GPM MICROWAVE IMAGER KEY TECHNOLOGIES, PERFORMANCE AND CALIBRATION RESULTS

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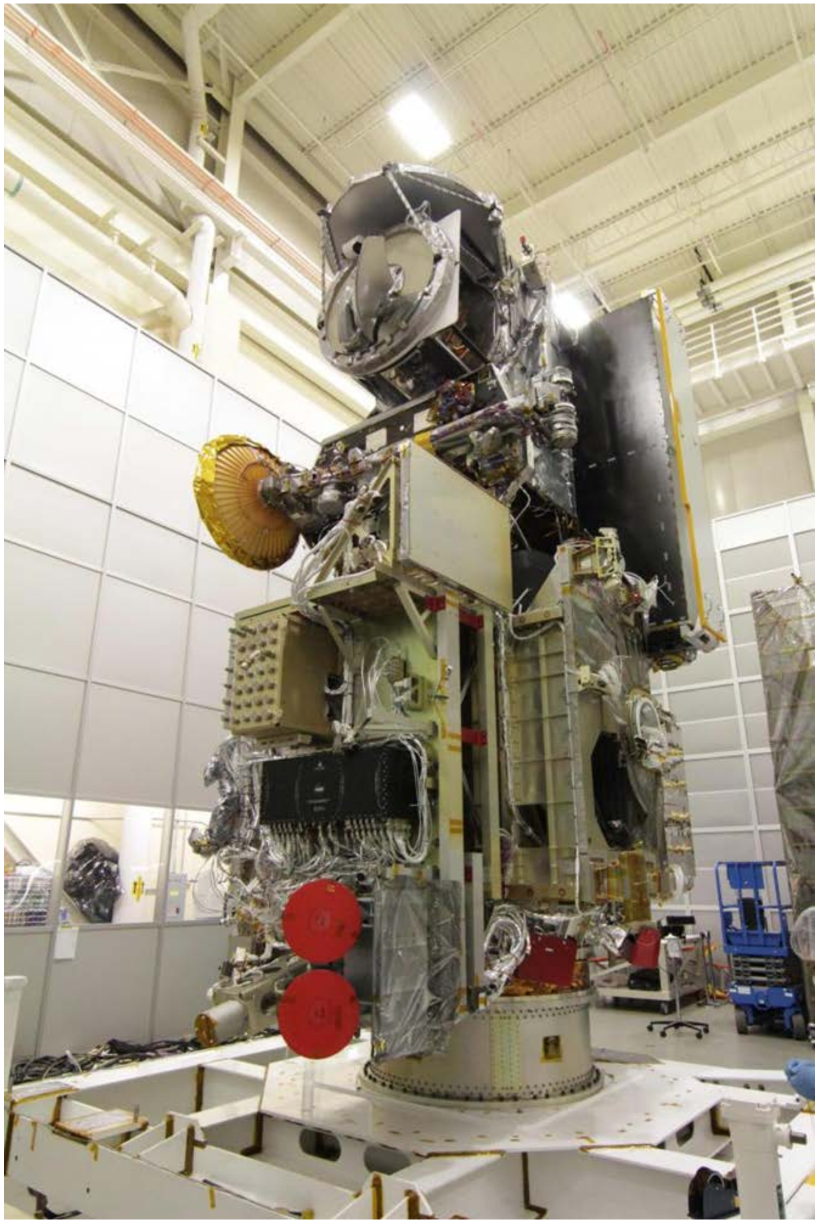
GMI is Operating On-Orbit and Providing Outstanding Performance

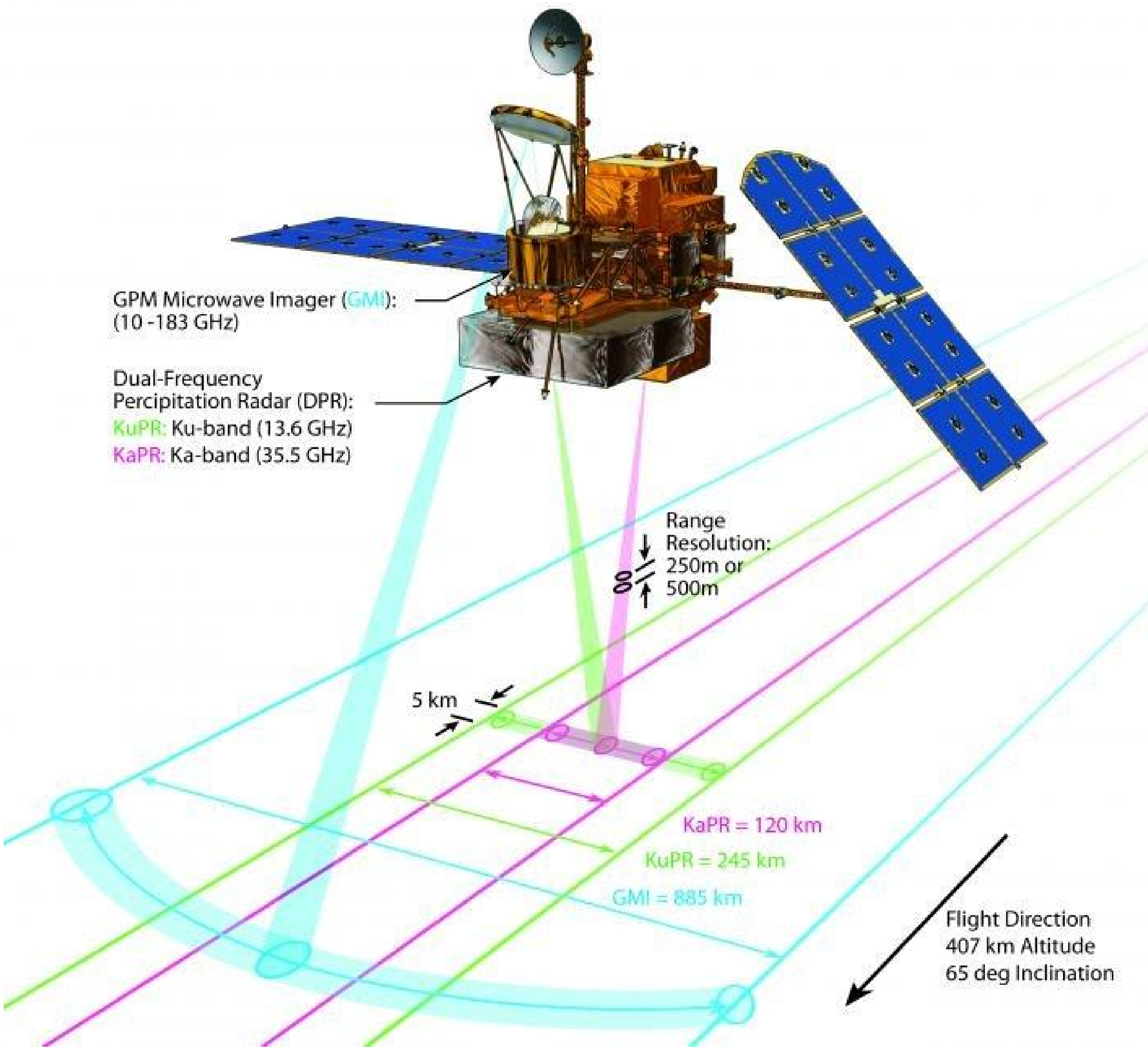
- GMI was launched February 28th from Tanegashima Japan.
- The GMI main reflector was successfully deployed with the deployment time similar to ground operations
- The spin mechanism launch restraints were all successfully released
- GMI was turned on 4 days after launch and has operated continuously with no anomalies
- The data from the first 3 months of operations has been analyzed and shows that the instrument is meeting all requirements with excellent performance for the key calibration uncertainty and NEDT requirements



