On-orbit Absolute Calibration of Advanced Technology Microwave Sounder (ATMS)

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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

Conclusion and Future Work

Peer Review Publications for ATMS Cal/Val Sciences

Calibration Algorithm

- 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

- Hu Yang and Xiaolei Zou, X, 2014. Optimal ATMS remapping algorithm for climate research. Geoscience and Remote Sensing, IEEE Transactions on Geoscience and Remote Sensing, 52(11), 7290-7296.

Lunar Contamination Correction

- 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

Vicarious calibration and Long-term stability Monitoring

- Hu Yang, Ninghai Sun, Kent Anderson, Quanhua Liu, Ed Kim, 2018, "Developing vicarious calibration for microwave sounding instruments using lunar radiation", EEE Transactions on Geoscience and Remote Sensing, accepted for publication

ATMS Instrument Noise Characteristic

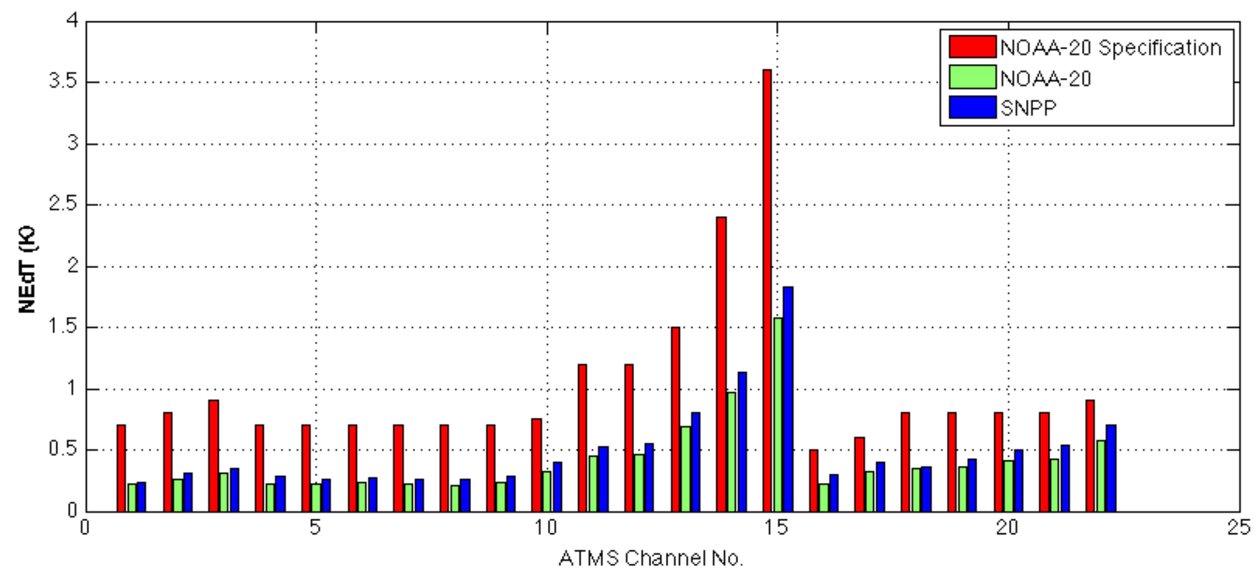
- ATMS has a 18ms integration time compared to 162ms integration time of AMSU. Channel NEdT in original observations is no larger than 0.5K for most of detection channels, except for channel 13~15, which were designed with very narrow band width

- Channel noise feature in N20 and SNPP is consistent

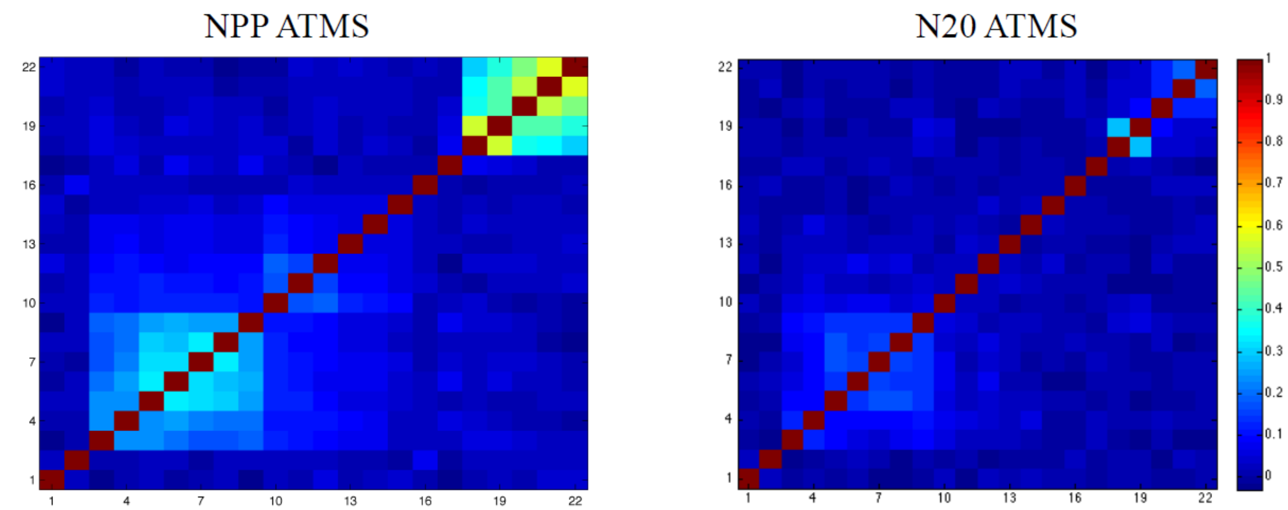
- N20 has significant improvement on channel correlation noise, with a much lower channel correlation compare to SNPP

- 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

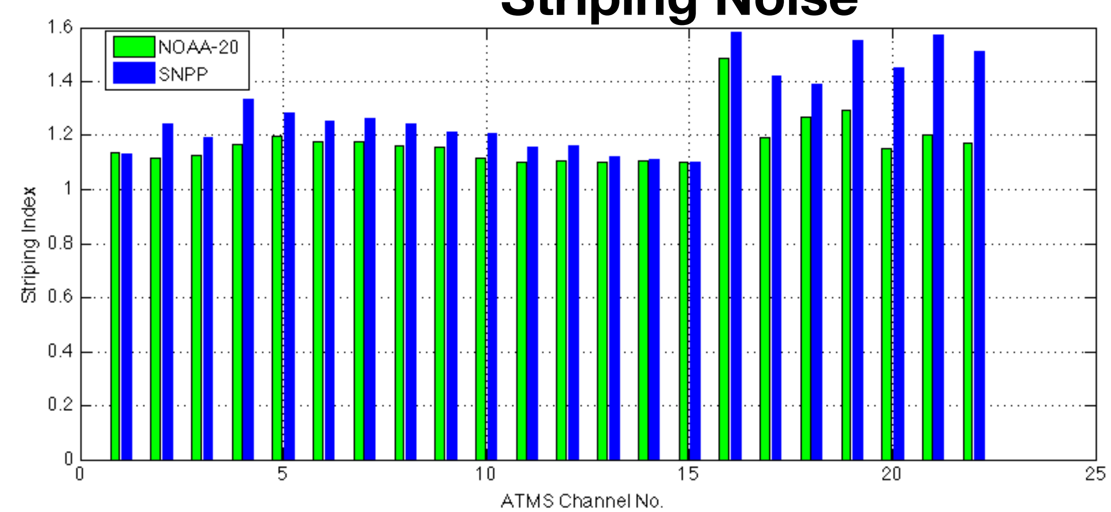
NEdT



Noise Correlation



Striping Noise



Radiance Calibration Equation and Error Budget Model for TDR Products

The ATMS radiometric calibration for antenna brightness temperature is derived as

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

Q is the calibration non-linearity term

$$Q = \mu (R_w - R_c)^2 \frac{(C_s - \overline{C_w})(C_s - \overline{C_c})}{(\overline{C_w} - \overline{C_c})^2} = 4Q_{\max}(x - x^2)$$

