SIMULTANEOUS DOUBLE STAR AND CLUSTER FTES OBSERVATIONS ON THE DAWNSIDE FLANK OF THE MAGNETOSPHERE

A. Marchaudon[(1)], C. J. Owen[(1)], J.-M. Bosqued[(2)], R. C. Fear[(1)], A. N. Fazakerley[(1)], M. W. Dunlop[(3)], A. D. Lahiff[(1)], C. Carr[(4)], A. Balogh[(4)], P.-A. Lindqvist[(5)] and H. Rème[(2)]

[(1)]*Mullard Space Science Laboratory, University College London, Holmbury St Mary, Dorking, RH5 6NT, UK, Email: am@mssl.ucl.ac.uk; cjo@mssl.ucl.ac.uk; rcf@mssl.ucl.ac.uk; anf@mssl.ucl.ac.uk; adl@mssl.ucl.ac.uk*
[(2)]*Centre d'Etude Spatiale des Rayonnements, CESR/CNRS, B.P. 4346, 31028 Toulouse Cedex, France, Email: jean-michel.bosqued@cesr.fr; henri.reme@cesr.fr*
[(3)]*Rutherford-Appleton Laboratory, Chilton, Didcot, Oxon, OX11 0QX, UK, Email: m.dunlop@rl.ac.uk*
[(4)]*Space and Atmospheric Physics, Blackett Laboratory, Imperial College, London, SW7 2BZ, UK, Email: c.m.carr@imperial.ac.uk; a.balogh@ic.ac.uk*
[(5)]*Alfvén Laboratory, Royal Institute of Technology, Stockholm, SE-10044, Sweden, Email: lindqvist@plasma.kth.se*

ABSTRACT

We present Cluster and Double Star-1 (TC-1) observations from a close magnetic conjunction on May 8, 2004. The five spacecraft were on the dawnside flank of the magnetosphere, with TC-1 located near the equatorial plane and Cluster at higher geographic latitudes in the southern hemisphere. TC-1, at its apogee, skimmed the magnetopause for almost 8 hours (between 08:00-16:00 UT). Flux Transfer Events (FTEs), moving southward/tailward from the reconnection site, were observed by TC-1 throughout almost all of the period. Cluster, travelling on a mainly dawn-dusk trajectory, crossed the magnetopause at around 10:30 UT in the same Magnetic Local Time (MLT) sector as TC-1 and remained close to the magnetopause boundary layer in the southern hemisphere. The four Cluster spacecraft observed FTEs for a period of 6.5 hours between 07:30 and 14:00 UT.
From the properties of these FTEs, the reconnection site was located northward of both TC-1 and Cluster on the dawn flank of the magnetosphere. Reconnection occurred between draped magnetosheath and closed magnetospheric field lines. Despite variable interplanetary magnetic field (IMF) conditions and IMF-B_z turnings, the IMF clock-angle remained greater than 70° and the location site appeared to remain relatively stable in position during the whole period. This result is in agreement with previous studies which reported that the dayside reconnection remained active for an IMF clock-angle greater than 70°. The simultaneous observation of FTEs at both Cluster and TC-1, separated by 2 hours in MLT, implies that the reconnection site on the magnetopause must have been extended over several hours in MLT. This event has been already presented in more details in [1].

1. INTRODUCTION

Magnetic reconnection between magnetospheric and interplanetary magnetic fields (IMF) is a commonly accepted process allowing transfer of energy and momentum from the solar wind to the magnetosphere. Many models and observations have shown different possible topologies for this process. Reconnection can occur between strictly anti-parallel field lines, at the nose of the magnetopause during dominant southward IMF ([2],[3]). In addition, as a consequence of the IMF draping, magnetopause reconnection may also occur on the lobes during dominant northward IMF ([4],[5]) or on the flanks during periods of dominant azimuthal IMF component ([6],[7]). Component reconnection between magnetic fields with a relatively low shear can also occur almost everywhere on the dayside magnetopause ([8],[9]). Indeed, observations of component reconnection equatorward of the cusp have been reported during periods of northward IMF [10]. Moreover, coexistence of high-latitude (lobe) and low-latitude reconnection sites has been observed [11]. Finally, simulations [12] and recent observations [13] suggested the possible existence of multiple X-lines forming isolated magnetic flux ropes on the dayside as well as on the flanks of the magnetopause, for various IMF conditions.
The reconnection process is very complex. In particular, the large-scale spatial and temporal nature of the reconnection is still poorly understood. Various observations from satellites and/or ground-based stations have shown that a reconnection line can be stable and extended, by up to 40 R_E, along the magnetopause ([14],[6],[15]), especially during stable IMF conditions. However, how the reconnection line evolves during variable IMF conditions remains an important question. A large number of studies have shown that reconnection is essentially a sporadic phenomenon forming small-scale flux tubes called flux transfer events ([16],[17]). The question of whether reconnection has an intrinsic sporadic nature or whether it is controlled by internal magnetospheric conditions or by variable IMF conditions is still open.
We thus need to develop an understanding of how variations of the IMF and/or magnetospheric conditions can change the topology and the properties of magnetopause reconnection. Measurements from several satellites located on different parts of the

Proceedings Cluster and Double Star Symposium – 5th Anniversary of Cluster in Space, Noordwijk, The Netherlands, 19 - 23 September 2005 (ESA SP-598, January 2006)

magnetopause will be needed to answer this question. We study an excellent conjunction between Cluster and Double Star-1 on May 8, 2004 [1]. The five spacecraft were all located in the southern hemisphere and simultaneously observed FTEs over a period of several hours. The different parts of the magnetopause probed by Cluster (high-latitude) and Double Star-1 (near-equatorial latitude) and the use of Cluster multi-spacecraft analysis allow us to develop an understanding of the reconnection geometry on the dawn flank magnetopause during this period and to document the effect of variable IMF conditions.