GPM Core Observatory Launched Feb 28, 2014

GPM Mission Overview

- The Global Precipitation Measurement (GPM) Mission is an international effort managed by the National Aeronautics and Space Administration (NASA) to improve climate, weather, and hydro-meteorological predictions through more accurate and more frequent precipitation measurements
- 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



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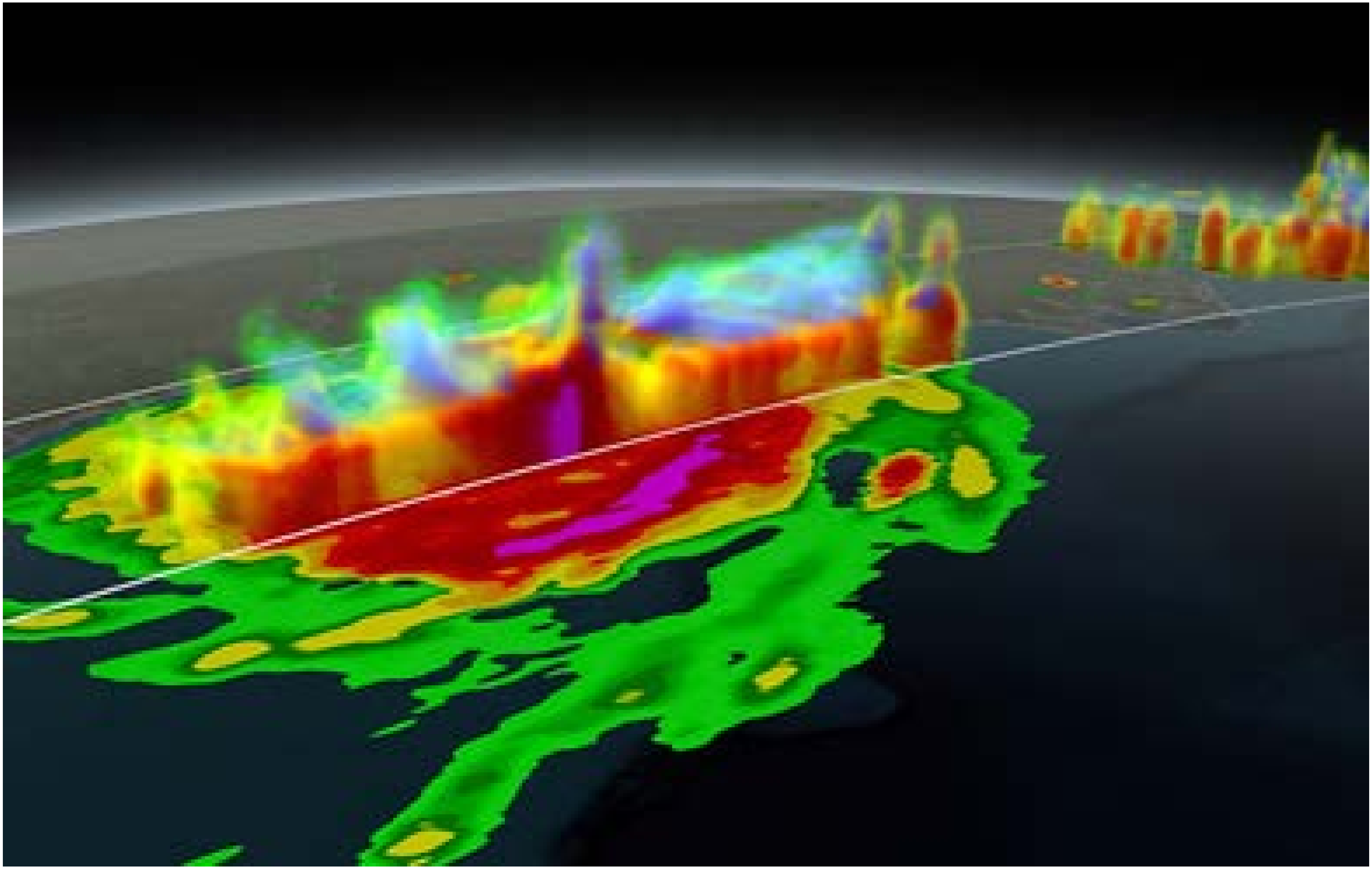
GPM Observation of Hurricane Arthur



GMI Instrument Overview

- The GMI design is a total power passive radiometer with through-the-feed 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), 18.7(V/H) GHz, 23.8 (V) GHz, 36.64 (V/H) GHz, 89 (V/H) GHz, 166 (V/H) GHz and 183.31 (V) GHz
- The measured mass is 168 kg and the measured on-orbit power is power is 146 watts.
- The allocated launch envelope requires the antenna to be stowed on the side of the instrument for launch
- The GMI instrument included a number of design features to ensure stability and calibration accuracy which have been proven effective on-orbit
  - Noise diodes in addition to hot and cold calibration targets for 10-36 GHz
  - Enclosed hot target to prevent sun loading
  - Sunshade to thermally isolate the receivers to minimize orbital temperature variations due to sun loading
  - Large cold sky reflector to minimize earth sidelobe contribution
  - Custom vapor deposited aluminum main reflector coating with high reflectivity up to 183 GHz

