ATMS SDR Overview

Fuzhong Weng

ATMS SDR Team

August 24, 2015

STAR JPSS 2015 Annual Science Team Meeting
August 24-28, 2015
5830 University Research Court, College Park, MD 20740

Outline

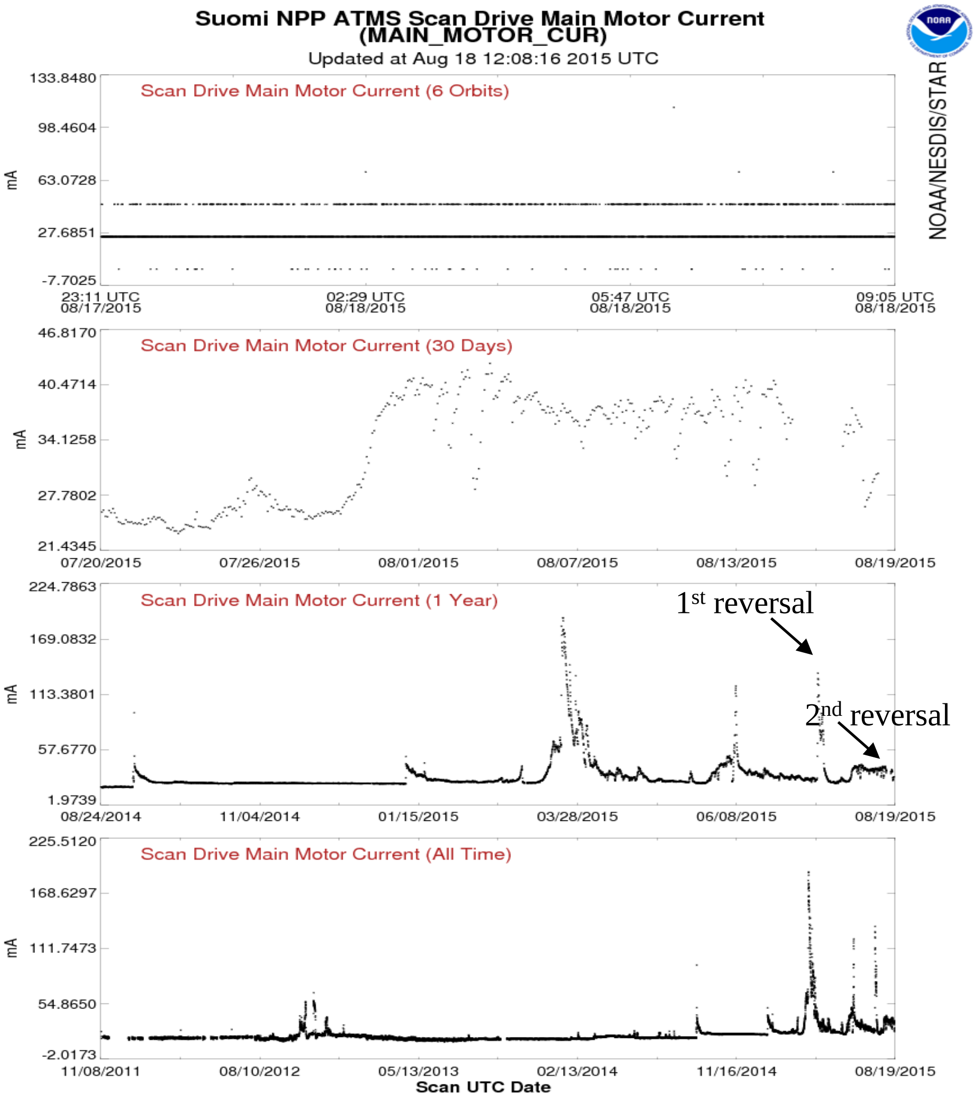
- ATMS SDR Team Members
- ATMS Instrument Overview
- ATMS SNPP Product Overview
- ATMS JPSS-1 Readiness
- Summary and Path Forward

ATMS SDR Team Members

PI Name	Organization	Primary Role and Responsibility
Fuzhong Weng	NOAA	Budget execution, calval task planning, and ATMS SDR sciences and algorithms
Ninghai Sun	ERT	Technical coordination, ATMS SDR processing in ADL, ATMS monitoring, anomaly investigation
Edward Kim	NASA	NASA ATMS instrument scientist, TVAC data, instrument anomaly investigation
Vince Leslie	MIT/LL	Calval support, SDR sciences, PCT/LUT, prelaunch TVAC data analysis, RDR generation
Xiaolei Zou	ESSIC/UMD	Striping analysis and mitigation, RFI analysis, xcal (ATMS vs. AMSU)
Kent Anderson	NGES	NGES ATMS instrument and engineering sciences, TVAC data
Wes Berg	CIRA	Xcal ATMS with GPM microwave imager, other WG band instruemnts
Wael Ibrahim	Raytheon	IDPS operational feedbacks and code implemention
Hu(Tiger) Yang	ESSIC/UMD	ATMS SDR algorithm sciences, full radiance calibration, lunar correction, antenna spill-over

ATMS Instrument Review

- SNPP and JPSS-1 ATMS instruments are identical in channel and spatial resolution. J1 ATMS design life should be longer than SNPP ATMS (e.g. better bearing system)
- SNPP ATMS has been commanded for daily scan reversal to extend the life time performance beyond 5 years. The motor current shows significant drops after the August 17 reversal.
  - The reversal was initiated above 75 degrees latitude North and repeats every 15 orbits after the previous reversal. The 15 orbits will "walk" the longitude across the earth in 14-15 days, with steps about 20 degrees longitude between successive orbits. Each reversal last no more than 1 minute
- Rework of JPSS-1 ATMS is nearly completed. The new TVAC data will be soon released. The sensor will be delivered on November 7
  - Team has evaluated the proposal of TVAC with less scene measurements from 11 to 6.
  - All the software for anlayzing TVAC data is ready at STAR



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

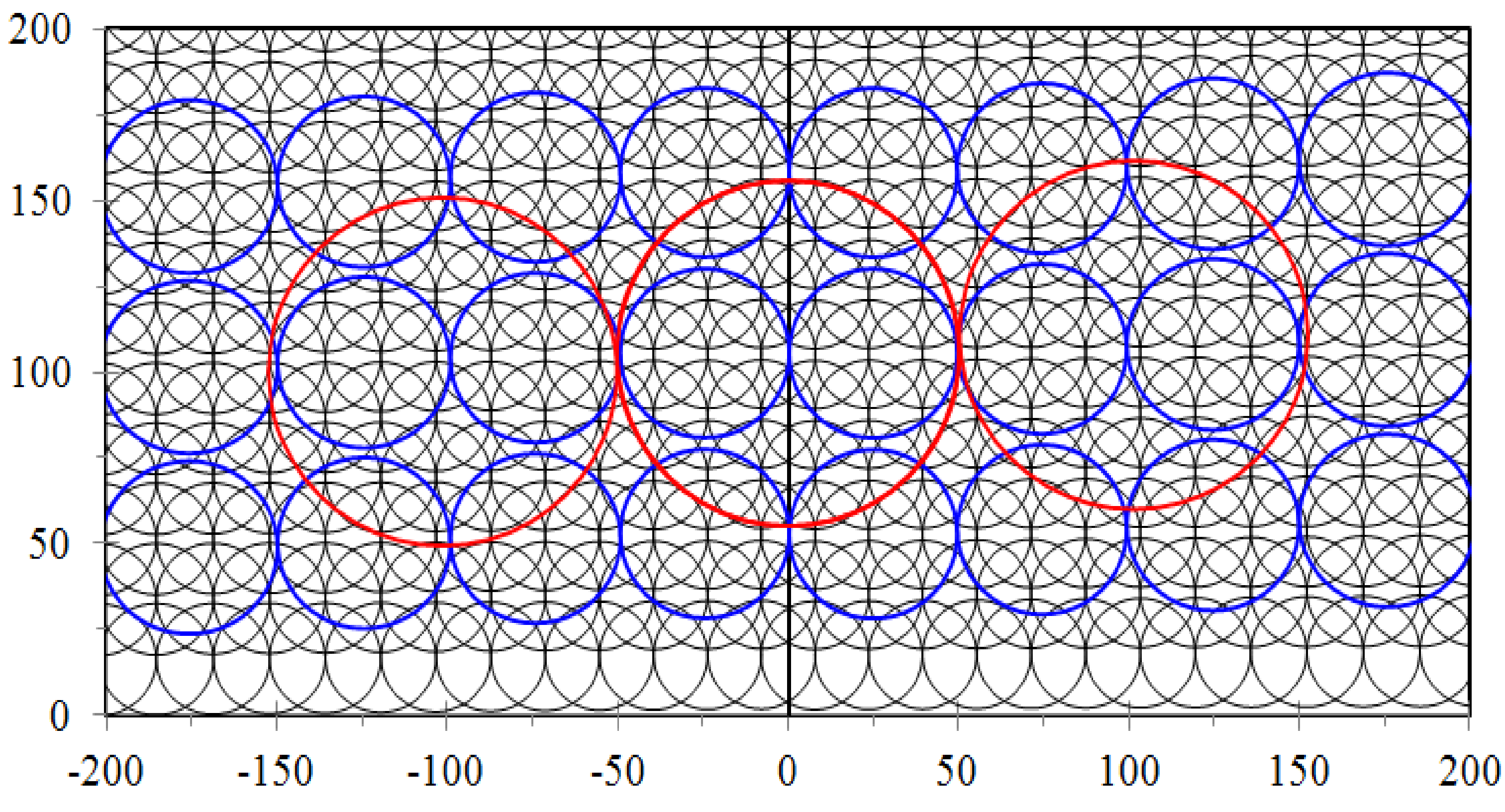
MSU			AMSU/MHS			ATMS		
Ch	GHz	Pol	Ch	GHz	Pol	Ch	GHz	Pol
			1	23.8	QV	1	23.8	QV
			2	31.399	QV	2	31.4	QV
1	50.299	QV	3	50.299	QV	3	50.3	QH
						4	51.76	QH
			4	52.8	QV	5	52.8	QH
2	53.74	QH	5	53.595 ± 0.115	QH	6	53.596 ± 0.115	QH
			6	54.4	QH	7	54.4	QH
3	54.96	QH	7	54.94	QV	8	54.94	QH
			8	55.5	QH	9	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

