Electric Fields in the Vicinity of L=20 Re During Substorms

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Abstract. Convective flows measured by the Electron Drift Instrument (EDI) on the Cluster spacecraft are studied during orbit segments that traverse the magnetotail of the Earth. These segments are often in the vicinity of L shells around 20 Re, corresponding to relatively high auroral latitudes. Time periods in which substorms and associated auroral displays are observed by space and ground-based instruments are closely examined for clues as to how the high-latitude magnetic-field lines are involved in the substorm and auroral processes. The L shell values for Cluster are computed by the Cluster Science Data System using the Galperin method: follow the field line to the northern hemisphere using the full field including external components, and compute L at that location using only the internal field. The CNES MAGLIB with IGRF95 and Tsyganenko89c is employed. The Galperin method greatly facilitates the association of Cluster data with auroral displays and other near-Earth phenomena.

1. Introduction

The Electron Drift Instrument (EDI) on the Cluster spacecraft measures the components of the electric field perpendicular to the magnetic-field vector by sending test electron beams into space and measuring beam directions and flight times after one or more gyro-turns [*Paschmann et al*, 1997; *Paschmann et al*, 1998, 1998; *Paschmann et al*, 1999; *Quinn et al*, 1999; *Paschmann et al*, 2001, *Quinn et al*, 2001]. The spacecraft velocity is subtracted during data anlaysis. Segments of the Cluster spacecraft orbits are in the vicinity of auroral field-lines and provide with EDI the opportunity to study the plasma covection before and after the onset of auroral displays.

2. Observations and Coordinates

The auroral brightening and associated plasma and field activity beginning at about 8 UT Oct. 9, 2001 was well observed from many locations in space and on Earth. The magnetic coordinates B, L, MLT, and invariant latitude of Cluster-3 at this time are shown in Figure 1. The TSY89c magnetic-field model puts Cluster-3 on an open field-line as shown in Figure 2. Now the computation of L requires closed field lines. How are the L values computed for Figure 1? The source of the method used to obtain these L values on open field lines can be found at URL
http://jsoc1.bnsc.rl.ac.uk/pub/jsoc_cats/psp.htm
which contains the following words:

"The Predicted Magnetic (or Scientific) Position (PMP) catalogues contain time-tagged records at five minute intervals giving predicted values of: the invariant latitude (Lambda) of the spacecraft. This is calculated from the predicted geometric position of the spacecraft using the CNES MAGLIB library. The McIlwain L-parameter (L) of the spacecraft is derived from the invariant latitude Lambda using the standard formula L=sec^2 Lambda."

The CNES MAGLIB library description at URL
http://logiciels.cnes.fr/MAGLIB/en/logiciel.htm
reveals that this library yields Galperin L values. This URL also provides a clear definition and description, reproduced in Figure 3.

The question about L values on open field lines is thus answered: the Cluster Joint Science Operations Centre (JSOC) is providing Galperin L values for assisting Cluster data analysis.

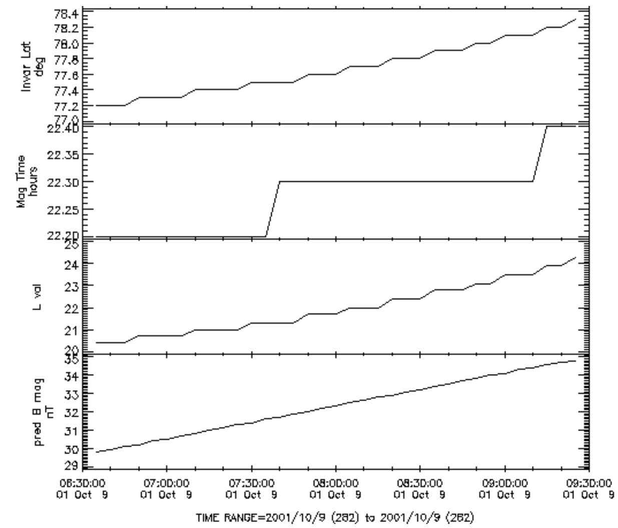


Figure 1. Predicted magnetic coordinates of Cluster-3 on Oct. 9, 2001 from 6:30 to 9:30 UT.