2. INSTRUMENTATION

Cluster has an elliptical polar orbit with a perigee of ~4 R_E, an apogee of ~19 R_E and a period of ~58 h. Double Star-1 (TC-1) has an elliptical equatorial orbit with a perigee of ~0.1 R_E, an apogee of ~12 R_E and a period of ~14 h. In this study, data from several plasma and field experiments on the Cluster and Double Star satellites are used. The Plasma Electron and Current Experiment (PEACE) [18] provides the electron velocity distribution every 4 s (spacecraft spin period), in the energy range from 0.7 eV to ~30 keV. Moments of the full three-dimensional distribution are obtained with a resolution up to 4 s. The Hot Ion Analyser (HIA) [19], which offers a good energy and angular resolution without mass resolution, provides a full three-dimensional energy/velocity distribution of ions (protons) from thermal energies up to about 32 keV/q, and moments also with a time resolution up to 4 s. The Flux Gate Magnetometer (FGM) [20] measures the 3-D magnetic field vector. We use data at 4 s resolution. In this study, we present energy spectrograms and moment data (density, temperature and velocity components of the ions and electrons) provided by the PEACE and the HIA experiments onboard Double Star and Cluster.

Finally, solar wind plasma and magnetic field data were obtained from the Solar Wind Experiment (SWE) and the Magnetic Fields Investigation (MFI) of the Wind satellite.

3. GEOMETRY OF THE CONJUNCTION AND INTERPLANETARY CONDITIONS

The trajectories of Double Star/TC-1 and Cluster/sc1 are presented in Fig. 1, in the *XY* and *YZ* GSM planes. The position of a modelled magnetopause, plotted respectively in the Z_{GSM} = 0 and X_{GSM} = 0 planes, is also superimposed. Between 08:00 and 16:00 UT, TC-1 was located just southward of the equatorial plane (Z_{GSM} ~ -3 R_E) and skimmed the dawnside magnetopause around Y_{GSM} ~ -12 R_E travelling about 4 R_E predominantly in the $+X_{GSM}$ direction. On the other hand, the four Cluster spacecraft entered the magnetosphere around 10:30 UT, at high geographic latitudes in the southern hemisphere and slightly downstream of the TC-1 position. Over the next few hours, the four spacecraft penetrate deeper into the magnetosphere, moving predominantly in the $-Y_{GSM}$ direction, at around X_{GSM} ~ -1 R_E and Z_{GSM} ~ -10 R_E.

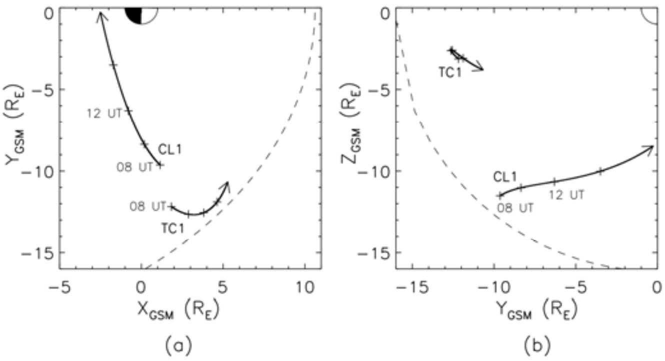

Fig. 1. Trajectories of Cluster/sc1 and TC-1 for the period 08:00-16:00 UT, in GSM coordinates. (a) in the XY plane, (b) in the YZ plane. Black crosses along the orbits are separated by 2 hours. A model of the magnetopause position (see text for details) is indicated in the Z_{GSM} = 0 plane (panel a) and in the X_{GSM} = 0 plane (panel b) by the dashed line.

The interplanetary conditions were monitored by the Wind satellite, situated upstream, southward and dawnward of the magnetosphere (X_{GSM} = 96 R_E, Y_{GSM} = -25 R_E, and Z_{GSM} = -19 R_E). For this study, the magnetic data have been lagged by 23 min to take into account the propagation of the solar wind from Wind's position to the Earth's magnetosphere (with a solar wind bulk speed of ~480 km s^{-1}). The IMF components in GSM as well as the clock-angle (arctan[$|B_y|/B_z$]) are plotted in Fig. 2, between 07:00 and 16:00 UT. The interplanetary magnetic field orientation was variable until 11:00 UT and then became more stable. The IMF-B_x component (panel 2.a) was strongly positive at the beginning of the period, but decreased from +6 to 0 nT until 11:00 UT and then varied between ±2 nT. Before 09:00 UT and after 11:00 UT, IMF-B_y (panel 2.b) was negative and very stable at around –5 nT. In between these times, B_y was more variable between –2 and 0 nT, with a strong positive excursion at 10:20-10:30 UT. Before 08:20 UT, IMF-B_z (panel 2.c) was slightly positive around +1 nT, turned negative (~ -4 nT) between 08:20 UT and 11:00 UT and then varied between +1 and -4 nT until the end of the period. Despite all these variations, the IMF clock-angle (panel 2.d) remained greater than or approximately equal to 70°, except some very short excursions at around 07:30 and 08:15 UT. On the other hand, the plasma parameters of the solar wind were very stable during the entire period, with a steady solar wind dynamic pressure of ~ 1.4 nPa (not shown).