- Exact match to AMSU/MHS
- Only Polarization different
- Unique Passband
- Unique Passband, and Pol. different from closest AMSU/MHS channels

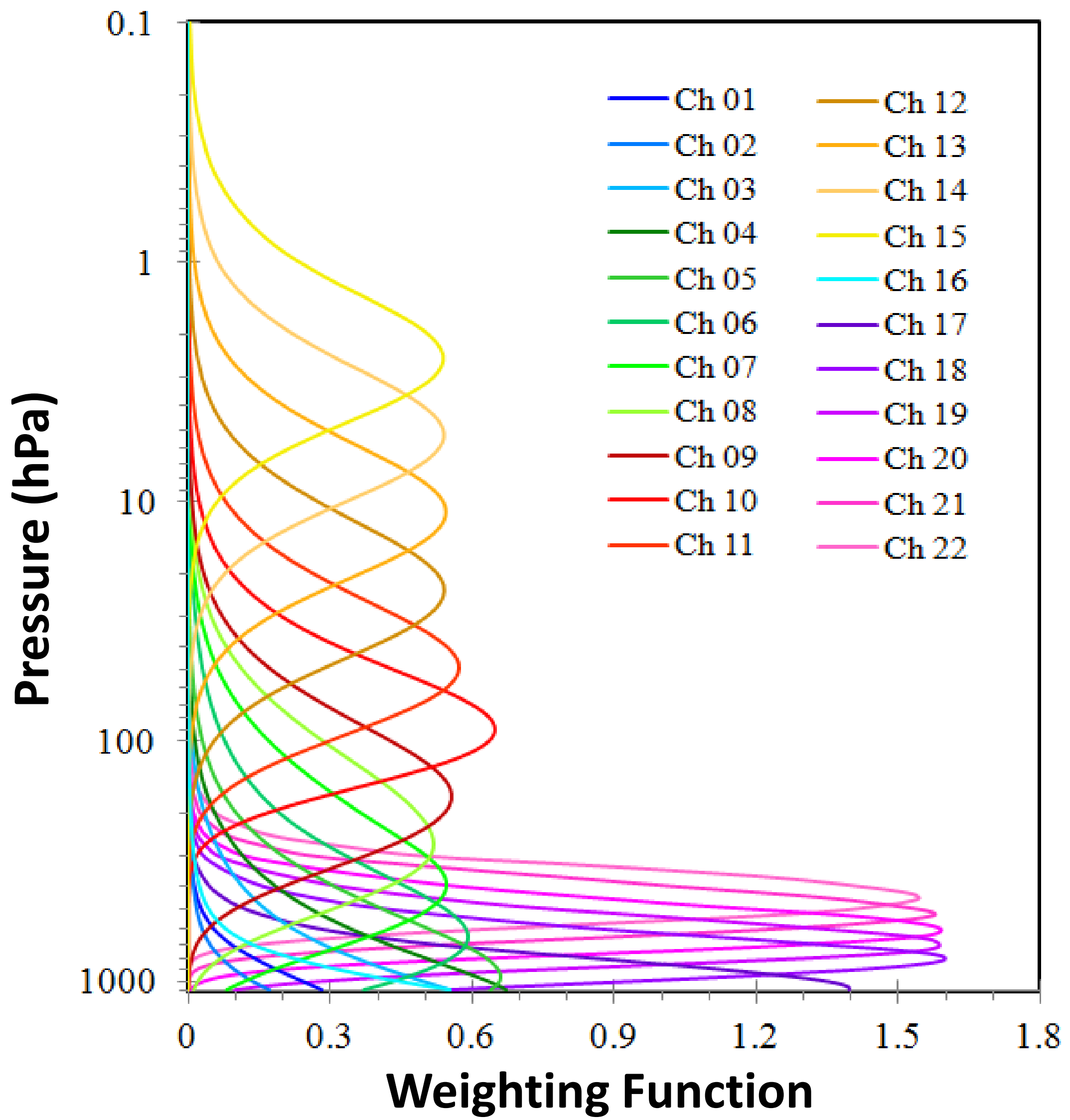
Microwave Sounding Instruments from MSU to AMSU/MHS to ATMS

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

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



ATMS Channel Weighting Functions



ATMS SDR Team 2015 Top Five Accomplishments

1. Developed the radiometric two-point calibration in radiance, instead of brightness temperature which is based on Rayleigh-Jeans approximation. The full radiance calibration algorithm will be in IDPS MX8.12 and IDPS Block 2

2. Standardized NEdT calculation for ATMS and other microwave sounding instruments using Allan Deviation. The new algorithm has resulted in much stable noise trending and is SI traceable

3. Optimized the ATMS de-striping algorithm for the earth scene brightness temperatures and generated 45 days of ATMS TDR data for NWP user community to experiment the impacts of ATMS on global forecast skills

4. Developed a physically based model for correcting the radiation from ATMS reflector emission contributed to the earth scene brightness temperature

