Plasma Characteristics of Upflowing Ion Beams in the Polar Cap Region

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The plasma characteristics of O⁺, H⁺ and He⁺ beam events in the polar cap region observed near solar maximum by the Dynamics Explorer 1 (DE 1) satellite are analyzed in this paper. The data analyzed were taken from both the energetic ion composition spectrometer (EICS), which operates in the 10 eV - 17 keV energy range, and the retarding ion mass spectrometer (RIMS), which operates in the low energy spectrum of less than 50 eV. Electron densities measured by the plasma wave instrument (PWI) provided limits on estimates of ion densities. Because the upflowing ion energies are sometimes comparable to the spacecraft potentials and the fluxes involved are close to the instrumental thresholds, it has been difficult to measure the densities and temperatures of these low energy ions. A subset of upflowing polar cap ion streams was identified from which it was possible to make estimates of the plasma characteristics using the three DE 1 instruments described above. In this paper, the data for two polar ion streams are presented in detail. The plasma was found to consist of multiple streaming and quasi-isotropic components. In both cases, estimates of temperatures and densities were made taking into account possible spacecraft potentials. The ion densities of several other events were also estimated. It was found that (1) the plasma often had a large content of upflowing O⁺ ions, (2) there was a significant amount of O⁺ in the plasma even during quiet auroral conditions when the AE index was only 37 nT, (3) in one event presented, the upflowing O⁺ population had both a cold and a warm field-aligned distribution, (4) in another event presented, the O⁺ and H⁺ temperatures (for an assumed spacecraft potential of 5 eV) were estimated to be 5 eV and 7.6 eV, respectively, suggesting that the ionospheric ions were heated, (5) the cold upflowing ion stream component observed in some of the polar ion streaming events exhibited a filamentary nature (with a time scale ranging from tens of seconds to minutes, which corresponds to spatial scales of tens to hundreds of kilometers in the ionosphere) and (6) there also often was a significant amount of He⁺ found in the plasma. The observations provide important plasma characteristics of the polar cap region, which will be useful in future theoretical and simulation work.

1. INTRODUCTION

It was thought for many years that the escape of ions from the polar ionosphere or "polar wind" was dominated by low energy light ion species such as H⁺ or He⁺ which could overcome gravitational bounds by acceleration due to a self-consistent ambipolar electric field. Although light ions could escape, the heavy ions such as O⁺ were shown to be essentially gravitationally bound [Banks and Holzer, 1969]. Measured ion densities and fluxes, based on observations from ISIS 2 up to altitudes of 3000 km during magnetically quiet times, were in general agreement with these classical polar wind theoretical predictions [Hoffman and Dodson, 1980]. Contrary to classical polar wind theory, however, there have been many satellite observations at higher altitudes, indicating an outflow of O⁺ ions from the Earth's polar ionosphere [Ghielmetti et al., 1978; Collin et al., 1981; Shelley et al., 1982; Yau et al., 1984; Waite et al., 1985; Moore et al., 1986].

The earlier studies focused on the auroral region. Energetic upflowing O⁺ ion beams and conics (~ keV) from the polar ionosphere were frequently observed up to altitudes of 8000 km during both magnetically quiet and disturbed times in the auroral zone [Ghielmetti et al., 1978; Collin et al., 1981]. Although ion beams thought to have been formed by parallel ion acceleration [Shelley et al., 1978; Misera and Fennell, 1977] are not typically observed below 5000 km, ion conics resulting from transverse ion acceleration [Sharp et al., 1977; Klumpar, 1979] are observed to much lower altitudes [Ghielmetti et al., 1978; Gorney et al., 1981]. In these statistical studies of upward flowing ion (UFI) events detected by the S3-3 satellite [Ghielmetti et al., 1978; Gorney et al., 1981], the events were reported to have a peak probability of occurrence in the auroral zone and to have only approximately a 10% occurrence frequency over the polar cap. Shelley et al. [1982] found a much higher occurrence...
frequency (~ 50%) of < 100-eV upflowing O\(^+\) ions in the polar cap in the first few months of operation of the Dynamics Explorer 1 satellite (DE 1). These UFI events were dominated by O\(^+\) ions with O\(^+\)/H\(^+\) up to ~ 10 [Shelley et al., 1982], whereas classical polar wind theory predicts an O\(^+\)/H\(^+\) ratio of ~ 10\(^{-3}\) [Banks and Holzer, 1969]. The observations of Shelley et al. [1982] suggest the importance of the polar cap as a possible source of significant outflow of O\(^+\) ions. Statistical studies by Yau et al. [1984] of low energy (< 1 keV) outflows of O\(^+\) over the high altitude polar cap support the importance of the polar cap as a source of ionospheric O\(^+\) ions.

Another possible source of O\(^+\) ions flowing outward from the polar ionosphere is the dayside polar cusp or polar cleft ionosphere [Shelley, 1979; Waite et al., 1985; Lockwood et al., 1985; Peterson, 1985; Moore et al., 1986]. Shelley [1979] found O\(^+\) ions of greater than 500 eV streaming up magnetic field lines in over half of the S3-3 cusp crossings. He suggested that ionospheric ions are being extracted from the cusp ionosphere on a nearly continuous basis. Later DE 1 studies confirmed this idea. Waite et al. [1985] considered large outflows of low energy (< 10 eV) O\(^+\) ions detected by the retarding ion mass spectrometer (RIMS) and mapped them back to the polar cusp region, assuming antisunward E x B convection. Lockwood et al. [1985] and Horwitz and Lockwood [1985] found that during high magnetic activity, convection is generally strong enough to fill the entire polar magnetosphere with low energy O\(^+\) ions. Moore et al. [1986] linked strong field-aligned current signatures associated with these ion flows or "upwelling ions" in the dayside polar cap boundary with transverse ion heating in the ionosphere between 2000 and 5000 km. It has been suggested that ion heating may be an important factor in producing heavy ion outflows from the polar region [Moore et al., 1986].