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

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

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

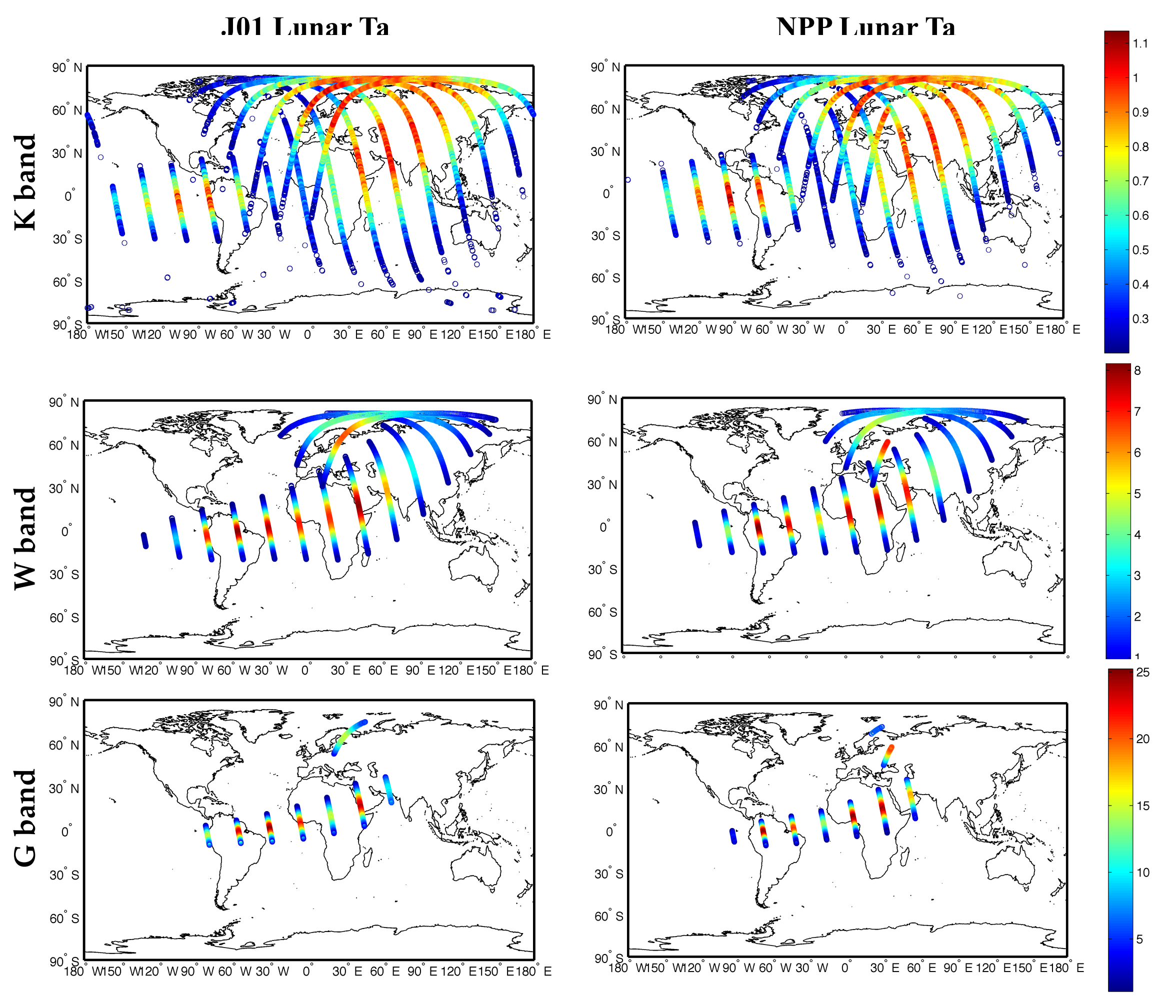
- **Pre-launch cal/val activity**
  - Antenna pattern measurements
  - SRF tests (data available at https://www.star.nesdis.noaa.gov)
  - TVAC tests for nonlinearity determination

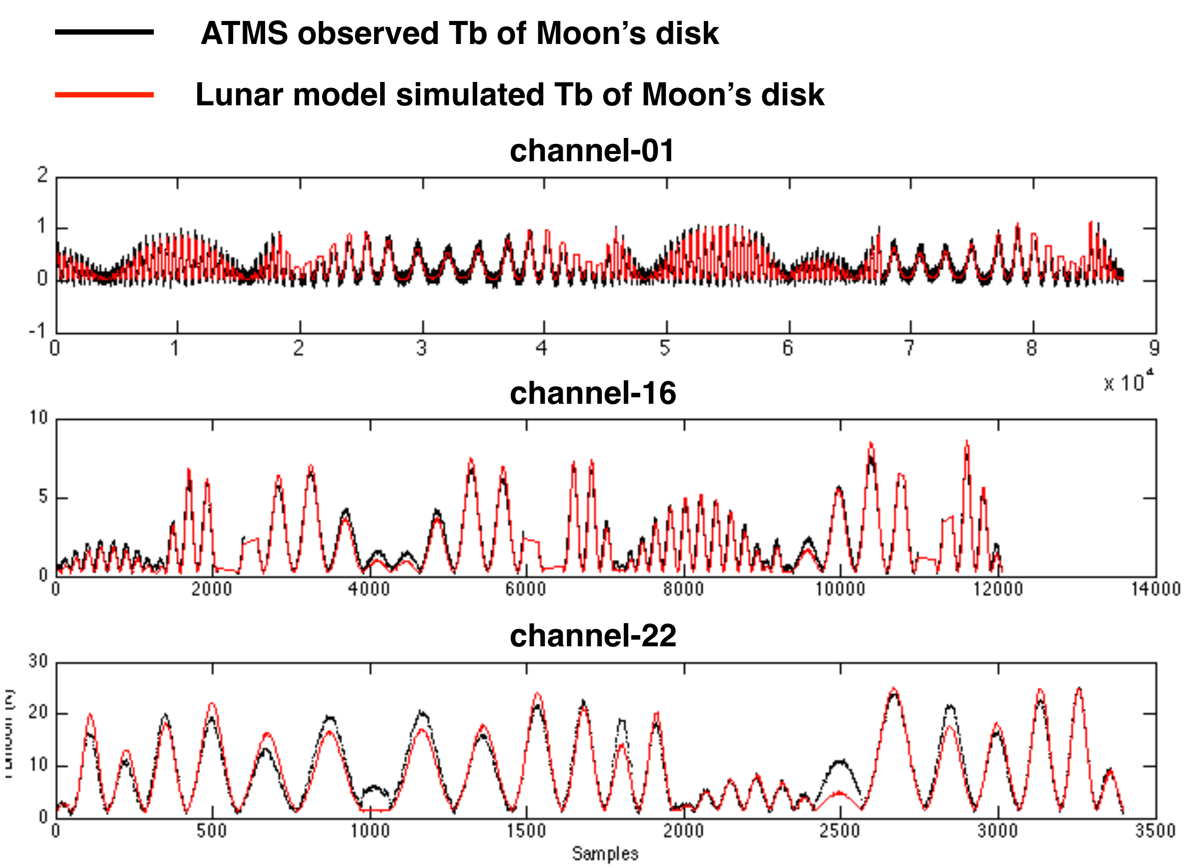
- **On-orbit cal/val activity**
  - Optimal cold space scan profile selection
  - Lunar intrusion correction
  - Earth side lobe correction for cold space view
  - Reflector emission correction for calibration targets and earth scene
  - Antenna pattern correction