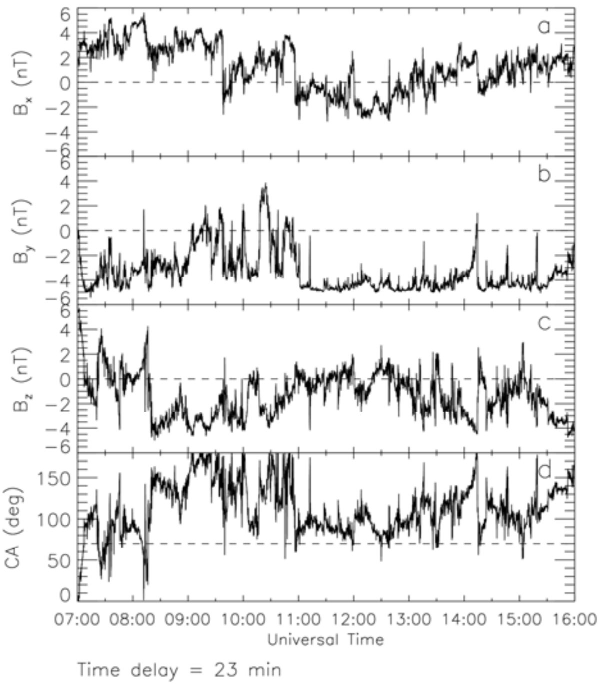

Fig. 2. Wind IMF data in GSM coordinates, lagged with 23 min, for the period 07:00-16:00 UT. Panels (a), (b), (c) show the B_x, B_y and B_z components of the IMF and panel (d) shows the IMF clock-angle.

4. OBSERVATIONS

4.1 TC-1 observations

a) Overview of the data

For the period 08:00-16:00 UT, data from the TC-1 satellite are presented in Fig. 3, together with the Wind IMF clock-angle, for ease of comparison (top panel a). Panels (b), (c) and (d) show energy flux spectrograms provided by the PEACE instrument, for electrons moving in the directions parallel, perpendicular and anti-parallel to the local magnetic field respectively. Panel (e) shows the omnidirectional energy flux ion spectrogram provided by the HIA instrument. Panels (f) and (g) display the electron density and temperature with 8 s resolution. Finally, panels (h) to (k) give the 3 components of the FGM magnetic field transformed in the L,M,N coordinate frame [15] and its magnitude. In this frame, the B_N component is normal to the magnetopause, the B_L component lies in the magnetopause plane and is parallel to the projection of the $+Z_{GSM}$ axis on that plane. Finally, the B_M component completes a right hand set. In the case of TC-1, several magnetopause crossings were observed between 08:00 and 16:00 UT. The magnetopause normals at each crossing were quite similar throughout the period and the ratios between intermediate and minimum eigenvalues were relatively high (~5). To select a representative L,M,N frame, we chose the normal from the 10:05 UT magnetopause crossing.

Throughout the period, TC-1 skimmed the dawnward magnetopause essentially on the magnetospheric side, but made two magnetosheath incursions between 08:50 and 10:05 UT and between 13:55 and 14:55 UT, characterised by dramatic changes of the plasma properties and very clear magnetic field rotations, typical of magnetopause crossings. Inside the magnetosphere, the plasma was hot and tenuous (panels 3.b to 3.e). The magnetic field was essentially pointing northward (B_L>0) and, as TC-1 progressed sunward on its orbit, the magnetic field direction became more sunward (B_M<0) (panels 3.i and 3.j). In the magnetosheath, the plasma was cold and dense and the magnetic field was directed southward (B_L<0) and tailward (B_M>0), consistent with a negative IMF-B_y draped around the magnetosphere and a mainly negative IMF-B_z during these periods. During the overall period between 08:00 and 16:00 UT, TC-1 observed clear signatures of reconnection, described in the paragraph below, except between 10:55 and 12:05 UT, when TC-1 appeared to move slightly deeper into the magnetosphere and was therefore not well located to observe reconnection activity on the magnetopause.

b) Detailed description of the reconnection signatures

Typical reconnection signatures were observed by TC-1 both in the magnetosphere and in the magnetosheath sides. The signatures were clearer in the magnetosphere, but showed the same properties in the two regions. A majority of the observed structures were characterised by a mixing of magnetospheric and magnetosheath plasma, field-aligned streaming of electrons (panels 3.b to 3.e).

The four top panels of Fig. 4 show an expansion of the TC-1 data, when the spacecraft was located in the magnetosphere (12:10-12:40 UT). Panel (a) shows the PEACE electron density, panels (b) and (c) show respectively the B_N and the magnitude of the FGM magnetic field and panel (d) shows the 3 components of the CIS-HIA ion velocity, in GSM coordinates. This expansion clearly highlights the features of the reconnection signatures: increase of the electron density (panel 4.a), "reverse" bipolar signature of the B_N magnetic field component (panel 4.b) and increase of the total magnetic field (panel 4.c). In the magnetosphere, the velocity was low and slightly sunward. Inside the reconnected structures, the ion velocity turned to the same direction as the magnetosheath velocity (tailward, dawnward and southward), but to an amplitude higher than that in the contiguous magnetosheath (panel 4.d). All these signatures are typical of FTE structures ([16],[21],[22]) and will be discussed in more detail in section 5. The signatures of reconnection (as described above) remained similar throughout the 8 hours in which TC-1 skimmed the magnetopause.