Center Freq (GHz)	Pol	Band-width (MHz)	Sample Time (msec)	Off-nadir Angle (deg)	Beam Width (deg)	Beam Effic-iency	IFOV @ 407km (km)
10.65	V	96.5	3.6	48.43	1.72	0.91	20x32
10.65	H	94.7	3.6	48.42	1.72	0.91	20x32
18.7	V	193	3.6	48.44	0.98	0.91	11x18
18.7	H	194	3.6	48.44	0.98	0.91	11x18
23.8	V	367	3.6	48.44	0.85	0.93	10x16
36.64	V	697	3.6	48.47	0.82	0.98	9x15
36.64	H	707	3.6	48.47	0.82	0.98	9x15
89	V	5862 RF	3.6	48.46	0.38	0.97	4x7
89	H	5917 RF	3.6	48.46	0.38	0.97	4x7
166	V	3850 RF	3.6	45.28	0.38	0.97	4x6
166	H	3893 RF	3.6	45.28	0.37	0.97	4x6
183.31±3	V	1482	3.6	45.27	0.37	0.95	4x5
183.31±7	V	1874	3.6	45.27	0.37	0.95	4x5

GMI Measured Performance Meets or Exceeds All Requirements

- The performance of the GMI instrument has been updated using the on-orbit performance
- The instrument performance against key requirements is shown in the adjacent tables
- In the key requirements of NEDT and calibration accuracy the GMI has significant margin to the required performance
- The receivers have operated with excellent thermal gain stability, varying by channel from 0.004 dB/K and 0.06dB/K
- This compares to the instrument thermal design of 0.1K/minute maximum thermal variation, the contribution to NEDT from thermal gain drifts is negligible.
- In addition, the receivers operate with very little 1/f noise, which contributes only a few percent to the NEDT
- The non-linearity has been verified on-orbit using the noise diodes and found to match the ground measurements closely
- The non-linearity will be monitored throughout the mission

		Bandwidth (MHz)		Frequency Stability (MHz)		NEΔT (K)			Calibration Accuracy (K, 3-σ)			Linearity (K)	
Channel	Freq / Pol	Rqmt.	W/C Perf.	Rqmt.	W/C Perf.	Rqmt.	Nom Perf[1].	W/C Perf.	Rqmt.	Nom Perf[2].	W/C Perf.	Rqmt	W/C Perf.
1	10.65 V-pol	<100	96.5	<10	1.2	<0.96	0.77	0.90	<1.35	0.15 bias	1.20	<0.5	0.14
2	10.65 H-pol	<100	94.7	<10	2.1	<0.96	0.78	0.90	<1.35	0.04 bias	1.20	<0.5	0.13
3	18.7 V-pol	<200	193	<20	8.9	<0.84	0.63	0.74	<1.35	-0.1 bias	1.26	<0.5	0.06
4	18.7 H-pol	<200	194	<20	6.0	<0.84	0.60	0.74	<1.35	-0.69 bias	1.26	<0.5	0.06
5	23.8 V-pol	<400	367	<20	7.4	<1.05	0.51	0.62	<1.35	-0.52 bias	0.97	<0.5	0.04
6	36.64 V-pol	<1000	697	<50	5.8	<0.65	0.41	0.50	<1.35	-0.35 bias	0.78	<0.5	0.46
7	36.64 H-pol	<1000	707	<50	5.8	<0.65	0.42	0.50	<1.35	-0.62 bias	0.78	<0.5	0.43
8	89 V-pol	<6000 RF	5865 RF	<200	14.2	<0.57	0.32	0.39	<1.35	-0.43 bias	1.06	<0.5	0.33
9	89 H-pol	<6000 RF	5918 RF	<200	15.7	<0.57	0.31	0.39	<1.35	-0.73 bias	1.06	<0.5	0.38
10	166 V-pol	<4000 RF	3850 RF	<200	15.2	<1.5	0.70	0.82	<1.5	0.54	1.11	<0.5	0.22
11	166 H-pol	<4000 RF	3893 RF	<200	13.2	<1.5	0.65	0.74	<1.5	0.54	1.11	<0.5	0.18
12	183.31 +/- 3 V-pol	<2000	1358	<200	35.2	<1.5	0.56	0.69	<1.5	0.50	1.08	<0.5	0.28
13	183.31 +/- 7 V-pol	<2000	1874	<200	10.2	<1.5	0.47	0.59	<1.5	0.50	1.08	<0.5	0.30