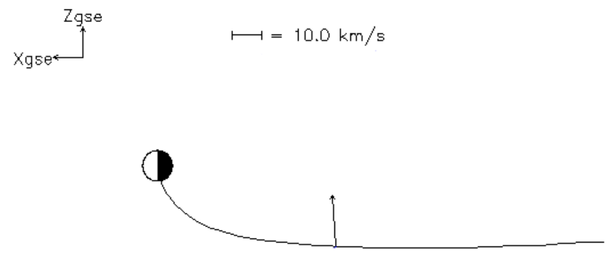
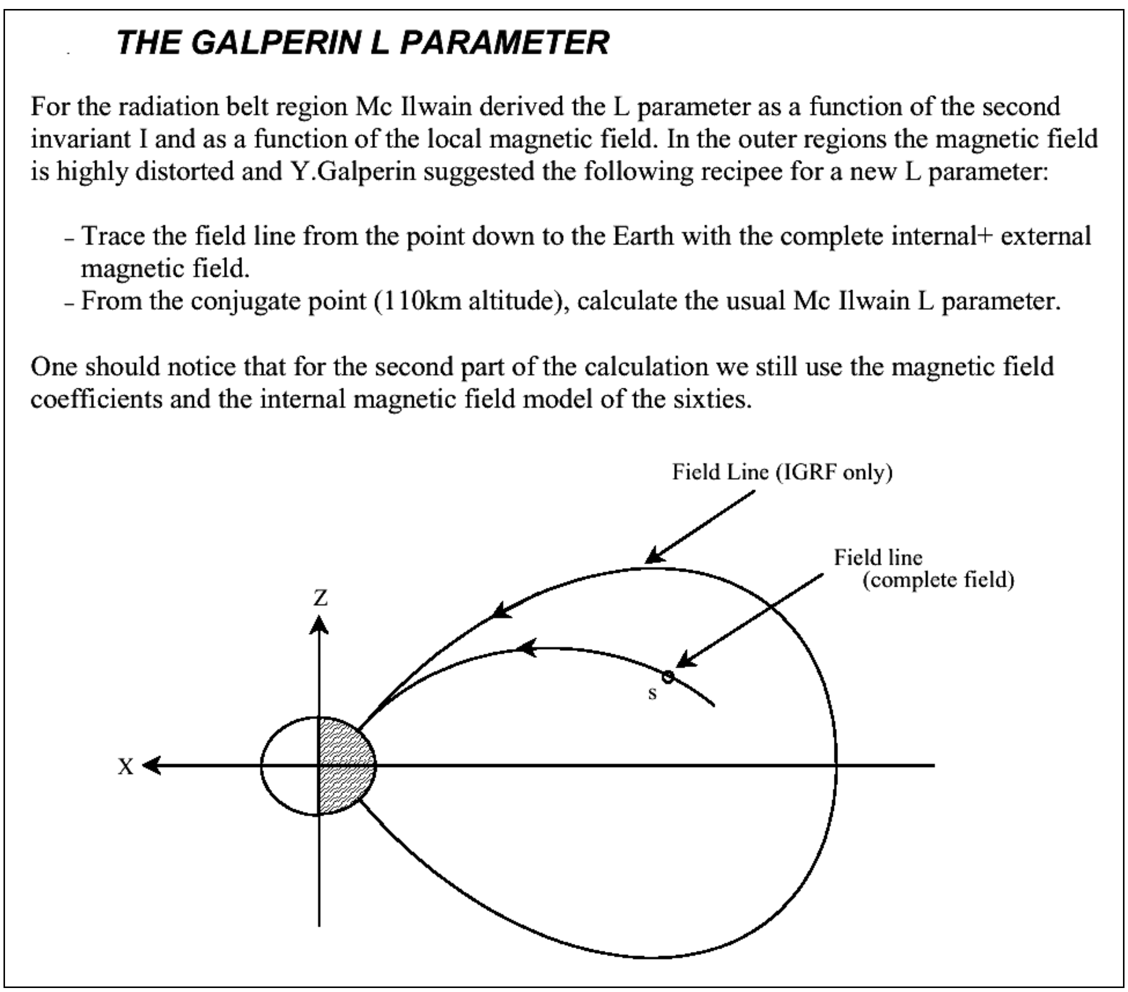


Figure 2. The magnetic-field line from Cluster-3 at 8 UT on Oct. 9, 2001 followed out to Xgse=-32 Re and in to the Earth, using the TSY89c model. The EDI flow vector is shown at the location of Cluster-3 and can be seen to be in the direction of lower latitudes toward inner field lines.



