Relevance of GPM XCAL Activities to Suomi NPP/JPSS

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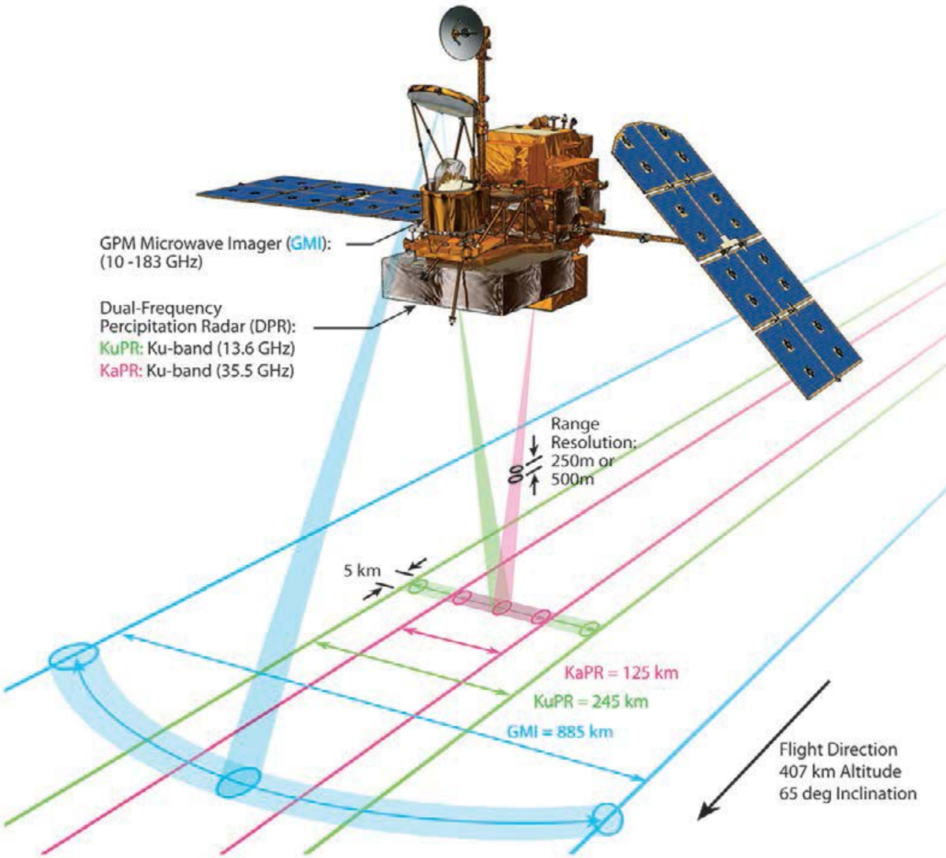
Colorado State University

GPM -> Global Precipitation Measurement

XCAL -> Precipitation Measurement Missions (i.e. TRMM/GPM) intercalibration working group

Global Precipitation Measurement (GPM) Mission



GPM Core Satellite

Dual-Frequency radar (DPR)
- Ku-band (13.6 GHz)
- Ka-band (35.5 GHz)

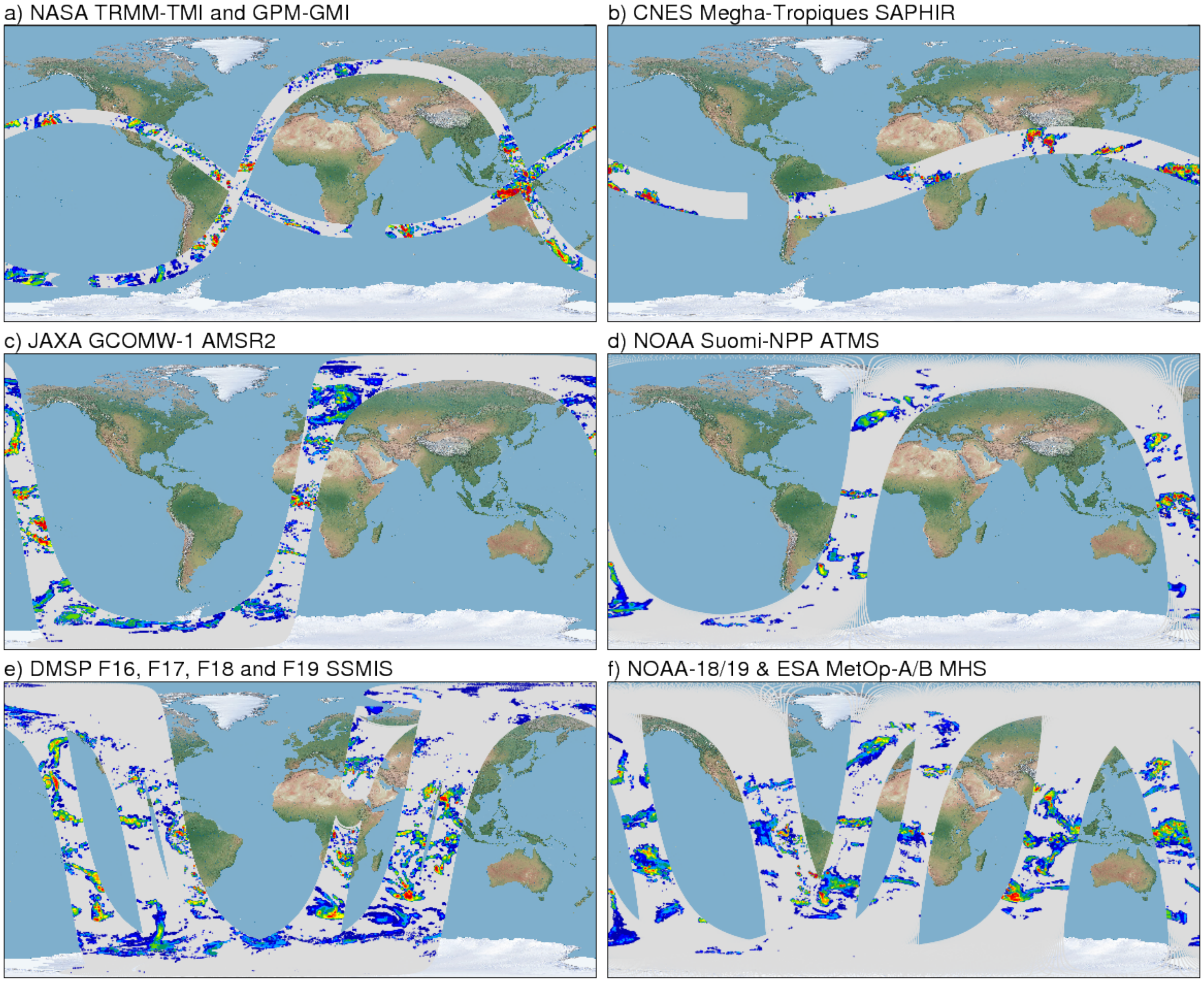
Microwave Imager (GMI)
- 13 channels
- 10-183 GHz

GPM was designed to provide the next generation of global precipitation products characterized by

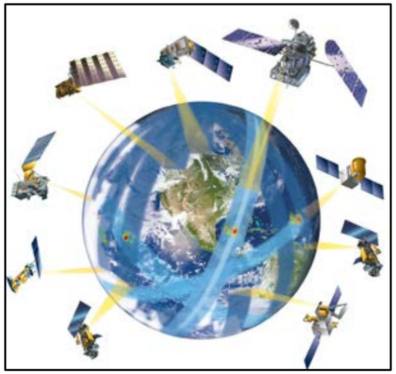
1. More accurate instantaneous precipitation estimates, particularly for light rainfall and cold season solid precipitation
2. **Unified precipitation retrievals from a constellation of microwave radiometers through the use of intercalibrated brightness temperatures** and a common observational hydrometeor database consistent with the combined radar/ radiometer measurements obtained by the GPM Core Observatory. Constellation needed to provide 3-hourly global sampling.

