The e-POP / Swarm-Echo Level 1B Like Data Product

ESA Living Planet Workshop

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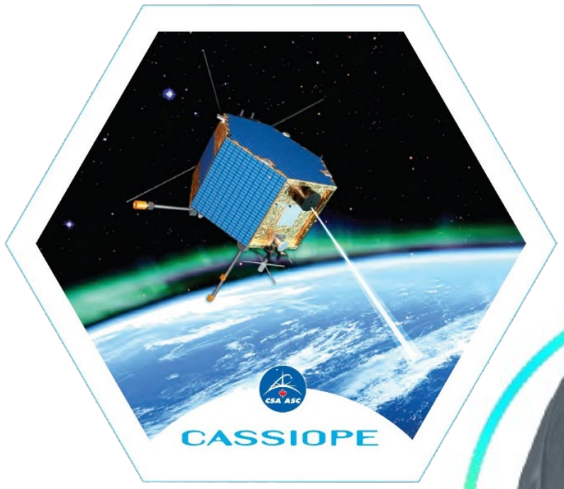
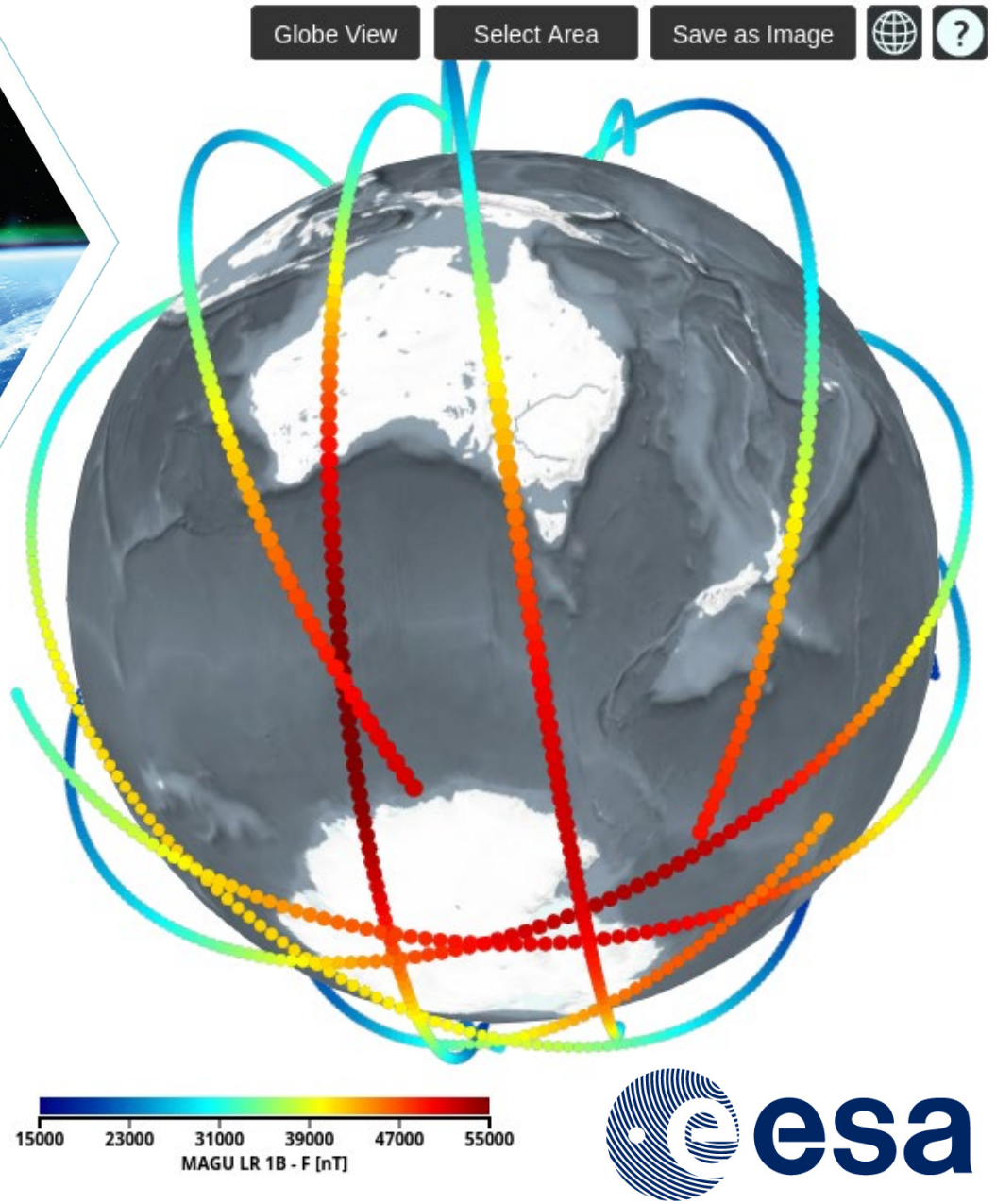
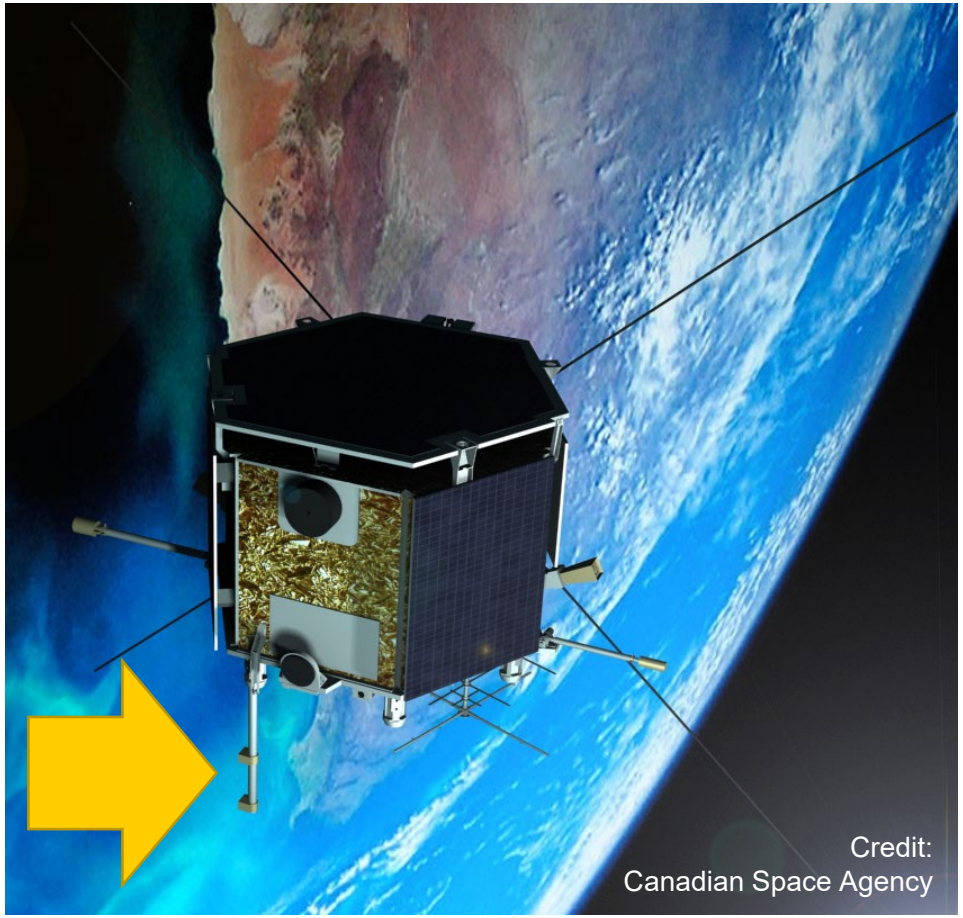
2022-05-26

