Updates on Operational Processing of ATMS TDR and SDR Products

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Outline

- ATMS Instrument Characterization
- ATMS in-orbit Performance Status
- Advanced ATMS SDR Sciences and Algorithms
- Upcoming Changes in ATMS TDR/SDR Processing
- Summary and Conclusions

ATMS Instrument Characterization

Ch	Channel Central Freq.(MHz)	Polarization	Bandwidth Max. (MHz)	Frequency Stability (MHz)	Calibration Accuracy (K)	Nonlinearity Max. (K)	NEΔT (K)	3-dB Bandwidth (deg)	Remarks	Characterization at Nadir
1	23800	QV	270	10	1.0	0.3	0.5	5.2	AMSU-A2	Window-water vapor 100 mm
2	31400	QV	180	10	1.0	0.4	0.6	5.2	AMSU-A2	Window-water vapor 500 mm
3	50300	QH	180	10	0.75	0.4	0.7	2.2	AMSU-A1-2	Window-surface emissivity
4	51760	QH	400	5	0.75	0.4	0.5	2.2		Window-surface emissivity
5	52800	QH	400	5	0.75	0.4	0.5	2.2	AMSU-A1-2	Surface air
6	53596±115	QH	170	5	0.75	0.4	0.5	2.2	AMSU-A1-2	4 km ~ 700 mb
7	54400	QH	400	5	0.75	0.4	0.5	2.2	AMSU-A1-1	9 km ~ 400 mb
8	54940	QH	400	10	0.75	0.4	0.5	2.2	AMSU-A1-1	11 km ~ 250 mb
9	55500	QH	330	10	0.75	0.4	0.5	2.2	AMSU-A1-2	13 km ~ 180 mb
10	57290.344(f_o)	QH	330	0.5	0.75	0.4	0.75	2.2	AMSU-A1-1	17 km ~ 90 mb
11	f_o± 217	QH	78	0.5	0.75	0.4	1.0	2.2	AMSU-A1-1	19 km ~ 50 mb
12	f_o±322.2±48	QH	36	1.2	0.75	0.4	1.0	2.2	AMSU-A1-1	25 km ~ 25 mb
13	f_o±322.2±22	QH	16	1.6	0.75	0.4	1.5	2.2	AMSU-A1-1	29 km ~ 10 mb
14	f_o±322.2±10	QH	8	0.5	0.75	0.4	2.2	2.2	AMSU-A1-1	32 km ~ 6 mb
15	f_o±322.2±4.5	QH	3	0.5	0.75	0.4	3.6	2.2	AMSU-A1-1	37 km ~ 3 mb
16	88200	QV	2000	200	1.0	0.4	0.3	2.2	89000	Window H_2O 150 mm
17	165500	QH	3000	200	1.0	0.4	0.6	1.1	157000	H_2O 18 mm
18	183310±7000	QH	2000	30	1.0	0.4	0.8	1.1	AMSU-B	H_2O 8 mm
19	183310±4500	QH	2000	30	1.0	0.4	0.8	1.1		H_2O 4.5 mm
20	183310±3000	QH	1000	30	1.0	0.4	0.8	1.1	AMSU-B/MHS	H_2O 2.5 mm
21	183310±1800	QH	1000	30	1.0	0.4	0.8	1.1		H_2O 1.2 mm
22	183310±1000	QH	500	30	1.0	0.4	0.9	1.1	AMSU-B/MHS	H_2O 0.5 mm

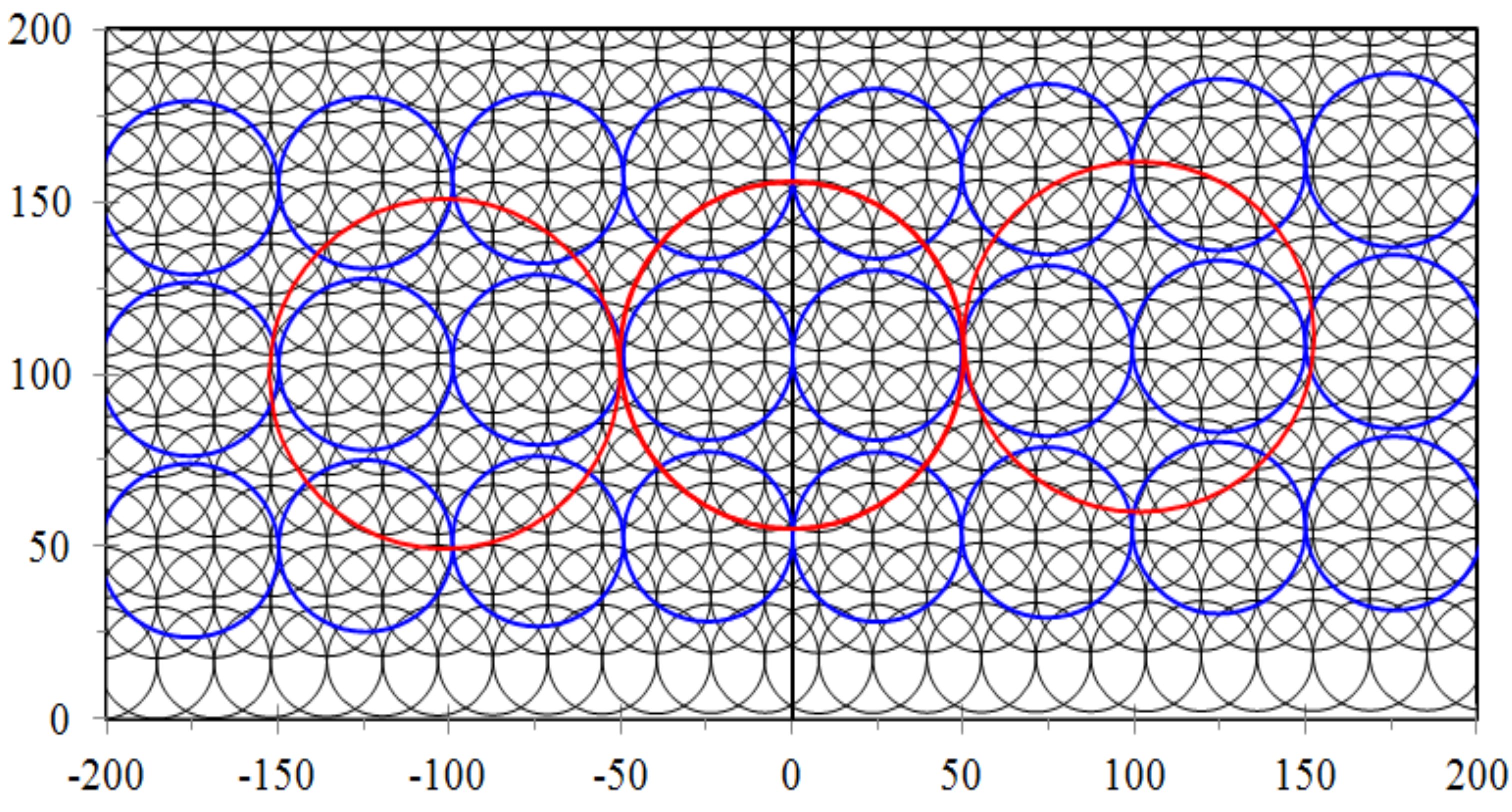
MSU			AMSU/MHS			ATMS		
Ch	GHz	Pol	Ch	GHz	Pol	Ch	GHz	Pol
			1	23.8	QV	1	23.8	QV
			2	31.399	QV	2	31.4	QV
1	50.299	QV	3	50.299	QV	3	50.3	QH
						4	51.76	QH
			4	52.8	QV	5	52.8	QH
2	53.74	QH	5	53.595 ± 0.115	QH	6	53.596 ± 0.115	QH
			6	54.4	QH	7	54.4	QH
3	54.96	QH	7	54.94	QV	8	54.94	QH
			8	55.5	QH	9	55.5	QH
4	57.95	QH	9	fo = 57.29	QH	10	fo = 57.29	QH
			10	fo ± 0.217	QH	11	fo±0.3222±0.217	QH
			11	fo±0.3222±0.048	QH	12	fo± 0.3222±0.048	QH
			12	fo ±0.3222±0.022	QH	13	fo±0.3222±0.022	QH
			13	fo± 0.3222±0.010	QH	14	fo±0.3222 ±0.010	QH
			14	fo±0.3222±0.0045	QH	15	fo± 0.3222±0.0045	QH
			15	89.0	QV			
			16	89.0	QV	16	88.2	QV
			17	157.0	QV	17	165.5	QH
						18	183.31 ± 7	QH
						19	183.31 ± 4.5	QH
			19	183.31 ± 3	QH	20	183.31 ± 3	QH
			20	191.31	QV	21	183.31 ± 1.8	QH
			18	183.31 ± 1	QH	22	183.31 ± 1	QH

- (green) Exact match to AMSU/MHS
- (yellow) Only Polarization different
- (orange) Unique Passband
- (red) Unique Passband, and Pol. different from closest AMSU/MHS channels

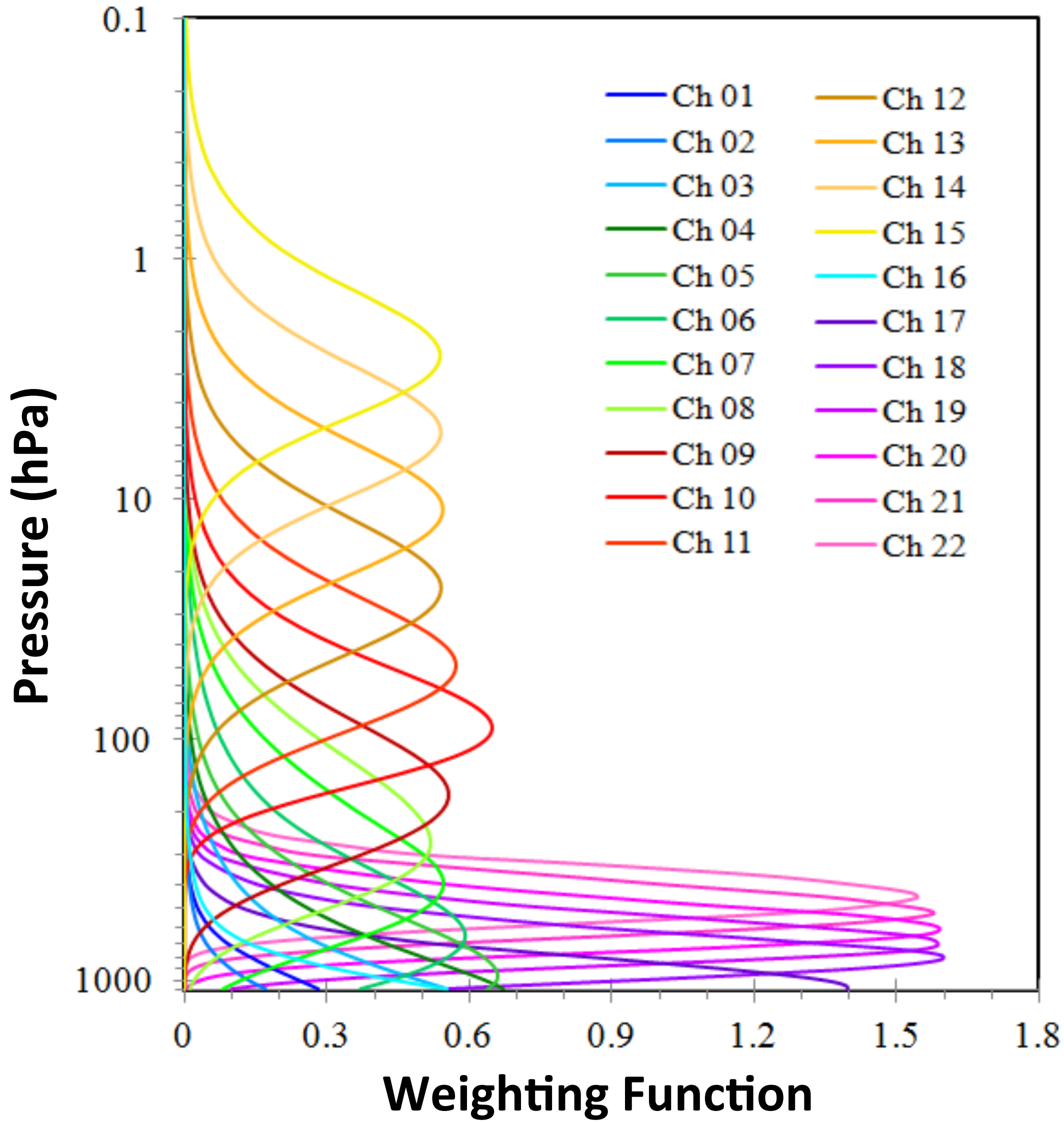
Microwave Sounding Instruments from MSU to AMSU/MHS to ATMS