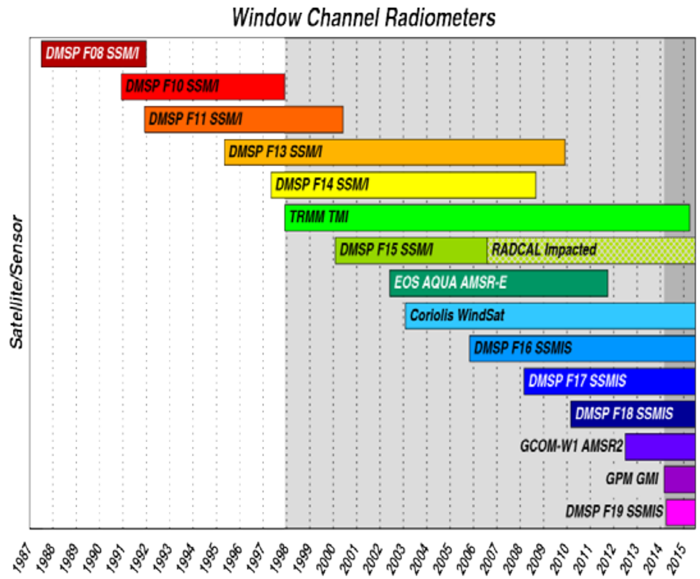
GPM Radiometer Constellation

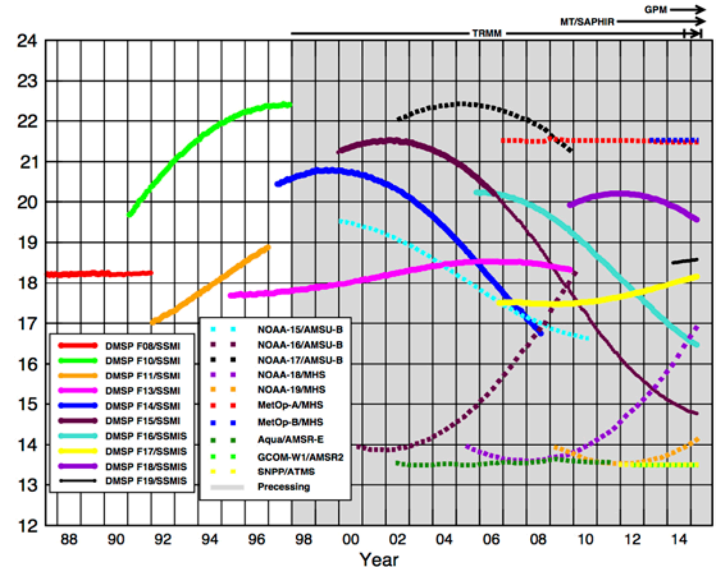
Conical Imagers | Cross-Track Sounders



GPM and TRMM Radiometer Constellations







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

*Not Currently part of GPM constellation

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 (6)**
  - NOAA 15, 16 and 17 AMSU-B
  - Metop A, NOAA 18 and 19 MHS
  - Suomi NPP ATMS
  - Megha-Tropiques SAPHIR

XCAL Responsibilities and Goals

The XCAL team was formed to address the issue of radiometer calibration consistency. Primary activities include:

1. Identify sensor issues affecting the calibration and stability of the Tb for each of the constellation radiometers. This involves Investigating calibration errors across scan and/or along orbit (i.e. time-dependent)
2. Develop and apply corrections for sensor calibration issues.
   - Limited to NASA/DMSP instruments
   - Work with instrument teams for other sensors
3. Derive and deliver intercalibration tables to adjust for residual sensor calibration differences in a physically consistent manner.
   - Assess calibration of reference radiometer (GMI)
   - Estimate calibration differences between sensors using multiple approaches (e.g. double differences, vicarious, polar matchups)
   - Investigate both cold and warm-scene differences where applicable

Result is the **Level 1C intercalibrated brightness temperature files** used as input to the operational radiometer precipitation retrieval algorithms.

Additional Tasks include:

1. Assess uncertainties
   - Investigate errors in RTM and geophysical parameters
   - Uncertainties in intercalibration techniques
2. Document results (full transparency)
3. Work to improve intercalibration techniques

