LESSONS LEARNED FROM FLIGHT OBSERVATIONS OF THE GOES-R MAGNETOMETER

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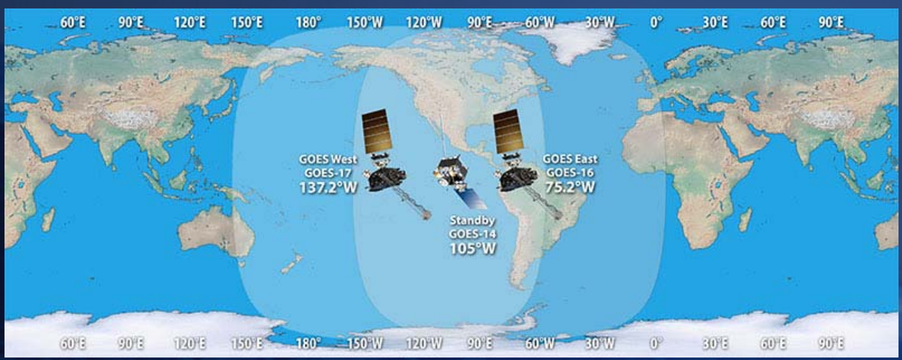
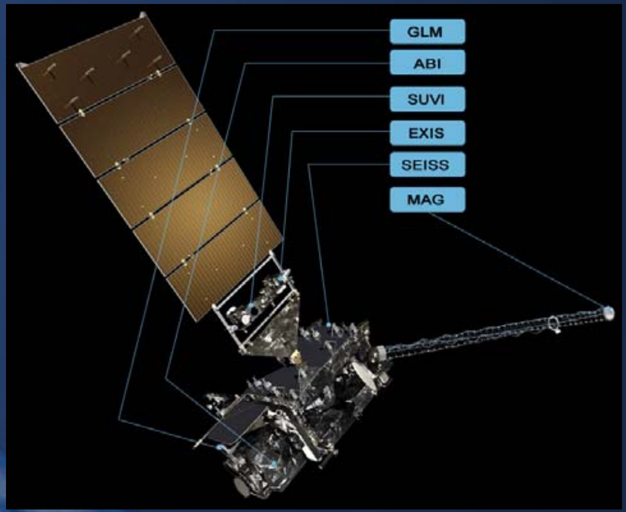
ESA Workshop on Aerospace EMC 2019 • May 20, 2019 • Budapest, Hungary

Introduction

<u>Geostationary Operational Environmental Satellites (GOES)</u>

- **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)**





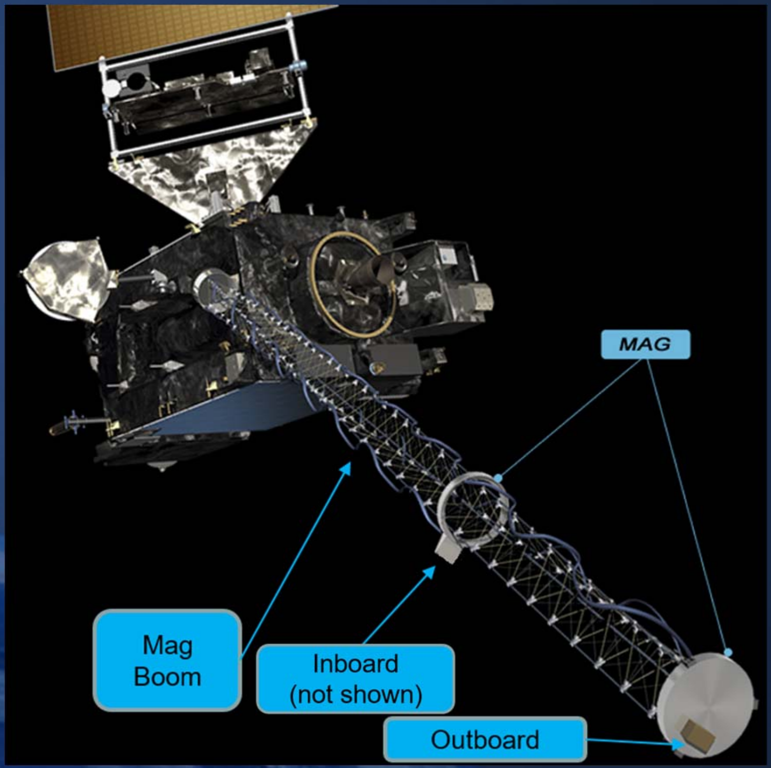
<u>GOES-16</u>

- **GOES-R launched November 19, 2016**
- **The first satellite in the series, GOES-R, was renamed GOES-16 upon reaching geostationary orbit**
- **GOES-16 at GOES-Checkout location (89.5⁰ W) during PLT**
- **The GOES-16 magnetometer boom was deployed on December 7, 2016 and magnetometer checkout began**