The importance of both the polar cap and dayside polar cusp as possible sources of O\(^+\) ions flowing outward from the polar ionosphere has been established [Shelley, 1979; Waite et al., 1985; Lockwood et al., 1985; Horwitz and Lockwood, 1985; Peterson, 1985; Moore et al., 1986]. In this paper, we present the plasma characteristics of ion beam (> 10 eV) events in the polar cap region near solar maximum that were analyzed using DE 1 data. Data taken from both the energetic ion composition spectrometer (EICS) [Shelley et al., 1981], the retarding ion mass spectrometer (RIMS) [Chappell et al., 1981] and the plasma wave instrument (PWI) [Shawhan et al., 1981] are presented in this paper. The EICS instrument can be programmed to cover a mass range of 1 amu per charge to over 150 amu per charge and an energy range from spacecraft potential to 17 keV. Several specialized operational modes were developed to sample rapidly a limited energy range for a small number of ion species at all pitch angles. In this study, data from two modes were used; both modes used 15 logarithmically spaced energy steps to cover the energy range from 10 eV to 17 keV. One of the modes returned data for four ion species, 48 distinct pitch angles, and 15 energies in 96 s; the other mode returned data for only H\(^+\) and O\(^+\) at 24 distinct pitch angles and 15 energies in 24 s. The complete 0° to 180° pitch angle range was covered twice per satellite spin so that the resolution in pitch angle for the two modes is 7.5° and 15°, respectively. The RIMS instrument consists of three separate sensor heads which lie in a plane perpendicular to the spin axis (the radial head) and parallel and antiparallel to the spacecraft spin axis (the +Z and –Z heads). There is a retarding potential analyzer (RPA)
followed by a mass spectrometer covering the range of 1 to 32 amu. In combination, the RIMS and EICS instruments cover the extended energy range from spacecraft potential to 17 keV. Electric field spectrum measurements from PWI were used to derive electron densities in the polar cap region. Signals from the 200-m (tip-to-tip) electric antennas, oriented perpendicular to the spacecraft spin axis, were processed by two frequency correlators which scan a frequency range of 1 Hz to 400 kHz every 32 s. Further details pertaining to these instruments can be found in the special Dynamics Explorer issue of Space Science Instrumentation, volume 5, number 4, 1981.

The plasma density can be estimated by each of these instruments but it must be taken into account that the accuracy of these estimates is limited. Only very approximate estimates of cold (~10 eV) plasma densities can be made using the EICS instrument alone. This instrument detects ions with energies from 10 eV above the spacecraft potential to ~125 eV in the lowest energy channel. (The sensitivity in this energy channel decreases rapidly above 100 eV.) Converting the measured counts to a density requires that assumptions be made on the angular and energy distribution of the ions. Density calculations inferred from the RIMS instrument are very sensitive to spacecraft charging effects; the fact that the observed ion fluxes in the polar cap are near the instrumental threshold may also affect the results. The PWI instrument provides a good estimate of the total density but provides no insight into the thermal and mass composition of the polar cap plasma.

In special cases, however, it is possible to use the data from all three of these instruments to obtain relatively good estimates of the density, mass and thermal composition of the ion plasma components. Specifically, if the upstreaming plasma has strong, relatively warm (~50 eV) components, it is possible to use flux ratios detected in the lowest EICS energy channel to obtain estimates of the relative densities of the warm streaming and quasi-isotropic plasma components. The RIMS instrument provides estimates of the relative densities of the cold plasma components. The PWI instrument provides an estimate of the total ion density. In some of these special cases, one of which is discussed below, it is possible to estimate the relative contribution to the total plasma density by using the streaming and quasi-isotropic plasma components from the angular distribution in the EICS lowest energy channel.

3. Observations

The DE 1 observations included in this study were made between October 27, 1981, and November 27, 1981. Data were selected from this time period because the RIMS instrument had begun sampling O+ ions and the RPA in the RIMS radial head was still fully operational. Polar cap electron density measurements were made by the PWI instrument. These electron densities were determined from the upper cutoff of whistler mode radiation at the electron plasma frequency (see Persoon et al. [1983] for details on the analysis method). To distinguish polar cap events, only times when the invariant latitude was 80° or more were considered. Events were selected for which PWI densities were measured and O+ beams with energies greater than 10 eV were observed. There were 41 ion beam events selected that satisfied this criteria. In 30 of these events, the ion fluxes were above the instrumental thresholds of both the RIMS and EICS instruments.

In 24 of the polar ion stream events studied, there was a quasi-isotropic warm H+ component detected in addition to the polar ion stream. Of the 41 events, 13 had strong, relatively cool (~50 eV) upflowing H+ and O+ components. In these cases it was sometimes possible to estimate the relative composition of the upstreaming components. For two selected cases we performed a detailed analysis based on a comparison of data from the three instruments to estimate the relative temperatures and densities of the multiple ion components identified.

The first polar ion stream event we discuss is one where it is possible to make reasonable estimates of the densities of each of the ion components detected. The event occurred between 0246 UT to 0311 UT on October 27, 1981. During this period, the spacecraft was traveling from an altitude of 2.69 RE to 2.15 RE across the nightside polar cap near magnetic local time 1900. This can be seen in Figure 1, which is a plot of the orbit of the satellite for this time period. The auroral activity was moderate during this period as indicated by the hourly averaged AE index of 117 nT, 106 nT and 74 nT for the hours of 0100 UT, 0200 UT and 0300 UT, respectively. The general characteristics of this event can be seen in Figures 2–4, the spectrograms from the EICS and RIMS instruments for this event. Figures 2a, 2b and 2c are the EICS pitch angle spectrograms in the lowest energy channel (10 eV to ~100 eV) between 0230 UT and 0345 UT for the H+, O+ and He++ ions, respectively. The energy averaged flux in units of (cm² s sr keV)⁻¹ is encoded by the gray bar shown on the right

![Fig. 1. DE 1 orbit for the time period of 0246 UT to 0311 UT on October 27, 1981.](image)
Fig. 2. The EICS pitch angle versus time spectrogram in the lowest energy channel from 10 eV to ~ 100 eV for the October 27, 1981, event for H⁺ ions (Figure 2a), O⁺ ions (Figure 2b) and He⁺⁺ ions (Figure 2c). The gray intensity scale indicates fluxes in units of \((\text{cm}^2 \text{ s sr keV})^{-1}\).

of the plot. A pitch angle of 180° corresponds to flow from the northern hemisphere whereas a pitch angle of 0° corresponds to flow from the southern hemisphere. The H⁺ angular distribution consisted of intermittent field-aligned H⁺ beams which are indicated by a band of fluxes around a pitch angle of 180° at 0246 UT to 0248 UT, 0251 UT to 0254 UT and 0302 UT to 0304 UT and quasi-isotropic distributions. This can be seen in Figure 2a. Figure 2b shows signatures of upflowing field-aligned O⁺ beams at 0246 UT to 0248 UT, 0251 UT to 0255 UT, 0257 UT to 0259 UT, 0302 UT to 0304 UT, and 0305 UT to 0307 UT. The fluxes were more intense from 0246 UT to 0248 UT, 0251 UT to 0254 UT and 0302 UT to 0304 UT, periods which corresponded to occurrences of upflowing H⁺ beams. There were almost no He⁺⁺ ions present, as is indicated in Figure 2c.