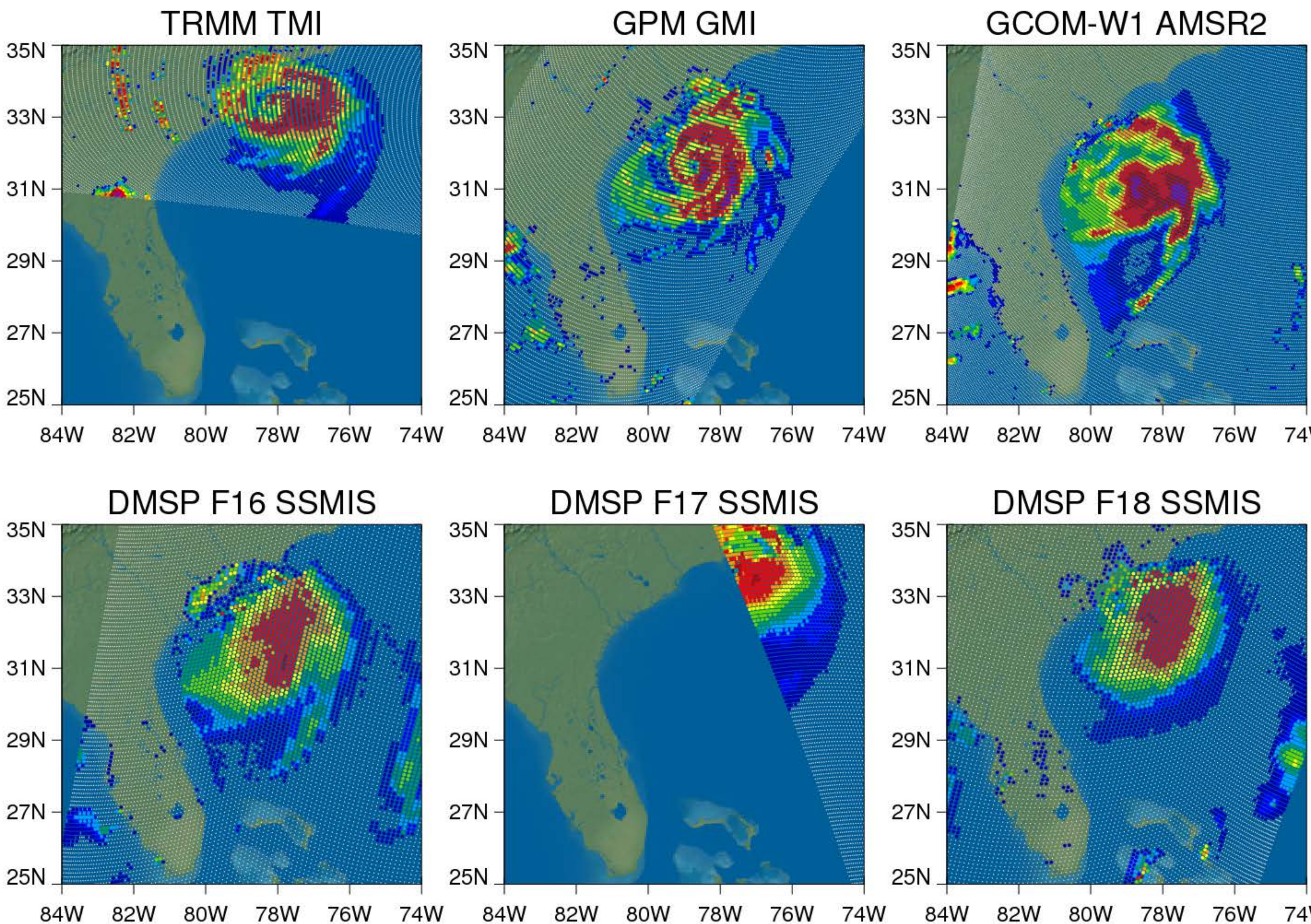
GPM Constellation Radiometers

Variations in Channel Frequencies

Satellite (Sensor)	6-7 GHz	10 GHz	19 GHz	23 GHz	31-37 GHz	85-92 GHz	150-166 GHz	183 GHz
GPM (GMI) Conical		10.65v 10.65h	18.7v 18.7h	23.8v	36.64v 36.64h	89.0v 89.0h	166v 166h	183.31±3v 183.31±7v
*TRMM (TMI) Conical		10.65v 10.65h	19.35v 19.35h	21.3v	37.0v 37.0h	85.5v 85.5h		
GCOM-W1 (AMSR-2) Conical	6.925v 6.925 7.3v 7.3h	10.65v 10.65h	18.7v 8.7h	23.8v 23.8h	36.5v 36.5h	89.0v (A) 89.0h (A) 89.0v (B) 89.0h (B)		
DMSP F16, F17, F18, & F19 (SSMIS) Conical			19.35v 19.35h	22.235v	37.0v 37.0h	91.655v 91.655h	150h	183.31±1h 183.31±3h 183.31±6.6h
METOP-A/B, NOAA-18/19 (MHS) Cross-track						89qv	157qv	183.31±1qh 183.31±3qh 190.31qv
Suomi NPP (ATMS) Cross-track				23.8qv	31.4qv	88.2 qv	165.5qh	183.31±1.0qh 183.31±1.8qh 183.31±3.0qh 183.31±4.5qh1 83.31±7.0qh
Megha-Tropiques (SAPHIR) Cross-track								183.31±0.2qh 183.31±1.1qh 183.31±2.8qh 183.31±4.2qh 183.31±6.8qh 183.31±11qh
**Coriolis (WindSat) Conical	6.8v 6.8h	10.7v 10.7h 10.7-3rd 10.7-4th	18.7v 18.7h 18.7-3rd 18.7-4th	23.8v 23.8h	37.0v 37.0h 37.0-3rd 37.0-4th			

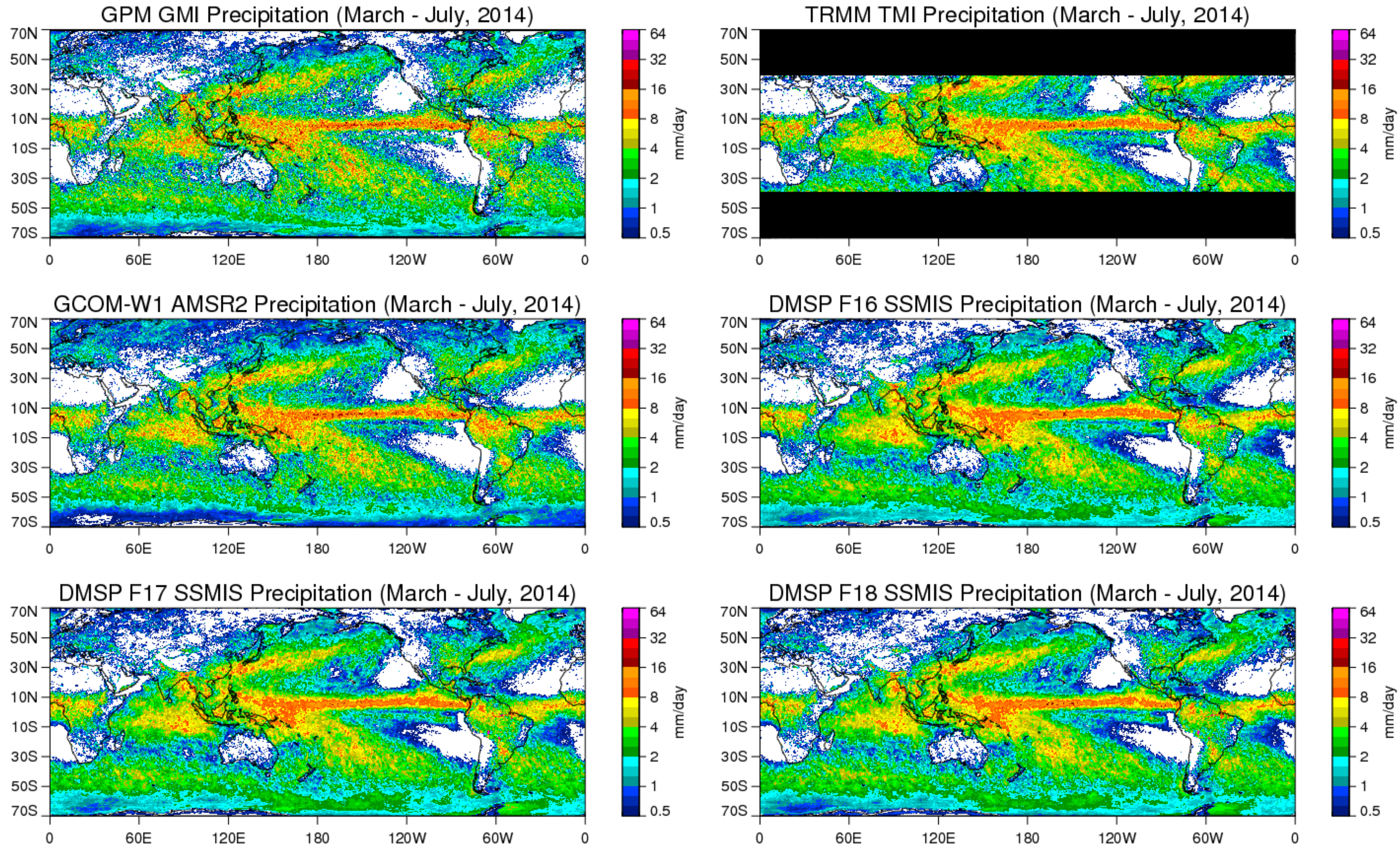
Hurricane Arthur Precipitation from GPM Constellation

(Conical Scanners, GPROF 2014v1-3, 3 July 2014)



