

A.J. Rogers¹, C.J. Farrugia¹, R.B. Torbert¹

¹The University of New Hampshire, Department of Physics, Durham, NH

June 27, 2018

Parameter	Expression
Kappa: K	$K = \sqrt{\frac{r_{gyro}}{R_{curvature}}}$
Agyrotropy: \sqrt{Q}	$Q = \frac{4I_2}{(I_1 - P_{\parallel})(I_1 + 3P_{\parallel})}$; $I_1 \equiv \text{Tr}(\hat{P}_i)$, $I_2 \equiv$ sum of principal minors
Agyrotropy: AG	$AG = \frac{ 4 \det(\hat{P}) - P_{\parallel}(\text{tr}(\hat{P}) - P_{\parallel})^2 }{4 \det(\hat{P}) + P_{\parallel}(\text{tr}(\hat{P}) - P_{\parallel})^2}$; $\hat{P} \equiv$ Pressure Tensor
Adiabatic Expansion parameter: Γ	$\Gamma_{\perp,i} = \frac{ \vec{E}_{\perp} + \vec{u}_i \times \vec{B} }{w_{\perp,i} B}$; $w_{\perp,i} \equiv \sqrt{\frac{2K_B T_{\perp,i}}{m_i}}$

Table 1: List of the chosen diffusion scalar parameters, their expressions in terms of *in situ* measurements.

