On-orbit Cross-Calibration of GMI High Frequency Channel Brightness Temperatures

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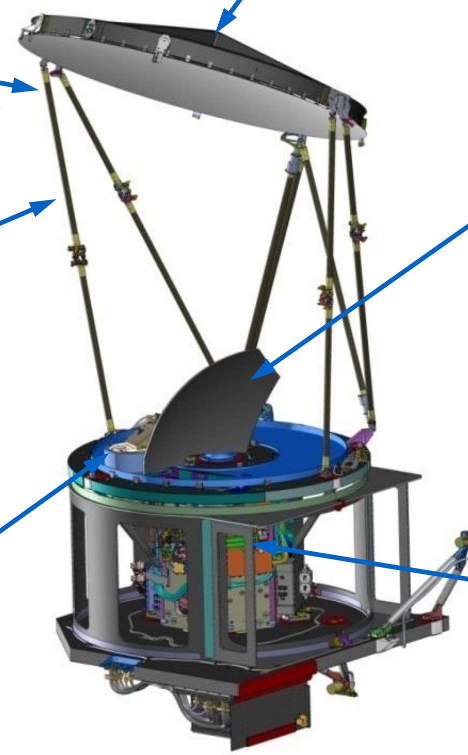
Global Precipitation Mission (GPM) Microwave Imager (GMI) Radiometer Overview

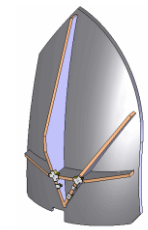
- **Radiometric**
  - 13 channels at 7 frequencies : 10.65, 18.7, 23.8, 36.5, 89, 166 and 183.31
- **Spatial**
  - Main reflector is 1.22 meters compared to TRMM and SSMIS 0.8 meter reflector providing improved spatial resolution
- **Calibration**
  - GMI is the calibration standard for all orbiting radiometers used for GPM rain retrieval
  - Many design features were incorporated to improve calibration including isolation of the hot load, the size of the cold sky reflector and the use of noise diodes as an additional calibration source
- **Mechanical**
  - Compact self contained design allows for easy accommodation on the GPM spacecraft and future spacecraft
- **GPM launched on 27 February 2014**

GMI Calibration Architecture Utilizes Lessons Learned from Previous Microwave Sensors

Extensive GMI reflector VDA risk reduction study resolved the reflector high frequency emissivity issues observed on SSMIS



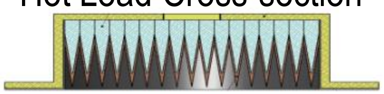
Antenna pattern measurement facilities, equipment, and techniques enable accurate antenna pattern corrections

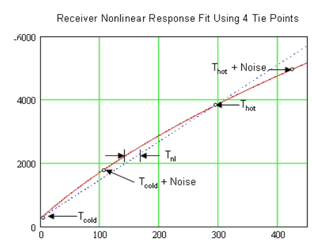


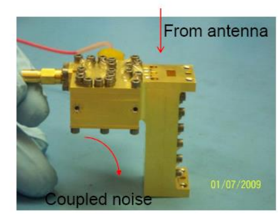
Narrow beam elliptical cold-sky reflector reduces contributions from spacecraft and earth

Efficient strut design minimizes extraneous brightness temperature contributions

Hot Load Cross-section







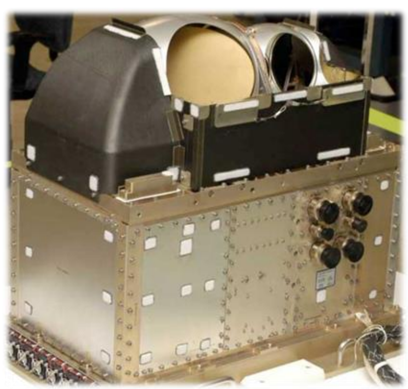
Hot load design isolates black-body from solar intrusion: high emissivity blackbody includes embedded precision temperature sensors

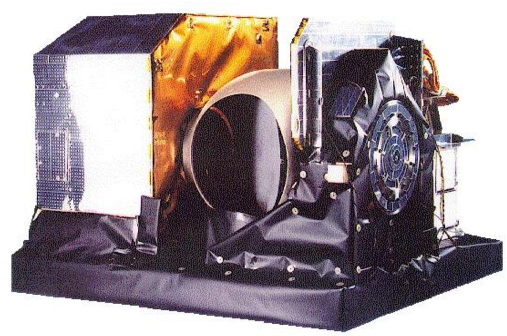
Noise diodes enable four-point calibration for low frequency channels (10-36 GHz) resulting in more accurate on-orbit calibration

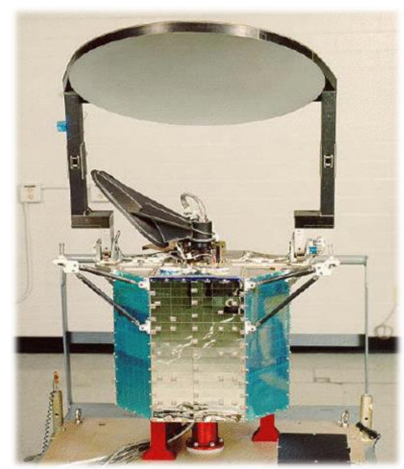
- Extensive calibration / validation have been performed on the GMI 10-89 GHz channels
- This study performs a comparison of the 166 and 183 GHz channels with other sensors