ATMS Field of View Size for the beam width of 2.2^o – black line

ATMS Resample to the Field of View Size for the beam width of 3.3^o- blue line



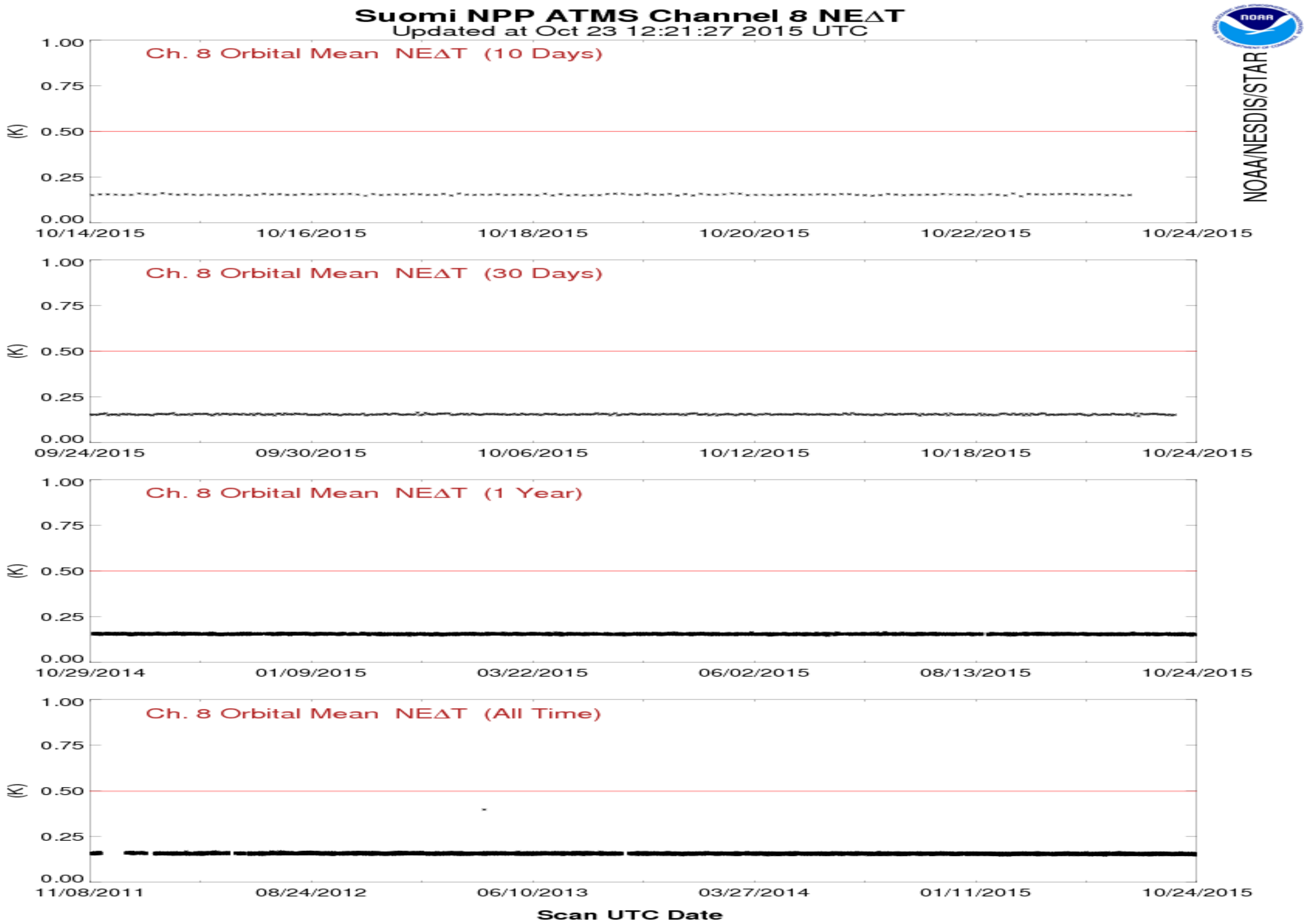
ATMS Channel Weighting Functions



SNPP ATMS in-orbit Performance

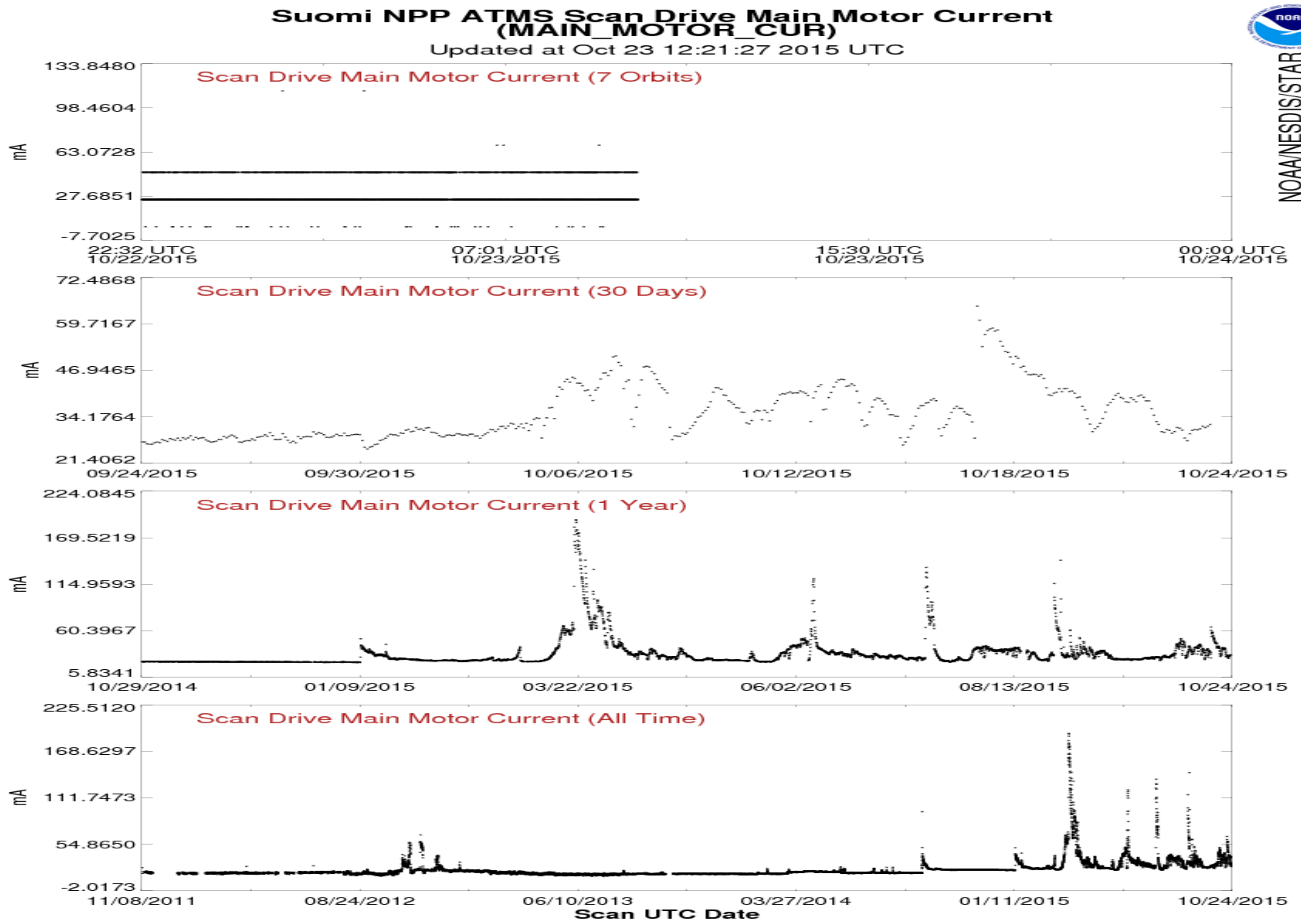
- Stable instrument noise and calibration gain since its launch on October 28, 2011
- Several major anomalies occurred in scan motor current (>120 mA) with its magnitude well below the threshold
- Starting on August 23, 2015, a periodical spike has been observed in scan motor current due to executions of daily scan reversal
- TDR/SDR data quality is not affected by scan motor current spikes and anomalies

ATMS Noise Equivalent Differential Temperature (NEDT) Derived from Allan Variance



NEDT for other channels can be viewed from http://www.star.nesdis.noaa.gov/icvs/

ATMS Scan Drive Main Motor Current Monitoring



Scientific Advances in ATMS SDR Algorithm

- Standardized NEdT calculation for ATMS and other microwave sounding instruments using Allan deviation. The new algorithm has resulted in much stable noise trending

- Developed and implemented a physical model for correcting the lunar emission in cold calibration count

- Optimized the ATMS de-striping algorithm for the earth scene brightness temperatures and generated a dataset for NWP user community to assess impacts of ATMS de-striped data on forecast skills

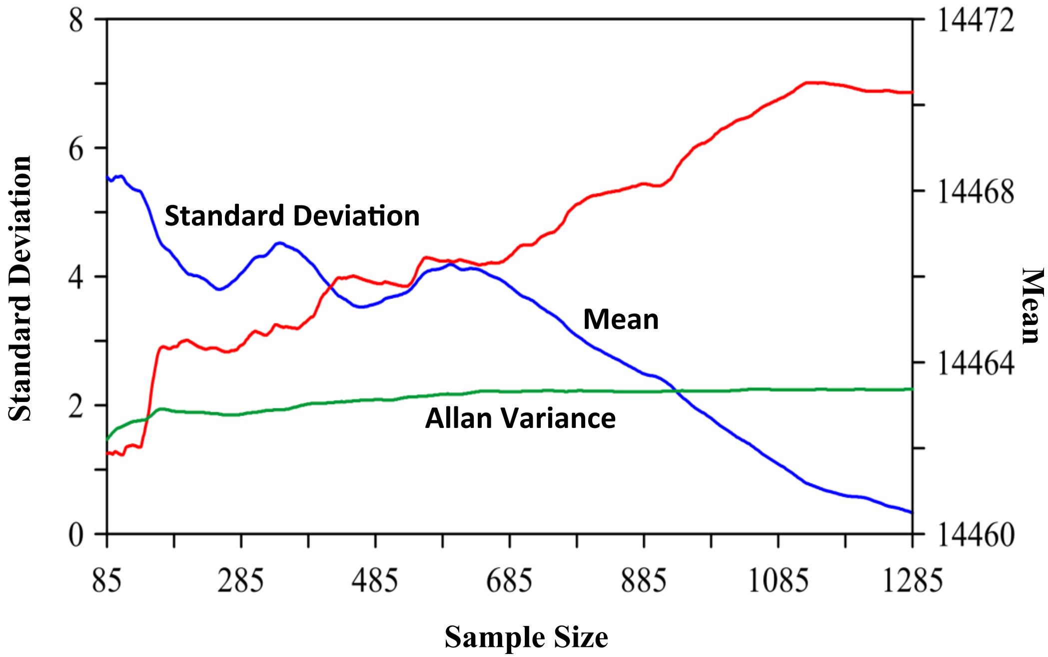
- Updated the quality flags related to spacecraft maneuvers and scan reversals in TDR and SDR datasets