The energy spectra of the H⁺, O⁺ and He⁺⁺ distributions are shown in Figures 3a, 3b and 3c. In these spectrograms, energy values ranging from 10 eV to 17 keV are plotted against time. The fluxes, averaged over spin phase angle, are again encoded in gray. During the interval of 0246 UT to 0311 UT, the most intense H⁺ fluxes occurred within the first energy channel (below ~ 100 eV) as seen in Figure 3a, but detectable fluxes were observed with energies of over 1 keV during the interval. Figure 3b shows that there were intense O⁺ ion fluxes below 100 eV with some significant fluxes of up to 200 eV from 0251 UT to 0254 UT and 0302 UT to 0304 UT. The higher energy population of O⁺ ions corresponds to the more intense O⁺ beams noted earlier. Again, there are insignificant He⁺⁺ fluxes as indicated in Figure 3c. Note that at this time the EICS instrument was in a mode that sampled the lowest energy channel only one spin period out of 16 (i.e., 6 out of 96 s).

Data from the RIMS instrument were examined to determine the characteristics of the lower energy ions.
Fig. 3. The EICS energy versus time spectrograms averaged over the pitch angles for the October 27, 1981, event for H\(^+\) ions (Figure 3a), O\(^+\) ions (Figure 3b) and He\(^{++}\) ions (Figure 3c).

The RIMS instrument allows for detection of lower energy ions (< 50 eV) and in this case has a higher time resolution for the lower energy ions than does the EICS instrument. The RIMS spin–time spectrograms for H\(^+\) and O\(^+\) are shown in Figures 4a and 4b, respectively. The upper line indicates the phase angles at which the RIMS radial detector viewed particles with 180° pitch angles (flow from the northern hemisphere) while the lower line indicates the phase angles at which the RIMS radial detector viewed particles with 0° pitch angles (flow from the southern hemisphere). Between 0246 UT and 0311 UT, both the H\(^+\) and O\(^+\) field–aligned fluxes in the northern hemisphere were observed (Figures 4a and 4b), thus indicating that the O\(^+\) and H\(^+\) beams identified from the EICS spectrograms extended to lower energies (0 – 50 eV). The filamentary nature of upflowing polar ion streams is clearly seen in Figure 4. The time scales of 20 s for detection of polar ion streams seen in Figure 4 correspond to spatial scales of 70 km at the 2.3–Re altitude point of observation and 20 km at ionospheric altitudes.

We have examined in some detail the EICS and RIMS data for the interval 0300:31 UT to 0307:00 UT and have identified seven components in the ion plasma. We found two low energy streaming components in the RIMS data, three warm streaming and two quasi-isotropic components in the EICS data. In this paper, we refer to cold streams as those that appear primarily in the RIMS energy range, which is from spacecraft potential to 50 eV. Warm streams, on the other hand, are referred to as those that appear primarily in the EICS lowest energy channel, which ranges from 10 eV above spacecraft potential to ~ 100 eV. There is an overlap of energies of the RIMS and EICS as a result of the broad energy ranges of both instruments. However, we use the terms cold and warm mainly to identify the energy range and instrument associated with the observed streams. Our goal was to characterize each of
Fig. 4. The RIMS phase angle versus time spectrograms for the October 27, 1981, event for O⁺ ions (Figure 4a) and H⁺ ions (Figure 4b). The gray scale indicates the intensity of the fluxes.

the seven components by a temperature and density. We also wanted to estimate the bulk streaming energies (velocities) of the streaming components. We first consider the warm streaming plasma components.

If the relative energy and angular distributions of the mass constituents of a polar ion stream are nearly identical and peak in the EICS lowest energy channel, then the ratio of fluxes in the lowest energy channel is a very good estimate of the ratios of the densities of the constituents. These conditions were met in 13 of the 41 polar ion stream events examined in detail, including the interval from 0300:31 UT to 0307:00 UT, October 27, 1981. Flux values in units of (cm² s sr keV)⁻¹ versus pitch angle averaged over 0300:31 UT to 0307:00 UT are shown in Figure 5. The fluxes are divided into pitch angle bins of 15° each. The relative ion compositions of this warm polar ion stream can be calculated by taking the ratios of the ion fluxes in the last angular bin (165° - 180°). The percentages of H⁺, O⁺, He⁺, He++ in the warm ion streams estimated from the flux ratios are (41.5 ± 1.1)%, (48.9 ± 1.3)%, (9.5 ± 0.5)%, and (0.1 ± 0.1)%, respectively. The uncertainties shown are those arising from uncertainties in the flux values used to make the estimate. We see that the O⁺ and H⁺ ion streams have comparable percentage compositions, with O⁺ slightly greater than H⁺. He⁺ represents a small but significant percentage of the warm streaming population at this time, while He++ is negligibly small.

We want to characterize these warm streaming populations by two characteristic energies (temperatures), a streaming energy and a thermal energy. If the po-

Angular Distribution of Ion Fluxes

Fig. 5. The differential ion fluxes in units of (cm² s sr keV)⁻¹ versus pitch angle averaged over 0300:31 UT to 0307:00 UT. The fluxes are plotted on a logarithmic scale.
Fig. 6. A plot of the counts per sample versus spin phase angle in the first energy step from 10 to 60 eV at 0302:51 UT on a logarithmic scale. The dashed line represents the pitch angle at a given spin phase angle.

We can estimate characteristic thermal energies for the warm streaming components using a simple graphical technique. Because the fluxes of both the H\(^+\) and O\(^+\) components in the 165° to 180° angular range are significantly above the background level in the lowest three EICS energy channels (i.e., <400 eV), the slope of the log velocity space density versus energy in the field-aligned direction is inversely related to the streaming temperature. We find that both the H\(^+\) and O\(^+\) streaming, field-aligned components fit well to ~70-eV Maxwellian distributions. It is apparent in Figure 6 that the H\(^+\) plasma is not characterized simply by just a warm streaming component. Examination of the H\(^+\) energy distributions in nonstreaming directions reveals two quasi-isotropic components. One component can be characterized by a temperature of ~100 eV and the second by a temperature of ~1.3 keV. The relative densities of the quasi-isotropic components can be estimated from the relative z axis intercepts in log velocity space density versus linear energy plots used to determine the temperatures. Analysis also shows that the 1.3-keV component has a density ~0.6% that of the 100-eV component.

