 in the southern hemisphere are remarkably similar to the nightside crossing of DMSP in the north but rather different from the northern dayside observations in terms of ion flux. It is likely that these NOAA-6 observations show the occurrence of a transpolar arc in the southern hemisphere which is similar to that imaged in the northern hemisphere.

## Discussion

The observations presented in the previous section describe an event which is similar in character if not in detail to other observations of polar cap arcs, theta arcs, and transpolar arcs (see Frank et al., 1982; Meng, 1981; Murphree et al., 1982; Gussenhoven, 1982). The term "transpolar arc" has been applied in this report following the simplifying but descriptive terminology of Petersen and Shelley (1984). The event described here can be considered "unusual" mainly in the sense that the IMF conditions were unusually stable, providing a good temporal basis for the measurements. Conclusions based on this "single event" are likely to have rather general application to the occurrence of high-latitude auroras for IMF $B_z > 0$ and $B_y > 0$. The multiple satellite observation presented here shows the existence of a broad (~ 250 km) linear auroral feature extending approximately along the earth-sun line across the entire high-latitude region. The plasma distribution within the trans-polar arc is similar in character to that previously reported by Frank et al. (1982), Petersen and Shelley (1984) and to some extent that of McDiarmid et al. (1980); namely, the plasma within the arc is of plasma sheet origin. The almost coincident measurements of NOAA-7 and DMSP-F6 show a dramatic differ-ence in ion flux near the nightside and toward the dayside. Electron flux is also somewhat diminished within the dayside portion of the arc in the northern hemisphere. NOAA-6 observations in the southern hemisphere show very high electron and ion flux at the expected position of the arc. These southern hemisphere fluxes are similar in intensity, characteristic energy and spatial distribution to those observed near the nightside in the northern hemisphere. These observations of a fairly conjugate occurrence of a transpolar arc reflect somewhat different properties than the steady state polar cap current systems observed by several experimenters (e.g., Potemra et

23

al., 1984; Zanetti et al., 1984; Iijima et al., 1984) which showed clear north-south asymmetries in the occurrence of both field-aligned and Hall current patterns for IMF $B_y \neq 0$. It will be difficult to reconcile this difference without simultaneous particle, field and image data from a number of similar events.

The important morphological features of this set of observations are a) the arc occurs away from either the dawn or dusk oval; b) the arc contains plasma of the same character and, potentially, origin as the dawn auroral oval; c) fluxes within the arc diminish toward the dayside over the northern hemisphere; d) a similar arc occurs in the southern hemisphere with relatively high flux on the dayside; and e) electron acceleration in every case seems to occur primarily at both edges of the broad ion flux enhancement.

Some of these morphological features lend themselves to comparisons with a number of theoretical concepts in the literature. The fact that the transpolar arc appears separate from either the dawn or dusk auroral oval is consistent with the original observations and interpretations of Frank et al. (1982) who first discussed the formation of the "θ-aurora" or transpolar arc in terms of a bifurcation of the tail lobe by a protrusion of the plasma sheet. Frank et al. make no direct statement about the expected spatial distribution of auroral arcs due to electron acceleration within the broad structure. An interpretation of this event as a discrete feature on the high-latitude edge of a poleward-expanding auroral zone such as Meng (1981) and Murphree et al. (1982) have applied to other observations does not appear to apply here because of the clear separation of oval and transpolar arc plasma by low-intensity fluxes characteristic of lobe plasma. The interpretations of Meng and Murphree et al. may well be appropriate to other auroral features, however.

24

Recently there have been a number of theoretical attempts to specifically describe the occurrence of discrete auroras (e.g., upward current with downward electron acceleration over a small spatial scale) at high latitudes (see Chiu and Gorney, 1983; Lyons, 1985; Cornwall, 1985; Reiff and Burch, 1985; Kan and Burke, 1985; and Chiu et al., 1985). Chiu and Gorney (1983) describe the case of convection eddies in the polar cap producing the condition of $\nabla \cdot E_{conv} < 0$ required for discrete aurora formation over small spatial scales. While their treatment adequately explained a number of observed high latitude small scale auroral events, it was not intended to treat features with the scales or morphology of the transpolar arc.