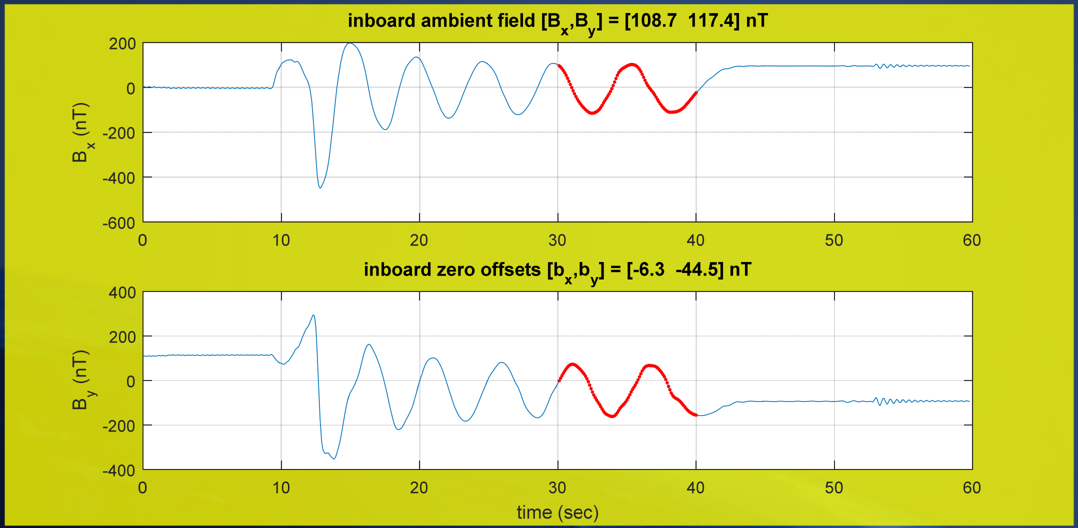
Introduction

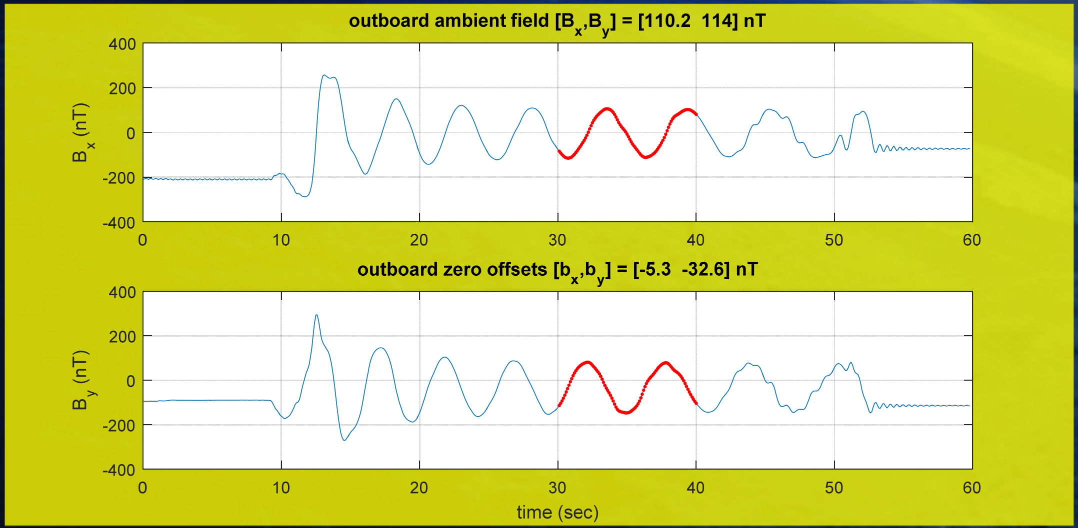
GOES-16 Magnetometer

- Measures the “in-situ” ambient magnetic field at geostationary orbit
- 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



On-Orbit Observations
Large Zero Offset

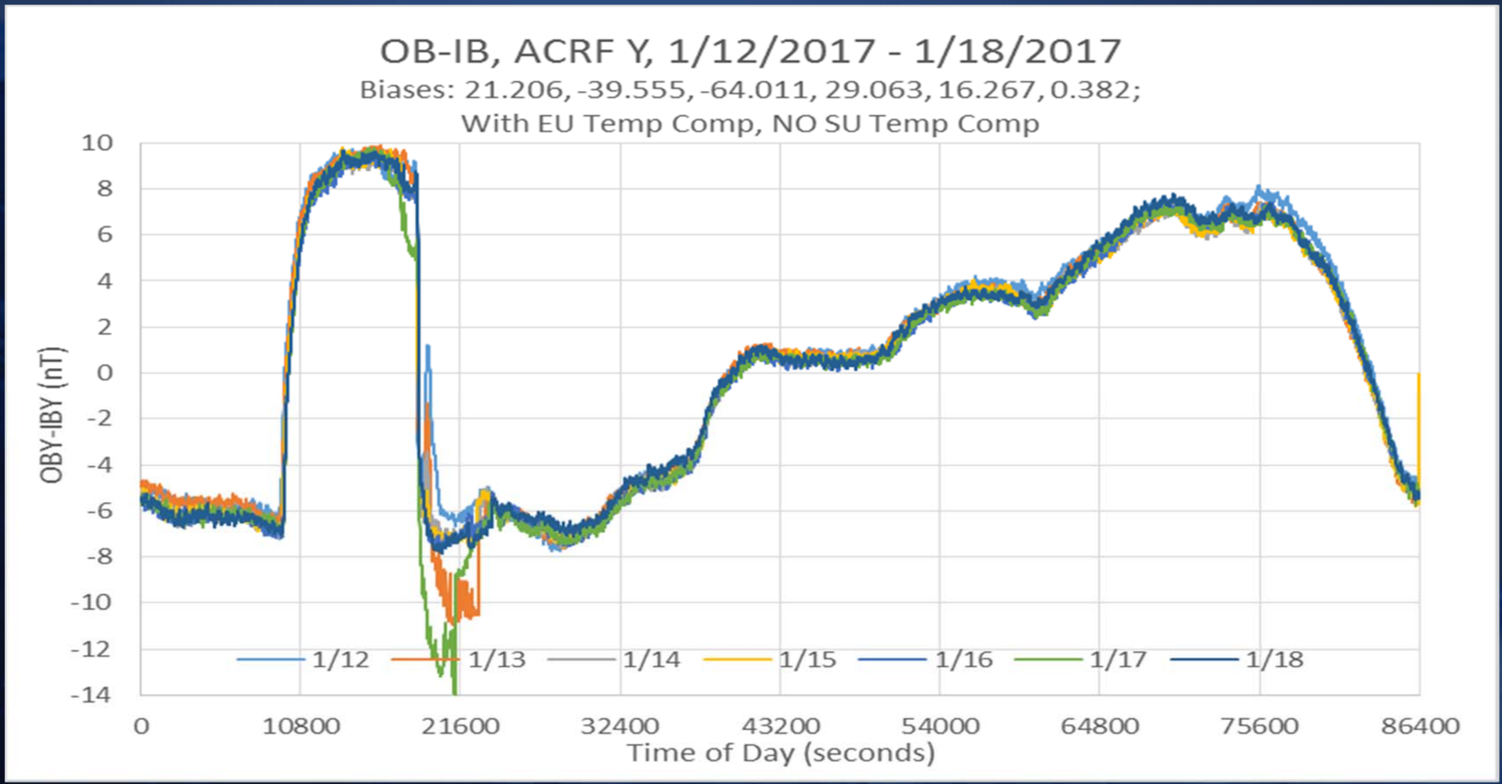




- Boom rotates about sensor Z axis providing visibility into X and Y axis zero offset
- Inboard Offset:
  - X axis = -6.3 nT
  - Y axis = -44.5 nT
- Outboard Offset:
  - X offset = -5.3 nT
  - Y offset = -32.6 nT
- ~ 30 to 40 nT change in Y axis relative to ground calibration