Because ion fluxes at large pitch angles make a larger relative contribution to the total density than do field-aligned ions, the quasi-isotropic H\(^+\) component represents the largest contribution to the total density. However, the quasi-isotropic component is also the most difficult to characterize, because the fluxes are generally too small to allow for accurate estimation of the densities from the data. The temperature of the quasi-isotropic component is also obtained from the data by fitting a Maxwellian distribution to the log velocity space density versus energy plots. The temperature obtained from this analysis is ~70 eV, which is consistent with the value obtained from the analysis of the field-aligned component. The density of the quasi-isotropic component is estimated to be ~0.6% of the total density.
sents a nonnegligible fraction of the total plasma density. Estimating the relative densities of the streaming and isotropic components is more difficult than simply taking the flux ratios of components with similar angular distributions because in this case details of the instrument angular and energy response function are needed. In addition, the energy range accepted by the lowest energy channel of the EICS instrument is so broad (from 10 eV to over 100 eV) that details of the measured energy and angular distributions must be considered when making estimates of plasma parameters. There is no unique way to approach this problem. However, we can use both the EICS angular distributions and the RIMS measurements in conjunction with the PWI total ion density determination to estimate the relative contribution of the polar ion streams to the total ion density. To do this, we first present and discuss the PWI and RIMS observations for this event. We will then complete our characterisation of the warm polar ion streams and background plasma.

The PWI electric field spectrogram for this event is shown in Figure 7. The spectrogram shows the electric field amplitude measurements from 1 Hz to 410 kHz as the spacecraft crosses the nightside polar cap, descending in altitude as it approaches the nightside auroral zone. Auroral hiss emissions, used to derive the electron densities in the polar cap, can be seen propagating below the electron cyclotron frequency (shown in a solid dark line on the spectrogram). Electron densities are derived from the upper frequency cutoff of these emissions at the local electron plasma frequency. The electron densities measured for the interval 0300:39 UT to 0307:03 UT on October 27, 1981, are shown in Table 1. The electron densities range from 0.65 cm\(^{-3}\) (maximum uncertainty of 22\%) at 0300:07 UT to 4.61 cm\(^{-3}\) (maximum uncertainty of 14\%) at 0307:03 UT during this interval. Persoon et al. [1983] have shown a power law altitude dependence of the observed PWI electron densities, with the densities decreasing with increasing

<table>
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<th>UT (UT)</th>
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<th>Uncertainty</th>
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<td>2.39</td>
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altitude. The range of densities above are consistent with those reported by Persoon et al. [1983] in this altitude range. The variability of the density in the PWI 32-s measurement time scale is consistent with the filamentary nature of the plasma detected by the RIMS instrument and illustrated in Figure 4. We take 2.5 cm\(^{-3}\) as the density that characterizes the average plasma seen from 0300:31 UT to 0307:00 UT.

As stated earlier, densities of low energy ions are difficult to determine from the RIMS and EICS instruments for several reasons. For thermal ions the largest uncertainty in the density determination by the RIMS instrument arises because the spacecraft potentials may be of the same order as the ion energies. A curve fitting procedure for the RIMS radial head RPA data can take into account spacecraft potentials. In this procedure a drifting Maxwellian distribution is fitted to the RPA data, and the ion temperature, density, and drift velocity can be determined from this distribution. We have used this procedure on the RIMS data acquired from 0303:00 UT to 0304:00 UT, where the O\(^+\) fluxes are most intense. Figure 8 shows the fitted curve for the O\(^+\) ions from 0303:00 UT to 0304:00 UT on October 27, 1981, for three assumed spacecraft potentials, 0 eV, 5 eV, and 10 eV. The choice of the largest spacecraft potential value of 10 eV was based on an estimate of correlated spacecraft potential values versus plasma density [Comfort et al., 1988]. The plasma density was taken to be the PWI electron density at that time (i.e., \(n_e \sim 1 \text{ cm}^{-3}\)). We emphasize again that we are attempting to characterize the temperatures and densities of each of the plasma components detected in this interval. For this reason it is appropriate to use a local rather than an average density to determine the characteristics of the streams. The counts per sample are plotted versus the ion energy. There are 756 samples per minute. The O\(^+\) temperature, density, and drift velocity for the three spacecraft potential are listed in Figure 8. The fitting procedure gives O\(^+\) estimated densities of 0.15 cm\(^{-3}\), 0.09 cm\(^{-3}\), and 0.07 cm\(^{-3}\) for spacecraft potentials of 0 eV, 5 eV, and 10 eV, respectively. Likewise, the inferred temperature decreases with increasing spacecraft potential. The inferred O\(^+\) temperatures are 0.13 eV, 0.04 eV, and 0.03 eV for spacecraft potentials of 0 eV, 5 eV, and 10 eV, respectively, indicating a cold O\(^+\) ion distribution. The drift velocity inferred from the RIMS data increases with increasing spacecraft potential. The drift velocity is 6.00 km s\(^{-1}\), 9.85 km s\(^{-1}\), and 12.55 km s\(^{-1}\) for spacecraft potentials of 0 eV, 5 eV, and 10 eV, respectively. The “knee” or high energy tail of the fitted distribution depends strongly on the drift velocity in this case. As the spacecraft potential is increased, the drift velocity must increase to keep the high energy tail fitted to the data. Thus, the decrease in the O\(^+\) density is mainly due to the increase of the drift speed rather than to screening effects of the potential. Since the EICS energy threshold (10 eV) corresponds to an O\(^+\) velocity of \(~ 10 \text{ km s}\(^{-1}\)\) and the upstreaming O\(^+\) velocity inferred from the 10 – 100 eV fluxes above is low (\(~ 10 \text{ km s}\(^{-1}\)\)), we take as the best estimate of the cold O\(^+\) streaming component a streaming velocity of 0 km s\(^{-1}\) (3 eV), a temperature of 0.1 eV, and a density of 0.1 cm\(^{-3}\). As discussed above, the EICS data showed a different streaming O\(^+\) component, at a higher energy. The streaming O\(^+\) plasma thus has two components, with thermal energies of \(~ 0.1 \text{ eV} \) (“cold” component) and 70 eV (“warm” component). The single bulk streaming velocity of 12 km s\(^{-1}\) (12 eV) determined from a simple geometric analysis of the O\(^+\) angular distribution in the lowest EICS energy channel is, as we noted above, a weighted average of the upstreaming velocities of the cold and warm O\(^+\) ion streams. The warm O\(^+\) ion stream thus has a streaming velocity > 12 km s\(^{-1}\) (12 eV).