High Frequency Channel Characteristics of Inter-Calibration Sensors

GMI (GPM)	ATMS (NPP)	MHS (Metop-A)	SSMIS (F18)
Freq: 183.31±3 GHz BW: 2x1482 MHz Pol: V	Freq: 183.31±3 GHz BW: 2x980 MHz Pol: QH	Freq: 183.31±3 GHz BW: 2x1000MHz Pol: QH	Freq: 183.31±3 GHz BW: 2x1019 MHz Pol: H
Freq: 183.31±7 GHz BW: 2x1874 MHz Pol: V	Freq: 183.31±7 BW: 2x1930 MHz Pol: QH	Freq: 190.31 GHz BW: 2200 MHz Pol: QV	Freq: 183.31±6.6 GHz BW: 2x1526 MHz Pol: H
Freq: 166 GHz BW: 2x1600 MHz Pol: V & H	Freq: 165.5 GHz BW: 2x1125 MHz Pol: QH	N/A	N/A





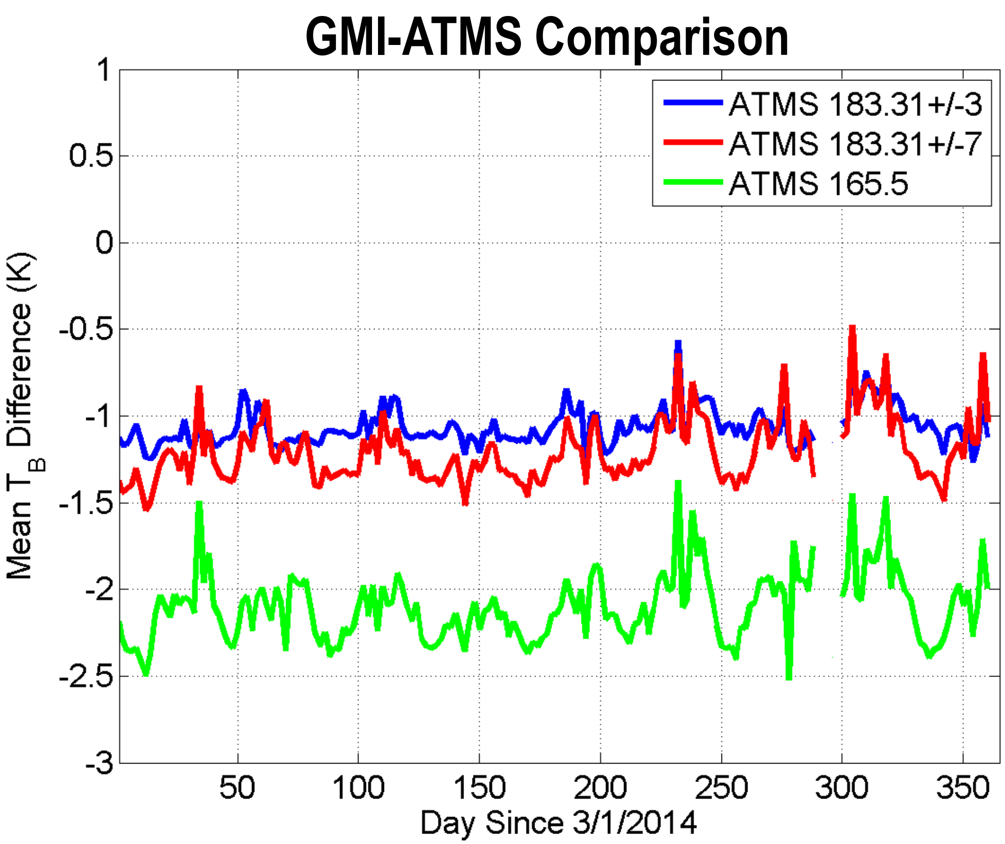


GMI High Frequency Channel Cross-Calibration Analysis Approach

- One year's worth of GMI high frequency channel data from 3/1/2014 through 2/28/2015 are compared with ATMS, MHS, and SSMIS
- GMI 166 GHz V & H channels are combined to match the ATMS "Quasi-H" polarization
- Data colocations found using the following criteria
  - Within 30 minute window
  - GMI footprints falling within other sensor's footprints
  - Matching incidence angles (to within defined tolerances)
- GMI footprints falling within the other sensor's footprint are averaged together
  - Results in significant averaging of GMI measurements for comparison with MHS and ATMS
  - Much less averaging for GMI to SSMIS comparisons due to since both are conically scanning radiometers
- Co-located data are further refined as follows
  - Ocean only
  - Rain free
  - Low cloud liquid water content
  - Water vapor content > 10 mm (to reduce surface emission effects)
- Co-located data are analyzed by comparing differences stratified against several parameters

GMI Day-one Calibration Brightness Temperature Comparison

- Day-one calibration comparisons illustrated biases when the GMI high frequency channel brightness temperatures are compared with ATMS, MHS, and SSMIS
- Day-one GMI antenna pattern correction algorithm did not include a feed horn spillover correction for the high frequency channels
- Performed on-orbit spacecraft maneuver to measure the antenna spillover for improved calibration accuracy