NOTES: [1]At average on-orbit Instrument Temperature

[2]At average on-orbit ocean brightness temperature w/out magnetic correction

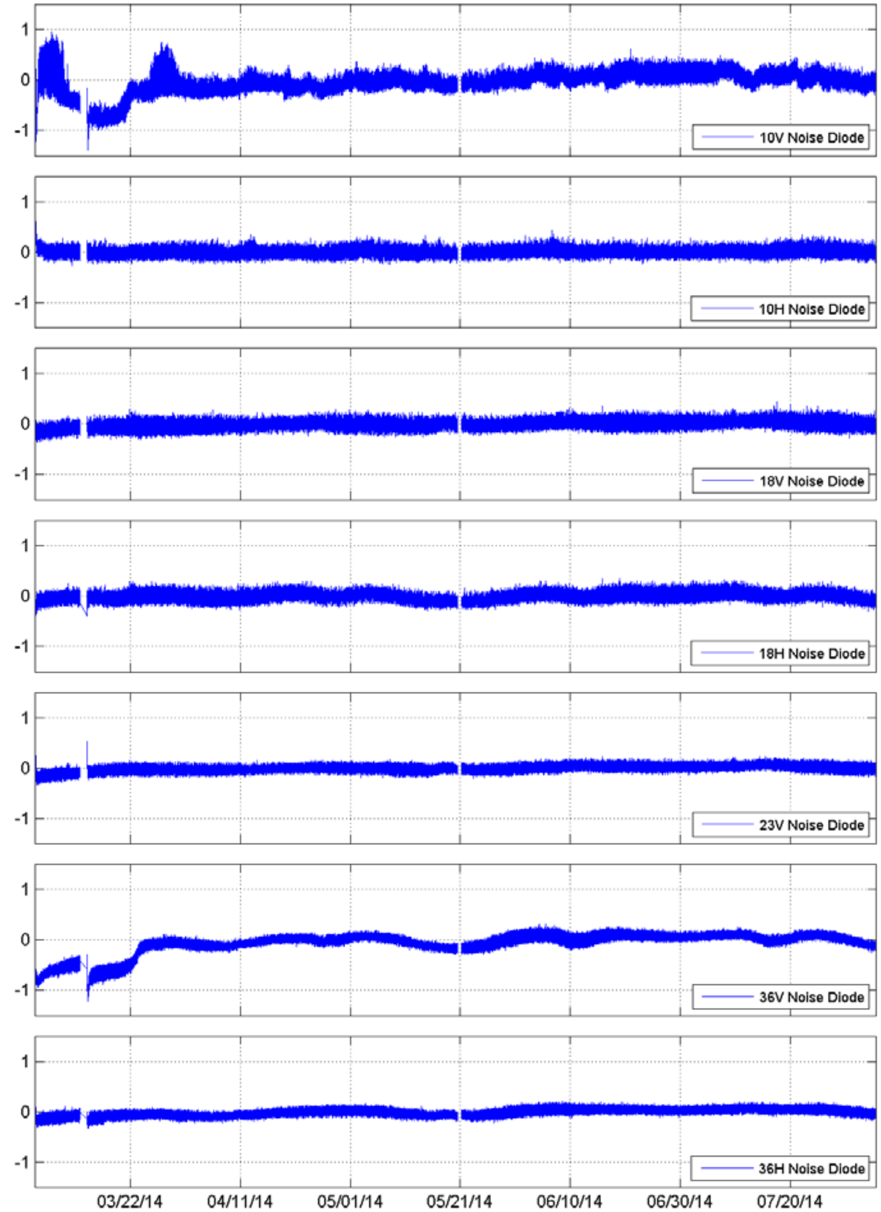
		Samp. Intvl (msec)	Off Nadir Angle (deg)		Beam Pointing Accuracy (deg)			Beam Width (deg)		Beam Efficiency (deg)		Reliability (%)	
Channel	Freq / Pol	Perf.	Rqmt.	Perf.	Rqmt.	Cross Scan Perf.	Along Scan Perf.	Rqmt.	Perf.	Rqmt.	Perf.	Rqmt.	Perf.
1	10.65 V-pol	3.6	Ch 7±0.1	48.43	<0.12	0.07	0.07	<1.75	1.72	>0.90	0.91	>87% over 38 mos.	88.3% over 38 mos.
2	10.65 H-pol	3.6	Ch 7±0.1	48.42	<0.12	0.07	0.07	<1.75	1.72	>0.90	0.91		
3	18.7 V-pol	3.6	Ch 7±0.1	48.44	<0.12	0.07	0.07	<1.00	0.98	>0.90	0.91		
4	18.7 H-pol	3.6	Ch 7±0.1	48.44	<0.12	0.07	0.07	<1.00	0.98	>0.90	0.91		
5	23.8 V-pol	3.6	Ch 7±0.1	48.44	<0.12	0.07	0.07	<0.90	0.85	>0.90	0.93		
6	36.64 V-pol	3.6	Ch 7±0.1	48.47	<0.12	0.07	0.07	<0.90	0.82	>0.90	0.98		
7	36.64 H-pol	3.6	48.5±0.2	48.47	<0.12	0.07	0.07	<0.90	0.82	>0.90	0.98		
8	89 V-pol	3.6	Ch 7±0.1	48.46	<0.12	0.07	0.07	<0.40	0.38	>0.90	0.97		
9	89 H-pol	3.6	Ch 7±0.1	48.46	<0.12	0.07	0.07	<0.40	0.38	>0.90	0.97		
10	166 V-pol	3.6	45.33±0.1	45.28	<0.12	0.07	0.07	<0.40	0.38	>0.90	0.97	>86% over 38 mos.	89.7% over 38 mos.
11	166 H-pol	3.6	45.33±0.1	45.28	<0.12	0.07	0.07	<0.40	0.37	>0.90	0.97		
12	183.31 +/- 3 V-pol	3.6	45.33±0.1	45.27	<0.12	0.07	0.07	<0.40	0.37	>0.90	0.95		
13	183.31 +/- 7 V-pol	3.6	45.33±0.1	45.27	<0.12	0.07	0.07	<0.40	0.37	>0.90	0.95		

Channel-Independent Requirements		
	Rqmt.	Perf.
Stowed Envelope Dimensions	within 1.48m x 1.36m x 1.70m	within 1.48m x 1.36m x 1.70m
Deployed Envelope Dimensions	within 1.60m x 1.48m x 3.03m	within 1.60m x 1.48m x 3.03m
Mass (kg)	<166	166
Operational Power (W)	<162	140
Science Data Rate (kbps)	<34.9	34.4
Housek. Data Rate (kbps)	<4.1	4.1
Dynamic Imbalance (kg m^2)	<0.055	0.022
Static Imbalance (kg m)	<0.032	0.017
Angular Momentum (N m s)	<37	35
Max Spin Torque (N m)	< 1.0	< 1.0