Lunar Intrusion Corrections

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



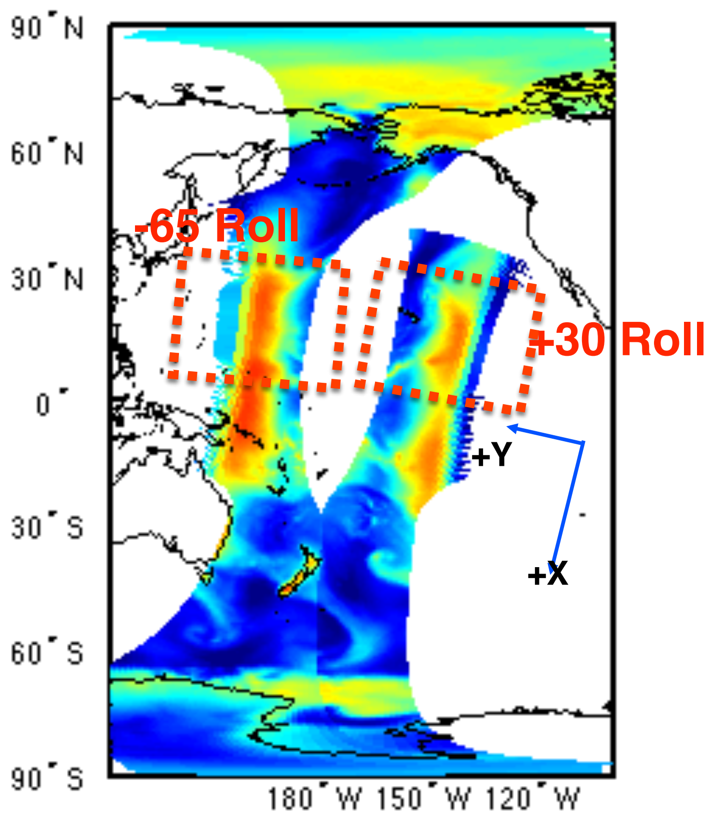


Earth Side Lobe Contamination Correction for Cold Space View

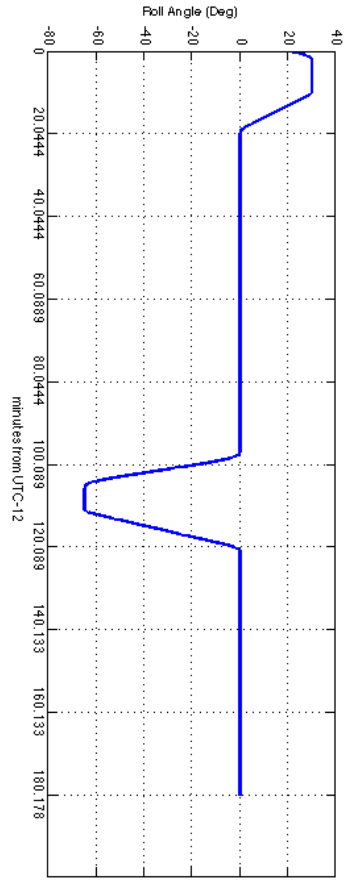
Earth side lobe for space view has been well characterized from roll maneuver data. Impacts of Earth side lobe for space view are around 0.2% for space view profile 1, lower than predicted from ground measured antenna pattern and are slightly depend on beam width

