Comparison of Diffusion Region Proxy Parameters in the Geomagnetic Tail Using the Magnetospheric Multiscale Mission

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Abstract

Parameters derived from direct field measurements and particle distribution functions such as the adiabatic expansion parameter and the Swisdak sqrt(Q) parameter are often used to identify or even define the detection of a reconnection diffusion region in *in situ* data. We calculate these and other "Proxy" parameters for known diffusion regions in the geomagnetic tail as observed by the MMS spacecraft during the 2017 and 2018 Tail Campaigns and identified using only the field and particle moment measurements directly. The reliability and efficacy of each proxy parameter is then discussed. Commonly held prerequisite conditions such as the value of the plasma β are also calculated and discussed.

Event Selection

The efficacy of scalar parameters is tested first on a selection of known diffusion regions which have been selected without prior bias regarding any of the parameters under review. The selection criteria for the test diffusion regions are primarily topological in nature and applied in three stages. The first stage looks for correlated reversals in B_Z and ion V_X, occurring $\leq$90 seconds apart. The second stage looks for $|\vec{E}| \geq 10mV$ where a low-pass filter of 1Hz has been applied to $\vec{E}$ to reduce false positives due to wave activity, The third stage looks for *i)*Hall $\vec{E}$ and *ii)*$\vec{B}$ in the neighborhood of the reversal in B_Z, again taken to be within 90 seconds. To maintain consistency with previous studies, GSM coordinates have been used throughout this study.

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Parameter	Expression	Condition
Plasma β	$\frac{P_{plasma}}{P_{\vec{B}}} = \frac{2\mu_0 K_B(T_e+T_i)}{B^2}$	$\beta >> 1$
δ_i	$\frac{r_{g,i}}{d_i} = \frac{\sqrt{2K_B T_{\perp,i} n_i \mu_0}}{B}$	$\delta_i \geq 1.0$
Lorentz Ratio	$\Gamma_{\perp,i} = \frac{\lvert\vec{E_\perp}+\vec{u_i}\times\vec{B}\rvert}{w_{\perp,i}B} : w_{\perp,i} \equiv \sqrt{\frac{2K_B T_{\perp,i}}{m_i}}$	$\Gamma_{\perp,i} \geq 1.0$
Agyrotropy:$\sqrt{Q}$	$Q = \frac{4I_2}{(I_1-P_\parallel)(I_1+3P_\parallel)} : I_1 \equiv \mathrm{Tr}(\bar{P_i}), I_2 \equiv$ sum of principal minors	$\sqrt{Q} \geq 0.1$
$E_\parallel$	$E_\parallel \equiv \vec{E}\cdot\vec{B}$	$E_\parallel \neq 0$

Table: **(1)** List of the chosen diffusion scalar parameters, their expressions in terms of *in situ* measurements, and the conditions for them to indicate ion diffusion.

Event(UT)	Probe	β	δ_i	$\sqrt{Q}$	$\Gamma_{\perp,i}$	$E_\parallel(\frac{mV}{m})$
2017-05-28/0358	3	115.05	0.06216	0.61275	2.8662	170.21
2017-07-06/1638	1	1140.5	0.27631	0.56487	0.75702	114.28
2017-07-11/2234	4	1326.0	0.29102	0.48432	1.8596	41.140
2017-07-17/0749	3	742.34	0.22869	0.40107	0.50212	45.364
2017-07-26/0701	4	33.386	0.04425	0.48139	1.0189	70.582
2017-07-26/0728	2	319.00	0.14316	0.55172	1.1150	236.89
2017-08-06/0514	4	1539.0	0.36497	0.40188	1.1933	9.5032
2017-08-10/1218	1	617.36	0.21699	0.22583	0.48436	2.3360
2017-08-23/1753	3	123.50	0.09614	0.66034	1.8703	108.81

Table: **(2)** A listing of the 9 ion diffusion regions identified in the 2017 MMS tail campaign with calculated values for each of the chosen scalar parameters.

