The Magnetometer on the SWFO-L1 Mission

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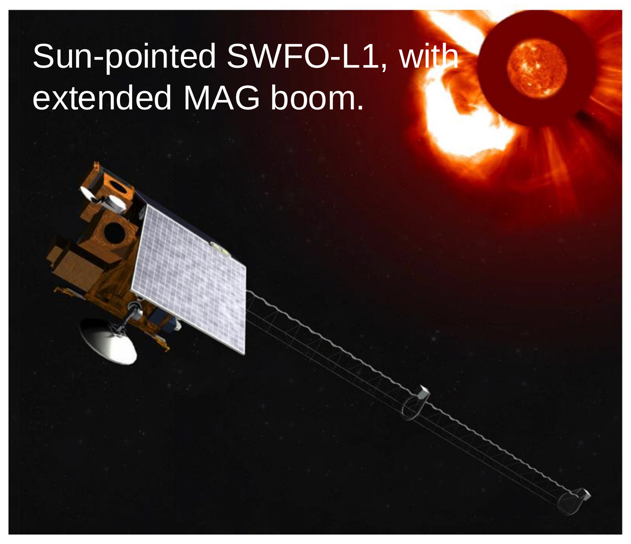
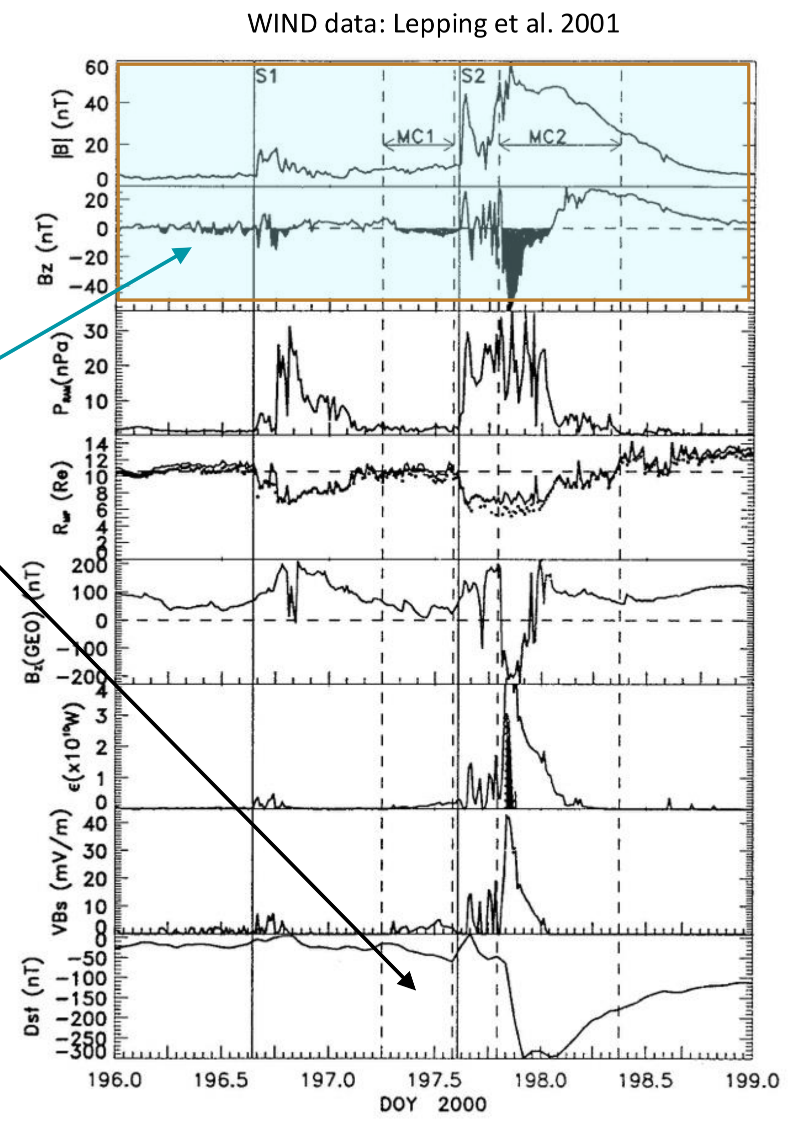
Abstract: SH11F-2862