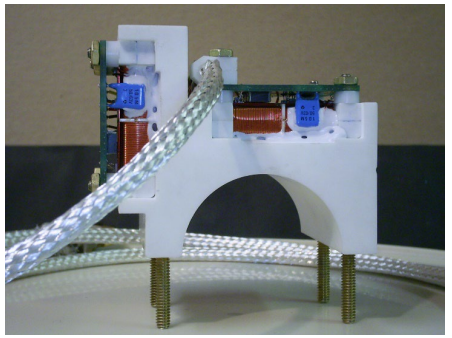


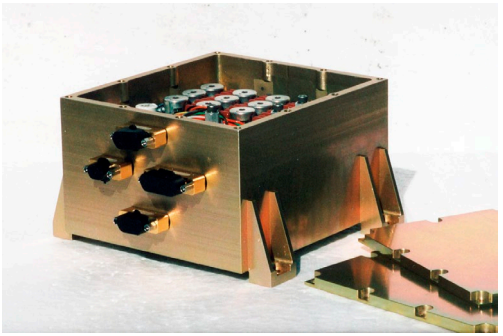


The e-POP/Swarm-Echo Magnetic Field Experiment (MGF)

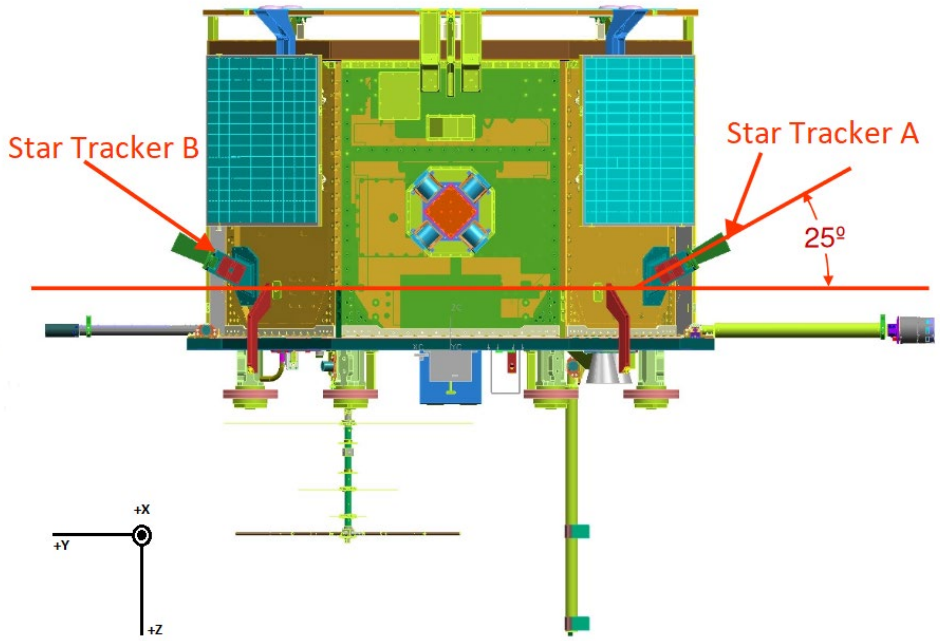
- e-POP launched in 2013
- Joined the Swarm constellation as Swarm-Echo in 2018
- End of routine science operation in Dec 31, 2021
- Dual fluxgate payload
- 160 sps vector data
- Swarm Level 1b like product available for community use