THE GALPERIN L PARAMETER

For the radiation belt region Mc Ilwain derived the L parameter as a function of the second invariant I and as a function of the local magnetic field. In the outer regions the magnetic field is highly distorted and Y.Galperin suggested the following recipee for a new L parameter:

- Trace the field line from the point down to the Earth with the complete internal+ external magnetic field.
- From the conjugate point (110km altitude), calculate the usual Mc Ilwain L parameter.

One should notice that for the second part of the calculation we still use the magnetic field coefficients and the internal magnetic field model of the sixties.

Figure 3. The definition of the Galperin L parameter in the CNES MAGLIB library Manual. CNES gives free access to a full suite of supporting subroutines written by J. C. Kosik.

To predict accurately the motion of charged particles on closed magnetic shells, one needs L values based on magnetic-field models that include all known space and time dependencies. However, the desired magnetic-field information usually is not immediately available. It is therefore very useful to have Galperin L values to provide a stable reference system for comparing data sets. Also, even on open field-lines, there remains the need for a method to describe the locations of particles that matches reasonably continuously to the coordinates used within the trapping region.

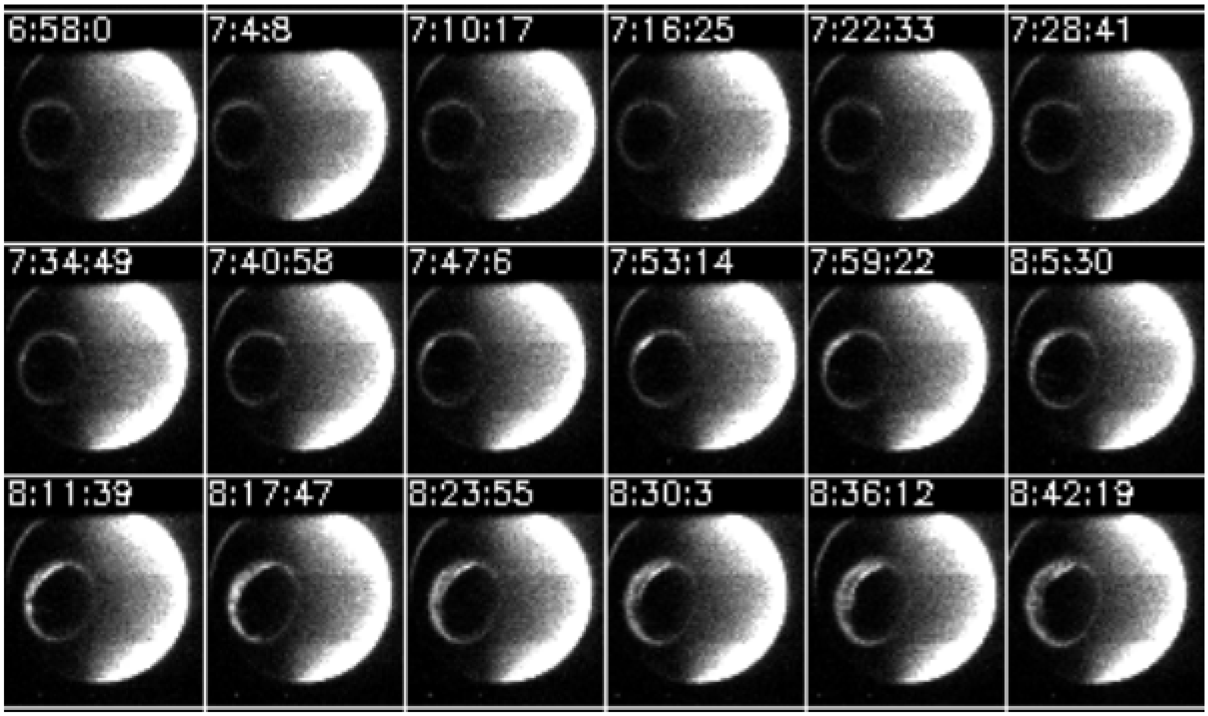


Figure 4. The Oct. 9 2001 event as viewed by the SI13 instrument on the Image spacecraft.