Overview



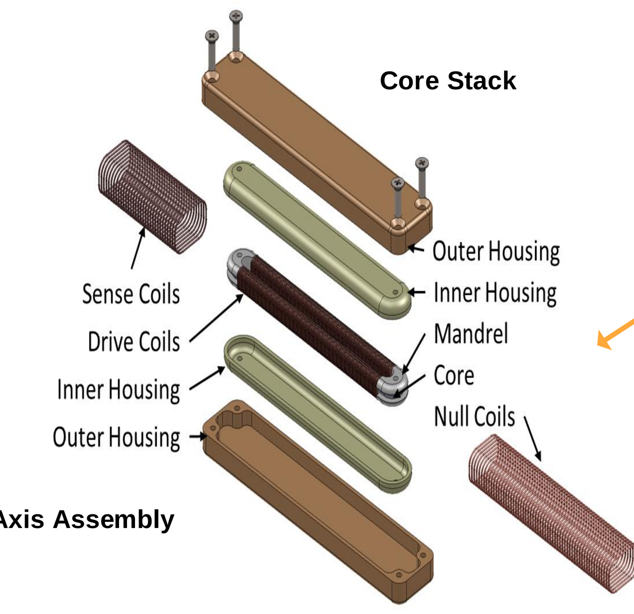
Interplanetary Magnetic Field leads the onset of a geomagnetic storm

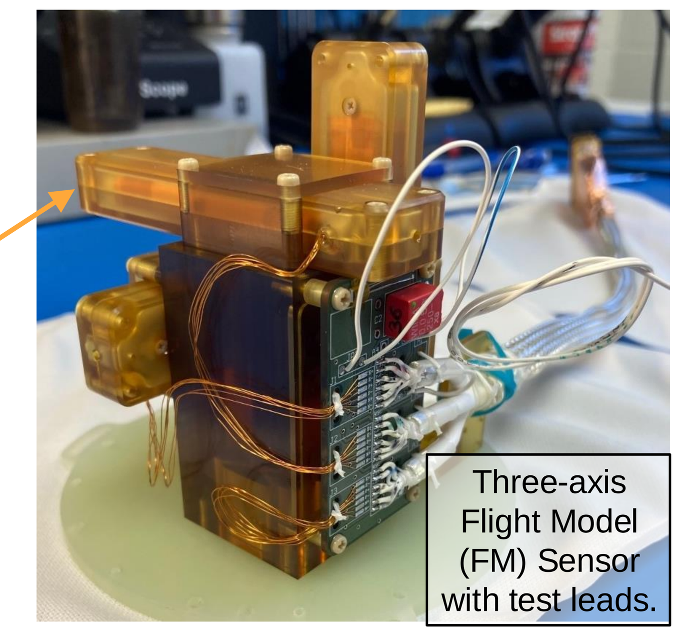


The Space Weather Follow-On mission at L1 (SWFO-L1) is a NOAA/NASA mission to place in-situ and sun-observing instruments at the Lagrangian L1 monitoring point in the solar wind. The magnetometer selected for this mission (MAG) will provide magnetic field measurements that are one of the most important indicators of geoeffectiveness for space weather. Led by SwRI, with engineering teams at UNH and IWF, MAG consists of two 3-axis sensors at the mid-point and end of a 5.6 meter extensible boom mounted on the 3-axis stabilized small satellite. SWFO is expected to be launched in Sept 2025 on a ride-share with NASA's IMAP satellite for a nominal five-year mission.

Sensor and Electronics

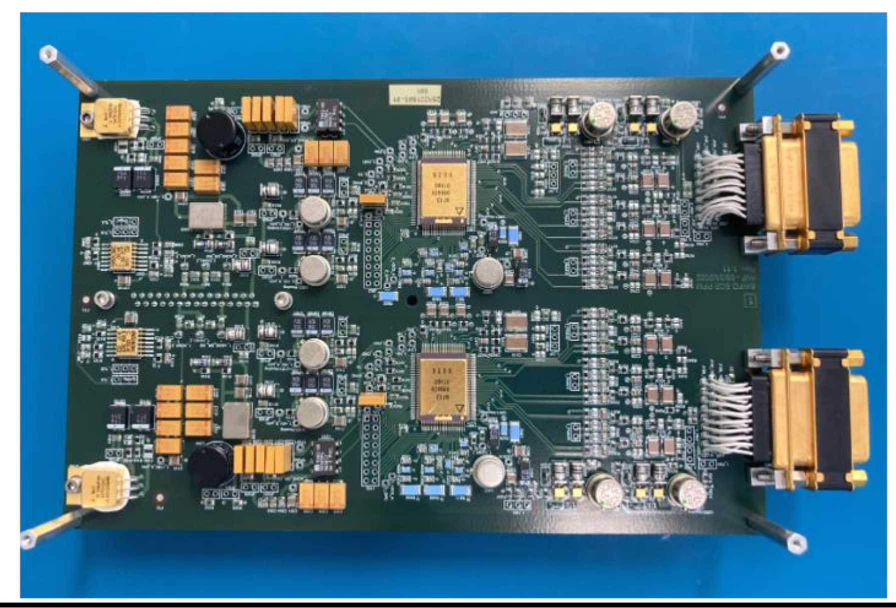
The 3-axis MAG sensor is a racetrack design, with three independent axes and a 6-81 permalloy core (formed from material fabricated by Canmet Materials) that is rolled, heat annealed, wound, and initially screened at UNH.