Examination of Figure 4 shows that during the interval from 0300:31 UT to 0307:00 UT intermittent field-aligned streams of cold H\(^+\) were detected by the RIMS instrument. During the minute period of 0303:00 UT to 0304:00 UT, there were unfortunately insufficient H\(^+\) counts to successfully use the fitting analysis although the best O\(^+\) RIMS fittings were obtained over this minute period. We have the EICS estimate of the ion streaming energy made under the assumption that there is only one H\(^+\) streaming component. The 5-eV (32 km s\(^{-1}\)) H\(^+\) streaming energy is thus a lower limit of the energy of the warm stream and eventually an upper limit of the energy of the cold ion stream if we assume that the H\(^+\) streams give two components, as observed in the O\(^+\) distribution.

In the discussion above, we have been able to separate the populations on the basis of mass, characteristic drift speed, and thermal energy. We have also been able to make some inferences about the density of the various components. The discussion has also emphasized that the upflowing ion streams in the interval under consideration are not steady. Nevertheless, it is desirable to
estimate the average plasma density for the principal mass and thermal constituents to characterize the environment in a way useful for modeling and simulation studies. Table 2 identifies the populations and summarizes the observations.

Included in Table 2 are estimates of the densities of each of the seven ion components. As noted above we used $2.5 \, \text{cm}^{-3}$ as the characteristic plasma density for the interval from 0300:30 UT to 0307:00 UT. We used several techniques to partition the density among the identified components. We used the cold O$^+$ stream density inferred from the RIMS data of $0.1 \, \text{cm}^{-3}$. The EICS data were used to get the ratios of the densities of the other components. The relative densities of the warm streaming components were estimated from the flux ratios in the streaming direction as discussed earlier. The relative densities of the quasi-isotropic components were estimated with the graphical technique discussed earlier. We used a model calculation to determine the relative densities of the warm, streaming and $\sim 100$-eV quasi-isotropic H$^+$ populations. Specifically we assumed that the energy dependence in the range of the lowest EICS energy channel was identical for both components. The fluxes in the lowest energy channel were then extrapolated into the third dimension assuming gyrotropy and integrated over all angles. This calculation showed $1/4$ of the H$^+$ density in the lowest energy channel came from the $165^\circ$ to $180^\circ$ angular range. We therefore assumed that the ratio of the warm streaming and $\sim 100$-eV, quasi-isotropic H$^+$ components was 1:3. Since the two H$^+$ components have similar thermal energies and have their maximum fluxes at energies within the range of the lowest EICS energy channel, the approximation is not unreasonable. The density estimates are, of course, subject to considerable uncertainty.

The second ion streaming event is another example in which both the EICS and RIMS instruments can be used to measure the plasma characteristics. Because in this case the H$^+$ streaming and quasi-isotropic distributions have vastly different temperatures, it is not possible to use the techniques discussed above to estimate the relative contribution of the streaming and quasi-isotropic distributions. The event occurred on November 3, 1981, between 1737 UT and 1831 UT. At this time, the satellite was crossing the dayside polar cap near 0500 magnetic local time as shown in Figure 9. The event occurred at a higher altitude, $3.64 \, R_E$ at 1737 UT, than in the previous case shown. The auroral activity was moderate with an AE index of 103 nT, 111 nT and 118 nT during the hours beginning with 1600 UT, 1700 UT and 1800 UT, respectively. Figures 10–12 display the EICS and RIMS spectrometers for this event.

The EICS spin-time spectrograms for the H$^+$, O$^+$ and He$^{++}$ ions for this event are shown in Figures 10a, 10b and 10c, respectively. The H$^+$ distribution is quasi-isotropic early on in the time period from 1737 UT to 1742 UT except for an intensification of the fluxes between 1738 UT and 1740 UT around a $180^\circ$ pitch angle as indicated in Figure 10a. Later, there are intermittent field-aligned H$^+$ beams from 1743 UT to 1744 UT, 1746:30 UT to 1749 UT and 1808:30 UT to 1812 UT. Upflowing field-aligned O$^+$ beams are indicated by the band of O$^+$ fluxes near a $180^\circ$ pitch angle from 1737 UT to 1748 UT, 1753 UT to 1756 UT, 1757 UT to 1804 UT, and 1808:30 UT to 1817 UT in Figure 10b. In this event, the He$^{++}$ ions are also near the detection threshold of the EICS instrument.

![Fig. 9. DE 1 orbit for the time period of 1737 UT to 1831 UT on November 3, 1981.](image-url)
Fig. 10. The EICS pitch angle versus time spectrogram in the lowest energy channel for the November 3, 1981, event for H⁺ ions (Figure 10a), O⁺ ions (Figure 10b) and He⁺ ions (Figure 10c).

The energy–time spectrograms for the H⁺, O⁺ and He++ ions are shown in Figures 11a, 11b and 11c, respectively. The H⁺ spin–averaged fluxes in the interval of 1737 UT to 1748 UT are the most intense in the first two energy channels (10 eV up to ~200 eV) although fluxes are evident up to ~5 keV. At this time, the H⁺ angular distribution was quasi-isotropic as noted in Figure 10a. Later the spin–averaged fluxes are much weaker. During the time period 1737 UT to 1817 UT, the most intense spin–averaged O⁺ fluxes were within the first energy channel (10 eV to ~100 eV) (see Figure 11b). There are short intervals of time in which there were no fluxes detected in the first energy channel during 1737 UT to 1817 UT. Those gaps correspond to times when no O⁺ beams were observed. Figure 11c shows negligible He++ fluxes, which is consistent with Figure 10c.

The RIMS spin–time spectrograms for the H⁺ and O⁺ ions are shown in Figures 12a and 12b. Upflowing field–aligned H⁺ ions are detected from 1737 UT to 1738 UT in Figure 12a. This signature appeared on the EICS H⁺ spin–time spectrogram as well. There is also an indication of a H⁺ beam from 1743 UT to 1746 UT in Figure 12a. These H⁺ beams have energy spectra which extend below 50 eV. In addition to the H⁺ beam, upflowing field–aligned O⁺ beams are detected around 1737 UT to 1746 UT in Figure 12b. Thus, the O⁺ beams also extend to lower energies.