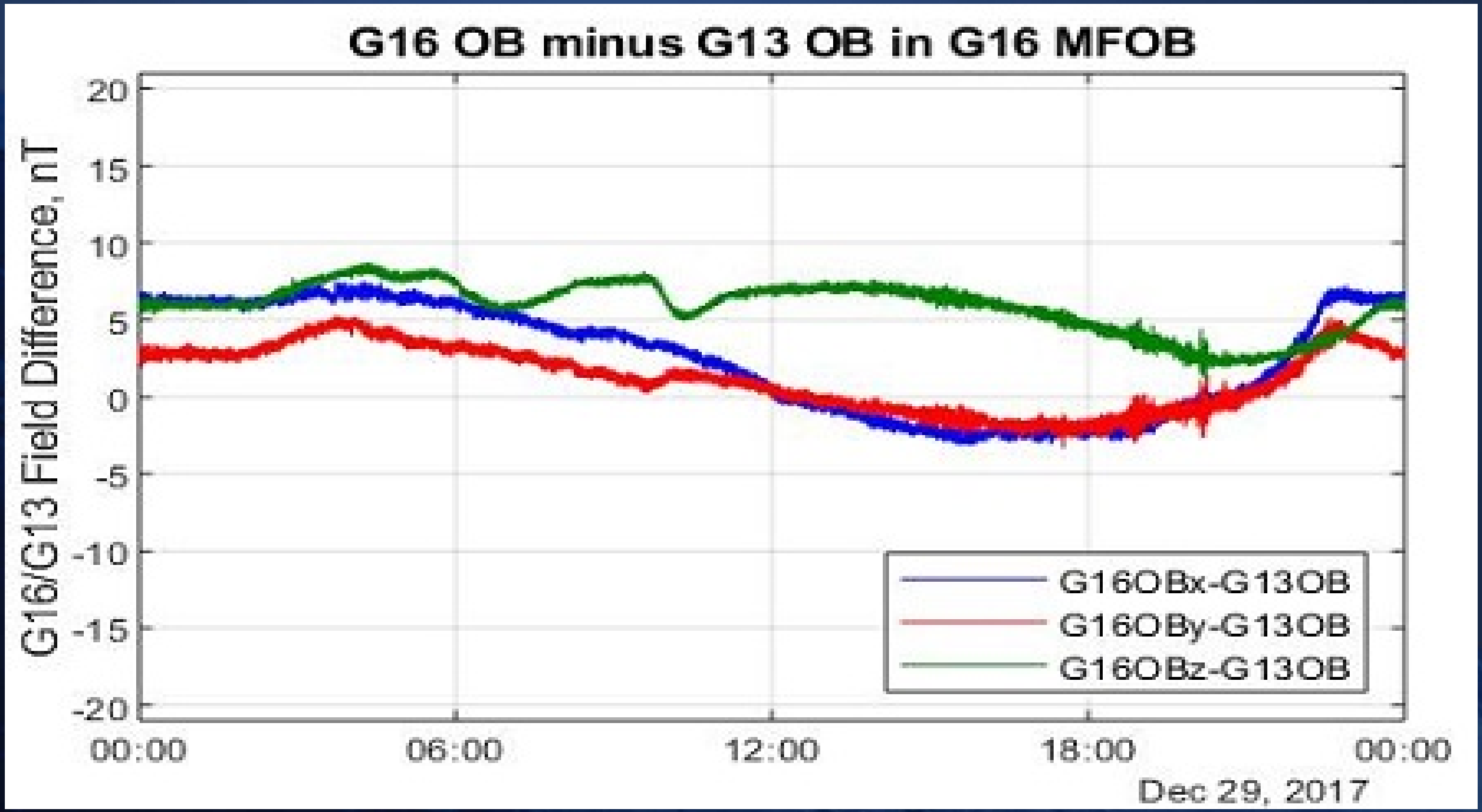
On-Orbit Observations
Large Variation Between Inboard and Outboard

- Expected difference between the two magnetometers should be <2 nT with small variances in the spacecraft field causing diurnal variation
- On-Orbit difference repeatable day to day with 15 to 20 nT swing in Y and Z axes
- Most of the variation is due to the Inboard Magnetometer