Three-axis Flight Model (FM) Sensor with test leads.

Dual Channel SCB Board



At IWF, the sensors are then tuned to the Sensor Control Board (SCB), using their MFA3 ASIC, for optimal performance in the Interplanetary magnetic field (IMF). Then IWF conducts a comprehensive performance evaluation, testing drifts in offset, gain, and linearity over temperature and time. The following results apply to the Flight Model (FM).

Requirements & Performance

MAG Requirements/Performance Summary

	Requirement		Expected Performance
Range	In-situ	±250 nT	±440 nT
	Ground test	± 20 µT	± 21 µT
Accuracy	|B| ≤ 100 nT	≤ ±0.5 nT	≤ ±0.32 nT
	|B| > 100 nT & |B| < 250 nT	≤ ±0.5%	±0.25%
	|B| ≥ 250 nT	< ±1000 nT	< ±250 nT
Noise	Integrated [0.05, 0.5] Hz	0.137 nT rms	< 9 pT rms
Quantization Error (Limited only by TM)	|B| ≤ 250 nT	≤ 0.05 nT	≤ 0.03 nT
	|B| ≤ 20,000 nT	≤ 13 nT	≤ 4.0 nT

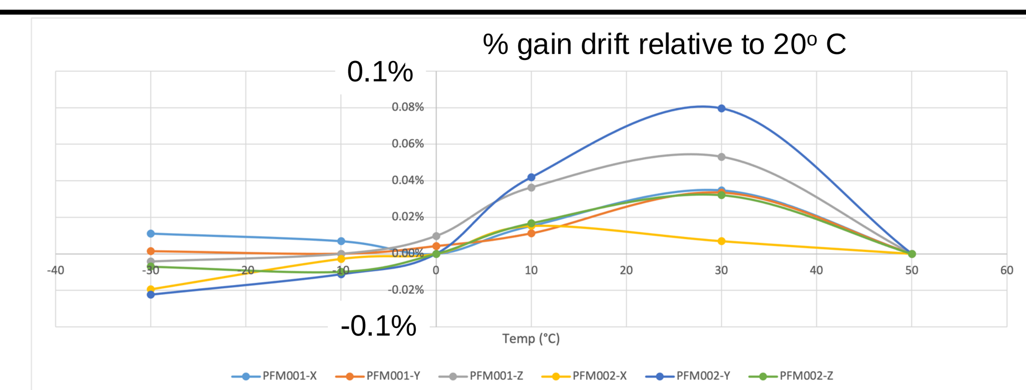
Resources

SWFO-L1 MAG

Sub-assembly	Mass (Kg)	Power (W)
MAG Sensor Pair	0.83	1.48
Boom Harness	1.48	0.04
Electronics Box	1.82	2.50
Total	**4.13**	**4.02**

