XCAL Status and Plans for GPM V5 and TRMM V8 Reprocessing

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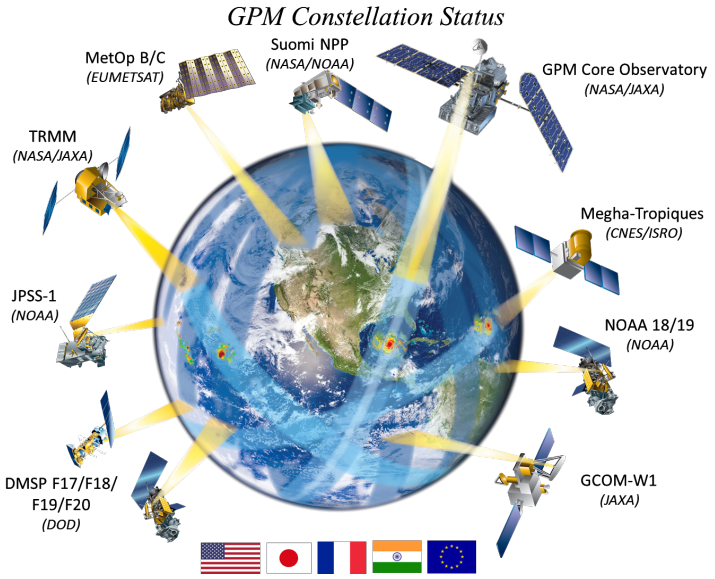


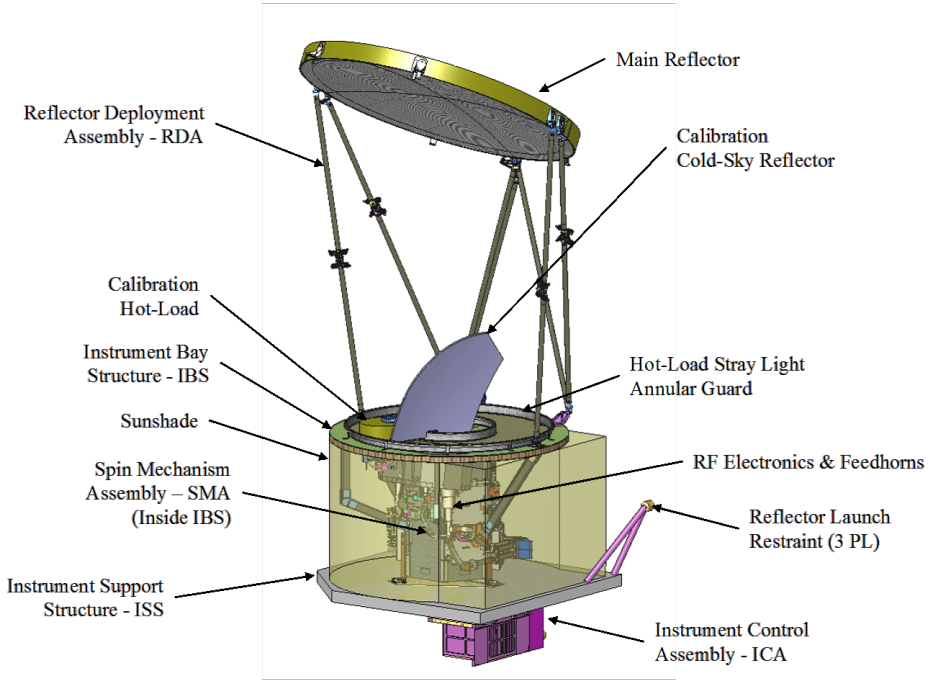
Intercalibration Working Group (XCAL)

The XCAL team is responsible for the **Level 1C intercalibrated brightness temperature files** used as input to the operational precipitation retrieval algorithm for all of the GPM constellation radiometers (and TRMM constellation radiometers). Specific tasks include:

1. Identify sensor issues affecting the calibration and stability of the Tb for each of the constellation radiometers.
2. Develop and apply corrections for sensor calibration issues.
3. Derive and deliver intercalibration tables to adjust for residual sensor calibration differences in a physically consistent manner.

GPM GMI: Calibration Reference Sensor

GMI Specs	10.65v/h	18.7v/h	23.8v	36.64v/h	89.0v/h	165.5v/h	183+3v	183+7v
DT x CT Res in km	32.1x19.4	18.1x10.9	16.0x9.7	15.6x9.4	7.2x4.4	6.3x4.4	5.8x3.8	5.8x3.8
Beamwidth (deg)	1.72	0.98	0.85	0.81	0.38	0.37	0.37	0.37
NEDT (K)	0.96	0.84	1.05	0.65	0.57	1.5	1.5	1.5
Beam Efficiency (%)	91.1	91.2	93.0	97.8	96.8	96.5	95.2	95.2
Uncorr Nonlinearity (K)	0.2 0.2	0.1 0.1	0.1 0.1	0.5 0.5	0.5 0.5	0.5 0.5	0.5	0.5
Band Width (MHz)	100	200	400	1000	6000	4000	3500	4500
Feedhorns	1	1	1	1	1	1	1	1
Integration Time (ms)	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6



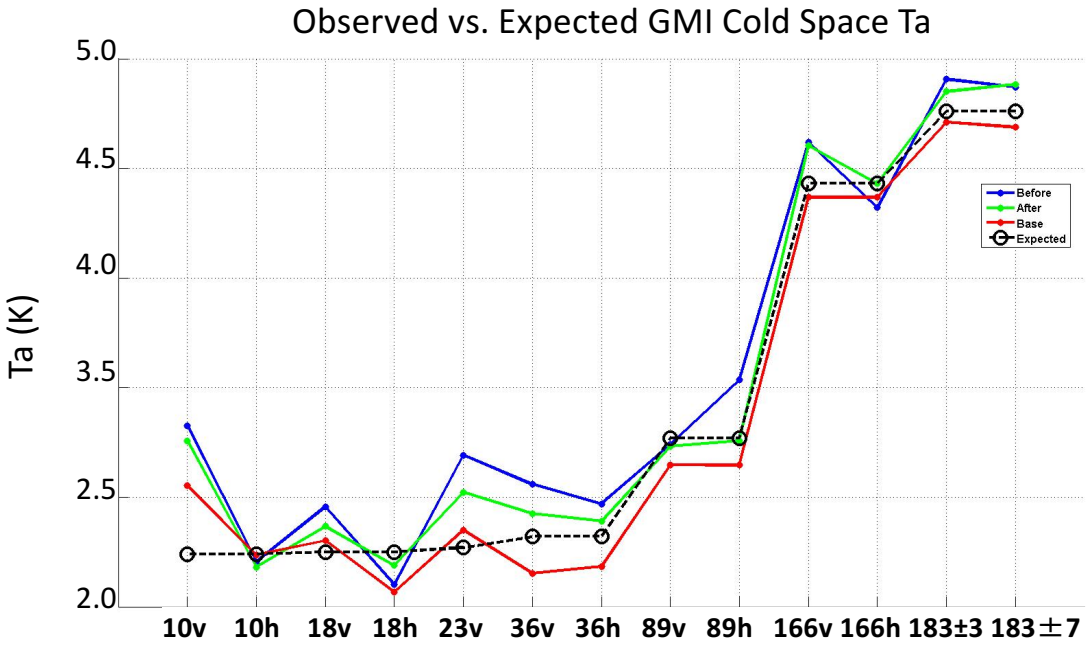
Satellite/Instrument Characteristics

Nominal EIA	52.8/49.2
Orbit Inclination	65.0 deg
Local Obs. Time	Variable (Precessing)
Altitude	407 km
Reflector Size	1.22 m
Sampling Interval	13.5 km