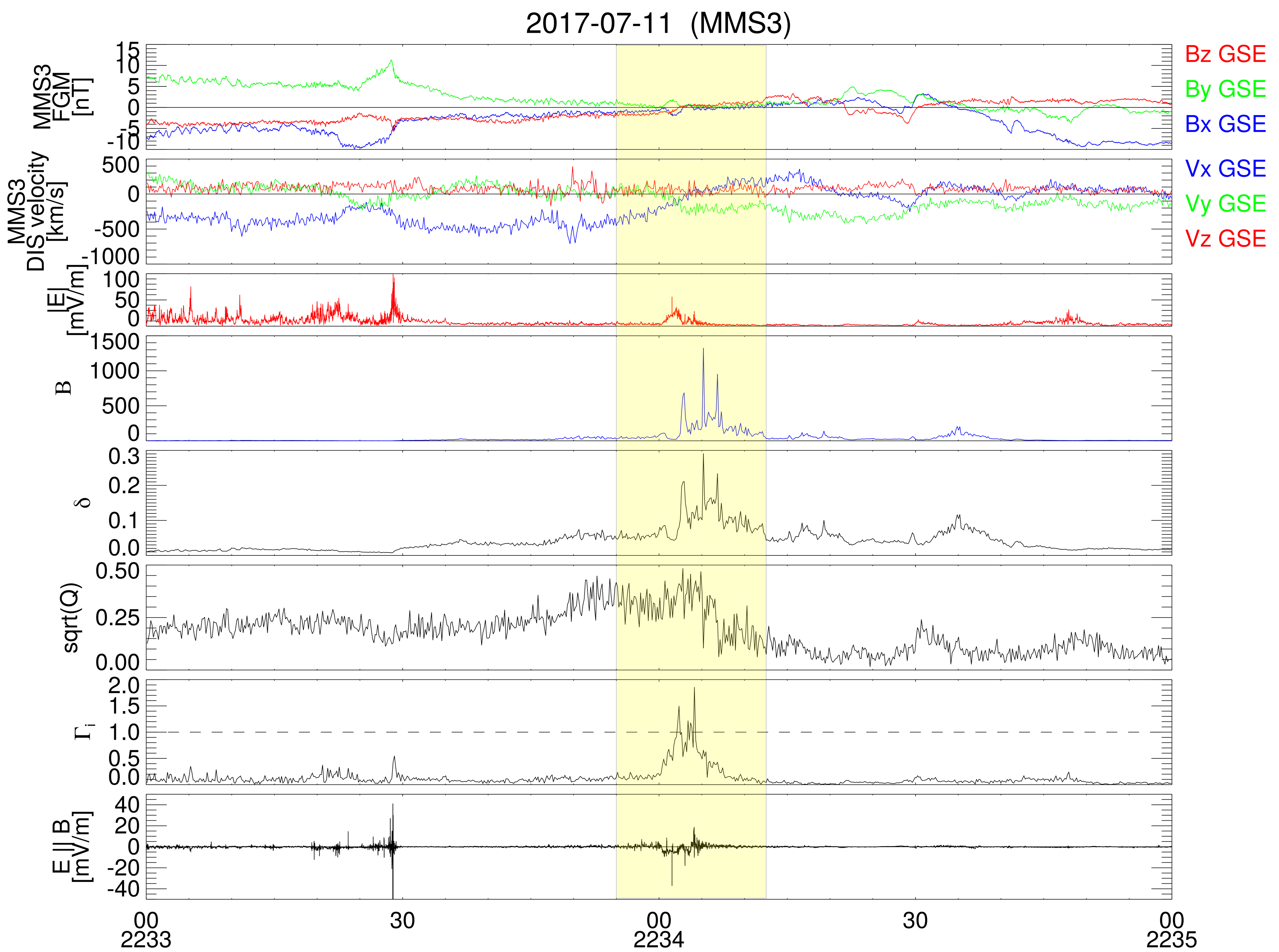

Figure: **(1)**An example event showing the $\vec{B}$ and ion velocity data used to identify the correlated field and flow reversal and the $|\vec{E}|$ used to satisfy Stage 2 of the selection criteria. Hall field analysis not shown here. Below are the time-series calculations of each of the five scalar parameters discussed here. The highlighted region is centered on the nearly-simultaneous magnetic field and ion flow reversal at the center of the canonical diffusion region. The extent of the highlighted area is to draw attention to the clear correlation in timing for each of the scalar parameters and the field and flow reversal. This correlation is a common feature for all nine diffusion region events analyzed.

Methodology

The 120s surrounding the correlated reversal from Stage 1 of the event selection algorithm is analyzed for each of the ion diffusion regions identified by the algorithm. The chosen scalar proxy parameters are calculated using an automated routine to ensure identical treatment of each example. The scalar parameters chosen for this study, as well as the expressions used for their calculation, are given in table 1. The maximum values of the five chosen scalar parameters within the 120s window surrounding the field and flow reversal for all nine magnetotail diffusion regions are given in table 2. An example event which shows Burst data for all scalar parameters as well as the data for selection stages 1 and 2 is shown in figure 1.

The null hypothesis of the typical values of these scalar parameters was not tested for this report but is in preparation for future investigation. As such any determination of reliability of each parameter as an indicator of the presence of an ion diffusion region must be considered preliminary at this time.

Discussion

Plasma β is often used as a search criteria for reconnection diffusion regions under the assumption that reconnection occurs near or in the dense plasma sheet. This study supports that assumption, although observational bias must be considered as the orbit of MMS strongly favored the plasma sheet during the tail campaign. δ_i, being the ratio of ion thermal gyroradius to inertial length, appears to be a poor indicator of ion diffusion as described in the associated reference. Although enhancements in δ_i do correlate with the observed diffusion region, the enhancements are not to the degree suggested in references. Ion agyrotropy as measured by $\sqrt{Q}$ is also supported as a reasonable indication of the diffusion region. The extent of enhanced $\sqrt{Q}$ as seen in figure 1 is also more similar to the extent of the region where Hall $\vec{E}$ and $\vec{B}$ are seen in many events.

The Lorentz ratio ($\Gamma_{\perp,i}$) is a less reliable indicator of the ion diffusion region but does correlate with the closest approach to the EDR, even in examples where $\Gamma_{\perp,i} < 1.0$ throughout the IDR. The parallel electric field is similar to the Lorentz ration in that it is strongest near the inner diffusion region. It is a reasonable indicator of ion diffusion as it is satisfied for all observed ion diffusion regions, if only as a transient near the center of the IDR.

Overall we find that the δ_i parameter is the poorest indicator and $\sqrt{Q_i}$ is the best, primarily due to its correlation with the extent of the Hall fields. The $\Gamma_{\perp,i}$ parameter appears to be an indicator of depth into the diffusion region, but is an unreliable indicator of the diffusion region in general. The presence of $E_\parallel$ appears to be a reliable indication of ion diffusion, but how its transient nature relates to the structure of the diffusion region is still under investigation.

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