GOES-17 Magnetometer On-Orbit Calibration Design and Results

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Photography encouraged

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Agenda

- Introduction to GOES/GOES-17 Magnetometer
- Magnetometer Bias Measurement Example
- Overview of GOES-16 (original) calibration maneuver
- Overview of GOES-17 (new) calibration maneuver
- GOES-16 vs GOES-17 calibration maneuver comparison
- Maneuver Analysis and Simulation
- GOES-17 Calibration Maneuver Results
- Conclusions/Acknowledgements

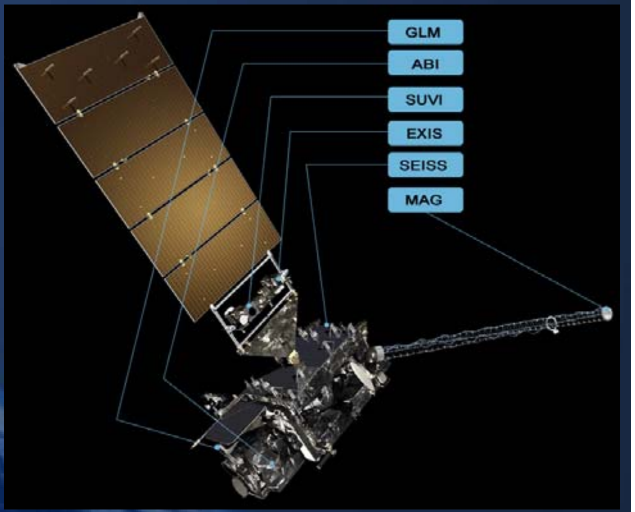
Geostationary Operational Environmental Satellites (GOES)

- United States weather satellites in geostationary orbits
- Joint project between the National Oceanic and Atmospheric Administration (NOAA) and the National Aeronautics and Space Administration (NASA)

www.goes-r.gov

GOES-17

- Identified as GOES-S prior to reaching geostationary orbit
- Newest GOES satellite and the second in the GOES-R series
- Payload of two Earth-observing and four space weather instruments



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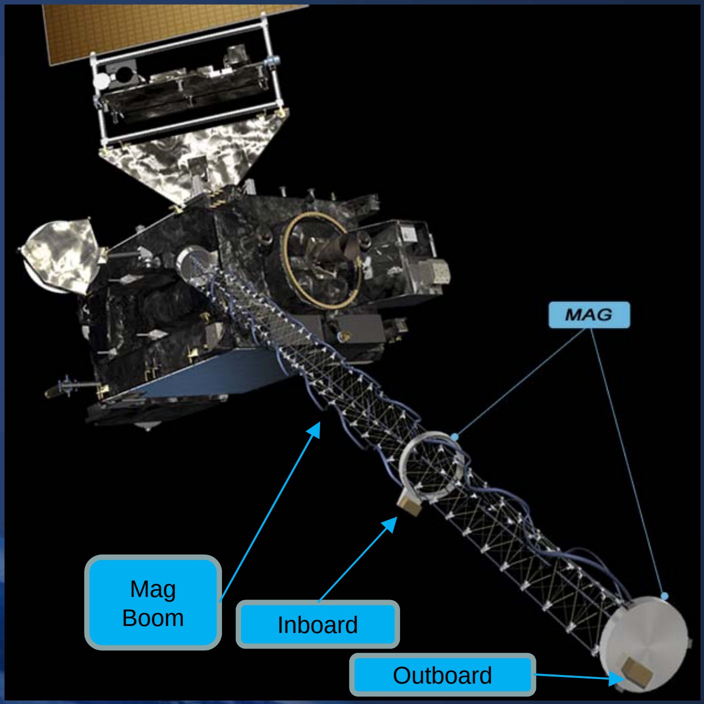
GOES-17 Magnetometer

