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REPLY

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In his comment Newell raises an important and interesting point which we chose to leave open, rather than discuss in insufficient space. We agree that the event we have presented [Lockwood and Smith, 1989] is typical of a satellite pass through the cusp for southward IMF, but believe all the characteristics are well explained in terms of recent theories of Flux Transfer Events (FTEs). The question is this: if our interpretation is valid, how many satellite cusp passes are really FTEs? Newell states there are only two possibilities: (1) all observations of the cusp during southward IMF are FTEs or (2) the one pass presented is an FTE, but other, almost identical, passes are not. Because he finds problems with both, he concludes the initial premise is wrong – i.e. the event was not an FTE but an intersection with a stable cusp. We believe there is a distinct third possibility, namely that the cusp is always present in some form but varies with time (on scales of a few minutes) when the IMF is southward. A pulse of enhanced particle injection (of greater latitudinal width) may then be one low-altitude signature of an FTE. This is different from (2) in that satellite observations will include all evolution phases of the southward IMF cusp, not just be "FTE" or "non-FTE" passes. This concept arises directly from the Southwood et al. [1988]/Scholer [1988] FTE model, whereby the magnetopause signatures are explained by transient increases in reconnection rate over a background level. In this view, many of the problems raised by Newell disappear. For example, the particles injected during an FTE must appear in the ionosphere at the latitude of the "background" cusp. It is not then a coincidence that this event is, as Newell points out, at the mean cusp latitude for the same IMF conditions. The Southwood et al./Scholer model also predicts that the ionospheric signature can indeed be elongated in east-west extent because the reconnection is not necessarily spatially confined (as in the original FTE paradigm), but takes place over a reconnection X-line which can cover a large part of the dayside magnetopause. The concept is also perfectly in keeping with the ground-based optical observations (see review by Sandholt [1988]) of transient enhancements superposed on a persistent background dayside aurora. Because the dominant motion of these events is zonal, not poleward [Lockwood et al., 1989 a;b] (as for the DE-2 event), they remain near the same latitude during their lifetime: the 1-2° of poleward motion is within the spread of cusp latitudes in the statistics quoted by Newell.

Here we argue that FTEs give transient variations in the cusp particle injections on time scales of about 2–10 minutes. However, a low-altitude polar-orbiting spacecraft, such as DE-2, would be largely unable to detect such variations because of the spatial/temporal ambiguity of the observed sequence of data.

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An important feature raised by Newell is the magnetometer signatures. We described (but did not have space to show) the hodograms of the magnetic field perturbation observed by the DE-2 magnetometer. Figure 5 of Smith et al. [1989] shows this hodogram for the period around the ion injection event. There is an overall rotation of the perturbation from south-westward at the start of the period to south-eastward at the end, via southward. Superposed are three smaller rotations which Smith et al. [1989] describe in terms of three very small filamentary current pairs close to the DE-2 path. If the currents were infinite sheets we would expect the hodogram to show discrete jumps as the satellite passed through them. The gross rotation could be explained if DE-2 passed just to the east of the end of a single, stable downward current sheet (as may be expected for the region 1 currents), but then failed to intersect a significant cusp current sheet. Alternatively, it could have passed to the east of a westward-moving matched filamentary current pair, which also explains the observed plasma drifts. Elongation of the filamentary currents to the west is possible and would be consistent with the Southwood et al./Scholer FTE model while the event is moving along the polar cap boundary. In his figure, Newell suggests that the hodogram is explained if the upward cusp currents are stable and also peak at an MLT before 11:00 (which is not consistent with the IMF B_y). However, this would give a second magnetic field rotation from east to west via north, due to the cusp currents, which is not observed.

Note that the eastward component of the magnetic perturbation alone could be interpreted in terms of the satellite intersecting the region 1 and then the cusp sheet currents. This raises an important point about the Iijima and Potemra [1976] study of field-aligned currents, to which Newell refers, suggesting that the currents are steady and large scale. In fact, Iijima and Potemra only employed the east-west component to calculate currents, which is an infinite sheet approximation. They state: "Implicit in the derivation of this formula [for the current in an infinite sheet] is the fact that the observed disturbances in the geomagnetic north-south direction are always smaller (less than 10%) than the east-west disturbances." For the event we describe, the north-south disturbance is 350 nT while the east-west is 800 nT (i.e. the ratio is 45%). Hence the north-south component cannot be ignored. We know of no publications which use both components to look at the region 1-cusp currents (i.e. sheet currents are always assumed rather than observed) and suggest this assumption must be reassessed when looking in the cusp region. We propose that the filamentary FTE currents would be transient and travelling intensifications of the region 1 and cusp currents.