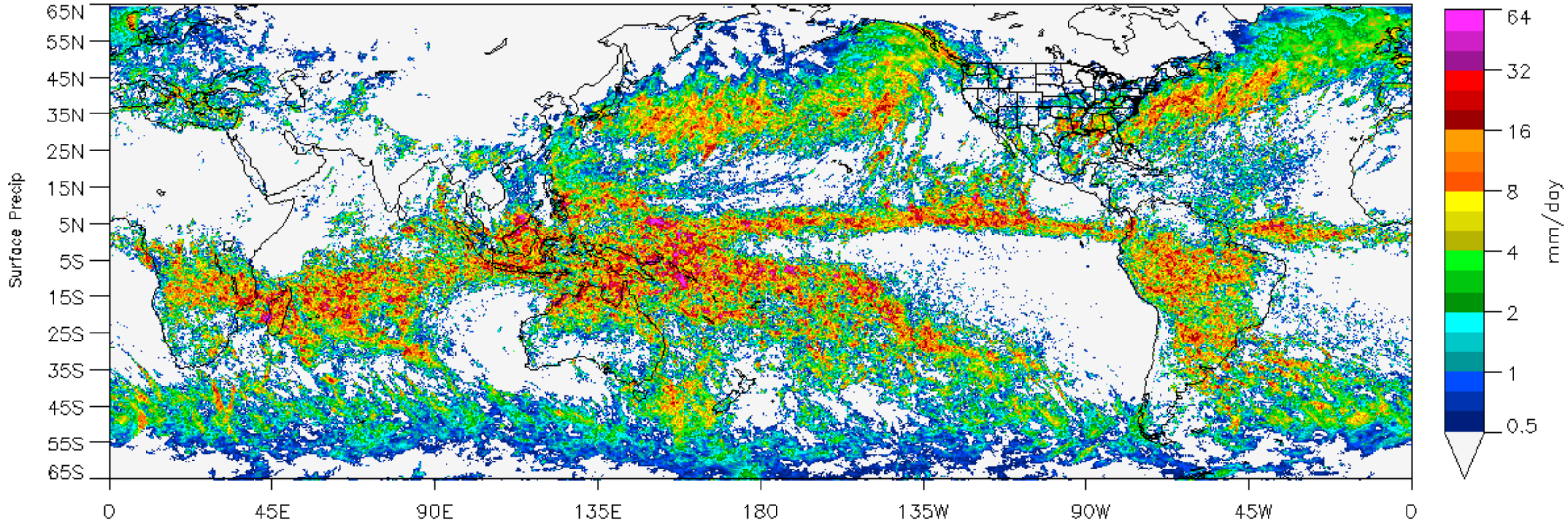
Global Mean Precipitation from GPM Constellation Radiometers

(Microwave Imagers, March – July, 2014)