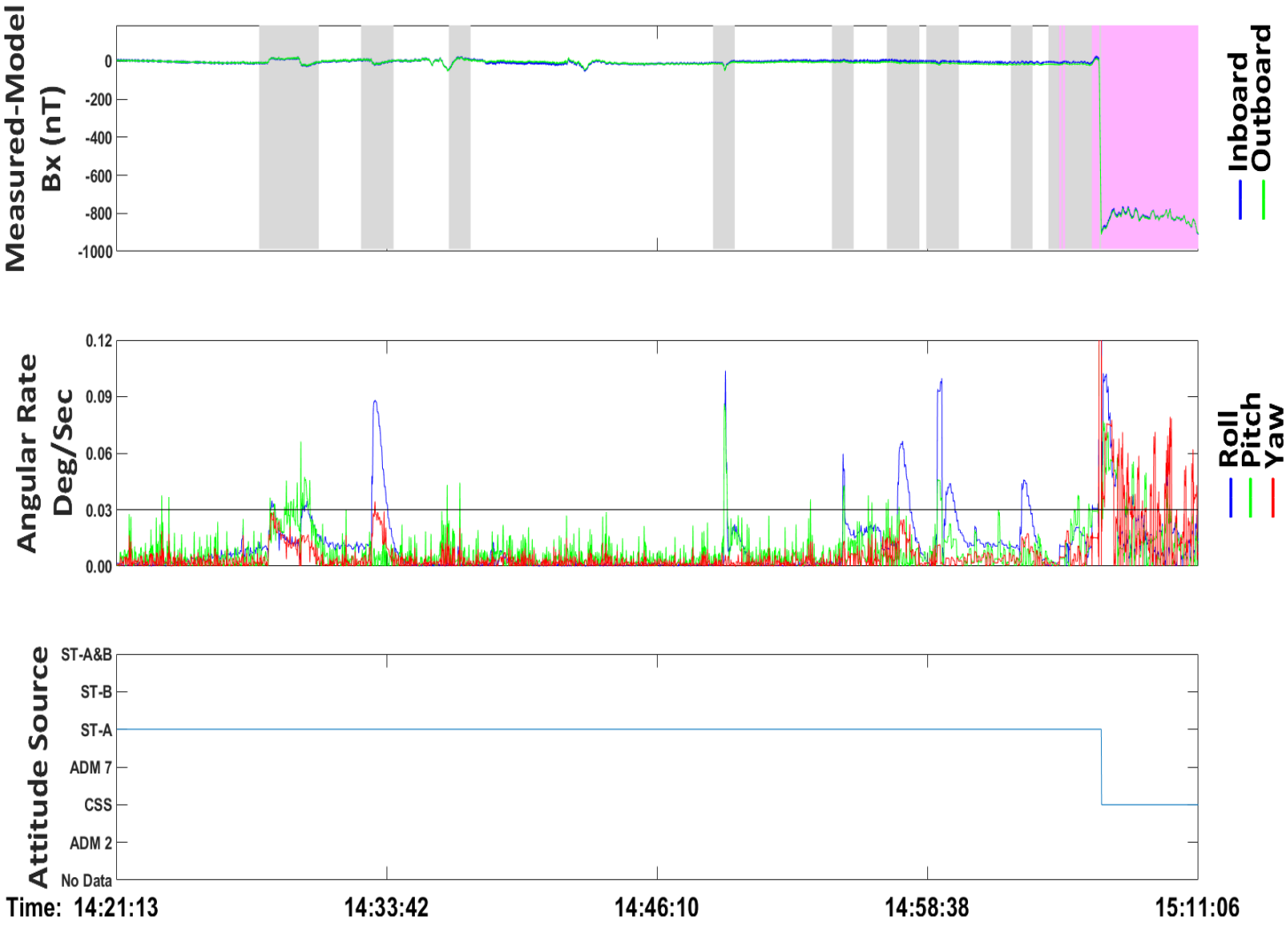






In-situ Calibration Enabled by Improved Attitude Solution





CDF Format – Similarities and Differences to Swarm

LR Product Variable Names	MAGA	MAGE	Comment
ASM_Freq_Dev	X	n/a	No scalar magnetometer on Swarm-E
Att_error	X	X	
B_VFM	X	X	As **B_CRF** in Swarm-E, values in spacecraft frame not instrument frame
B_NEC	X	X	As **B_NEC_Out** in Swarm-E, values from outboard sensor only
B_error	X	X	As **B_error_In** & **B_error_Out** in Swarm-E due to dual magnetometers
B_model_NEC		X	
B_inboard_CRF, B_outboard_CRF	n/a	X	Single vector magnetometer on Swarm-A
CalInbboard, CalOutboard		X	
F, F_error	X	n/a	No scalar magnetometer on Swarm-E
Flags_B	X	X	0 = nominal, 128 = Magnetorquer active
Flags_Platform	X	*	Variable present for Swarm-E but zero filled
Flags_q	X	X	0 = nominal, 2 = bus rotation above threshold, 32 = missing definitive attitude
Latitude, Longitude, Radius	X	X	
Timestamp	X	X	
dB_AOCS	X		Swarm-E magnetorquer activity flagged but not quantified
dB_Sun	X		
dB_Other	X	*	Variable present for Swarm-E but NaN filled
dF_AOCS, dF_Other	X	n/a	No scalar magnetometer on Swarm-E
q_NEC_CRF	X	X	

- Reference: SwarmE-RPT-001 “MGF Lv1b Data Product Description”

Data Product Calibration

- In-situ vector-vector calibration performed against the Chaos-7.7 field model (Finlay et al., 2020).
- Robust re-weighted linear fit following Olsen et al., 2020
- $\boldsymbol{B_{CRF} = R_A^{-1} P^{-1} S^{-1}(E - b) = AE + \tilde{b}}$
- Decomposed sensitivity, orthogonality, Euler angles, and offsets for instrument trending
- Rolling 7-day window for calibration
- Reference: Broadfoot et al., 2022 In Review for GI https://doi.org/10.5194/egusphere-2022-59

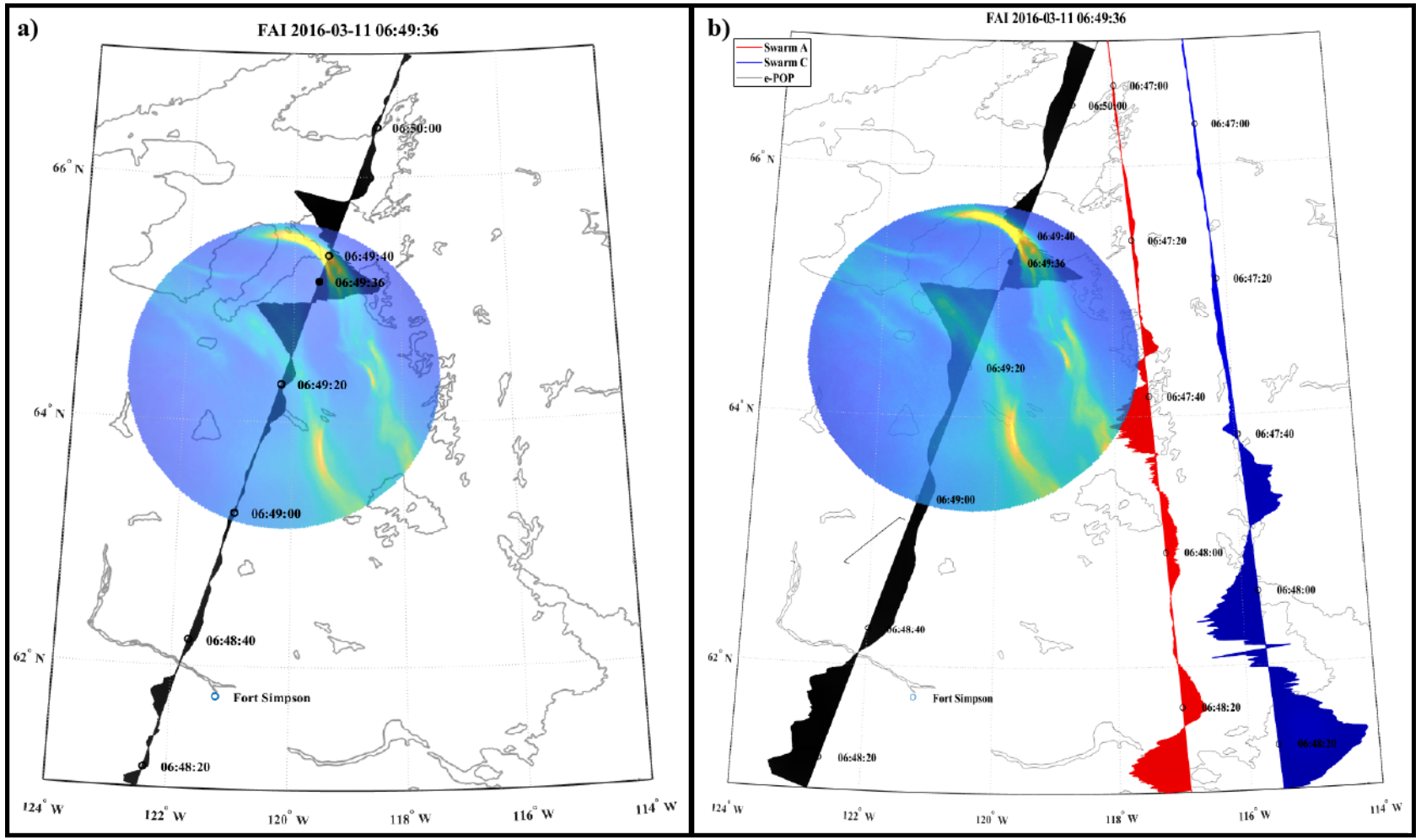
	In-situ Calibration		Preflight Calibration	
	Inboard	Outboard	Inboard	Outboard
Sx [eu/nT]	1.0044	1.0024	1.0044	1.0025
Sy [eu/nT]	0.9979	1.0020	0.9984	1.0029
Sz [eu/nT]	1.0503	1.0534	1.0473	1.0519
Oxy [°]	90.13	89.89	90.12	89.93
Oxz [°]	90.29	90.12	90.10	90.02
Oyz [°]	89.99	89.96	89.81	89.93
e1 [°]	-2.73	-2.68		
e2 [°]	0.09	-0.21		
e3 [°]	2.23	1.96		
offX [nT]	1.47	-199.41		
offY [nT]	2.10	1.20		
offZ [nT]	8.33	24.22		

