On-orbit Absolute Calibration of SNPP/NOAA-20 ATMS Instrument

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ATMS SDR Team
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Outline

Instrument noise characteristic

TDR calibration (Antenna Temperature Calibration)

- Calibration equation and error budget for TDR calibration
- Earth side lobe contamination correction
- Reflector emission correction
- lunar intrusion correction
- TDR calibration accuracy evaluation

SDR calibration (Antenna Pattern Correction)

- On-orbit satellite platform blockage analysis
- Side lobe approximation correction
- SDR calibration accuracy evaluation

Conclusions

ATMS Instrument Noise Characteristic

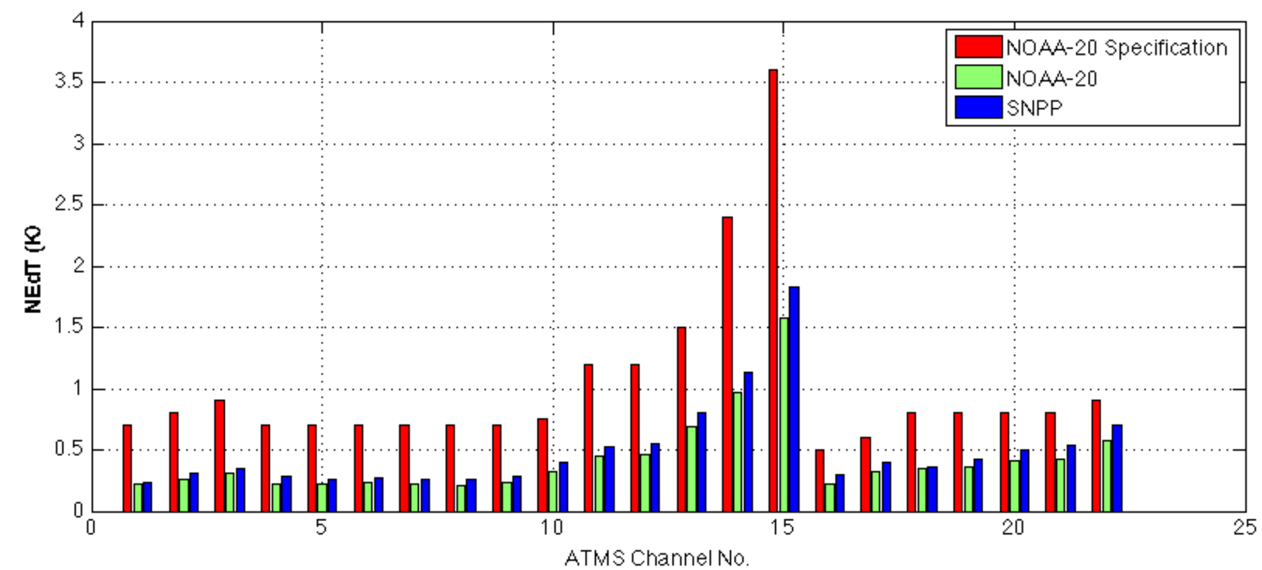
- ATMS has a 18ms integration time compared to 162ms integration time of AMSU. Channel NEdT in original observations is no larger than 0.5K for most of detection channels, except for channel 13~15, which were designed with very narrow band width

- Channel noise feature in N20 and SNPP is consistent

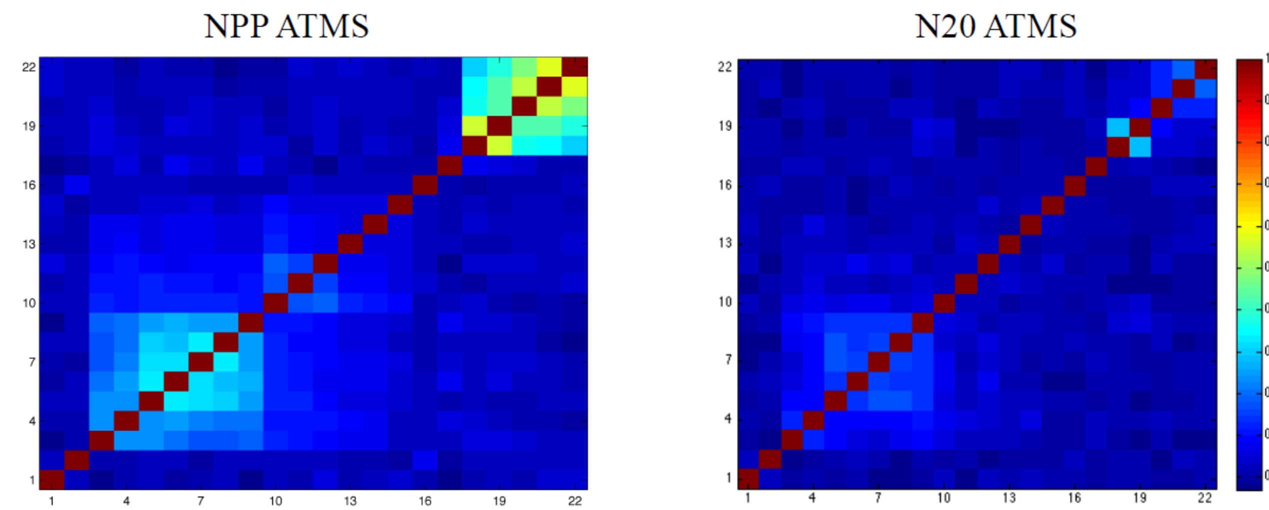
- N20 has significant improvement on channel correlation noise, with a much lower channel correlation compare to SNPP

- Striping noise is observed in both N20 and SNPP, root cause is pink noise in receiver outputs. Striping noise was reduced in N20, especially in G band
- There is potential to further reduce ATMS channels noise by using remapping algorithm

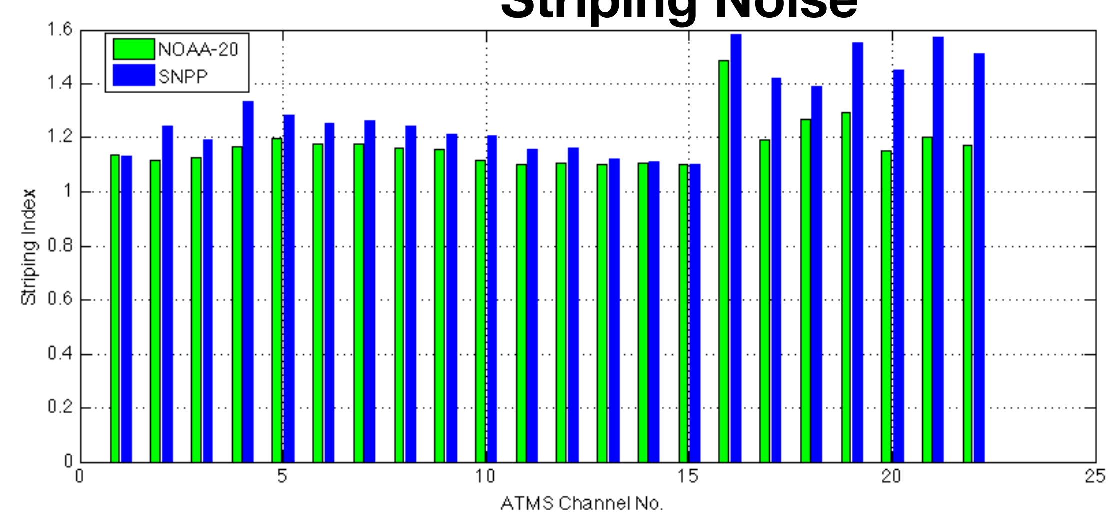
NEdT



Noise Correlation



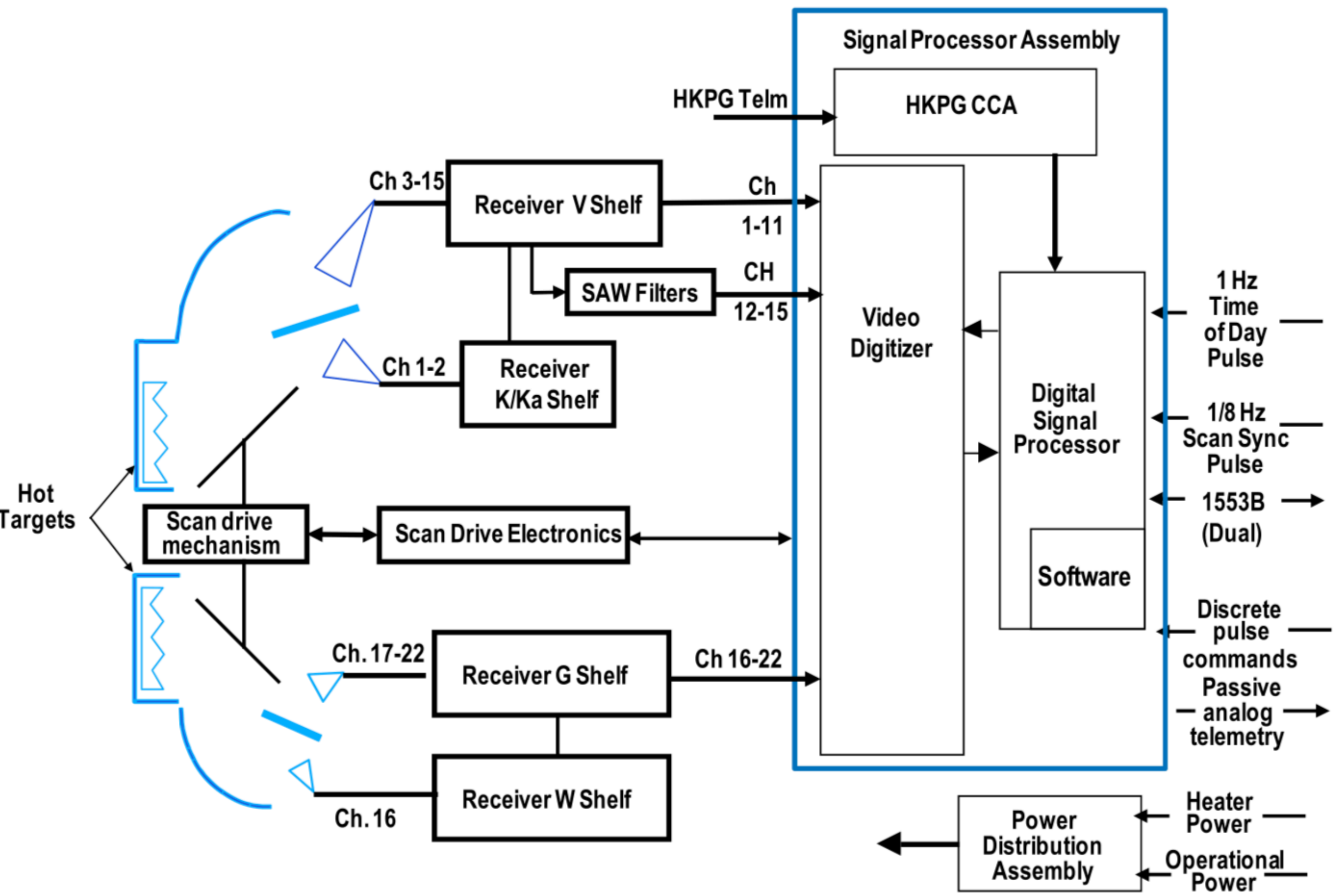
Striping Noise



ATMS Instrument Description

Edward Kim Cheng−Hsuan J. Lyu Kent Anderson R. Vincent Leslie William J. Blackwell, 2014, "S−NPP ATMS instrument prelaunch and on−orbit performance evaluation"JGR, 2014 https://doi.org/10.1002/2013JD020483

Simplified ATMS Block Diagram
(Ed Kim et al., JGR 2014)



ATMS Spectrometric and Radiometric Specification

Ch	RF path: Ant	Feed	Rcvr	Center frequency [MHz]: Value	Stab	Bandwidth [MHz]: Req	True	NEDT [K] Req	Pol	Beamwidth [°] Req
1	A	1	a	23800	<10	<270	1x270	0.5	V	5.2
2	A	1	b	31400	<10	<180	1x180	0.6	V	5.2
3	A	2	c	50300	<10	<180	1x180	0.7	H	2.2
4	A	2	c	51760	< 5	<400	1x400	0.5	H	2.2
5	A	2	c	52800	< 5	<400	1x400	0.5	H	2.2
6	A	2	c	53596±115	< 5	170	2x170	0.5	H	2.2
7	A	2	c	54400	< 5	400	1x400	0.5	H	2.2
8	A	2	c	54940	<10	400	1x400	0.5	H	2.2
9	A	2	c	55500	<10	330	1x330	0.5	H	2.2
10	A	2	d_1	57290.344 [f_0]	<0.5	330	2x155	0.75	H	2.2
11	A	2	d_1	f_0±217	<0.5	78	2x 78	1.0	H	2.2
12	A	2	d_2	f_0±322.2±48	<1.2	36	4x 36	1.0	H	2.2
13	A	2	d_2	f_0±322.±22	<1.6	16	4x 16	1.5	H	2.2
14	A	2	d_2	f_0±322.±10	<0.5	8	4x 8	2.2	H	2.2
15	A	2	d_2	f_0±322.±4.5	<0.5	3	4x 3	3.6	H	2.2
16	B	3	e	88200	<200	2000	1x2000	0.3	V	2.2
17	B	4	f	165500	<200	3000	2x1150	0.6	H	1.1
18	B	4	g	183310±7000	<30	2000	2x2000	0.8	H	1.1
19	B	4	g	183310±4500	<30	2000	2x2000	0.8	H	1.1
20	B	4	g	183310±3000	<30	1000	2x1000	0.8	H	1.1
21	B	4	g	183310±1800	<30	1000	2x1000	0.8	H	1.1
22	B	4	g	183310±1000	<30	500	2x 500	0.9	H	1.1