Noise Diode Performance

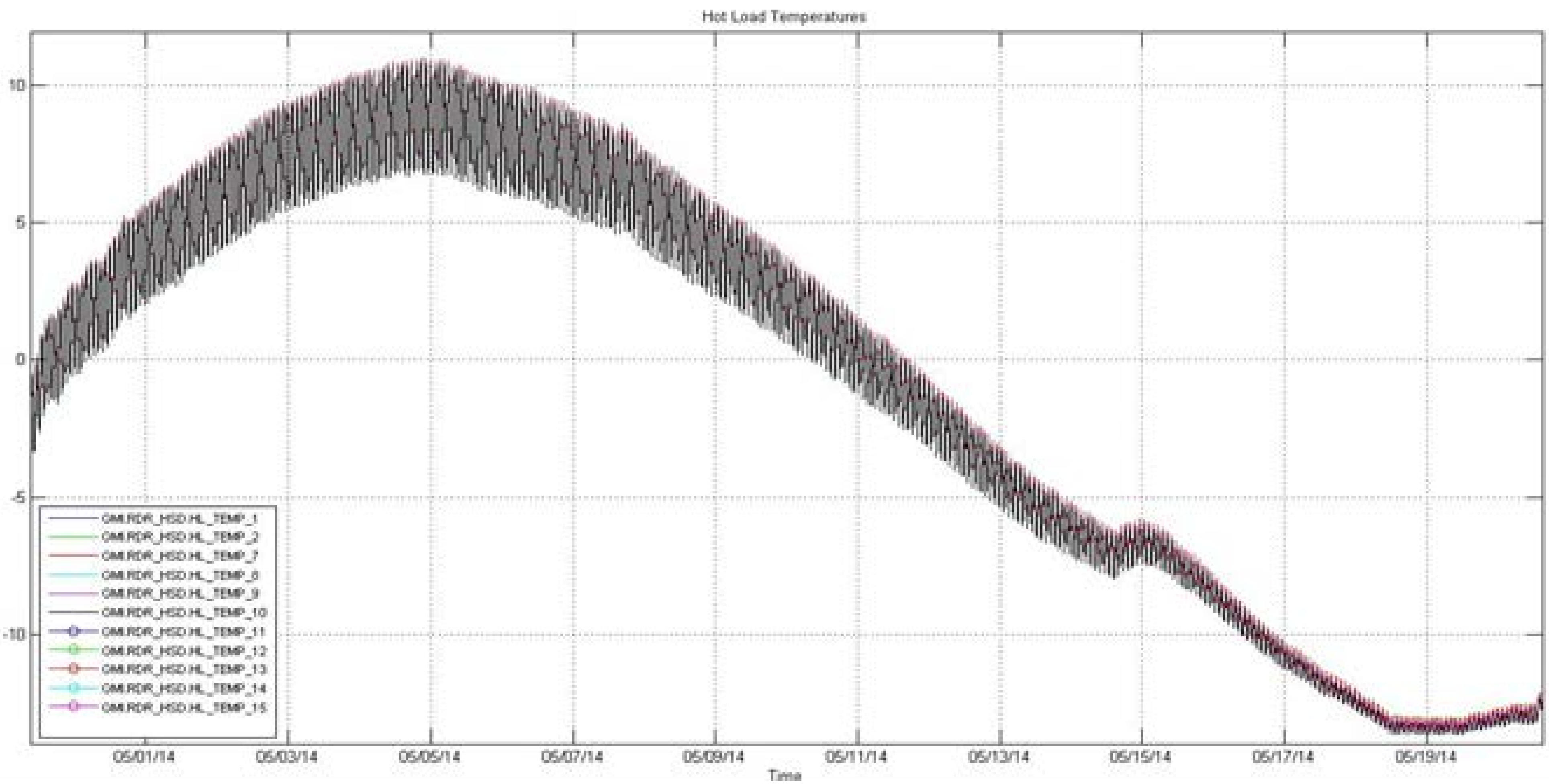
- The GMI provides noise diodes on the 10.65 through 36.64 GHz channels that provide a method to perform backup calibration if the hot load or cold sky views experience transient anomalies.
- The noise diodes also provide a method to trend non-linearity on orbit.
- The stability of the noise diode output power can be monitored using the radiometer calibrated using the hot and cold sky targets
- The graphs show the GMI noise diode deviation from the characterization as a function of time for the first 3 months of operations.
  - Spikes correspond to moon or RFI intrusion into the cold sky view. Long spikes are spacecraft maneuvers.
- The 10.65 V-pol noise diode and the 36 V-pol noise diode have experienced some on-orbit drift.
- There is a shift in noise diode excess temperature behavior around 3/22/2014 for the 10V and 36V noise diodes.
- The GMI noise diodes will continue to be monitored for stability.

Center Freq (GHz)	Pol	N. Diode Drift, 3 mo (K)	N.Diode Orbit Var ±pk (K)
10.65	V	0.7	±0.3
10.65	H	0.13	±0.3
18.7	V	0.11	±0.25
18.7	H	0.13	±0.25
23.8	V	0.14	±0.25
36.64	V	0.8	±0.35
36.64	H	0.14	±0.2



Hot Target Performance is Stable Over All Solar Beta Angles

- The figure shows the 15 thermistors located on the hot load over a 45 day beta angle cycle
- The temperatures are well behaved and do not show any spikes from solar intrusions
- This confirms that the design features added to the warm load are working