The direction of motion of the event is not "incongruous for an FTE." Newly-opened flux tubes will not initially move poleward (see Lockwood and Freeman [1989] and Saunders [1989]), but will initially move around the polar cap boundary due to the more immediate action of magnetic tension. Hence for this northern hemisphere case with IMF $B_y > 0$, newly open flux tubes should be moving slightly south of westward along the polar cap boundary. As we state in the paper, the motion is mainly westward and well-aligned with the polar cap boundary, as seen simultaneously by the DE-1 imager. The similarity with ground-based data on transient aurorae is clear: Lockwood et al. [1989 a;b] have described events (seen with all-sky TV cameras, photometers and EISCAT radar) during which transient dayside aurorae move around the polar cap boundary with velocity, $\mathbf{E} \times \mathbf{B}/B^2$, of 2–3 km s^{-1} before later drifting into the polar cap and fading.

Considering the ground-based observations of "dayside auroral breakup" events [Sandholt, 1988], we agree that the suggestion that the DE-1 imager observed the same features from space is highly tentative. However, the successive scans do reveal that there was some form of transient dayside auroral disturbance. We are now investigating if more details of this transient can be extracted from the imager data. An important misconception in Newell's comment is that dayside breakup events contain energized particles at all locations. The absence from the DE-2 data of electrons of sufficient energy to cause the 557.7 nm breakup arc is simply due to the path of DE-2 through the event. Lockwood et al. [1989a] conclude that the 557.7 nm arc is only at the region of upward field-aligned current which DE-2 did not intersect. DE-2 did see particles which could give the more extensive transient at 630 nm only.

The 557.7 nm arcs observed by Sandholt [1988] and Lockwood et al. [1989b] are usually 500–1000 km in east-west extent. The associated 630 nm transients and the plasma flow bursts are even longer and hence comparable with the statistical cusp widths described by Newell. As discussed earlier, this is explained if one adopts the Southwood et al./Scholer FTE model. To allow for this elongation, Figure 2 of our paper could have shown the newly opened flux tube as elliptical and not circular. In fact, the ion drift data are better explained by an elongated model flux tube. We alluded to this by saying that "these differences generalizing the shape of the event from a circle."

Newell also discusses the observed ion energies. On what we believe to be a newly-opened flux tube, DE-2 observed a range of ion energies between about 200 eV and 4 keV, very similar to the range of energies seen inside FTEs at the magnetopause [e.g. Farrugia et al., 1988], and which in turn is very similar to the range of energies in the magnetosheath. Observed ion energies in magnetopause FTEs are explained in terms of reconnection by the Southwood et al./Scholer theory.

We do not contend that the observations "prove" that this cusp pass was an FTE. Our aim is to show that the observed features are at least as well explained in terms of current theories of FTEs as they are by a model of a stable, constant cusp. We believe the major field-aligned currents were filamentary and that this is strong evidence that the event was an FTE. However, many other features are neatly explained by this idea: the ion drifts, the ion dispersion, the electrons on the boundaries, the 10 keV ions, the 35 keV electrons and the DE-1 imager scans. Many of these features are not addressed by Newell. Concerning other satellite cusp passes, we believe it is usually extremely difficult, if not impossible, to tell if the cusp was stable or showing some form of transient behavior. Note that the widths, latitudes and fluxes of the cusp quoted by Newell are all mean values: we believe there is considerable variability (particularly in latitudinal width) which must now be investigated in terms of time-dependent injection. Recent studies from the ground show that the cusp/cleft has transient features (recurring every 8 min. on average) superposed on a persistent background, when the IMF is consistently southward [Lockwood et al., 1989b], i.e. it is not "fairly stable." We think these ground-based data, along with the new theories of FTEs, demand that satellite data be re-assessed. Lastly, we note that the term "cusp," by definition, implies a spatial phenomenon: hence observations which readily detect spatial features (in particular those from low-altitude polar-orbiting spacecraft) will be most easily described by this term. On the other hand, observations which readily detect temporal features or moving structures (such as those from magnetometers near the magnetopause or from ground-based observatories) are described in terms of "events." Recent evidence suggests that the southward-IMF cusp is a region showing transient fluctuations on time scales of several minutes; it is neither stable nor a string of isolated events and both temporal and spatial descriptions are required.

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