Reference Sensor Attributes

- Has both imager and moisture sounding channels
- 65 degree orbit inclination provides regular daily coincident overpasses with other sensors
- Very well calibrated and stable

GMI Calibration Summary



On-Orbit Calibration Maneuvers

Calibration Checks

- Emissive Reflector (good -> plot on left)
- Polarization Check (< 0.3K at nadir)

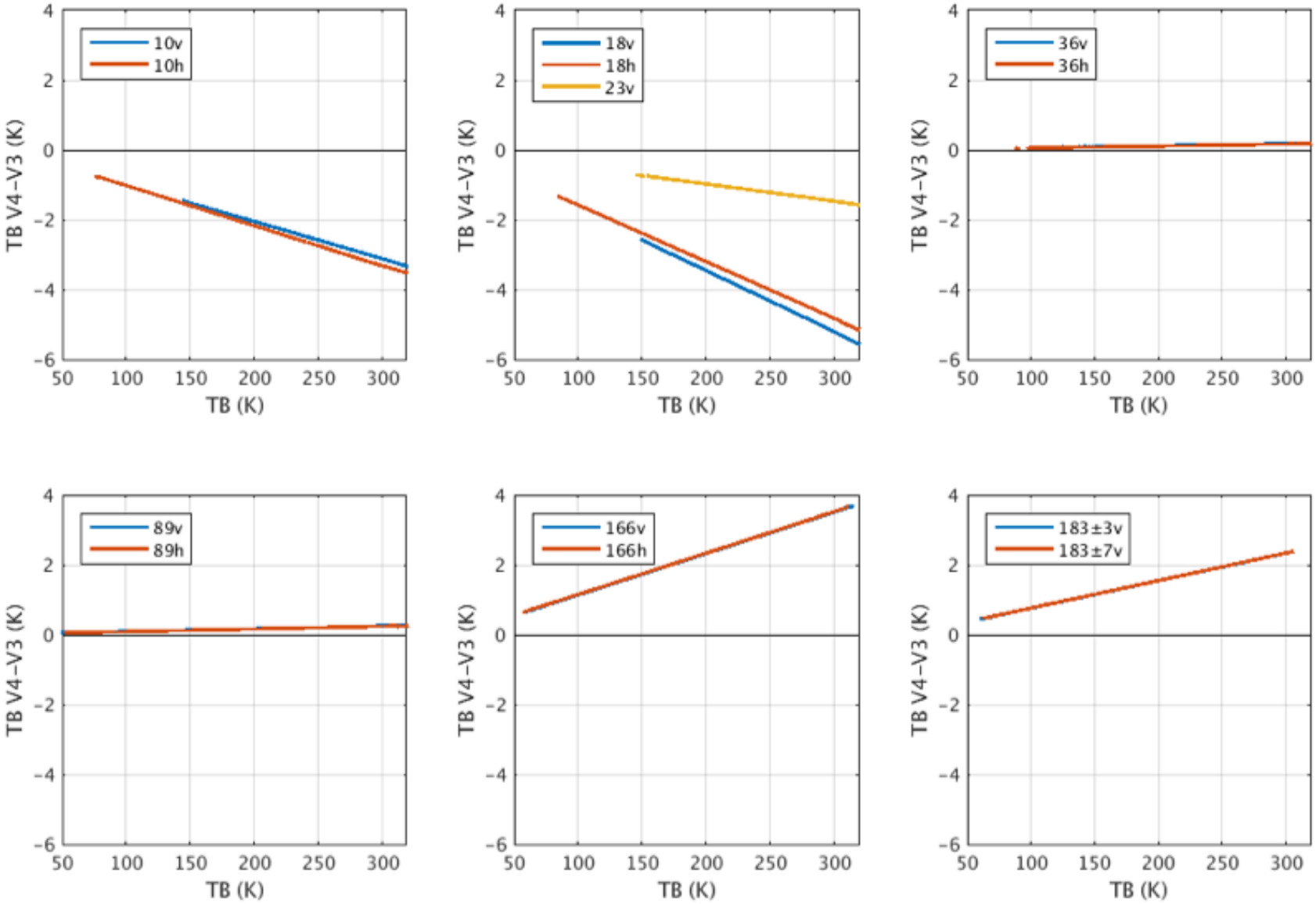
Calibration Corrections

- Magnetic anomalies
- Cross-track bias correction
- Spillover Corrections

- **Significant changes were made to the spillover corrections.** Given limitations of pre-launch measurements this is a likely a primary cause of large calibration differences between sensors, particularly for lower frequency channels.
- **Calibration corrections are based on data from on-orbit calibration maneuvers** and are not dependent on radiative transfer models
- Independent comparisons with by Ball/RSS and XCAL indicate that the GMI calibration is very consistent with clear-sky ocean simulated Tb. Conservative estimate for the **absolute calibration errors of GMI window channels are < 1K**
- Comparisons with the MHS and SAPHIR cross-track sounders indicate **absolute calibration errors of GMI 166 and 183 GHz channels of < 0.5K**

GMI V4 – V3 Tb Differences

Differences Primarily due to Updated Spillover Corrections



GMI V05 Calibration

Major changes

- Adjusted spillover coefficients for all GMI channels (largest changes for low frequency channels). This is based on data from the GMI deep space maneuver, inertial hold, and refinements of the analysis by Ball/RSS and the XCAL team.