Roll Maneuver on 12/15,2017

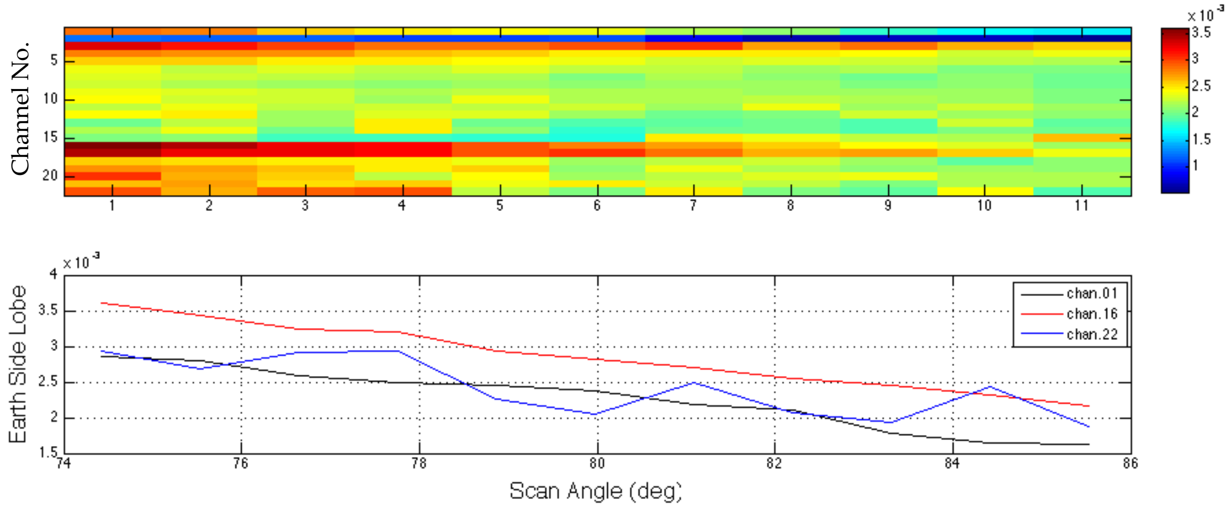
Channel-01 Ta



Satellite Attitude

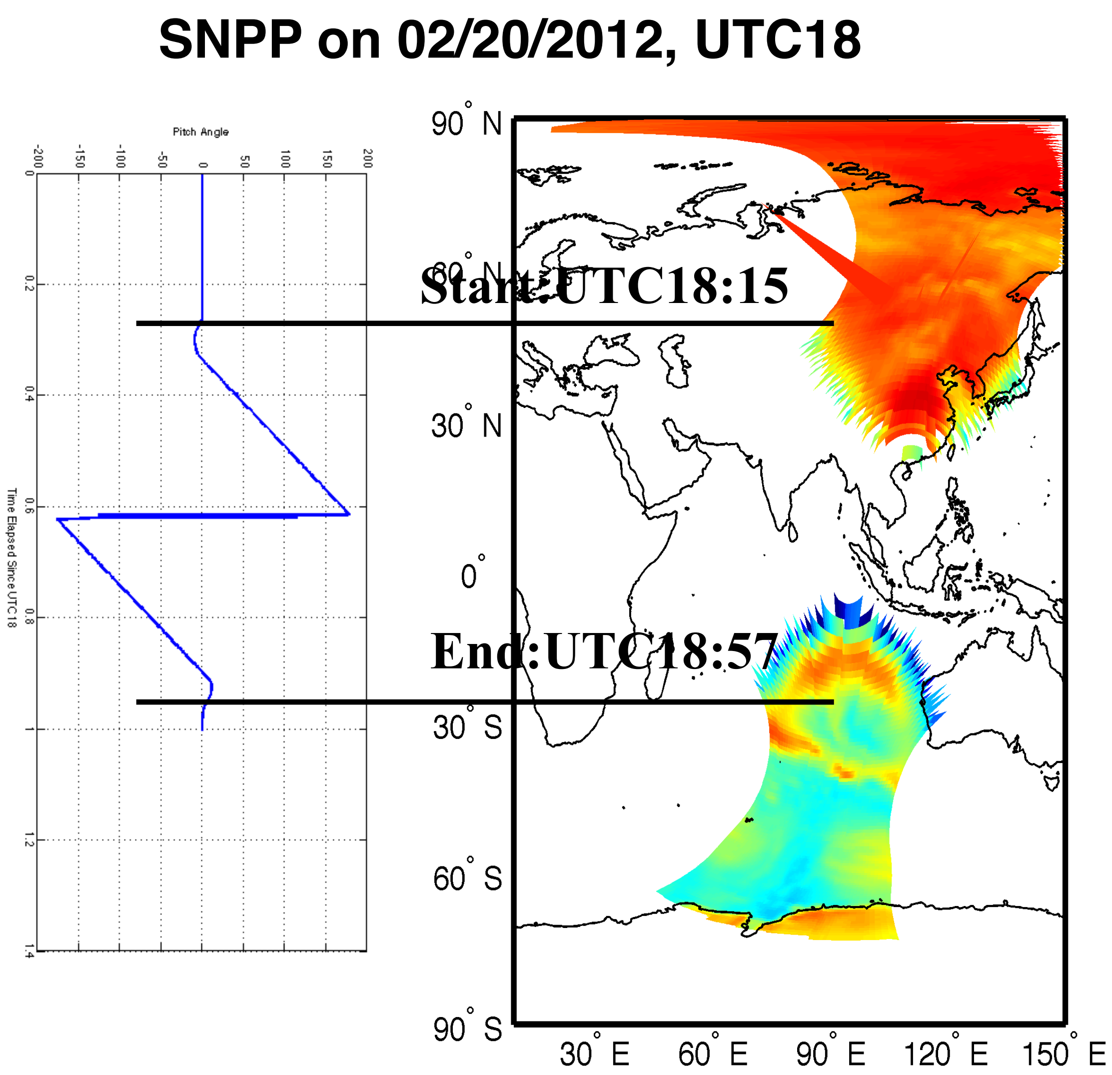


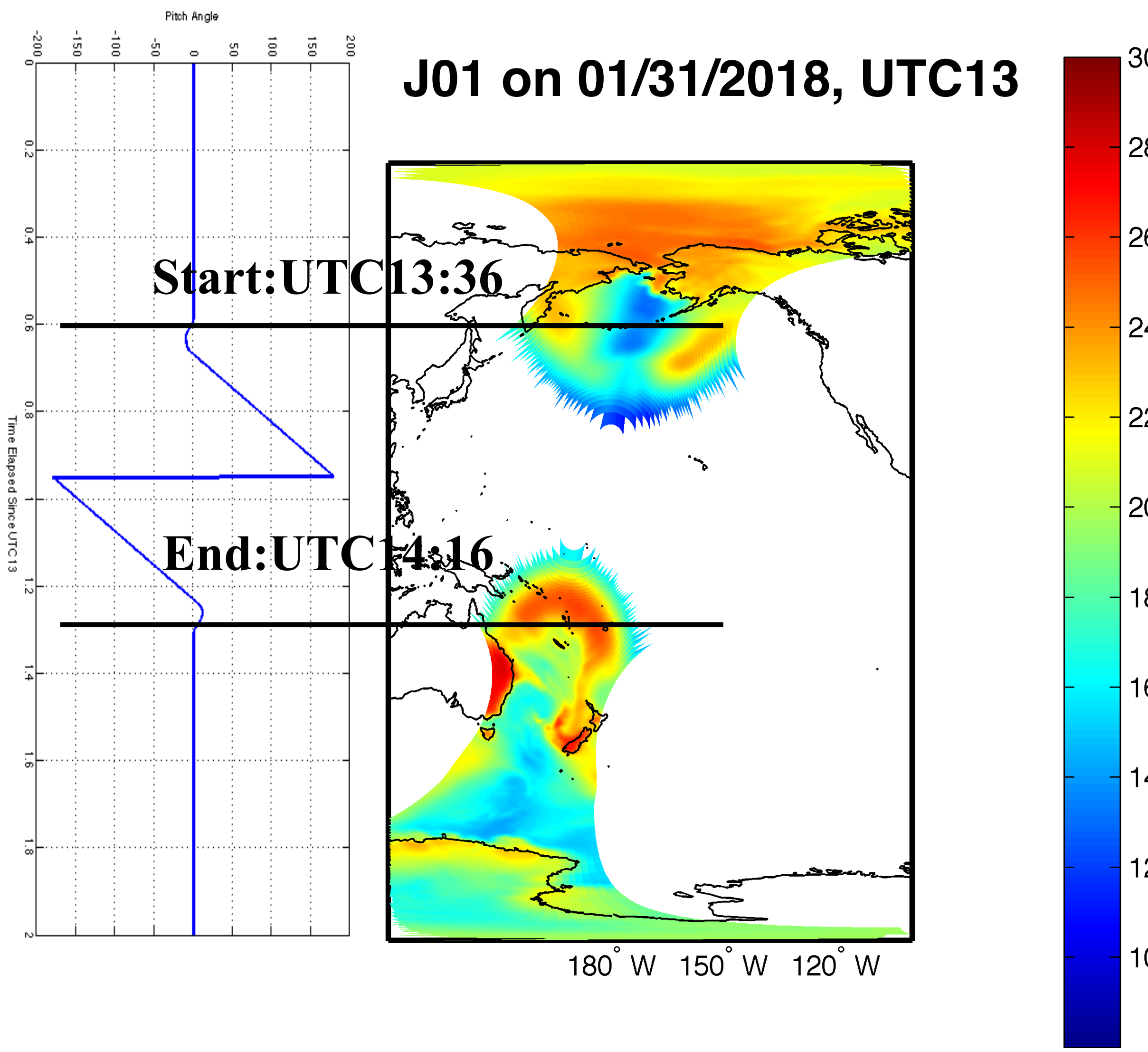
Earth Side Lobe for Deep Space View (derived from data on 12/15)



Pitch Maneuver Operation for Reflector Emission Correction

- 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



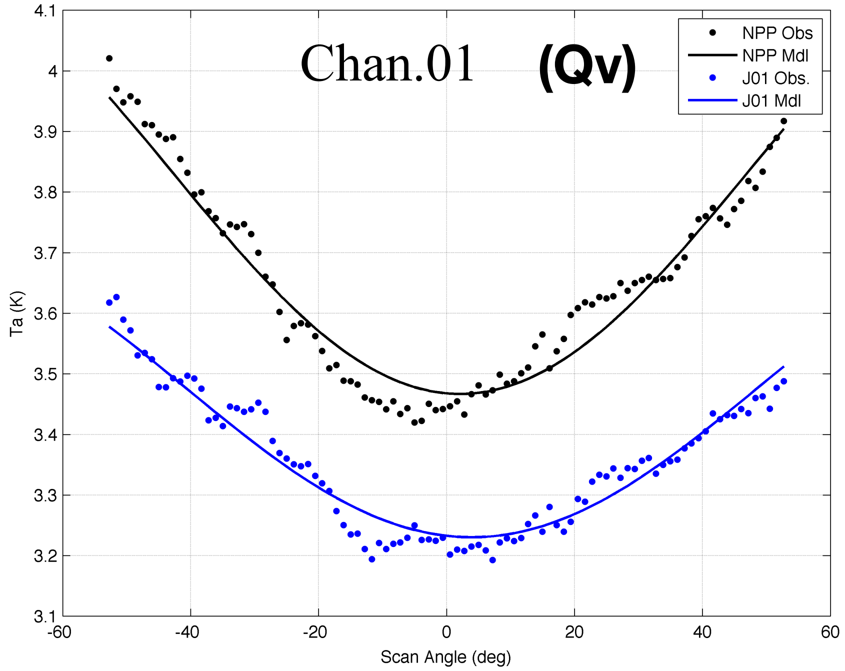


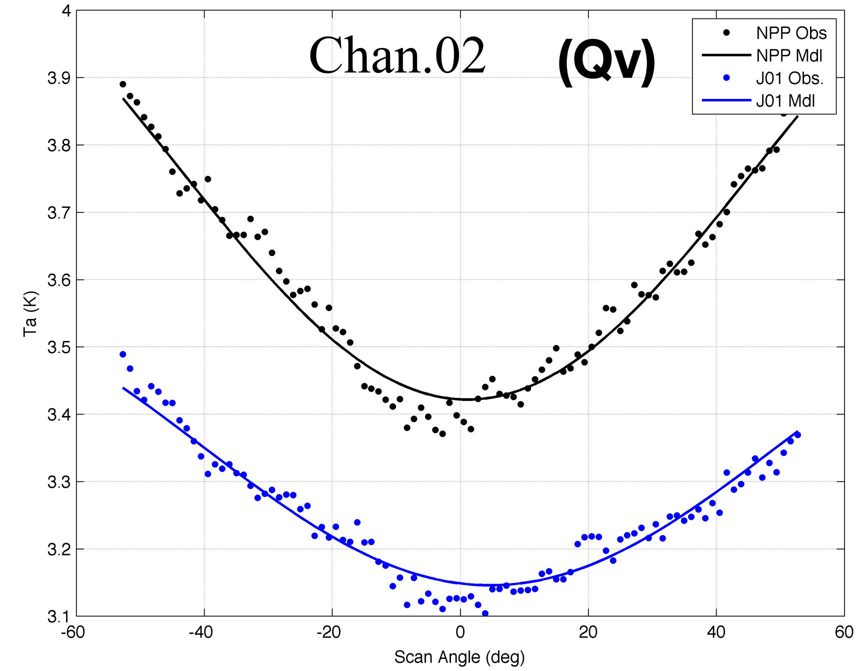
SNPP/J01 Deep Space Scan Brightness Temperature