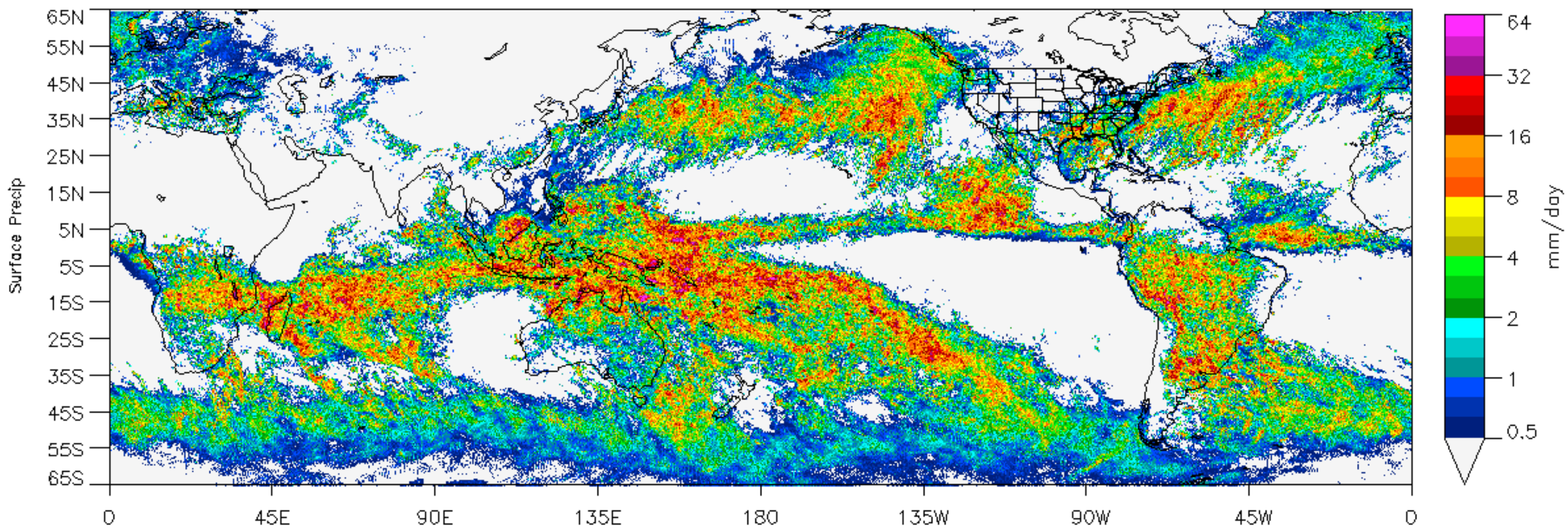


January 2015 Precipitation from GPM Constellation Radiometers

GPM GMI



Suomi NPP ATMS

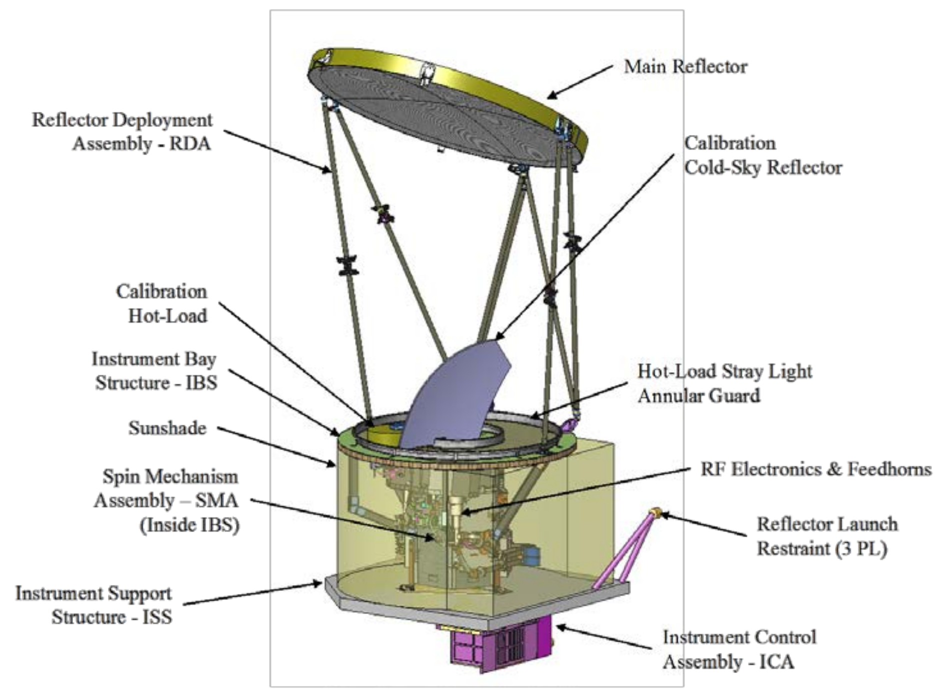


GPM GMI: Calibration Reference Sensor

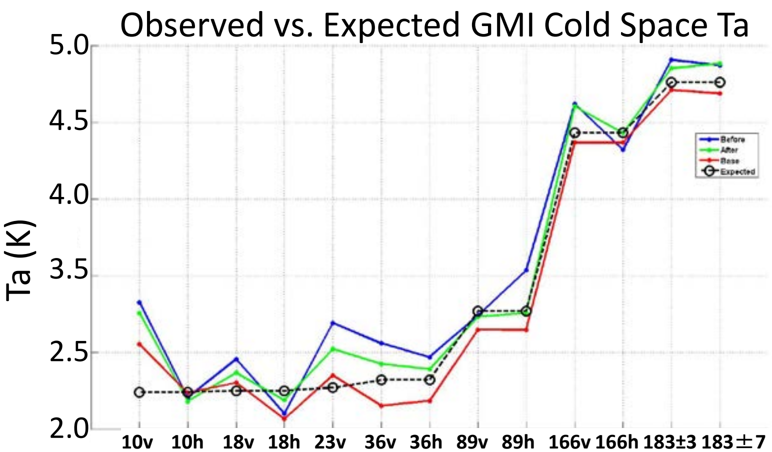
GMI Specs	10.65v/h	18.7v/h	23.8v	36.64v/h	89.0v/h	165.5v/h	183+3v	183+7v
DT x CT Res in km	32.1x19.4	18.1x10.9	16.0x9.7	15.6x9.4	7.2x4.4	6.3x4.4	5.8x3.8	5.8x3.8
Beamwidth (deg)	1.72	0.98	0.85	0.81	0.38	0.37	0.37	0.37
NEDT (K)	0.96	0.84	1.05	0.65	0.57	1.5	1.5	1.5
Beam Efficiency (%)	91.1	91.2	93.0	97.8	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

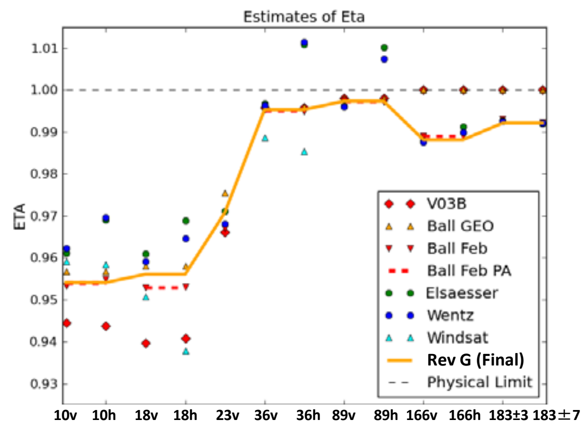
Nominal EIA	52.8/49.2
Orbit Inclination	65.0 deg
Local Obs. Time	Variable (Precessing)
Altitude	407 km
Reflector Size	1.22 m
Sampling Interval	13.5 km



GMI Calibration Summary



Observed vs. expected antenna temperatures by channel based on analysis of data from deep space calibration manuever (Courtesy Spencer Farrar, Univ. Central Florida).



Various estimates for spillover correction (eta) for each GMI channel. Final values are indicated by solid yellow line (Courtesy Tom Wilheit).

Channel	Pre-Launch (η_F)	On-Orbit (η_G)	ΔTb (ocean)
10v	0.94435	0.95404	1.7
10h	0.94369	0.95404	1.0
18v	0.93968	0.95603	3.3
18h	0.94082	0.95603	2.0
23v	0.96601	0.97075	1.1
36v	0.99590	0.99535	-0.1
36h	0.99590	0.99535	-0.1
89v	0.99810	0.99734	-0.2
89h	0.99810	0.99734	-0.2
166v	1.00000	0.98814	-3.2
166h	1.00000	0.98814	-3.2
183±3v	1.00000	0.99212	-2.1
183±7v	1.00000	0.99212	-2.1

- On-orbit calibration maneuvers used to check for calibration anomalies and to develop corrections.
- Calibration Checks
  - Emissive Reflector (No evidence found)
  - Polarization Check (Differences < 0.3K at nadir)
- Calibration Corrections
  - Magnetic anomalies
    - Along-track due to spacecraft flying through Earth’s magnetic field
    - Cross-track due to magnetic latches for GMI cover
    - Correction developed/applied. Residual anomalies are very small.
  - Spillover Corrections
    - Forward part of antenna pattern measured by Ball at near field range pre-launch, but spillover region could not be measured so they used two different models, which gave different answers.
    - Initial spillover corrections (Eta) for 166 and 183 channels were 1.0 (unphysical)
    - Data from 2 inertial hold maneuvers were analyzed by David Draper at Ball Aerospace, The resulting Eta values (see above table/figure) are based on physical observations rather than models (as used initially). These values are also not tuned to match any radiative transfer model.

Summary

- Significant changes were made to the spillover corrections (see above). Given limitations of pre-launch measurements this is a likely cause of significant 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 both Ball/RSS and XCAL indicate that the GMI calibration is very consistent with clear-sky ocean simulated Tb.
- A conservative estimate for the absolute calibration errors of the GMI window channels are < 1K
- Comparisons of the GMI 166 and 183 GHz channels with the MHS and SAPHIR cross-track sounders indicate differences of < 0.5K

Total GMI On-orbit Calibration RMS Error

- Overall, the GMI RMS calibration error for on-orbit operations is 0.25K RMS bias and 0.14K RMS time-varying component
  - Note that these are considered as 1-sigma numbers, i.e. 68% probability of a particular channel falling within this error range.
  - An individual channel's error may be higher or lower.
- Comparison with Independently Calibrated Radiometers Suggests Absolute Accuracy Better than 1K RMS Across All Channels

	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**

TA BIAS

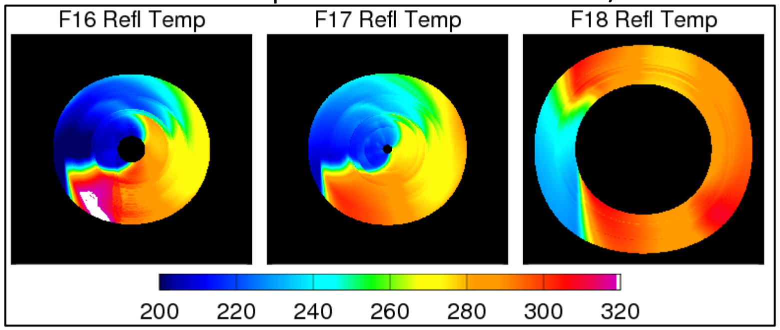
TB BIAS

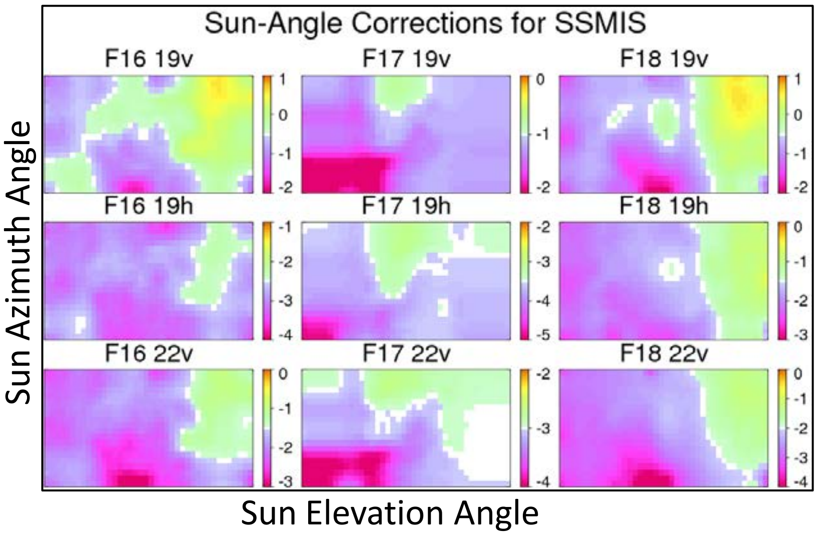
*Results provided courtesy David Draper, Ball Aerospace & Technologies Corp. Boulder, Colorado USA