- Measures the “in-situ” ambient magnetic field at geostationary orbit
- Used for space weather predications and “nowcasting”
- Consists of inboard (IB) and outboard (OB) fluxgate sensors mounted on a deployable boom 6.3 and 8.5 meters from the spacecraft, respectively
- Both the IB and OB measure the magnetic field in three orthogonal axes. The Z-axis follows the centerline of the deployed boom while X and Y are parallel to the mounting plate



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GOES-17 Magnetometer Bias

- Both the spacecraft and the magnetometer itself generate magnetic fields that corrupt ambient field measurements
- This generates a bias, or zero-offset, that must be measured so that it can be removed in calibrated field data

Measuring Magnetometer Bias: A Simplified Example

B

Constant ambient field

$Measurement\ 1 = B_z + bias_z$

Rotate 180°. Bias “rotates with” instrument

$Measurement\ 2 = -B_z + bias_z$

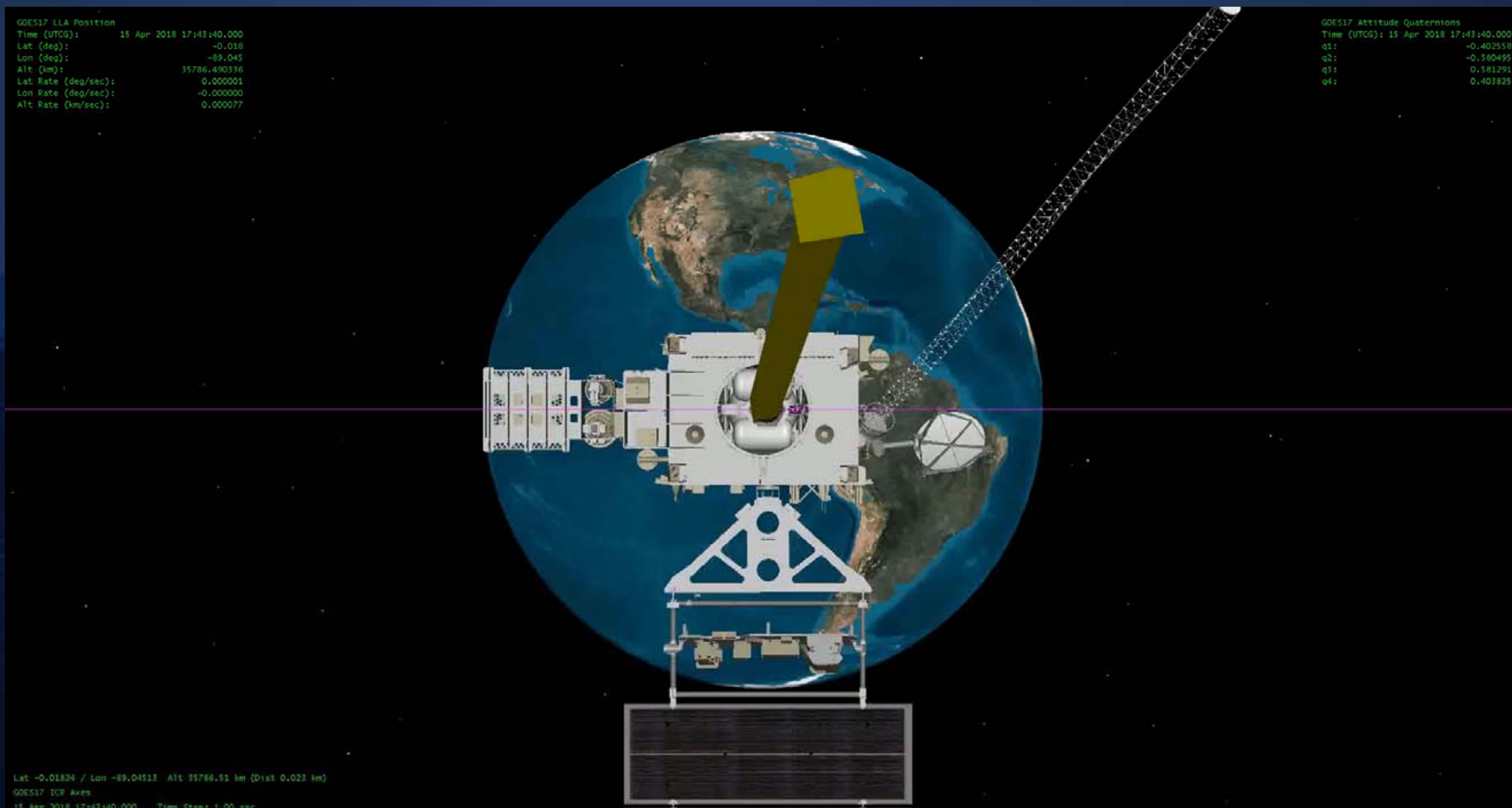
z

$$bias_z = (Measurement\ 1 + Measurement\ 2)/2$$

In practice, a 180° rotation is not required, but is ideal from a signal-to-noise perspective (maximum “observability”).

Also, note that the assumption that the ambient field is constant is improved by reducing the time between measurements.

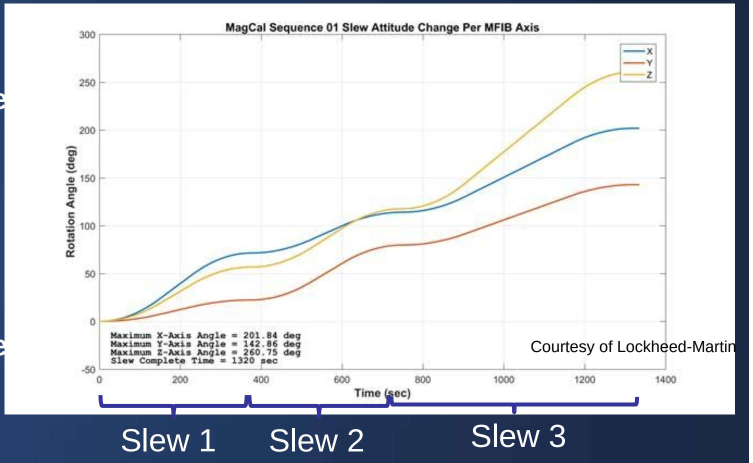
GOES-16 (Original) Magnetometer Calibration Maneuver