ATMS Instrument Calibration Error Budget Analysis

Weng, F. and Yang, H., 2016. Validation of ATMS calibration accuracy using Suomi NPP pitch maneuver observations. Remote Sensing, 8(4), p.332

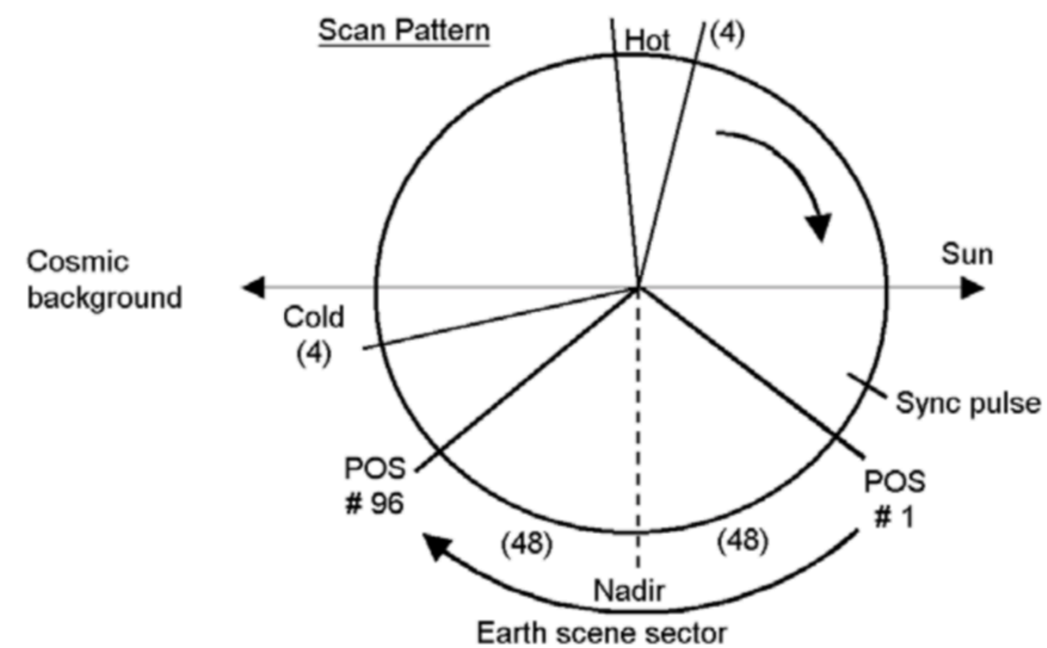
The ATMS radiometric calibration for antenna brightness temperature is derived as

$$R = R_c + (R_w - R_c)\left(\frac{C_s - \overline{C_c}}{\overline{C_w} - \overline{C_c}}\right) + Q$$

Considering the system noise and gain drift errors, the error model for ATMS calibration can be derived as:

$$\Delta R = x\Delta R_w + (1-x)\Delta R_c + 4Q^{\max}(x - x^2) \pm RMSError$$

ATMS Scan Geometry



ΔR_w Error in determine warm target radiance

ΔR_c Error in determine cold target radiance

$Q^{\max}$ Maximum nonlinearity

$RMSError$ System noise and gain drift errors

Major Pre-launch and On-orbit Tests for Instrument Calibration

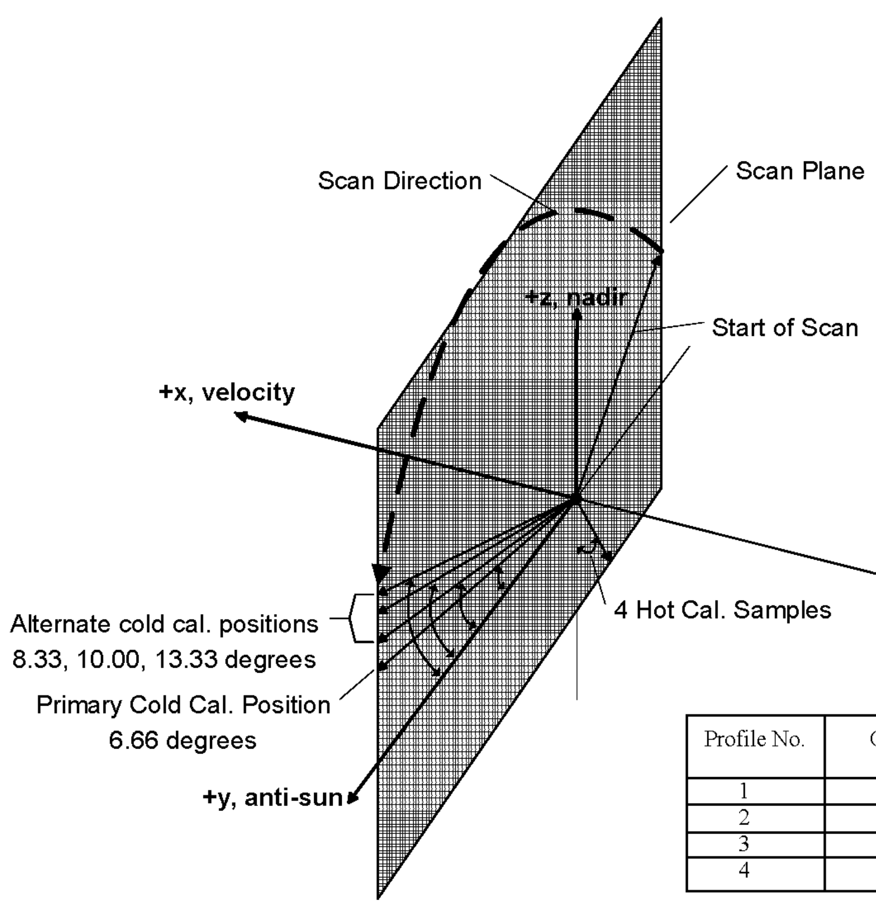
- **Pre-launch cal/val tests**
  - Antenna pattern measurements
  - SRF tests (data available at https://www.star.nesdis.noaa.gov)
  - TVAC tests for nonlinearity determination

- **On-orbit cal/val tests**
  - Roll maneuver to determine side lobe contamination
  - Pitch maneuver to determine reflector emissivity, investigate possible RFI and stripping noise etc.
  - Environment test to determine space platform blockage and near filed radiation
  - Scan profile switch test to determine optimal cold space scan profile
  - Lunar intrusion tests to evaluate LI correction algorithm

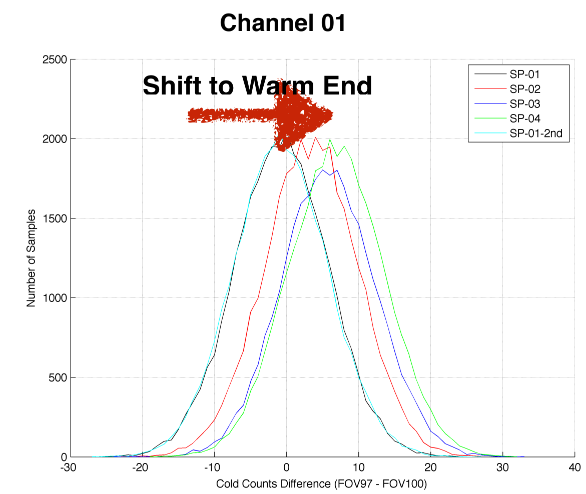
Scan Profile Switch Test

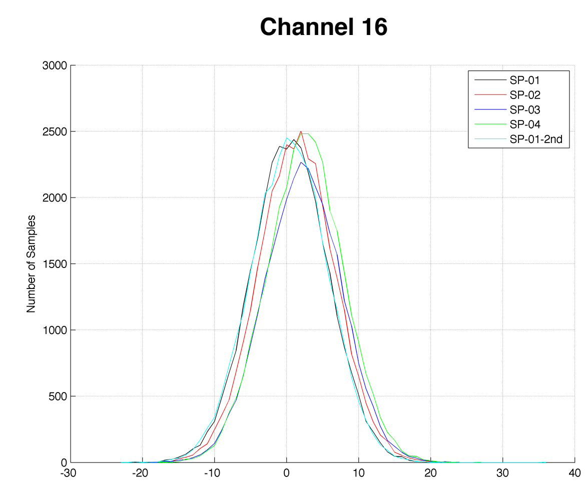
- Three space view profile switch carried out on 12/02, 12/05 and 12/08
- With SP switch from 1 to 4, space view scan position shift from spacecraft side to the Earth side
- Impact of Earth side lobe contamination are studied from data collected from different SP profile

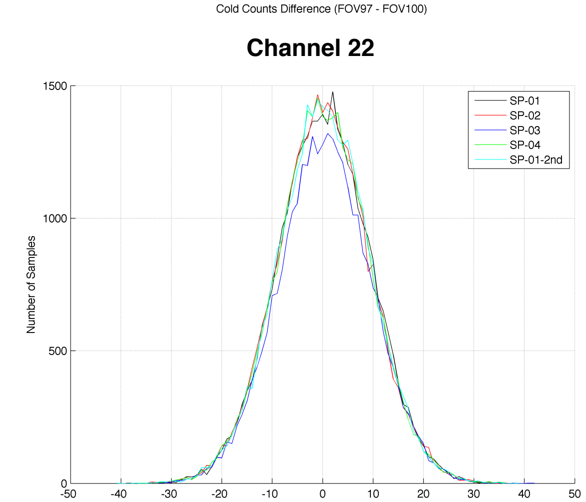
	SP1	SP2	SP3	SP4
FOV-97	81.6639	79.9894	78.3331	74.9843
FOV-98	82.7899	81.1175	79.4491	76.1161
FOV-99	83.9058	82.2330	80.5650	77.2338
FOV-100	85.0134	83.3450	81.6737	78.3457