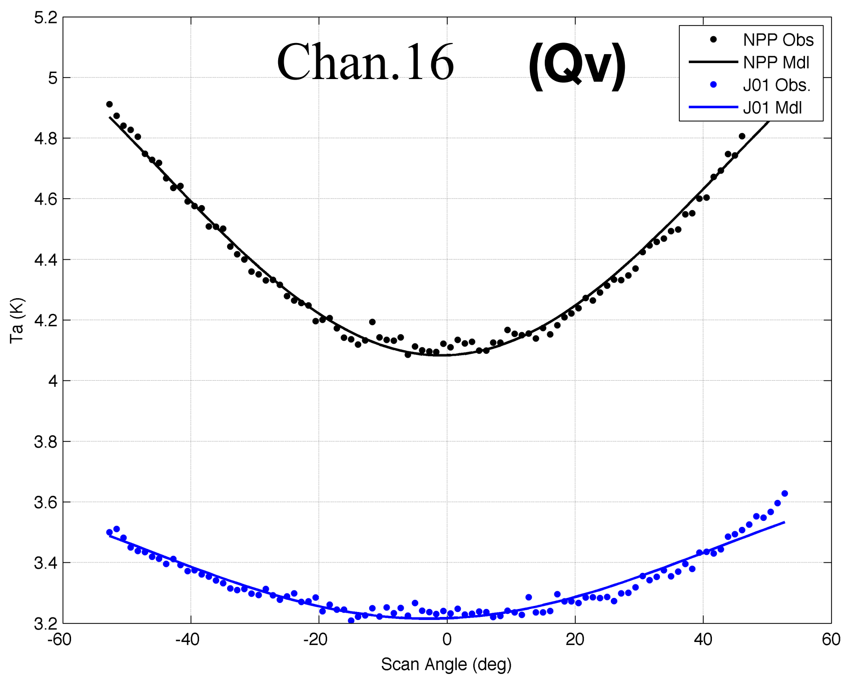
- J01 ATMS QV channel Ta has 'smile' shape scan dependent feature, which is consistent with SNPP but with smaller magnitude
- J01 ATMS QH channel Ta has very minor 'frown' shape scan dependent feature compare to SNPP

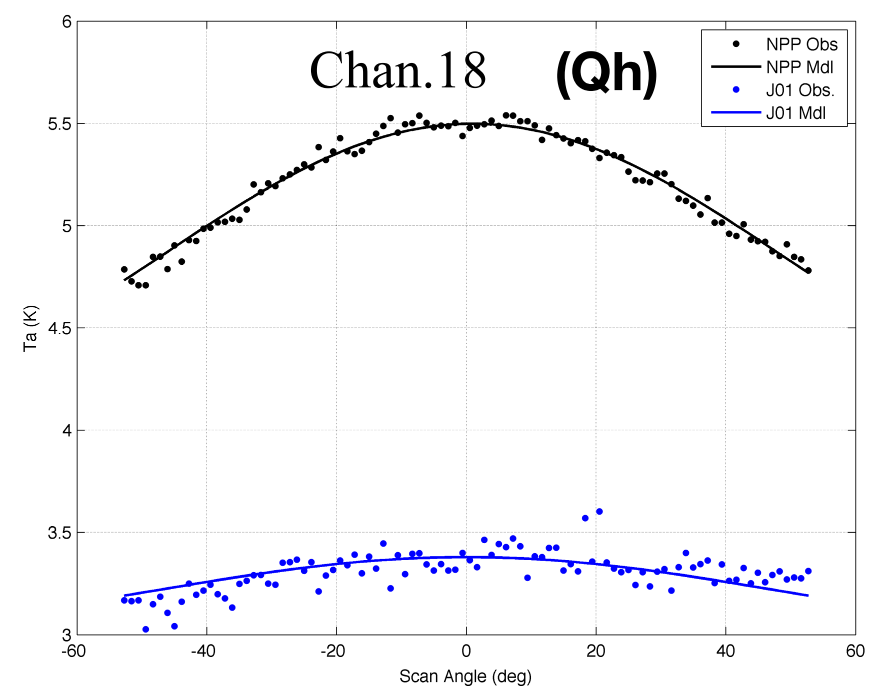
Qv channel Correction Term: $\Delta T_a = e_h \cdot (T_{rfl} - T_a) + (T_{rfl} - T_a)(e_v - e_h)sin^2\theta$

Qh channel Correction Term: $\Delta T_a = e_h \cdot (T_{rfl} - T_a) + (T_{rfl} - T_a)(e_v - e_h)cos^2\theta$







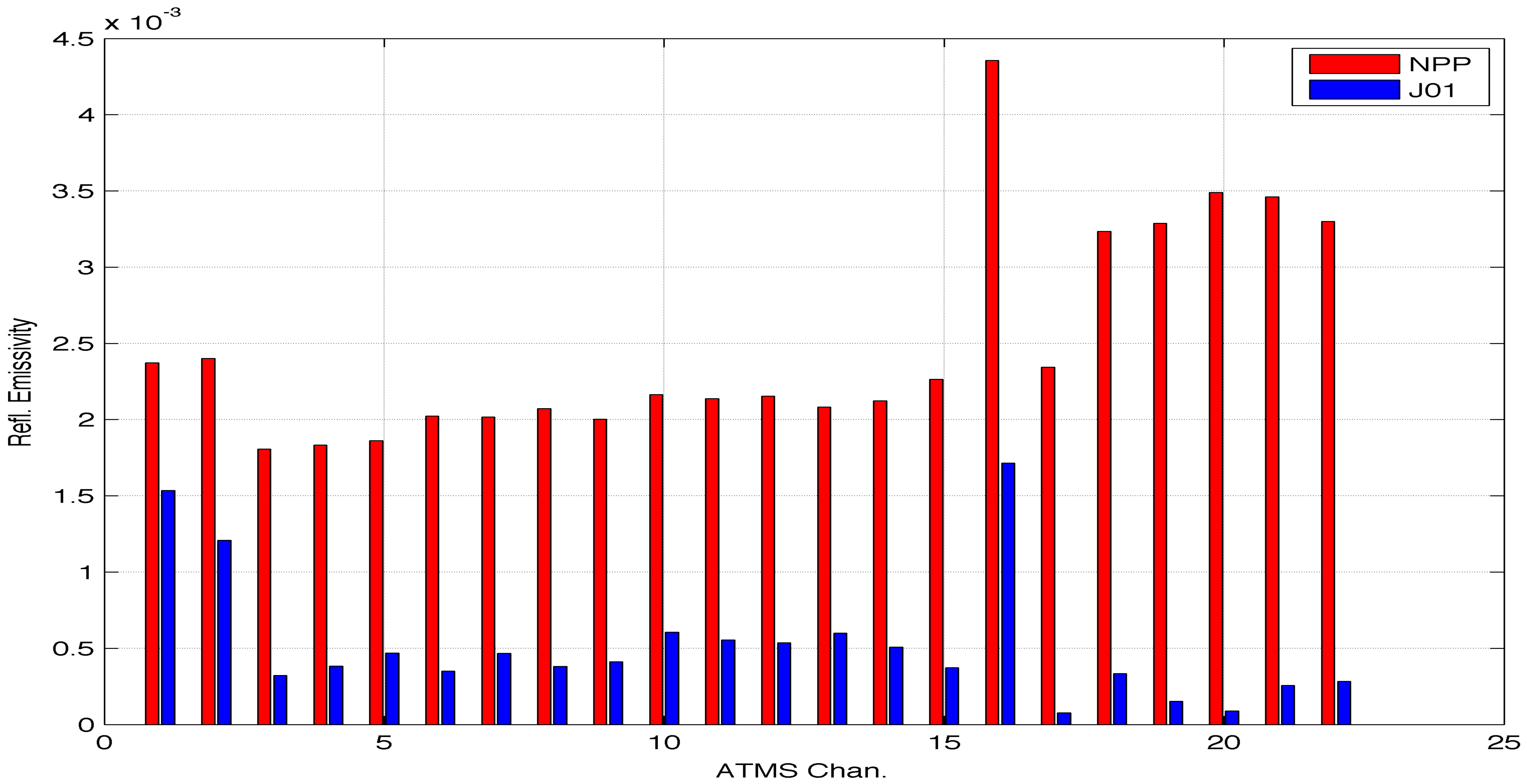


Reflector Emissivity Retrieval from Pitch Maneuver Datasets

- 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.