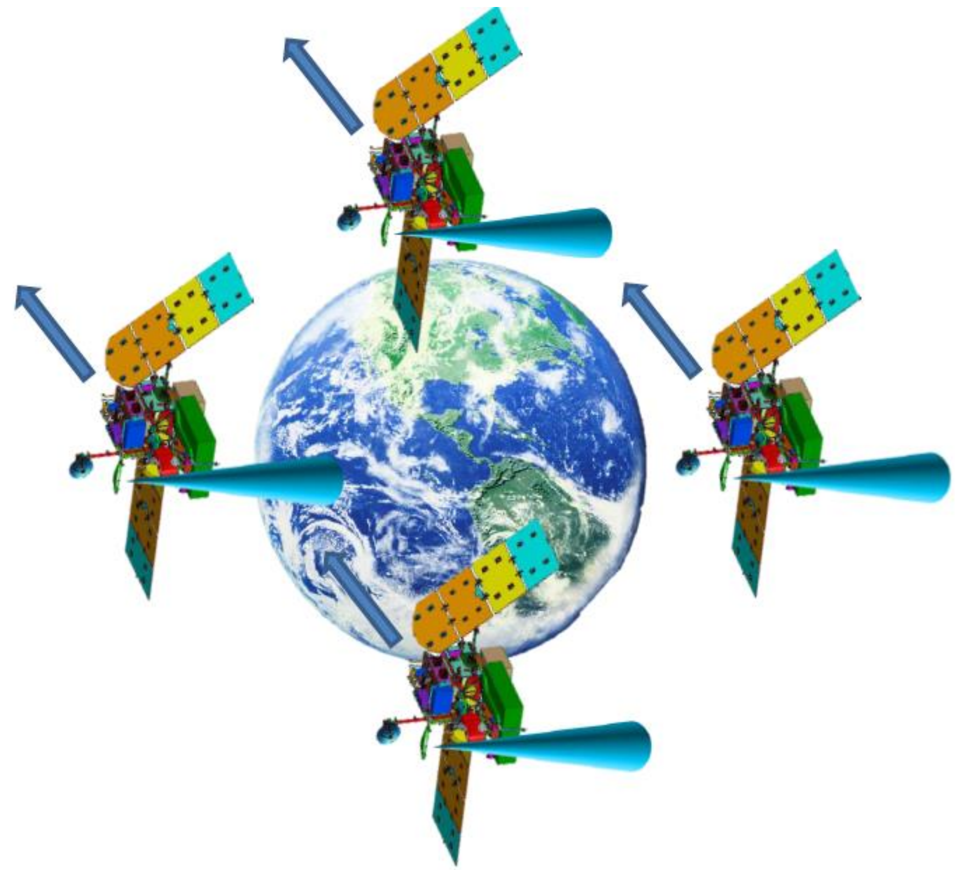
Day-one Calibration T_B Comparison Statistics

GMI Channel	GMI-ATMS	GMI-MHS	GMI-SSMIS
183.31±3 V	μ = -1.1 σ = 1.2	μ = -1.5 σ = 1.1	μ = -0.7 σ = 2.4
183.31±7 V	μ = -1.3 σ = 1.6	μ = -1.7 σ = 1.6	μ = -1.0 σ = 3.0
166 VH*	μ = -2.2 σ = 2.0	NA	NA

*GMI 166 V & H-pol data are combined to approximate the polarization of the comparison sensor

“Inertial Hold” Affords Evaluation of the Antenna Pattern Correction, Including the Spillover Effects

- In an inertial hold, the spacecraft does not attempt to maintain geodetic pointing, but rather maintains the same inertial position throughout the orbit
- The result is that the spacecraft appears to pitch from 0 to 360 degrees around the orbit
- Two inertial holds were performed with the GPM spacecraft
  - May 20, 2014 16:48:31 UTC – 18:21:04 UTC
    - Spacecraft flying forward +X (0° yaw)
    - Pitch from 55 degrees (FCS) to 415 degrees (FCS) over the orbit
  - Dec 9, 2014 01:30:00 UTC – 03:02:32 UTC
    - Spacecraft flying backward –X (180° yaw)
    - Pitch from 0 degrees (FCS) to 360 degrees (FCS) over the orbit
- The inertial hold affords a view of the earth through the antenna backlobe
- The antenna “spillover” correction may be evaluated based on the inertial hold data



GMI Inertial Hold Measurement Data Were Used to Calculate Spillover Correction Coefficients

- In the antenna pattern correction portion of the calibration algorithm, the spillover correction is expressed as

$$T_b \cong \frac{1}{\eta} T_A - \frac{(1-\eta)}{\eta} T'_{cs}$$

- When the spacecraft is “upside down”, the antenna temperature can be approximated as,