Figure 4 shows a brightening of the aurora shortly before 8 UT. The Poker Flat meridian-scanning photometer also observed the brightening from a magnetic latitude of 65 degrees and magnetic local time of about 21 hours, as can be seen in Figure 5. Figure 6 shows the associated particle injection into geosynchronous orbit quite close to the same local time. Figure 1 indicates the local time at Cluster-3 is 22.3 hours as derived from the Solar-Magnetospheric longitude. However, following the magnetic-field line from the spacecraft down to 110 km altitude, the local time at this footpoint is found to be 20.6 hours. Thus MSP, MPA, and EDI are all at the same local time within about 15 minutes.

The Galperin technique of using the best magnetic-field model available to locate a footpoint in the ionosphere is evidently very useful for obtaining a reference magnetic local time (MLT) as well as an L value. In the current case with the expected bending of the magnetotail field line toward midnight, it is more meaningful for auroral studies to use the MLT at the ionospheric footpoint than the MLT at the spacecraft.

3. Flow Directions and L Shells

EDI measures the plasma flow perpendicular to the local magnetic field. The direction of the flow relative to magnetic shells is more meaningful than in any of the usual coordinate systems such as GSE, GSM, and SM. The local magnetic field provides the flow plane, and we chose to set the zero azimuth in this plane to point toward outer shells. To facilitate the discussion of convection-velocity data from EDI, we introduce a coordinate system whose axes include the direction of measured **B** and two other directions **S** and **T** in the B-perp plane. We choose **S** so that it points outward (i.e., towards higher L shells) in the local-time plane. **T** completes the right-handed system and points nominally in the local eastward direction from the spacecraft position, in the "L-invariant" direction. Specifically, if **R** is the spacecraft position vector and **Z** is the Earth's magnetic axis (i.e., the Z axis in SM coordinates) then:

$$\mathbf{S} = (\mathbf{Z} \times \mathbf{R}) \times \mathbf{B} / |(\mathbf{Z} \times \mathbf{R}) \times \mathbf{B}|$$

$$\mathbf{T} = (\mathbf{S} \times \mathbf{B}) / |\mathbf{B}|$$

Since EDI provides convective-flow data only in the B-perp plane, this data can be described completely by its magnitude and its azimuthal direction measured counter-clockwise from S in this plane.

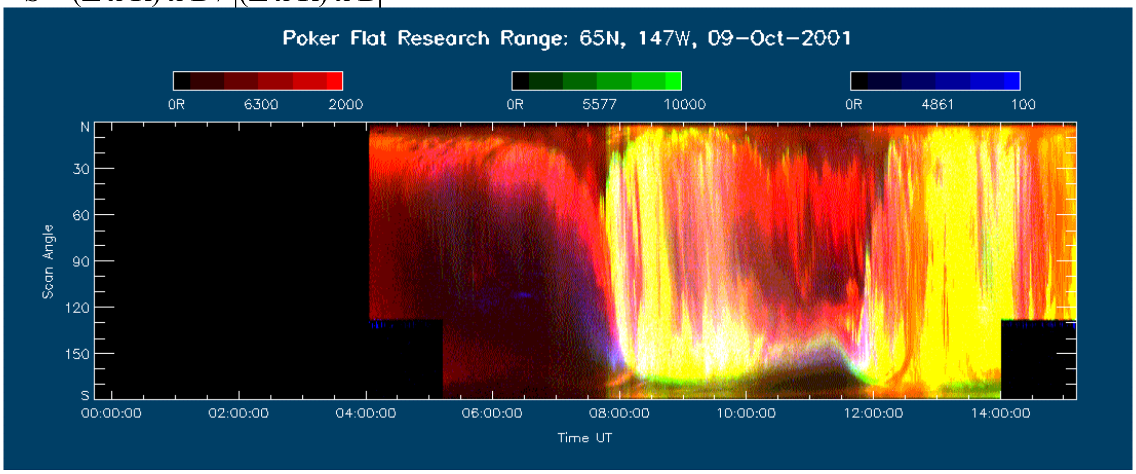


Figure 5. Color composite keogram of the Oct. 9, 2001 event as seen from Poker Flat by the meridian-scanning photometer (MSP) Note the equatorward motion beginning near 7 UT.