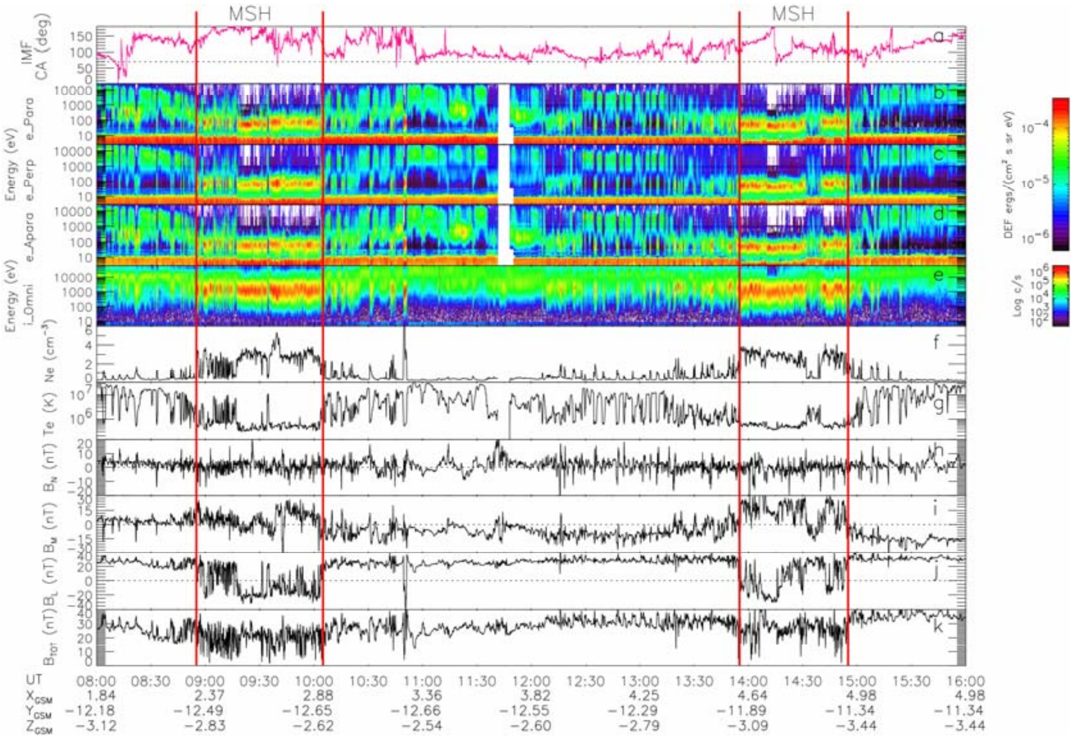

Fig. 3. Wind and Double Star TC-1 data for the period 08:00-16:00 UT. (a) IMF clock-angle obtained from the Wind data and lagged with 23 min, (b) to (d) PEACE electron spectrograms in the parallel, perpendicular and anti-parallel directions, (e) HIA omnidirectional ion spectrogram, (f) PEACE electron density, (g) PEACE electron temperature, (h) to (k) B_L, B_M, B_N components and field magnitude of the FGM magnetic field.

4.2 Cluster data

a) Overview of the data

The Cluster/spacecraft 4 (sc4) data are presented on Fig. 5 for the period 07:30-14:00 UT. For convenience, panel (a) again shows the Wind IMF clock-angle for this period. The full 3-D electron distribution was available with a 16 s resolution, enabling calculation of ground moments at this resolution. Panels (b) to (d) show electron spectrograms in the parallel, perpendicular and anti-parallel directions. Panel (e) gives the electron density in a logarithmic scale to highlight the density variations in the boundary layer. Panels (f) to (h) show the three components of the magnetic field in the L,M,N system. As no clear magnetopause crossing was observed in the magnetic data in order to define the L,M,N frame, we chose a magnetopause normal deduced from a model [23] at the Cluster position, where the magnetopause crossing was detected in the plasma data (10:30 UT). Finally, panel (i) shows the magnitude of the magnetic field for all four spacecraft, which can be used to discriminate between the spatial and temporal variations. During the entire period 07:30-14:00 UT, the four Cluster spacecraft were in an approximately co-linear formation, with sc1, sc4 and sc2 leading and sc3 trailing with a slight delay. The spacecraft were aligned essentially along the Y_{GSM} direction, with a separation of ~ 6000 km between the leading and the trailing spacecraft (sc1 and sc3 respectively).