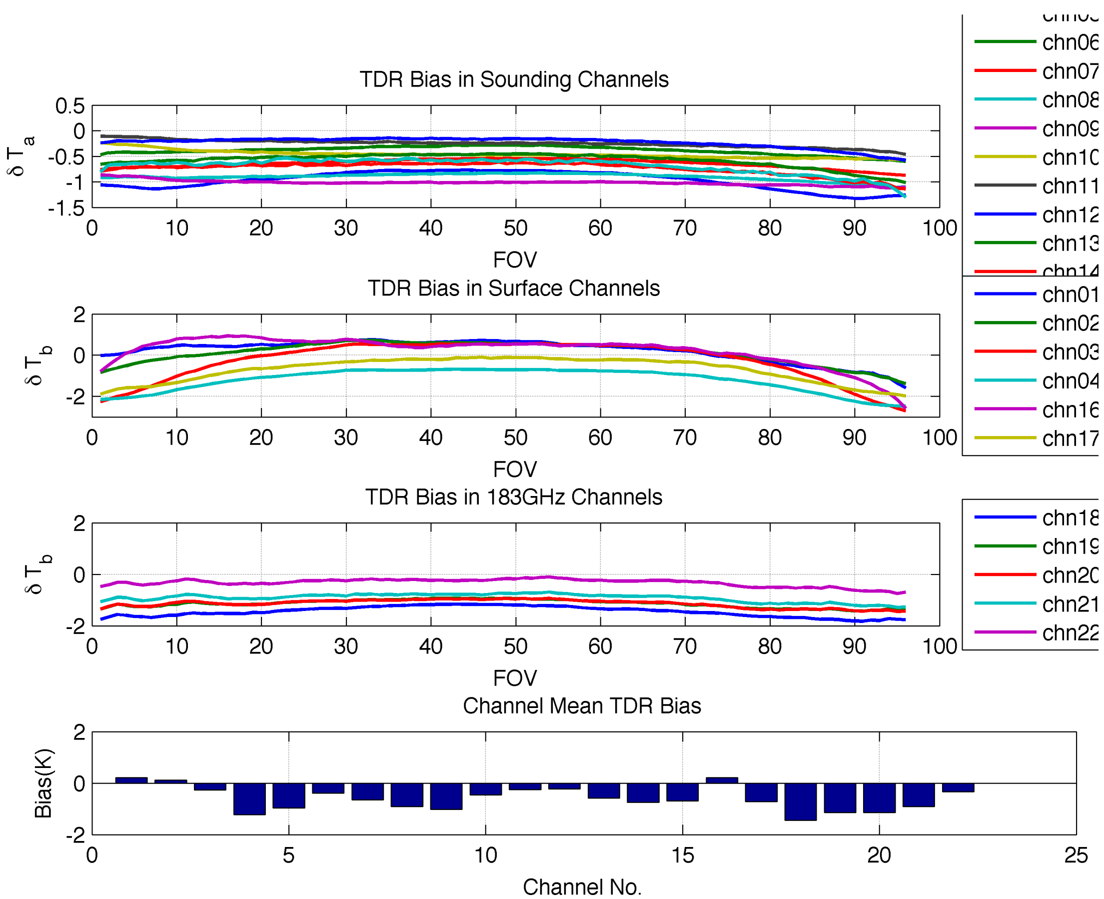
$$\varepsilon_h = \frac{\delta(R_w - R_c)}{\delta\left[(R_w - R_{\text{rfl}})\sin^2\theta_w - (R_c - R_{\text{rfl}})\sin^2\theta_c\right] - (R_c - R_{\text{rfl}})(\sin^2\theta_s - \sin^2\theta_c)}. \quad (13a)$$