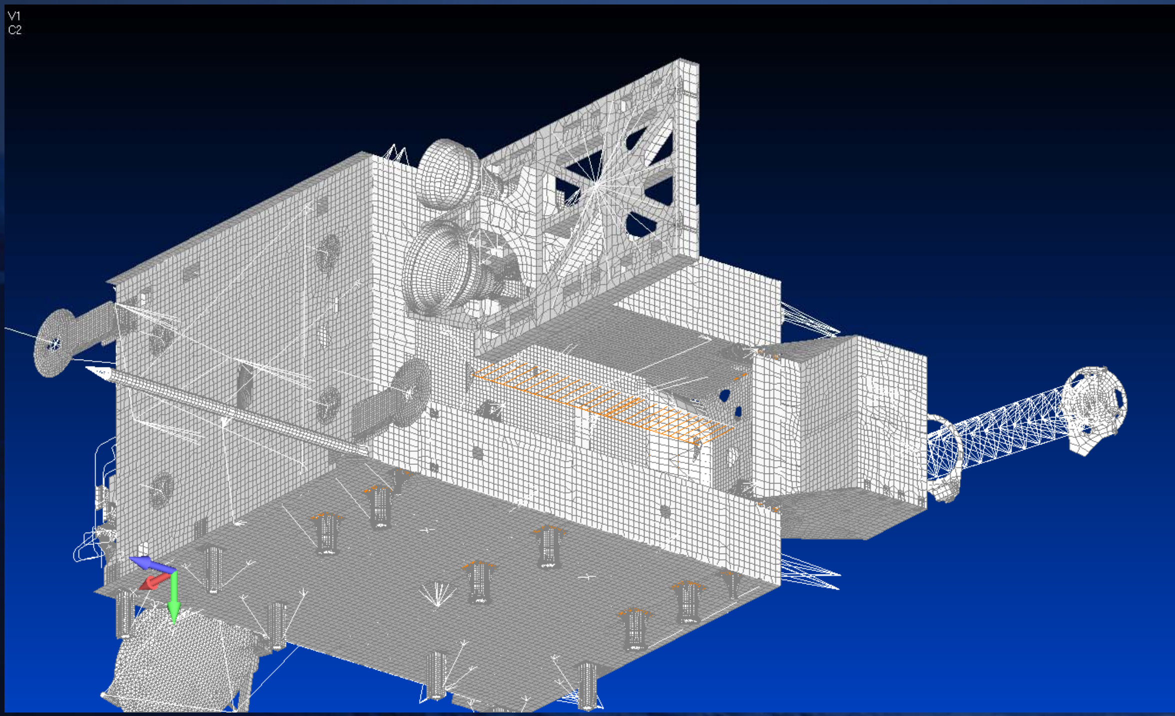
On-Orbit Observations
Variation In Outboard Magnetometer

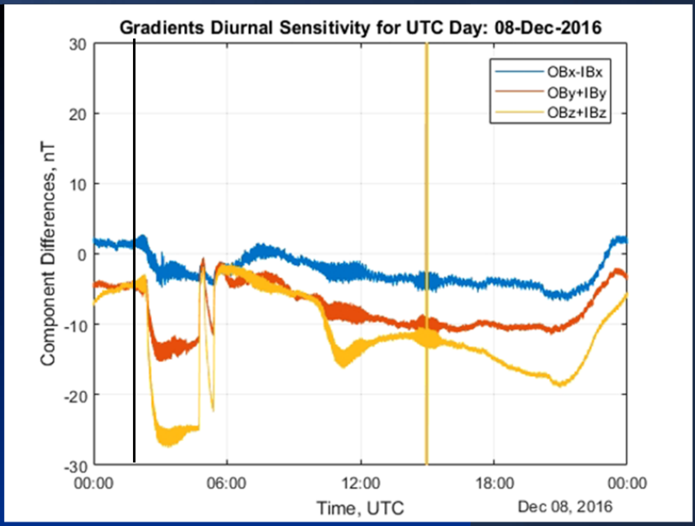
- **Outboard Magnetometer has 5 to 10 nT variation when compared to existing on-orbit GOES satellites**



Root Cause Investigation
Inboard Shadowing

- **Large swings in Inboard measurements correlates to shadowing of magnetometer by Spacecraft body and antenna**