The work of Chiu et al. (1985) combines predictions from the antiparallel merging hypothesis (Crooker, 1979) to determine flow patterns on open field lines with the connection between the condition $\nabla \cdot E_{conv} < 0$ and the formation of discrete aurora to predict likely high latitude arc formation regions as a function of the IMF in the $B_y$, $B_z$ plane. Their results for IMF $B_z > 0$ and $B_y \neq 0$ are a single open cell with a specified sense of circulation flanked always by two weak closed cells, presumably viscous in origin. Two types of high-latitude arcs are possible, one occurring on open field lines near the dusk for IMF $B_y < 0$ (in the northern hemisphere) and the other occurring on the boundary between open and closed field lines in the dawn sector for IMF $B_y > 0$. Chiu et al. regard the dawn arc as a likely candidate for producing a visible feature such as a transpolar arc. However, their treatment does not seem to be appropriate for the case presented in this report because of the clear observed separation between the oval and the transpolar arc. Also, Chiu et al. would predict that the high latitude arc in the opposite hemisphere would be of greatly different character, both in spatial occurrence and plasma source, and this does not appear to be the case here.

25

Cornwall (1985) developed a model describing currents, electric fields and aurora formation for a symmetric transpolar arc under the conditions IMF $B_z > 0$, $B_y = 0$. His model involves a symmetrical four-cell convection pattern in which sunward flow occurs over the central polar cap on closed field lines (see also Zanetti et al., 1984; Reiff and Burch, 1985; Burke et al., 1979). Cornwall solves the height-integrated current conservation equation and relates parallel current to the parallel potential drop as in previous works on the evening discrete aurora (Chiu and Cornwall, 1980; Chiu et al., 1981; Lyons, 1980; 1981) to predict regions of auroral arc formation. He predicts discrete auroral arc formation along the evening auroral oval and along the dawn edge of the sunward, flowing closed-field-line region over the polar cap. This prediction is not consistent with our observations of discrete arcs at both edges of the transpolar arc, although it might be too ambitious to extend Cornwall's work for IMF $B_y = 0$ to our observed case of $B_y > 0$. Cornwall's model is symmetric in opposite hemispheres, again for IMF $B_y = 0$.

Lyons (1985) computes the convection electric field patterns over the polar cap by mathematically superimposing a uniform IMF and the earth's magnetic field. He performs this calculation for a range of IMF orientations, and for the conditions $B_z > 0$, $B_y > 0$ he predicts that "upward field-aligned currents and polar cap aurora should be more common and intense in the northern (southern) hemisphere as $B_y$ ($-B_y$) increases." His predicted anti-symmetry between auroral activity over opposite poles is not borne out in our example. Lyons (1985) makes no predictions concerning the plasma characteristics or distribution within the polar cap auroras since his model develops somewhat unphysical convection streamlines which originate and terminate at singular points.

26

Kan and Burke (1985) present a model of polar cap arcs in which they attempt to generalize the occurrence of both transpolar arcs and other weaker arcs during northward IMF. In their model, recently merged anti-sunward convecting field lines drive anti-sunward convection along the dawn and dusk flanks of the polar cap. Subsequent reconnection in the distant tail, which might be either steady or irregular (Bythrow et al., 1985), then forms closed field lines which convect sunward over the central polar cap, carrying the plasma-sheet particles responsible for the transpolar auroral arc. Their model implies hemispheric conjugacy for the transpolar arc for IMF $B_y$ = 0, but no prediction is made for IMF $B_y$ = 0. Kan and Burke show a schematic representation of the polar cap arc dynamo, including convection, field-aligned currents and electrical potential distributions. Their diagram shows a parallel potential drop occurring on one side of the sunward-convecting closed field line region (i.e., the transpolar arc) and extending into the adjacent open field region. Although this particular feature of their model is not consistent in detail with the observations presented in this report, it is unfair to attempt such a detailed comparison of a single event with an idealized theoretical representation.

Reiff and Burch (1985) present a versatile qualitative model of high-latitude convection patterns for all orientations of the IMF. Their model includes closed viscous cells, merging cells whose flow consecutively opens and closes on the dayside and nightside, and lobe cells whose flow occurs entirely on open field lines. They make some specific predictions concerning transpolar arcs. Reiff and Burch (1985) argue, similar to Cornwall (1985), that since the sunward flow over the polar cap should occur on closed field lines, at least a conjugate diffuse aurora should occur over both poles, consistent with our observations. Other features of the transpolar arc,

27

including discrete aurora, are not expected to be hemispherically conjugate. They predict the occurrence of an upward current sheet on the dawn side of the sunward flow region in the northern hemisphere for $B_y < 0$ and "in the southern hemisphere for $B_y < 0$, or for the northern hemisphere for $B_y > 0$, a downward current sheet on the dusk side of the sunward flow region." This prediction, of anti-symmetry, at the outset, does not appear to describe the conditions discussed in this report, although Reiff and Burch (1985) state that inverted-V events can occur even in a downward current sheet. To the extent that their latter statement is correct, Reiff and Burch's model accounts for a number of the features observed in the 11 January event.