$$T_{A-upsidedown} = \eta T'_{cs} + (1-\eta) T_{b-earth}.$$

- Solving for the spillover coefficient, we get

$$\boxed{\eta = (T_{b-earth} - T_{A-upsidedown}) / (T_{b-earth} - T'_{cs})}$$

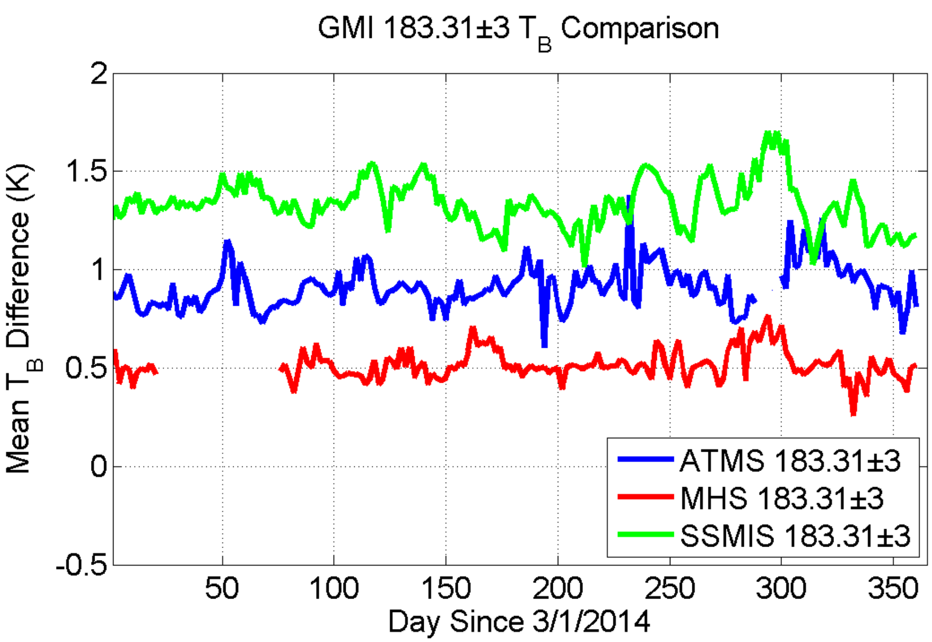
Sensor Channel Brightness Temperature Difference Statistics After Application of GMI Spillover Correction

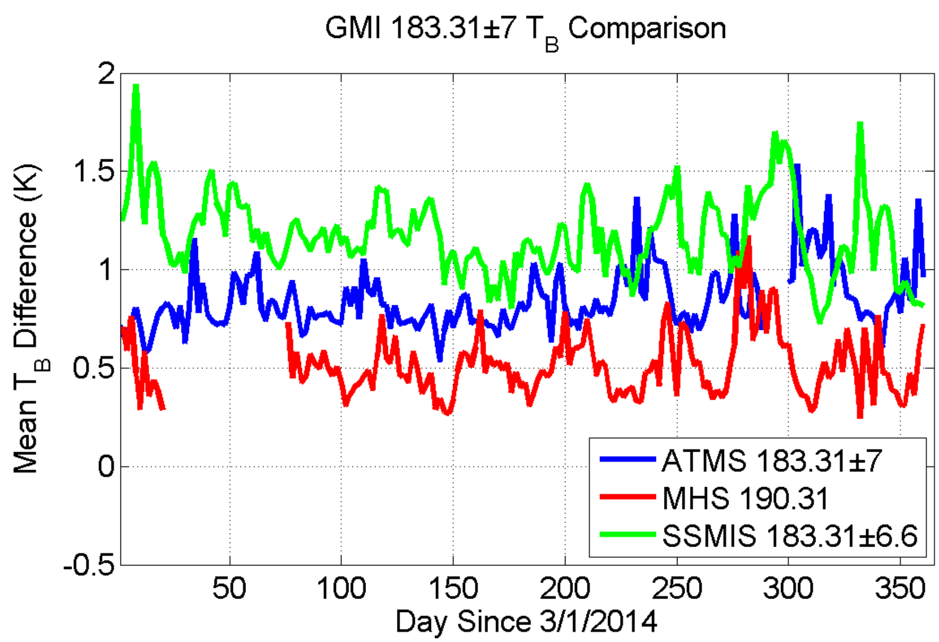
- The updated GMI spillover correction coefficients provide improved cross-calibration results for ATMS and MHS
  - GMI is now more in-family with these two sensors
- The GMI – SSMIS comparison does not exhibit the same improvement
  - Past studies have indicated that the SSMIS calibration is subject to drifts likely due to thermal effects, reducing confidence in its stability over time

GMI Channel	GMI-ATMS	GMI-MHS	GMI-SSMIS
183.31±3 V	μ = 0.9 σ = 1.2	μ = 0.5 σ = 1.1	μ = 1.32 σ =2.4
183.31±7 V	μ = 0.8 σ = 1.6	μ = 0.4 σ = 1.6	μ = 1.1 σ = 3.0
166 VH*	μ = 1.0 σ = 2.0	NA	NA