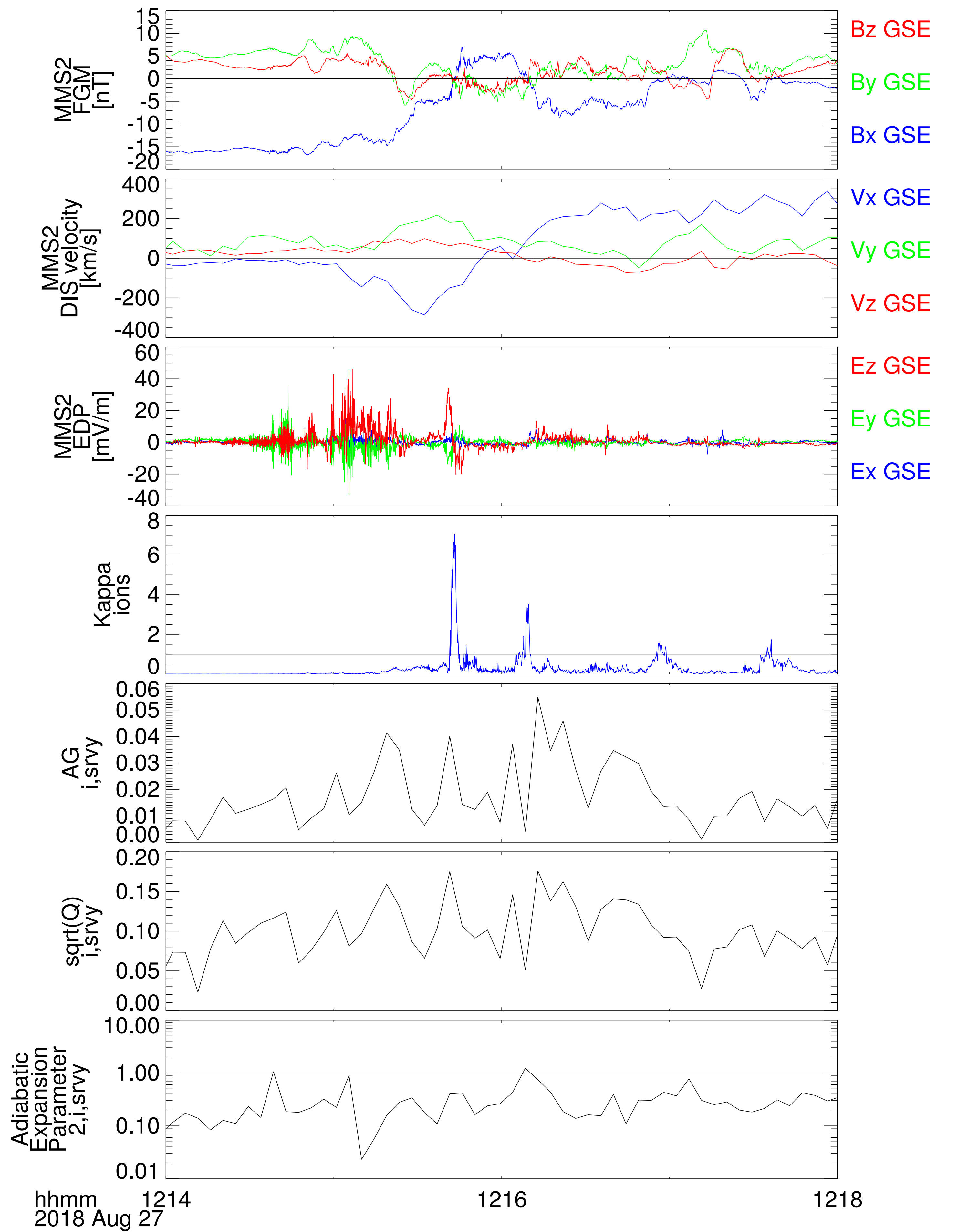
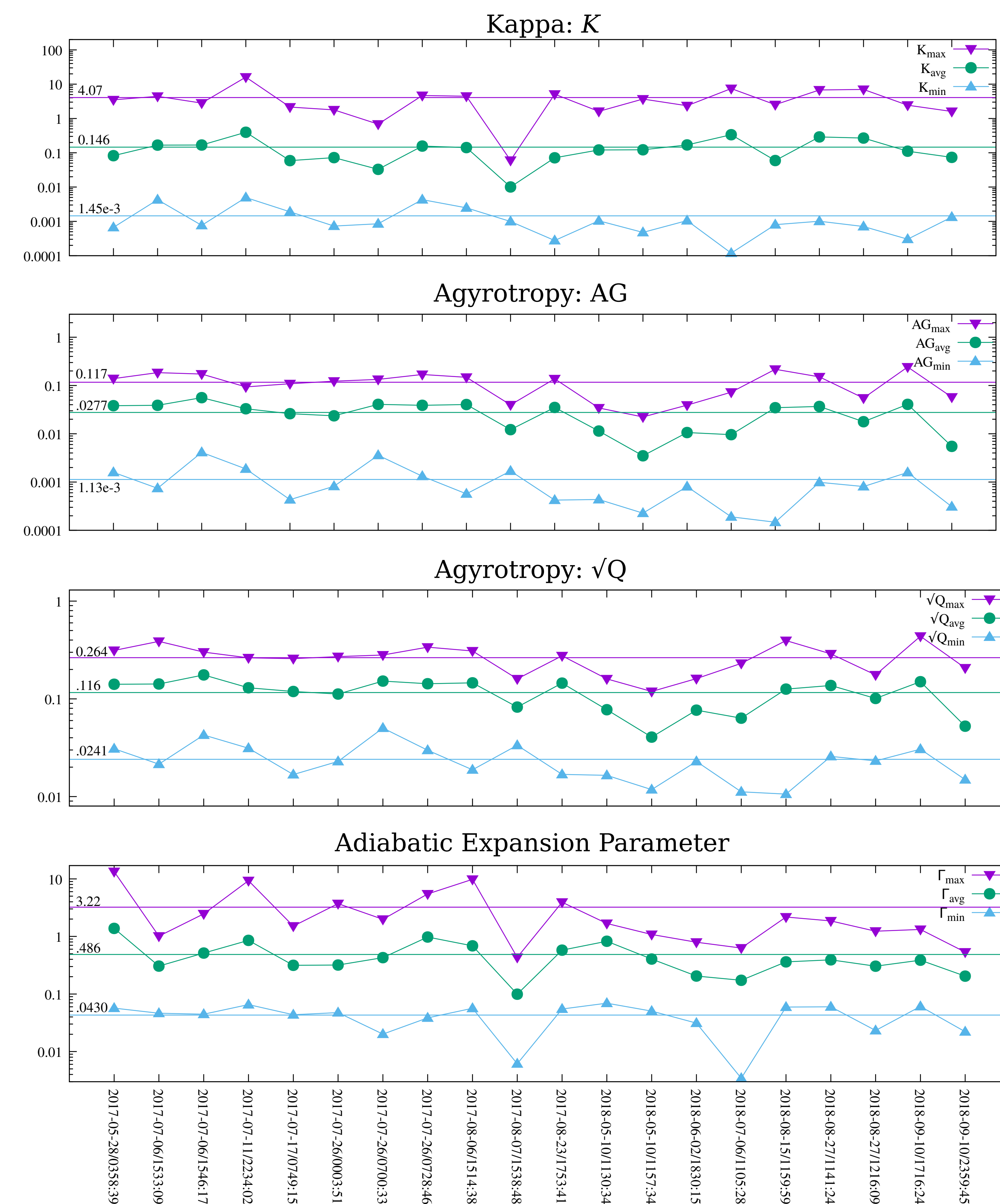


Figure 1: An example event showing the \vec{B} and bulk ion velocity data used to identify the correlated field and flow reversal, and the $|\vec{E}|$ used to satisfy Stage 2 of the selection criteria. Hall field analysis not shown here. Below are the time-series calculations of each of the five scalar parameters discussed here. Note 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 twenty diffusion region events analyzed.

Figure 2: (left) Plots show (i) Kappa, (ii) the agyrotropy parameter AG , (iii) the agyrotropy parameter \sqrt{Q} , and (iv) the adiabatic expansion parameter Γ on log-scale plots. Each plot shows the maximum, average, and minimum values of the associated parameter across the 240s sample window centered around the reversal time shown at the bottom. The average of each statistic across all 20 events analyzed is shown as a bar across each plot in the associated color.