ATMS Noise Equivalent Temperature (NEDT)

For a time series with a stable mean, the standard deviation of the measurements can be used as NEDT:

$$\sigma_{ch} = \left[\frac{1}{4N} \sum_{i=1}^{N} \sum_{j=1}^{4} \left(\frac{C_{ch}^{w}(i,j) - \overline{C_{ch}^{w}}(i)}{\overline{G_{ch}}(i)} \right)^2 \right]^{1/2}$$

For a non-steady mean such as ATMS warm count from blackbody target, Allan variance works the best for NEDT:

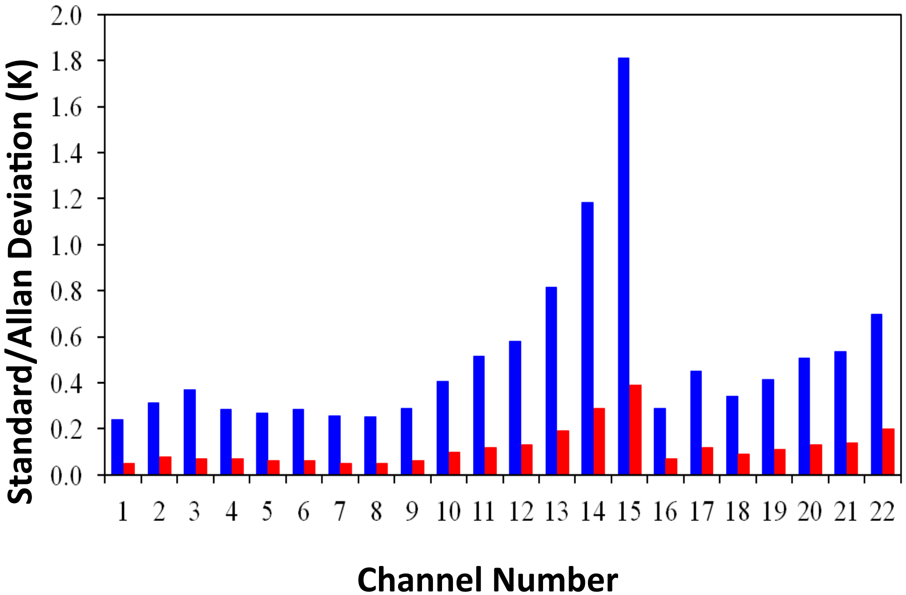


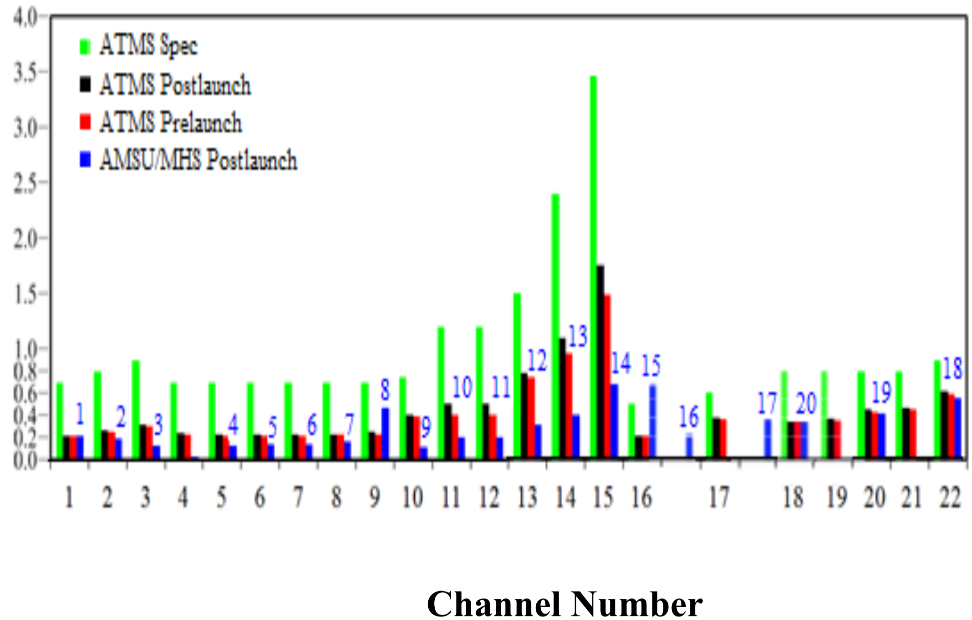
$$\sigma^{Allan}(m) = \sqrt{\frac{1}{2m^2(N-2m)} \sum_{j=1}^{N-2m} \left(\sum_{i=j}^{j+m-1} \left(C_{ch}^{w}(i+m) - C_{ch}^{w}(i) \right) \right)^2}$$

ATMS channel 1 warm count mean (blue, y-axis on the right), the standard deviation (red, y-axis on the left) and the overlapping Allan deviation (green, y-axis on the left) of the 17-scanline (m) average as a function of the total sample size (N).

M. Tian, X. Zou and F. Weng, "*Use of Allan Deviation for Characterizing Satellite Microwave Sounders Noise Equivalent Differential Temperature (NEDT)*", IEEE Geosci. Remote Sens. Lett., Digital Object Identifier 10.1109/LGRS.2015.2485945

ATMS Noise Equivalent Temperature (NEDT)





ATMS standard deviation (blue) and Allan deviation (red) with channel number. The sample size (N) is 150 and the averaging factor (m) for the warm counts is 17. The standard deviation is much higher than Allan deviation.

On-orbit ATMS noise from the standard deviation is lower than specification but is higher than AMSU/MHS. ATMS resample algorithm can further reduce the noise comparable to AMSU/MHS

S-NPP ATMS On-orbit Performance

Channel	Accuracy (K) On-Orbit/Spec	NEΔT (K) On-Orbit/Spec	Channel	Calibration (K) On-Orbit/Spec	NEΔT (K) On-Orbit/Spec
1	/1.00	0.25/0.5	**12**	0.24/0.75	0.59/1.0
2	/1.00	0.31/0.6	**13**	0.13/0.75	0.86/1.5
3	/0.75	0.37/0.7	**14**	0.02/0.75	1.23/2.2
4	/0.75	0.28/0.5	**15**	0.09/0.75	1.95/3.6
5	0.18/0.75	0.28/0.5	**16**	/1.00	0.29/0.3
6	0.09/0.75	0.29/0.5	**17**	/1.00	0.46/0.6
7	0.02/0.75	0.27/0.5	**18**	0.50/1.00	0.38/0.8
8	0.06/0.75	0.27/0.5	**19**	0.36/1.00	0.46/0.8
9	0.06/0.75	0.29/0.5	**20**	0.31/1.00	0.54/0.8
10	0.18/0.75	0.43/0.75	**21**	0.13/1.00	0.59/0.8
11	0.22/0.75	0.56/1.0	**22**	0.40/1.00	0.73/0.9

Note: On-orbit calibration accuracy for ATMS antenna brightness temperatures at upper air sounding channels is derived from the forward model (*see Zou, X., Lin Lin and F. Weng, 2013: Absolute Calibration of ATMS Upper Level Temperature Sounding Channels Using GPS RO Observations , IEEE Trans. Geosci. and Remote Sens., 10.1109/TGRS.2013.2250981*)

ATMS Lunar Intrusion Correction Algorithm

Brightness temperature increment arising from lunar contamination can be expressed as a function of lunar solid angle, antenna response and radiation from the Moon

Space view Tb or radiance increment:

$$\Delta T_{moon} = G * \Omega * T_{moon}$$

Antenna response function:

$$G = e^{\frac{-(\beta' - \alpha_0)^2}{2\delta^2}}, \quad with\ \delta = \frac{0.5 \cdot \theta_{3dB}}{\sqrt{2 \cdot log2}}$$

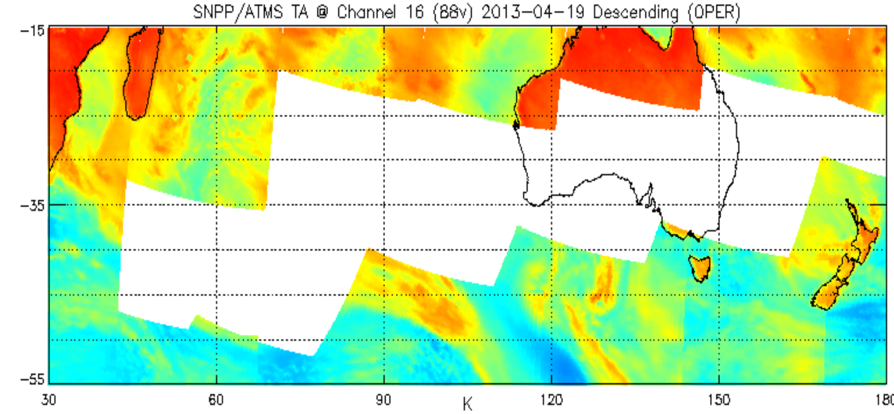
Weights of the Moon in antenna pattern:

$$\Omega_{moon} = \frac{\pi\left(\frac{r_{moon}}{D_{moon}}\right)^2}{\iint G(\theta,\varphi)d\theta d\varphi}$$

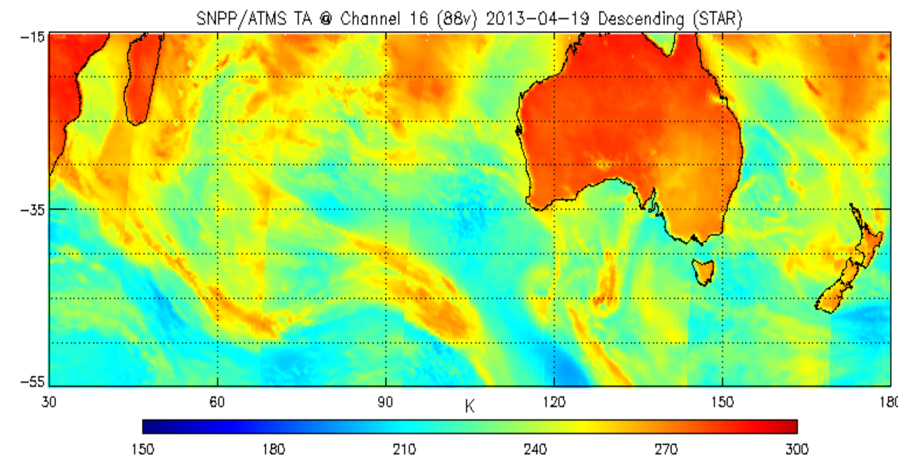
Brightness temperature of the Moon:

$$T_{moon} = 95.21 + 104.63 \cdot (1 - cos\Theta) + 11.62 \cdot (1 + cos2\Theta)$$