Near simultaneous, multi-satellite observations of the particle precipitation associated with an individual high-altitude auroral feature, even when comprehensive and supplemented by auroral imagery as is the case here, are not yet *sufficient to permit* the selection of one of these theoretical models as being superior to the others. However, our observations that the particles responsible for this high-latitude auroral structure originated from a plasma reservoir of the same density and temperature as that responsible for the dawn auroral precipitation and that the ion precipitation displayed a large variation along this aurora, together with the evidence we present that this auroral feature was present symmetrically in both the northern and southern hemispheres, place important constraints upon any model which accounts for this phenomena.

# References

Akasofu, S. I. and B. Tsurutani, Unusual auroral features observed on January 10-11, 1983 and their possible relationships to the interplanetary magnetic field, Geophys. Res. Lett., 11, 1086, 1984.

Bythrow, P. F., W. J. Burke, T. A. Potemra, L. J. Zanetti, and A. T. Y. Lui, Ionospheric evidence for irregular reconnection and turbulent plasma flows in the magnetotail during periods of northward interplanetary magnetic field, J. Geophys. Res., 90, 5319, 1985.

Burke, W. J., M. C. Kelley, R. C. Sagalyn, M. Smiddy and S. T. Lai, Polar cap electric field structures with a northward interplanetary field, Geophys. Res. Lett., 6, 21, 1979.

Chiu, Y. T. and J. M. Cornwall, Electrostatic model of a quiet auroral arc, J. Geophys. Res., 85, 543, 1980.

Chiu, Y. T., A. L. Newman and J. M. Cornwall, On the structure and mapping of auroral electrostatic potential, J. Geophys. Res., 86, 10029, 1981.

Chiu, Y. T. and D. J. Gorney, Eddy intrusion of hot plasma into the polar cap and formation of polar cap arcs, Geophys. Res. Lett., 10, 463, 1983.

Chiu, Y. T., N. V. Crooker and D. J. Gorney, Model of oval and polar cap auroral configurations, J. Geophys. Res., in press, 1985.

Cornwall, J. M., Idealized model of polar cap currents, fields and auroras, J. Geophys. Res., 90, 3541, 1985.

Crooker, N. V., Dayside merging and cusp geometry, J. Geophys. Res., 84, 951, 1979.

Frank, L. A., J. D. Craven, J. L. Burch and J. D. Winningham, Polar views of the earth's aurora with Dynamics Explorer, Geophys. Res. Lett., 9, 10001, 1982.

Gussenhoven, M. S., Extremely high latitude auroras, J. Geophys. Res., 87, 2401, 1982.

Kan, J. R. and W. J. Burke, A theoretical model of polar cap auroral arcs, J. Geophys. Res., 90, 4171, 1985.

Lyons, L. R., Generation of large-scale regions of auroral currents, electric potential and precipitation by the divergence of the convection electric field, J. Geophys. Res., 85, 17, 1980.

Lyons, L. R., Discrete aurora as the direct result of an inferred high-altitude generating potential distribution, J. Geophys. Res., 86, 1, 1981.

Lyons, L. R., A simple model for polar cap convection patterns and generation of theta auroras, J. Geophys. Res., 90, 1561, 1985.

McDiarmid, I. B., J. R. Burrows, and M. D. Wilson, Comparison of magnetic field perturbations and solar electron profiles in the polar cap, J. Geophys. Res., 85, 1163, 1980.

Meng, C. I., Polar cap arcs and the plasma sheet, Geophys. Res. Lett., 8, 273, 1981.

Murphree, J. S., C. D. Anger and L. L. Cogger, The instantaneous relationship between polar cap and oval auroras at times of northward interplanetary magnetic field, Can. J. Phys., 60, 349, 1982.

Petersen, W. K. and E. G. Shelley, Origin of the plasma in a cross-polar cap auroral feature (Theta aurora), J. Geophys. Res., 89, 6729, 1984.

Potemra, T. A., L. J. Zanetti, P. F. Bythrow, A. T. Y. Lui, and T. Iijima, By-dependent convection patterns during northward interplanetary magnetic field, J. Geophys. Res., 89, 9753, 1984.

Reiff, P. H. and J. L. Burch, IMF $B_y$-dependent plasma flow and Birkeland currents in the dayside magnetosphere, 2. A global model for northward and southward IMF, J. Geophys. Res., 90, 1595, 1985.

Zanetti, L. J., T. A. Potemra, T. Iijima, W. Baumjohann and P. F. Bythrow, Ionospheric and Birkeland current distributions for northward interplanetary magnetic field:   Inferred polar convection, J. Geophys. Res., 89, 7453, 1984.

END

2-87

DTIC