Courtesy of Lockheed-Martin

GOES-16 (Original) Magnetometer Calibration Maneuver Summary

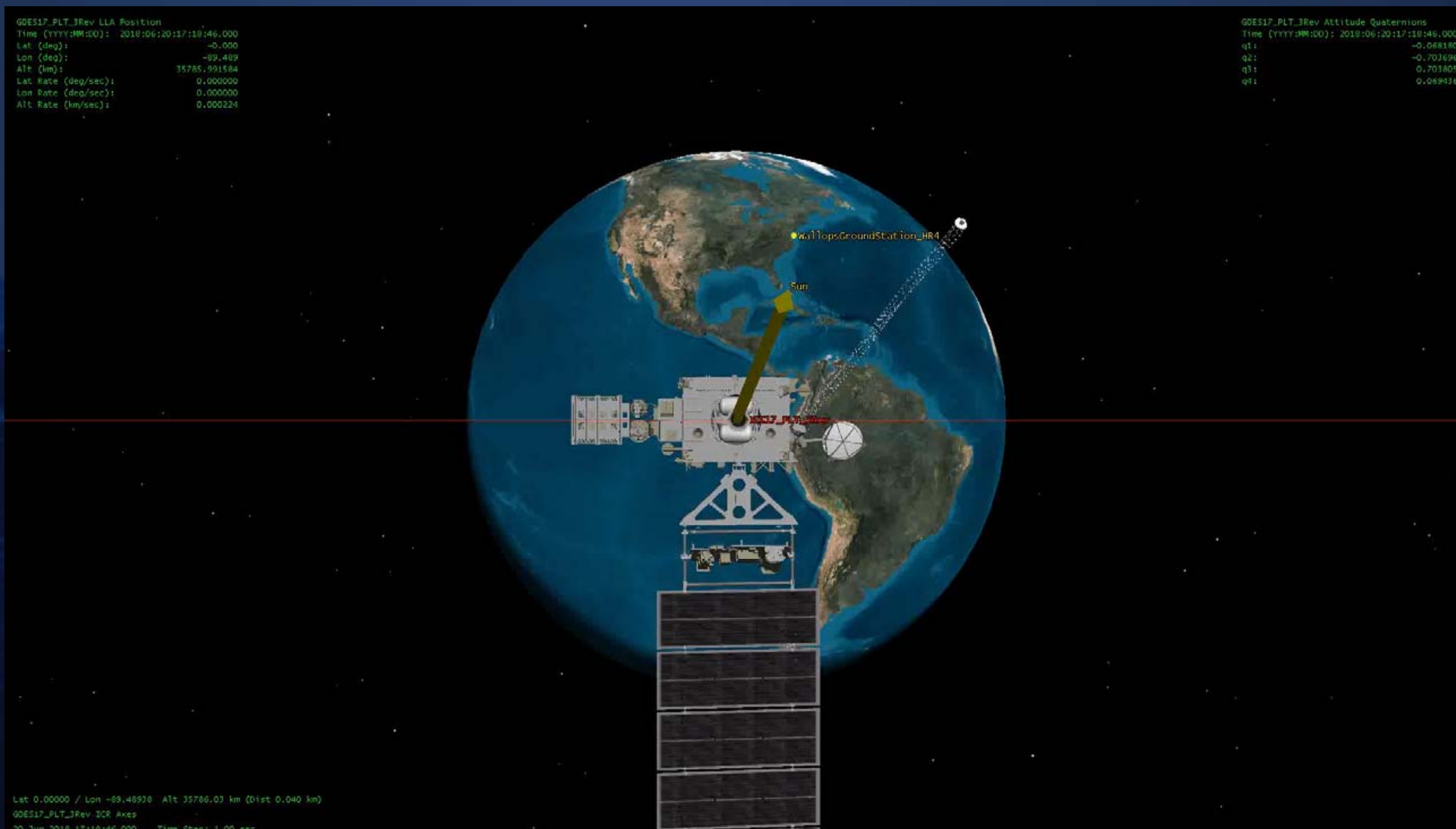
1. **Relative Slew #1**
   - **6 min, 15 sec in duration**
   - **Max angular rate: 0.43 °/second**
   - **Inboard magnetometer sensor frame axes amount of rotation (Euler angle**
     - **X-axis: ~75°**
     - **Y-axis: ~25°**
     - **Z-axis: ~60°**
2. **Relative Slew #2**
   - **6 min, 15 sec in duration**
   - **Max angular rate: 0.43 °/second**
   - **Inboard magnetometer sensor frame axes amount of rotation (Euler angle**
     - **X-axis: ~45°**
     - **Y-axis: ~50°**
     - **Z-axis: ~60°**
3. **Nadir Slew #3 – back to Nadir Pointing (standard operational attitude)**
   - **9 min, 30 sec in duration**
   - **Inboard magnetometer sensor frame axes amount of rotation (Euler angles):**
     - **X-axis: ~80°**
     - **Y-axis: ~65°**
     - **Z-axis: ~145°**



Constrained by maximum spacecraft +Z axis offpoint of 29° to ensure adequate communications coverage. Constraint was based upon pre-launch predictions.

Estimate of GOES-16 maneuver bias measurement error from three maneuvers ranged from 3.1 to 5.1 nT, precipitating the need for an improved calibration maneuver for GOES-17.