Without LI correction



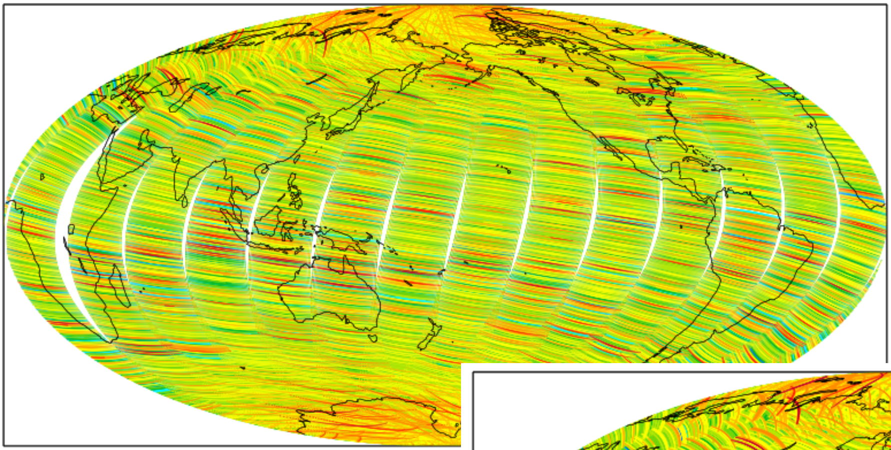
With LI correction



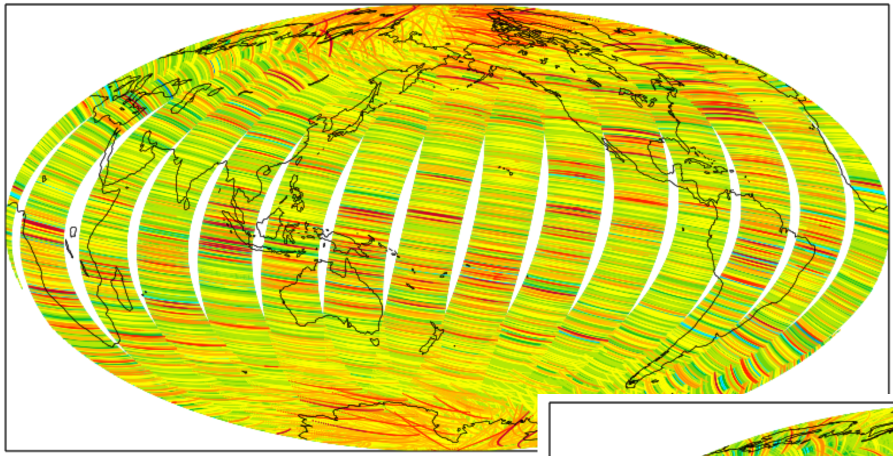
ATMS Striping Noise Shown in O-B

Striping noise are found in ATMS, MHS, and AMSU-B. The magnitudes of ATMS temperature and water vapor sounding channels are about±0.3K and ±1.0K, respectively

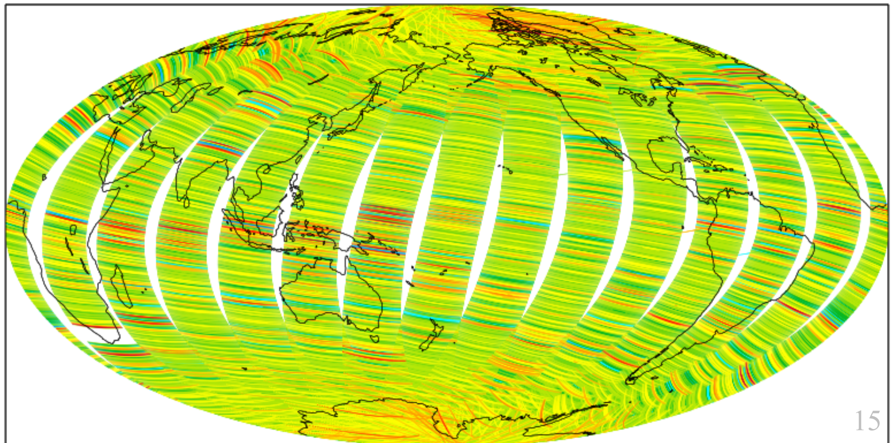
SNPP ATMS Ch 22



NOAA-18 MHS Ch3



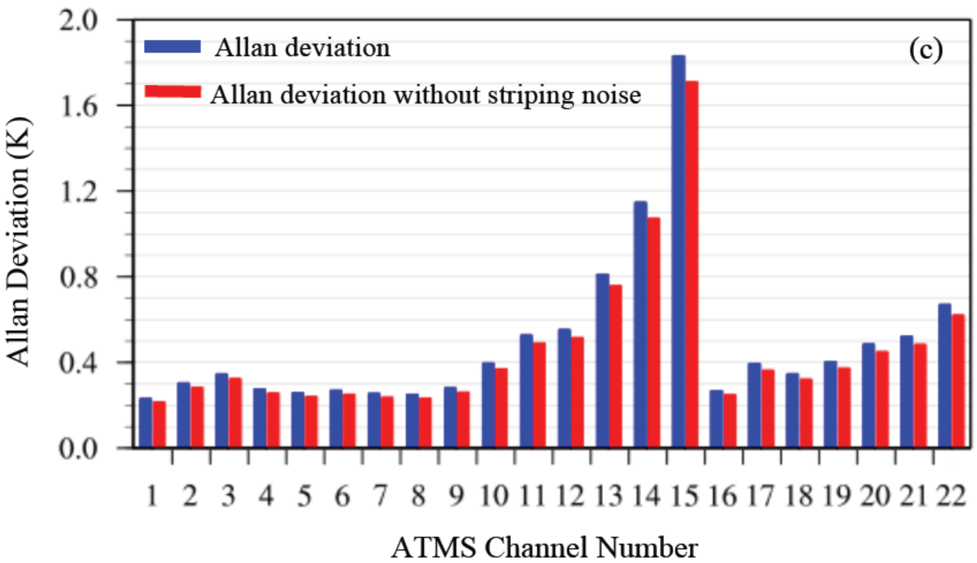
NOAA-16 AMSU-B Ch3



Impacts of ATMS Striping Effects on Channel Noise Characterization

Channel	NEDT (K)		Allan Deviation (K)	
	Before	After	Before	After
1	0.3490	0.3256	0.2324	0.2171
2	0.3977	0.3593	0.3052	0.2843
3	0.3945	0.3464	0.3473	0.3248
4	0.3279	0.2883	0.2772	0.2581
5	0.3232	0.2871	0.2603	0.2422
6	0.3433	0.3069	0.2714	0.2526
7	0.3518	0.3201	0.2559	0.2382
8	0.3453	0.3138	0.2518	0.2345
9	0.3421	0.3046	0.2816	0.2628
10	0.4542	0.3968	0.3981	0.3716
11	0.5675	0.4900	0.5277	0.4922
12	0.6140	0.5365	0.5534	0.5174
13	0.8718	0.7527	0.8123	0.7593
14	1.1849	1.0179	1.1479	1.0727
15	1.8476	1.5651	1.8319	1.7110
16	0.3914	0.3578	0.2692	0.2501
17	0.9237	0.8865	0.3954	0.3650
18	0.5496	0.5103	0.3479	0.3230
19	0.6637	0.6149	0.4041	0.3740
20	0.7636	0.7039	0.4859	0.4508
21	0.8862	0.8202	0.5239	0.4848
22	1.1194	1.0337	0.6712	0.6217

- Channel noise reduced after applying striping mitigation algorithm
- 45-day de-striping BUFR data generated for NWP impact study



Qin, Z., X. Zou and F. Weng, 2013: Analysis of ATMS and AMSU striping noise from their earth scene observations. J. Geophy. Res., 118, 13,214-13,229, doi: 10.1002/ 2013JD020399

Ma, Y. and X. Zou, 2015: Optimal filters for striping noise mitigation within ATMS calibration counts. IEEE Trans. Geo. Remote Sensing, (in revision)

Upcoming Changes in ATMS SDR Processing

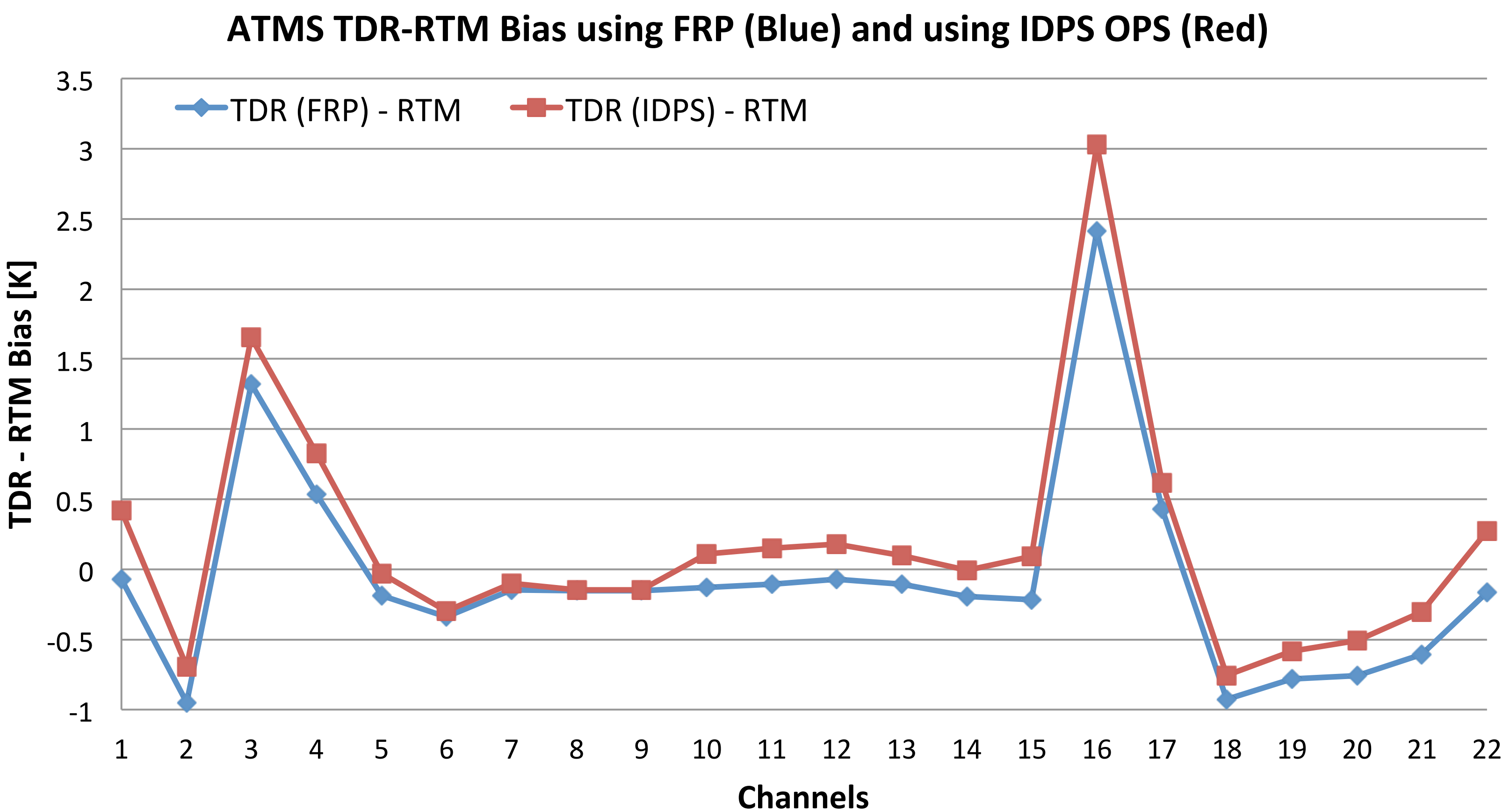
1. SNPP ATMS nonlinearity calibration term was implemented incorrectly in the early IDPS processing and its sign to the linear term needs to be reversed

2. A radiometric two-point calibration in radiance has been developed and the full radiance calibration algorithm will be implemented in IDPS Block 2.0 or ADL5.3(direct readout users)

3. A physical model has been developed and will be implemented for correcting the emitted radiation from ATMS flat reflector

4. SNPP ATMS RDR data will be reprocessed with the latest IDPS version to generate a climate quality of TDR and SDR products