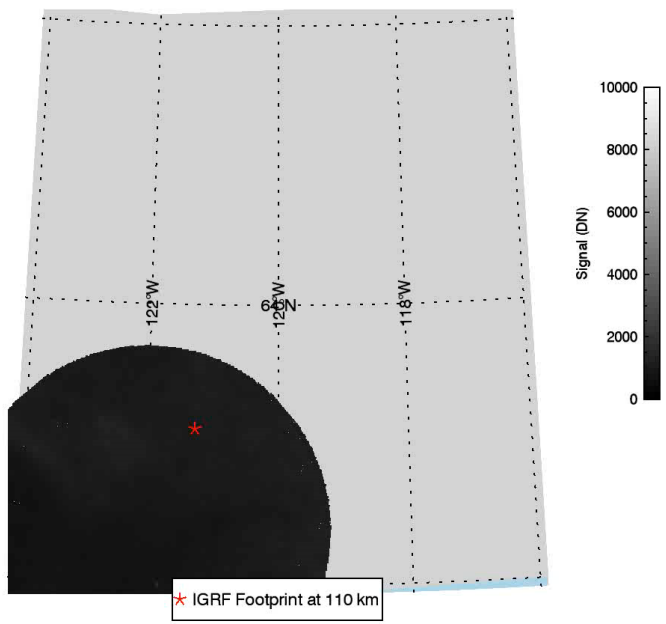
Performance of Current Calibration

	Inboard													
	2014		2015		2016		2017		2018		2019		2020	
	mean	rms	mean	rms	mean	rms	mean	rms	mean	rms	mean	rms	mean	rms
B_x	-2.80	13.97	-2.91	14.61	-0.21	13.73	0.61	13.23	0.40	12.79	0.33	11.65	0.26	11.58
B_y	0.86	20.34	-0.81	22.13	0.15	11.19	-0.04	10.64	0.16	10.30	0.27	9.91	-0.14	9.32
B_z	-1.53	10.71	0.75	12.12	-0.18	11.26	0.09	10.77	-0.17	10.84	0.03	11.11	0.00	10.67
$\|B\|$	-2.80	16.21	-2.91	19.23	-0.21	9.23	0.61	9.76	0.40	9.05	0.33	8.81	0.26	8.85
	Outboard													
	2014		2015		2016		2017		2018		2019		2020	
	mean	rms	mean	rms	mean	rms	mean	rms	mean	rms	mean	rms	mean	rms
B_x	2.87	17.12	3.63	18.73	0.46	13.58	0.53	12.99	0.42	12.67	0.27	11.71	0.07	11.61
B_y	1.27	14.70	-1.29	14.92	0.17	11.22	-0.10	10.48	0.28	10.14	0.25	9.80	-0.10	9.17
B_z	-0.52	19.91	1.59	21.99	-0.39	11.00	0.13	10.40	-0.23	10.41	0.02	10.64	-0.01	10.15
$\|B\|$	2.87	11.35	3.63	13.28	0.46	8.81	0.58	9.34	0.42	8.57	0.27	8.45	0.07	8.33

- RMS deviation from Chaos at ~9 nT (~18 nT before 2016)
- Reference: SwarmE-RPT-002 “Swarm-Echo MGF lv1b Data Calibration Validation Report”