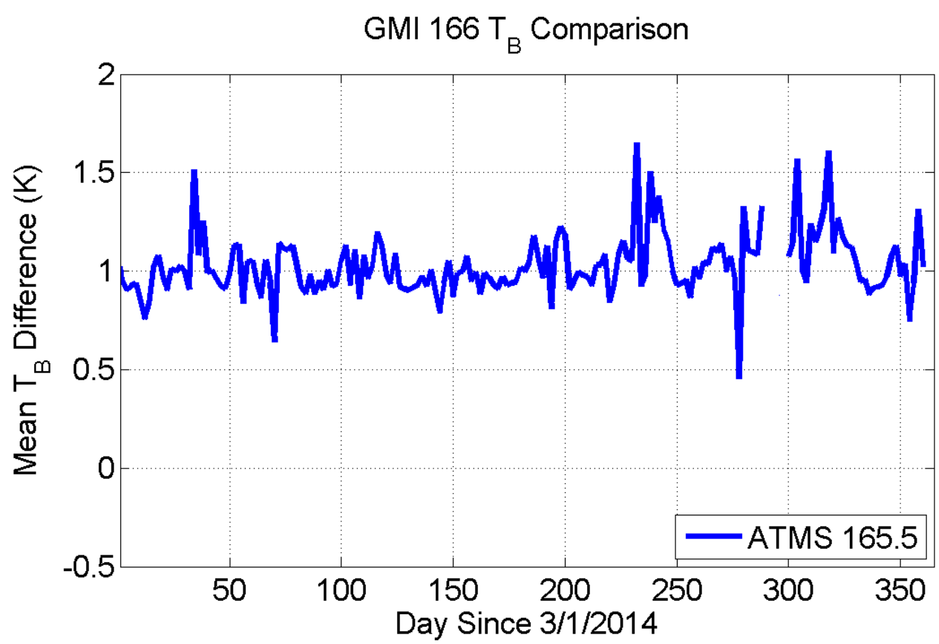
*GMI 166 V & H-pol data are combined to approximate the polarization of the comparison sensor

GMI Calibrated Mean Brightness Temperature Difference vs. Time

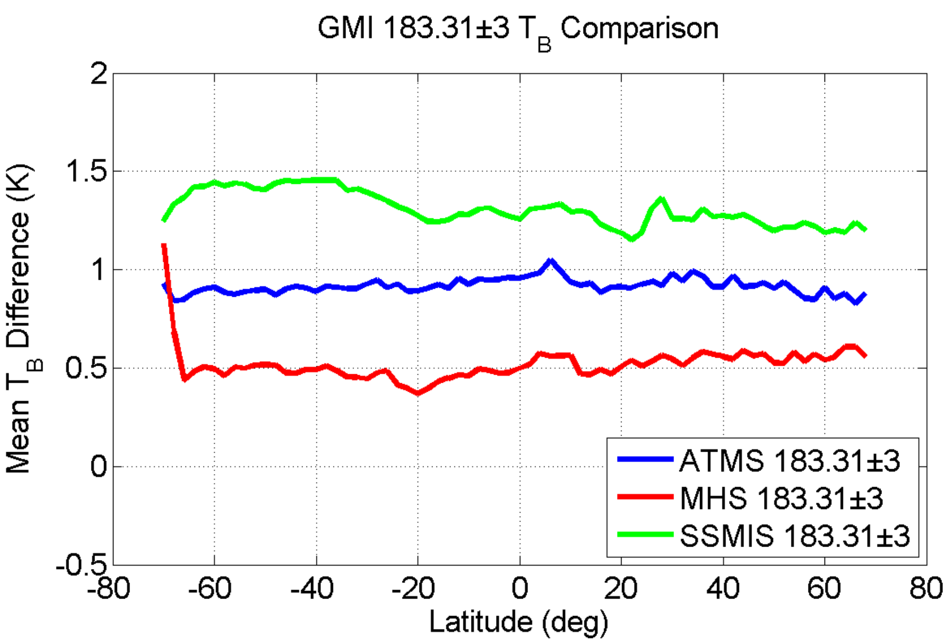


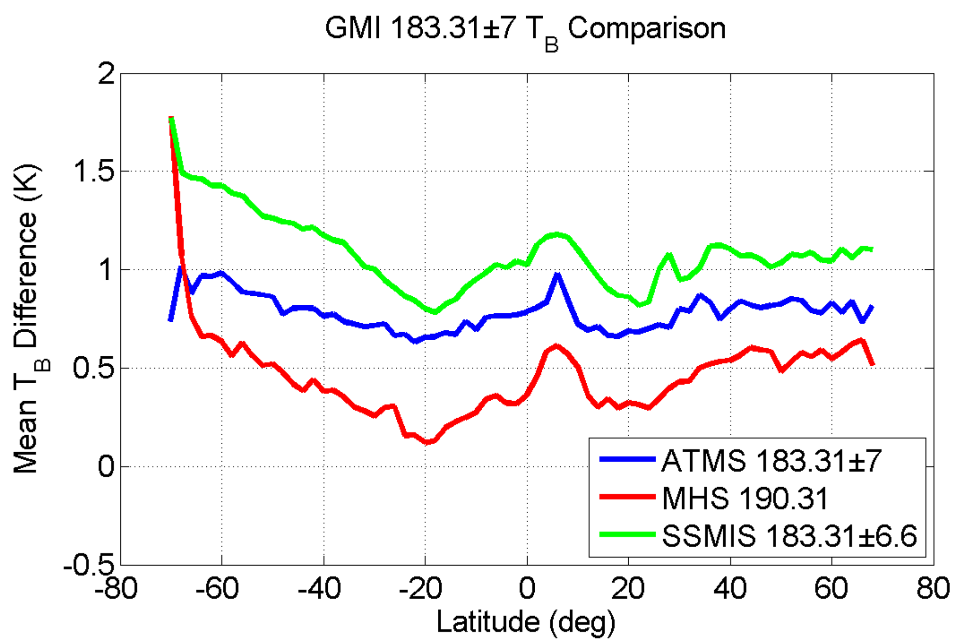


- Plots show mean (2-day average) T_B differences over the one year period
- Variations may be due to:
  - Measurement geometry differences
  - Surface polarization effects
  - Spatial co-location effects
  - Temporal co-location effects
  - Calibration drifts of the two sensors