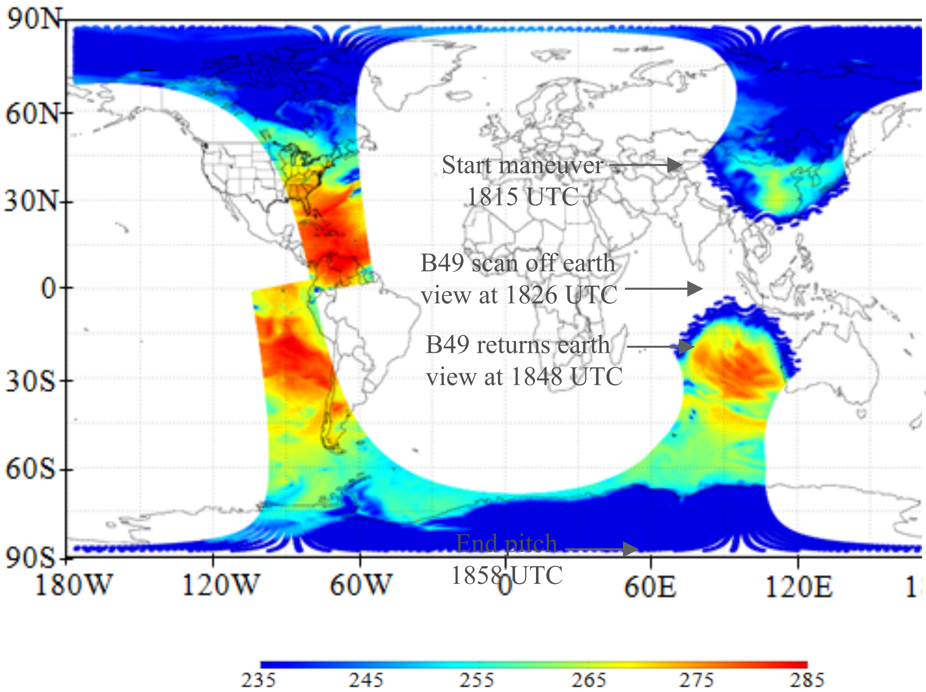
Global Mean O-B Bias from ATMS Full Radiance Calibration



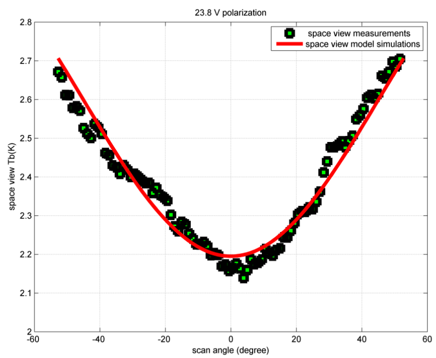
ATMS full radiance calibration (FRC) performs two corrections: 1) replacing the brightness temperatures (R-J approximation) with Plank function radiance and 2) reversing the sign in nonlinearity term. WG bands are affected by two corrections where other channels are mainly affected by the nonlinearity term.

ATMS TDR Pitch Maneuver Data for Characterizing the Antenna Emission

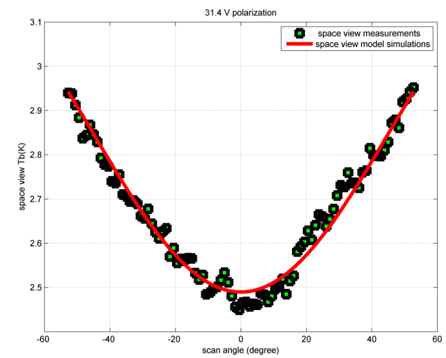
ATMS TDR at Ch18 on February 20, 2012



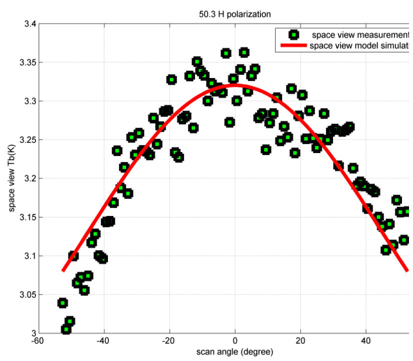
Channel 1



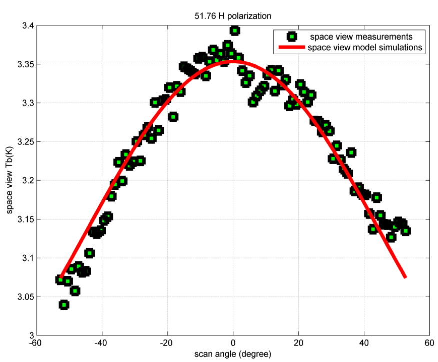
Channel 2



Channel 3



Channel 4



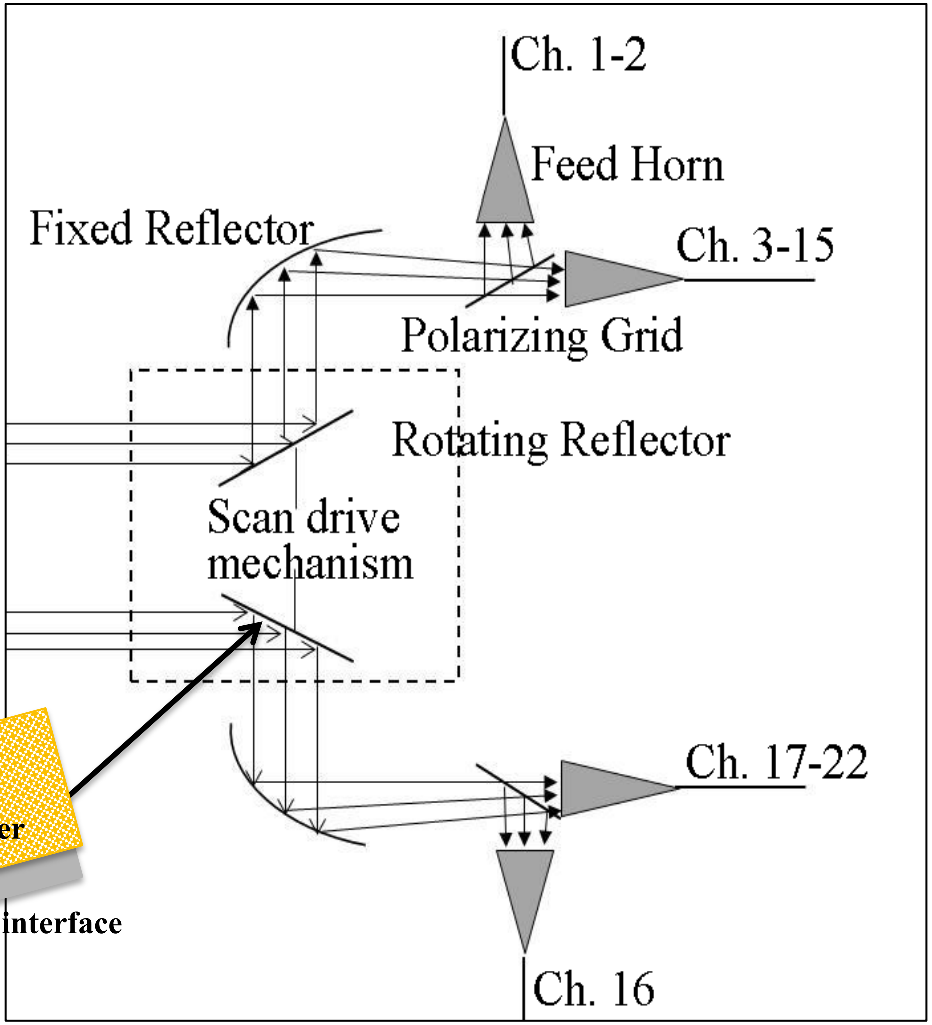
NPP ATMS pitch maneuver observations show channel related scan angle dependent feature, indicate the scan bias is not inherent feature of the scene

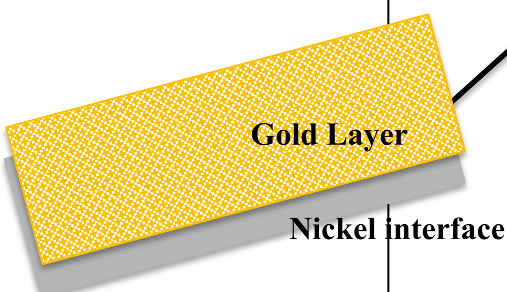
ATMS Reflector Emission and Its Effects on TDR

- Flat rotating reflector has an emission and affects the accuracy in computing the calibration target temperatures in two point calibration equations
- In the earth scene scanning, the antenna brightness temperature in the two-point calibration equation contains the emission from the antenna that must be further corrected
- Hagen-Rubens equation

$$\varepsilon_N = \sqrt{16\pi e_0 f / \sigma}$$

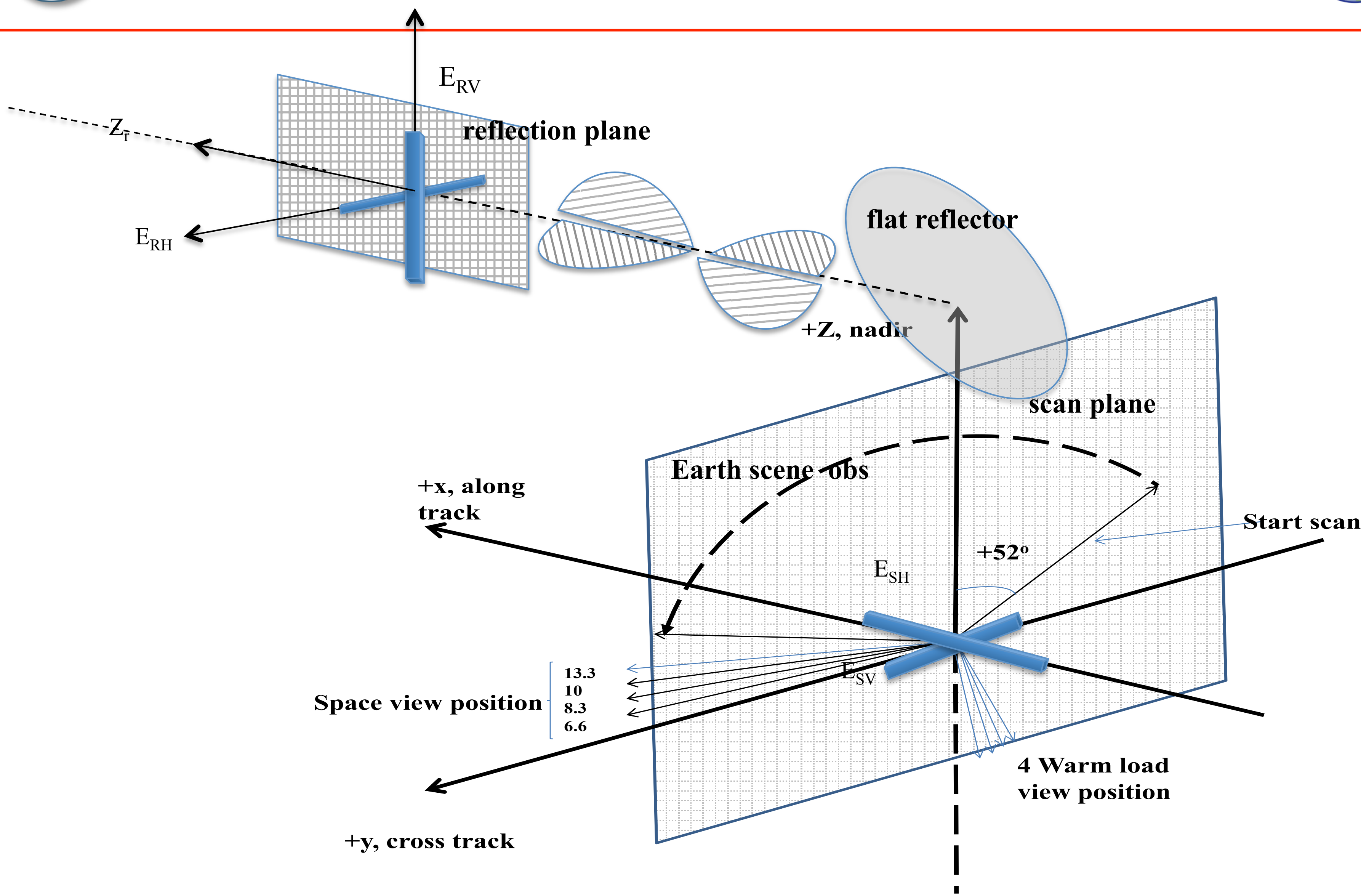
0.0025 to 0.0065





- An algorithm is being developed for ATMS TDR correction

Flat Reflector Emissivity Model



Effects of ATMS Flat Reflector Emission on Brightness Temperature

Quasi-V (TDR) :

$$R_{qv}^{c} = R_{qv} + \varepsilon_h (R_r - R_h) + [\varepsilon_v (R_r - R_v) - \varepsilon_h (R_r - R_h)]\sin^2\theta - \frac{R_3}{2}(1-\varepsilon_h)^{3/2} sin2\theta$$