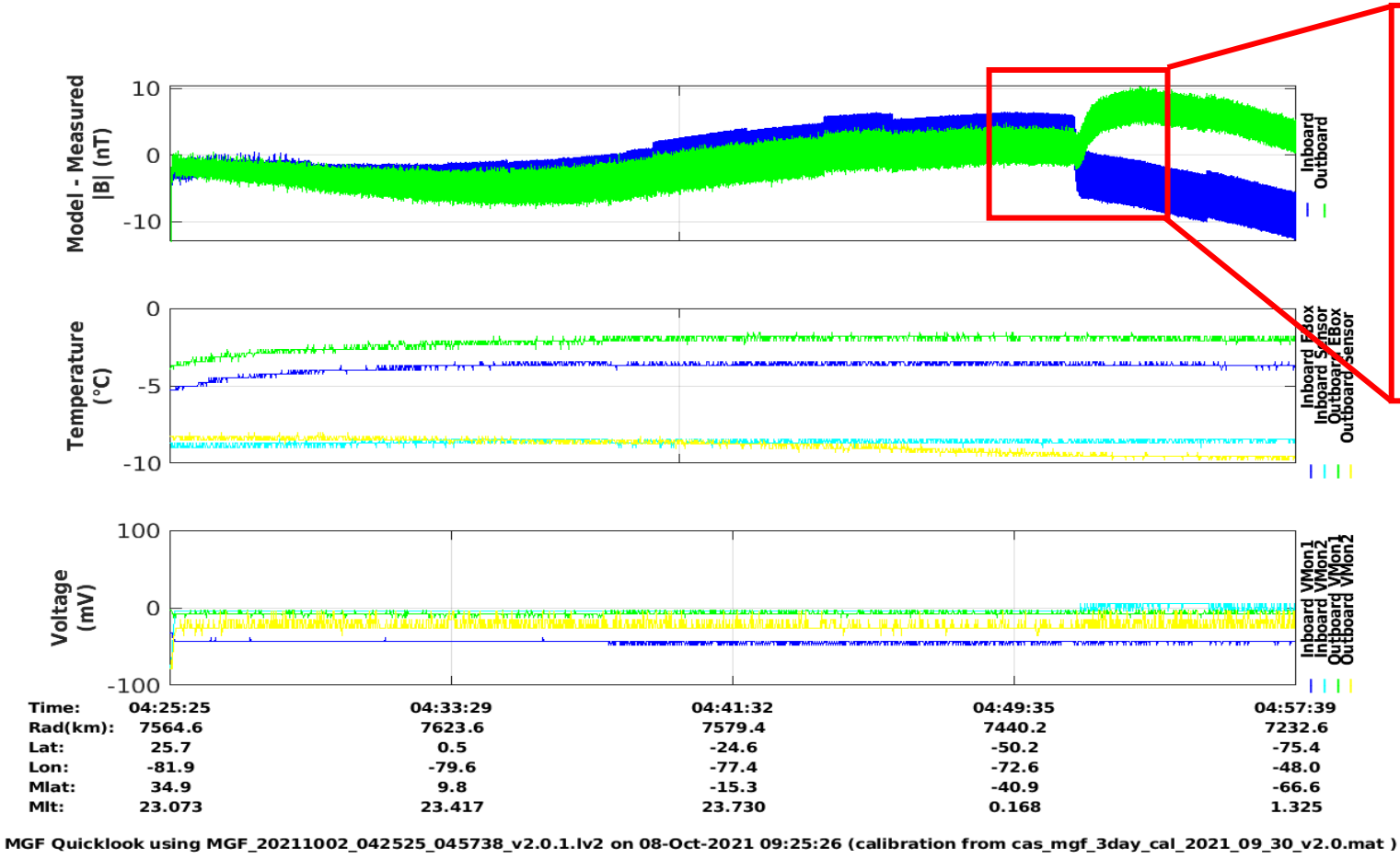
Example of Improved Data Utility: Alfvenic Discrete Aurora

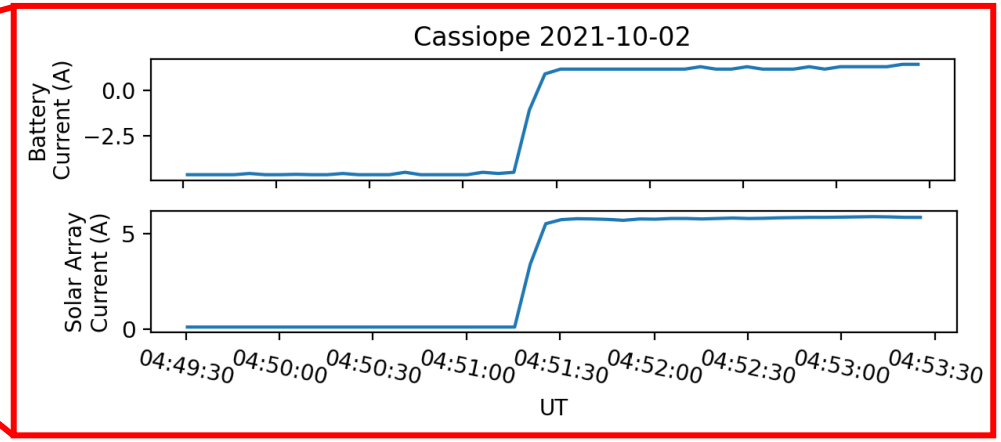




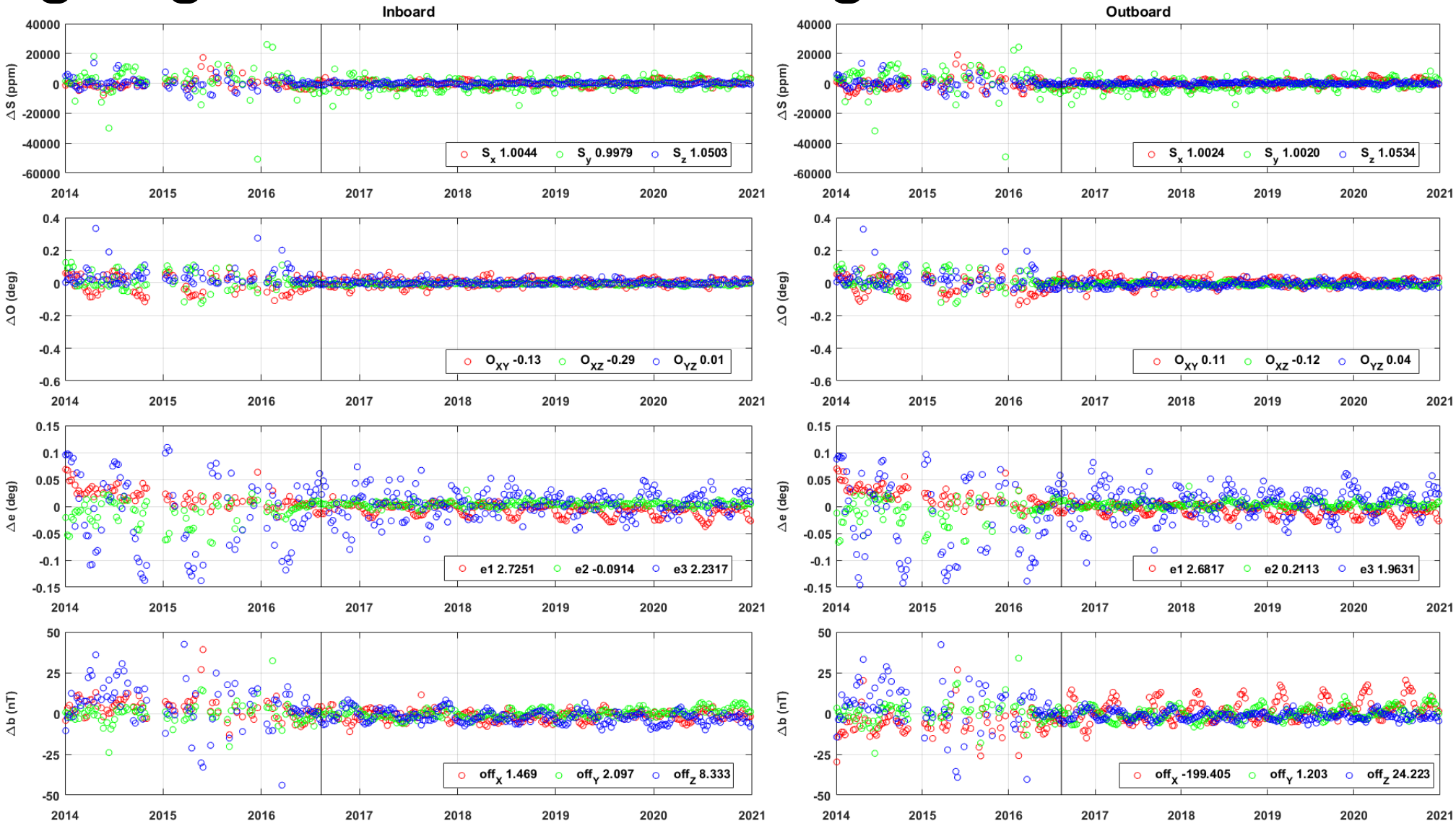
- Reference: Miles et al., 2018, Broadfoot et al., 2022 (In Review for GI)