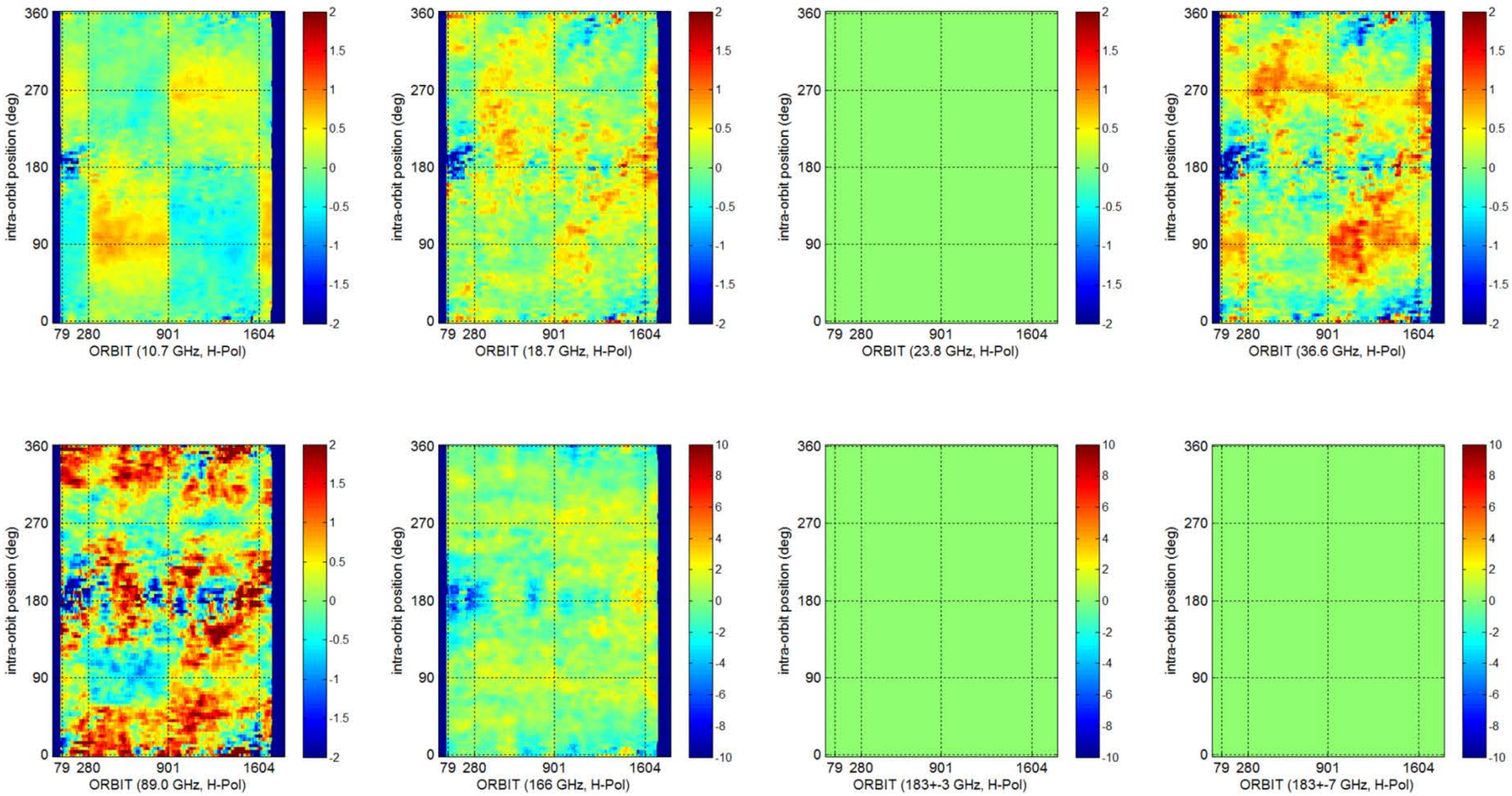


Calibration Uncertainty

- The basic tool for the GMI post-launch calibration method is to compare antenna temperatures (TA) that are measured from the radiometer with those computed from the radiative transfer model (RTM) developed by Remote Sensing Systems (RSS).
- The difference between measured and RTM computed TA is used to remove the variability of the environmental scene.
- WindSat and AMSR-2 measurements that are collocated with GMI and temporally located within one hour are used for comparison
  - The collocated WindSat and AMSR-2 measurements are used to determine ocean surface wind speed, columnar water vapor and columnar liquid cloud water
    - The WindSat and AMSR-2 ocean products have been carefully validated by RSS to remove WindSat/AMSR-2 instrument biases using ground truth data
  - For SST the Reynolds OI product is used. The wind direction is taken from NCEP GDAS
  - These parameters are input into the RTM and a TA calculated for GMI
  - The calculated GMI TA is compared to the measured TA
- The first 90 days of data is shown on the following slides
- Along scan biases have been determined and removed
- Orbital biases due to a small magnetic susceptablity in some changes has been determined and removed

GMI Minus RTM TA Difference Versus Orbit Number and Orbit Position: H-POL No Magnetic Susceptibility Correction

- A 0.5 Kelvin bias that is orbit position dependent can be seen at 10.7 GHz
- This has been determined to be caused by the magnetic field of the earth and a correction algorithm is planned to be implemented in the flight algorithm in September