The energy distribution of the ion fluxes averaged over the time period 1737 UT to 1748 UT in the pitch angular range of 165° to 180° is shown in Figure 13. Note that the H⁺ fluxes do not have the same energy dependence in the lowest three energy channels. Significant O⁺, He⁺, and He++ fluxes above ~10⁴ (cm² s sr keV)⁻¹ occur below ~200 eV. However, there are H⁺ fluxes above ~10⁴ (cm² s sr keV)⁻¹ up to ~4 keV. This is consistent with the ion signatures shown in the energy spectrograms (Figures 11a and 11b). No estimates were made of the streaming energy of the ion beams in the interval from 1737 UT to 1748 UT.
using the graphical technique discussed above because the technique does not apply in this case.

The EICS energy and angular distributions were examined in detail for five intervals on November 3, 1981 (1737 – 1748 UT, 1753 – 1804 UT, 1808:30 – 1817 UT, 1821 – 1834 UT, and 1826 – 1831 UT). Oxygen ion streams were detected above the 10-eV EICS threshold in each of these intervals. In only the first interval, 1737 UT to 1748 UT, did we detect significant upstreaming H+ and O+ components. However, the H+ distribution detected by the EICS instrument in the streaming direction is qualitatively different from the O+ and He+ components. Here we present an overview of the energetic ion plasma from 1737 UT to 1831 UT and a detailed analysis of the ion plasma components detected during the interval 1737 UT to 1748 UT.

As discussed above, if the energy and angular distributions of the various ion species are similar and peak in the lowest EICS energy channel, we can use flux ratios in the field-aligned direction to estimate relative densities of the warm streaming ion components. Figure 14 shows a plot of the angular distribution of the ion fluxes on a log scale. Figures 13 and 14 show that the H+ energy and angular distributions are not identical to those of O+ and He+, so we can only estimate the relative densities of O+ and He+. Table 3 shows the relative densities of these two components. Note that the low flux levels, especially after ~ 1820 UT, result in relatively large uncertainties in the relative densities. Note also that the composition changes systematically, becoming more rich in He+ as the satellite moves further into the polar cap. In all of the intervals the flux of upstreaming He++ was at or below the EICS threshold of detection. Two warm quasi-isotropic H+ components were detected in the 1737 UT to 1748 UT interval; warm quasi-isotropic H+ was detectable in all of the intervals listed in Table 3.

Data from the PWI instrument for the interval from 1737 UT to 1748 UT were only able to place a lower limit on the total density. The PWI electric field spec-

Fig. 11. The EICS energy versus time spectrograms averaged over the pitch angle for the November 3, 1981, event for H+ ions (Figure 11a), O+ ions (Figure 11b) and He++ ions (Figure 11c).
Fig. 12. The RIMS phase angle versus time spectrograms for the November 3, 1981, event for O\(^+\) ions (Figure 12a) and H\(^+\) ions (Figure 12b). The gray scale indicates the intensity of the fluxes.

Fig. 13. The differential ion fluxes versus energy per charge averaged over the time period of 1737 UT to 1748 UT in the angular bin of 165° to 180° pitch angle.

Fig. 14. The angular distribution of the differential ion fluxes averaged over 1737 UT to 1831 UT.
TABLE 3. Estimated Percentage Composition of Warm O⁺ and He⁺ Streams for Intervals Between 1737 UT and 1831 UT on November 3, 1981

<table>
<thead>
<tr>
<th>Interval</th>
<th>O⁺ %</th>
<th>He⁺ %</th>
</tr>
</thead>
<tbody>
<tr>
<td>1737:00 – 1748:00</td>
<td>90 ± 2</td>
<td>10 ± 1</td>
</tr>
<tr>
<td>1753:00 – 1804:00</td>
<td>92 ± 6</td>
<td>8 ± 1</td>
</tr>
<tr>
<td>1808:30 – 1817:00</td>
<td>63 ± 9</td>
<td>37 ± 6</td>
</tr>
<tr>
<td>1821:00 – 1824:00</td>
<td>45 ± 18</td>
<td>55 ± 20</td>
</tr>
<tr>
<td>1826:00 – 1831:00</td>
<td>18 ± 6</td>
<td>82 ± 1</td>
</tr>
</tbody>
</table>

The spacecraft is approaching the apogee as it enters the polar cap near local dawn. Auroral hiss emissions propagate below the electron cyclotron frequency poleward of the auroral zone, but the amplitude falls off with increasing latitude and frequency after 1740 UT. The PWI measurements indicate that the electron density exceeds 0.7 cm⁻³ during the time interval of 1738 UT to 1748 UT. The plasma characteristics of the low energy O⁺ ions were measured using a drifting Maxwellian fit of the RIMS data. As in the earlier case, spacecraft potentials of 0 eV, 5 eV, and 10 eV were considered. The density, nO⁺, temperature, T_O⁺, and drift velocity, v_d, of the O⁺ ions at 1744 UT to 1745 UT for each of these spacecraft potentials are listed in Figure 16. The O⁺ density is 0.11 cm⁻³, 0.08 cm⁻³, and 0.05 cm⁻³ for spacecraft potentials of 0 eV, 5 eV and 10 eV, respectively, and decreases with increasing potential. The O⁺ temperatures also decrease with increasing spacecraft potentials. The temperatures are 6.00 eV, 5.00 eV and 3.50 eV for potentials of 0 eV, 5 eV and 10 eV, respectively, suggesting that the ionospheric ions are heated. The O⁺ drift velocity increases with increasing spacecraft potentials. In this case, the decrease of the density with increasing spacecraft potentials is mainly due to the greater drift speeds.

A similar plot of the fitted curve for the H⁺ ions for the same minute period is shown in Figure 17. The parameters for spacecraft potentials of 0 eV, 5 eV and 10 eV are listed on this figure. For the case of the H⁺ ions, the density increases with larger potentials. The H⁺ density is 0.26 cm⁻³, 0.45 cm⁻³ and 0.71 cm⁻³ for potentials of 0 eV, 5 eV and 10 eV, respectively. The H⁺ temperature remains nearly the same at about 7.60 eV, 7.60 eV, and 7.30 eV for potentials of 0, 5 eV, and 10 eV, respectively. These temperatures suggest that the ionospheric H⁺ ions are heated as well. The H⁺ drift velocities increase with spacecraft potential although not as much as for the O⁺ ions. The H⁺ drift velocities are 5.00 km s⁻¹, 5.50 km s⁻¹, and 8.00 km s⁻¹, respectively. In this case, the knee of the distribution is more a function of the thermal energy than of

Fig. 15. The PWI electric field spectrogram for the November 3, 1981, event.
drift speed. Thus, as the spacecraft potential increases, more of the H⁺ distribution is screened off and the H⁺ density increases.

