COUNTERSTREAMING HYDROGEN AND OXYGEN IONS OBSERVED IN THE MAGNETOSPHERE ON ISEE-1

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ABSTRACT

Counterstreaming ions or ions travelling simultaneously both parallel and antiparallel to the magnetic field direction have been briefly noted in the literature but have not been studied previously in depth. We have studied over 60 counterstreaming ion (CSI) events observed on the ISEE-1 satellite. They were found to occur at altitudes of about 2 to 8 Earth radii on L shells of about 5 to 12 in the evening-to-morning sector from about 1700 - 0900 LT. Often both oxygen and hydrogen ions at a number of energy levels are counterstreaming but some events show only either oxygen or hydrogen ions involved. One particularly interesting event shows only counterstreaming oxygen ions with 417 eV energy; oxygen ions of lower energy (215 eV) and above (630-17000 eV) and all the hydrogen ions between 215 - 17000 eV energy have lower fluxes and/or nearly isotropic pitch angle distributions. This event correlates well with wave activity in the 17 - 100 Hz band and is also accompanied by 200 eV downgoing and 400 eV upgoing electrons. Details of this event and the other counterstreaming events are presented.

INTRODUCTION

Ion distributions in the ionosphere and magnetosphere have been studied extensively in the past decade by many researchers /e.g. 1,2 and refs. therein/. Generally, the pitch-angle distributions have been found to be field-aligned (UFI or upward flowing ions and DFI or downward flowing ions), conic, or pancake /e.g. 3,4/; these distributions have the ion flow parallel or antiparallel to the magnetic field, upward with strong perpendicular anisotropies, or peaked at 90° to the magnetic field.

A phenomenon which has been briefly mentioned in the literature involves counterstreaming ions or ions travelling simultaneously both parallel and antiparallel to the magnetic field direction /2,5-7/. Countersstreaming electrons have also been observed and studied /6,9/.

In our study we have defined counterstreaming ion (CSI) events as those events with maxima in the ion flux around 0° and 180° pitch angle where both maxima are at least ten times as large as the value at the minimum. In many cases the ratio of maximum to minimum values is around 30 to 100.

We have made a study of over 60 CSI events and have obtained general characteristics which may prove useful in providing answers to the many questions concerning ion composition and dynamics in the magnetosphere /10/. We present below the observations of the counterstreaming oxygen and hydrogen ions as well as additional data obtained on other scientific instruments on ISEE-1.

COUNTERSTREAMING OXYGEN IONS

Ion Flux Data

A unique counterstreaming oxygen ion event was observed on the ISEE-1 satellite on 21 Nov. 1980 during the time interval 1105:10 to 1113:42 UT. Figure 1 shows the ion flux vs. pitch angle during the interval of interest. The top panels labelled a,c,e,g,i,k,m,o show the oxygen ion flux while the lower panels show the hydrogen ion flux; the panels above and below each other correspond to the same time interval, e.g. panels a and b give the data during the time interval 1105:10 to 1106:14 UT.

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The hydrogen ion flux shows little activity, all the energies having similar flux values and exhibiting isotropic distributions. The oxygen ion flux, however, exhibits low values for the higher ion energies 630 eV to 17 keV while the lowest energy sampled of 215 eV shows some activity varying from isotropy. The dramatic activity is seen in the 417 eV oxygen ion data represented by the large dots. Beginning during the interval 1108:22 to 1109:26 UT the flux reaches high values at pitch angles about 0° and 180° with minima below 90°. The arrows in panels g, i, k, and m indicate the time sequence of measurement and reveal the movement of the flux minimum to higher pitch angles with time. In panel g, the first minimum at 65° pitch angle is higher than the second minimum at 83° taken 1.3 second later at 1108:34.4 UT. The next oxygen panels i and k show that the minimum has moved to higher pitch angle values of 95° and 107° respectively. Finally panel m shows the oxygen ion flux increasing from the first measurement at 85° rising to a maximum at 29° but the later measurement 0.5 second later at 31° indicates the satellite has left the region of downgoing oxygen ion flux. The last panel o shows the ion flux no longer has high values as in the immediately preceding panels.

The important feature to note in this sequence of data is the activity in the oxygen ion flux primarily at one energy level with no activity in the hydrogen ion flux at all energies sampled. The activity at the one energy level of 417 eV is quite remarkable, with ion fluxes flowing both parallel and antiparallel to the field lines with values 100 times the minimum flux at pitch angles at or near 90°. It is a unique event where hydrogen ions of the same energy are unaffected by the mechanism involved.