Profile No.	Cold Cal Angle
1	6.66°
2	8.33°
3	10.00°
4	13.33°



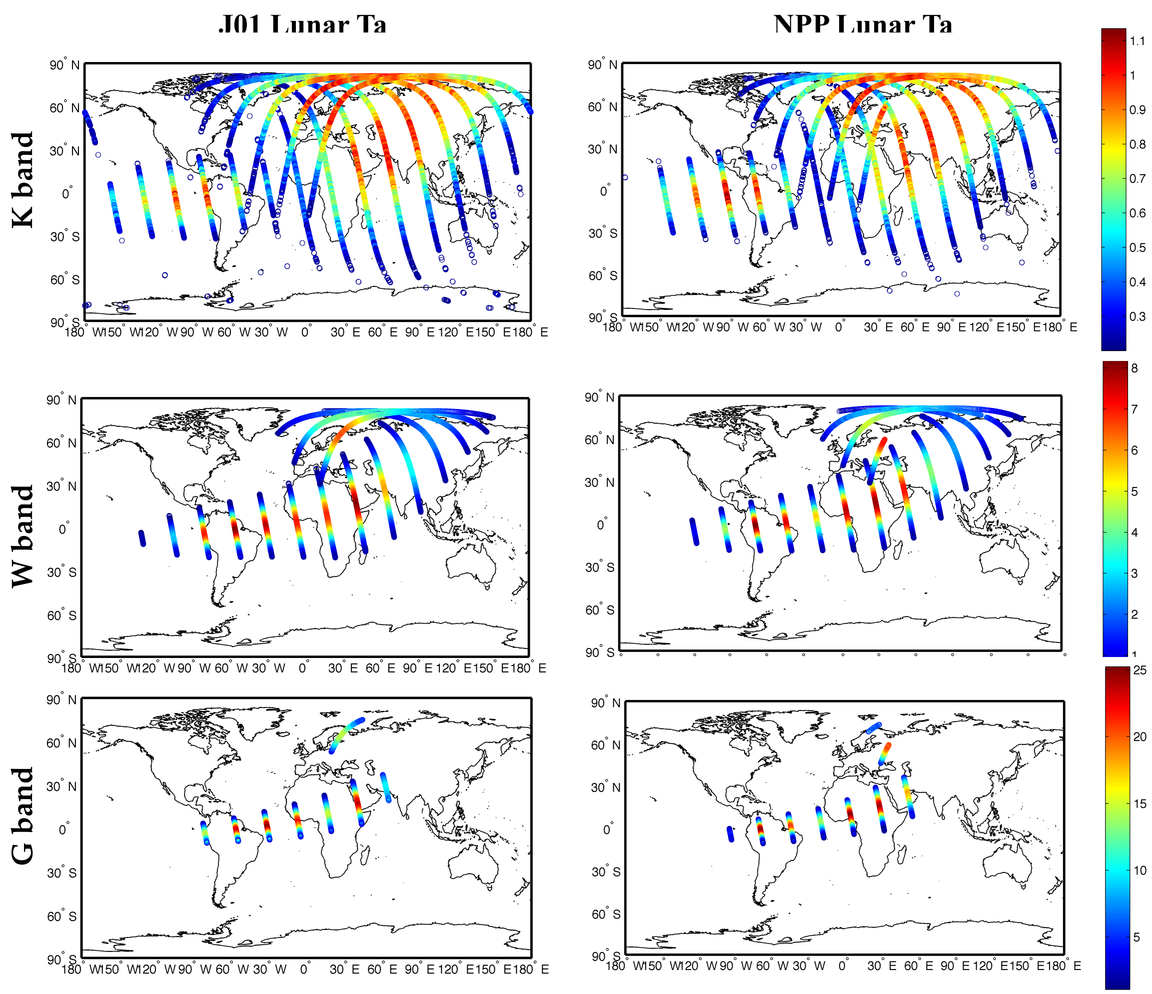


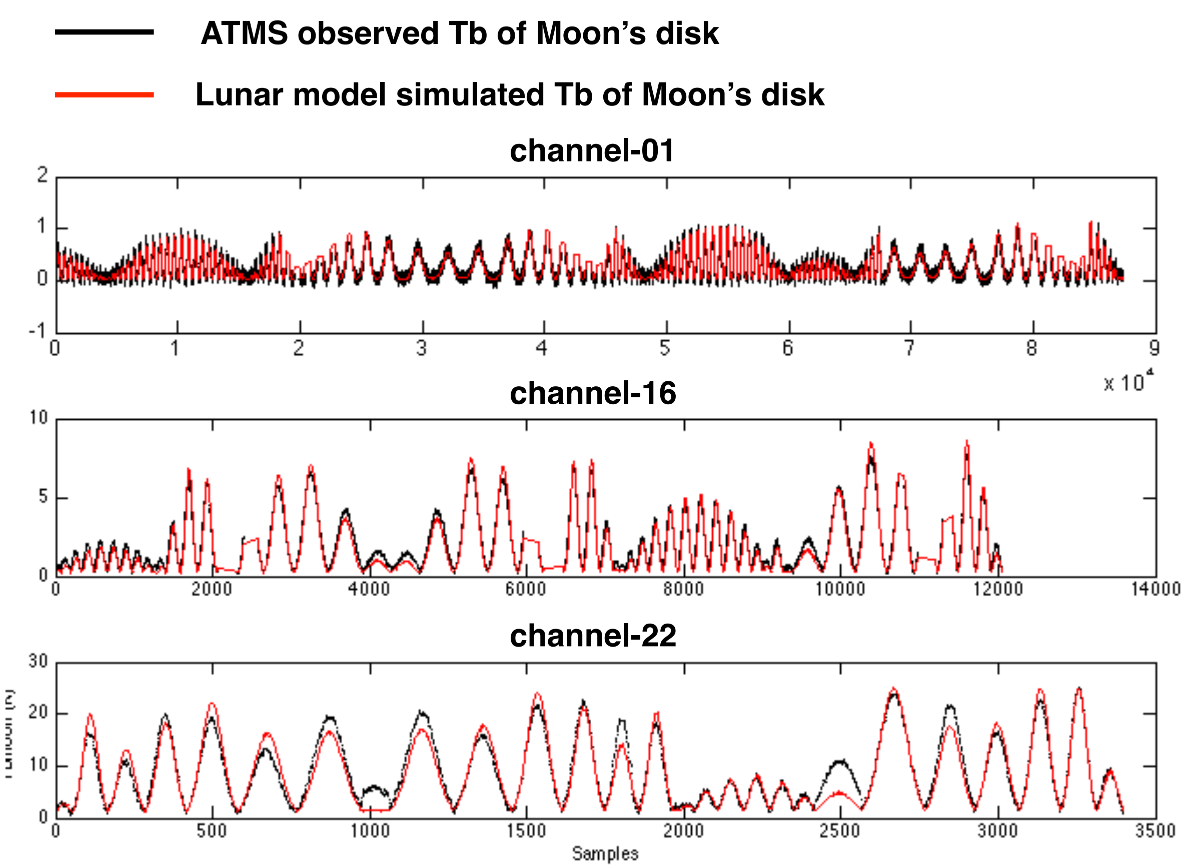


Lunar Intrusion Mitigation Test

Hu Yang and Fuzhong Weng, 2016, "On-Orbit ATMS Lunar Contamination Corrections", IEEE Transactions on Geoscience and Remote Sensing, Vol. 54 Issue: 4, page(s): 1-7

- Lunar observations from ATMS instrument from January 2012 to January 2017 are calibrated and compared with the model simulations
- Lunar model performance is reliable and can be used for LI mitigation in TDR calibration



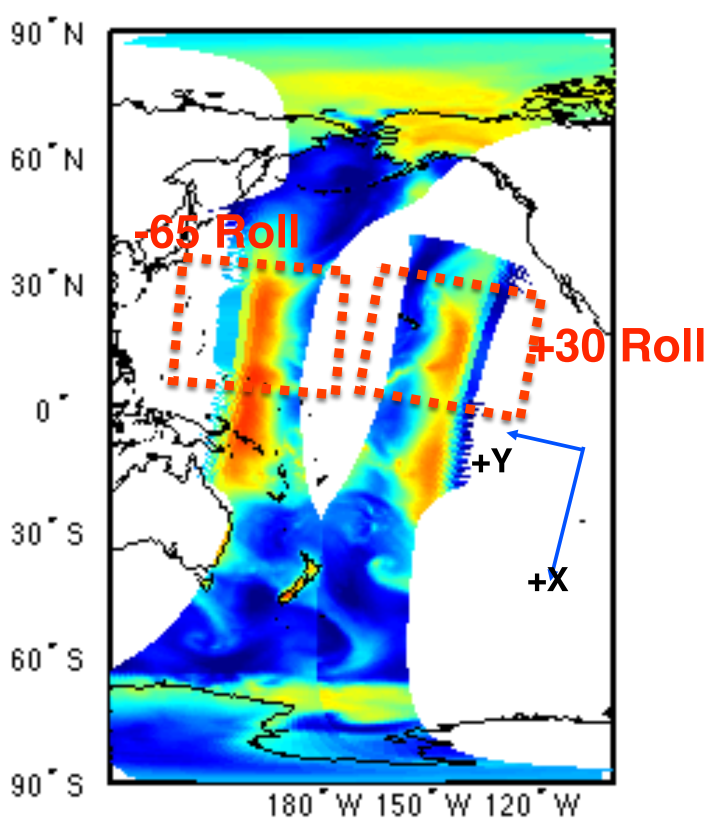


Roll Maneuver Test for Earth Side Lobe Contamination Correction

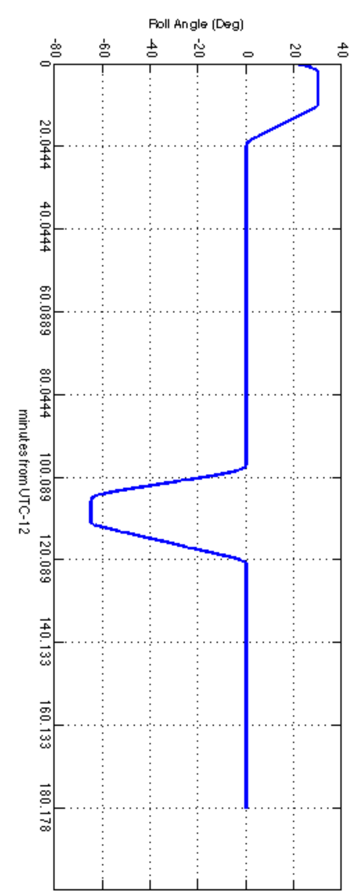
Earth side lobe for space view has been well characterized from roll maneuver data. Impacts of Earth side lobe for space view are around 0.2% for space view profile 1, lower than predicted from ground measured antenna pattern and are slightly depend on beam width

Roll Maneuver on 12/15,2017

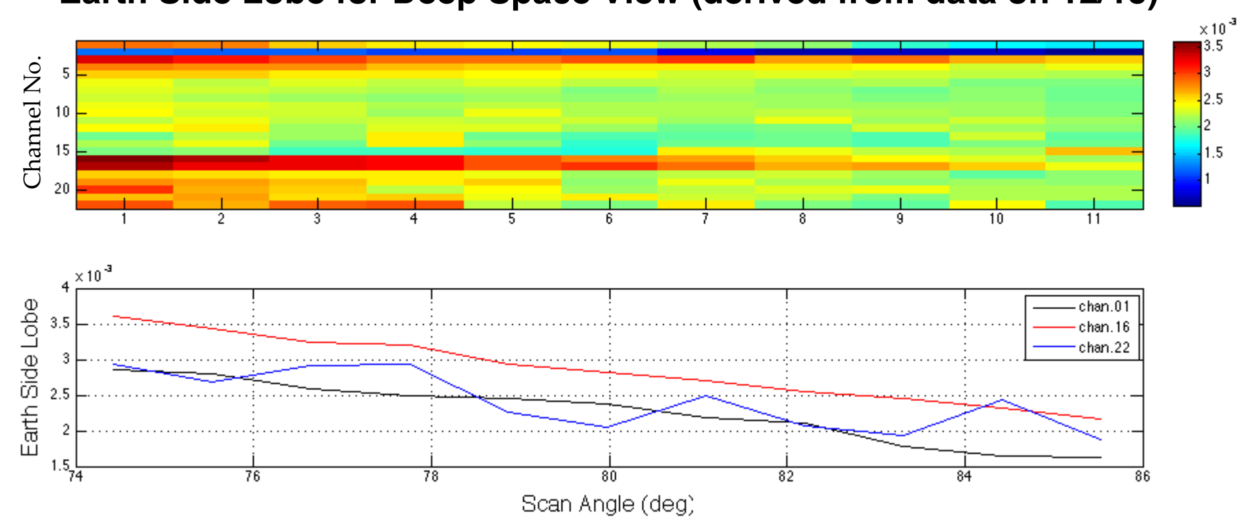
Channel-01 Ta



Satellite Attitude

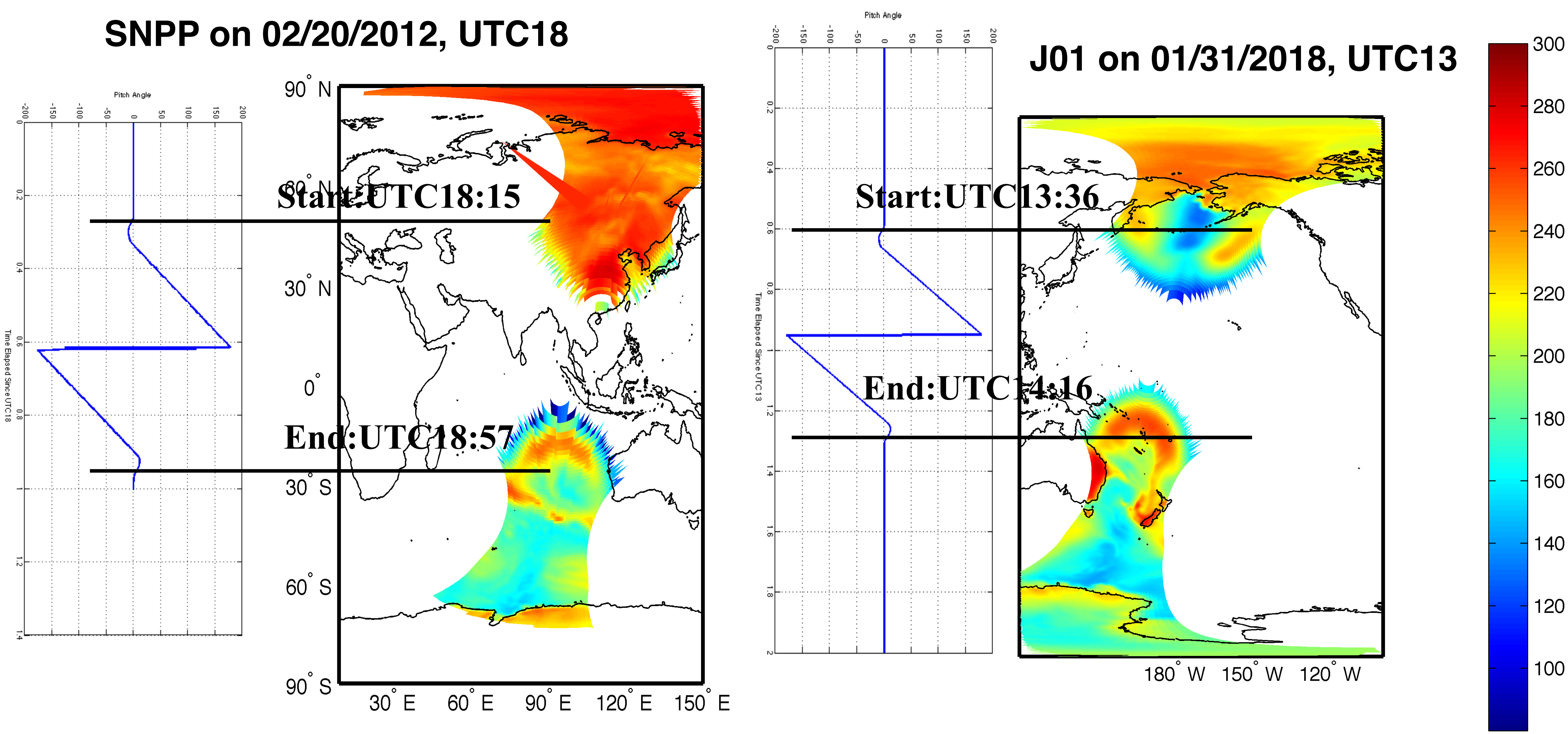


Earth Side Lobe for Deep Space View (derived from data on 12/15)