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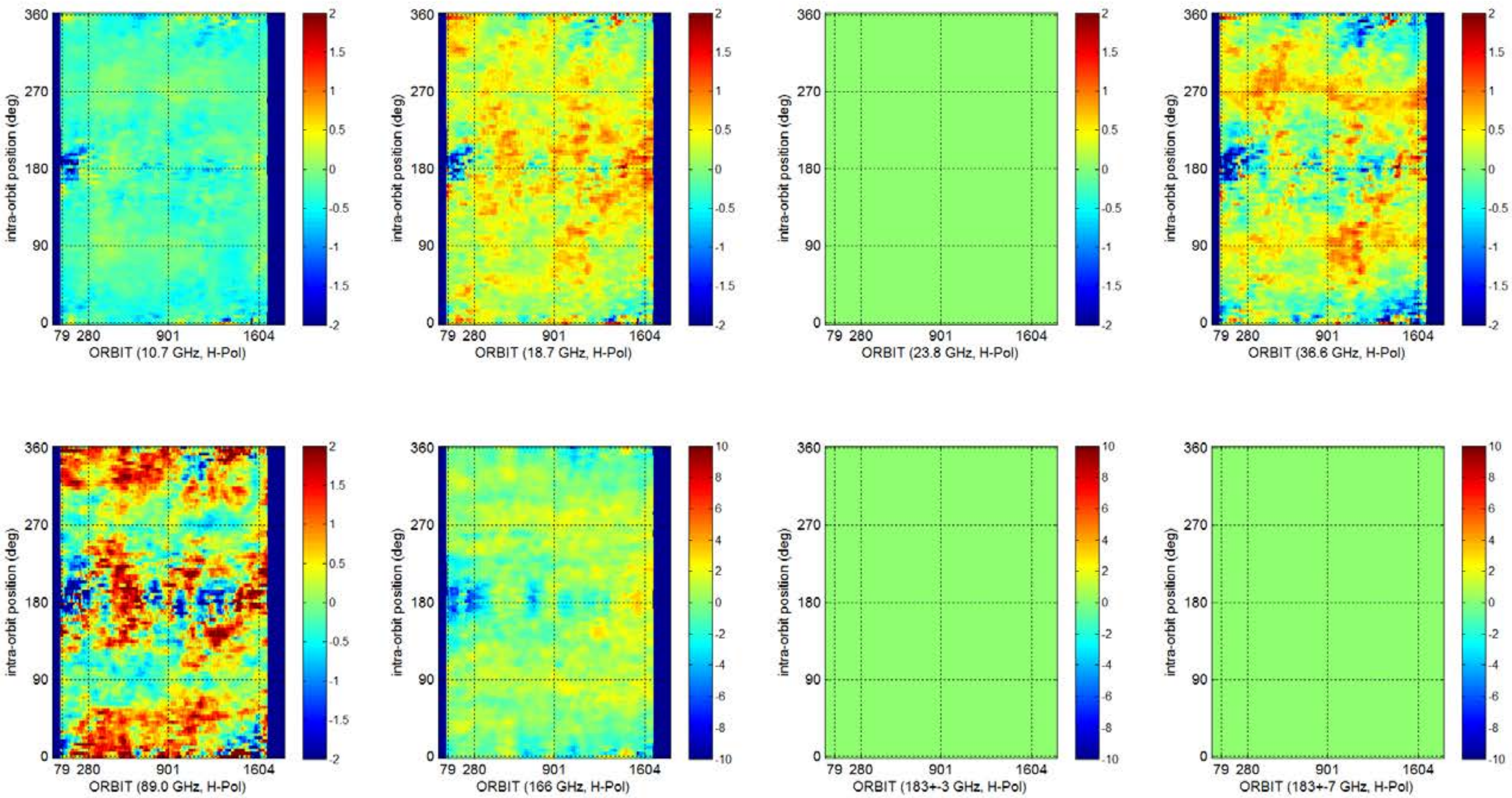
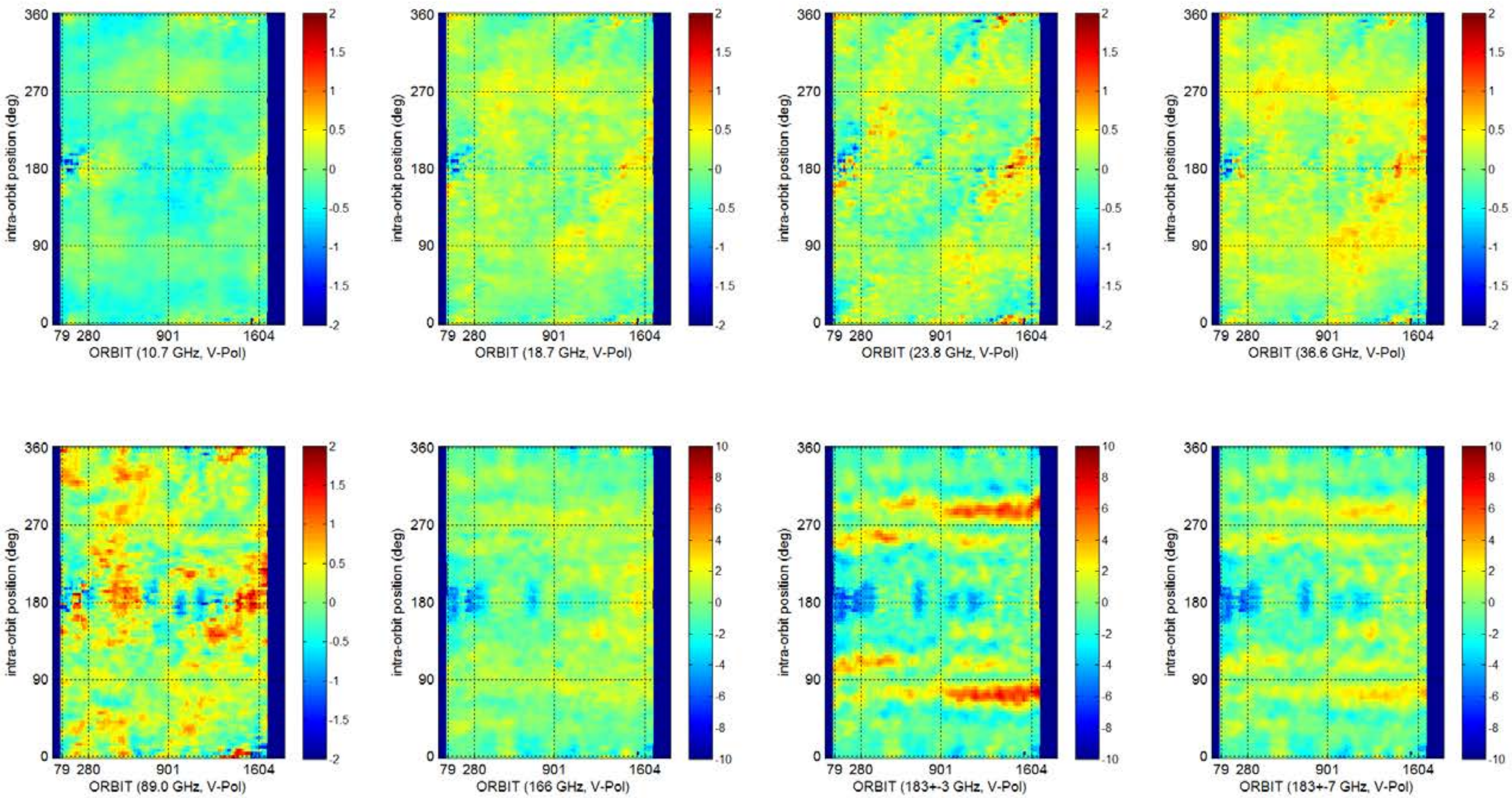
GMI Minus RTM TA Difference Versus Orbit Number and Orbit Position: H-POL

- Magnetic Correction Removes the orbital-dependent biases
- 23 GHz and 183 GHz do not have horizontal polarization channels



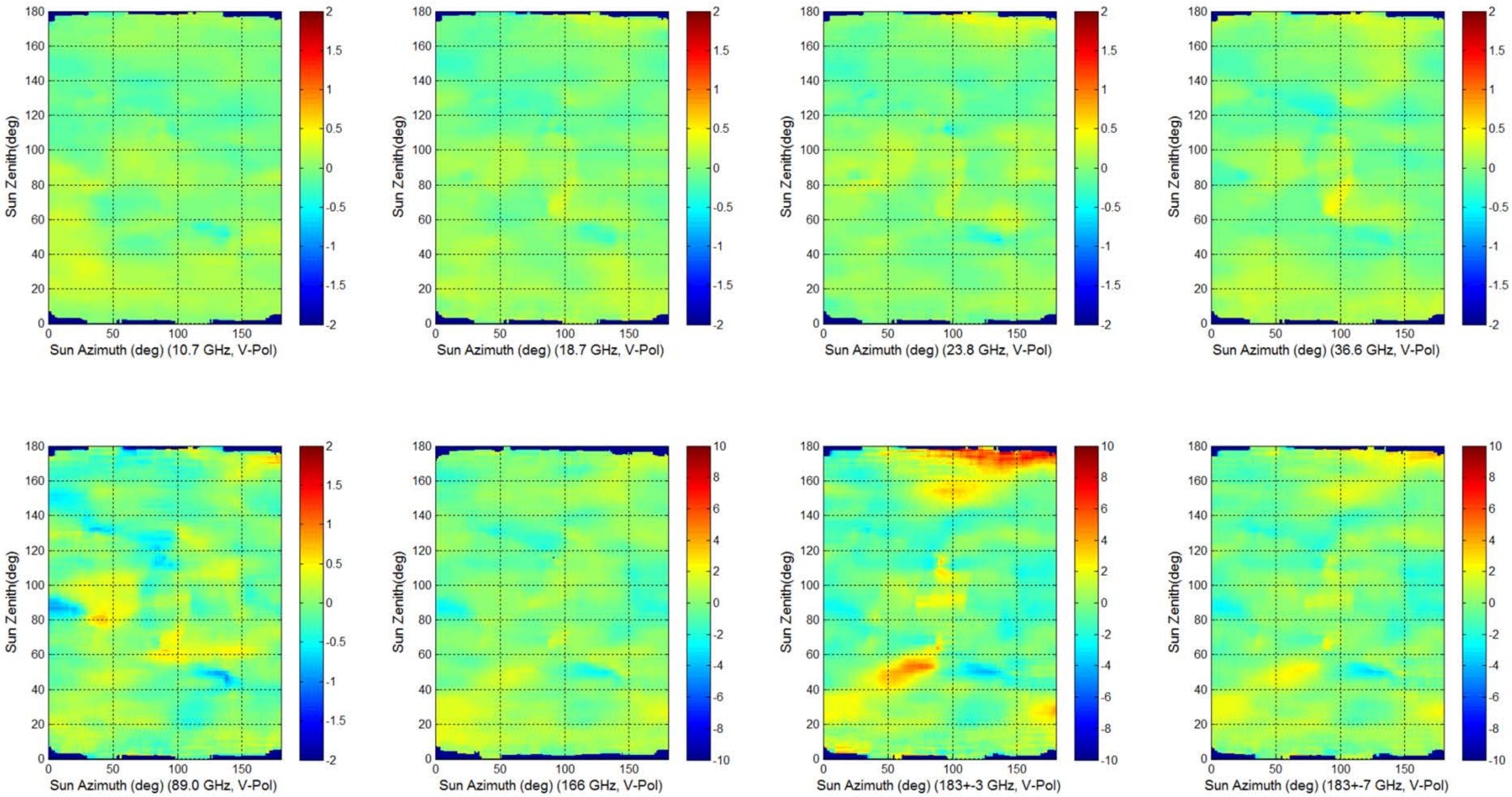
GMI Minus RTM TA Difference Versus Orbit Number and Orbit Position: V-POL

- Outstanding performance out of the box with magnetic correction

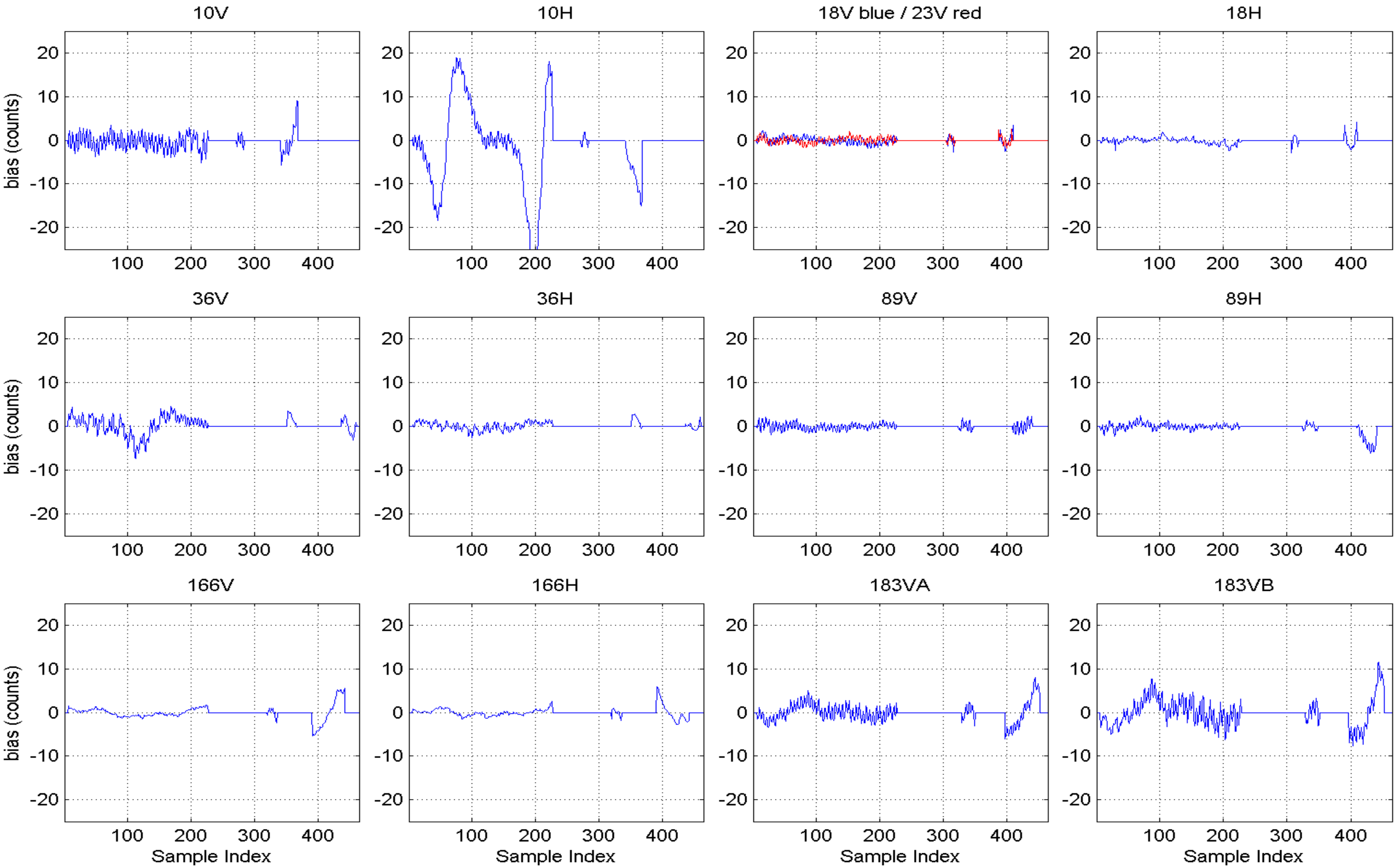


GMI Minus RTM TA Difference Versus Solar Angles: V-POL

- Analyzing the data this way allows for solar intrusions on the hot load to be identified
- The performance of the hot load is excellent



Instrument-Induced Magnetic Correction



GMI Summary

- The initial commissioning of the GMI instrument is complete
- The first 3 months of data show 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