Minor changes

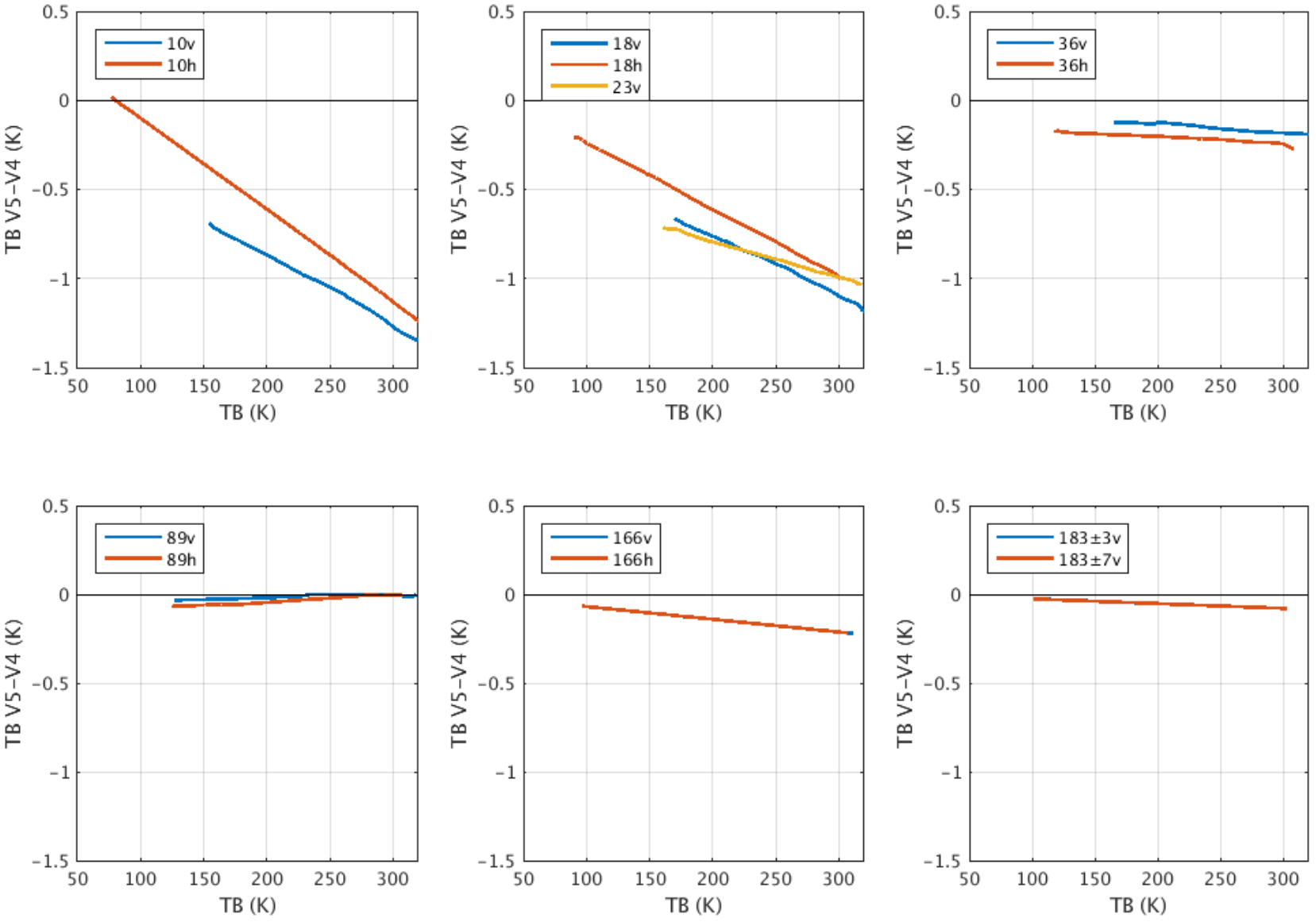
- Adjusted cold load temperature for 10 GHz channels (< 0.2 K)
- Added count adjustment to magnetic correction (<0.2 K)
- Updated magnetic correction coefficients (<0.2 K)
- Added Earth-view antenna induced along scan correction

Status

- Approved and finalized for V5 reprocessing (June 2016)
- Used for V5 algorithm development (ITE101)

GMI V5 – V4 Tb Differences

Refinements to Spillover Corrections



GMI On-orbit Calibration Error Assessment

- Detailed error analysis by Ball indicates **0.25K RMS bias** and 0.14K RMS time-varying component
- Conservative estimate based on comparison with independently calibrated radiometers suggests **absolute accuracy < 1K RMS across all channels**
- **Excellent relative calibration reference** due to orbit and channel complement
- **High quality absolute calibration reference** due to accuracy, stability, traceable error budget, and independence from radiative transfer models. Result of instrument design and on-orbit maneuvers.

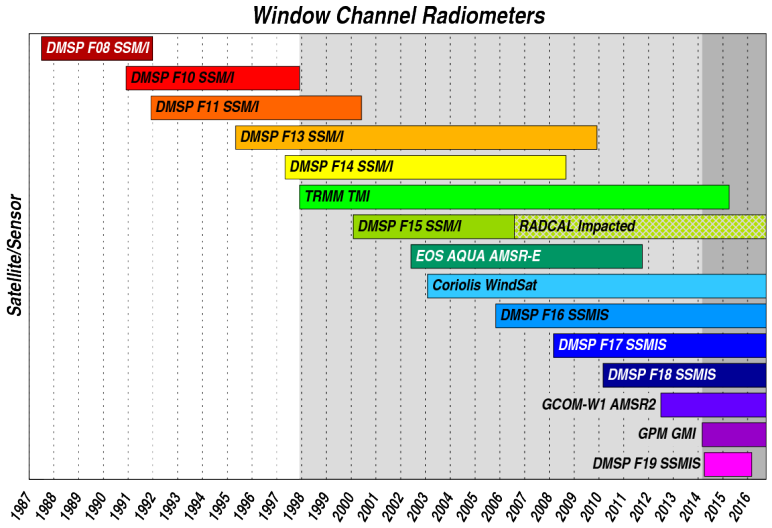
	Magnetic Correction		TA Calibration		Antenna-Induced Bias		**Total TA ERROR (ocean)**		Spillover		Cross-pol		**Total TB ERROR (ocean)**	
Channel	Total Bias	Total Time-varying error	Total Bias	Total Time-varying error	Total Bias	Total Time-varying error	**Total Bias**	**Total Time-varying error**	Total Bias	Total Time-varying error	Total Bias	Total Time-varying error	**Total Bias**	**Total Time-varying error**
10V	0.09	0.09	0.12	0.07	0.00	0.03	**0.15**	**0.12**	0.29	0.02	0.07	0.00	**0.34**	**0.12**
10H	0.05	0.11	0.18	0.06	0.00	0.04	**0.18**	**0.13**	0.17	0.02	0.07	0.00	**0.26**	**0.13**
18V	0.05	0.05	0.09	0.08	0.00	0.02	**0.10**	**0.10**	0.26	0.02	0.05	0.00	**0.28**	**0.10**
18H	0.04	0.07	0.09	0.06	0.00	0.03	**0.09**	**0.09**	0.17	0.03	0.05	0.01	**0.20**	**0.09**
23V	0.06	0.08	0.09	0.09	0.00	0.01	**0.11**	**0.12**	0.23	0.03	0.02	0.03	**0.25**	**0.13**
36V	0.01	0.11	0.08	0.11	0.00	0.00	**0.08**	**0.16**	0.21	0.01	0.01	0.00	**0.23**	**0.16**
36H	0.02	0.07	0.07	0.08	0.00	0.00	**0.07**	**0.11**	0.15	0.02	0.01	0.00	**0.17**	**0.11**
89V	0.00	0.03	0.07	0.14	0.00	0.00	**0.07**	**0.14**	0.22	0.01	0.01	0.00	**0.23**	**0.14**
89H	0.02	0.09	0.08	0.12	0.00	0.01	**0.08**	**0.15**	0.20	0.02	0.01	0.00	**0.21**	**0.15**
166V	0.04	0.05	0.05	0.14	0.00	0.01	**0.06**	**0.15**	0.28	0.01	0.02	0.02	**0.29**	**0.16**
166H	0.04	0.09	0.05	0.14	0.00	0.01	**0.06**	**0.17**	0.28	0.02	0.02	0.02	**0.29**	**0.17**
183VA	0.02	0.06	0.04	0.14	0.00	0.01	**0.04**	**0.15**	0.24	0.01	0.01	0.07	**0.24**	**0.16**
183VB	0.02	0.09	0.03	0.14	0.00	0.01	**0.04**	**0.17**	0.24	0.01	0.01	0.07	**0.25**	**0.18**
RMS	0.04	0.08	0.09	0.11	0.00	0.02	**0.10**	**0.14**	0.23	0.02	0.03	0.03	**0.25**	**0.14**