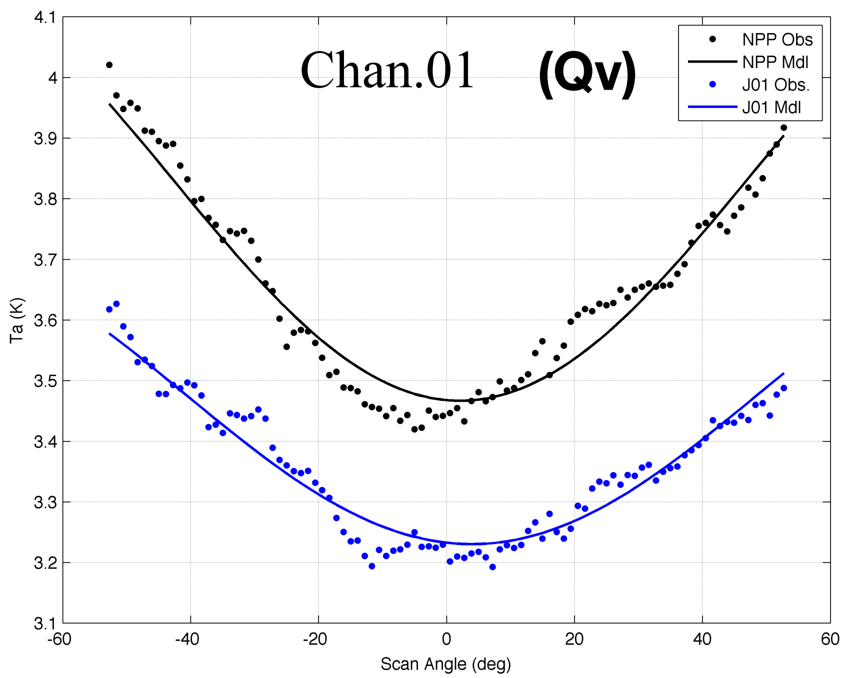
NPP/J01 Pitch Maneuver Operation

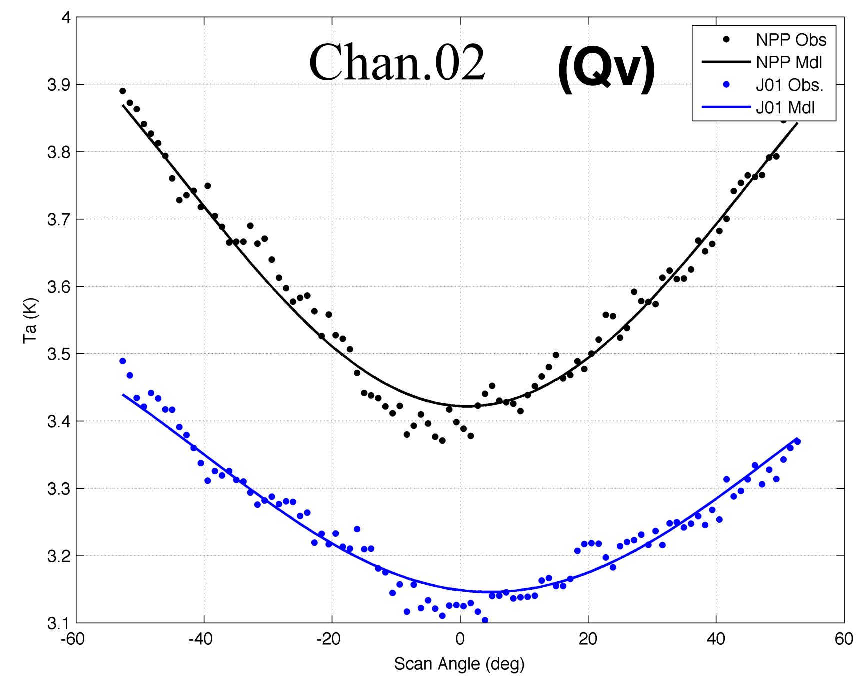
- Pitch maneuver operation is successful and the ATMS observation sample and data quality being collected during the test is good enough to perform antenna reflector emission evaluation

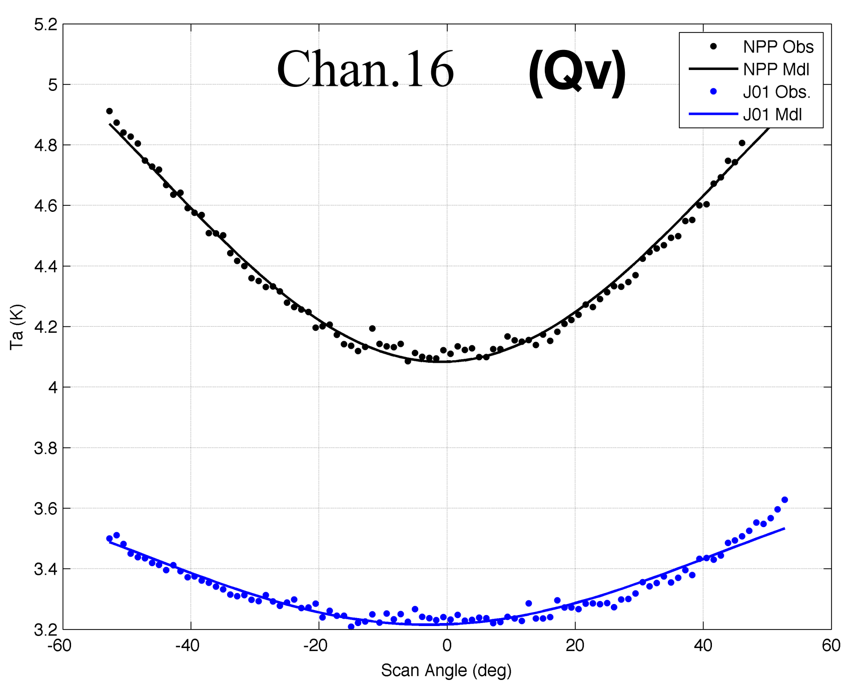


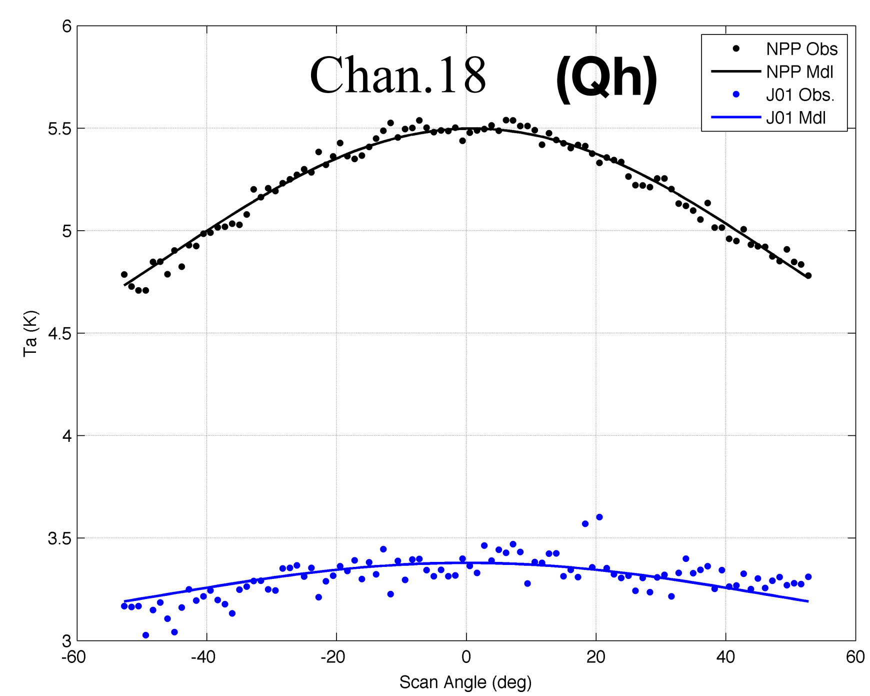
SNPP/J01 Deep Space Scan Brightness Temperature

- J01 ATMS QV channel Ta has ‘smile’ shape scan dependent feature, which is consistent with SNPP but with smaller magnitude
- J01 ATMS QH channel Ta has very minor ‘frown’ shape scan dependent feature compare to SNPP







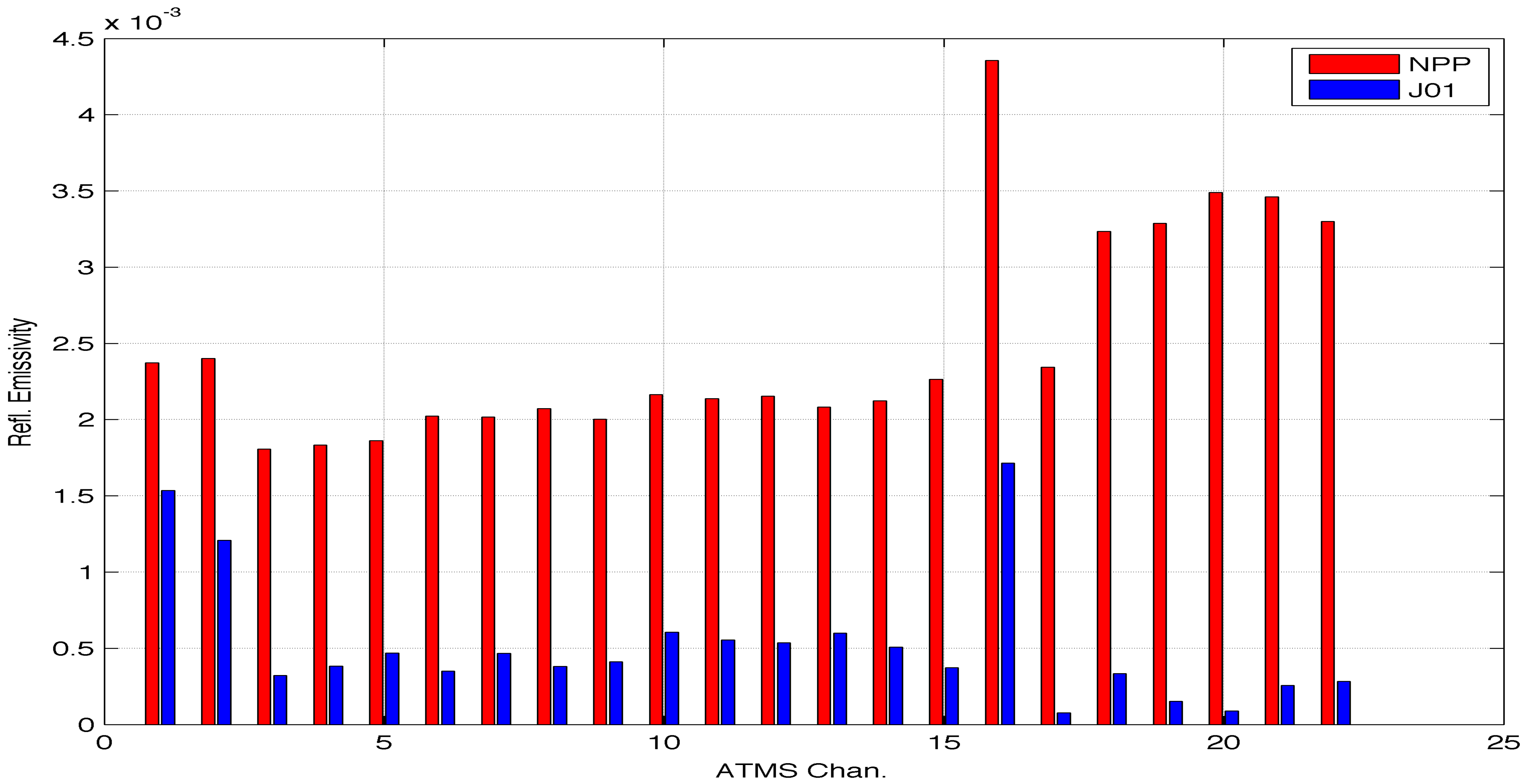


Reflector Emissivity Retrieval from Pitch Maneuver Datasets

- Earth Side Lobe contamination in cold calibration counts need to be corrected
- Pixels with potential spacecraft contamination need to be removed
- J01 ATMS reflector emissivity can be retrieved from pitch data by using the same algorithm developed in SNPP era
- Results show that the J01 ATMS reflector has much low emission than SNPP

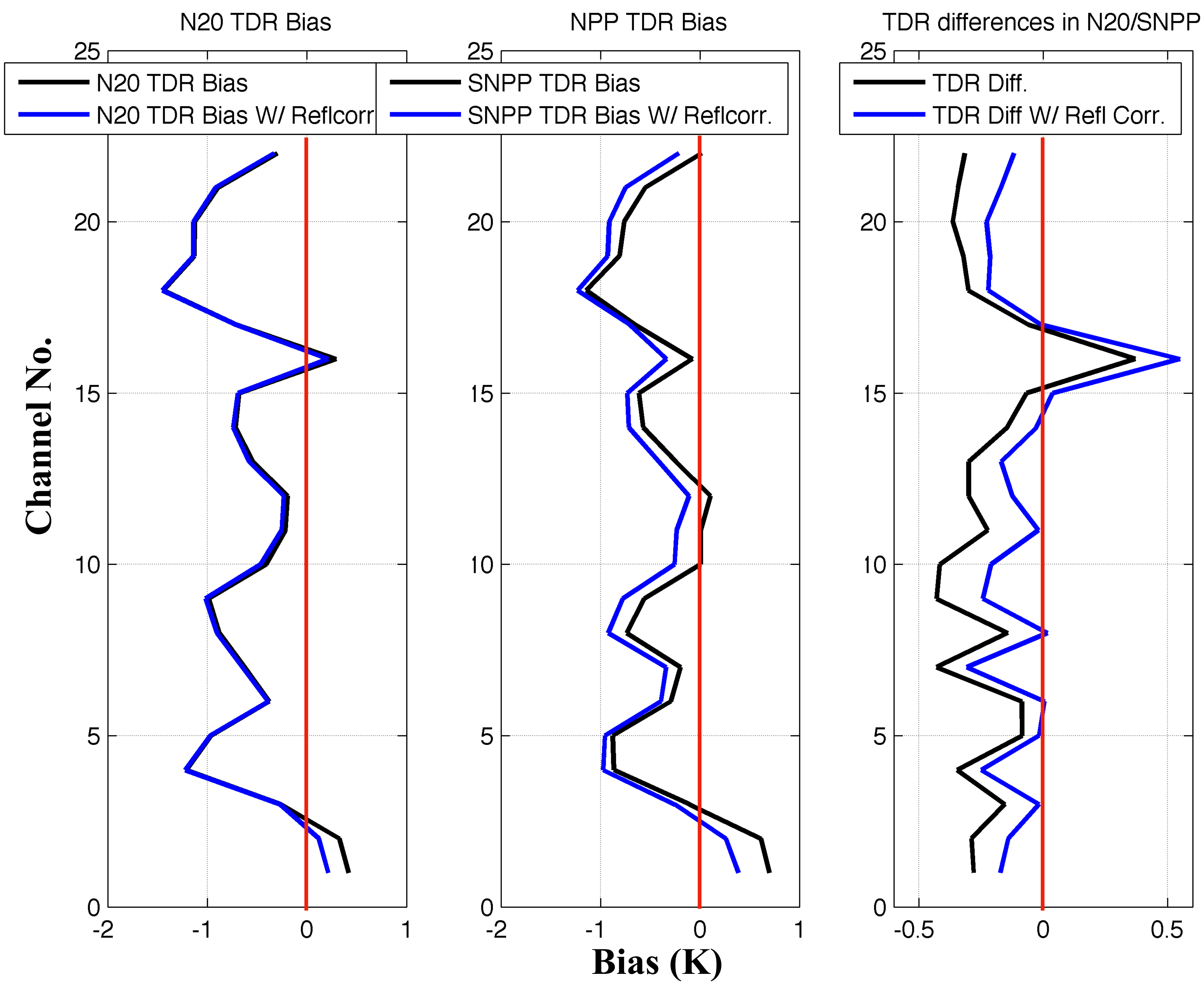
Yang, H., Weng, F. and Anderson, K., 2016. Estimation of ATMS antenna emission from cold space observations. IEEE Transactions on Geoscience and Remote Sensing, 54(8), pp.4479-4487.