FM MAG – Power and Mass Resources

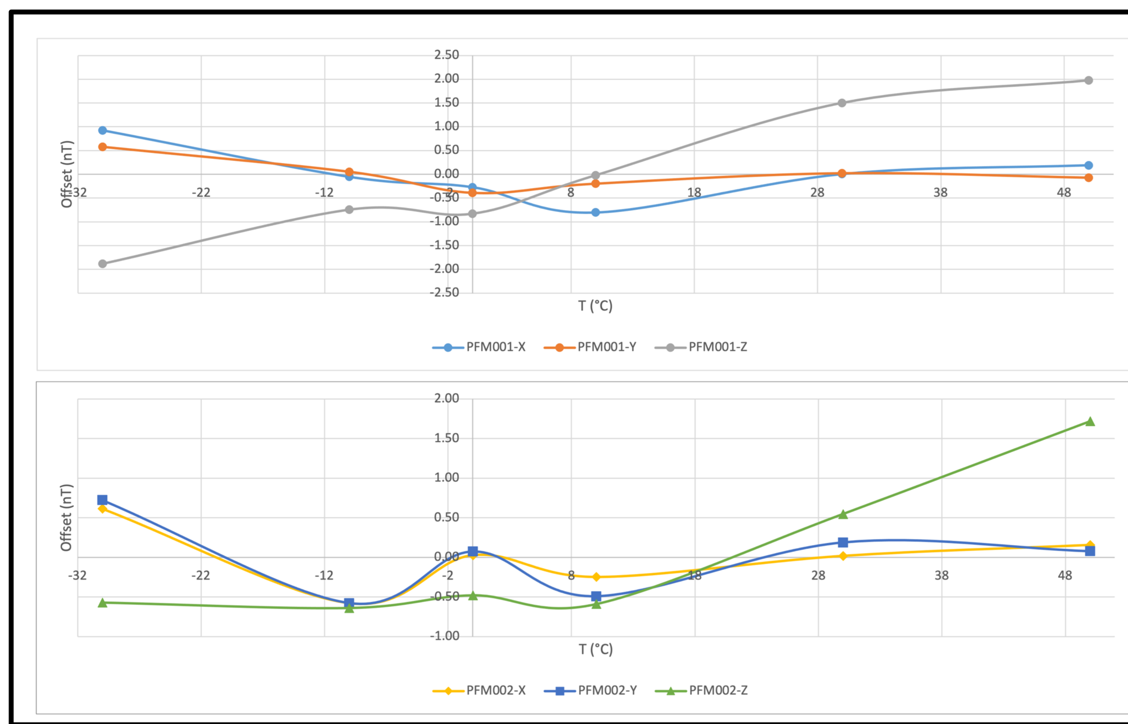
Temperature Dependence: Gains



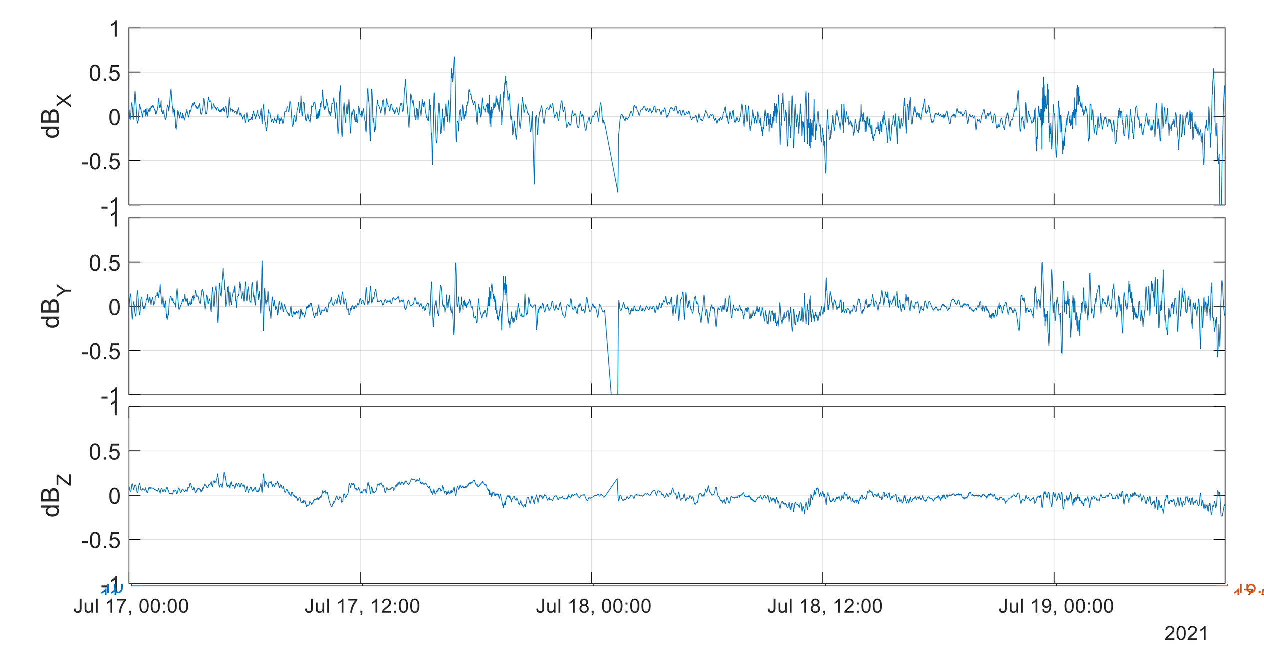
- Exceptionally low gain drift
- For comparison, MMS: ~+60 ppm/°C

PFM	001-X	001-Y	001-Z	002-X	002-Y	002-Z
Linear drift [ppm/°C]	2.0	3.3	8.5	3.3	16.8	5.2
Span [ppm]	348	335	629	347	1355	419

Temperature Dependence: Offsets



Offset Stability



Long-term offset variation at Conrad Observatory (inside mountain). Difference from high-standard reference magnetometer (high frequency differences are due to differences between the two magnetometers in frequency response and group delay).