Ongoing Calibration Work: Sensor Temperature / Solar Panel Current



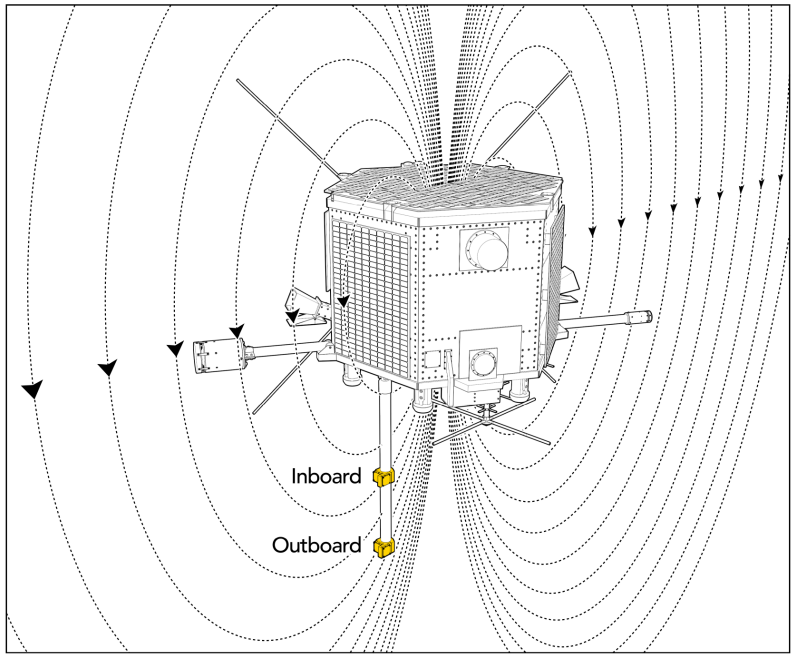


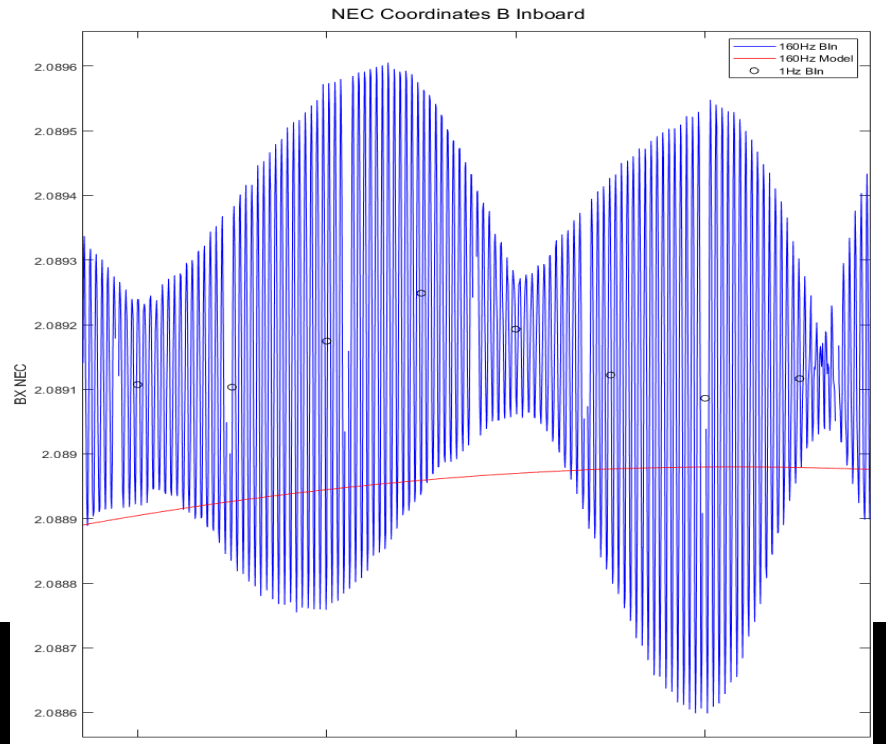
Ongoing Calibration Work: Regularization / Wheels



Reaction Wheel Noise

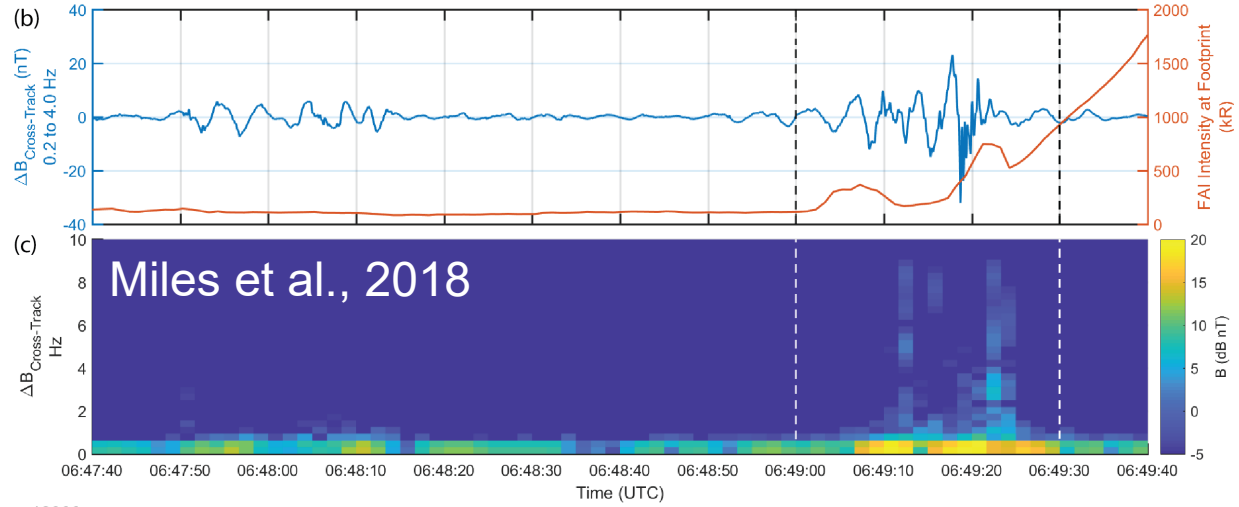
- e-POP had a limited magnetic cleanliness plan
- Significant reaction wheel noise in high-cadence data
- 1 sps data decimated by robust linear regression on 1.5-second interval
- Phase-beating of the reaction wheels passes through this reduction