$$\varepsilon_h = \frac{\delta(R_w - R_c)}{\delta\left[(R_w - R_{\mathrm{rfl}})\sin^2\theta_w - (R_c - R_{\mathrm{rfl}})\sin^2\theta_c\right] - (R_c - R_{\mathrm{rfl}})(\sin^2\theta_s - \sin^2\theta_c)}. \tag{13a}$$



N20/SNPP TDR Channel Average Bias after Reflector Emission Correction

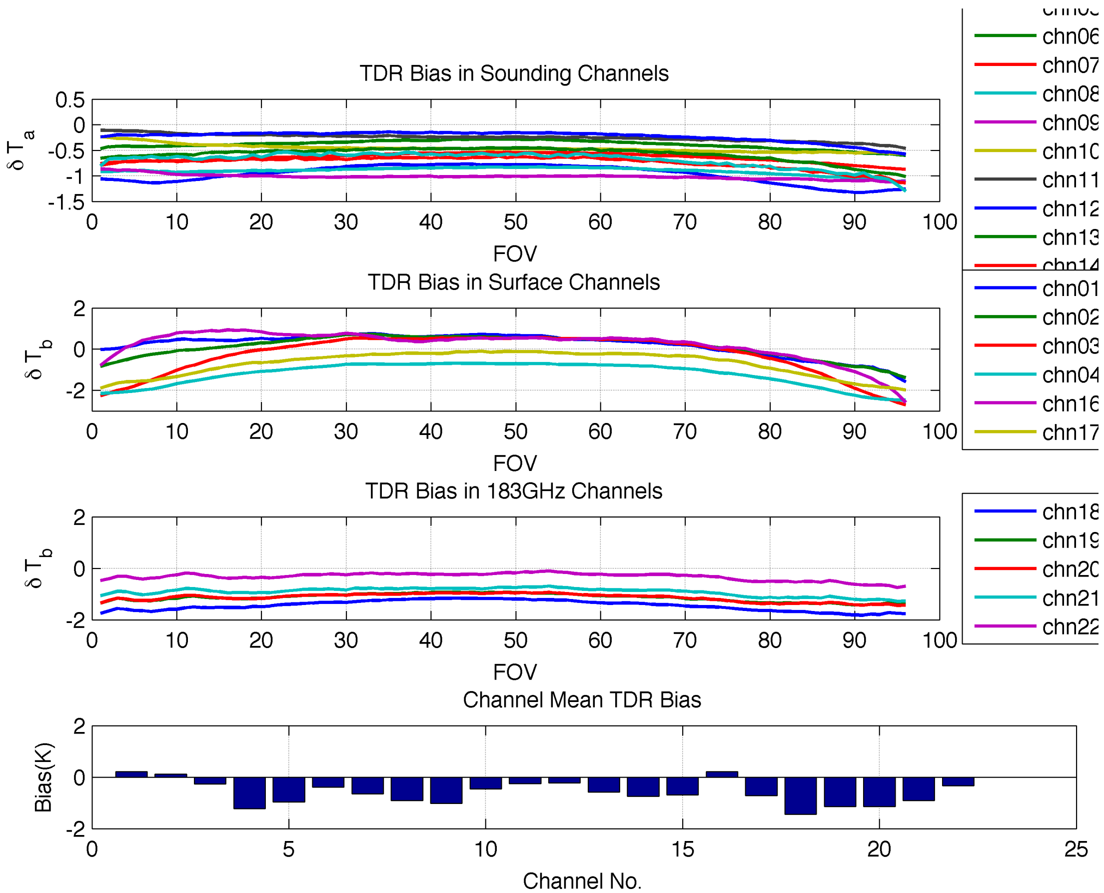
- Channel mean bias in N20/SNPP become more consistent after reflector emission correction
- Bias difference between N20 and SNPP from any further corrections should be no larger than bias difference in reflector emission corrected TDRs



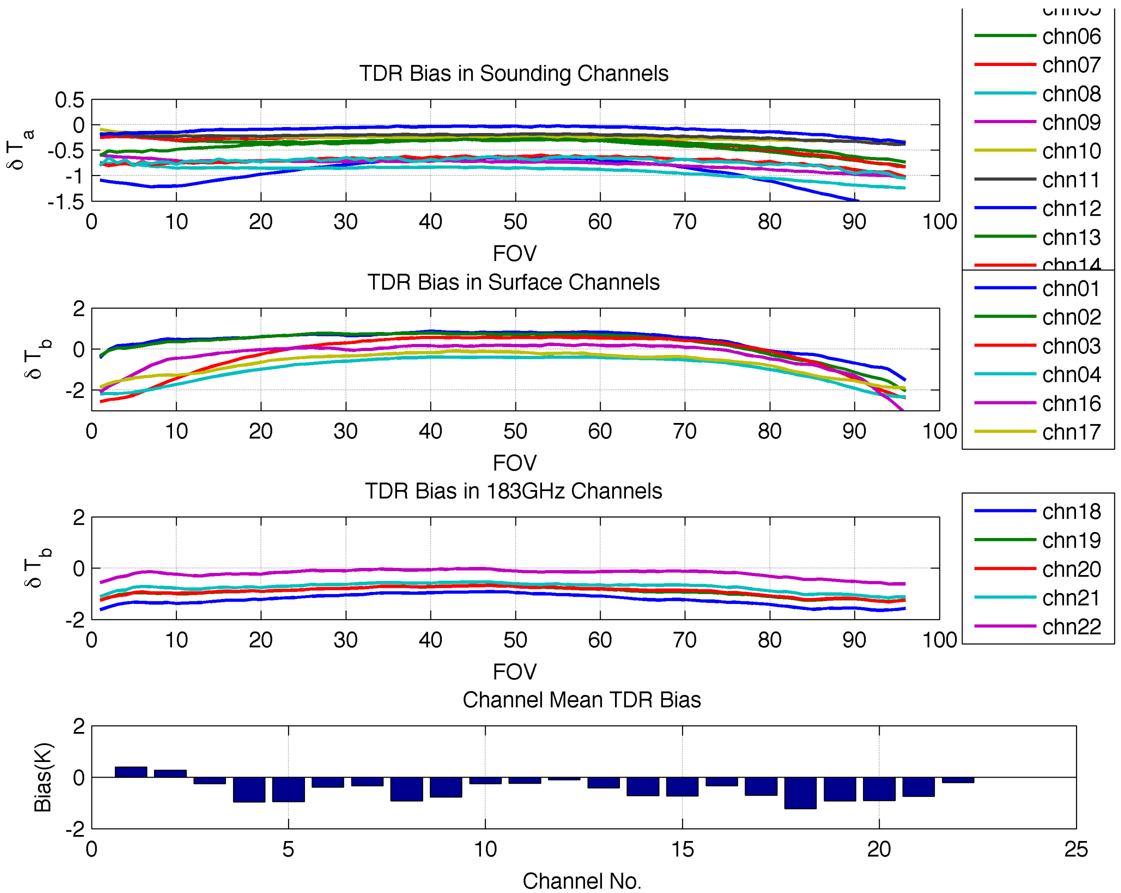
TDR Calibration Accuracy Evaluation

- More consistent scan dependent feature in N20/SNPP were observed after reflector emission correction
- No positive biases were observed in TDRs for both N20 and SNPP means reflector emission has been corrected