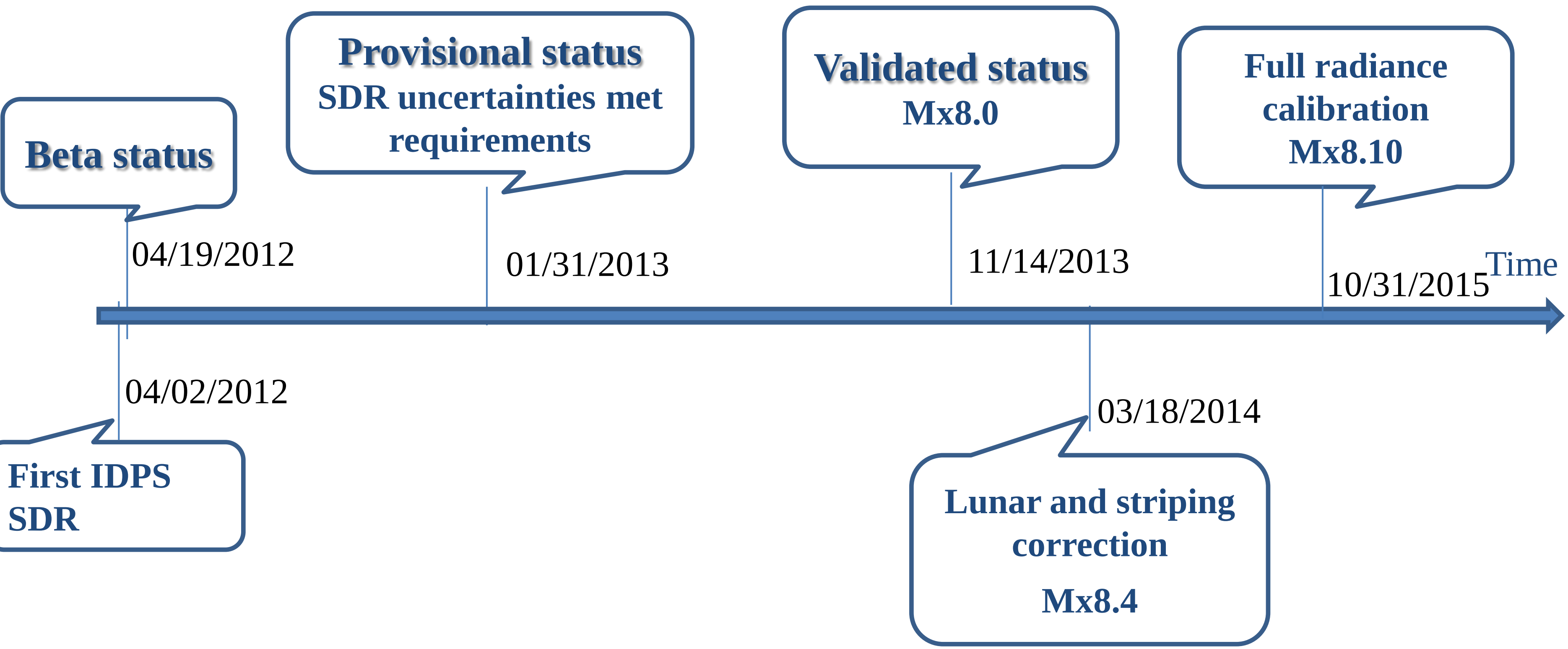
5. Updated ATMS processing coefficient tables (e.g. nonlinearity coefficients, threshold for calibration counts)

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*)

SNPP ATMS SDR CalVal Major Milestones

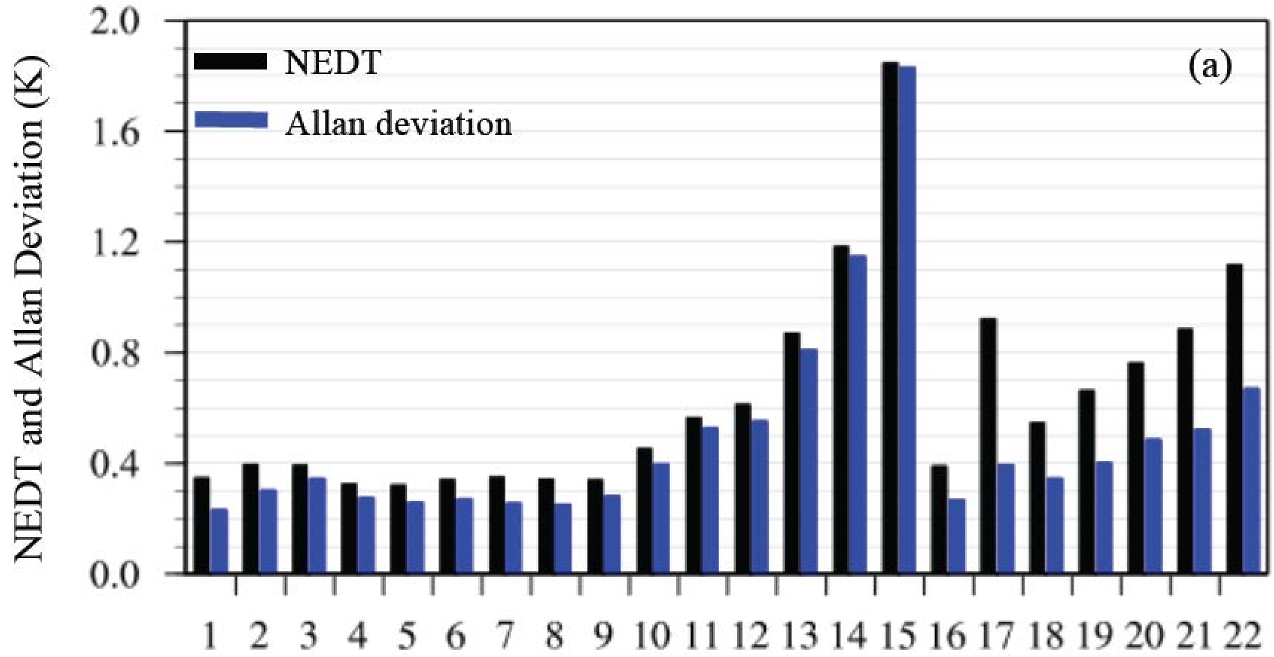


ATMS SDR Science Advances

- Radiometric Calibration
  - ✓ *Non-linearity correction*
  - ✓ *Calibration accuracy*
  - ✓ *Lunar intrusion correction*
- Noise Characterization
  - ✓ *Standard deviation*
  - ✓ *Allan deviation*
- SDR Algorithm
  - ✓ *TDR to SDR conversion*
  - ✓ *Resampling SDR through Back-Gilbert theory*
  - ✓ *Xcal with respect to AMSU for climate applications*
  - ✓ *Striping and characterization*
- Advanced Developments
  - ✓ *TDR correction from antenna emission*
  - ✓ *Full radiance calibration*

ATMS Noise Equivalent Temperature (NEDT)

- Define SI-traceable noise evaluation algorithm using Allan deviation method*
- Channel noise by Allan deviation based algorithm is lower than that provided by heritage standard deviation based algorithm
- Annual oscillation of channel noise is removed
- Long term trending of S-NPP ATMS channel noise by Allan deviation algorithm started to be provided in STAR ICVS-LTM from June 17, 2015

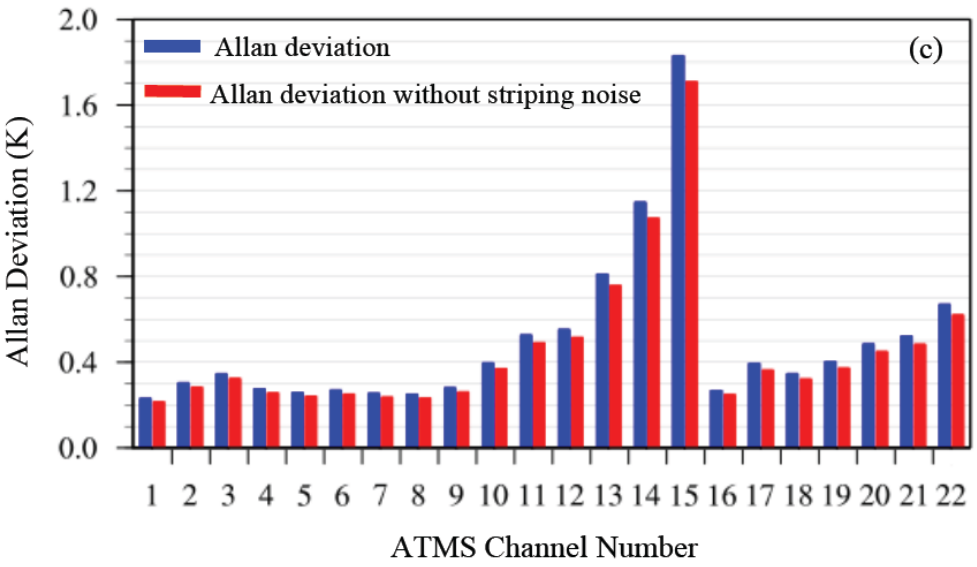


Tian, M., X. Zou and F. Weng, "*Use of Allan Deviation for Characterizing Satellite Microwave Sounders Noise Equivalent Differential Temperature (NEDT)*", *IEEE Geosci. Remote Sens. Lett., (Accepted).*