TB BIAS

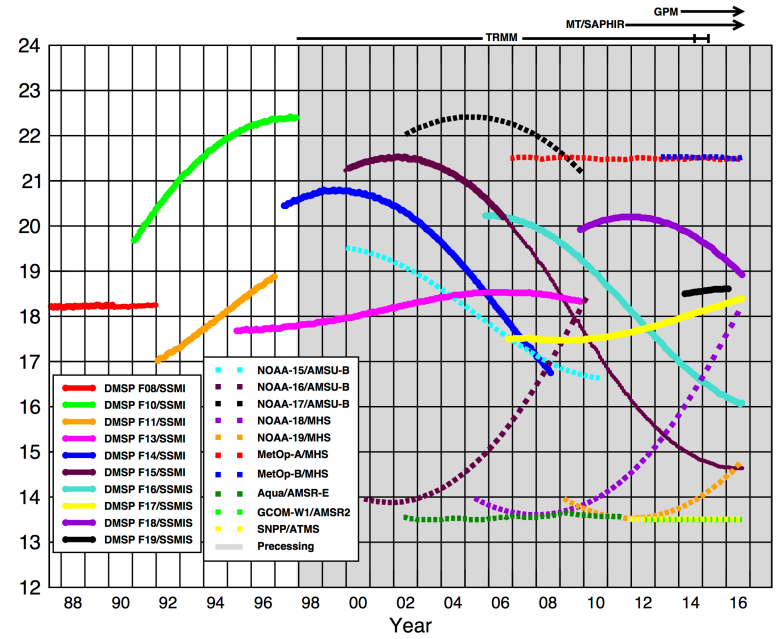
*Courtesy David Draper, Ball Aerospace & Technologies Corp. Boulder, Colorado USA

GPM/TRMM Radiometer Constellations

Research and Operational Sensors with Different Capabilities and Calibrations



Satellite (Sensor)	6-7 GHz	10 GHz	19 GHz	23 GHz	31-37 GHz	85-92 GHz	150-166 GHz	183 GHz
GPM GMI		10.65vh	18.7v/h	23.8v	36.64v/h	89.0v/h	166v/h	183.31±3, 7
TRMM TMI		10.65v/h	19.35v/h	21.3v	37.0v/h	85.5v/h		
GCOM-W1 AMSR-2	6.925v/h 7.3v/h	10.65v/h	18.7v/h	23.8v/h	36.5v/h	89.0v/h (B) 89.0v/h (B)		
DMSP F16, F17, F18, F19 SSMIS (4)			19.35v/h	22.235v	37.0v/h	91.655v/h	150h	183.31±1, 3, 6.6
METOP A/B, NOAA 18/19 MHS (4)						89qv	157qv	183.31±1, 3 190.31
Suomi NPP ATMS				23.8qv	31.4qv	88.2 qv	165.5qh	183.31±1.0, 1.8, 3.0, 4.5, 7.0
Megha-Tropiques SAPHIR								183.31±0.2, 1.1, 2.8, 4.2, 6.8, 11



Ascending passes (F08 descending); satellites depicted above graph precess throughout the day.
Image by Eric Nelkin (SSAI), 22 September 2016, NASA/Goddard Space Flight Center, Greenbelt, MD.

GPM Era (Mar 2014 – Present)

- **GPM Imager Constellation (7)**
  - **GPM GMI (reference sensor)**
  - TRMM TMI
  - GCOM-W1 AMSR2
  - DMSP F16, F17, F18 and F19 SSMIS
  - *Coriolis WindSat
- **GPM Sounders (6)**
  - Metop A and B MHS
  - NOAA 18 and 19 MHS
  - Suomi NPP ATMS
  - Megha-Tropiques SAPHIR
  - **JPSS1 ATMS

*Not currently part of the GPM constellation,
**To be launched in 2nd quarter 2017

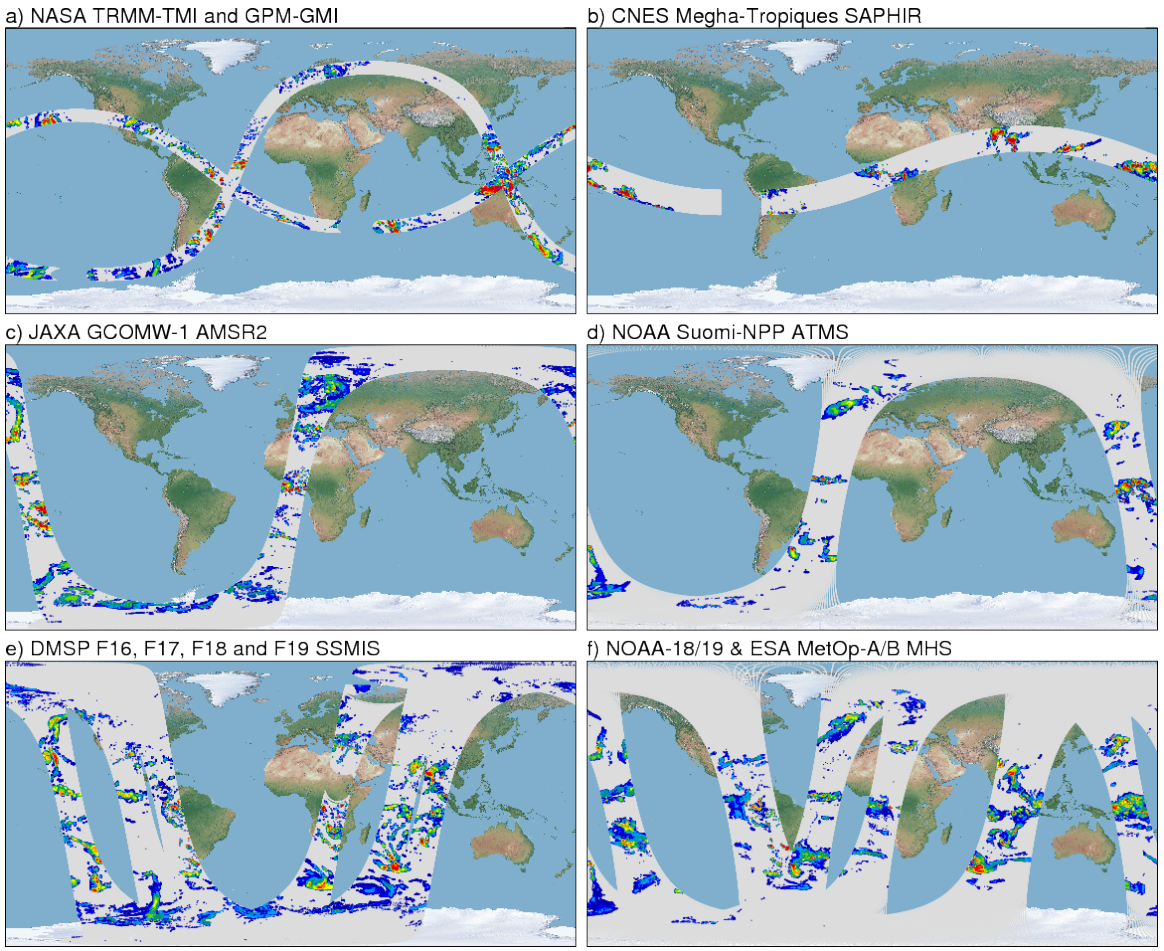
TRMM Era (Dec 1997 – Apr 2015)