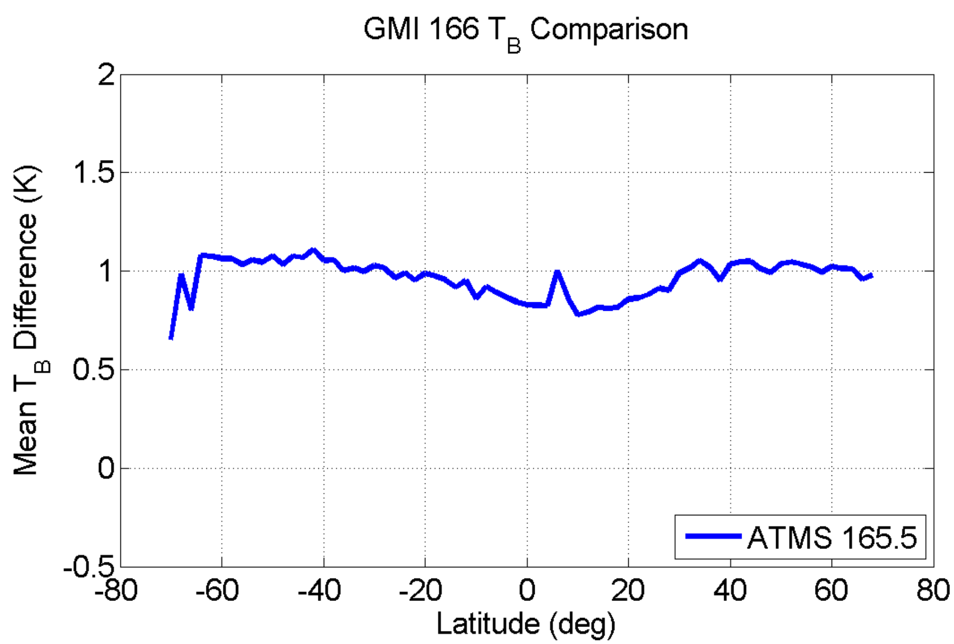


GMI Calibrated Mean Brightness Temperature Difference vs. Latitude

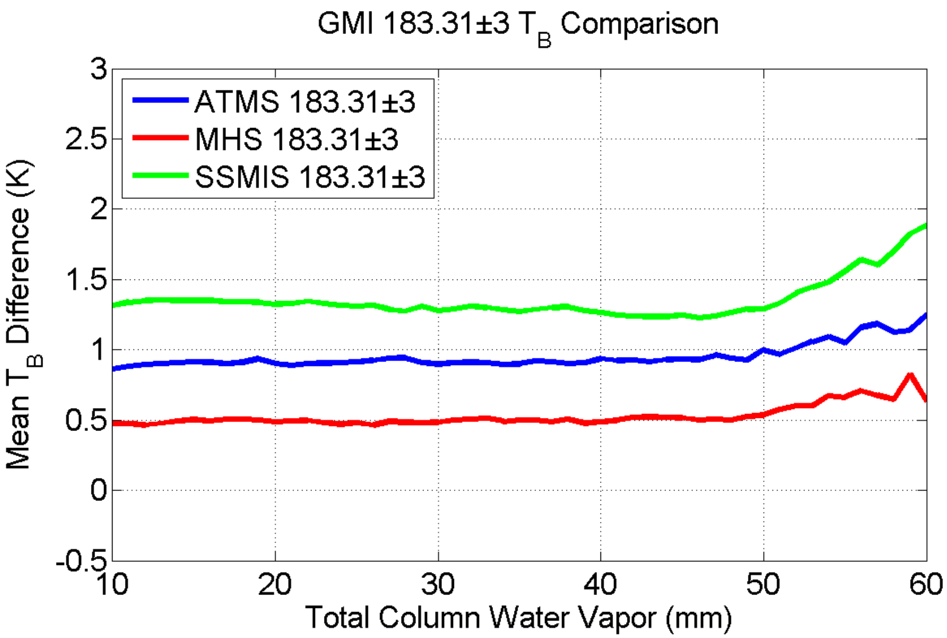


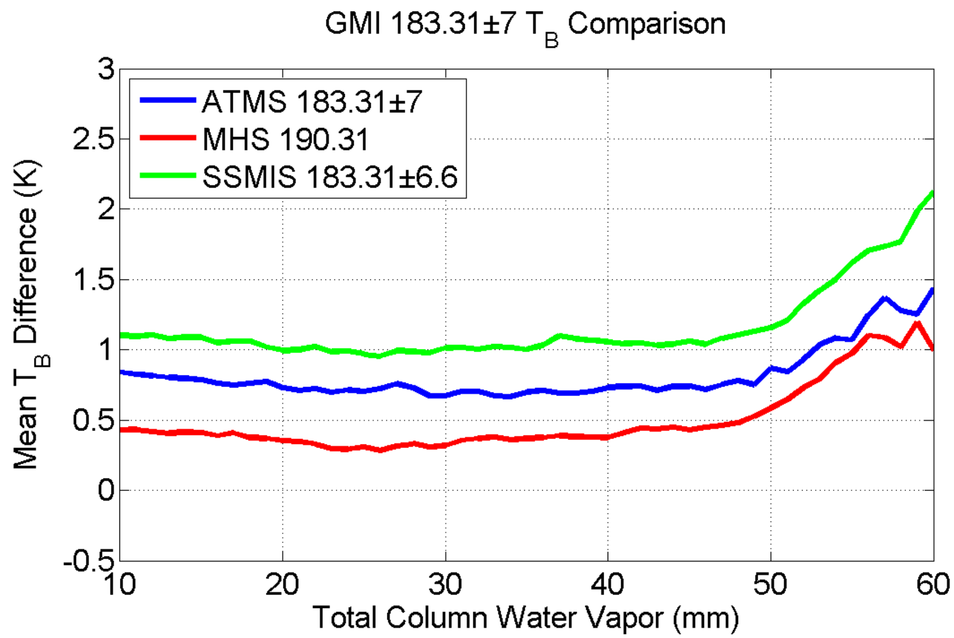


- Comparisons exhibit relatively low dependence on latitude for the 183.31±3 and 166 GHz channels