The total cold plasma density estimated from the RIMS instrument ranges from 0.3 cm⁻³ to 0.7 cm⁻³. Two different graphical methods of estimating the density of the 120-eV quasi-isotropic H⁺ component give 0.1 cm⁻³ and 0.5 cm⁻³. The total density estimated from the particle data alone is thus in the range 0.4 cm⁻³ to 1.2 cm⁻³. The PWI instrument sets a lower limit of 0.7 cm⁻³. Table 4 reports our final estimates of the densities and temperatures of the five ion components detected during the interval from 1737 UT to 1748 UT. These estimates are more uncertain than the estimates for the interval presented in Table 2 because we used a less reliable method to estimate the density of the quasi-isotropic H⁺ components.

Comparison of the EICS and RIMS data shows that only cold streaming H⁺ and O⁺ components are present; there are no warm streaming components similar to those detected on October 27, 1981, which was discussed earlier. The low streaming energies inferred from the RIMS data are comparable to energies characteristic of either the spacecraft potential, the drift of ions in the convection electric field, or both. Hydrogen ions were also detected in the first energy channel. The angular distribution was bell-shaped and centered at a pitch angle of about 172°, indicating a beam distribution, and included low counts extending to other pitch angles, indicating a quasi-isotropic background. Comparison of the EICS and RIMS observations in the streaming direction shows that there is only one streaming H⁺ component in this time interval. The H⁺ fluxes detected by EICS in the streaming direction are consistent with the high energy part of the cold H⁺ stream detected by RIMS.

Plasma characteristics for two ion beam events have been presented in detail. For a reasonable range of magnetospheric parameters the O⁺ ions in these two events were mapped to the ionospheric source by I. B. Cladis and W. E. Francis of Lockheed using their particle tracing code. Their results suggest that the primary O⁺ beams originated from the dayside polar cleft or "upwelling ion" region. The > 9-eV streaming O⁺ com-

---

**TABLE 4. Estimated Plasma Components for the Interval 1737 UT to 1748 UT on November 3, 1981**

<table>
<thead>
<tr>
<th>Species</th>
<th>Beam Energy, eV</th>
<th>Thermal Energy, eV</th>
<th>Density, cm⁻³</th>
</tr>
</thead>
<tbody>
<tr>
<td>O⁺</td>
<td>1</td>
<td>5</td>
<td>0.1</td>
</tr>
<tr>
<td>H⁺</td>
<td>1</td>
<td>7</td>
<td>0.3</td>
</tr>
<tr>
<td>He⁺</td>
<td>&lt;1</td>
<td></td>
<td>0.01</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Quasi-Isotropic Components</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature</td>
</tr>
<tr>
<td>120eV</td>
</tr>
<tr>
<td>1keV</td>
</tr>
</tbody>
</table>
The plasma characteristics of polar ion stream events near solar maximum were analyzed using the EICS, RIMS and PWI instruments on board the DE 1 satellite. Events were selected for which PWI densities were significantly greater than 9 eV and this streaming energy was acquired at ionospheric altitudes.

Several other events were estimated using the EICS data. The relative densities of the upflowing ion streams, the PWI electron densities, and qualitative features of the cold upflowing ion streams from the RIMS data for four polar ion stream events are listed in Table 5. The events are ordered according to increasing $AE$ index. The first event of Table 5 or event A occurred during very quiet auroral conditions with an $AE$ index of 37 nT. Despite this, the estimated upflowing $O^+$ component is significant. A large content of upflowing $O^+$ was a common feature of the events in Table 5 as well as all the events studied. In 22 of the 41 events studied, $O^+$ was the dominant upflowing ion species. The $He^+$ ions were the dominant upflowing ion species in event A. In fact, significant amounts of upflowing $He^+$ ions were a common feature found in many of the polar ion streaming events. Cold intermittent upflowing $H^+$ and $He^+$ streams were observed in the RIMS data for event A. The time scales of the beam durations were approximately 1 min. The relative density of the upflowing $H^+$ plasma was not estimated because in this event there was a nonnegligible quasi-isotropic $H^+$ component.

Event B in Table 5 occurred under quiet auroral conditions and had an $AE$ index of 56 nT. In this event the $O^+$ ions were the dominant upflowing ion species. Cold $H^+$ beams were evident in the RIMS data. Again, the $H^+$ streams were intermittent with durations of approximately 2 min. EICS was in a mode that was not sampling $He^+$ ions during the time of this event.

Events C and D in Table 5 occurred under moderate auroral conditions. Oxygen and hydrogen were the dominant upflowing ion species in the third and fourth events, respectively. In both cases, there were cold $H^+$ streams observed by the RIMS data. Again, these cold streams exhibited filamentary nature. The duration of the intermittent cold $H^+$ streams was about 1 min and 4 min for the third and fourth events in the table, respectively.

### 4. Discussion

The plasma characteristics of polar ion stream events

<table>
<thead>
<tr>
<th>Event</th>
<th>Interval (year,day,UT)</th>
<th>$AE$, nT</th>
<th>Upflowing Beams $O^+,H^+,He^+$ (%)</th>
<th>$n_e$, cm$^{-3}$</th>
<th>Cold Upflowing Beams (Duration)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>81304 1629 - 1631</td>
<td>37</td>
<td>29,...,70</td>
<td>2.0 - 6.0</td>
<td>$H^+,He^+$ ($\sim$ 1 min)</td>
</tr>
<tr>
<td>B</td>
<td>81307 0543 - 0549</td>
<td>56</td>
<td>66,34,...</td>
<td>0.3 - 0.8</td>
<td>$H^+$ ($\sim$ 2 min)</td>
</tr>
<tr>
<td>C</td>
<td>81300 0253 - 0259</td>
<td>106</td>
<td>67,19,14</td>
<td>1.3 - 3.7</td>
<td>$H^+$ ($\sim$ 1 min)</td>
</tr>
<tr>
<td>D</td>
<td>81331 0400 - 0410</td>
<td>111</td>
<td>24,57,19</td>
<td>0.1 - 0.2</td>
<td>$H^+$ ($\sim$ 4 min)</td>
</tr>
</tbody>
</table>

The plasma often had a high content of upflowing $O^+$ ions. In 22 of the 41 polar ion streaming events studied, $O^+$ was the dominant ion constituent in the upflowing beam components. Even during quiet auroral conditions when the $AE$ index was only 37 nT, significant amounts of upflowing $O^+$ ions were found.