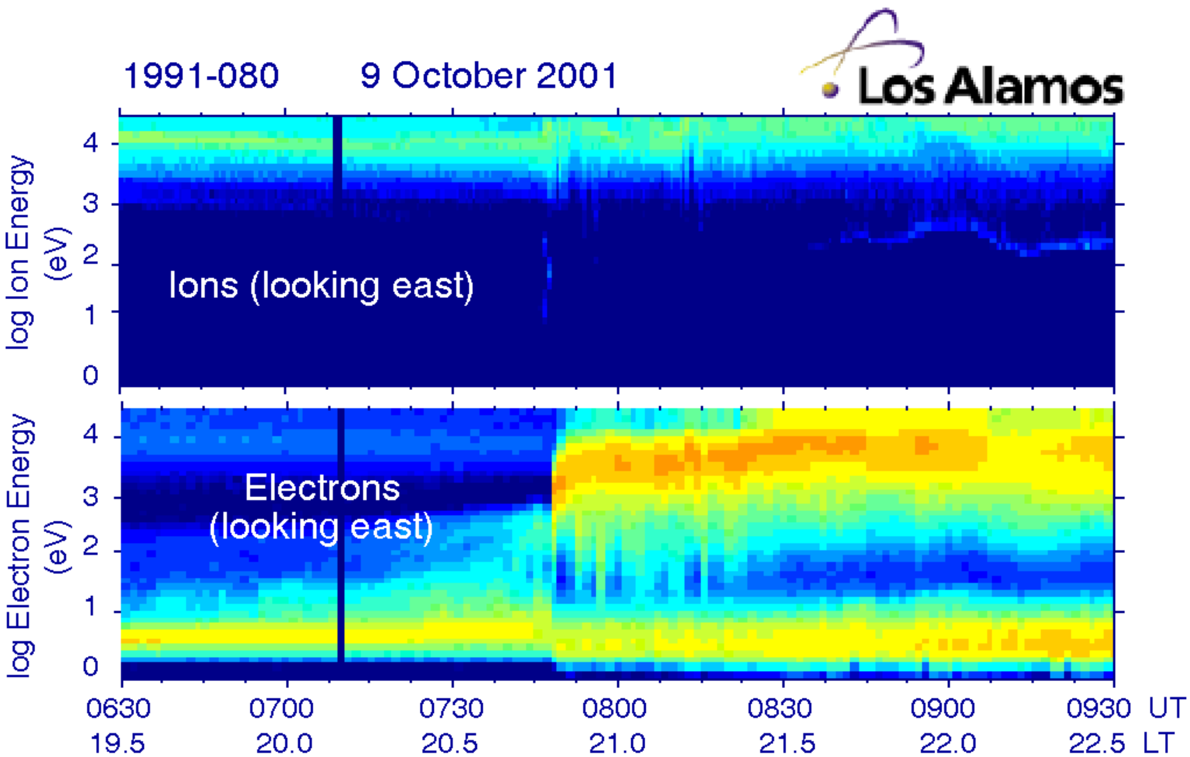


Figure 6. Spectrogram of the LANL MPA data from 1991-80 showing a dispersionless injection at 6.6 Re. At the 7:47 UT onset, the magnetic local time is quite close to the MLT at Poker Flat and Cluster-3.