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

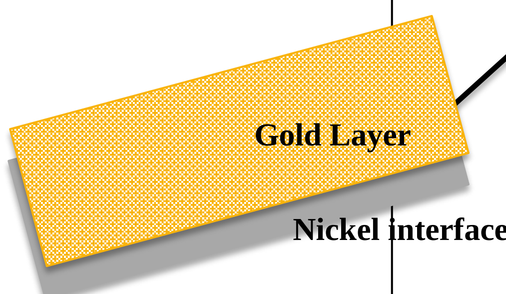
Ma, Y. and X. Zou, 2015: Optimal filters for striping noise mitigation within ATMS calibration counts. IEEE Trans. Geo. Remote Sensing, (in revision)

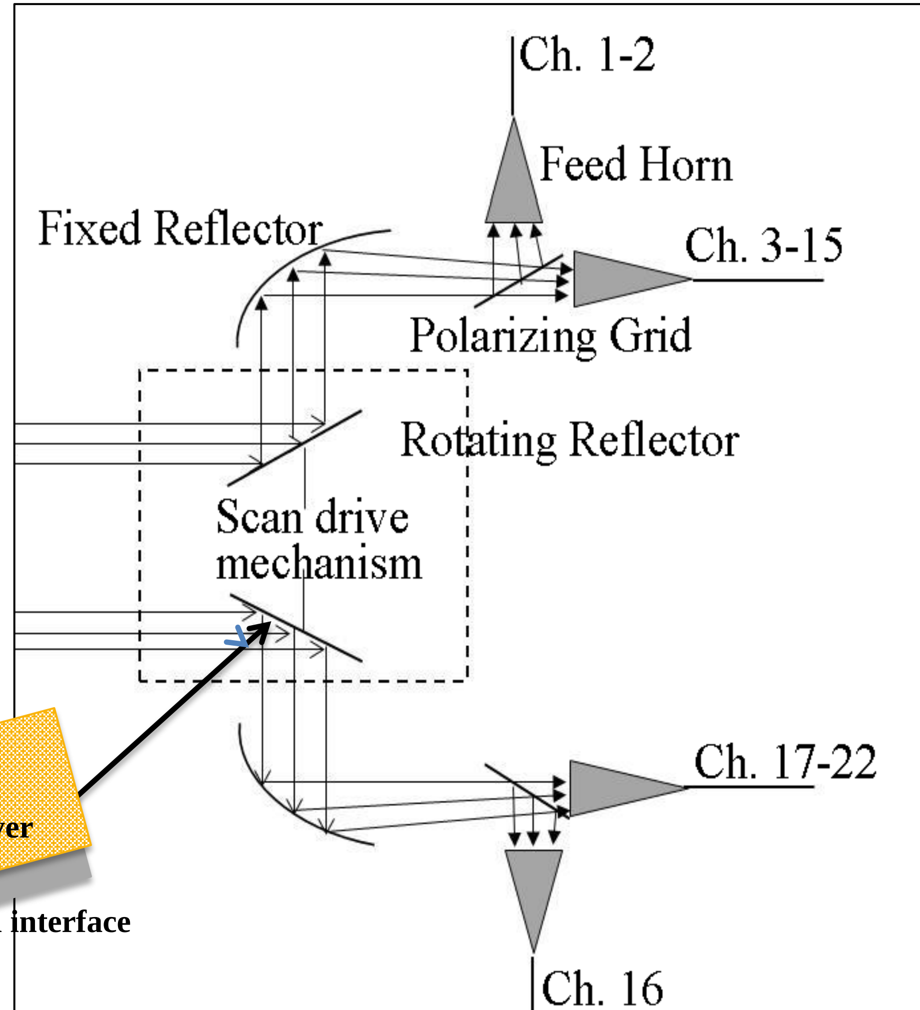
ATMS Reflector Emission and Its Effects on TDR

- 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 emission that must be further corrected
- Hagen-Rubens equation

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

0.0025 to 0.0065

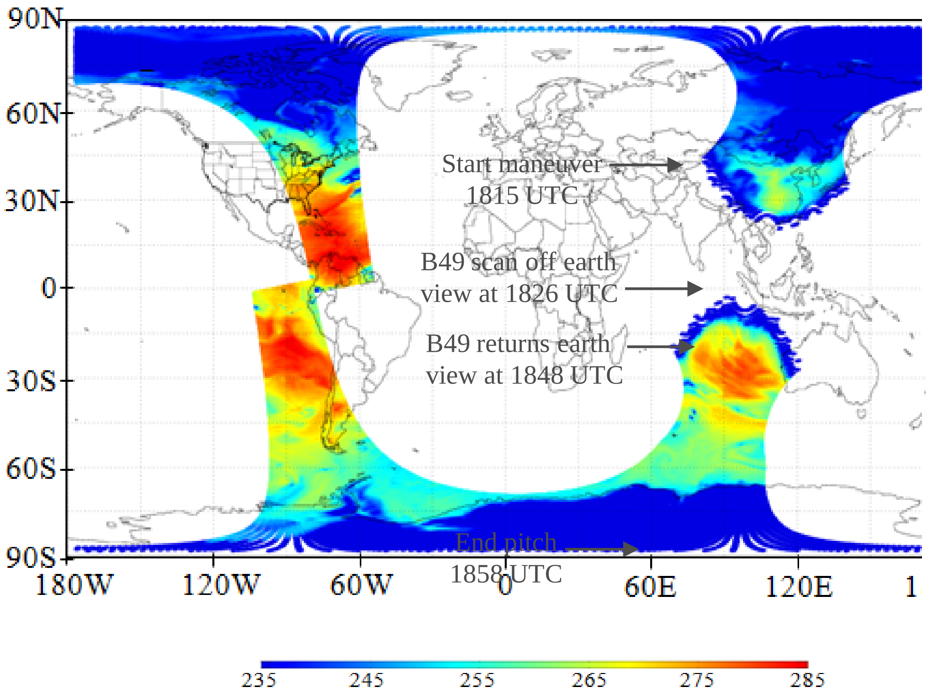




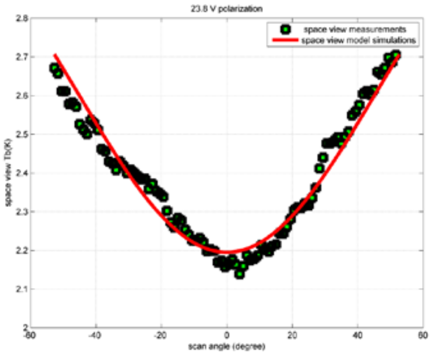
- An algorithm is being developed for ATMS TDR correction

ATMS TDR Scan Bias from Pitch-Over Maneuver Data

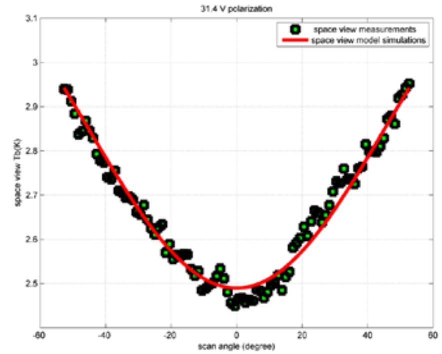
ATMS TDR at Ch18 on February 20, 2012



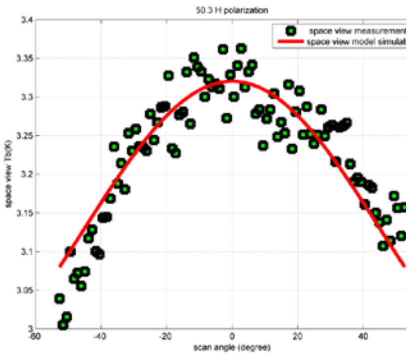
Channel 1



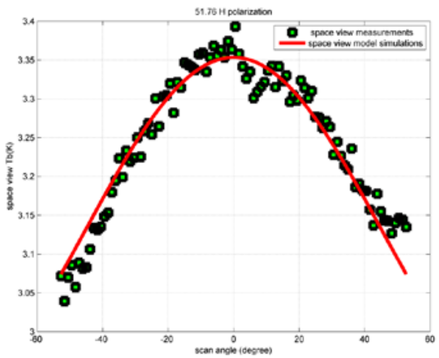
Channel 2



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

Effects of ATMS Plane Reflector Emission on Brightness Temperature

For Quasi-V (TDR) :

$$T_{b,r}^{Qv} = T_b^{Qv} + \varepsilon_h (T_r - T_b^h) + [\varepsilon_v (T_r - T_b^v) - \varepsilon_h (T_r - T_b^h)]\sin^2\theta$$