Noise

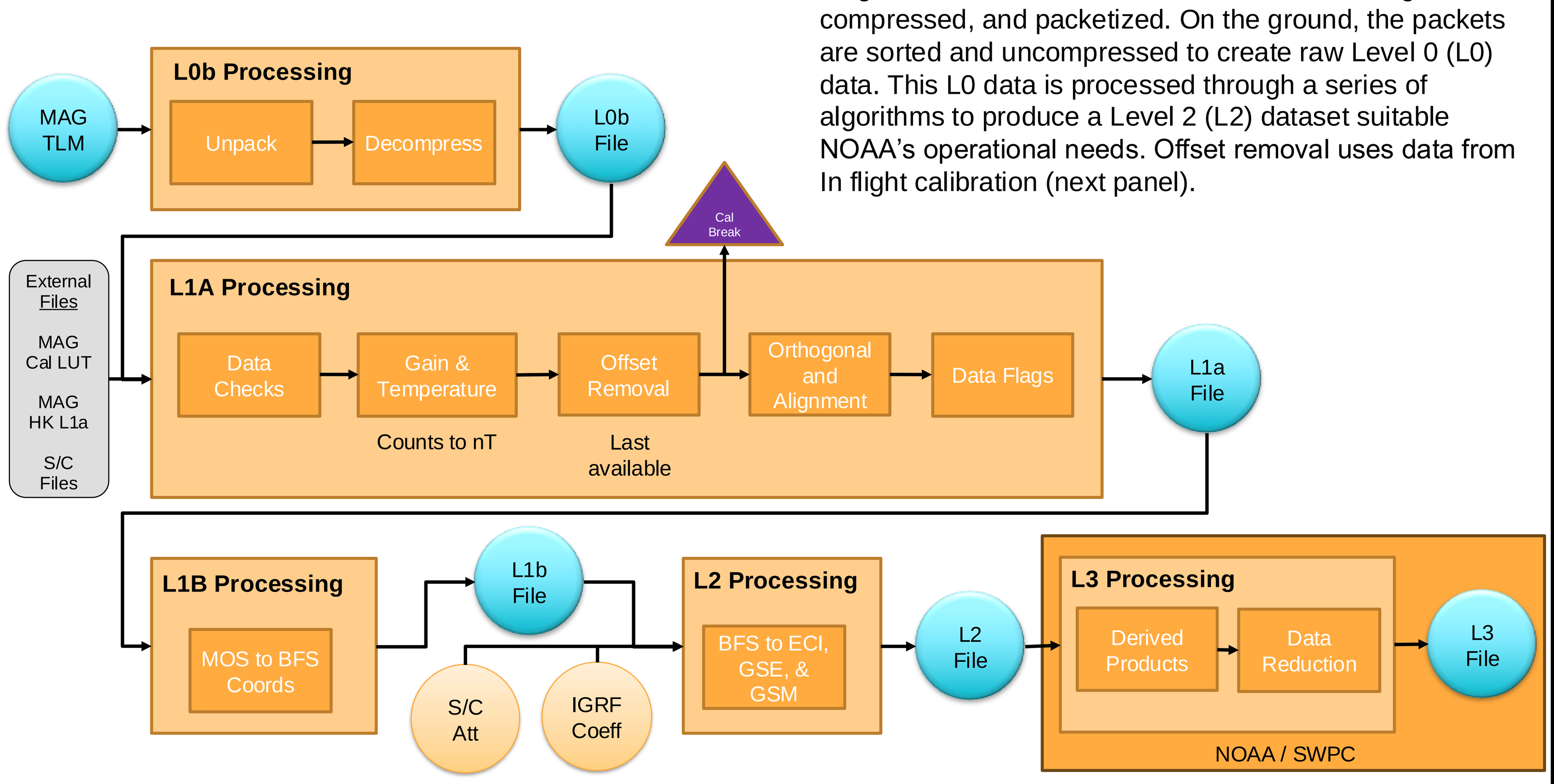
Noise Tests on the Flight Models

Flight Model	X(pT/√Hz) @ 1Hz	Noise X pT RMS	Y (pT/√Hz) @ 1Hz	Noise Y pT, RMS	Z (pT/√Hz) @ 1Hz	Noise Z pT, RMS
FM001	6.92	6.16	6.14	6.33	6.63	8.29
FM002	6.98	6.50	5.68	5.24	6.01	5.48