GOES-17 (New) Magnetometer Calibration Maneuver



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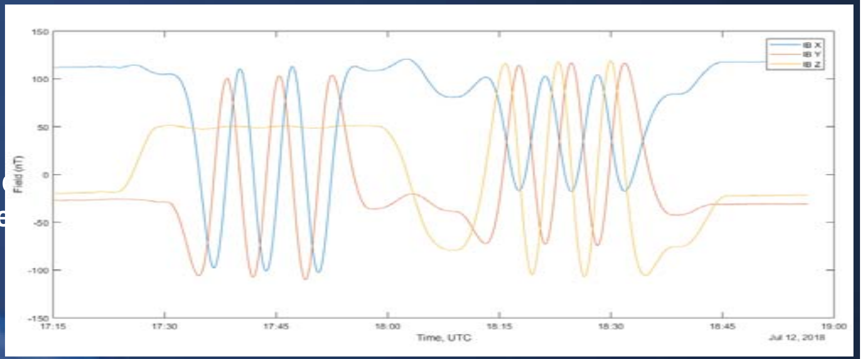
GOES-17 (New) Magnetometer Calibration Maneuver Summary

1. **Relative Slew #1**
2. **Relative Slew #2 – Calibration slew for X and Y axes**
   - **27 min, 4 sec in duration**
   - **Fastest (middle) 360° is 7 min, 3.53 sec**
   - **Max angular rate: 0.85 °/second (original maneuver: 0.43 °/second)**
   - **Six 180° rotations about the MAG sensor frame Z-axis (parallel to the boom)**
     - **"Full observability" of sensor frame X and Y axes bias**
3. **Relative Slew #3**
4. **Relative Slew #4 – Calibration slew for Z axis**
   - **29 min, 2 sec in duration**
   - **Fastest (middle) 360° rotation is 7 min, 3.53 sec**
   - **Max angular rate: 0.85 °/second (original maneuver: 0.43 °/secon**
   - **Six 180° rotations about axis perpendicular to MAG sensor frame Z-axis (perpendicular to the boom)**
     - **"Full observability" of sensor frame Z axis bias**
5. **Nadir Slew #5 – back to Nadir Pointing (standard operational attitude)**



MAG IB Field data from Jul 12, 2018 maneuver

Re-evaluation of comm coverage from GOES-16 flight data allowed a larger spacecraft +Z axis offpoint from nadir than with original maneuver.

An additional version of the new calibration maneuver was created for use during operations (instead of the post-launch period), consisting of one 360° rotation for each calibration slew instead of three, which minimizes operations outage.

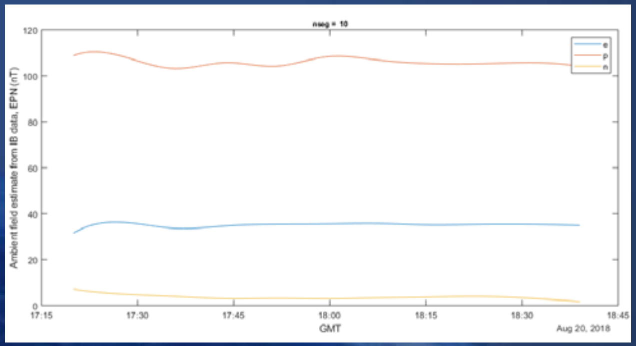
GOES-16 vs GOES-17 Magnetometer Calibration Maneuver Comparison

	GOES-16 Maneuver	GOES-17 Maneuver
Maximum Angular Rate	0.43 °/second	0.85 °/second
Calibration Slew #1 Rotation Amount	94°	6x180°
Calibration Slew #2 Rotation Amount	94°	6x180°
Calibration Slew Rotation Axes	None aligned with MAG boom axes	One aligned with MAG boom, one normal to MAG boom (“Full observability” of X/Y and Z axes)
Overall maneuver time	22 minutes	82 minutes
Forward Hemi Antenna Comm Constraint	ACRF Z-axis within 30° of nadir	ACRF Z-axis within 60° of ground station