- **TRMM Imager Constellation (10)**
  - TRMM TMI
  - EOS-AQUA AMSR-E
  - GCOM-W1 AMSR2
  - DMSP F11, F13, F14 and F15 SSM/I
  - DMSP F16, F17 and F18 SSMIS
  - *Coriolis WindSat
- **TRMM Sounders (8)**
  - NOAA 15, 16 and 17 AMSU-B
  - Metop A, NOAA 18 and 19 MHS
  - Suomi NPP ATMS
  - Megha-Tropiques SAPHIR

GPM Radiometer Constellation

Conical Imagers

Cross-Track Sounders

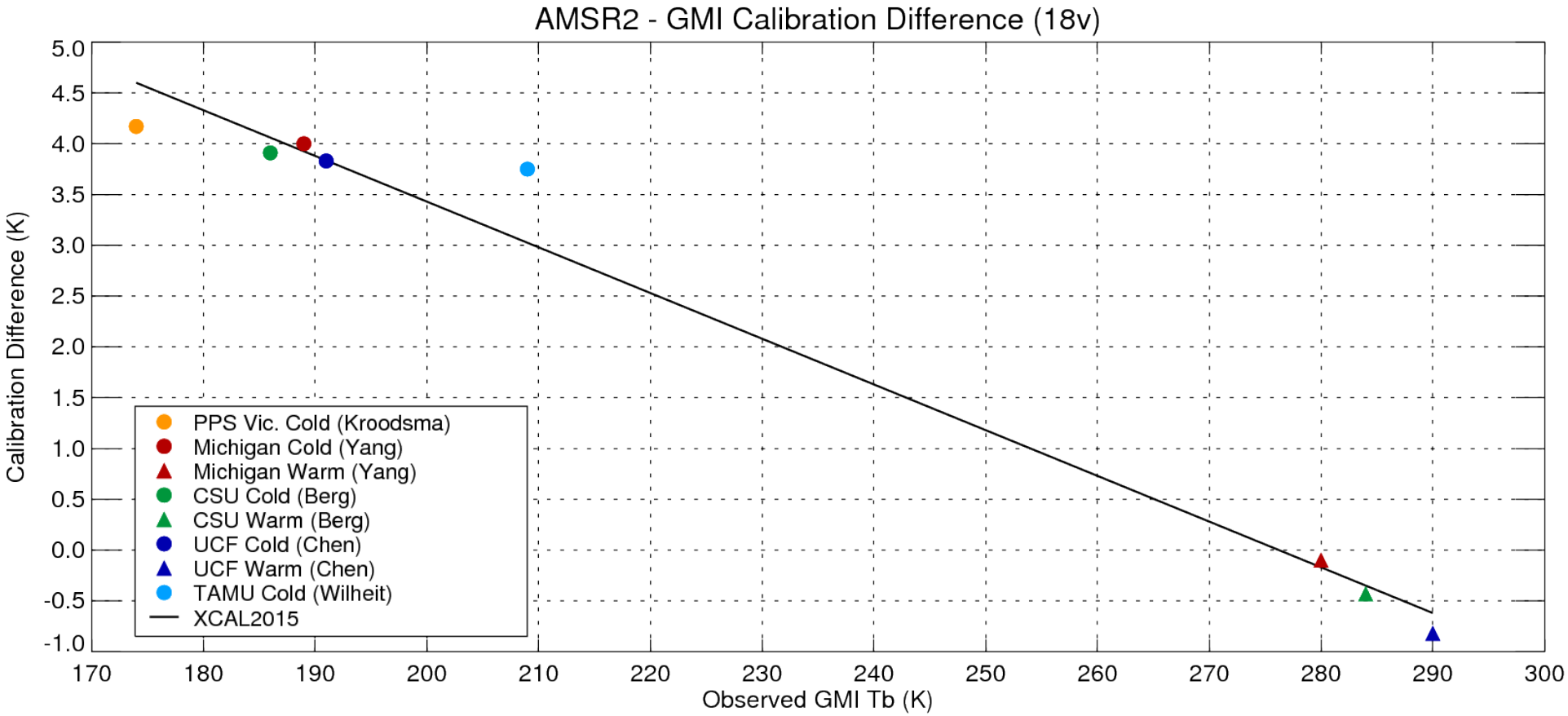


Status of Constellation Sensors

- TRMM data record ended April 2015
- F19 SSMIS died 11 February 2016
- F16 150 & 183 channel issues
- F17 37v channel issues
- F20 launch cancelled
- NPP ATMS scan motor drive issues
- JPSS1 ATMS launch (2nd quarter 2017)
- Updated L1C calibration tables for V5 delivered September 2016

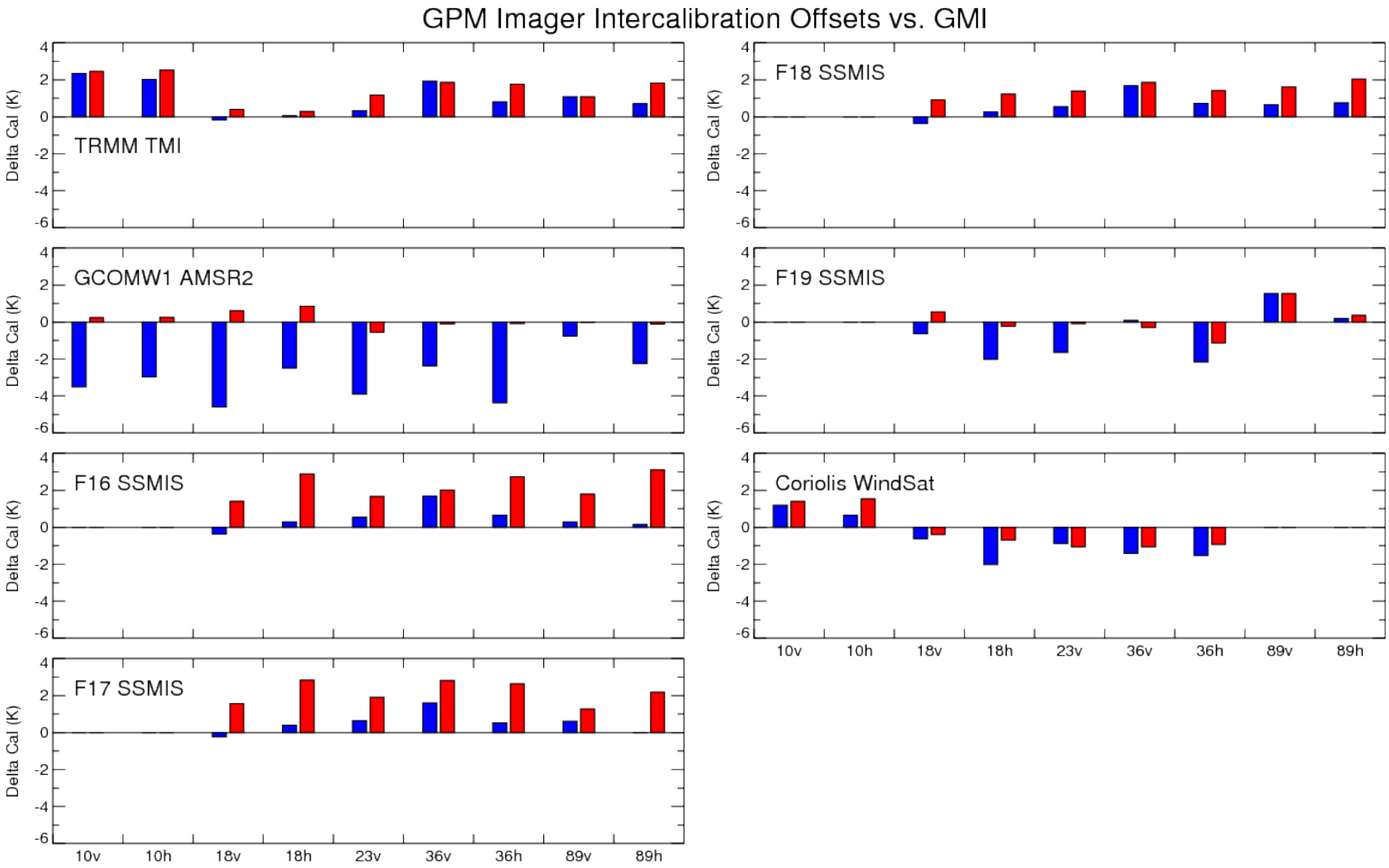
Constellation Radiometer Intercalibration

Multiple Independent Techniques

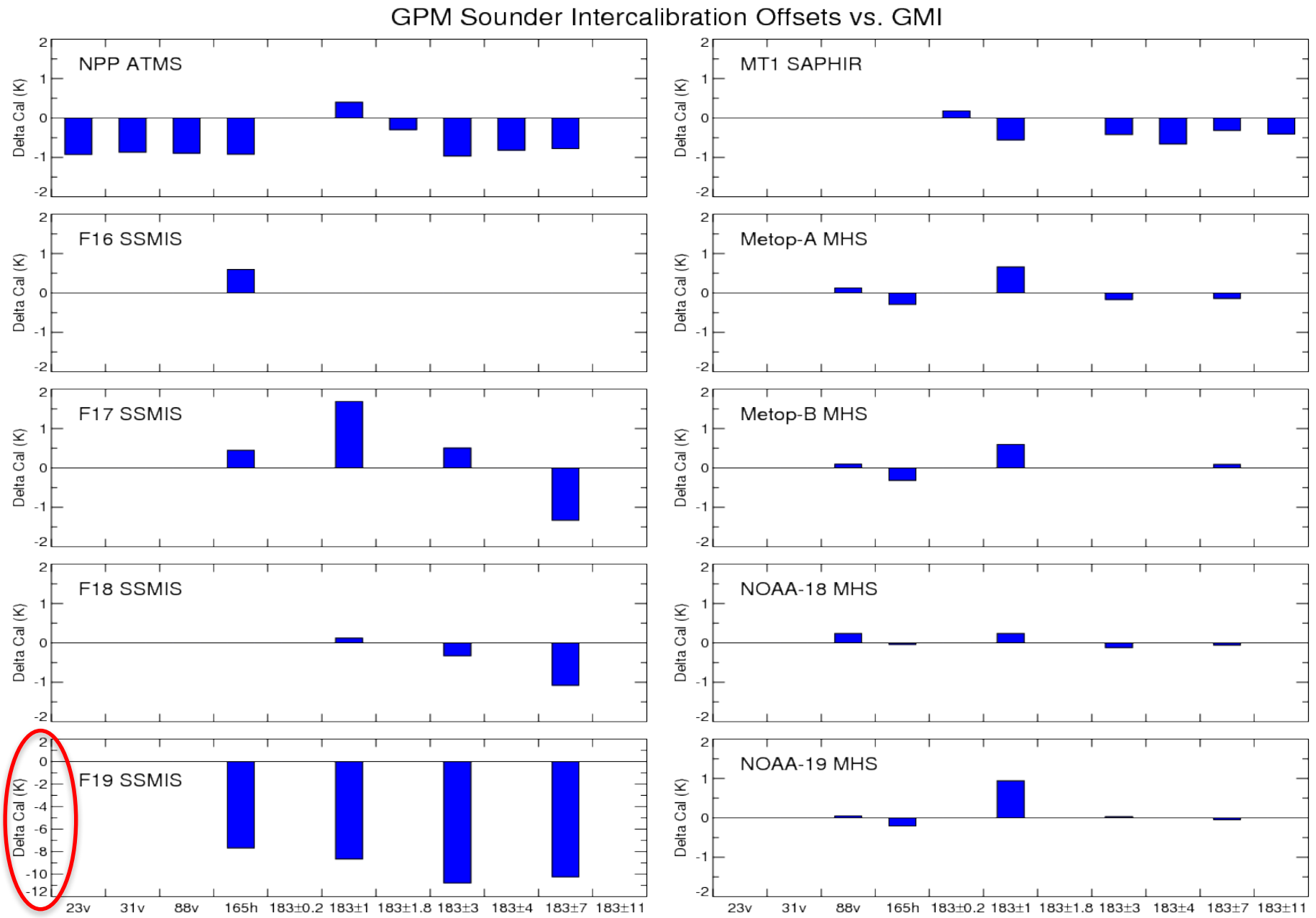


- Above example for the 18 GHz V-Pol channel on AMSR2 shows a “worst” case example of calibration inconsistencies.
- Five groups within XCAL produced calibration offsets for cold ocean scenes and three groups produced offsets for warm land scenes.
- While this case exhibits large biases and variations with scene temperature, results between teams are consistent within 1K.
- The XCAL team has a high degree of confidence that the final adjusted Tb values are consistent within 1K.

GPM Conical-Scanning Imager Intercalibration Offsets



GPM Cross-Track Sounder Intercalibration Offsets



TMI V8 Updates

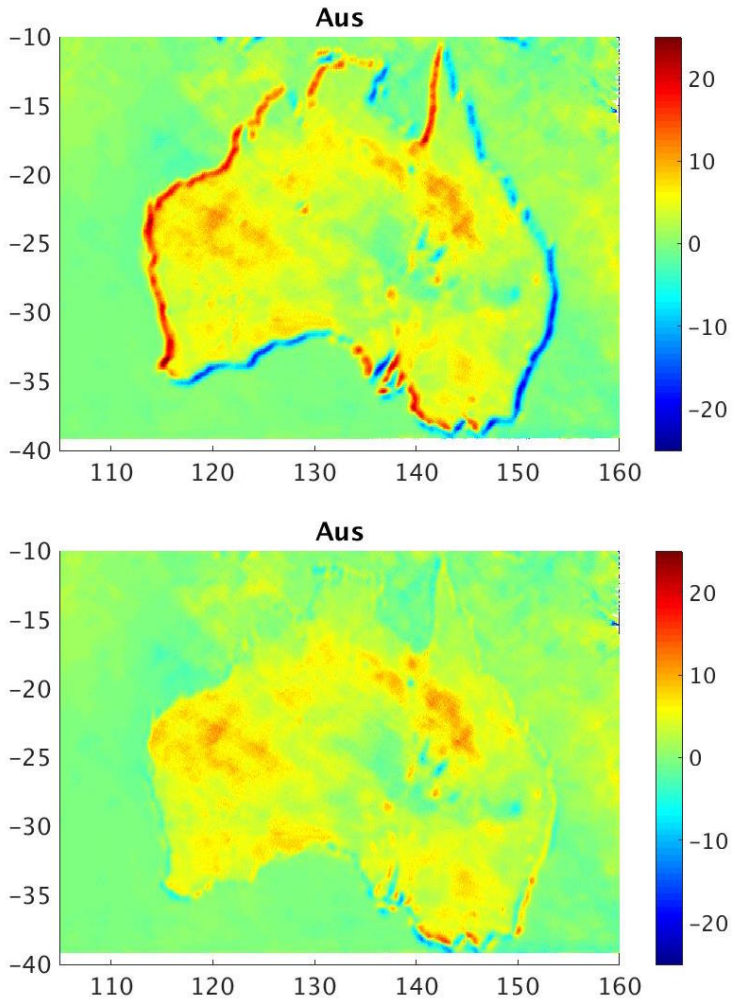
Updated TMI V8 brightness temperature (L1C) files