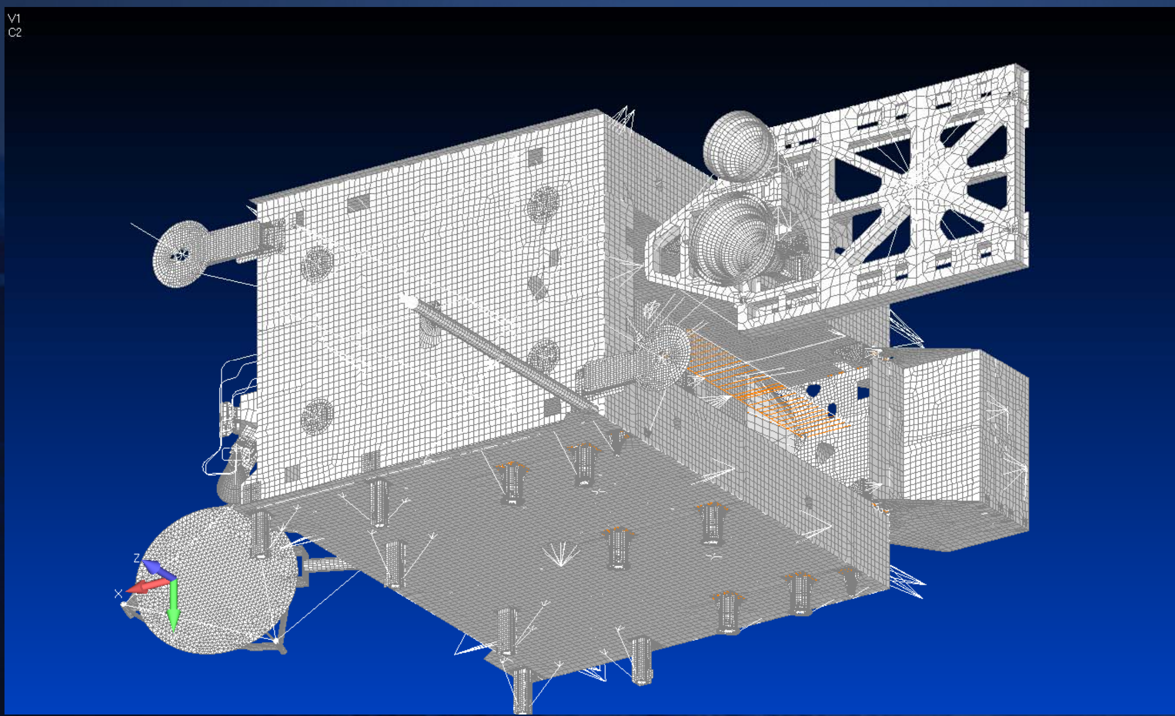


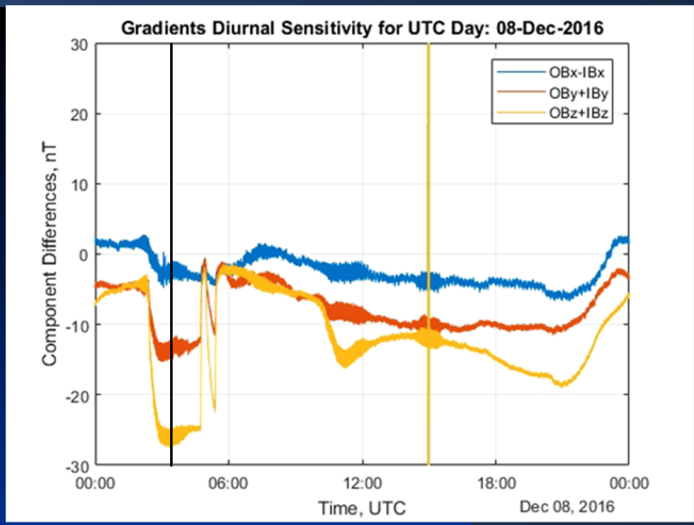


View from the Sun immediately prior to Inboard shadowing

Root Cause Investigation
Inboard Shadowing

- **Large swings in Inboard measurements correlates to shadowing of magnetometer by Spacecraft body and antenna**

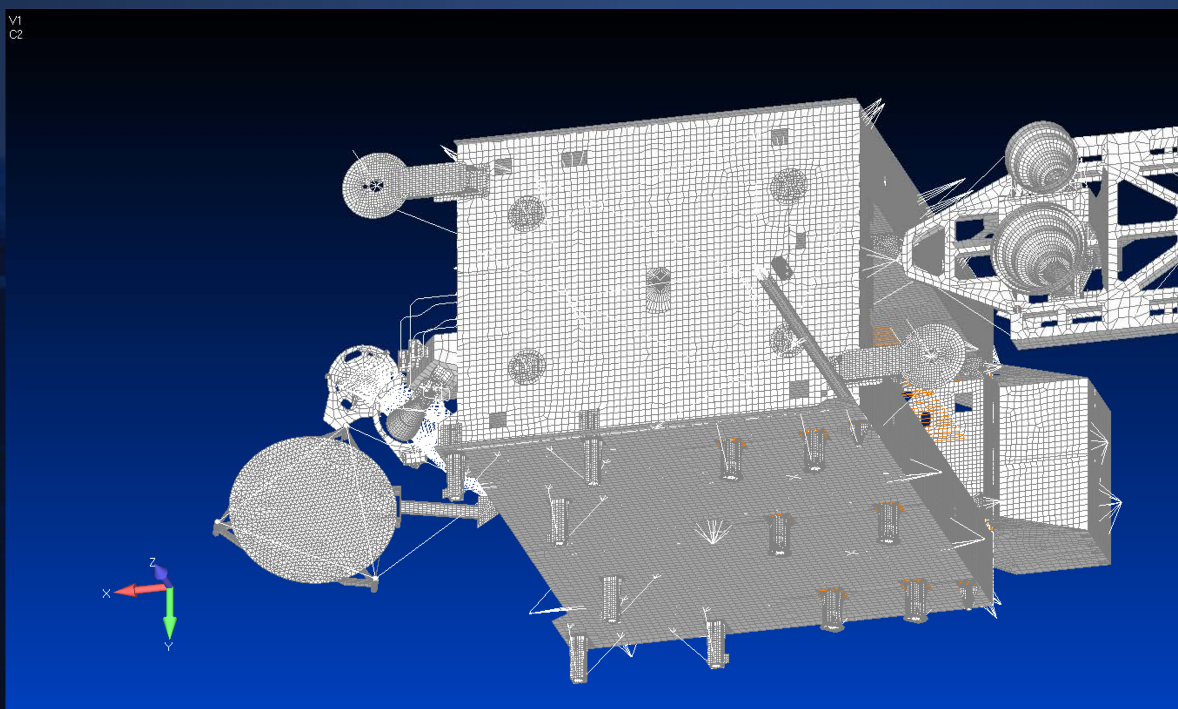


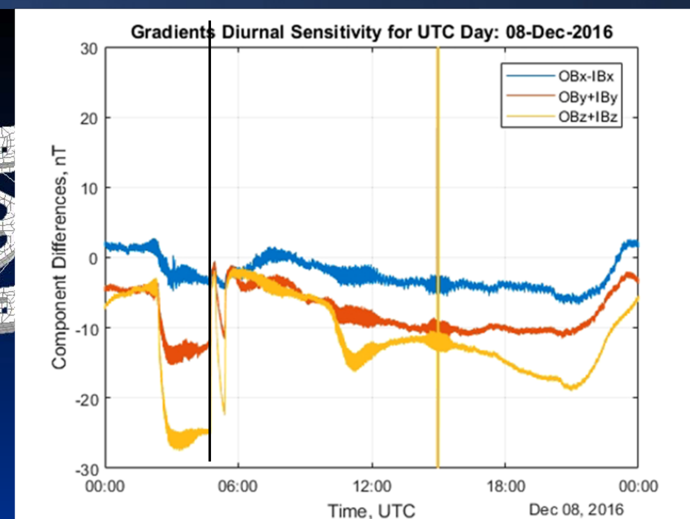


View from the Sun - Inboard shadowed

Root Cause Investigation
Inboard Shadowing

- **Large swings in Inboard measurements correlates to shadowing of magnetometer by Spacecraft body and antenna**