GOES-17 (New) Calibration Maneuver Analysis

- **New calibration maneuver is 78 minutes in duration as opposed to 22 minutes for the original maneuver. Improved analysis is needed where the background is not assumed to be constant, as it was with GOES-16.**

- **New analysis spline-fits background field in EPN coordinates (improvement over G16 analysis method, which assumed constant background), minimizes field estimate errors (same as G16 method)**



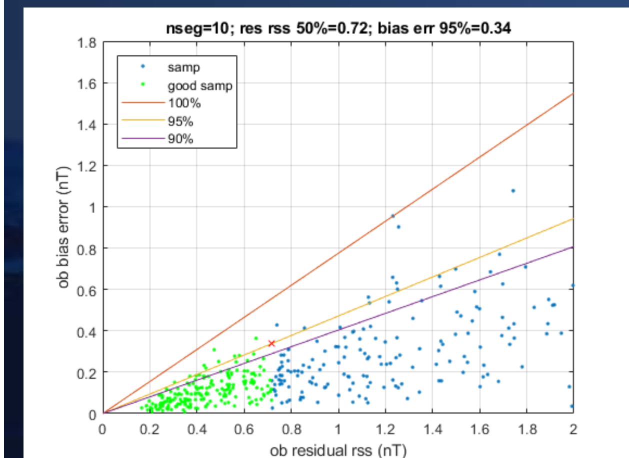
Background spline fit from Aug 20, 2018 maneuver

- **New method finds sensor bias and misalignment (same as G16 method)**

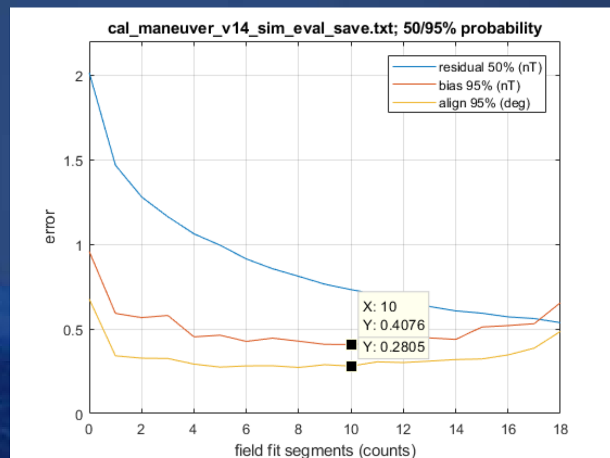
- **Simulations were run to validate the method, find the optimal number of spline fit segments**
  - **One year of GOES-16 data was used**
  - **For each day, data corresponding to the maneuver time period was artificially rotated using the maneuver rotations**
  - **The error for that day was the bias computed from the artificially rotated data**

New Maneuver Analysis Simulation Results

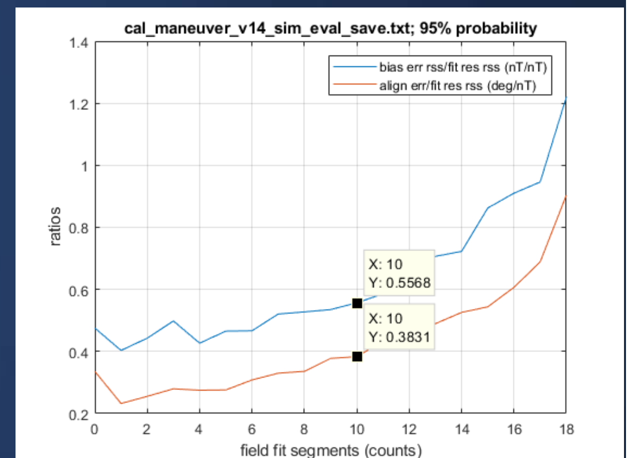
Simulations were run, varying the number of segments, to find the number of segments with the least bias error and the bias error-to-spline fit residual RSS ratio for which 95% of the data points were at or below. A similar analysis was completed for the alignment measurement error.