Before 10:30 UT at sc1 and sc4 and before 11:00 UT at sc2 and sc3, the variations of the B_y and B_z magnetic field components measured by the FGM experiment were nearly identical to the variations of the B_y and B_z components of the IMF measured by the Wind satellite. This suggests that the Cluster spacecraft were within the magnetosheath at these times, as supported by the magnetosheath-like plasma observed by PEACE (panels 5.b to 5.d). The Cluster spacecraft then successively entered the southern hemisphere dawnside magnetosphere, in the order 1-4-2-3. The magnetopause crossing for each spacecraft was very clearly identified by the plasma changes, around 10:30 UT for sc1 and sc4 and around 11:00 UT for sc2 and sc3. Unfortunately, the magnetic rotation observed by each spacecraft during the magnetopause crossing was identical to the IMF-B_y variation. A possible explanation for this lack of clear magnetic field rotation during the magnetopause crossing itself could be explained by the relatively low shear between the magnetosheath and magnetospheric fields in this flank region and/or by the IMF variations hiding the magnetopause magnetic field rotation. After 10:30-11:00 UT, the four Cluster spacecraft skimmed the inner side of the magnetopause, remaining in the southern High-Latitude Boundary

Layer (HLBL), characterised by a more tenuous plasma than in the magnetosheath. At about 14:00 UT, they finally entered the lobe-proper. Throughout the time interval, between 07:30 UT and 14:00 UT, the PEACE instruments onboard Cluster detected numerous bursty signatures of field-aligned electron injections. After 09:20 UT, these plasma observations were clearly associated with bipolar signatures in the normal magnetic field B_N component recorded by FGM.

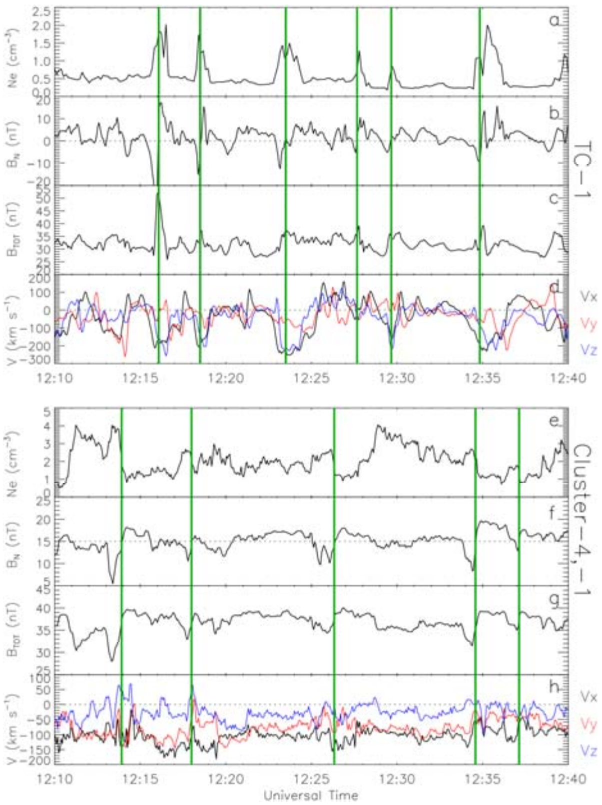

Fig. 4. Zoom in of the TC-1 (four top panels) and Cluster (sc1 and sc4) (four bottom panels) data, for the 12:10-12:40 UT period. The data sets are identical for TC-1 and Cluster. Panels (a) and (e) shows the PEACE/TC-1 and PEACE/sc4 electron density, panels (b) and (f) show the B_N component of the FGM/TC-1 and FGM/sc4 magnetic field, panels (c) and (g) shows the magnitude of the FGM/TC-1 and FGM/sc4 magnetic field and panels (d) and (h) shows the 3 components of the CIS-HIA/TC-1 and HIA/sc1 ion velocity, in GSM coordinates.

b) Detailed description of the injection signatures

In the dawnside southern hemisphere magnetosheath (07:30-10:30 UT), PEACE/sc4 observed a cold, dense and quasi-isotropic plasma. Between 08:00 and 10:30 UT, the detected plasma injections were a mixture of high-energy omnidirectional plasma of magnetospheric origin (up to 10 keV) and low-energy plasma of magnetosheath origin (panels 5.b and 5.d). However, clear associated magnetic signatures were not evident, except for some “reverse” bipolar signatures in the B_N component. These B_N signatures were not accompanied by an observable increase in the magnetic field magnitude.

In the magnetosphere (10:30-14:00 UT), electron injections were still observed, along with the more tenuous boundary layer plasma. These injections were characterized by a mixture of high-energy omnidirectional plasma and, now, of low-energy plasma mainly bi-directionally field-aligned, slightly heated with respect to the magnetosheath plasma (up to ~ 1 keV) (panels 5.b and 5.d), and by a slight increase in the electron density (panel 5.e). After 10:30 UT, the Cluster spacecraft entered more deeply into the magnetosphere and an almost continuous increase of the magnetic field strength was clearly observed until 14:00 UT, even on the B_N component. However, it is worth noticing that clear “reverse” bipolar signatures in the B_N component relative to its background value were observed.

Returning to Fig. 4, the four bottom panels show an expansion of the Cluster (sc1 and sc4) data, for the same period as TC-1 (12:10-12:40 UT). Again, panel (e) shows the PEACE/sc4 electron density, panel (f) and (g) show respectively the B_N component and the magnitude of the FGM/sc4 magnetic field and panel (h) shows the 3 components of the CIS-HIA/sc1 ion velocity, in GSM coordinates. Once again, this expansion displays clearly the signatures of the injections: “reverse” B_N bipolar signatures (panel 4.f) associated with decreases of the total magnetic field (panel 4.g) and increases of the electron density (panels 4.e). Finally, the ion velocity flow, which was mainly directed tailward, dawnward and southward in the HLBL, turned northward inside some of these injections, as evidenced by a slight reversal of the V_z component (panel 4.h). As for TC-1, we conclude that all these signatures are typical of FTEs structures.