The high content of $O^+$ ions in the plasma is contrary to what is expected from classical polar wind theory. Studies of the steady state hydrodynamic flow of ions from the polar ionosphere with a plasma temperature of 3000 K predict $O^+$ densities of less than $\sim 10^{-3}$ cm$^{-3}$ beyond 4 $R_E$ [Banka and Holzer, 1969]. At low altitudes below about 1000 km, where chemical reactions predominate, $O^+$ ions are produced by photoionisation and resonant charge exchange between the $H^+$ ions and neutral O. The $O^+$ ions are also depleted through reverse charge exchange and collisions with neutrals such as $N_2$ and $O_2$. Both the depletion of $O^+$ ions through reactions with neutrals and the gravitational force hinder the escape of $O^+$ ions into the polar magnetosphere.

More recent models of the polar wind have addressed this problem. Using a semikinetic approach to the polar wind at altitudes above the collisional regime, Barakat and Schunk [1983] have shown that with large electron temperatures, $\sim 10^4$ K, the $O^+$ outflows can become somewhat larger than predicted by the hydrodynamic studies. The large electron temperature increases the ambipolar electric field thereby accelerating more $O^+$ ions outward. By varying ion temperatures instead of electron temperatures in the semikinetic model used by Barakat and Schunk [1983], Li et al. [1988] found that the $O^+$ fluxes can reach values similar to those in the Barakat and Schunk [1983] study for ion temperatures ($\sim 3$ eV). It is possible that the energisation of the $O^+$ ions plays a role in the increased outflow of $O^+$ ions from the polar region. A time-dependent polar model used by Gombosi et al. [1985] has shown large transient $O^+$ fluxes, greater than $10^{10}$ cm$^{-2}$ s$^{-1}$, produced by arbitrary ion heating.

The possible sources of free energy that may contribute to ion heating include field–aligned currents and perpendicular electric fields associated with the plasma convection jet. Wave–particle interactions also possibly play a role in ion heating. Ashour-Abdalla et al. [1988] have shown that $O^+$ ions on the auroral field lines are transversely heated due to their interactions with electrostatic waves generated from an electron beam instability. Although the field–aligned currents on the polar cap field lines are more subdued, they may possibly generate waves through plasma instabilities in the polar cap region. These plasma instabilities and possible ion heating will be investigated in future studies.
In the first event presented in the observations section, the upflowing O\(^+\) population was found to consist of both a cold and a warm distribution. Earlier DE 1 observations of the polar wind have found a conic component resulting from perpendicular heating in addition to a low-energy field-aligned component [Gurgiolo and Burch, 1982]. In our study, we found a warm component in the field-aligned direction which could possibly have resulted from an ion heating process. Another interesting feature of the polar ion streams is the filamentary nature of the streams. The upflowing streams vary on a time scale ranging from tens of seconds to minutes which corresponds to spatial scales of tens to hundreds of kilometers in the ionosphere.

The He\(^+\) densities measured are also much larger than expected from classical polar wind theory. The He\(^+\) density was found theoretically to be at least 100 times smaller than the O\(^+\) density throughout regions below 5000 km, due to rapid loss of He\(^+\) ions through reactions with N\(_2\) [Banks and Holzer, 1969]. It was assumed for many years that He\(^+\) was an insignificant ion constituent. Other recent observational studies have also shown this not to be the case. A study by Nagai et al. [1984] of the polar wind outflow in the high altitude polar cap during a substorm has shown a He\(^+\)/H\(^+\) ratio varying from 0.01 to ~ 1. Collin et al. [1986] reported an intense He\(^+\) conic in which He\(^+\) was the major ion species in the auroral region. Reiff et al. [1988] reported that some of four ion beam events in the auroral region had a relative He\(^+\) component of over 30%. Collin et al. [1988] reported that about 13% of the upflowing ion events that they studied had He\(^+\) fluxes which exceeded the highest predicted polar and limiting flux.

It has become apparent that it is necessary to study multicomponent plasmas, both the kinetic instabilities and the macroscopic dynamics, to reach an understanding of the outflow of the O\(^+\) and He\(^+\) ions from the polar ionosphere.

5. Conclusions

The plasma characteristics of upflowing ion stream events with energies greater than 10 eV in the polar cap region near solar maximum were analyzed using DE 1 data. Data from three instruments, the EICS, RIMS and PWI instruments, were used. The EICS detects ions in the energy range of 10 eV to ~ 17 keV while the RIMS detects low energy ions below 50 eV. Electron densities measured by the PWI provide limits on the ion densities. Because the upflowing ion energies are sometimes comparable to the spacecraft potentials and the fluxes involved are close to the instrumental thresholds, it has been difficult to measure densities and temperatures of these low energy ions. We considered a subset of upflowing polar cap ion streams in which it was possible to make estimates of the plasma characteristics using the three DE 1 instruments. The plasma was found to consist of multiple streaming and quasi-isotropic components. The data for two polar ion streams were presented in detail.

Several other polar ion stream events were studied and the general features were presented and discussed in the paper. A summary of the important results follows.

1. It was found that in 22 of the 41 polar ion stream events studied, O\(^+\) was the dominant ion constituent in the upflowing beam components. Thus, the plasma was often found to have a high content of upflowing O\(^+\) ions.

2. There were significant amounts of upflowing O\(^+\) in the plasma even during quiet auroral conditions when the AE index was only 37 nT.

3. In one event presented, the upflowing O\(^+\) population had two components, a cold distribution with \(T_0 \sim 0.1\) eV, \(n_0 \sim 0.1 \text{ cm}^{-3}\) and \(v_0 \sim 6 \text{ km s}^{-1}\) and a warm distribution with \(T_0 \sim 70\) eV, \(n_0 \sim 0.4 \text{ cm}^{-3}\) and \(v_0 \sim 12 \text{ km s}^{-1}\).

4. In another event, for an assumed spacecraft potential of 5 eV, the O\(^+\) and H\(^+\) temperatures were estimated to be 5 eV and 7.6 eV, respectively, suggesting that the ionospheric ions were heated.

5. The cold upflowing ion stream component observed in some of the polar ion streaming events exhibited a filamentary nature. The cold ion streams varied on a time scale ranging from tens of seconds to minutes which corresponds to spatial scales of tens to hundreds of kilometers in the ionosphere.

6. A significant amount of He\(^+\) was also found in some of the events studied.

The observations in this study have raised more theoretical problems such as explaining the unexpectedly high He\(^+\) densities often found in the plasma on the polar cap region. It has also reaffirmed the need to explain the large outflows of O\(^+\) from the polar ionosphere and to explain the ion heating in this region. The observations established important plasma characteristics in this region which will be valuable in future theoretical and simulation work.

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