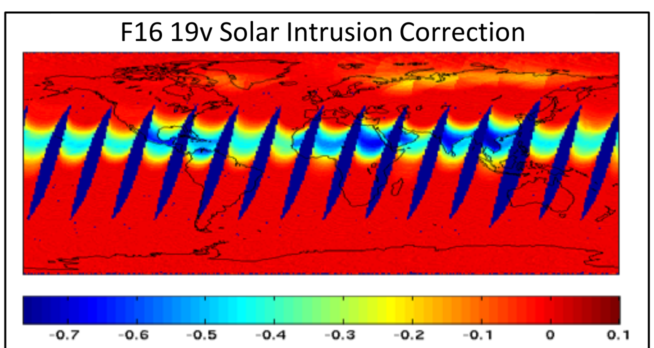
Pre-Screening

Dealing with Time-Dependent Calibration Errors

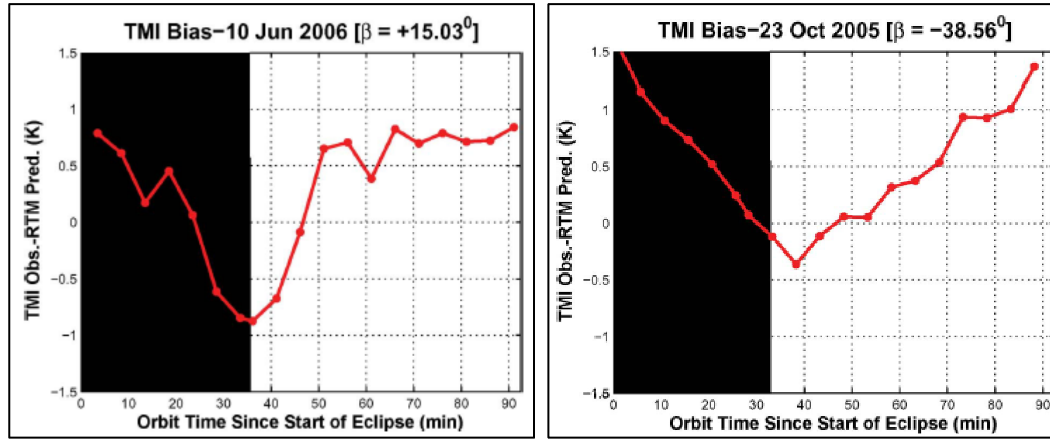
SSMIS Reflector Temperature vs. Sun Elevation/Azimuth







TMI Emissive Antenna Biases vs. Time

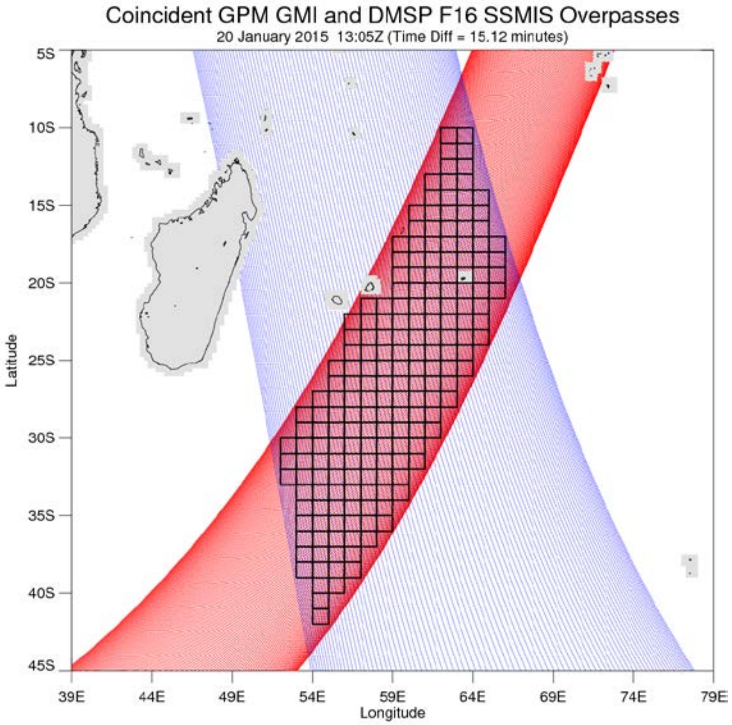


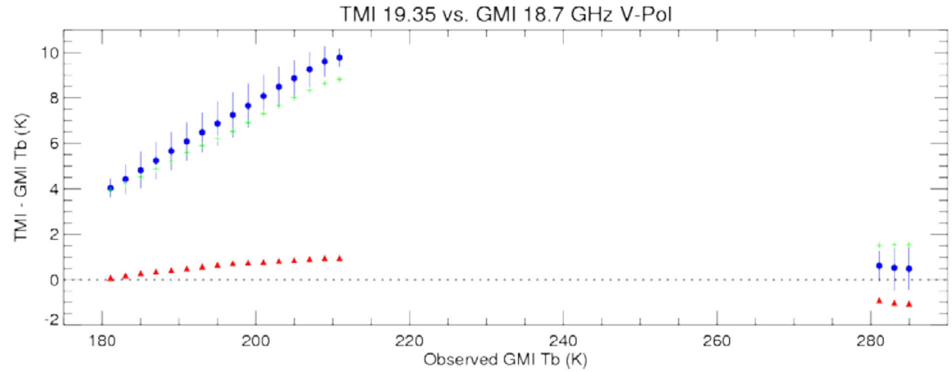
From Gopalan et al. 2009

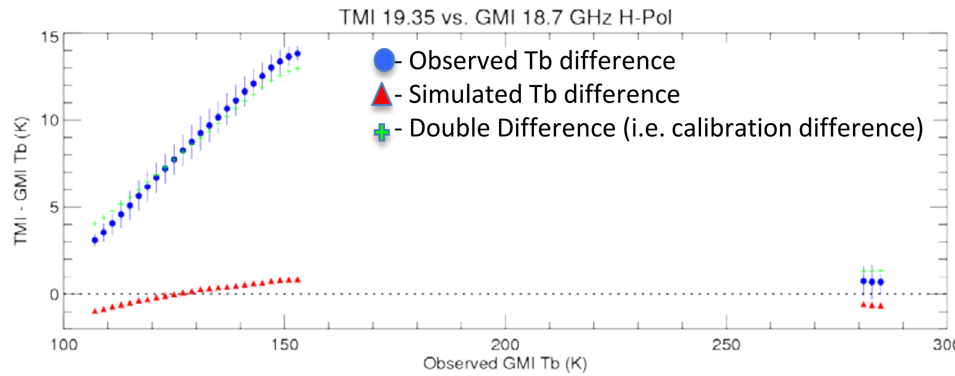
- Emissive Antenna
  - TMI (~4% emissivity) correction by UCF applied to 1B11 v7 and GPM L1C
  - SSMIS -> Problem for F16 and F17. Difficult to correct for due to intrusions and other issues
  - **GMI looks good!**
- Solar/Lunar Intrusions
  - Solar intrusions into warm load lead to biases in warm calibration point
  - Lunar intrusions into cold-sky mirror bias cold end calibration
  - **No evidence of significant intrusion issues for GMI**
- SSMIS Sun-Angle Corrections
  - Combined corrections for emissive antenna, solar intrusions, and other instrument temperature-dependent biases
  - Computed from multiple years of data using double differences
  - Substantial (2-6K) corrections are different for F16, F17, and F18.
  - Eliminates biases between ascending and descending orbit passes