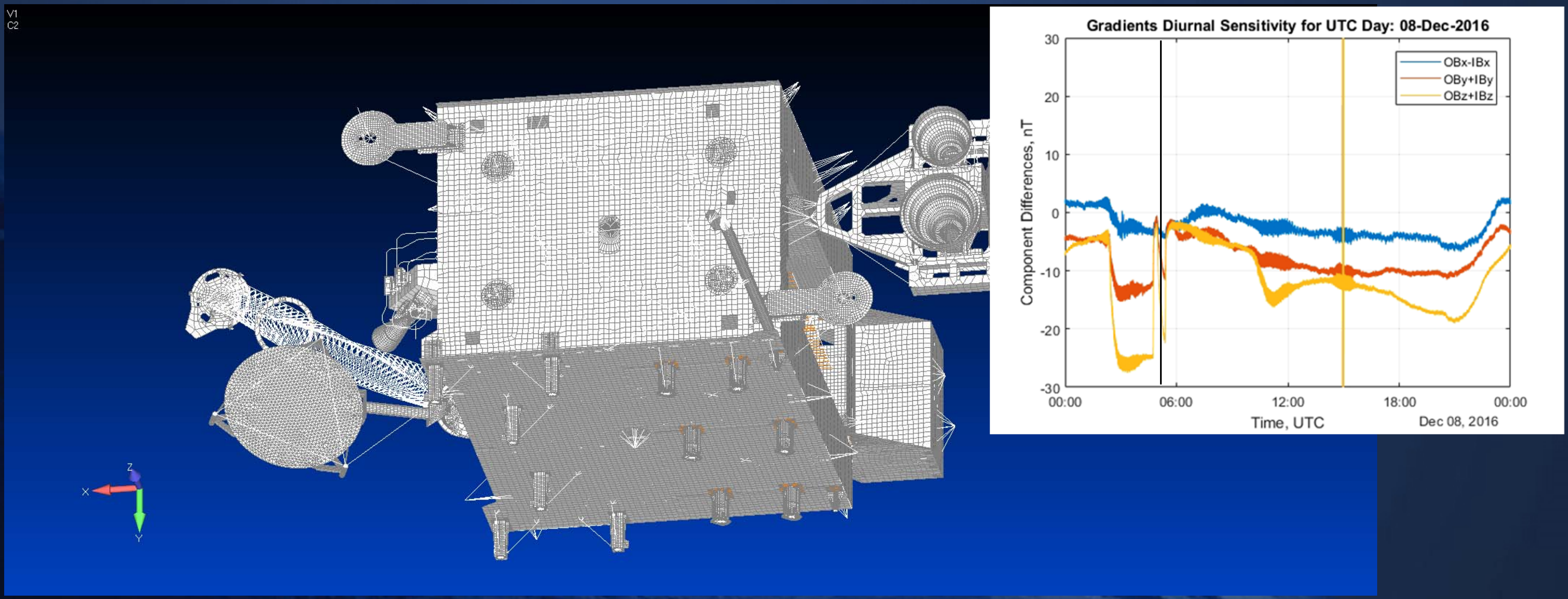




View from the Sun - End of Inboard shadowing by Spacecraft body

Root Cause Investigation
Inboard Shadowing

- Large swings in Inboard measurements correlates to shadowing of magnetometer by Spacecraft body and antenna



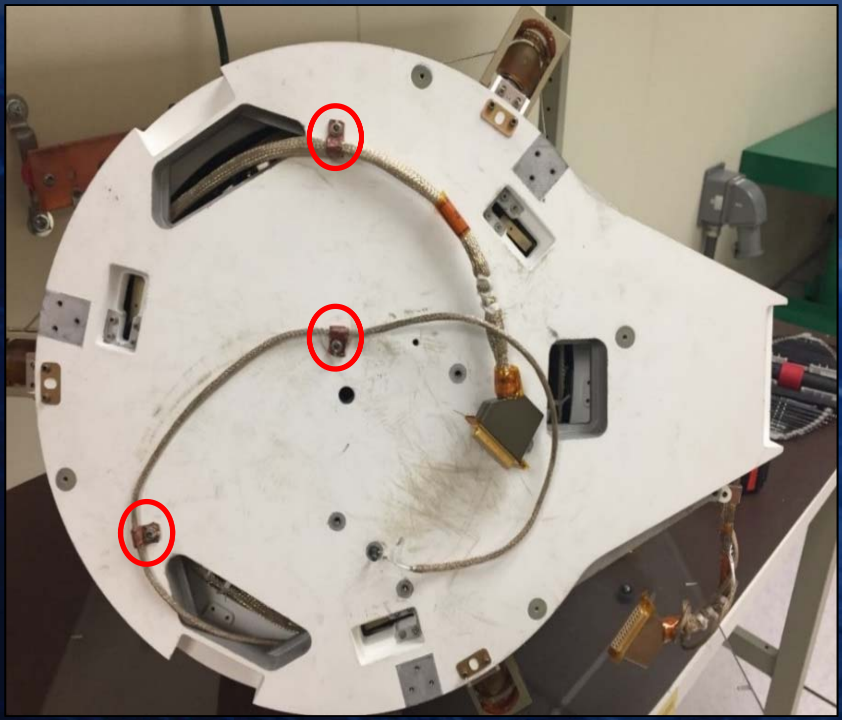
View from the Sun - Inboard shadowing by Spacecraft Antenna

Corrective Action Approach for GOES-S

- Identify all potential sources of magnetic contamination and eliminate
  - Thermo-electric effect (Seebeck or loop currents), or
  - Unintended contamination from magnetic material
- Perform ground tests where possible
  - Conservative approach is to eliminate regardless of test results
- Areas of concern:
  - Mounting plate and p-clamps
  - Mounting plate to boom bracket
  - Metallic backshell and grounding plug
  - Thermal blanket copper ground wires
  - Thermal blanket closeout tape
  - Incorrect cable length between sensor unit and electronics unit
  - Thermal design

Corrective Action
Sensor Plate

- Harness p-clamps wrapped in copper tape in contact with vapor deposited aluminum (VDA) on the magnetometer sensor plate
  - Potential for current loops in the VDA
  - Potential to create voltage difference (Seebeck effect) along the loop formed by the harness, cooper tape, and VDA.



Ground Testing did not generate stray magnetic field.