- Larger dependence is shown in the 183.31±7 GHz channels, likely due to surface polarization effects
- GMI 166 GHz V&H polarization was rotated to match ATMS

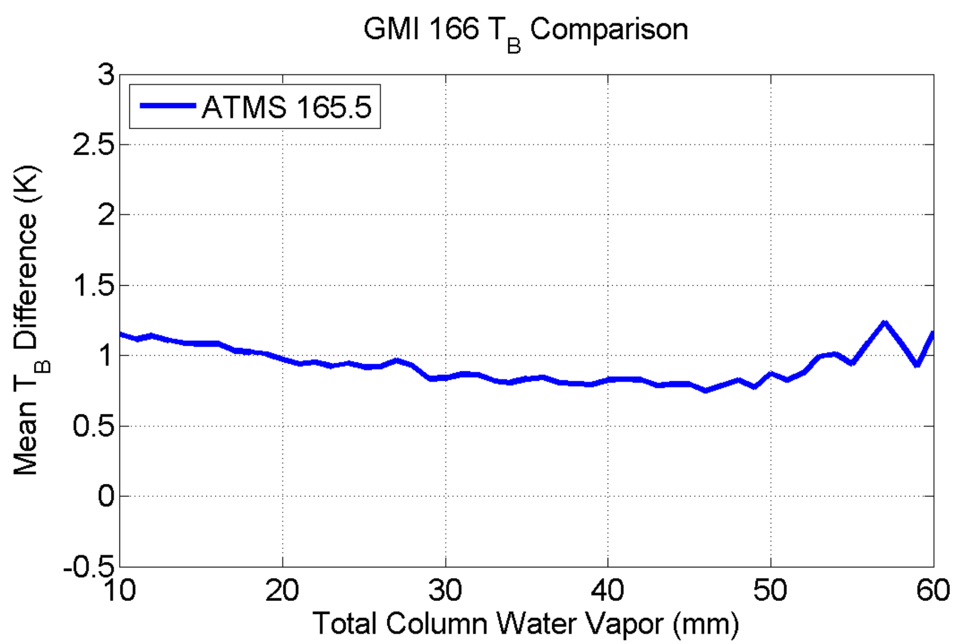


GMI Calibrated Mean Brightness Temperature Difference vs. Atmospheric Water Vapor

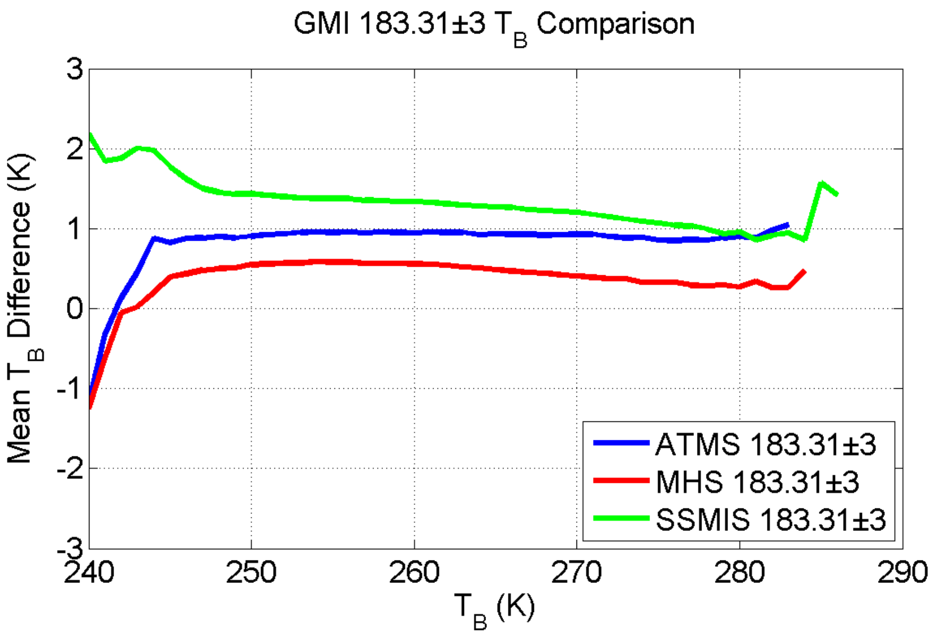


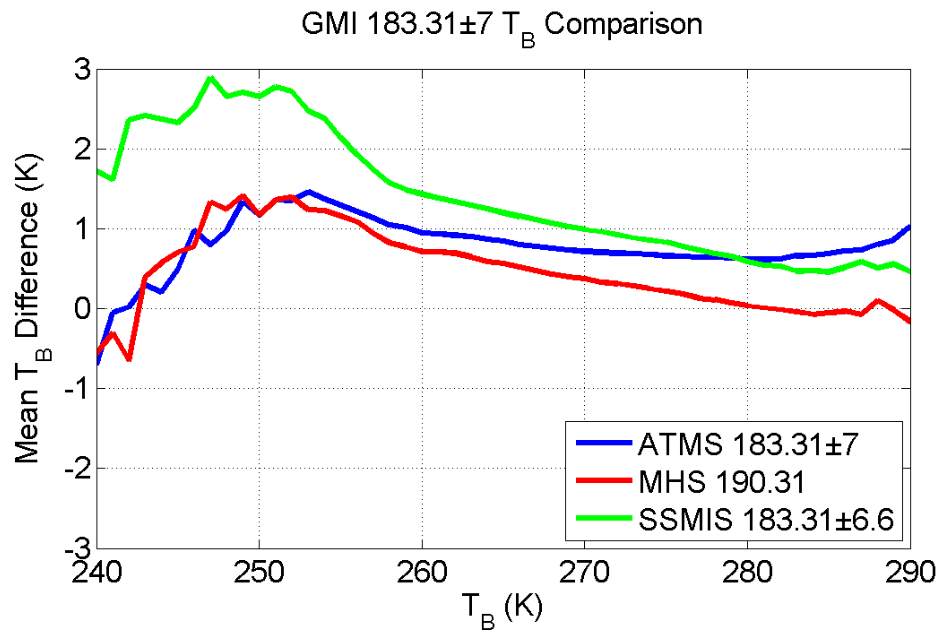


- Low water vapor (< 10 mm) removed to minimize surface polarization effects evident in dry atmospheres
- Results show low sensitivity to water vapor over mid-range values (10-50 mm)
- High water vapor cases (>50 mm) begin to show larger deviations, likely due to dynamic convective storms

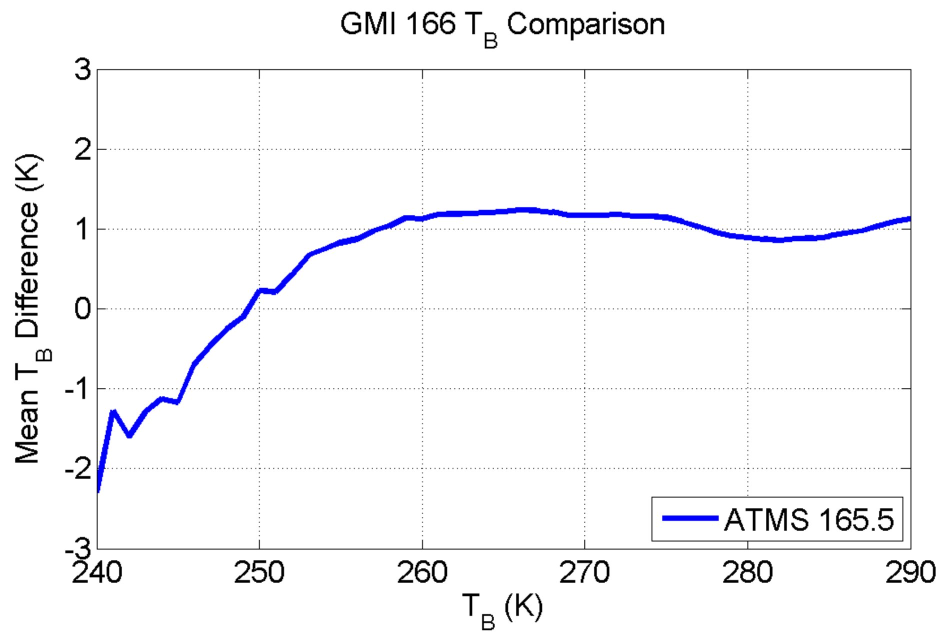


GMI Calibrated Mean Brightness Temperature Difference vs. GMI Brightness Temperature





- **The deviations at the lower brightness temperatures is believed to be due to dynamic convective storms that introduce differences in measurements occurring at different times**



Summary and Conclusions

- Lessons learned from past microwave radiometers were incorporated into the GMI calibration design.
- One year's worth of GMI high frequency channel brightness temperatures were compared with similar channels from ATMS (NPP), MHS (Metop-A), and SSMIS (F18)
- Initial comparisons using the "Day-one" calibration algorithm showed biases between the GMI high frequency channel brightness temperatures and the other sensors
  - Suspected that the lack of a spillover correction in the GMI calibration may be the cause
- An inertial hold orbital maneuver facilitated the measurement of the GMI spillover coefficients
- The updated GMI calibration algorithm provides improved comparisons with ATMS and MHS with the residual biases falling well within the required calibration accuracies of the sensors
- Future work may include the use of a radiative transfer model to correct for differences in sensor channel center frequencies, bandwidths, polarizations, and incidence angles and further reduce the residual errors
- GMI is planned for use as the calibration standard for all microwave radiometers used in the NASA Global Precipitation Measurement satellite constellation.