N20

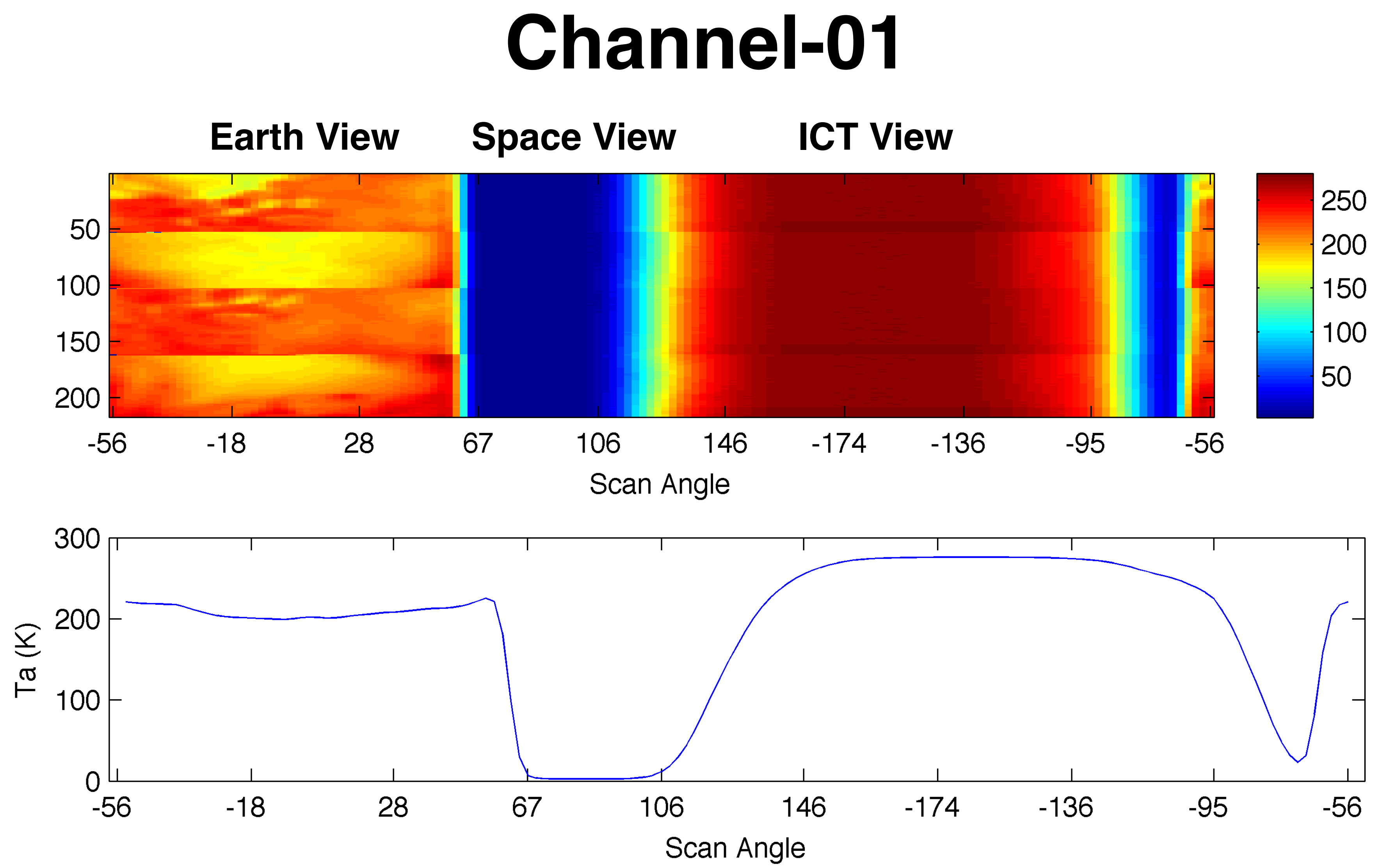


SNPP

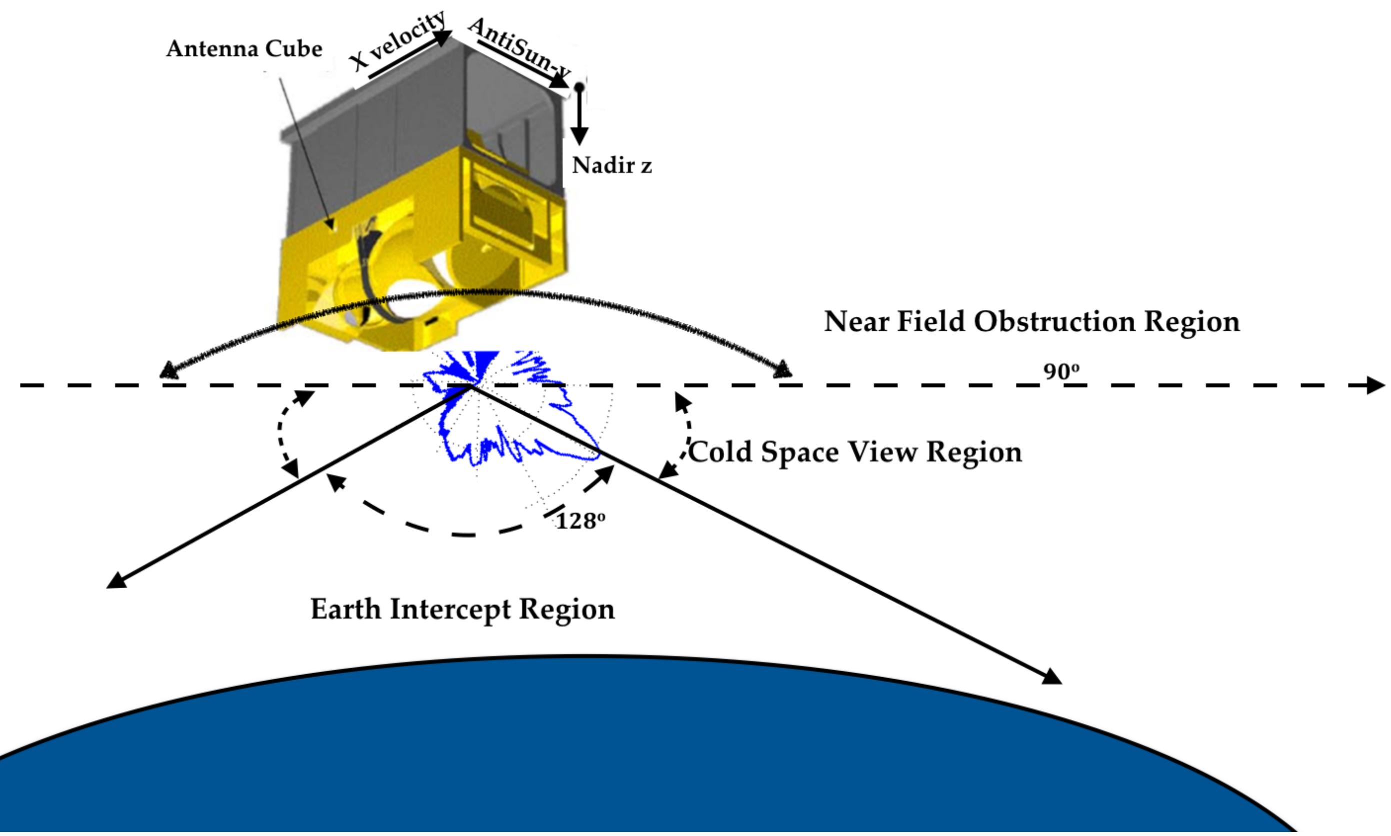


Environment Test for Satellite Blockage Analysis

- 148 samples are collected during one scan with scan rate of 0.135 deg/ms
- Antenna temperature is derived from regular calibration process with nonlinearity included
- Asymmetry obstruction feature was observed from the data: more spacecraft obstructions in -Y direction than +Y direction
- Less obstruction in narrow beam width bands



SDR Algorithm Description



Antenna temperature Ta includes radiation from both far-field and near-field radiation sources

$$
\begin{aligned}
Ta^{Qp} = &\int_0^{2\pi}\int_{esv} G_{pp}(\theta,\phi)\cdot T_b^{pp}(\theta,\phi)d\theta d\phi \\
&+\int_0^{2\pi}\int_{esv} G_{pq}(\theta,\phi)\cdot T_b^{pq}(\theta,\phi)d\theta d\phi \\
&+Tc\cdot\int_0^{2\pi}\int_{spc}[G_{pp}(\theta,\phi)+G_{pq}(\theta,\phi)]d\theta d\phi \\
&+Sa
\end{aligned}
$$

Normalization of Gpp and Gpq by using Total gain of antenna pattern:

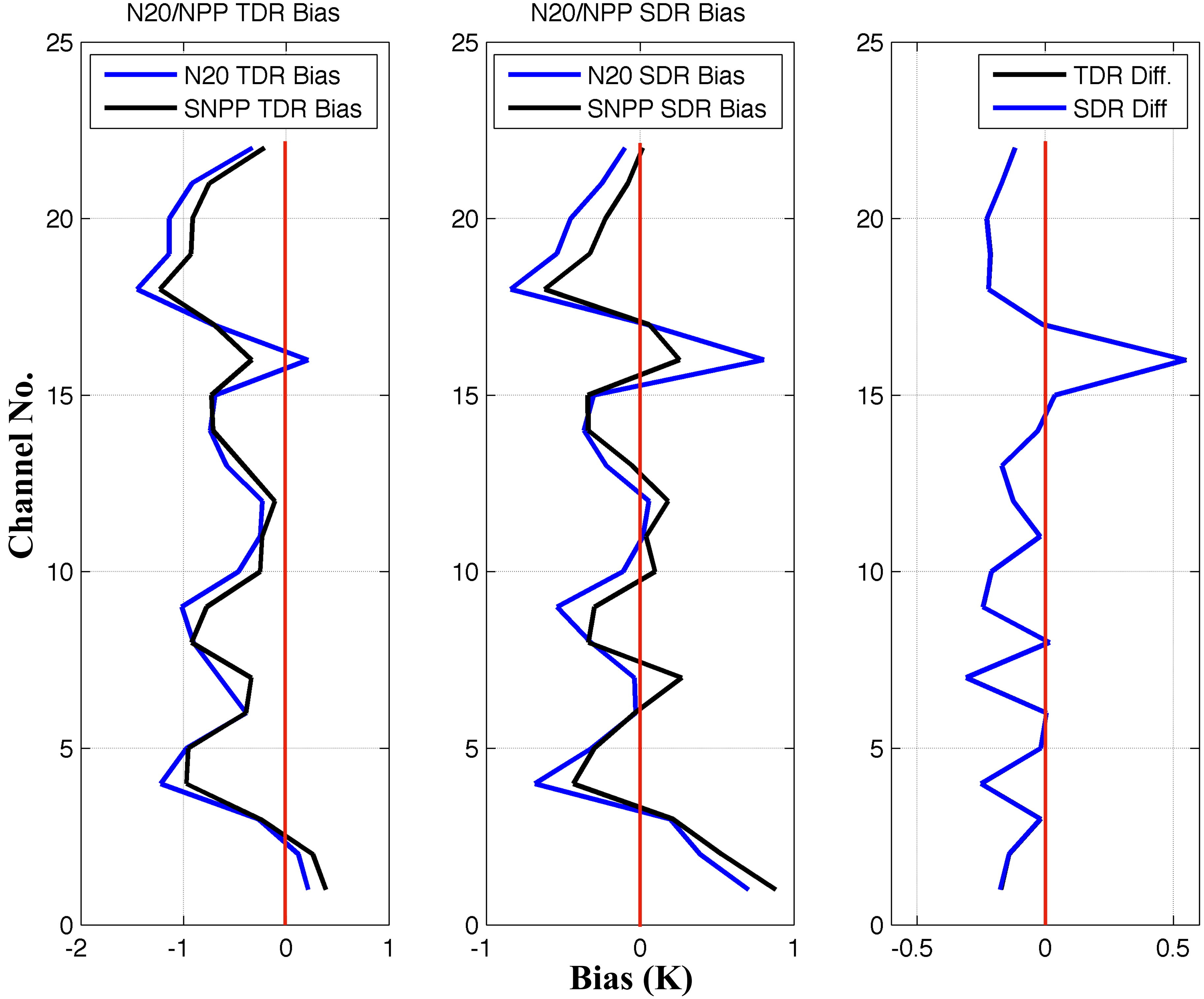
$$G_{total}(\beta) = \int_0^{2\pi}\int_{esc}[G_{pp}(\theta,\phi)+G_{pq}(\theta,\phi)]d\theta d\phi + \int_0^{2\pi}\int_{spc}[G_{pp}(\theta,\phi)+G_{pq}(\theta,\phi)]d\theta d\phi$$

Antenna Pattern Correction Model

$$T_b^{pp} = \frac{Ta^{'} - \eta_c\cdot T_c}{\eta_{pp}+\eta_{pq}}$$

Channel Average Bias in SDR

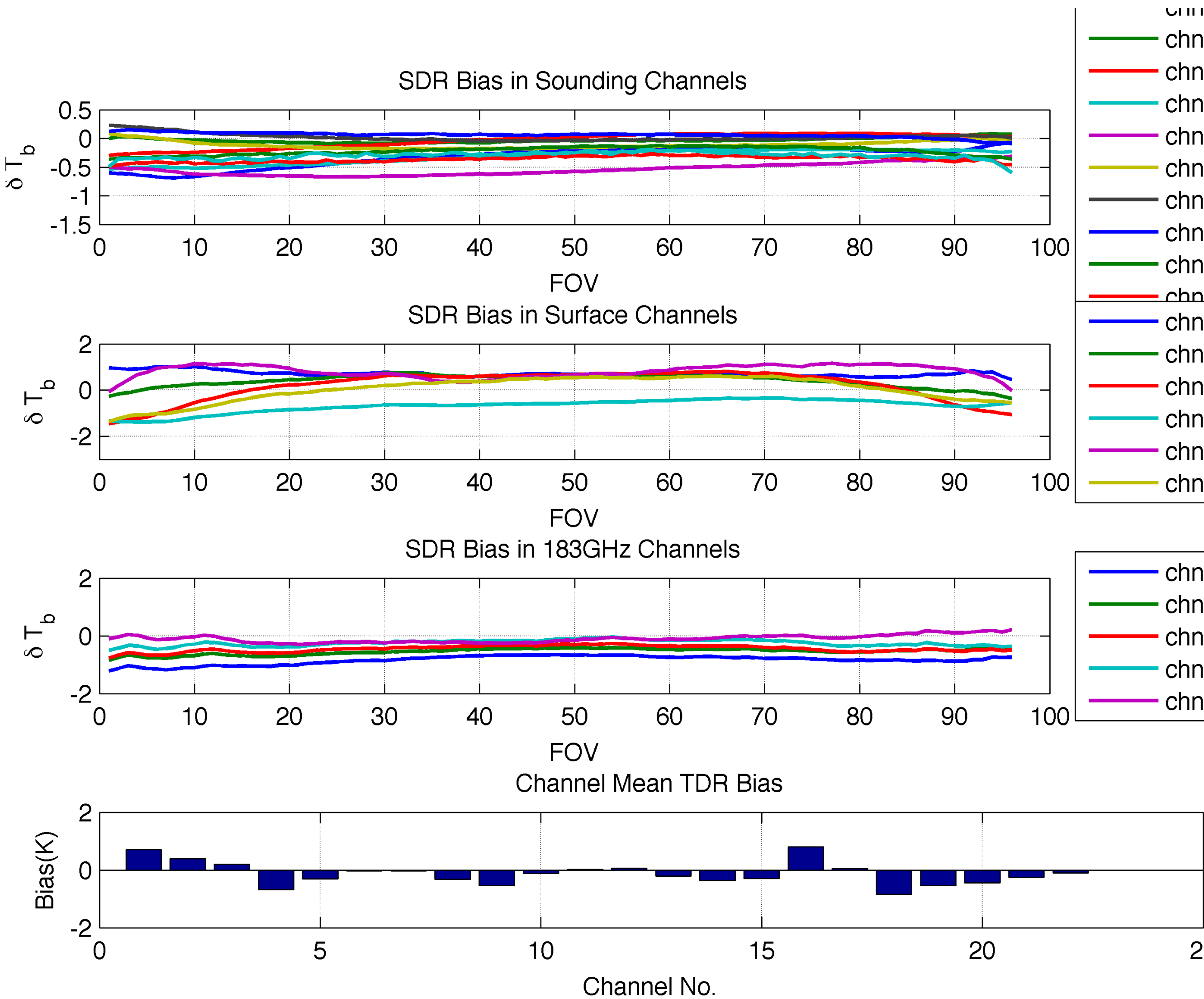
- Compared to TDR, channel mean bias in SDRs for both N20 and SNPP decreased about 0.5K for almost all channels except for QV band channels.
- Difference in N20/SNPP SDRs is very consistent with TDRs, proved correctness of APC corrections in SDRs
- Relative large remaining bias scan dependent feature in QV band indicate uncorrected reflector-related bias terms in these cha