Quasi-H (TDR): **Bias due to the reflector emission**

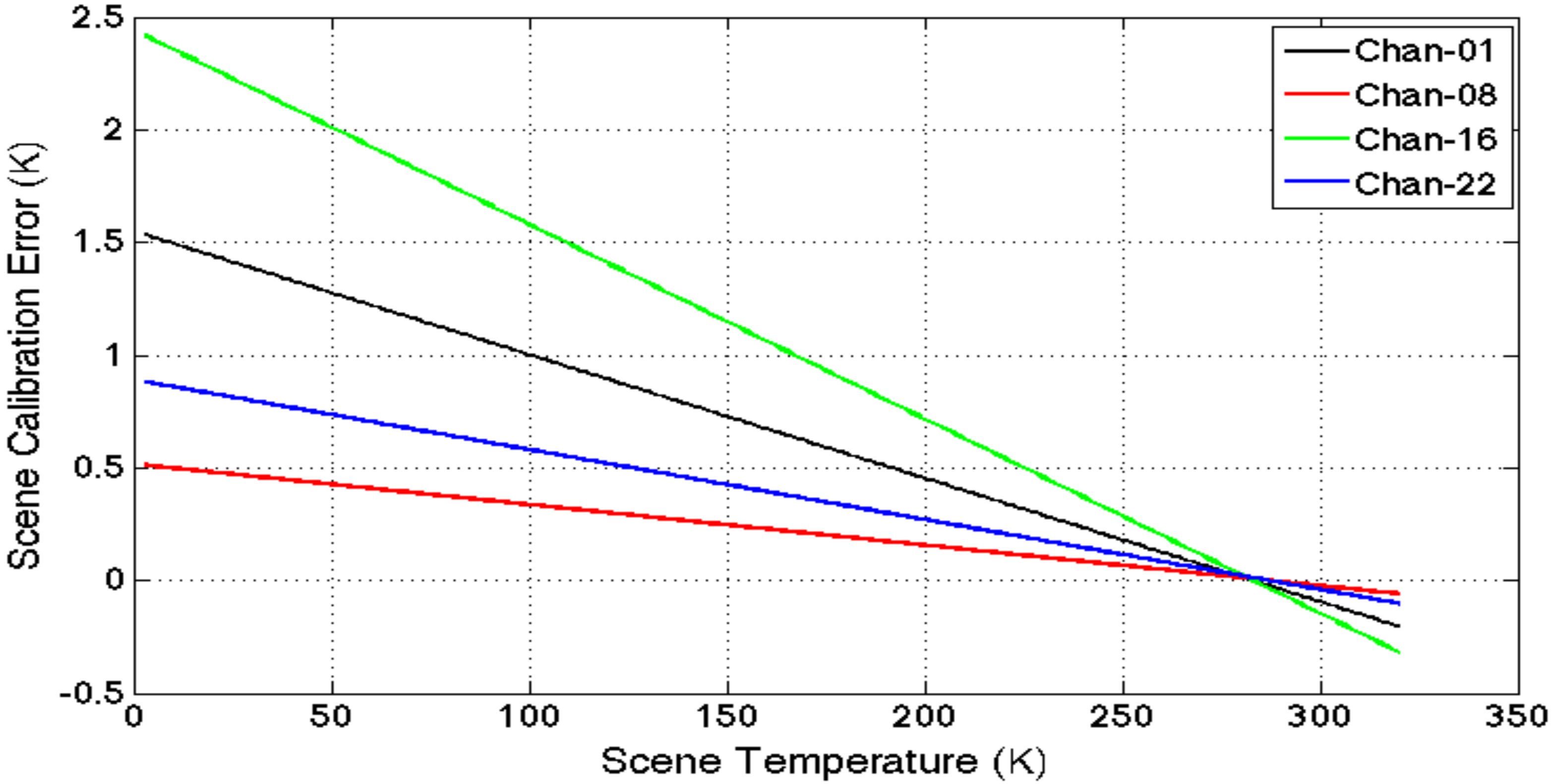
$$R_{qh}^{c} = R_{qh} + \varepsilon_h (R_r - R_h) + [\varepsilon_v (R_r - R_v) - \varepsilon_h (R_r - R_h)]\cos^2\theta + \frac{R_3}{2}(1-\varepsilon_h)^{3/2} \sin 2\theta$$

where

R_{qv} and R_{qh} are the radiances at quasi vertical and horizontal polarzation which are further related to the radiances at pure vertical and horizontal polarization, R_v and R_h. ε_v and ε_h are the reflector emissivity at the vertical and horizontal polarization. R_3 is the third Stokes radiance component of the scene. R_r is the radiance emitted from the reflector. θ is the scan angle. Note that $\varepsilon_v = 2\varepsilon_h - \varepsilon_h^2$ at an indent angle of 45 degree to reflector normal.

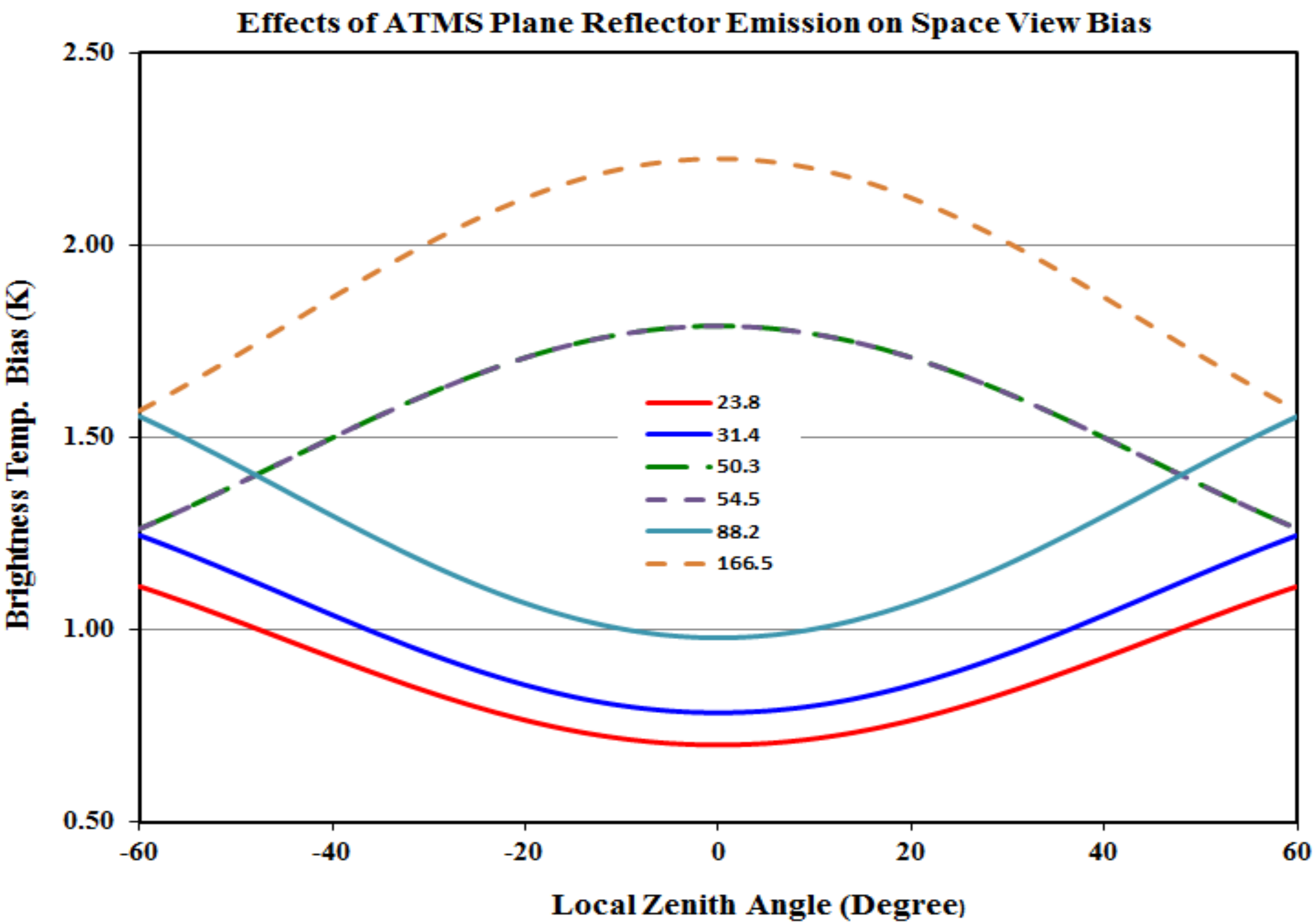
Yang, H. and F. Weng, 2015: Estimation of ATMS Antenna Emission from cold space observations, IEEE Geosci. Trans. Remote. Sens, in press

Impact of Antenna Emissivity Correction on Calibration Accuracy



- Error model was developed to evaluate the impact of reflector emission on calibration accuracy
- Error in linear part is dependent on reflector temperature, while for nonlinear part it is scene temperature dependent
- W band was observed with the largest error, which can be explained by the relatively large nonlinearity in this channel.

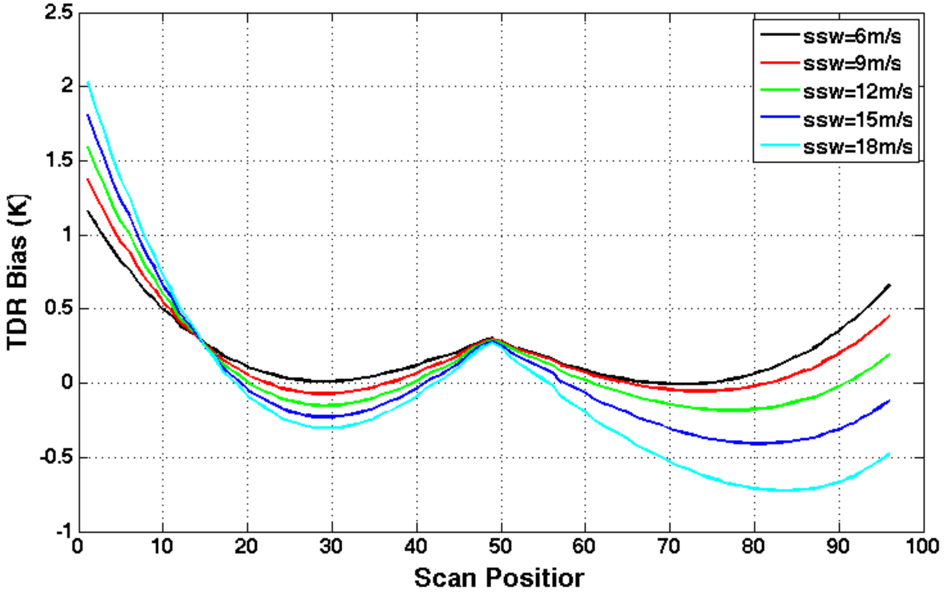
The Reflector-Emission Bias for Space View