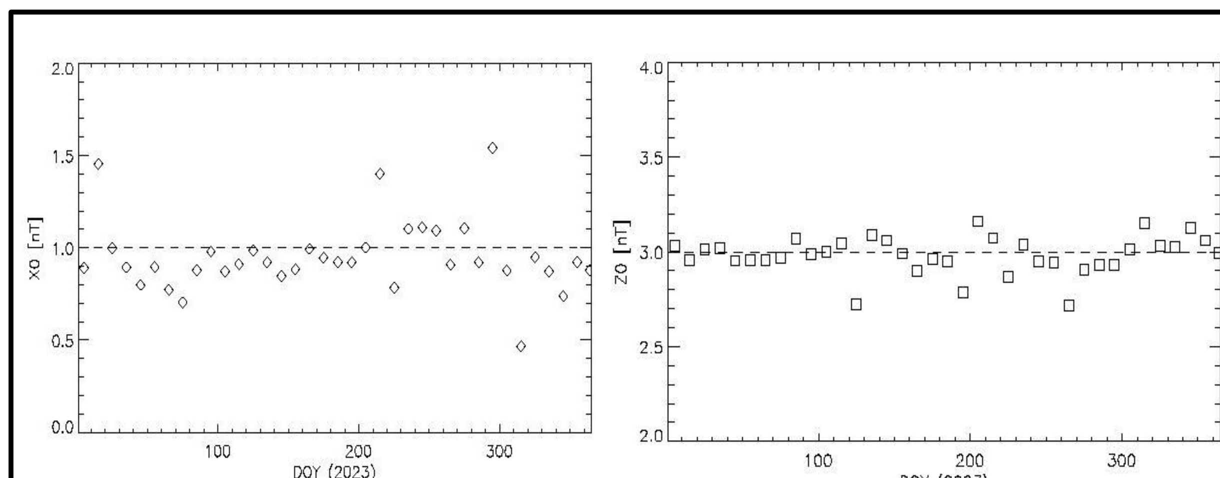
RMS noise integrated from 0.05 to 0.5 Hz

Ground-Processing Algorithms

The MAG measures the three components of the ambient magnetic field. In-situ, the data is then filtered, digitized, compressed, and packetized. On the ground, the packets are sorted and uncompressed to create raw Level 0 (L0) data. This L0 data is processed through a series of algorithms to produce a Level 2 (L2) dataset suitable NOAA's operational needs. Offset removal uses data from In flight calibration (next panel).



In-Flight Calibration



Following a magnetic control program to reduce any contamination sources, the calibration of in-flight data is a continual process that accounts for changing offsets arising from currents originating with spacecraft subsystem and other instruments. We use periodic spacecraft maneuvers and the statistical analysis of solar wind magnetic field fluctuations. To facilitate the latter analysis, we have developed a calibration code based on Leinweber et al. [Meas. Sci. Technol., 19, 055104, 2008] using calibrated, de-spun magnetic field data from the ACE spacecraft to which we add a known offset (horizontal dashed line). The error budget allows for an uncertainty in the instrument calibration of ±0.3 nT. In the year shown, calibration is obtained using four days of data every ten days with the results being almost always less than the allowed uncertainty. (Bx and Bz shown).

Summary

After IWF testing, the sensors and SCB are integrated with the digital electronics at UNH, followed with usual acceptance testing. The units are then fully calibrated at GSFC for linearity, offsets, gains and orthogonality. MAG is then integrated into the boom and spacecraft at Ball Aerospace (now BAE).

In flight, 64 sample/sec data flows to NOAA's Space Weather Prediction Center (SWPC) where it is processed to L2 level for integration into the space weather models and deposited into the publicly available servers at the National Centers for Environmental Information (NCEI).

Magnetometer offsets are routinely determined by both rotation of the satellite and analysis of flight data with the Davis-Smith method (panel to left) which relies on the Alfvenic variations of the IMF where the magnitude is approximately constant.