Simulation result for 10 spline fit segments. The yellow line represents the 95% confidence level, i.e. 95% of the data points are at or below the bias error-to-residual RSS ratio represented by the yellow line.



Alignment and bias error vs. number of spline segments at median RSS with 95% confidence



Alignment and bias 95% confidence error-to-residual ratios vs. number of spline segments

Simulations indicate that ~10 spline segments is ideal. Larger numbers of spline segments over-fit the background, i.e. fit noise. Error-to-residual ratios from simulations can be used to estimate error based on spline fit residual.

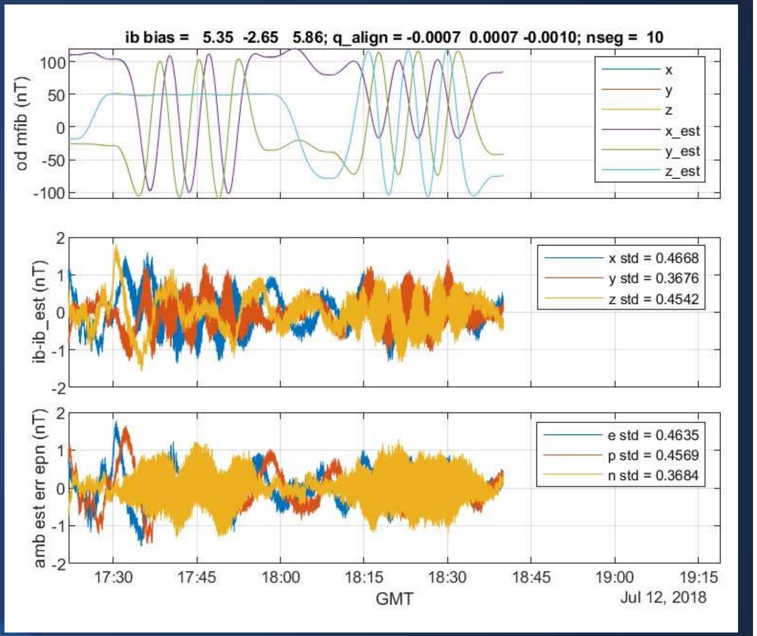
GOES-17 Calibration Maneuver Results

July 12, 2018 calibration maneuver:

- Kp index (measure of geomagnetic activity) = 1
- IB bias measurement error estimate: 0.42 nT
- OB bias measurement error estimate: 0.38 nT
- IB alignment measurement error estimate: 0.29°
- OB alignment measurement error estimate: 0.26°

August 20, 2018 calibration maneuver:

- Kp index = 3 at start of maneuver, 4 by end of maneuver
- IB bias measurement error estimate: 0.73 nT
- OB bias measurement error estimate: 0.74 nT
- IB alignment measurement error estimate: 0.50°
- OB alignment measurement error estimate: 0.51°



GOES-17 IB fields (top), background fit residual in IB frame (middle), and background fit residual in EPN/error estimate (bottom) from July 12, 2018 calibration maneuver

Error estimates are RSS of all three axes.

Since the Kp index was higher on August 20, it is not surprising that the errors are larger.

Estimate of GOES-16 maneuver bias measurement error: 3.1 to 5.1 nT

Conclusions/Acknowledgements

Conclusions

- New/GOES-17 Magnetometer calibration maneuver is a marked improvement over the original/GOES-16 maneuver in angle of rotations/axis “observability”. New maneuver has twelve 180° calibration rotations parallel/perpendicular to boom axes vs. two 94° calibration rotations not aligned with boom axes for GOES-16
- Maneuver rotation speed increased by a factor of ~2x, reducing background variability
- New maneuver analysis spline-fits the background field, instead of assuming it is constant as in the old method
- Simulations determined the optimal number of spline fit segments
- GOES-17 calibration maneuver bias measurement uncertainty is improved by about an order of magnitude over GOES-16

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