- Updates to spacecraft attitude
- Correction for RFI in cold reflector
- Updates to feedhorn view-angle offsets
- Updates to cross-track bias correction
- Changes to APC (originally SSM/I F13 APC used)
- Improved emissive reflector corrections
- TMI V8 corrections on track for 28 February 2017 delivery

TRMM constellation radiometers

- Addition of AMSR-E and SSM/I F11, F13, F14 and F15 imagers
- Addition of N15, N16 and N17 AMSU-B sounders
- On track for 1 May 2017 delivery

TMI V8 View Angle Offset Updates

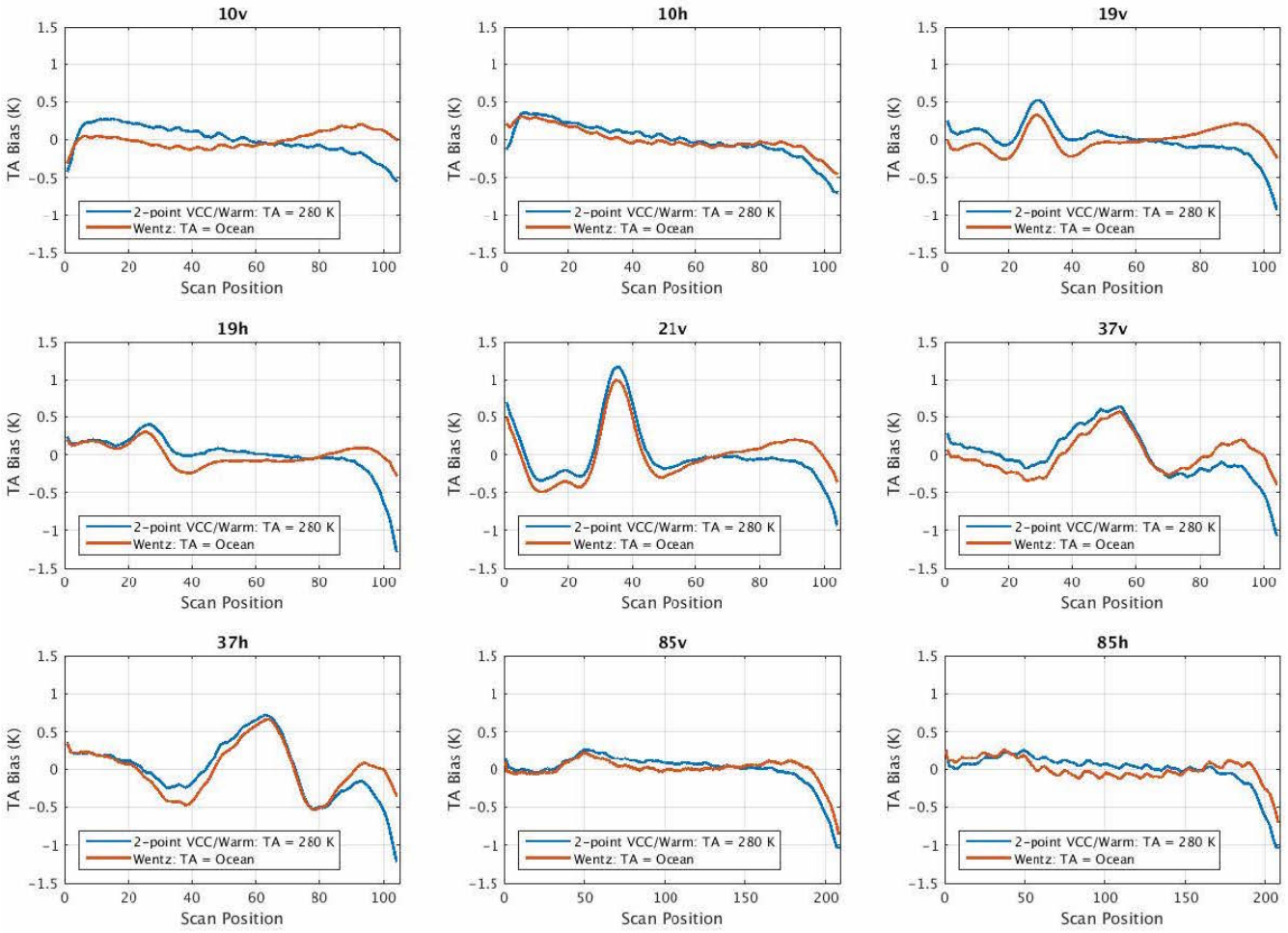


Cone Angle Offsets for EIA

Feedhorn	1B11 V7	GPM 1C V4	GPM V5/TRMM V8
10v	49.0	49.65	49.40
10h	49.0	49.22	49.49
19/21/37	49.0	49.0 (19v/21/37) 49.12 (19h)	49.27
85	49.0	49.0	49.20

- TMI based on SSM/I design with 10 GHz channels added
- Pre-launch measured offsets applied for GPM L1C
- Uses updated TRMM attitude
- Coastline analysis based on yaw 0 – yaw 180 differences used to compute EIA and start angle offsets
- Verified using multiple years of TMI data
- Accurate EIA is critical for intercalibration and retrievals

TMI V8 Scan Bias Correction



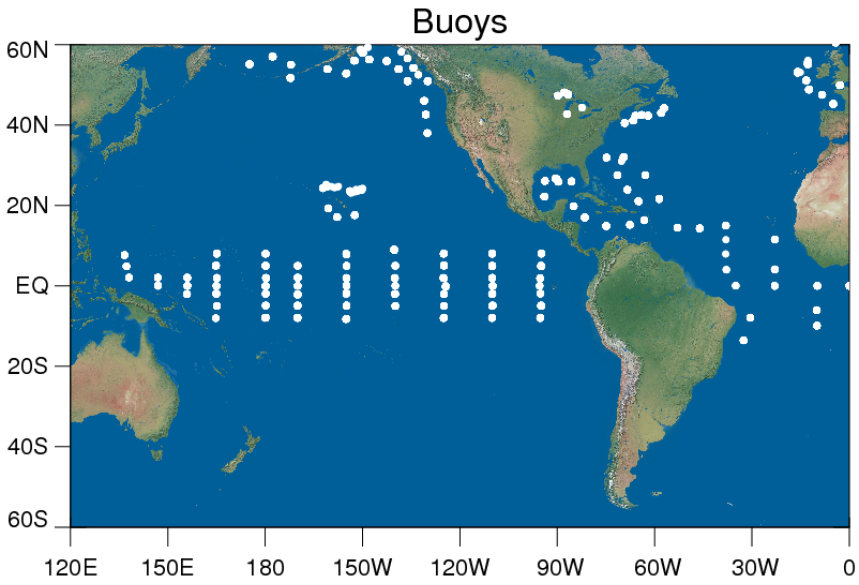
- Updated correction based on analysis over both cold (ocean) and warm (vegetated land) surfaces.
- Minimal change over oceans, but significant change to edge-of-scan correction over warm scenes
- For more information see poster by Darren McKague and Rachael Kroodsma