For Quasi-H (TDR)

$$T_{b,r}^{Qh} = T_b^{Qh} + \varepsilon_h (T_r - T_b^h) + [\varepsilon_v (T_r - T_b^v) - \varepsilon_h (T_r - T_b^h)]\cos^2\theta$$

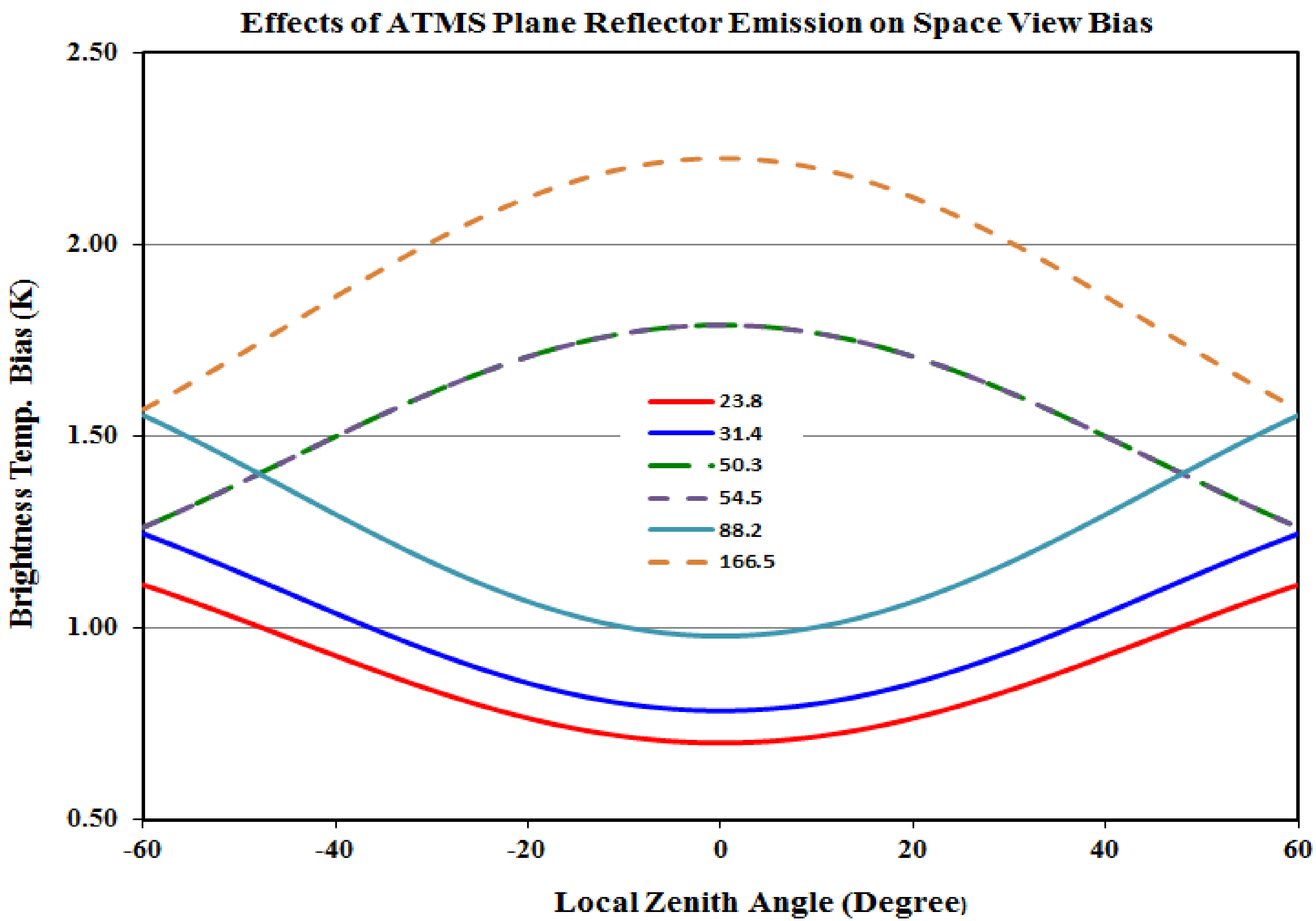
The second and third terms are the biases related to the reflector emission

At an incident angle of 45 degree to the plane reflector, the Fresnel equation becomes

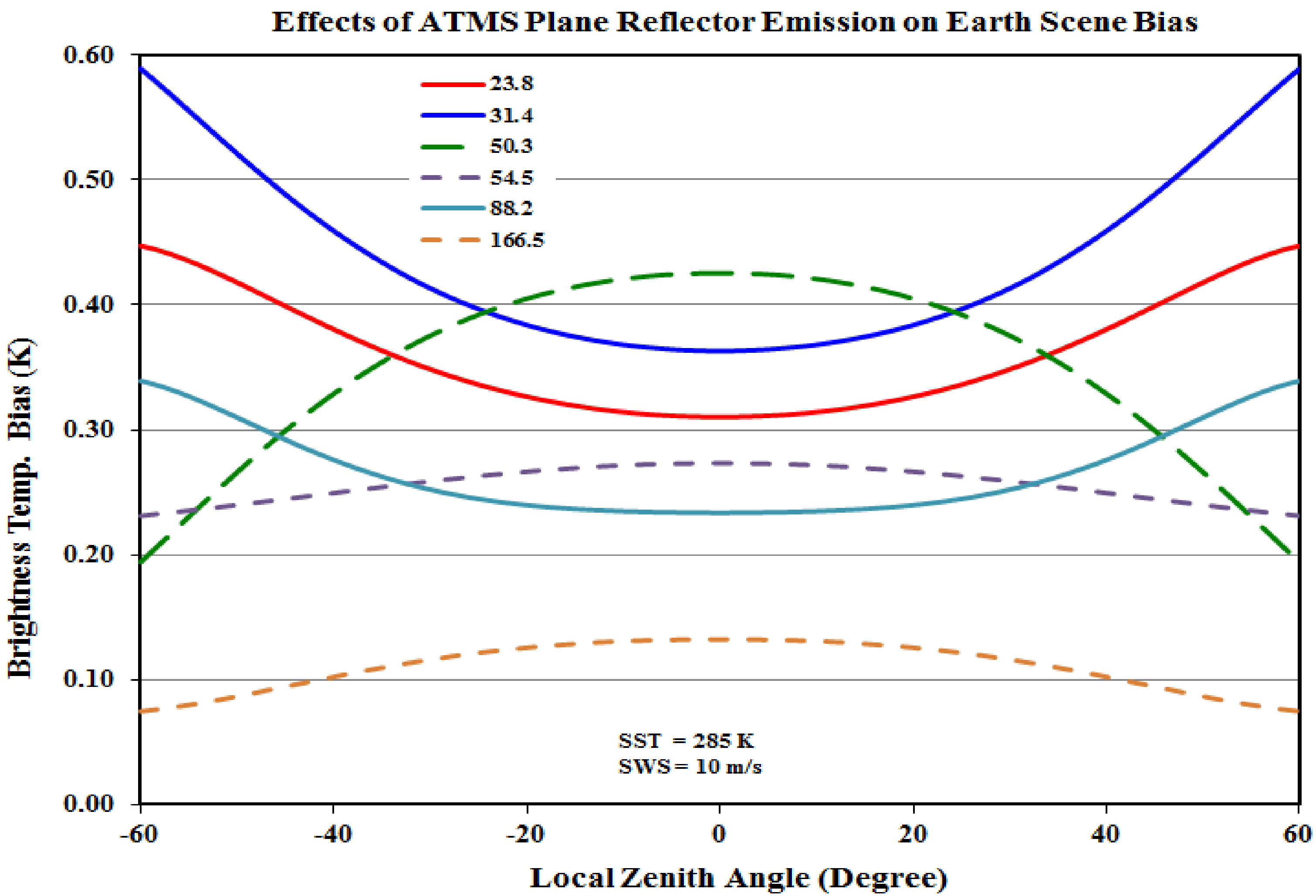
$$\varepsilon_v = 2\varepsilon_h - \varepsilon_h^2$$