c) Multi-spacecraft observations

Inside the magnetosphere, all of the injections were observed by all four-spacecraft and the order of entry (exit) into (from) each injection tube was the same throughout the period, i.e. 3-2-4-1. Therefore the injection signatures observed by the four spacecraft were convective and not nested. Due to the linear geometrical configuration of the spacecraft tetrahedron, it was not possible to determine precisely the direction of motion and the phase velocity of the injection tubes [24]. However, knowing the timing and the order of entry into the injections tubes, we can infer one component of the direction of motion. As the Z_{GSM} positions of all the spacecraft were very similar, a large uncertainty exists about the FTE motion (direction, velocity) in the Z_{GSM} direction. On the other hand, we can deduce the direction of displacement in the XY_{GSM} plane, which was mainly tailward/duskward.

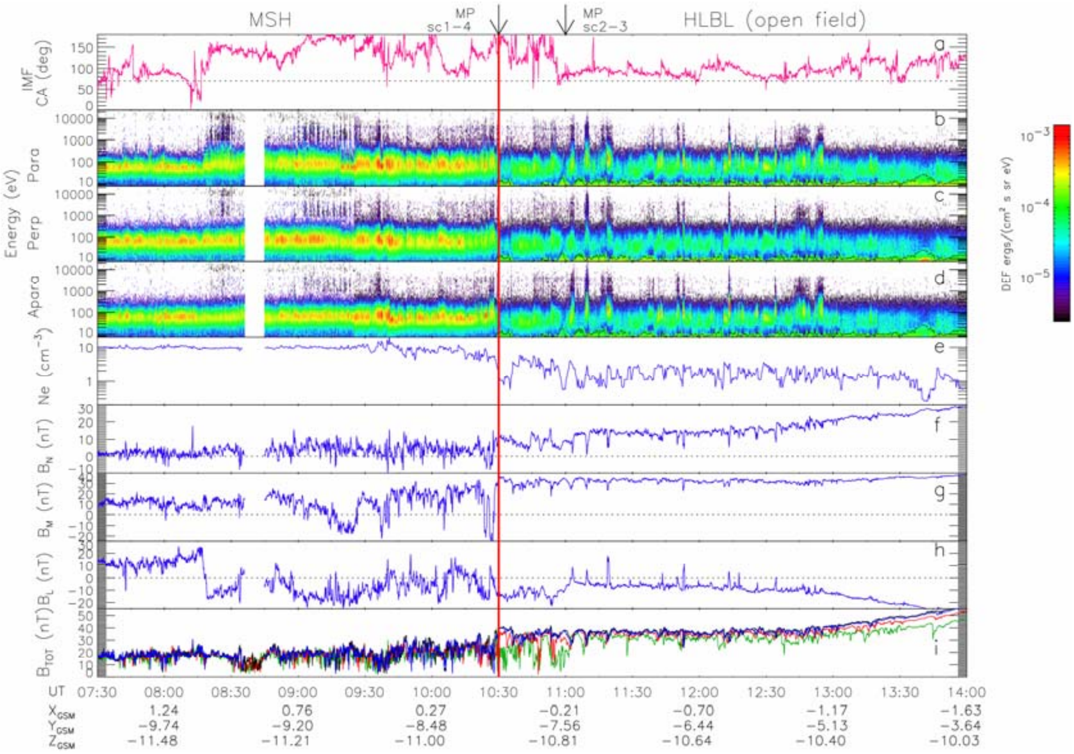

Fig. 5. Wind and Cluster data for the period 07:30-14:00 UT. (a) IMF clock-angle obtained from the Wind data and lagged with 23 min, (b) to (d) PEACE/sc4 electron spectrograms in the parallel, perpendicular and anti-parallel directions (flux below 2.4x10-6 ergs cm-2s-1sr-1eV-1 has been removed), with the EFW spacecraft potential superimposed (e) PEACE/sc4 electron density plotted with a logarithmic scale, (f) to (h) B_L, B_M, B_N components of the FGM/sc4 magnetic field (i) FGM magnetic field magnitude for the four spacecraft.

5. DISCUSSION

5.1 Interplanetary context of the TC-1 and Cluster observations and location of the reconnection site

In this subsection, we try to relate the plasma properties observed by Cluster and TC-1 over an extended period of ~8 hours (08:00-16:00 UT) near the dawnward magnetopause, with the changes in the interplanetary magnetic field orientation observed by Wind.

The observed FTEs signatures remained very similar between 08:00 and 16:00 UT for TC-1 and between 08:20 and 14:00 UT for Cluster. The detection of high-energy magnetospheric plasma mixed with low-energy magnetosheath plasma strongly suggests that reconnection was occurring between magnetosheath and closed magnetospheric field lines despite the IMF-B_y and B_z variations. The similar “reverse” FTE bipolar signatures observed by Cluster and TC-1, imply that the reconnected flux tubes were moving southward from a common reconnection site [25]. The flow acceleration inside the TC-1 flux tubes was in the same direction throughout the period 08:00-16:00 UT (tailward, southward and dawnward) and was in agreement with de Hoffman-Teller velocity obtained when performing the Walén test on some of the FTEs observed by TC-1. Although the flow acceleration inside the injections observed by Cluster was not very clear, the order of entry of the four spacecraft inside each of the injections remained identical (tailward and dawnward). These results suggested that the reconnection geometry was relatively stable throughout the period, with a single reconnection line.