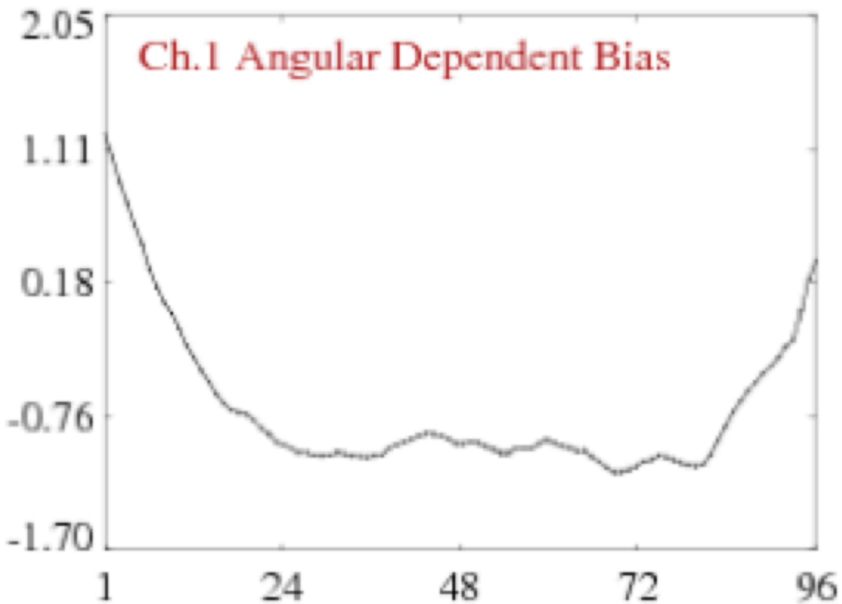
The Reflector-Emission Bias at Earth Views

ATMS channel-1 (23.8 GHz, QV polarization) scan position dependent TDR Bias

Simulated (Under different SSW conditions)

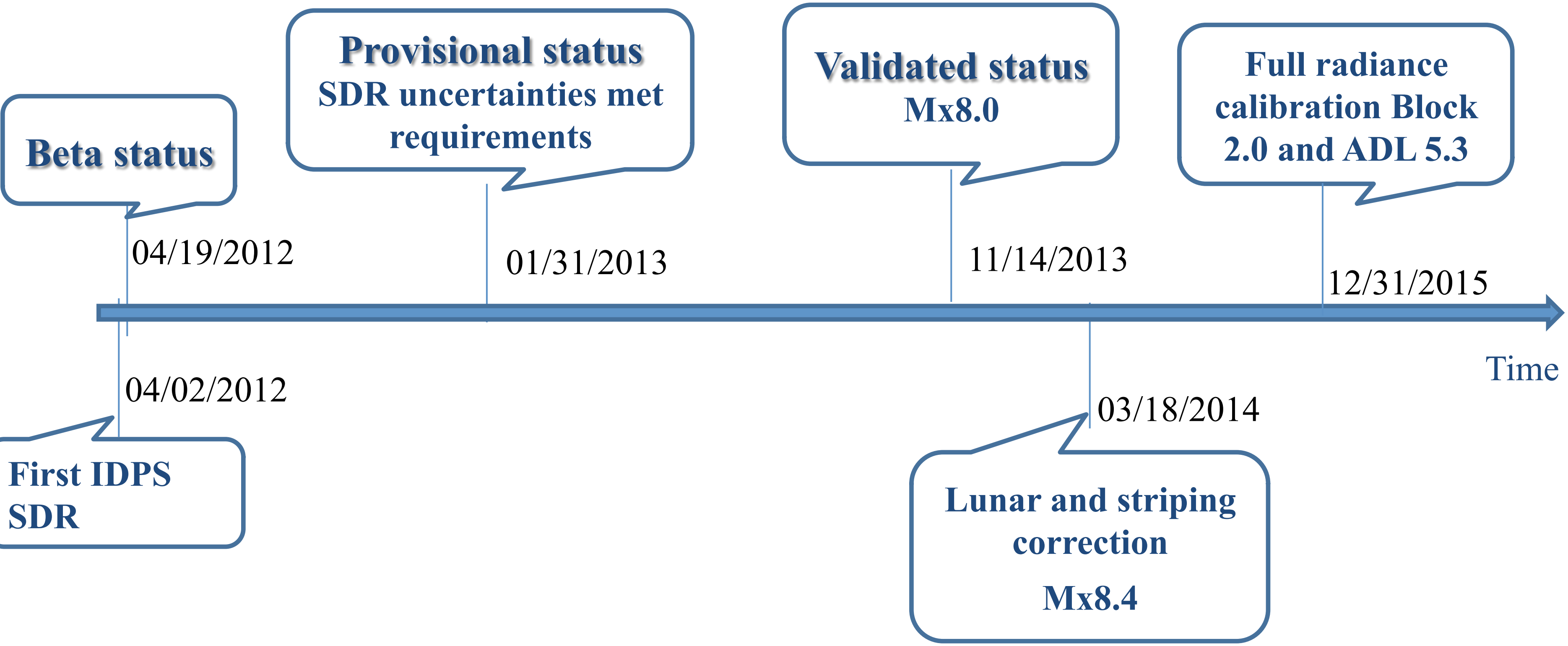


O(TDR)-B(CRTM simulation)



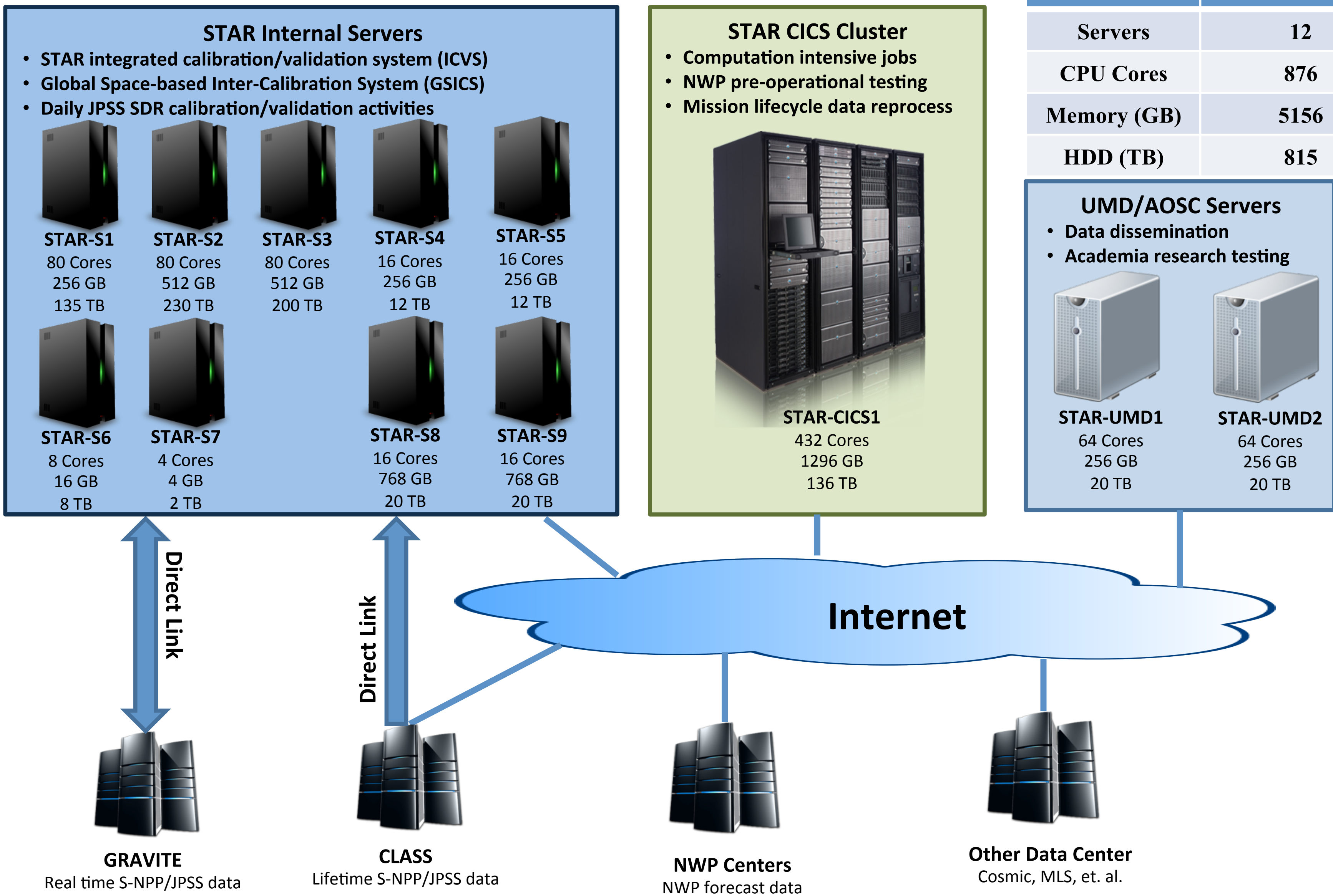
- For polarized scene, the impact of reflector emission is dependent on the temperature difference between antenna reflector and V-pol scene
- The scan angle dependent feature in the error is mainly dominated by the third Stokes component of the scene radiation.
- The simulated scan bias in TDR is consistent with those in real observations