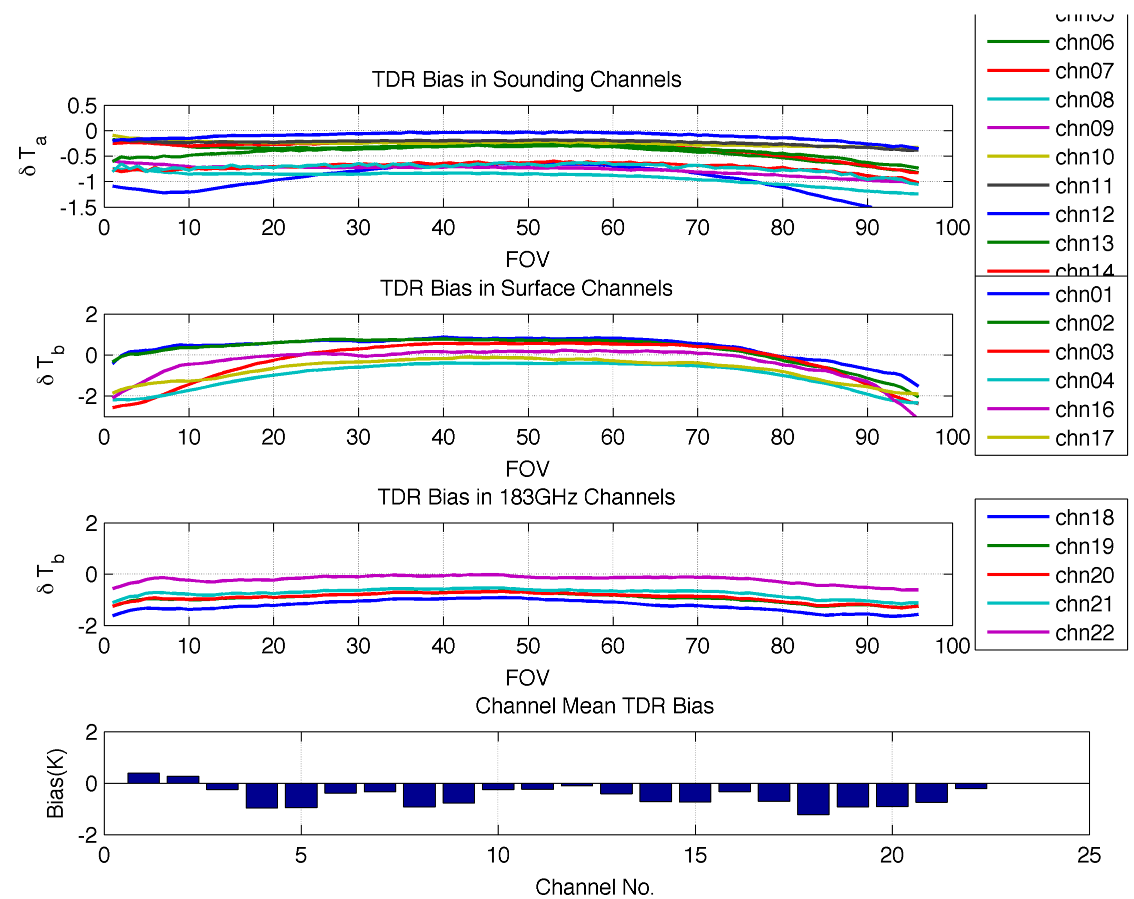
TDR Calibration Accuracy Evaluation

- 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

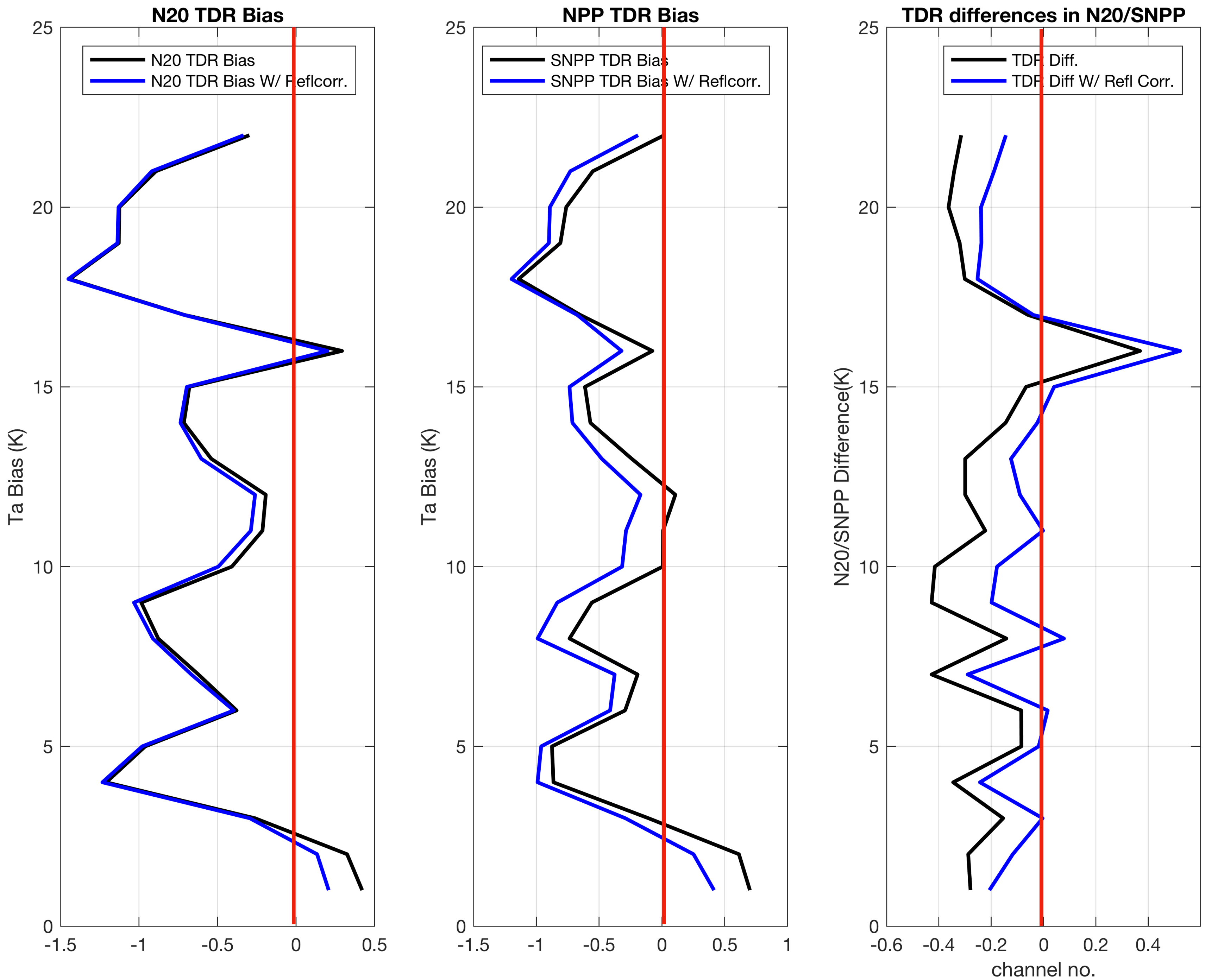


SNPP

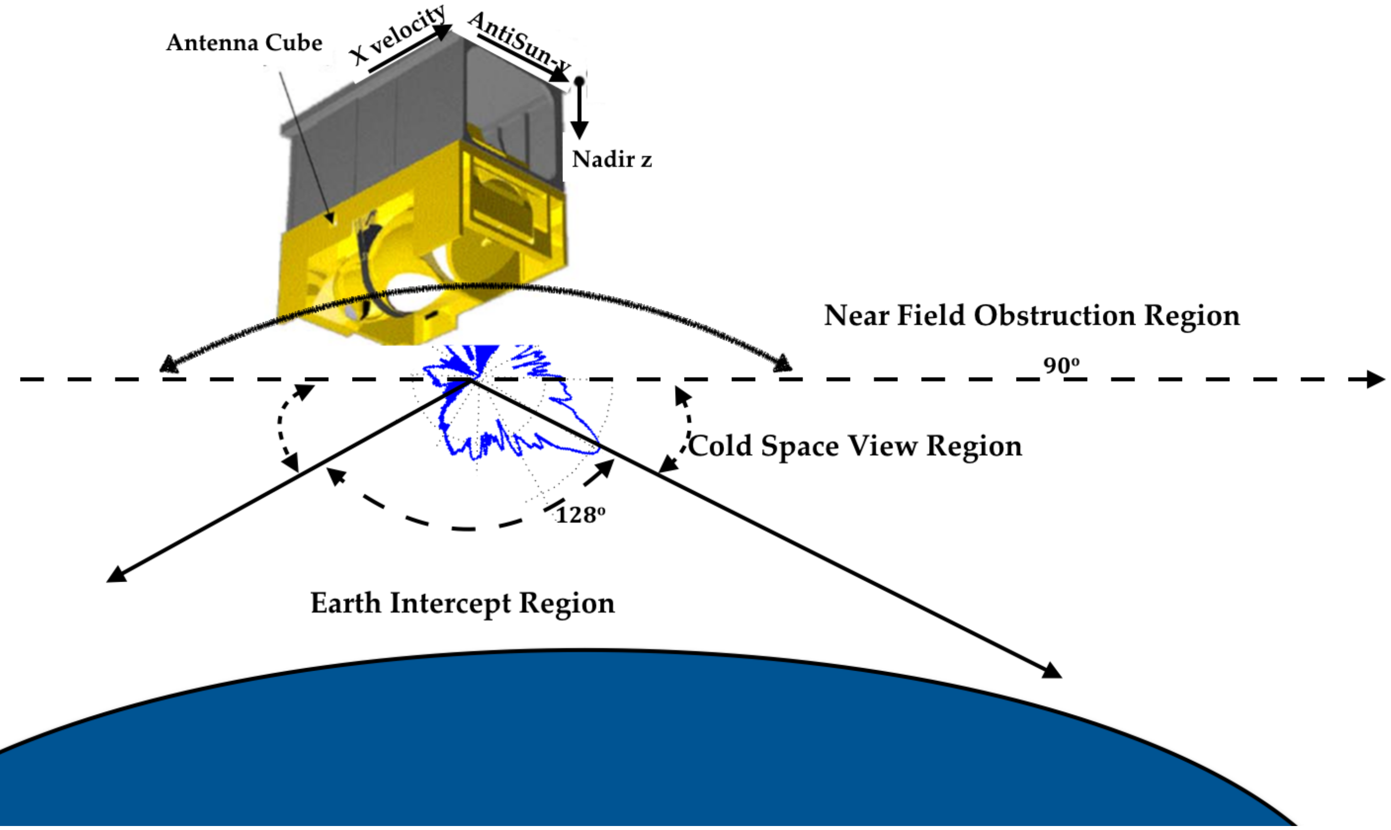


N20/SNPP TDR Channel Average Bias after Reflector Emission Correction

- 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



SDR Algorithm Description



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

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

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

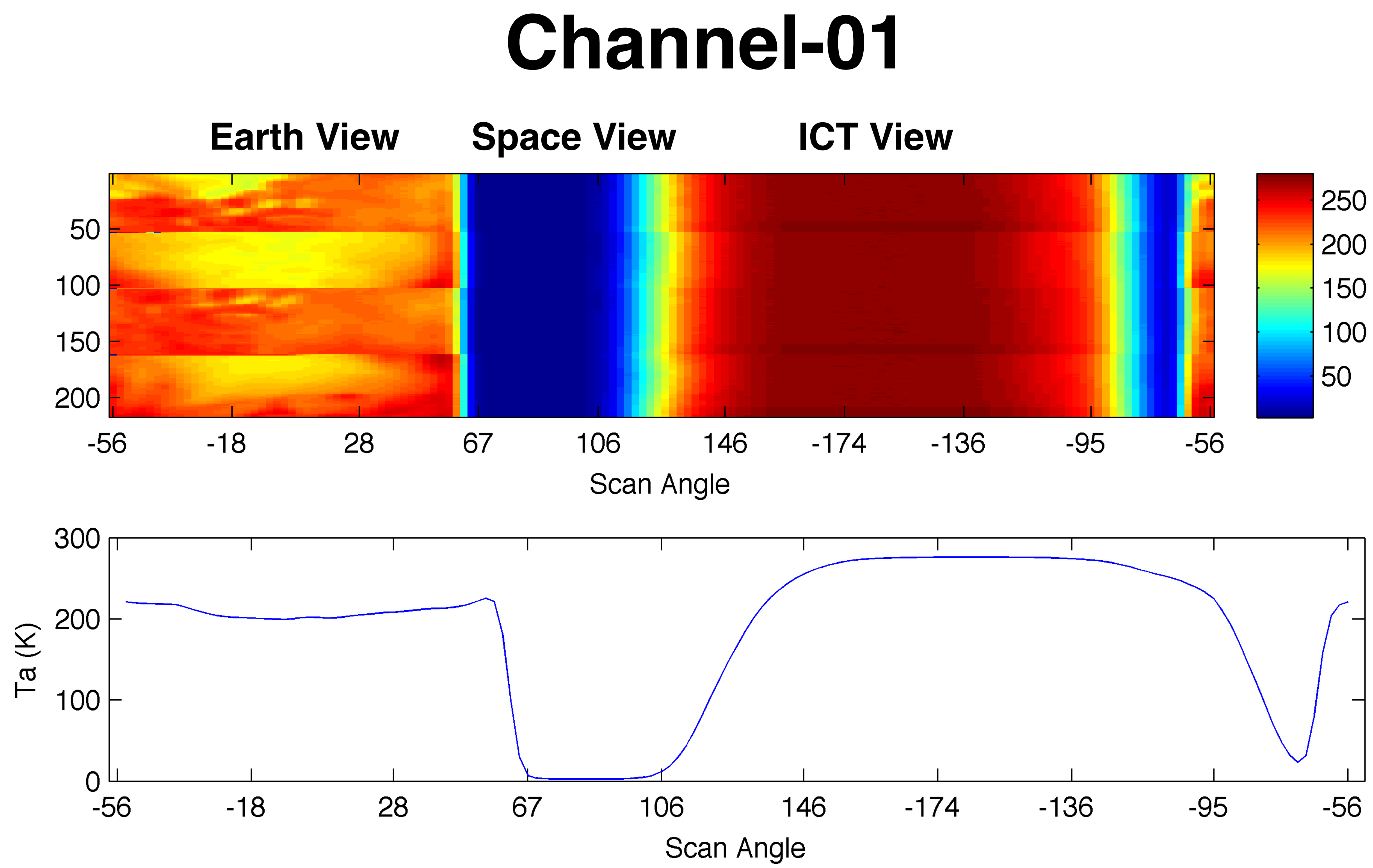
$$G_{total}(\beta) = \int_0^{2\pi}\int_{esc}[G_{pp}(\theta,\phi)+G_{pq}(\theta,\phi)]d\theta d\phi + \int_0^{2\pi}\int_{spc}[G_{pp}(\theta,\phi)+G_{pq}(\theta,\phi)]d\theta d\phi$$

Antenna Pattern Correction Model

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

Satellite Blockage Analysis

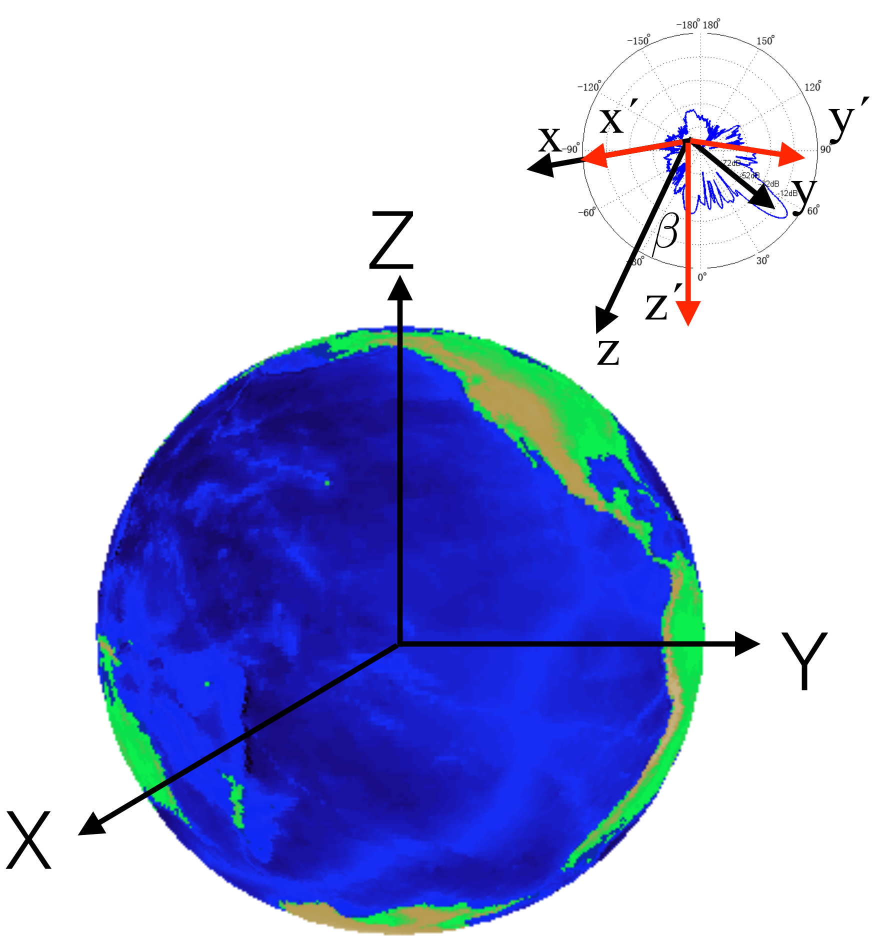
- 148 samples are collected during one scan with scan rate of 0.135 deg/ms