We first supposed a long dayside reconnection line centred at the subsolar point. Thanks to the Cooling model [26], we modelled the velocity of the flux tubes generated from this reconnection line. However, the velocity of the flux tube crossing TC-1 was then tailward, northward and dawnward, in disagreement with the velocity inside the FTEs measured by the HIA experiment onboard TC-1, which was tailward, southward and dawnward. We then inferred a reconnection line located on distorted field lines of the dawn flank of the magnetosphere [27], but northward of both spacecraft, in agreement with expectations based on the negative IMF-B_y orientation. The position of this reconnection line is then in good agreement with the TC-1 and Cluster observations. A schematic of the magnetosphere seen from dawn with the position of the reconnection site is presented in Fig. 6.

The small turnings of the IMF-B_z component did not seem to significantly affect the location of the reconnection region, as might be expected on the basis of the anti-parallel merging model. If the reconnection site had changed from closed field lines to open, lobe field lines, TC-1 should have stopped observing high-energy plasma of magnetospheric origin in the FTEs. Moreover Cluster, located at Z_{GSM} ~ -10 R_E in the southern hemisphere of the magnetosphere (after 10:30 UT), could not be connected with northern lobe reconnected flux tubes and would stop detecting associated FTEs. References [28] and [29] showed that dayside reconnection is not controlled simply by the IMF-B_z, but rather by the IMF clock-angle. These authors concluded that dayside reconnection occurs when the clock angle is as low as ~70 deg. Our results are in good agreement with these previous studies, since FTEs were always observed when the IMF clock-angle was ≥ 70°, irrespective of the IMF-B_z orientation. In summary, from our observations, it can be inferred that the reconnection site remained relatively stable in position and operated on closed field lines of the dawn flank of the magnetosphere between 08:00 and 16:00 UT (and maybe even during the 07:30-08:00 UT period), because the clock-angle remained greater than 70°. This is a direct demonstration that the reconnection line can be stable in position for periods of at least 8 hours, despite variable IMF conditions.

5.2 Comparison of observations between Cluster and Double Star

The FTEs observed by Cluster and TC-1 were filled by a mixture of magnetospheric and magnetosheath plasma, even when observed by Cluster far inside the magnetosphere. Consequently, we suggest that these flux tubes were newly-reconnected and had probably not convected too far between the location of the reconnection site and the spacecraft positions. As Cluster and TC-1 were separated by ~2 hours in MLT but observed simultaneously very newly reconnected flux tubes, the reconnection line had to be extended by at least 2 hours in MLT.

On the other hand, no clear one-to-one correlation (even using a finite delay) was observed between the successive FTEs detected by Cluster and by TC-1, as seen on Fig. 4. This result could be due to the unknown convection time of the reconnected flux tubes between the reconnection site and Cluster and between the reconnection site and TC-1, which introduces an ambiguity and makes the observations hard to compare. Two alternative explanations are described below. First, the reconnection rate may not be uniform along the length of the reconnection line. Cluster and TC-1 could then observe flux tubes coming from different parts of the reconnection line. Second, several reconnection lines could co-exist on the dawnside flank ([12]). Cluster and TC-1 could then observe FTEs coming from different reconnection lines.

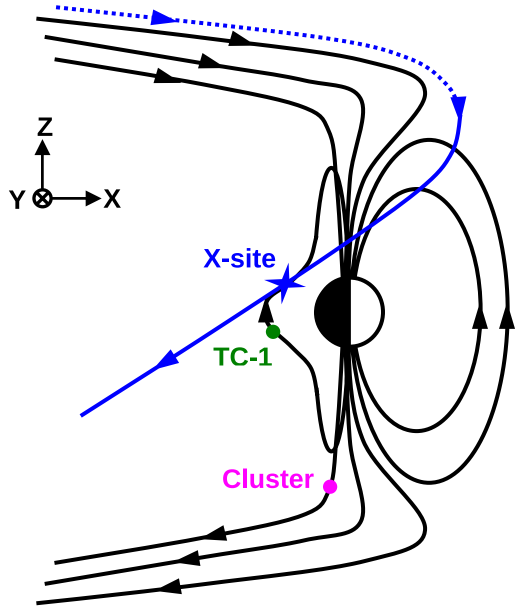

Fig. 6. Sketch in a meridian plane of the magnetosphere (Sun on the right of the figure). The reconnection site located on low-latitude (X-site) as suggested in the discussion section is represented by a blue cross. The approximate positions at ~10:00 UT of Cluster-1 and TC-1 are also indicated by pink and green dots.

6. CONCLUSION

On May 8, 2004, between 08:00 and 16:00 UT, the TC-1 and Cluster spacecraft were located at low- and high-latitudes respectively on the southern dawn flank of the magnetosphere. Both spacecraft observed clear and successive FTE signatures, with "reverse" bipolar signatures of the magnetic field normal component. These conjugate observations suggest that reconnection was occurring at a reconnection site located northward of both TC-1 and Cluster. Despite variable IMF conditions (particularly changes in the IMF-B_z orientation), the reconnection site was relatively stable in location throughout the period and remained on closed magnetospheric field lines on the dawn flank of the magnetosphere, presumably as the IMF clock-angle was always ≥ 70°.