SNPP ATMS SDR CalVal Major Milestones



STAR SDR Testbed for JPSS Reprocessing

Parts	Total
Servers	12
CPU Cores	876
Memory (GB)	5156
HDD (TB)	815



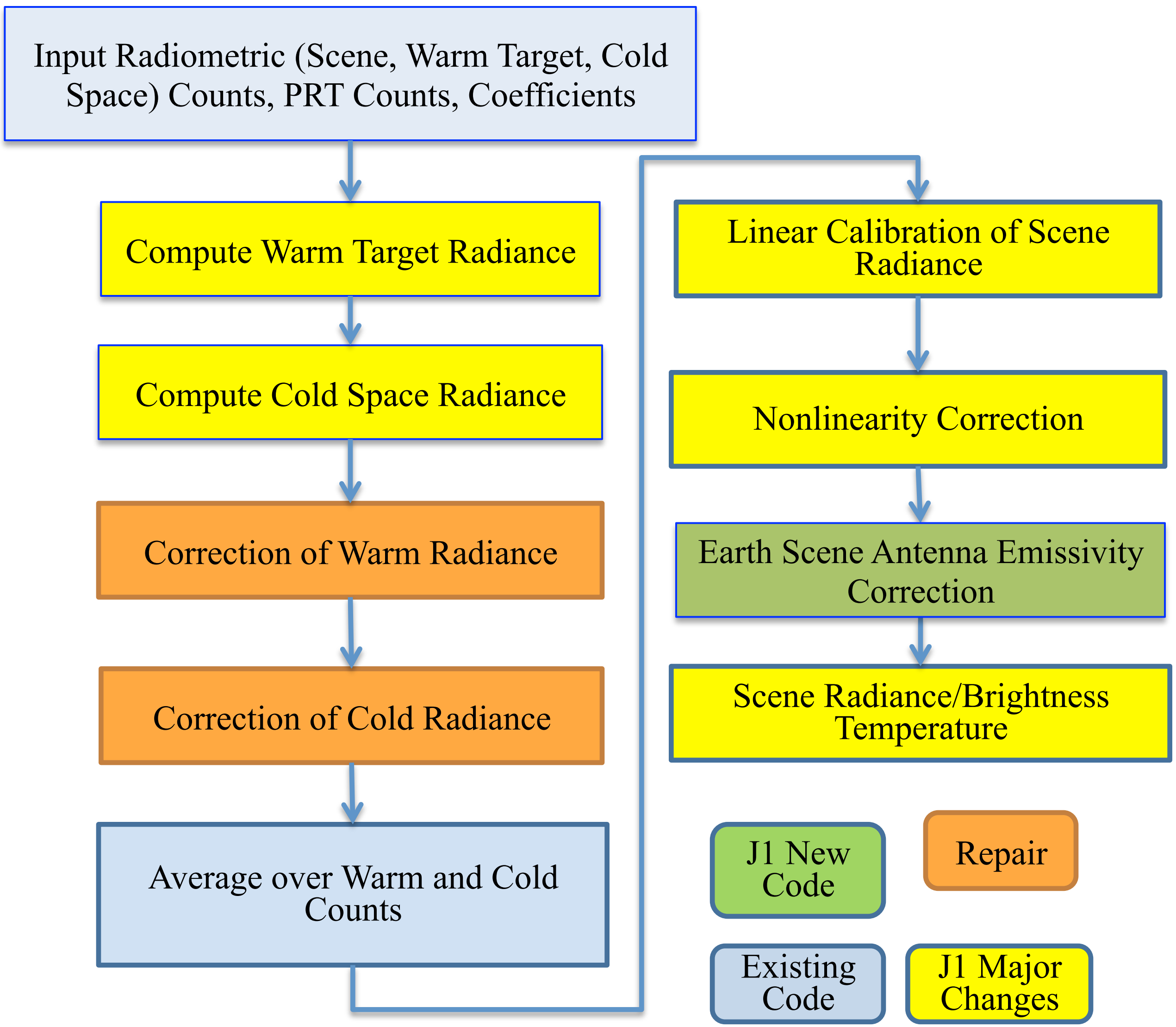
STAR SDR Testbed Utilities

- RDR/TDR/SDR Generation
  - Space Sensor Simulator (S3)
  - Community Radiative Transfer Model (CRTM)
  - Line by Line RTM (LBLRTM)
  - Advanced RT models: TOMRAD, 6S, VLIDORT, VDIOSRT
- RDR to SDR Transformation
  - CrIS Full Spectral Resolution Processing System (CFSR)
  - Advanced Radiance Transformation System (ARTS)
  - Algorithm Dynamic Library (ADL)
- Quality Assurance of SDR
  - SI Traceable Noise Calculation Software (STNC)
  - NOAA Products Validation System (NPROVS)
  - Integrated Calibration and Validation System (ICVS)
- Inversion from SDR to EDR
  - Microwave Integrated Retrieval System (MIRS)
  - NOAA Unique CrIS and ATMS Processing System (NUCAPS)
  - Ocean coloring processing with Multi-Sensor Level 1 to Level-2 (MSL12)
  - Advanced Clear Scene Processor for Oceans (ACSPO)
  - Cloud from AVHRR-x (CLAVR-x)

STAR SDR Testbed Main Functions

- Tests innovative sciences and algorithms to improve JPSS SDR product quality
- Transitions the new software developed from extramural community to IDPS
- Performs the NWP impact studies using improved SDR data
- Transitions the ICVS-Lite to GRAVITE for NASA and OSPO operations
- Archives anomaly reports regarding all NOAA/METOP/JPSS instruments
- Conducts new research on future JPSS and other satellite constellation
- Provides the online supports to Global Space-Based Inter-Calibration System
- Performs the JPSS SDR mission life cycle reprocessing

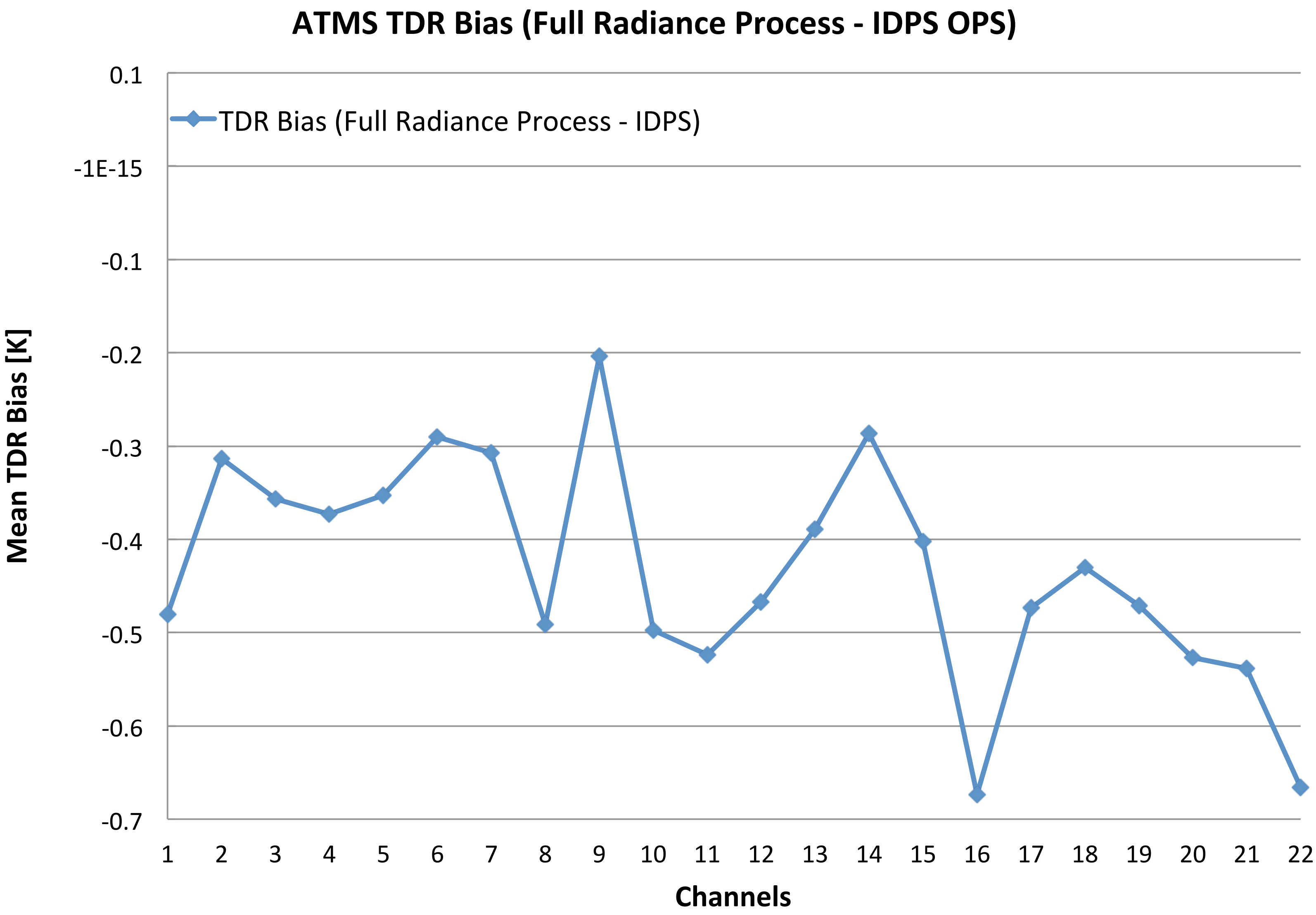
ATMS SDR Algorithm Change from SNPP to JPSS



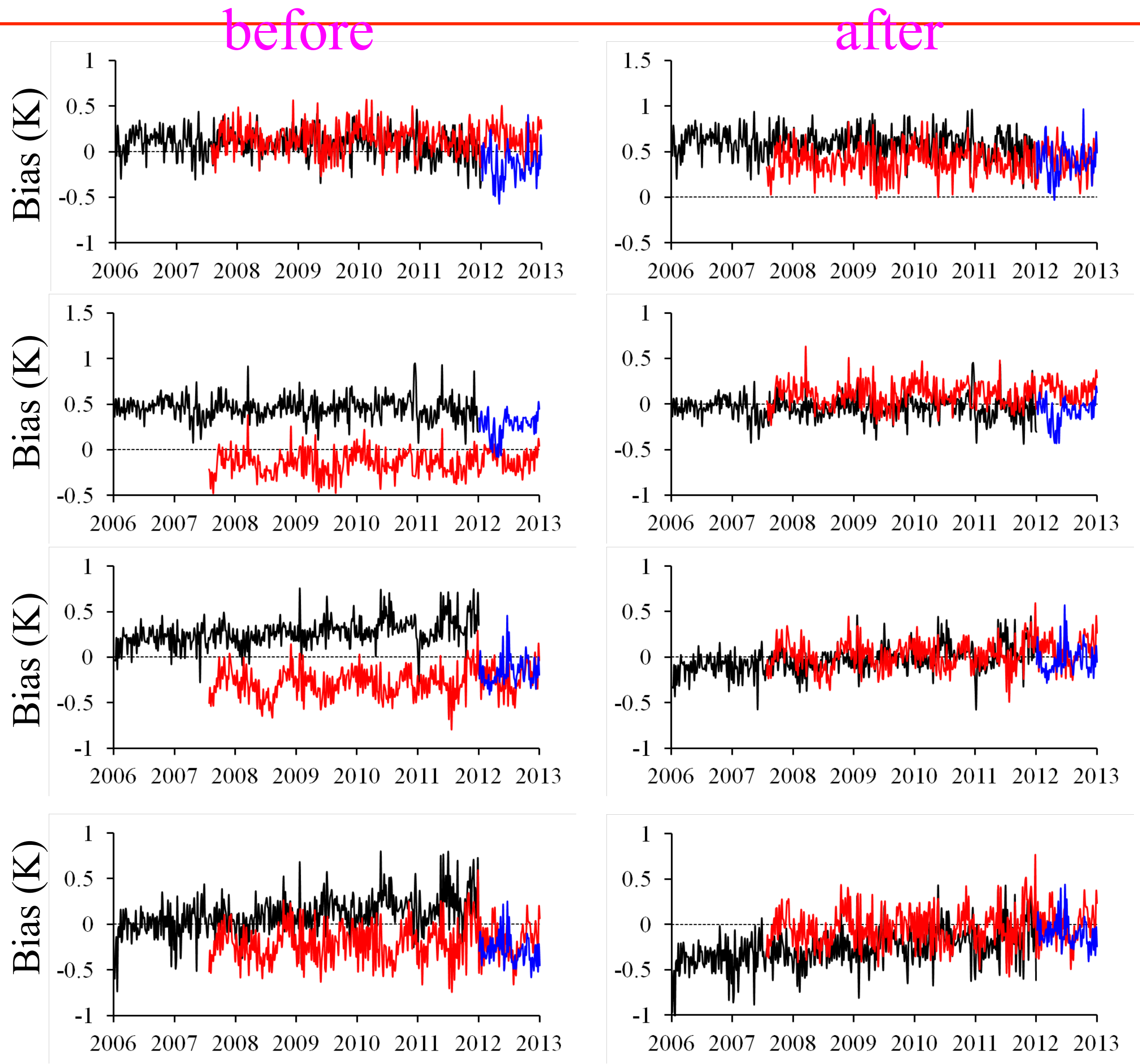
Major Changes:

- Radiance based calibration
- Model based lunar contamination correction
- Updated parameterized nonlinearity correction
- Model based antenna reflector emissivity correction

Global Mean TDR Bias



Biases in the Tropics (NOAA-15, MetOp-A, SNPP)



ATMS channel 10

ATMS channel 11

ATMS channel 13

ATMS channel 14

NOAA-18 is subtracted. The pentad data set within ±30º latitudinal band.

Summary and Conclusions

- ATMS on-orbit NEDT is well characterized by new Allan deviation method, resulting in much lower NEDT values
- ATMS scan motor has been commanded for one reversal every 14 orbits for the purpose of extending its design life beyond 5 years
- ATMS full radiance calibration algorithm has been developed and will be implemented into IDPS Block 2.0
- ATMS flat reflector emission is fully characterized by using a physical model and pitch-over maneuver data. The algorithm for correcting this emission is ready for implementation into IDPS processing system
- ATMS O-B bias can be fully characterized if a full polarimetric RT model is used in simulation. The third Stokes component contributes to the simulated radiance in quasi-V and quasi-H channels
- J1 ATMS went through rework and V-band IF receiver and WG band video components were replaced with new parts. ATMS SDR science team is currently analyzing the TVAC data