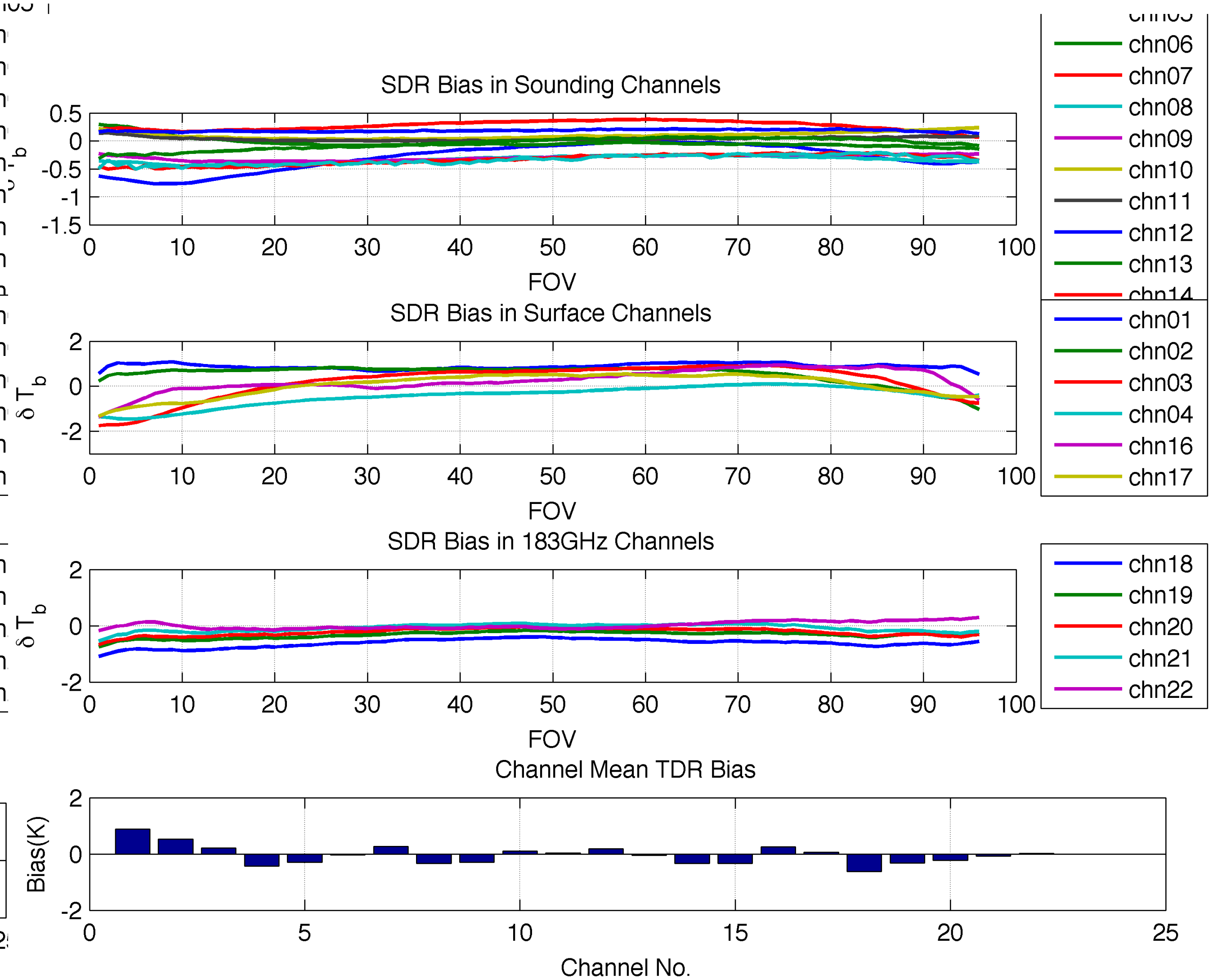
Evaluation Results for Proposed SDR Algorithm

More consistent scan dependent bias and channel average bias were observed by using proposed APC coefficients and SDR algorithm

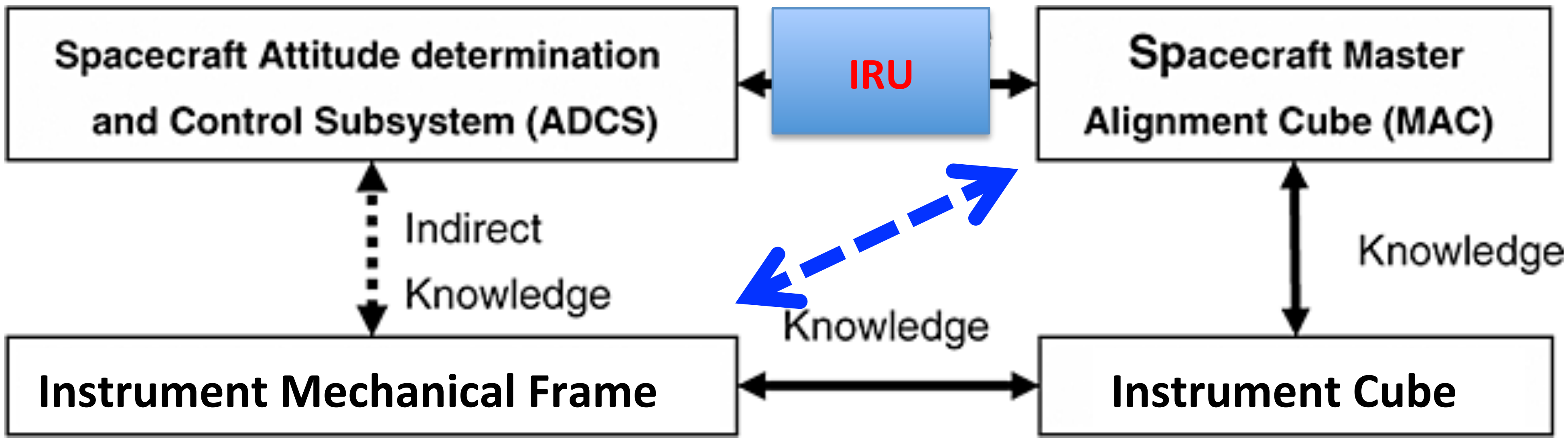
N20



SNPP



Prelaunch Measurements for Instrument Mounting Errors



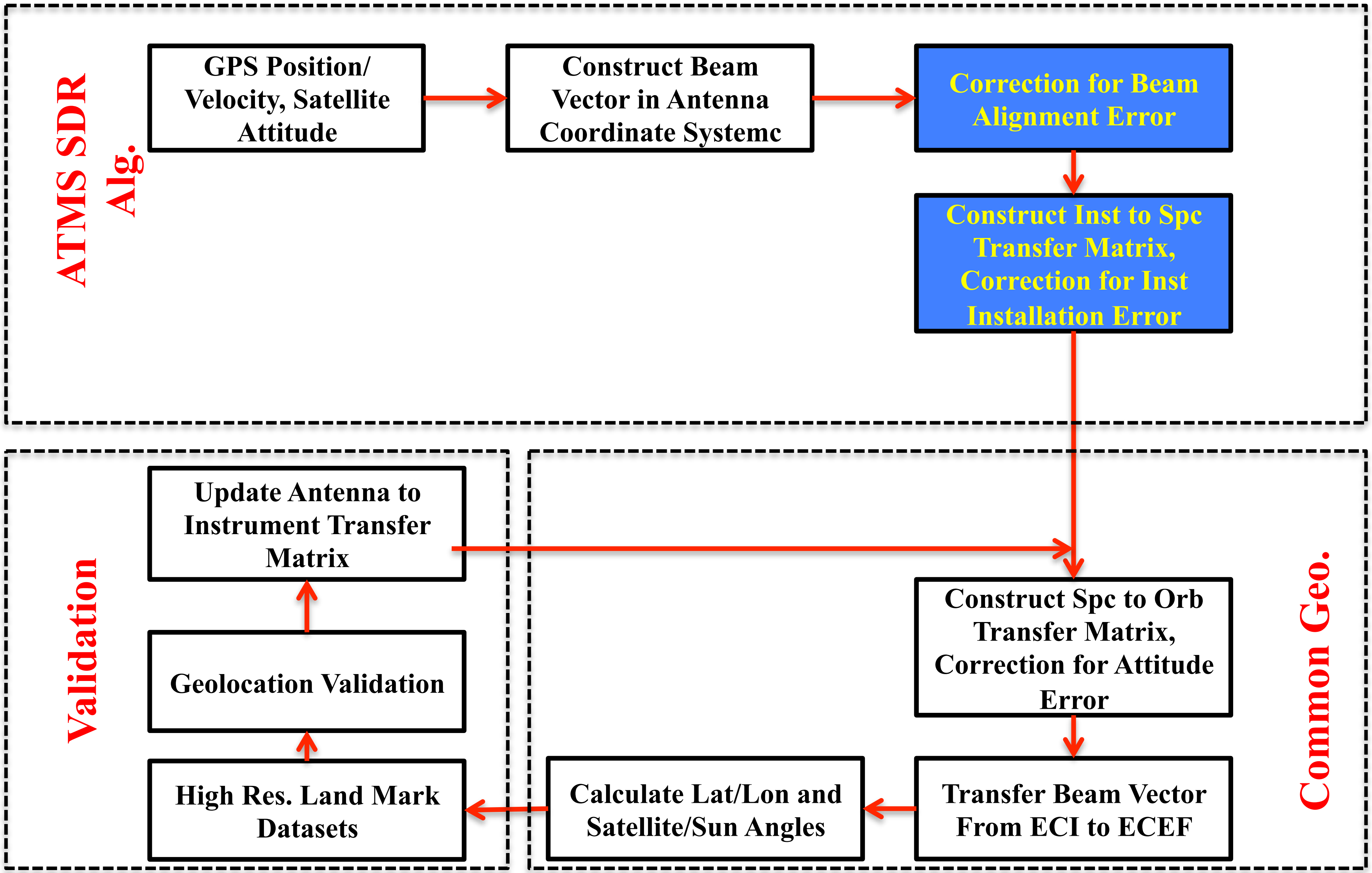
Instrument Cube to IMF: Rx, Ry, Rz
Instrument Cube to MAC: Rx, Ry, Rz

→ **Instrument IMF to MAC: Rx, Ry, Rz**

ADCS to MAC: (all the instrument share the same value)
Rx', Ry', Rz' → (41, -601, -241-50) (Table 3+4)

IMF to ADCS: **Tadcs/imf = Tadcs/iru*Tiru/mac*transpose(Timf/iac*Tiac/mac)**

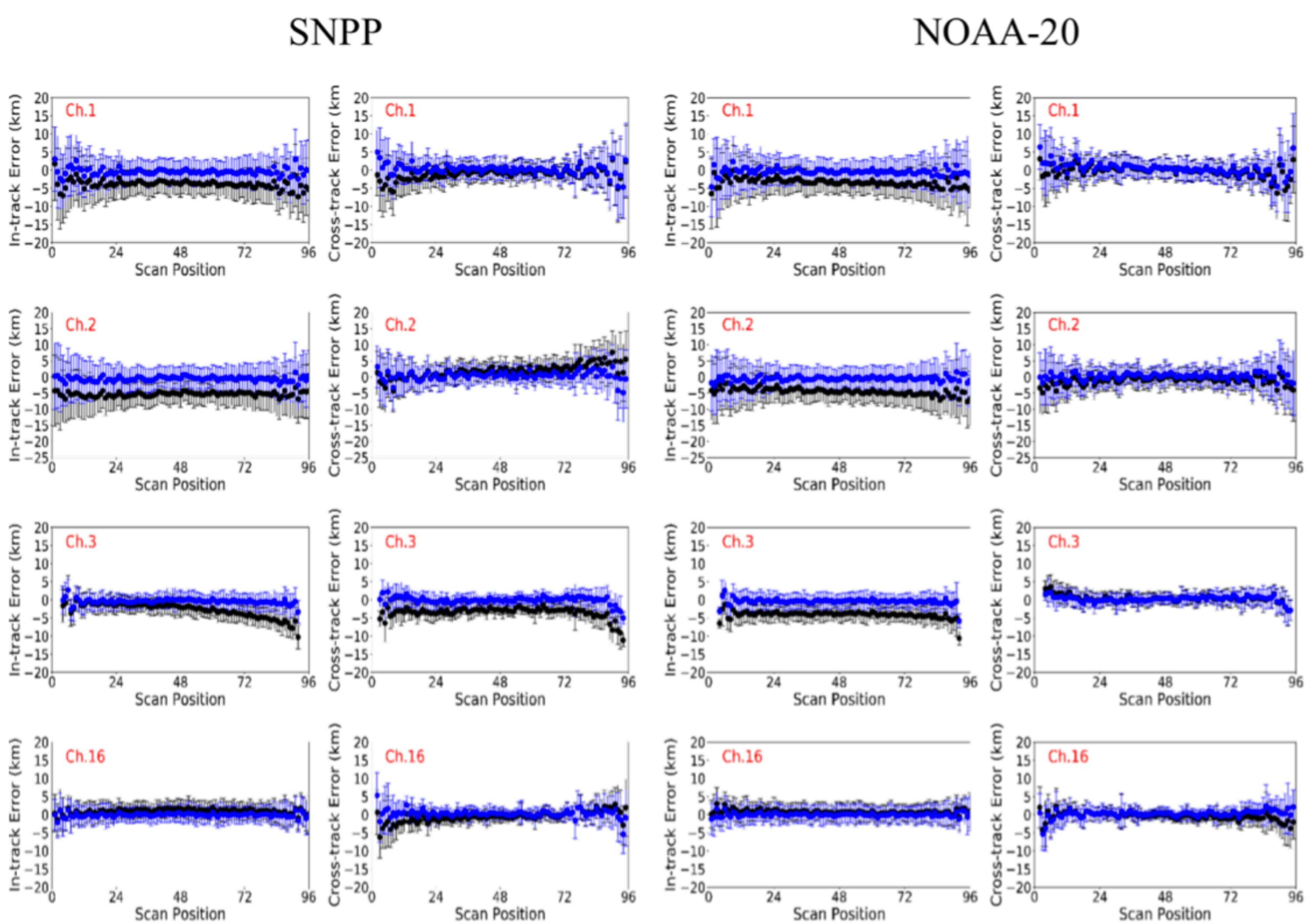
Satellite Geolocation/Validation Diagram



Geolocation Error Correction by Using Retrieved Euler Angles

Jun Zhou, Hu Yang and Kent Anderson, 2019, "SNPP ATMS On-Orbit Geolocation Error Evaluation and Correction Algorithm", IEEE Transactions on Geoscience and Remote Sensing 57 (6), 3802-3812