The simultaneity of the FTE observations by TC-1 and Cluster implies that the reconnection line extended over at least 2 hours in MLT. However, no one-to-one correlation was observed between the FTEs seen by Cluster and by TC-1.

7. REFERENCES

1. Marchaudon, A., et al., Simultaneous Double Star and Cluster FTEs observations on the dawnside flank of the magnetosphere, in press, Ann. Geophys., 23, 2877-2887, 2005.

2. Dungey, J. W., Interplanetary magnetic field and the auroral zones, Phys. Rev. Lett., 6, 47-48, 1961.

3. Crooker, N. U., Dayside merging and cusp geometry, J. Geophys. Res., 84, 951-959, 1979.

4. Dungey, J. W., in C. DeWitt, J. Hieblot, and A. Lebeau (eds.), The Earth's Environment, Gordon and Breach, New York, 1963.

5. Maezawa, K., Magnetospheric convection induced by the positive and negative Z components of the interplanetary magnetic field: quantitative analysis using polar cap magnetic records, J. Geophys. Res., 81, 2289-2303, 1976.

6. Phan, T. D., et al., Fluid and kinetic signatures of reconnection at the dawn tail magnetopause: Wind observations, J. Geophys. Res., 106, 25,489–25,502, 2001.

7. Marcucci, M. F., et al., Evidence for interplanetary magnetic field B-y controlled large-scale reconnection at the dayside magnetopause, J. Geophys. Res., 105, 27,497-27,507, 2000.

8. Sonnerup, B. U., Magnetopause Reconnection Rate, J. Geophys. Res., 79, 1546-1549, 1974.

9. Chandler, M. O., et al., Evidence of component merging equatorward of the cusp, J. Geophys. Res., 104, 22623-22633, 1999.

10. Fuselier, S. A., et al., Cusp observations of high- and low-latitude reconnection for northward interplanetary magnetic field, J. Geophys. Res., 105, 253-266, 2000.

11. Sandholt, P. E., et al., A classification of dayside auroral forms and activities as a function of interplanetary magnetic field orientation, J. Geophys. Res., 103, 23,325-23,345, 1998.

12. Berchem, J., et al., Magnetic flux ropes at the high-latitude magnetopause, Geophys. Res. Lett., 22, 1189-1192, 1995.

13. Vaisberg, O. L., et al., Ion velocity distributions within the LLBL and their possible implication to multiple reconnections, Ann. Geophys., 22, 213-236, 2004.

14. Milan, S. E., et al., Convection and auroral response to a southward turning of the IMF: Polar UVI, CUTLASS, and IMAGE signatures of transient magnetic flux transfer at the magnetopause, J. Geophys. Res., 105, 15,741-15,755, 2000.

15. Pinnock, M., et al., The location and rate of dayside reconnection during an interval of southward interplanetary magnetic field, Ann. Geophys., 21, 1467–1482, 2003.

16. Russell, C. T., and Elphic, R. C.: Initial ISEE magnetometer results: magnetopause observations, Space Sci. Rev., 22, 681-715, 1978.

17. Owen, C. J., et al., CLUSTER PEACE observations of electrons during magnetosheric flux transfer events, Ann. Geophys., 19, 1509-1522, 2001.

18. Johnstone, A. D., et al., Peace: A Plasma Electron and Current Experiment, Space Sci. Rev. 79, 351-398, 1997.

19. Rème, H., et al., First multispacecraft ion measurements in and near the earth’s magnetosphere with the identical CLUSTER Ion Spectrometry (CIS) Experiment, Ann. Geophys., 19, 1303–1354, 2001.

20. Balogh, A., et al., The Cluster magnetic field investigation: overview of in-flight performance and initial results, Ann. Geophys., 19, 1207–1217, 2001.

21. Paschmann, G., et al., Plasma and magnetic field characteristics of magnetic flux transfer events, J. Geophys. Res., 87, 2159-2168, 1982.

22. Farrugia, C. J., et al., A multi-instrument study of flux transfer event structure, J. Geophys. Res., 93, 14,465-14,477, 1988.

23. Roelof E. C. and Sibeck, D. G.: Magnetopause shape as a bivariate function of interplanetary magnetic field and solar wind dynamic pressure, J. Geophys. Res., 98, 21,421–21,450, 1993.

24. Dunlop, M. W., et al., Four-point Cluster application of magnetic field analysis tools: the discontinuity analyzer, J. Geophys. Res., 107 (A11), 1385, doi:10.1029/2001JA005089, 2002.

25. Rijnbeek, R. P., et al., Observations of reverse polarity flux transfer events at the earth's dayside magnetopause, Nature, 300, 23-26, 1982.

26. Cooling, B. M. A. et al., Role of the magnetosheath flow in determining the motion of open flux tubes, J. Geophys. Res., 106, 18763-18776, 2001.

27. Tsyganenko, N. A., Modeling the Earth's magnetospheric magnetic field confined within a realistic magnetopause, J. Geophys. Res., 100, 5599-5612, 1995.

28. Freeman, M. P., et al., The interaction of a magnetic cloud with the Earth: Ionospheric convection in the northern and southern hemispheres for a wide range of quasi-steady interplanetary magnetic field conditions, J. Geophys. Res., 98, 7633–7655, 1993.

29. Senior, C., et al., Strong sunward propagating flow bursts in the night sector during quiet solar wind conditions: SuperDARN and satellite observations, Ann. Geophys., 20, 771-779, 2002.

COPYRIGHT: