Leveraging the GPM Microwave Imager (GMI) Calibration Standard For Next Generation Defense Weather Missions

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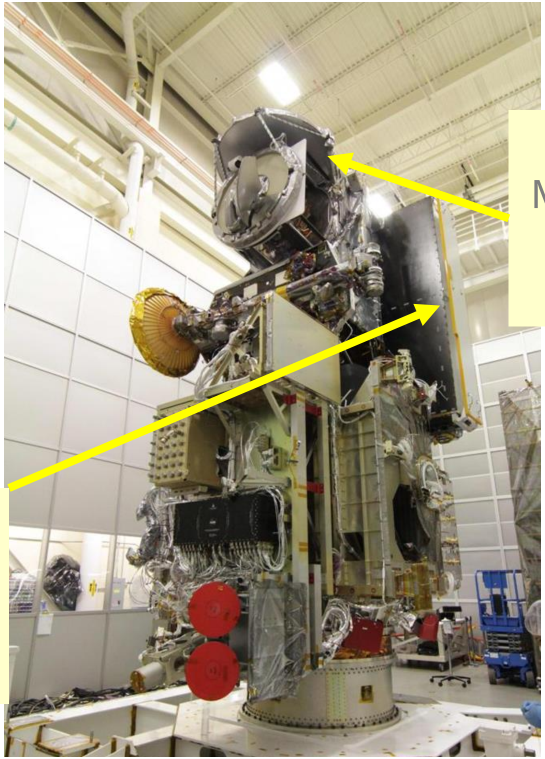
Global Precipitation Measurement (GPM): Unifying and Advancing Ocean Precipitation Measurements

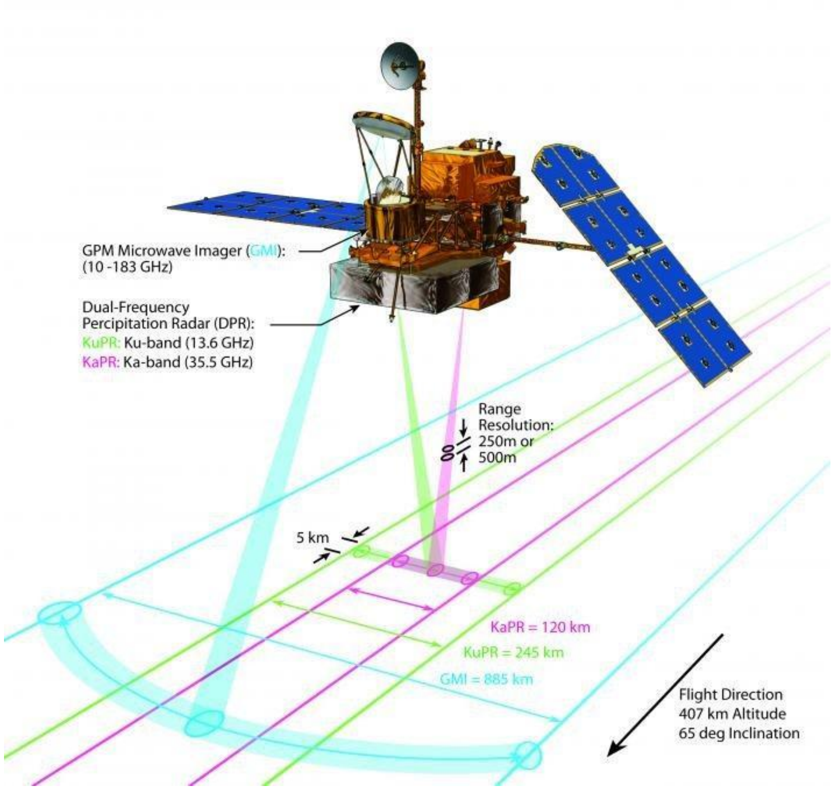
- GPM is a Joint mission between NASA and the Japanese Aerospace Exploration Agency (JAXA)
- GPM measures precipitation
  - Actively: With a dual-frequency precipitation radar
  - Passively: With a microwave imager (Ball-built)
- GPM unifies precipitation measurements by acting as a cross-calibration standard for a constellation of precipitation sensors
- GPM advances precipitation measurements with additional capability compared to previous sensors
- GMI was launched February 28th, 2014 from Tanegashima Japan.



GPM Core Observatory

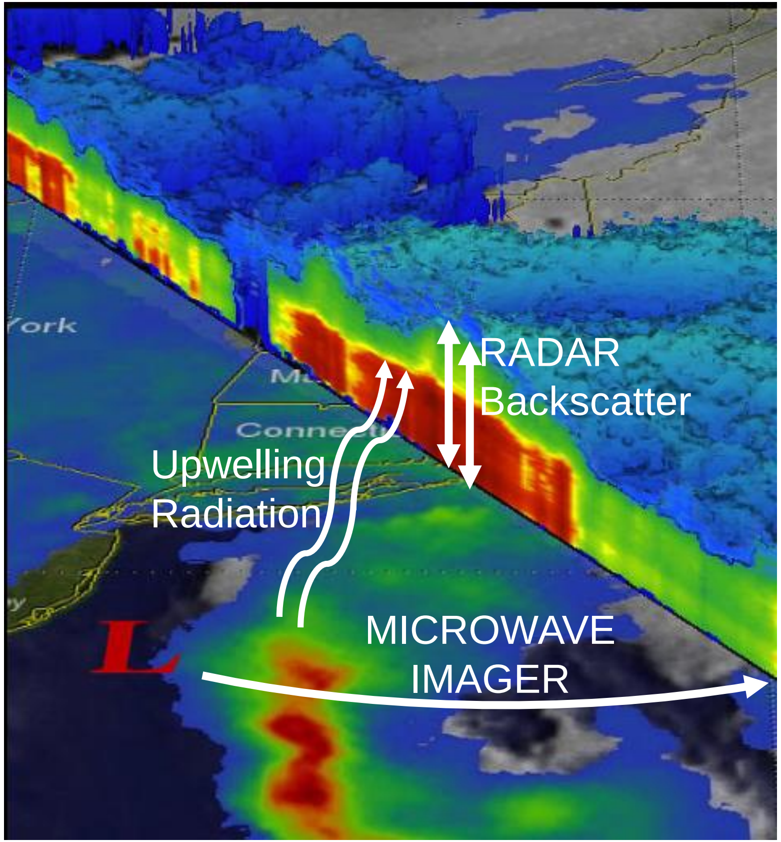
GPM Mission Overview

- The GPM Microwave Imager (GMI) is currently operating on the Core GPM Spacecraft and being used to make calibrated, radiometric measurements from space at multiple microwave frequencies and polarizations
- The Core GPM Spacecraft is flying at 407 km in a circular 65 degree inclination orbit
- The GPM orbit crosses the paths of all the other polar orbiting radiometers allowing GMI to be the calibration standard that is transferred to all the other radiometers in the GPM constellation



Precipitation Measurements: How it Works

- Dual Precipitation Radar:
  - Near-nadir viewing
  - Transmits a radar pulse
  - Measures the backscatter return from falling precipitation in the atmosphere
  - The range and magnitude of the backscatter is used to estimate the rain rate and vertical profile
- GPM Microwave Imager
  - Conically scans to measure the “brightness temperature” of the earth, including rain in the atmosphere
  - Rain disrupts the upwelling radiation from the earth, providing a unique brightness temperature signature that can be translated to a rain rate.



Credit: NASA

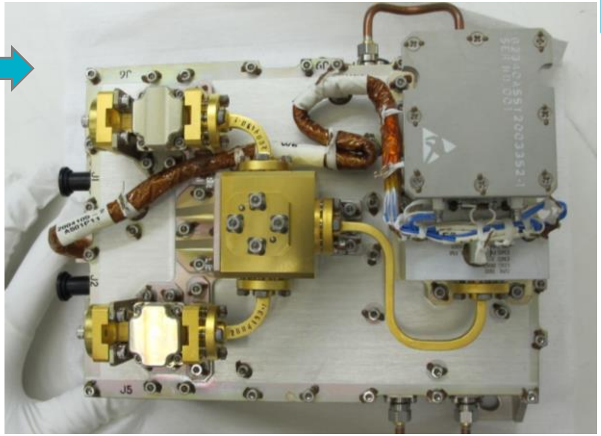
GMI Instrument Overview (Ball-built)

- The GMI design
  - Is a total power passive radiometer
  - Utilizes hot and cold calibration
- The instrument is conically scanned with rotation about the vertical axis
- The radiometer has channels at
  - 10.65 GHz (V/H) – **Ocean surface winds, Soil Moisture**, Sea surface temperature
  - 18.7(V/H) GHz – **Ocean Surface winds**, **Soil Moisture, Snow depth**, **Sea ice characterization,** precipitation
  - 23.8 (V) GHz – Atmospheric water vapor
  - 36.64 (V/H) GHz – **Ocean surface winds**, **Snow depth, Sea ice characterization**, precipitation
  - 89 (V/H) GHz – **Tropical cyclone intensity,** Convective rain,
  - 166 (V/H) GHz – Light Rain / Snow
  - 183.31+/-3, +/-7 (V) GHz – Atmospheric moisture profiling

KEY: **Useful Science and Tactical Data Products**
Useful Science Products

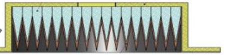
The GMI is built for High Precision and Accuracy

- The GMI uses state-of-the art receiver technology to sense very small signals from the earth (high sensitivity)



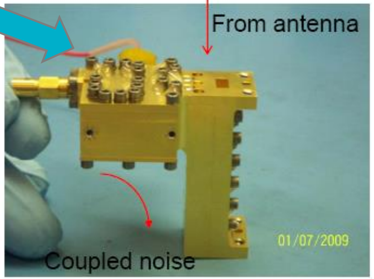
- The GMI has a 1.2m dish antenna to focus energy into the receivers (scalable design)

Hot Load Cross-section



- The GMI uses a hot load blackbody as a hot calibration reference (highly stable)
- The GMI uses a cold sky reflector to measure the microwave background signal for a cold calibration reference (highly stable)

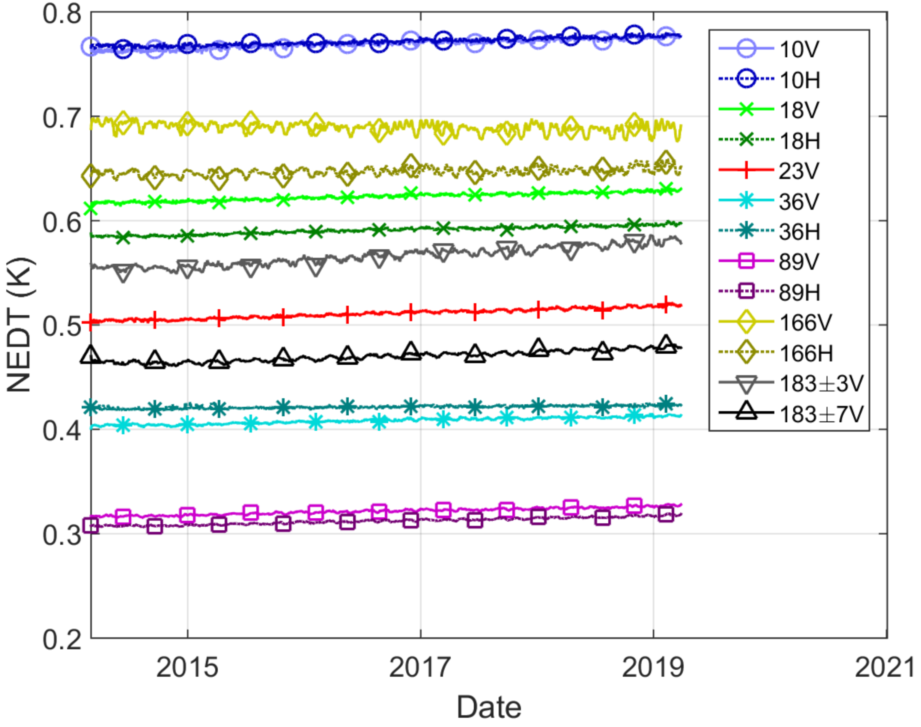
- Noise diodes on most channels provide a backup calibration source to tease out additional calibration errors (may be used as part of a fully polarimetric calibration system)



GMI is Highly Sensitive and Stable

- The Noise Equivalent Delta Temperature (NEDT) is a measure of the sensitivity of each channel in units of Brightness Temperature (K)
- NEDT has been tracked on-orbit
- The GMI performance is significantly better than required with margins of between 20% and 70%
- The NEDT performance of all the channels has been stable over the first 4 years of operation
- Slight Rise in NEDT is due to receiver temperature rise over time.

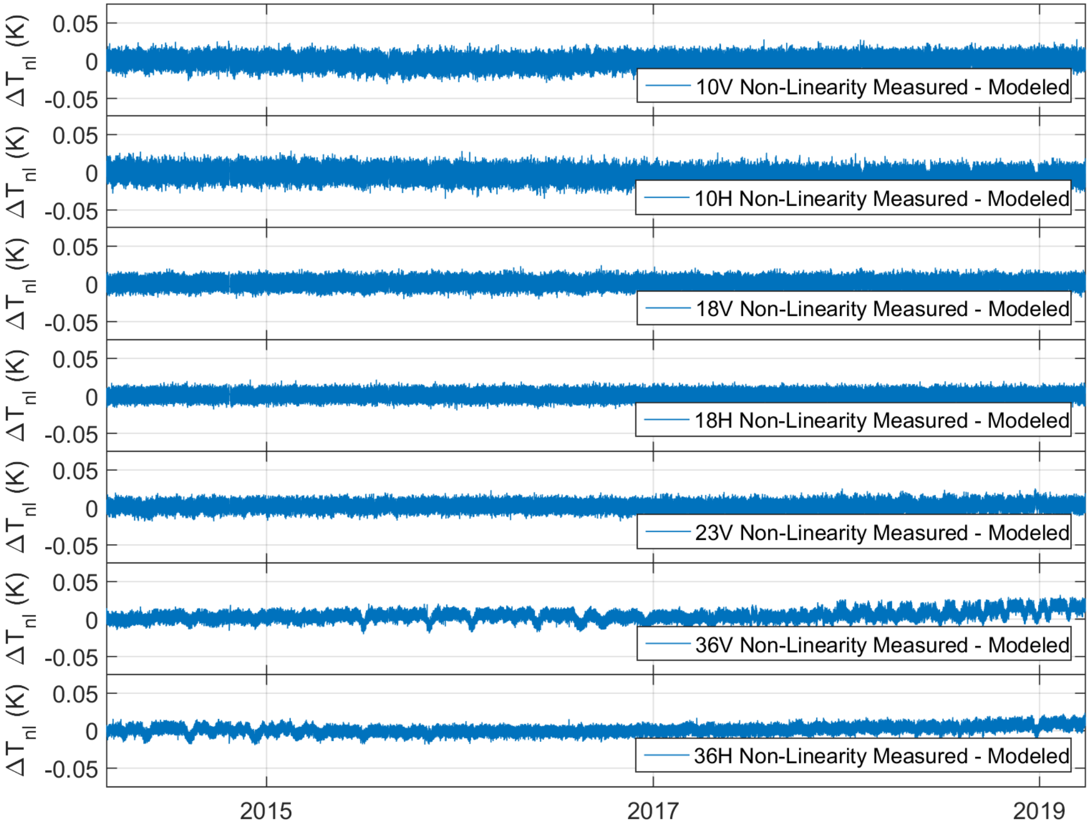
NEDT



* Corrected to common Tb with cyclical temperature variations removed.

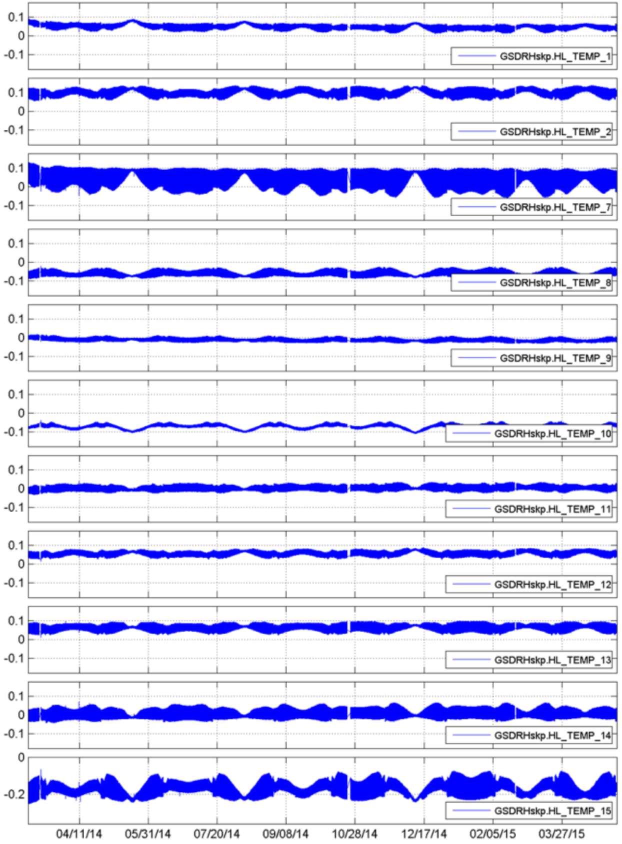
GMI Non-Linearity Performance Is Very Stable

- GMI is the first operational radiometer to track the stability of the non-linearity
- The stability of the non-linearity over the first 3 years has been under 0.01K, which is excellent



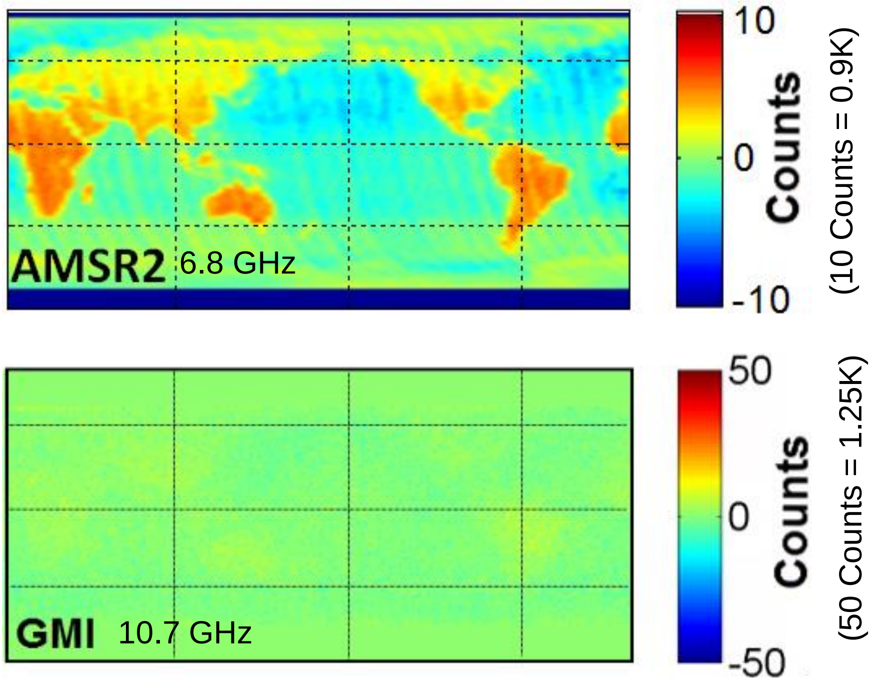
The GMI Design Has Eliminated Solar Loading On The Hot Load To Provide Minimal Hot Load Gradients

- The GMI design incorporated a number of features into the hot load to eliminate the solar loading induced temperature gradients that have plagued previous radiometers
- In addition GMI includes 11 PRTs to allow the temperature gradients to be tracked
- The data from the PRTs shows that the design features have succeeded in eliminating the solar loading and the resulting temperature gradients
- The difference between each hot load PRT and the average as a function of time is plotted
- The maximum gradient across the operational area of the hot load is less than 0.1 K



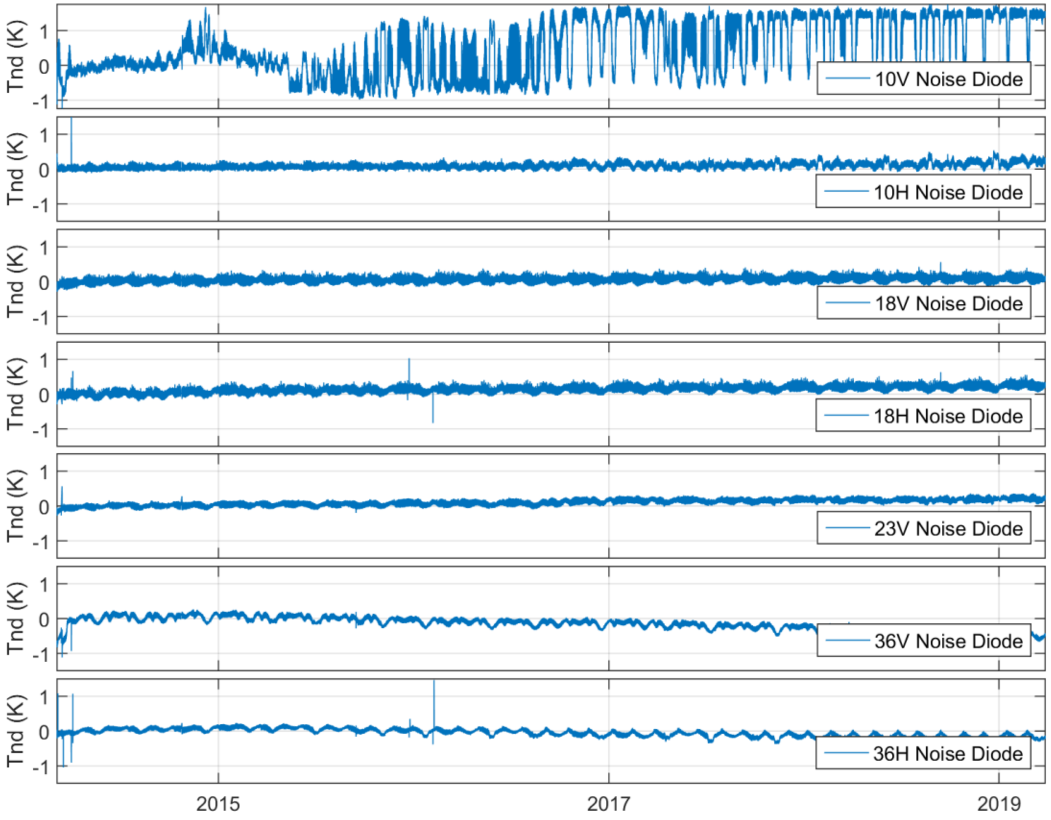
Cold Sky Reflector Performance

- The GMI design incorporated a number of features into the design of the Cold Sky Reflector to optimize the performance and improve calibration
  - The Cold Sky Reflector was made as large as possible
  - The pointing was optimized to reduce the sidelobes on the Earth
- The figure at right shows the average cold counts for the lowest frequency channels as a function of latitude and longitude for AMSR2 and GMI
- The GMI design has decreased the spillover on the Earth which has reduced the corruption of the cold sky measurement



Noise Sources have been sufficiently Stable

- Noise source excess temperature anomaly shown on the right.
  - Only the 10V noise source is shown to have some instability (within +/- 1.5K, sufficient for 3rd and 4th Stokes Calibration)
  - Other channels have been exceptionally stable (within +/- 0.25K)
- For fully polarimetric calibration (V, H, 3rd, 4th Stokes) the noise sources would need stable phase coupling between v-pol and h-pol channels.
  - Fully polarimetric systems such as WindSat provide both Wind Speed and Direction (to fulfill tactical needs)



The GMI Calibration Performance Shows Significant Margin To The Required Performance

- Ball developed the calibration algorithm and to verify the on-orbit performance
- Day 1 performance using the initial calibration algorithm met the performance requirements
- Two deep space calibration maneuvers were performed which pointed the main reflector to deep space
- The maneuvers identified minor biases which could be removed further improving the calibration performance
- The calibration algorithm was updated based on the deep space maneuvers
- The final performance using the latest calibration algorithm shows significant margin to the calibration requirements
  - 0.25 K +/- 0.14 K (1σ) versus 1.35K spec

Error Term	**Static Bias RMS (K)**	**time-vary error (1σ) (K)**
Earth Magnetic field Correction	0	0.08
Instr. Magnetic field Correction	0	0.02
Count Bias Corr	0.04	0
Hot Load	0.06	0.10
Cold Sky	0.04	0.01
Non-linearity	0.05	0
Along-scan Bias Correction	0.00	0.02
Total TA Error	**0.10**	**0.13**
Inertial hold backlobe earth TB	0.07	0.01
Inertial hold TA calibration	0.21	0.02
Inertial hold spillover annulus	0.07	0.01
Total Spillover Correction Error	**0.23**	**0.02**
X-pol Correction Error	**0.03**	**0.03**
Total TB Error (ocean scene)	**0.25**	**0.14**

The GMI provides a low-risk starting point for a defense weather microwave imager

- GMI heritage provides
  - 1. Large reflector with a scalable design to meet spatial resolution
  - 2. Frequency bands required for tactical products
    - Ocean Surface Vector Winds
    - Soil Moisture
    - Sea Ice Characterization
    - Snow Depth
    - Tropical Cyclone Intensity
  - 3. High Calibration Accuracy, Radiometric Sensitivity and Stability
  - 4. Noise sources that can be incorporated into a fully polarimetric calibration system (for ocean surface vector winds)

GMI Summary

- GMI is operating smoothly 5 years after launch
- The on-orbit data shows that the instrument is performing well and meeting all requirements
- The NEDT and calibration uncertainty performance is much better than the requirements
- We are looking forward to many years of excellent data from GMI