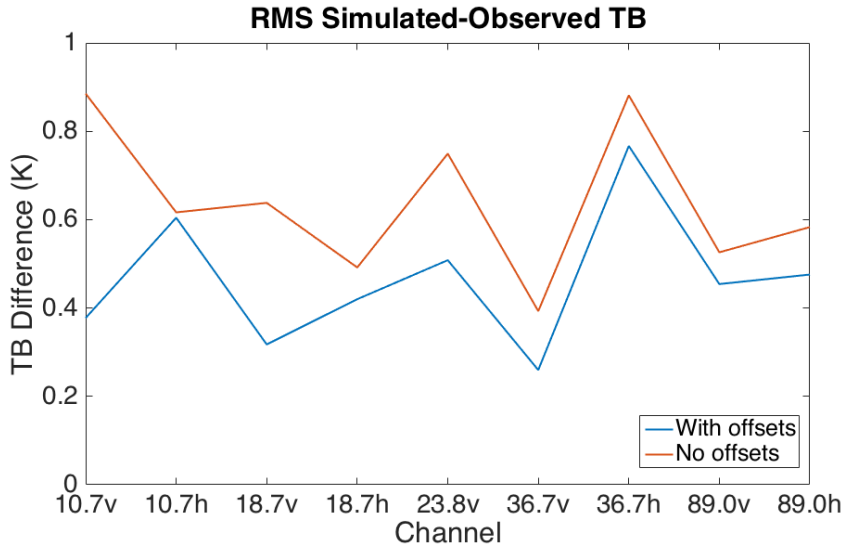
Updates to TMI V8 APC and Emissive Reflector Corrections

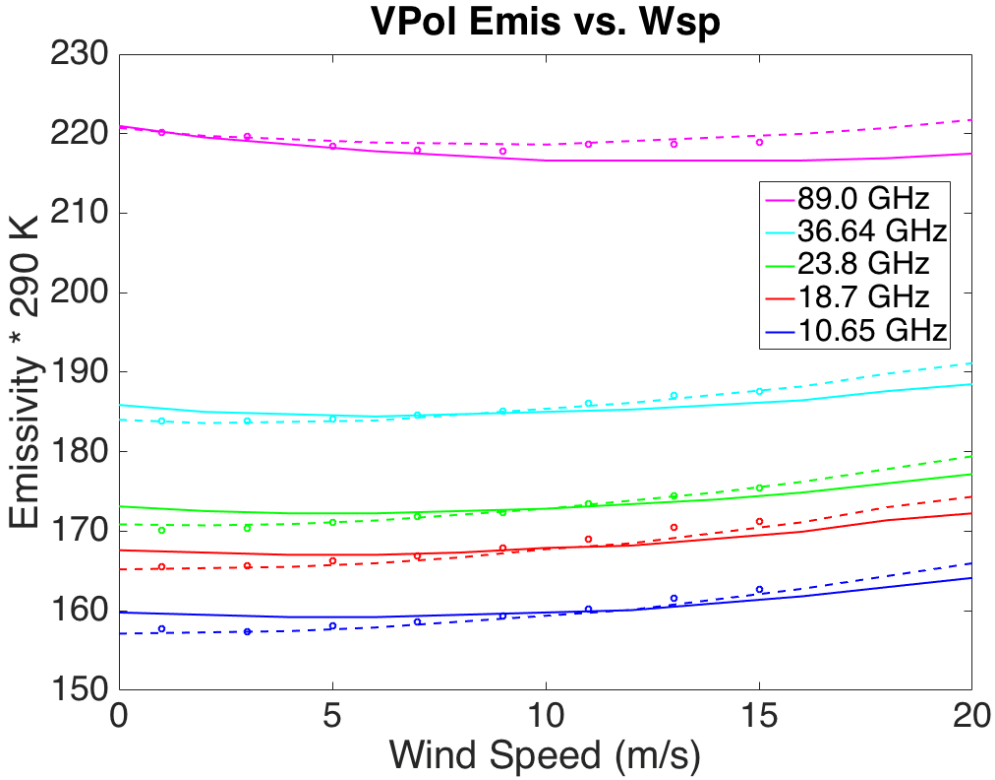
- The V7 Tb product, incorporates a number of ad hoc adjustments, made over the sensor lifetime to fix various radiometric calibration issues
- For V8, the University of Central Florida has developed an improved radiometer counts-to-Tb radiative transfer model.
  - Based on rigorous EM theory and analysis of on-orbit "Deep Space Calibration" (DSC) maneuvers conducted in 2015 prior to end of the TRMM mission.
  - This new DSC maneuver allowed the TMI antenna beams to simultaneously view space and to derive a correction for the effects of an emissive main reflector.
  - This analysis forms the basis of the new TMI V8 brightness temperature dataset and is on schedule to be completed by the end of Dec 2016.
- See poster by Linwood Jones and Faisal Alquaied for more details!

Assessing/Correcting Errors in Ocean Emissivity

Using GMI as Absolute Calibration Reference







- Used ocean buoy observations of ocean surface temperature/winds matched with GMI overpasses
- Used residual Tb differences (observed minus simulated) to compute corrections to ocean emissivity as a function of wind speed
- Applied corrections to non-precipitating 1DVAR retrieval to assess impact (RMS shown on left)
- Also see poster by Saswati Datta and Linwood Jones

Summary

- GMI is extremely well calibrated and stable, providing an ideal calibration reference for the constellation radiometers. Also provides excellent absolute calibration reference!
- The current operational Level 1C Tb datasets for the radiometer constellation have been intercalibrated to GMI V4 and is available from NASA Precipitation Processing System (PPS).
- For details on the GPM V4 intercalibration: Berg et al. 2016: Intercalibration of the GPM Microwave Radiometer Constellation, *J. Atmos. Oceanic Technol.*, available as early online release.
- GPM V5 reprocessing (April 2017)
  - Changes to the GMI calibration, primarily to low frequency channels (~1K max)
  - Associated updates to the GPM constellation radiometers
- TRMM V8 reprocessing (late 2017)
  - TMI updates (spacecraft attitude, geolocation, cross-track biases, APC, emissive reflector etc.)
  - Consistent with GMI V5 calibration
  - Constellation sensors back to December 1997 (SSM/I, AMSR-E, AMSU-B, etc.)
- Ongoing Activities
  - Constellation changes (SSMIS, JPSS1 ATMS, MetOp-C MHS)
  - Investigate clear-sky radiative transfer model errors using GMI as absolute reference
  - Quantify residual calibration errors
  - Radio Frequency Interference (RFI)