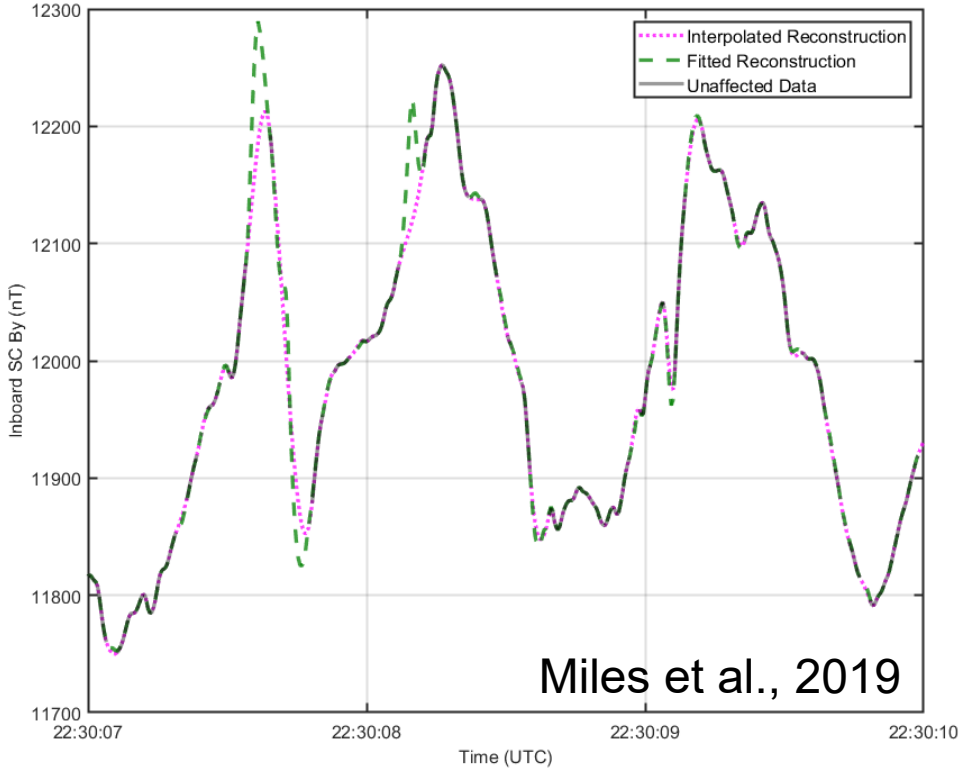




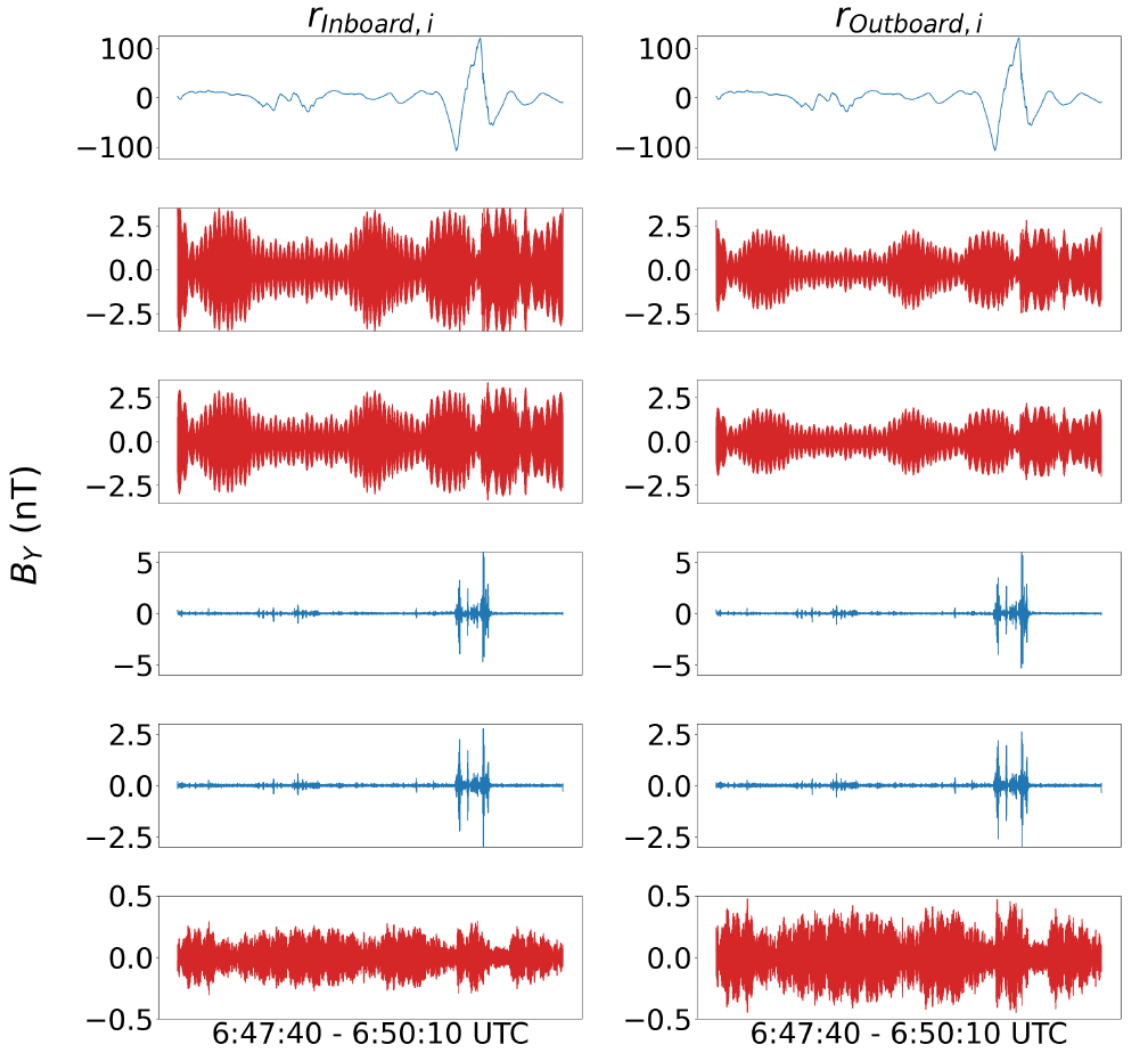
Wheel Frequencies

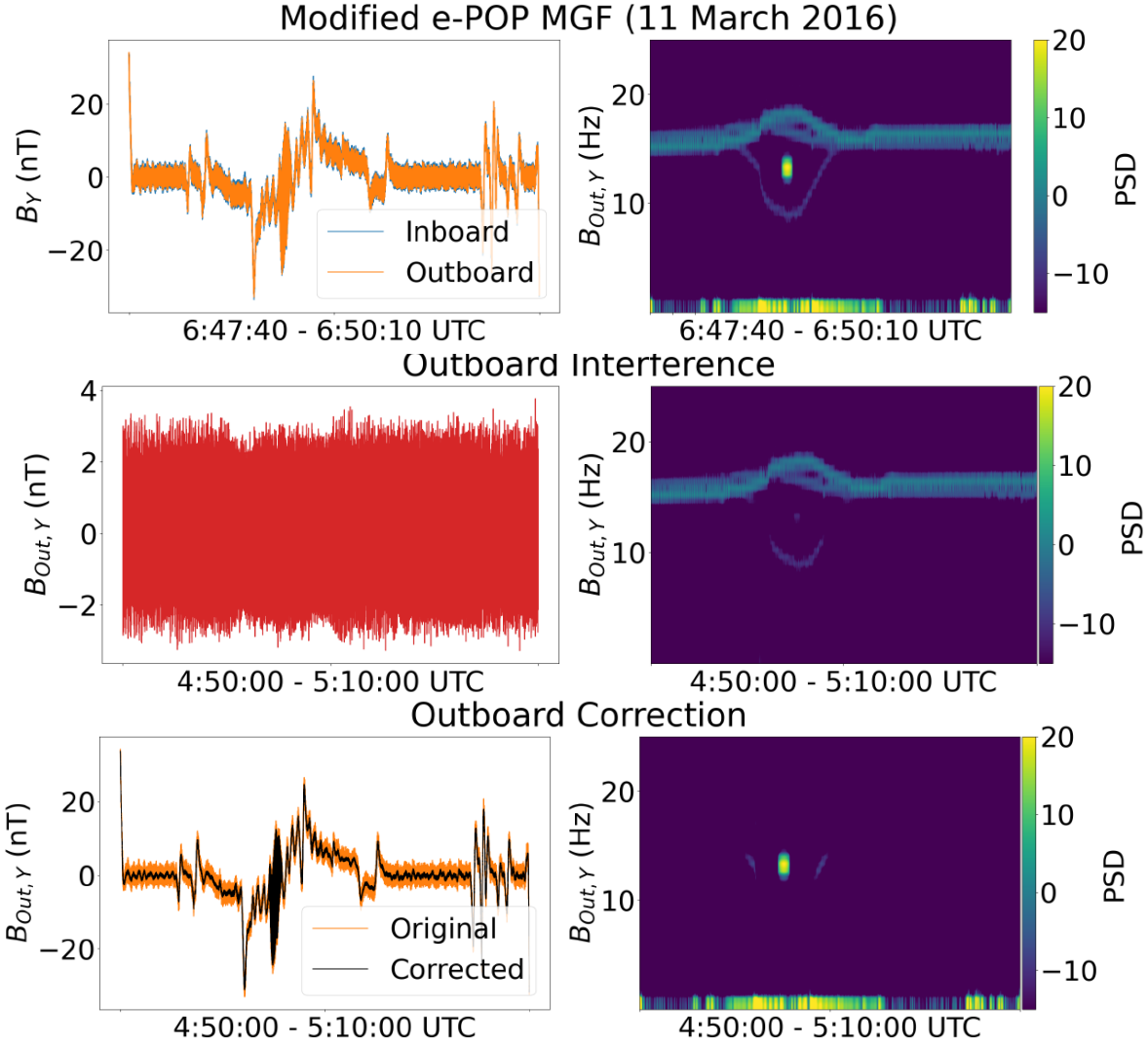
- ~15 Hz prior to 2016 (4 wheels)
- ~1 Hz after 2016 (3 wheels)
- Significant spectral overlap with geophysically interesting phenomena
  - ~1-10 Hz Alfven waves (e.g., Miles et al., 2018)
  - ~1 Hz Small-scale FACs (e.g., Shen et al. 2016, Miles et al., 2019)
- Want a way to remove the reaction wheels without removing the high-frequency information content
- Multichannel Singular Spectrum Analysis (M-SSA) reduces wheel noise from 2.886 to 0.163 nTrms (94.4%) in case studies





Multichannel Singular Spectrum Analysis (M-SSA)





- Reference: Finely et al., 2022 (In Review for JGR)

- Swarm-Echo Level 1B Like Data available at the Swarm repositories and https://epop-data.phys.ucalgary.ca/MGF_lv1b_Reprocessed_Data/
- Plan for next release:
  - Reaction wheel removal
  - Solar panel current removal
  - Sensor temperature correction

- SwarmE-RPT-001 “MGF Lv1b Data Product Description” (Rev -)
- SwarmE-RPT-002 “Swarm-Echo MGF lv1b Data Calibration Validation Report” (Rev -)
- Broadfoot, R. M., Miles, D. M., Holley, W., Howarth, A.D., In-situ calibration of the e-POP/Swarm-ECHO Magnetic Field Experiment, In Review for Geoscientific Instrumentation, methods, and Data systems; https://doi.org/10.5194/egusphere-2022-59
- Finley, M., Shekhar, S., Miles, D. M., Identification and Removal of Reaction Wheel Interference from In-Situ Magnetic Field Data using Multichannel Singular Spectrum Analysis, In Review for JGR Space Physics; https://www.essoar.org/doi/pdf/10.1002/essoar.10511290.1

Thank-you!

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Future Mission Synergy - TRACERS/MAGIC

- TRACERS Small Explorers Mission of dual-spacecraft studying magnetic reconnection
- MAGIC Technology Demo of new low-noise fluxgate cores and high-stability sensor design
- Geospace Dynamics Constellation (GDC) studying M-I-T coupling

Residual Plots