Intercalibration vs. GPM GMI

Double Difference Approach







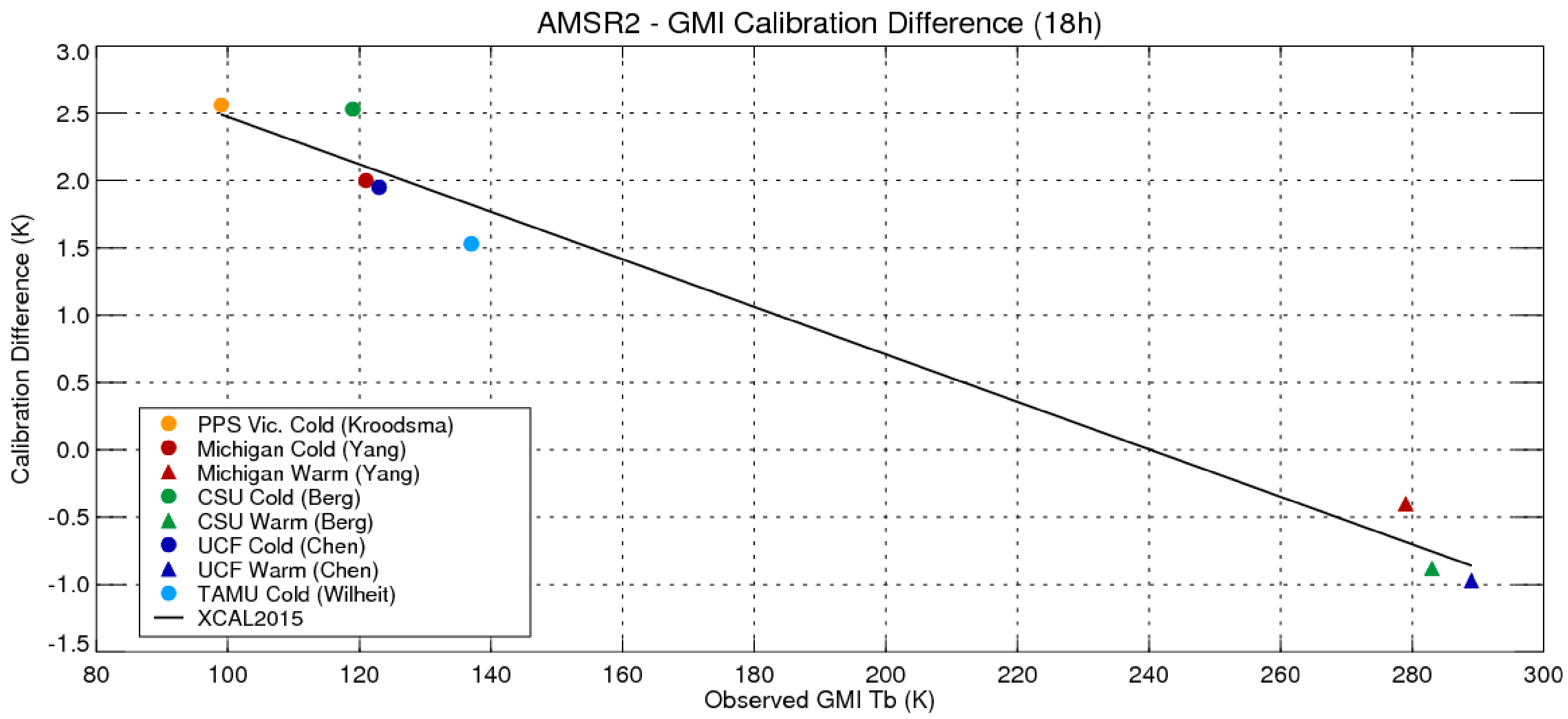
Double Difference Technique

- Identify and collect near-coincident observations between target sensor (e.g. TMI) and reference sensor (i.e. GPM GMI).
- Grid Tb into 1x1 degree boxes and screen for precipitation, land etc.
- Get geophysical parameters from global model analysis or use retrieval algorithm run on GMI for clear-sky scenes.
- Compute simulated Tb for target and reference sensors to account for differences in channel frequencies, bandwidths, view angles etc.
- Compute double difference as follows.
  - Tb_obs(DIF) = Tb_obs(REF) – Tb_obs(TGT)
  - Tb_sim(DIF) = Tb_sim(REF) – Tb_sim(TGT)
  - Ddiff = Tb_obs(DIF) – Tb_sim(DIF)

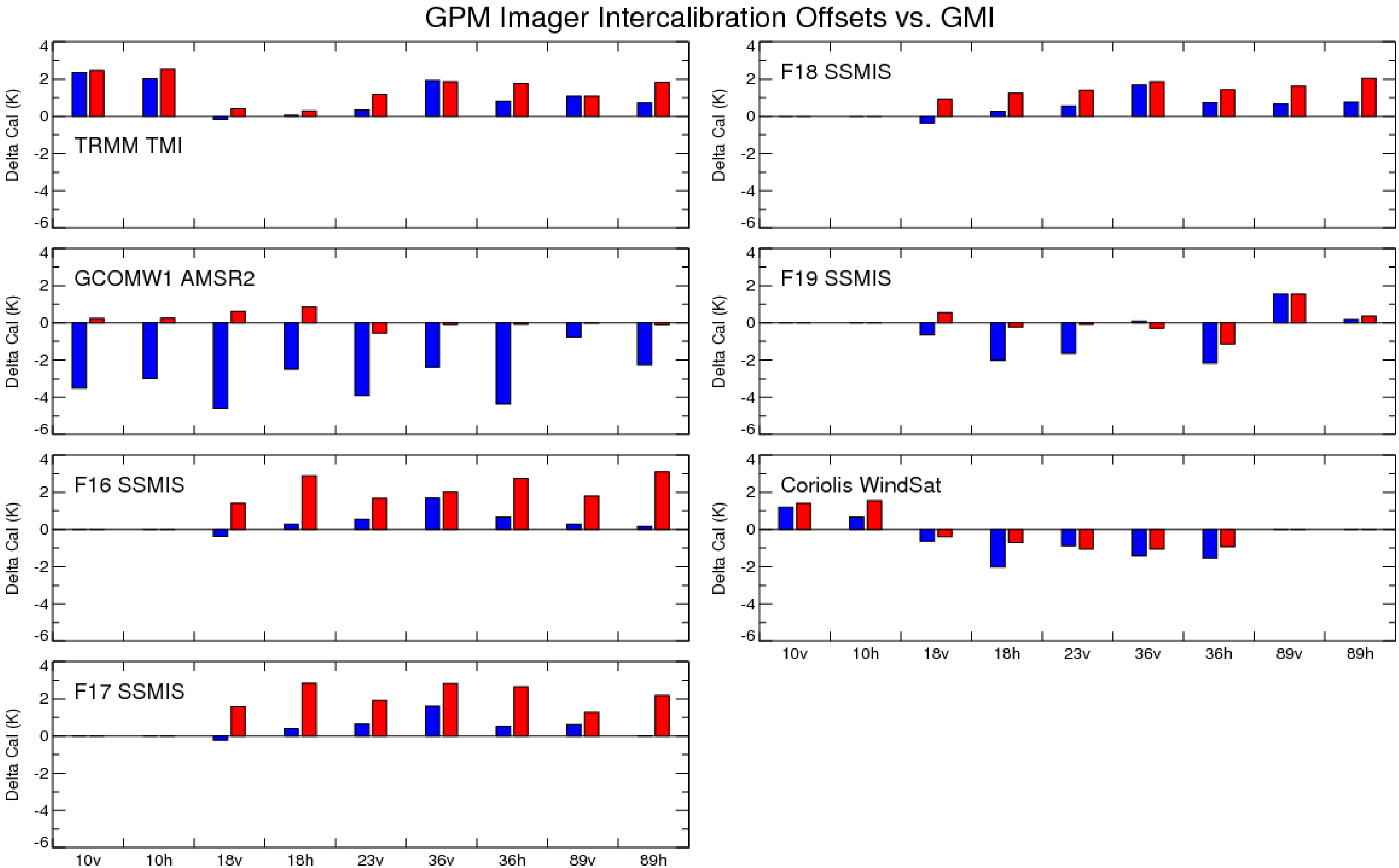
Intercalibration comparisons for the 19.35 GHz channels on TRMM TMI versus the equivalent channels on GPM GMI. The observed differences, simulated differences, and double differences (i.e. calibration differences), are shown as a function of Tb for the reference sensor (GMI). Cold temperature Tbs correspond to ocean scenes while warmer Tb values correspond to unpolarized vegetated scenes.