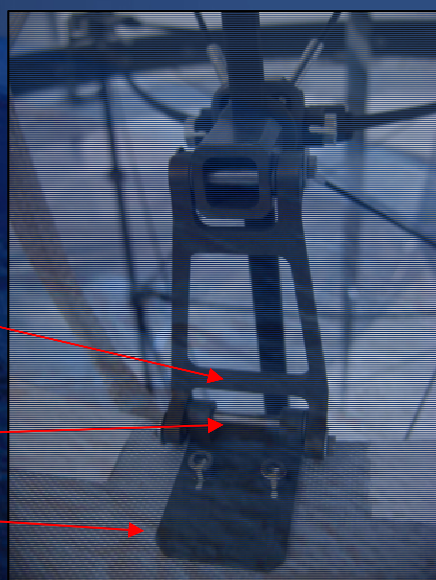
- Created 80C gradient across plate with harness and p-clamps
- Expected on-orbit gradient is ~90C

Design Changes:

- Score inboard and outboard VDA-coated mounting plates
- Replace copper tape on the p-clamps with non-conductive GBK tape
- Isolate multiple harnesses from each

Corrective Action
Mounting Bracket

- **Mounting bracket of the inboard plate has a chromium plated pin in contact with aluminum and titanium.**
  - **Seebeck coefficient for chromium and aluminum is 20.1 and -2.9 μV/K**
  - **Potential for field at magnetometer of 0.26 nT/K.**



No Ground Testing Performed

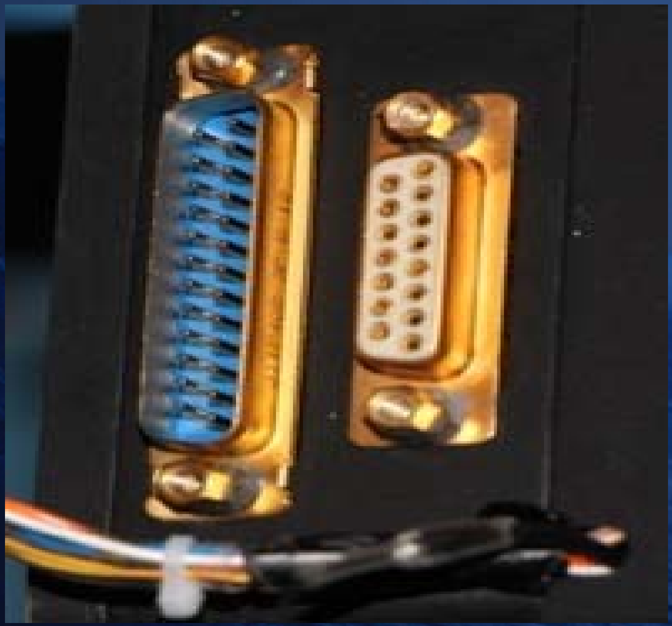
- **77C gradient needed to create field unlikely due to size and high thermal conduction**

Design Change:

- **Replace the chrome-plated pin with a ceramic pin**

Corrective Action Backshells

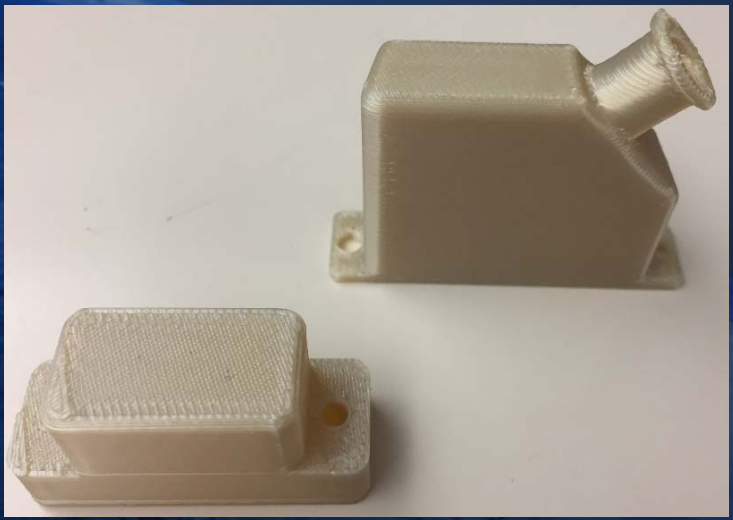
- **Metallic backshell and grounding plug allowing loop currents to form near the magnetometer**



No Ground Testing Performed

Design Change:

- **Replace backshell and grounding plug cover with non-conductive polymeric 3-D printed parts**



Corrective Action
Thermal Blankets

- **Thermal blanket has two grounding wires emanating from ends of the blanket.**
  - **Blanket are aluminum sheet and the wire is copper creating possible Seebeck effect**

Ground Testing did not generate stray magnetic field.

- **One side of blanket heated to 80C**

Design Change:

- **Eliminate second ground wire and lug**

Corrective Action
Ferromagnetic GBK Tape

- **Germanium Black Kapton (GBK) tape with nickel coated beads for ESD inadvertently used during close out**
  - **Tape remained on the blankets for about three days**
  - **Tape removed and the correct GBK tape applied**

Ground Testing:
- **ESD tape can have up to 60 nT field at magnetometer**
- **Residual tape adhesive can have up to 5 nT field at magnetometer**
- **Magnetic field of tape can change by ~0.05 nT/C**
  - **Blanket expected temperature change from -175C to 75C**

Corrective Action
- **Enhanced magnetic screening and monitoring.**

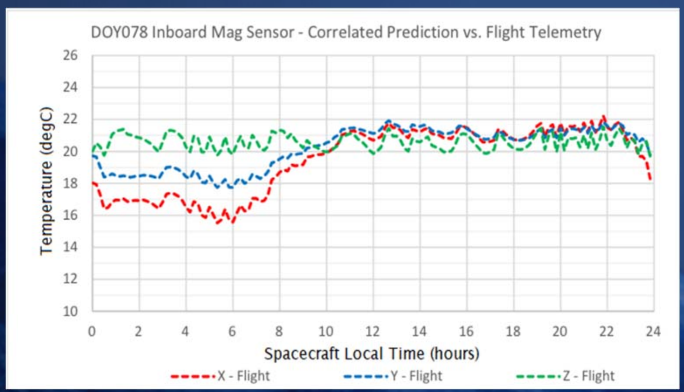
Corrective Action
Incorrect Cable Length