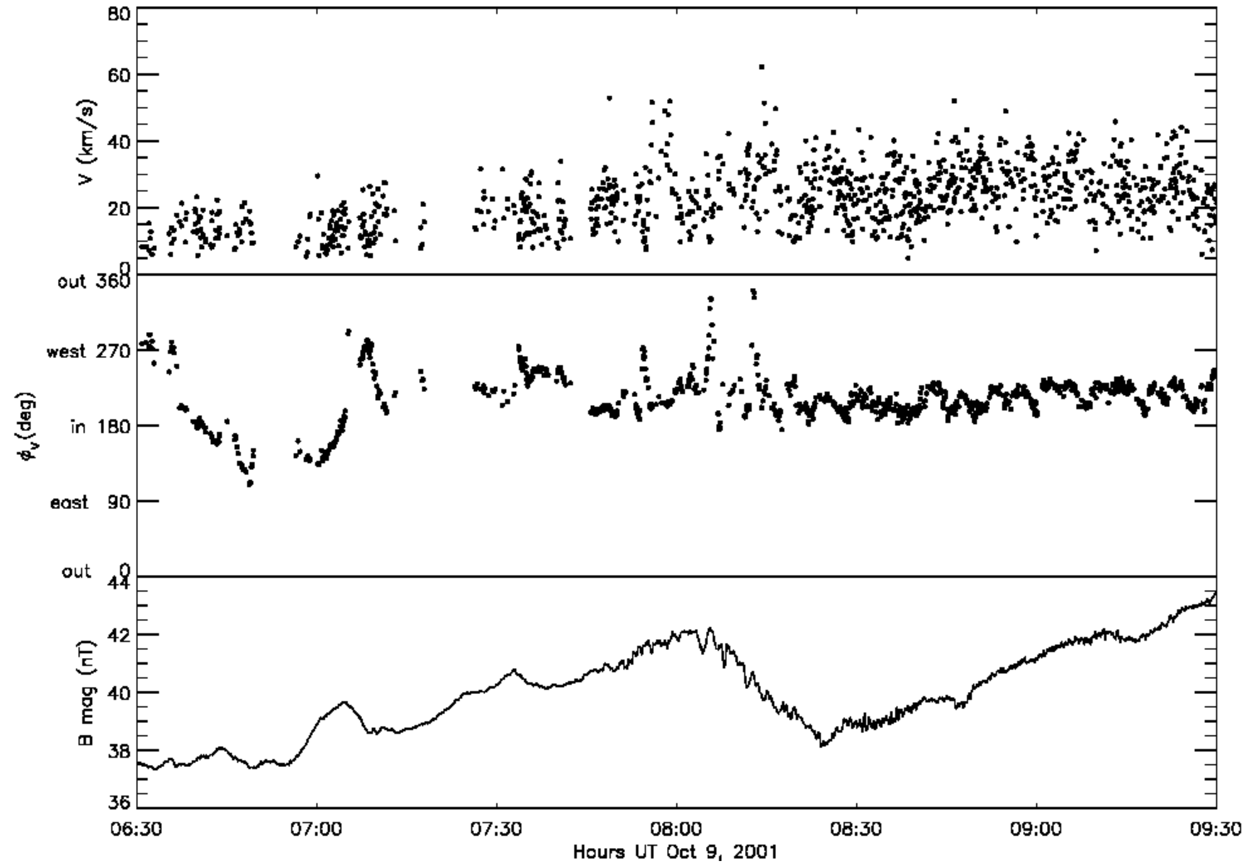


Figure 7. Convective-flow speed and azimuth measured by the Electron Drift Instrument. Before and after the auroral event at 8 UT, the flow has a magnitude of about 25 km/s primarily directed toward inner magnetic shells with a smaller component in the westward direction (towards dusk). The magnetic-field values were provided by A. Balogh at ICSTM and CDAWeb.

4. Discussion

The mapping of auroral magnetic field lines is a very difficult but essential task [*Galperin and Feldstein*, 1991; *McIlwain*, 1992; *Galperin and Feldstein*, 1996]. L values found using the Galperin technique have the very useful property of remaining constant along field lines even in the presence of external currents. L values based on adiabatic invariants do not have this property [*McIlwain*, 1966].

For the Oct 9, 2001 event discussed here, the convection speed observed by EDI, as is shown in Figure 7, has large variations around a typical value of 25 Km/s. In the period before the 8 UT event and afterward, the flow direction stays in the inward to westward sector. The IMF had a relatively constant Bz value of -5 nT during this period. EDI thus observed the expected inward flows during the period the Poker Flat MSP observed equatorward motion of auroral bands that are presumably associated with a substorm growth phase. From its location at 74 degrees invariant latitude, EDI did not witness the high flows expected at lower invariant latitudes where auroral activity was being observed.

5. Conclusions

The Galperin L values being made available for Cluster data analysis are very useful because they:
1. Provide a stable reference system for relating observation at widely separated locations including open field-line regions; and

2. Require no knowledge of current geomagnetic conditions.
It should be noted that Galperin L values become even more useful when magnetic-field models based on magnetospheric currents estimated for the observation time are used to determine the ionospheric footpoint.

In an extention of the Galperin technique, it is found that using the MLT of the footpoint rather than the spacecraft MLT has the highly desireable property of keeping the same value all along a field line. The MLT at points along magnetotail field lines can vary by hours, making data comparisons difficult.

Keeping the usual concepts of adiabatic plasma flows from one magnetic shell to another and azimuthal drifting, we present the EDI data in newly-defined shell coordinates that preserve these directions, even on highly distorted field lines.

EDI observed inward flows that were probably associated with the southward IMF Bz observed by several spacecraft. There were no clear indications of the activity on the neighboring lines of force with bright auroral displays at their footpoints.

Acknowledgements

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