GPM Constellation Radiometer Intercalibration

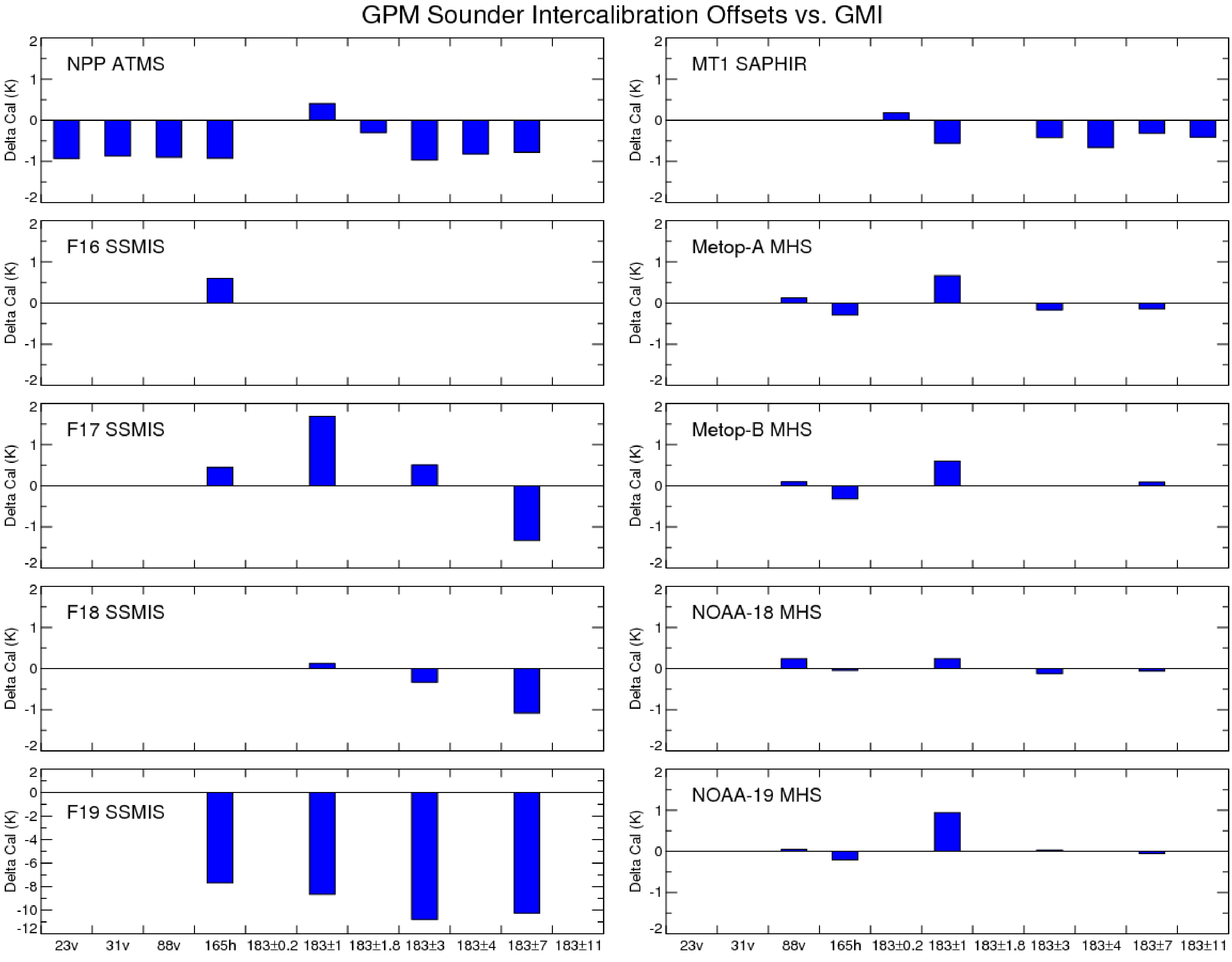
Multiple Independent Techniques



- The above example for the 18 GHz H-Pol channel on AMSR2 shows a “worst” case example of inconsistencies in the calibration between GMI and one of the constellation radiometers.
- Five groups within XCAL produced calibration offsets for cold ocean scenes and three groups produced offsets for warm land scenes.
- While this case exhibits both large biases relative to GMI as well as variations in the bias with scene temperature, the results between teams are consistent within 1K.
- While the XCAL team continues to investigate physical explanations for this discrepancy, we have a high degree of confidence that the adjusted Level 1C Tb values are consistent within 1K.



GPM Imager Intercalibration Offsets vs. GMI
TRMM TMI
F18 SSMIS
GCOMW1 AMSR2
F19 SSMIS
F16 SSMIS
Coriolis WindSat
F17 SSMIS
Delta Cal (K)
10v
10h
18v
18h
23v
36v
36h
89v
89h


GPM Sounder Intercalibration Offsets vs. GMI
NPP ATMS
MT1 SAPHIR
F16 SSMIS
Metop-A MHS
F17 SSMIS
Metop-B MHS
F18 SSMIS
NOAA-18 MHS
F19 SSMIS
NOAA-19 MHS
Delta Cal (K)
23v
31v
88v
165h
183±0.2
183±1
183±1.8
183±3
183±4
183±7
183±11

Summary

- XCAL team lessons learned
  - Value of multiple approaches for calibration analysis
  - Importance of transparency
  - Value of working with instrument developers to identify instrument issues
- GPM GMI
  - Has both standard imager channels and several water vapor sounding channels
  - Four point calibration for lower frequency channels (standard cold/warm cal plus noise diodes)
  - On-orbit calibration maneuvers
    - Identification of and correction for magnetic interference
    - Adjustments to spillover corrections point to difficulties in characterizing antenna pattern pre-launch
    - Detailed GMI calibraiton uncertainty analysis
  - GMI appears to have the best calibration of any microwave imager to date
- Sounder intercalibration results
  - Very good consistency between current cross-track sounders (water vapor channels)
  - MHS instrument appears very well calibrated and consistent across four satellites
  - Slightly larger differences with NPP ATMS (still within 1K0
  - SSMIS calibration much more problematic
- Specific relevance to ATMS
  - Provide an independent calibration assessment relative to other microwave radiometers
  - Expertise related to the on-orbit identification and corrections for a variety of calibration errors
  - Currently investigating uncertainties in radiative transfer models (Thursday morning talk in GSICS microwave session)