Data From Other Experiments On ISEE-1

Data from other experiments on board ISEE-1 were obtained for the period of the unique counterstreaming ion event. Figure 2 shows the electric field amplitudes from the 20-channel spectrum analyzer. The field strengths are on a logarithmic scale with a 100 dB dynamic range from the baseline of one channel to the baseline of the next higher channel. Note the peaks in the electric field amplitude from 1109:37 to 1109:47 UT in the 17.8 to 178 Hz channels with largest amplitudes of about 1 mV/m in the 31.1 Hz channel. This time interval corresponds to panel 'i' in Figure 1 where the minimum ion flux occurs at a pitch angle of about 95°.

Another experiment on board the ISEE-1 satellite is the electron spectrometer experiment. The electron data on the standard plots show some effect and to further isolate the effect time plots were made of the parallel cut through the distribution function...
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\[ f(v_1, v_2) \] relative to the perpendicular cut at the differential electron speeds \( v_1 = 200 \text{ eV} \) and \( v_2 = 400 \text{ eV} \). These are given by \( A^+ = \frac{F^+}{F} \), \( A^- = \frac{F^-}{F} \), and

\[ S = A^+ - A^- \]

The parameters \( A^+ \) and \( A^- \) should measure the anisotropy parallel (downgoing) and anti-parallel (upgoing) respectively to the magnetic field at the given energy. The difference \( S \) should be a measure of the skew.

Figure 3 shows the data for the 200 eV electrons on the left and the 400 eV electrons on the right. The times of the ion and wave events are indicated by the arrows. The plots indicate an increase in \( A^+ \) at 200 eV and an increase in \( A^- \) at 400 eV just prior to and during the 417 eV O\(_2\) CSI event respectively.

Another experiment onboard the ISEE-1 satellite with relevance to this counterstreaming oxygen ion event is the quasi-static electric field experiment. The data from this experiment show no marked activity in the electric field during and around the time of the 417 eV oxygen CSI event /11/.

LOCATIONS OF COUNTERSTREAMING ION EVENTS

Over 60 CSI events involving oxygen and/or hydrogen ions were studied. Figure 4 shows the locations in L value and local time of the events. The figure is not in the equatorial plane and the events occur at geomagnetic latitudes north of the equatorial plane between about 15° - 55°. The unique 417 eV O\(_2\) CSI event on 21 Nov. 1980 occurs between 45.9° - 44.4° geomagnetic latitude. The counterstreaming oxygen ions are indicated by solid circles and the hydrogen ions by open circles. It can be noted that the CSI events occur in the local time sector between 1800 - 0900 LT and between L values of about 5 to 12. There were a number of satellite passes covering the local time sector about noon but none of these showed any CSI events. Fig. 4 also shows that the majority of the oxygen CSI events occur at the lower end of the L range from about 5 to 8 while the majority of the hydrogen CSI events occur at the upper end from about 8 to 12.

Figure 5 is a similar plot to Fig. 4 where the radius now represents the radial distance in Earth radii from the Earth's centre. The CSI events occur in the range from 3 to 9 Earth radii geocentric distance (altitude 2 to 8 Earth radii). The majority of the CSI events at altitudes between 2 to 5 Earth radii are O\(_2\) events while H\(_2\) events predominate at altitudes from 5 to 8 Earth radii.

Fig. 4. Locations of counterstreaming hydrogen and oxygen ions in L value and local time. Fig. 5. Locations of CSI events in geocentric distance and local time.
DISCUSSION

The unique counterstreaming 417 eV oxygen ion event on 21 Nov. 1980 raises a number of questions as to the process taking place. For example, why is just this one energy level of 417 eV oxygen ions involved? Why are the hydrogen ions in the energy range measured not affected? Then, in other cases, why are only H+ ions counterstreaming?

Theories for parallel acceleration appear to invoke primarily electric fields and double layers. In the case of counterstreaming electrons Sharp et al. /8/ and Barfield /9/ have discussed a number of alternatives such as acceleration by wave-particle interactions, fluctuating electric fields and multiple flickering double layers. Barfield has proposed wave-particle interactions for what he termed Type 1 events and oppositely-directed electric fields pointing toward the satellite along magnetic field lines for Type 2 events. Our unique O+ CSI event appears to be due to wave-particle interaction as the data in Fig. 2 indicate some correlation with wave activity; in addition, there is a suggestion of a minimum parallel resonant energy. Fig. 6 is a plot of the ion flux versus parallel energy E_p. The solid circles represent the data for the time interval 1109:36.6 - 1109:39.4 UT; they indicate a greater dependence on E_p at the beginning than at the end of the period as seen by the dashed line with slope m = 2.93 and the dashed line with smaller slope m = 1.13 respectively. The other data points for the other time intervals are similar and the solid lines approximately bracket the points. The slope m takes values usually between about 2 and 3, being consistent over 1.5 second. Fig. 6 suggests a minimum parallel resonant energy of about 20 eV above which the oxygen ions are accelerated and/or organized as ion flux 0 % E_p. The organization apparently gives diminished fluxes around the minimum parallel resonant energy before increasing fluxes to high values. More details of the CSI phenomenon will be given in a paper in extended form.

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