Geolocation Error Correction Results for SNPP and NOAA-20 ATMS



Correction Steps in Geolocation Process

Step 1. Construct rotation matrix from Euler angles

$$\mathrm{ROT_{corr}} = \mathrm{ROT_y}(\xi_y) \cdot \mathrm{ROT_r}(\xi_r) \cdot \mathrm{ROT_p}(\xi_p)$$

$$\mathrm{ROT_y}(\xi_y) = \begin{bmatrix} \cos\xi_y & -\sin\xi_y & 0 \\ \sin\xi_y & \cos\xi_y & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

$$\mathrm{ROT_r}(\xi_r) = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\xi_r & -\sin\xi_r \\ 0 & \sin\xi_r & \cos\xi_r \end{bmatrix}$$

$$\mathrm{ROT_p}(\xi_p) = \begin{bmatrix} \cos\xi_p & 0 & \sin\xi_p \\ 0 & 1 & 0 \\ -\sin\xi_p & 0 & \cos\xi_p \end{bmatrix}$$

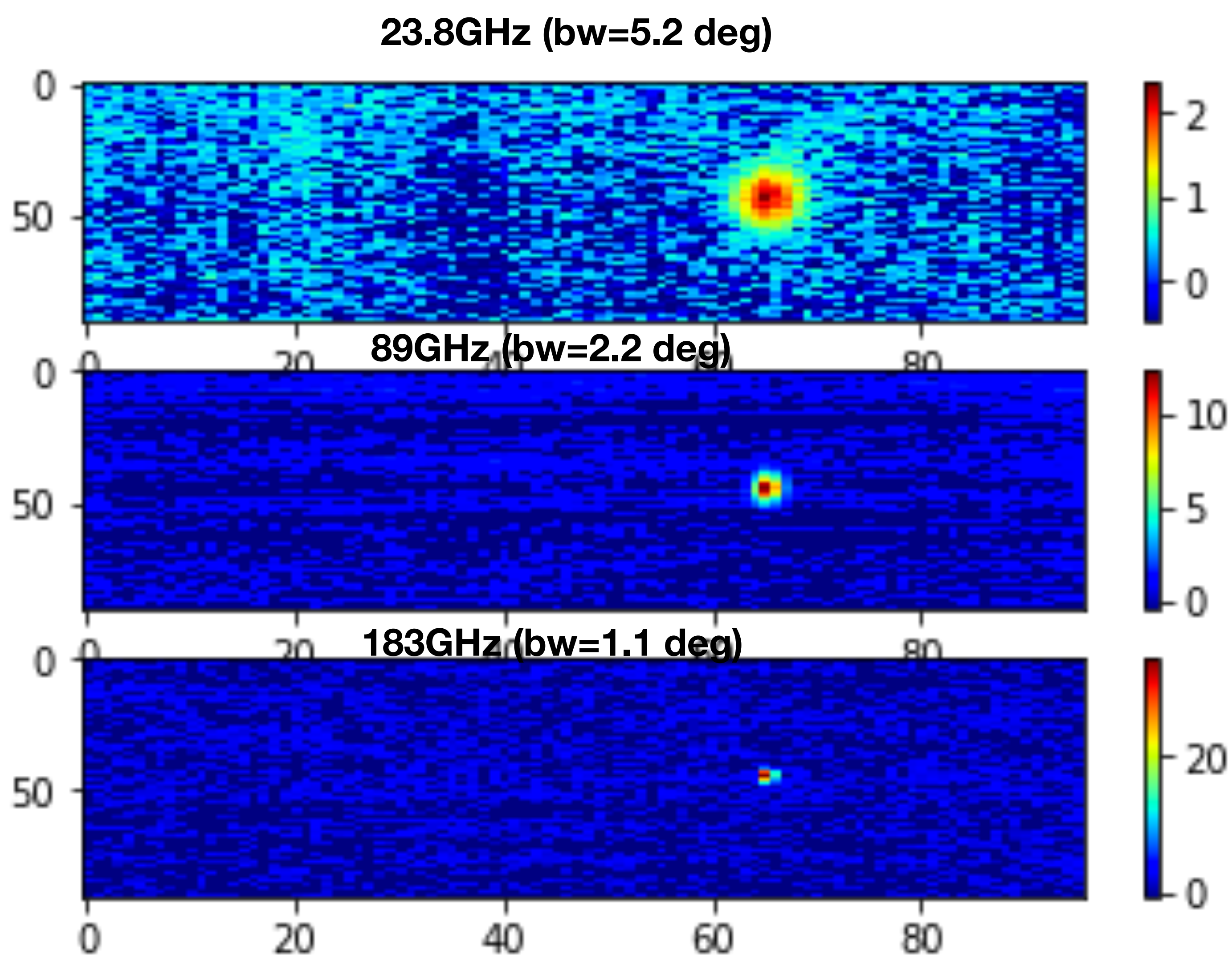
Step 2. Apply correction matrix right after instrument mounting error correction

$$\vec{b}_{ECEF} = ROT_{ECEF/ECI} ROT_{ECI/Orb} ROT_{Orb/SC} \boldsymbol{ROT_{Corr}} ROT_{SC/Inst} ROT_{Inst/Ant} \vec{b}_{Ant}$$

2D Lunar Raster Scan for Geolocation Error Correction

- *Jun Zhou and Hu Yang, 2019, "On Study of Two-Dimensional Lunar Scan for Advanced Technology Microwave Sounder Geometric Calibration", Atmospheric Measurement Technique, https://doi.org/10.5194/amt-2019-177*

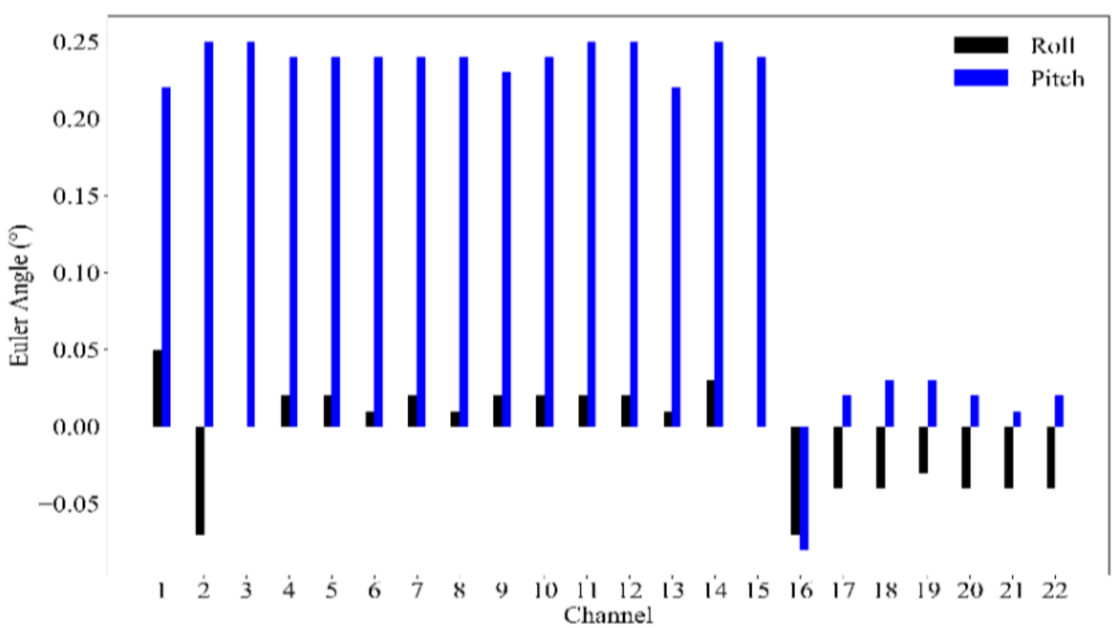
- The observed raw data counts were transferred to brightness temperature by using the calibration equation with the warm load and cold space observations.
- Further corrections for warm bias, earth side lobe contamination, as well as the reflector emission contamination are needed.
- To derive the pure lunar signal, the cosmic background radiation is subtracted from the calibrated brightness temperature.



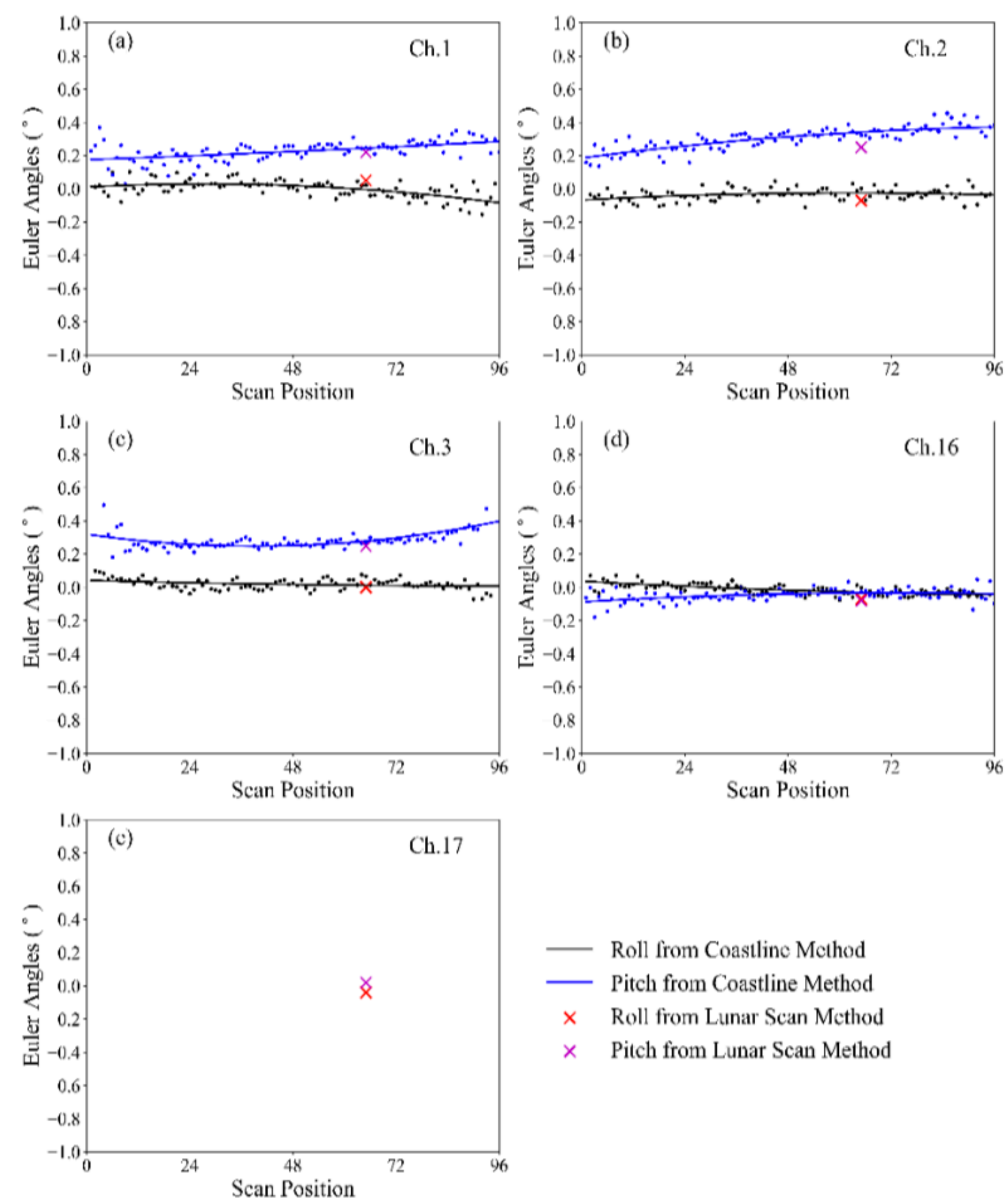
Retrieving Results and Validation

- Retrieving results from lunar scan represent beam misalignment around FOV 66
- Euler angles independently derived from lunar scan and coastline inflection point are highly consistent
- For sounding channels such as 4-15 and 17-22, the coastline method is not applicable, the lunar scan can still provide accurate information of geometric calibration error

Retrieving Results for Roll and Pitch Angles



Validation with Results from Coastline Method



Conclusions

- Several major improvements have been made for N20 AMTS SDR products based on the lessons learned from SNPP calibration and new findings in N20 on-orbit calibration
  - accurate antenna pattern measurements are critical for SDR correction
  - on-orbit environment tests are necessary to determine satellite platform blockage
  - reflector emission correction and beam inhomogeneous correction can help to reduce scan dependent bias and improve the SDR data quality

Peer Review Publications for ATMS Cal/Val Sciences

Calibration Algorithm

- Edward Kim Cheng-Hsuan J. Lyu Kent Anderson R. Vincent Leslie William J. Blackwell, 2014, "S-NPP ATMS instrument prelaunch and on-orbit performance evaluation"JGR, 2014 https://doi.org/10.1002/2013JD020483
- Fuzhong Weng, Xiaolei Zou, Ninghai Sun, Hu Yang, Xiang Wang, Lin Lin, Miao Tian, and Kent Anderson, 2013, "Calibration of Suomi National Polar-Orbiting Partnership (NPP) Advanced Technology Microwave Sounder (ATMS) ", Journal of Geophysical Research, Vol.118, No.19, PP. 11,187~11,200
- Weng, F. and Yang, H., 2016. Validation of ATMS calibration accuracy using Suomi NPP pitch maneuver observations. Remote Sensing, 8(4), p.332

Antenna Correction

- Hu Yang and Fuzhong Weng, Kent Anderson, 2016, "Estimation of ATMS Antenna Emission from Cold Space Observations", , IEEE Geoscience and Remote sensing, 10.1109/TGRS.2016.2542526"
- Fuzhong Weng, Hu Yang, Xiaolei Zou,2013, "On Convertibility From Antenna to Sensor Brightness Temperature for ATMS", IEEE Geoscience and Remote sensing Letters, 2012, Vol.99, pp 1-5

Remapping SDR

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Lunar Contamination Correction

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