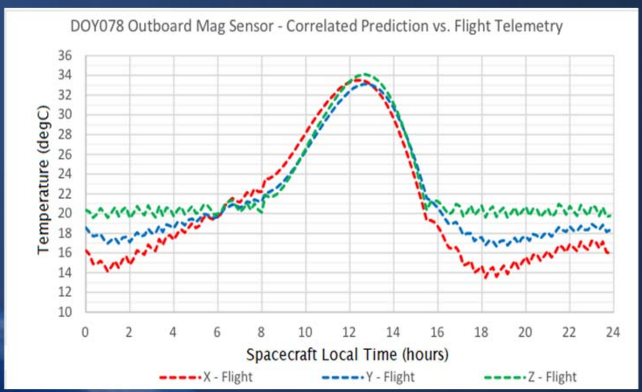
- Shield Can test added to the GOES–S spacecraft testing
  - Magnetometers removed from the stowed boom and placed in magnetic shield cans
  - Measure noise and zero offset in ambient conditions
  - Zero offsets measured by manually rotating the sensors in the shield cans.
- GOES-S Zero offsets significantly different from expected based on box level calibration
  - up to 12 nT different
- Discovered tuning and calibrations performed with cable configuration inconsistent with the flight configuration
  - 2.4m difference in length.
- Determined GOES-R flown with same configuration that was inconsistent with tuning and calibrations

- Design Change:
  - Flight cables from electronics box to boom swapped to more closely match lengths of cables used during tuning and calibration

Corrective Action
Thermal Control

- Insufficient thermal control requirements result in large swings in the bobbin temperature.
  – Temperature compensation applied but calibration accuracy and zero offset stability concern for such large temperature variations

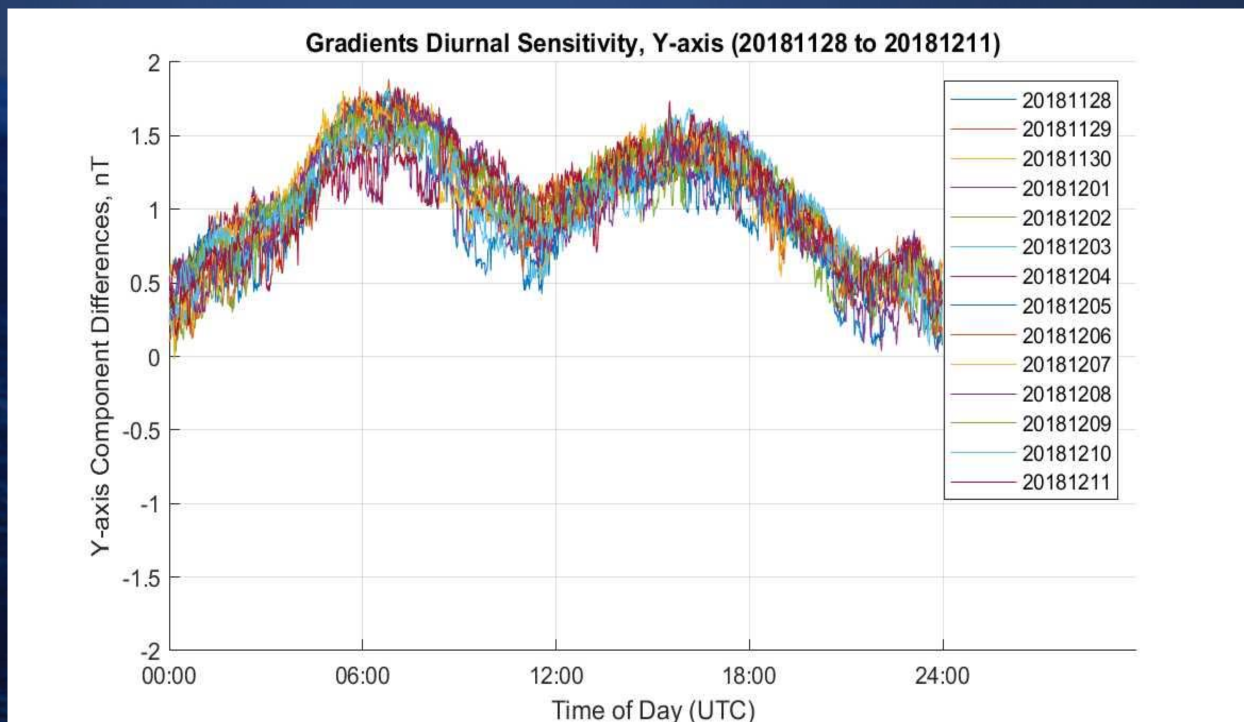




- Design Changes:
  - Addition of blanket over the existing blanket
  - Addition of blankets over the harnesses
  - Addition of a heater and control thermistor to the harness adjacent to the sensor unit to reduce heat loss through the harness.

GOES-17 Results

- GOES-17 launched March 1, 2018.
- No large excursions during shadowing period from November December.
- Diurnal variation is greatly reduced.



Conclusions/Lessons Learned

- Stringent magnetic screening and monitoring needs to be in place and followed at all times.
  - All material used near the magnetometer needs to be screened and tagged as magnetically clean. Reliance on part numbers and kitting is insufficient.
- Calibration of the sensors needs to be performed at the highest level of accuracy if there is any chance of thermal drift or thermal gradients.
  - This includes measuring in a flight-like thermal environment.
- System level testing at the spacecraft needs to include the ability to trend the zero offsets through the integration and test program.
- The accommodation design must eliminate the possibility of current loops, including in thermal blankets and harnessing.
- Adequate thermal requirements need to be established to maintain minimal temperature swings across the bobbins.
- Sensor unit thermal accommodation thermal requirements need to be understood and defined early in program through accurate thermal characterization of the sensor.
- Instrument level thermal balance is needed since spacecraft level thermal balance is insufficient for the accuracy required.