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

The Reflector-Emission Bias for Space View



The Reflector-Emission Bias for Earth Scenes



ATMS Full Radiance Calibration (FRC) Tested in ADL Environment

Package:

ADL 4.2 with MX 8.8

Data Ingested:

6 orbits S-NPP RDR data (17829 – 17834 from GRAVITE) on April 7, 2015

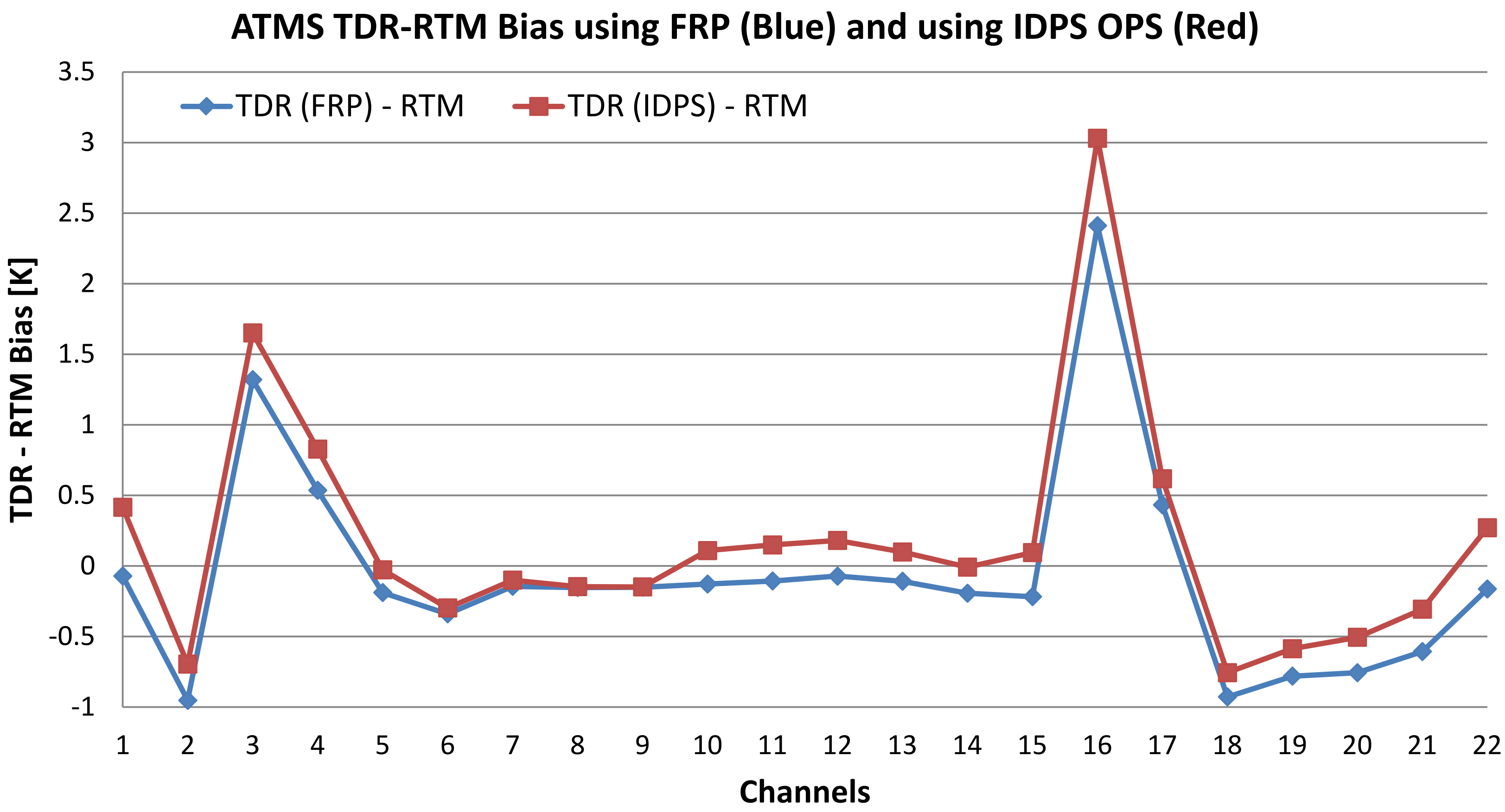
Output Data:

- TDR/SDR/GEO using full radiance calibration (FRC) algorithm

Analysis Provided:

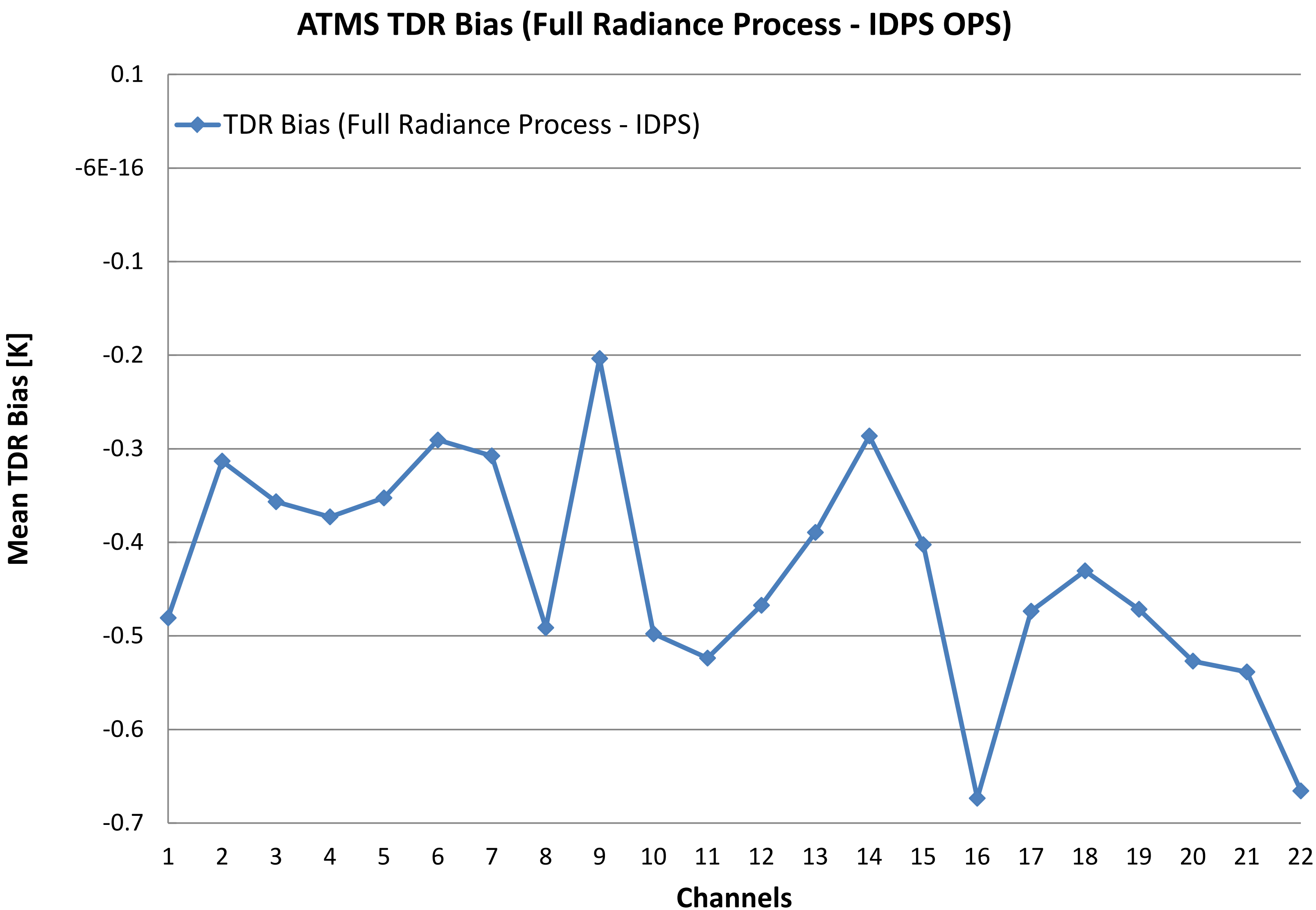
- Global mean TDR-RTM bias (ADL-FRC vs IDPS) by channels based on 6 orbits data
- Global mean TDR bias (ADL-FPC vs IDPS) by channels based on 6 orbits data

Global Mean TDR-RTM Bias



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 the rest bands are mainly affected by the nonlinearity term.

Global Mean TDR Bias



JPSS-1 ATMS SDR Algorithm Readiness

Radiance calibration algorithm

– A full radiance calibration is adopted as the standard calibration method for both the two-point linear calibration and non-linear correction

Nonlinearity correction algorithm consistent with NOAA/METOP AMSU-A/MHS

– Maximum nonlinearity was expressed as a function of μ parameter

– Nonlinear parameter was expressed as a function of instrument temperature

Reflector emissivity correction

– Physical model for antenna reflector emissivity correction

Lunar intrusion correction algorithm

– LI is modeled as a function of antenna response, solid angle of the Moon and the microwave emission from the Moon

– The new correction model with best fitted parameters from ATMS observations can effectively reduce the calibration error due to lunar contamination on cold counts

De-stripping algorithm

– Based on power spectrum analysis, stripping index and de-striping algorithm was developed to reduce the flicker noise in calibration data and TDR products

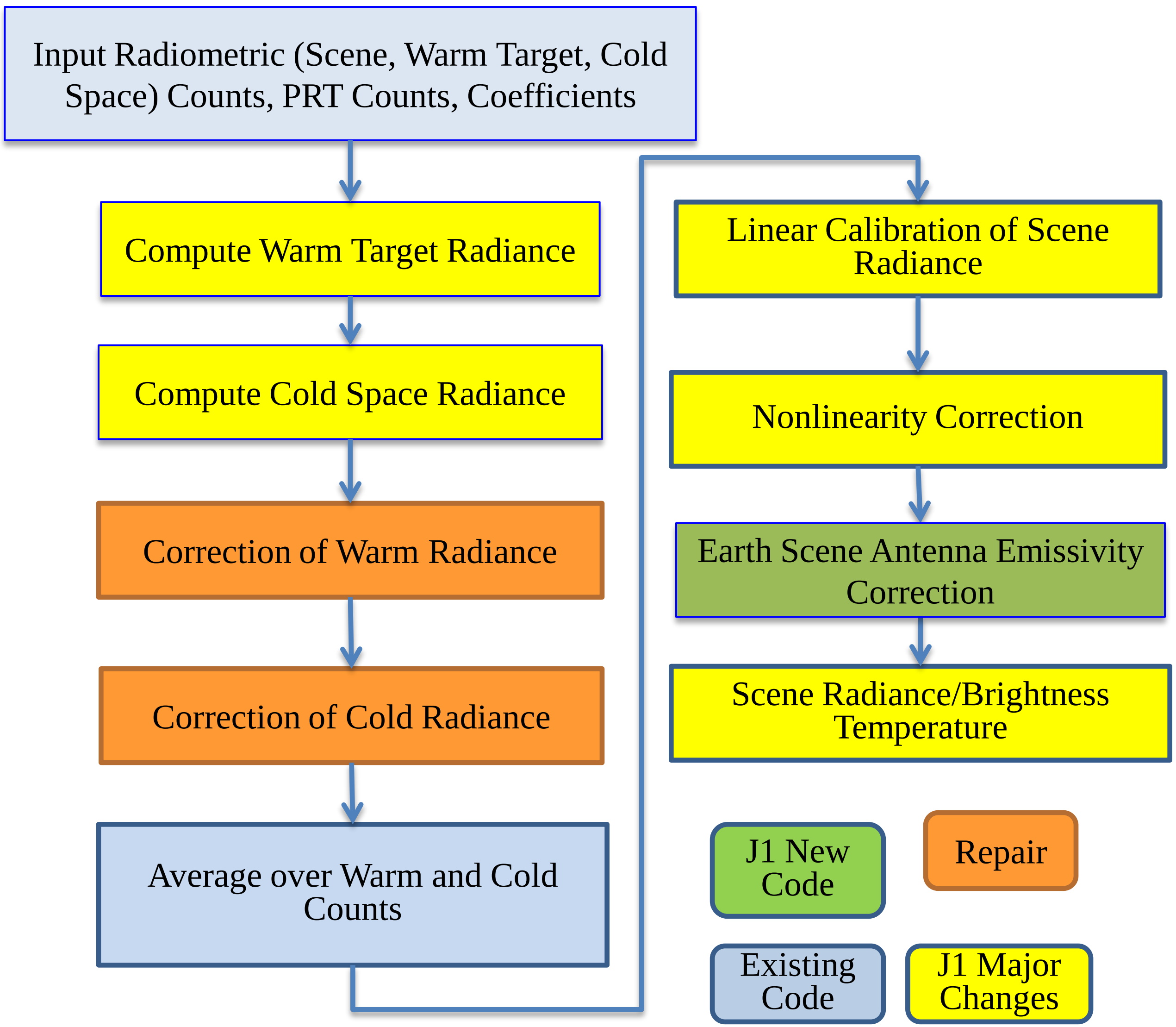
– The flicker noise and correlation on the JPSS1 ATMS is much lower than S-NPP ATMS

TDR Remapping algorithm

– B-G algorithm was developed to explore the advantage of ATMS oversampling feature

– By using B-G algorithm, remapping coefficients were generated offline, to remap ATMS observation to different FOV size

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

JPSS-1 Readiness

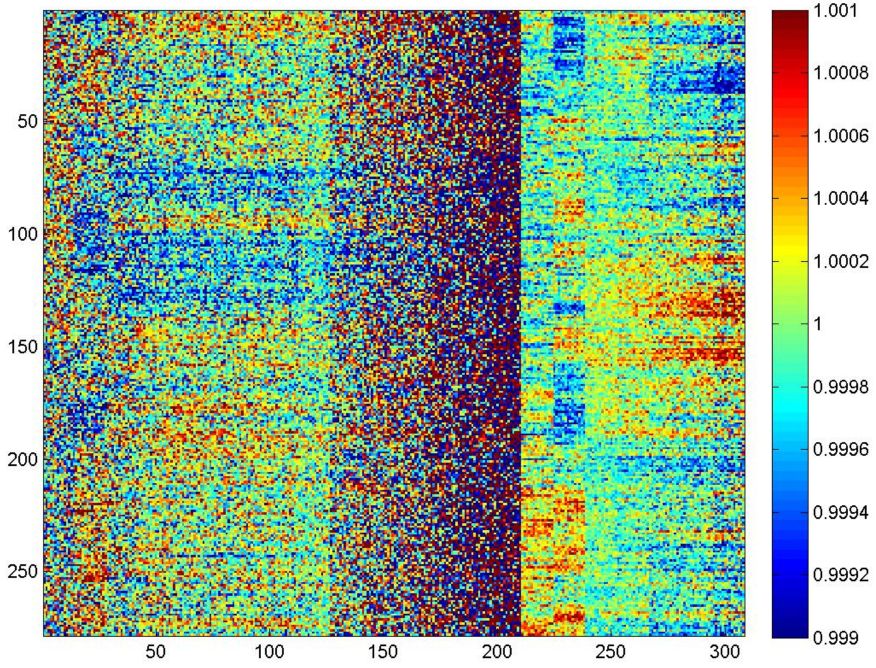
- J1 Cal/Val Overview
  - Beta Maturity: L+1 Month
  - Provisional Maturity: L+3 Months
  - Validated Maturity: L+12 Months
  - Pre-Launch Calibration/Validation Plans
    - Analyze J1 ATMS TVAC regression test data
    - Derive coefficients for SDR algorithm and deliver JPSS-1 ATMS SDR PCT
    - Test JPSS-1 proxy data for SDR algorithm functional testing
    - Use JPSS-1 proxy data (from TVAC) to verify delivered PCT
    - Analyze spectral response function datasets
    - Verify instrument mounting matrix for geolocation accuracy assessment
  - Post-Launch Calibration/Validation Plans
    - Conduct 30+ post-launch cal/val activities following JPSS ATMS Cal/Val plan

JPSS-1 ATMS SDR Algorithm Tests with Proxy Data

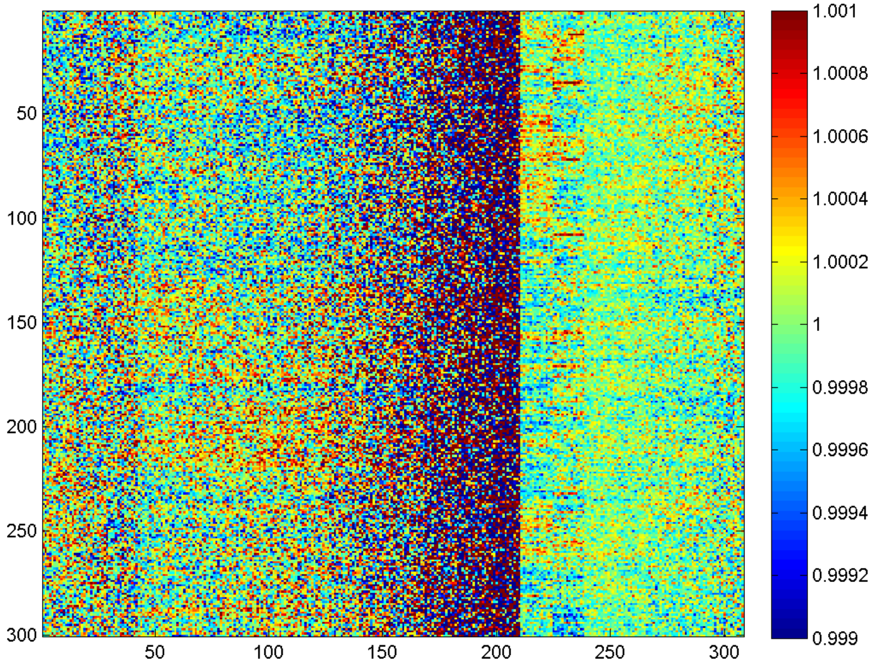
- **Proxy data**
  - JPSS-1 ATMS RDR from S-NPP mission data
  - JPSS-1 ATMS RDR from JPSS-1 ATMS TVAC data
  - JPSS-1 ATMS spacecraft level RDR
- **Test Results**
  - Test results using JPSS-1 ATMS RDR from S-NPP mission data have been compared with those from SNPP.
    - IDPS code was updated to handle JPSS-1 granule ID (J01)
    - Geolocation is not accurate. Updated data will be delivered for additional testing.
  - JPSS-1 ATMS PCT will be verified using RDR from JPSS-1 ATMS TVAC data
  - Validation system readiness:
    - The additional validation capabilities is currently being developed at STAR and will be ready well before J1 launch.

JPSS-1 ATMS TVAC Data Analysis Prior to Rework (1/2)

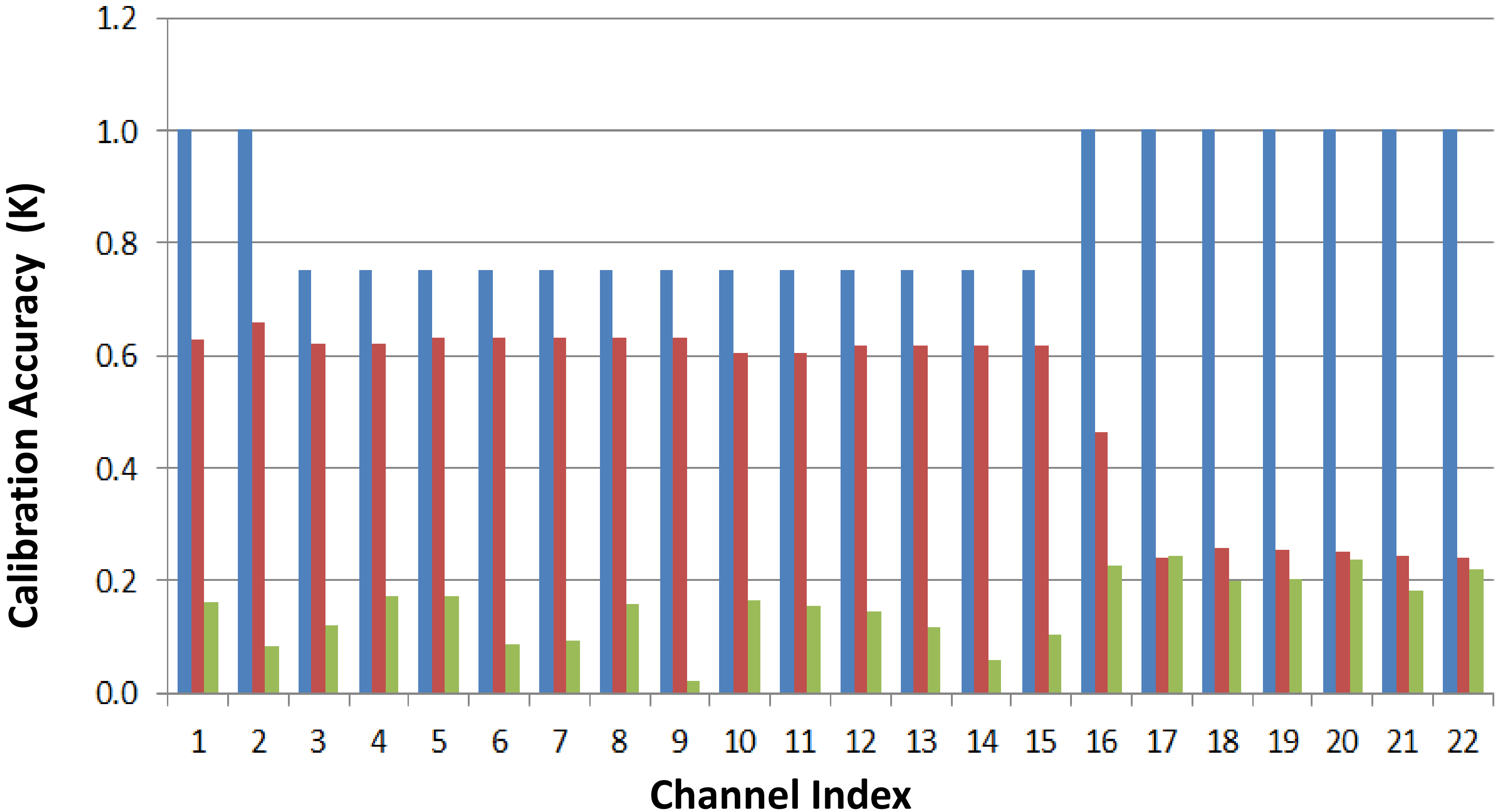
SNPP TVAC Data (RC1 230K)



J-1 TVAC Data (1/10/14)



JPSS-1 ATMS TVAC Data Analysis Prior to Rework (2/2)



Red – Calibration accuracy from nominal Thermal Vacuum (TVAC) data, Green – values obtained from the best TVAC data and Blue – specification

Summary

- JPSS-1 ATMS CalVal Plan has been developed, including task networks, role and responsibility, caval methodology, expected outcomes
- ATMS on-orbit NEDT is well characterized in new Allan deviation method. The performance meets specification
- ATMS house-keeping parameters are being monitored through ICVS to support NASA commanding operations of scan reversal.
- Antenna reflector emission is fully characterized and the algorithm for correcting the emission from the reflector is ready for implementation
- All the calval sciences are well documented and published through peer-reviewed process

Path Forward

- For Suomi NPP ATMS, we will continue refining the SDR processing system
  - Begin ATMS mission-cycle reprocessing
  - Closely monitor S-NPP ATMS health status after implementing scan drive daily reversal
  - Improve radiative transfer (RT) model for more accurate simulation of window channels and cloud radiance measurements for validation
  - Refine SDR algorithm modules, including lunar correction, antenna emission, TDR to SDR conversion at window channels, and de-striping algorithm
- For JPSS -1 ATMS, we continue supporting pre-launch testing, instrument characterization and calibration data development
  - Complete the analyze J1 ATMS TVAC regression data after rework
  - Characterize the ATMS side lobe and cross-pol from antenna pattern data
  - Study the impacts of J1 spectral response function on forward model
- For the JPSS polar follow-on mission
  - Support the waiver studies in future instruments
  - Support the new instrumentation