Abstract

Scalar parameters derived from direct field measurements and particle distribution functions such as the adiabatic expansion parameter and the \sqrt{Q} parameter have been suggested as tools to identify or even define magnetic reconnection when applied to *in situ* electron measurements. The physics which suggest these parameters to describe electron diffusion and demagnetization are equally applicable to ions to describe the same effects. We present four such scalar parameters, adapted for use with ion measurements, and apply them to 20 known ion diffusion regions, identified independently, for comparison and analysis.

Event Selection

The efficacy of scalar parameters is tested 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 (Rogers et al. 2019). The first stage looks for correlated reversals in B_Z and ion V_X , occurring ≤ 90 seconds apart. The second 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. The third 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. One IDR identified using this method is not included in this study due to data from one of the four MMS spacecraft being unavailable.

Methodology

240s of time-series data are analyzed, approximately centered on the correlated reversal from Stage 1 of the event selection algorithm, for each event. 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, average, and minimum values of the four chosen scalar parameters within the 240s window surrounding the field and flow reversal for all 20 magnetotail diffusion regions are given in figure 2. An example event which shows fast-survey data for all scalar parameters as well as data for event selection is shown in figure 1.

References

— Rogers, A.J, C.J. Farrugia, R.B. Torbert. (2019) "Numerical Algorithm for Detecting Ion Diffusion Regions in the Geomagnetic Tail with Applications to MMS Tail Season May 1–September 30, 2017". *JGR:Space Physics*. JGRA55058. doi:10.1029/2018JA026429.

— Eastwood, J.P, T.D. Phan, M. Oieroset, M.A. Shay. (2010) "Average properties of the magnetic reconnection ion diffusion region in the Earth's magnetotail: The 2001-2005 Cluster observations and comparison with simulations". *JGR*. 115. A08215.

— Scudder, J.D., R.D. Holdaway, R. Glassberg, S.L. Rodriguez. (2008) "Electron diffusion region and thermal demagnetization". *JGR*. 113. A10208.

— Swisdak, M. (2016) "Quantifying gyrotropy in magnetic reconnection". *GRL*. 43. 43-49.

— Nagai, T, I. Shinohara, S. Zenitani, R. Nakamura, T. Nakamura, M. Fujimoto, Y. Saito, T. Mukai. (2013) "Three-dimensional structure of magnetic reconnection in the magnetotail from Geotail observations". *JGR:SP*. 118. 1167-1678.

— Scudder, J.D, F.S. Mozer. (2005) "Electron demagnetization and collisionless magnetic reconnection in $\beta \ll 1$ plasmas". *Physics of Plasmas*. 12. 092903.

— Che, H., C. Schiff, G. Le, J. C. Dorelli, B. L. Giles, and T. E. Moore. (2018). "Quantifying the effect of non-Larmor motion of electrons on the pressure tensor". *Physics of Plasmas*. 25. 032101. doi:10.1063/1.5016853.

— Shen, C., X. Li, M. Dunlop, Z. X. Liu, A. Balogh, D. N. Baker, M. Hapgood, and X. Wang. (2003). "Analyses on the geometrical structure of magnetic field in the current sheet based on cluster measurements". *JGR*. 108. A5. 1168. doi:10.1029/2002JA009612

Acknowledgements

Thanks are owed to: Matt Argall, Akhtar Ardakani, John Marci, Ivan Dors, Christine Schultz, Hiroshi Matsui, Dominic Payne, Chris Moukris, Terry Forbes, Kevin Genestretti, Tim Rogers, and Carolyn Laroche.

This work has been supported by NASA via contract 499878Q

Discussion

The K parameter (Shen et al. 2003) is a ratio of scale lengths and provides an intuitive test for if an ion can remain in gyrotropic motion along a given field line. A values of $K \geq 1.0$ indicates that the gyroradius of the ion is larger than the radius of curvature of the magnetic field at that point, making continued Larmor motion problematic and strongly suggesting ion demagnetization. While most common very near the current sheet, it is generally present in and around known IDRs. The two measures of pressure anisotropy described by Swisdak (\sqrt{Q}) and Che et al. (AG) are both calculated and shown. In most events $AG \approx \frac{1}{2}\sqrt{Q}$ as applied to ions. The extent of enhanced \sqrt{Q} as seen in figure 1 is very similar to the region of Hall \vec{E} and \vec{B} in many events, while AG tends to respond very strongly to boundaries between regions.

The adiabatic expansion parameter (Γ) described by Scudder et al. (2005) reliably elevates above its local background value in and near known IDRs, but tends not to reach the positive diffusion region identification value of $\Gamma \geq 1.0$ given by its formulators until very near the X-line. The detection and identification scheme used to provide the test events is limited by relying on the geometric properties of the IDR aligning well with the GSM coordinate system. The scalar parameters which are coordinate system independent are an attractive tool to supplement the existing schemes for diffusion region identification. With the exception of a single event, all the parameters respond well to known IDRs, indicating they may be useful tools for improving the existing identification schemes in this way, or for improving confidence in problematic cases.