- Antenna temperature is derived from regular calibration process with nonlinearity included
- Asymmetry obstruction feature was observed from the data: more spacecraft obstructions in -Y direction than +Y direction
- Less obstruction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



Side Lobe Approximation Correction

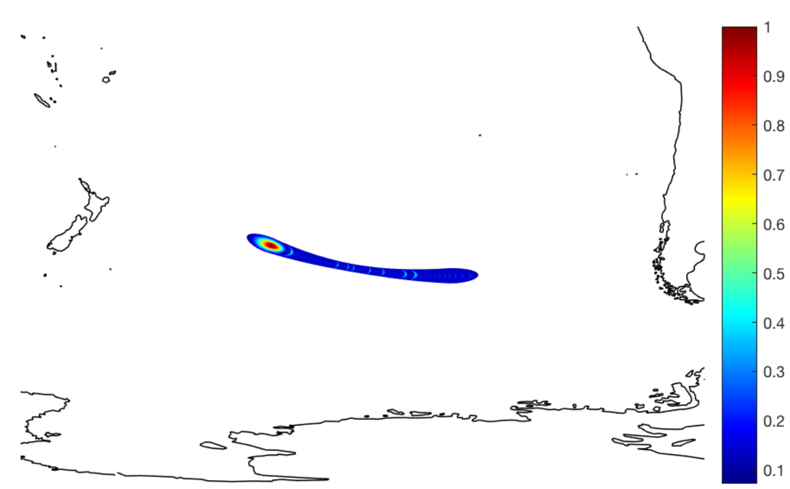
- Due to cross-track scan geometry and large beam width of ATMS observations, brightness temperature inhomogeneous within one single FOV will introduce additional error and need to be corrected in SDR algorithm
- For each scan angle, antenna pattern is projected on selected area of open ocean with a 0.01deg resolution in elevation direction and 1 deg resolution in azimuth direction
- Antenna temperature is calculated as convolution of projected antenna pattern and simulated scene brightness temperature
- The main beam antenna correction coefficient is derived from simulated antenna temperature with correction for cross-pol and cold space spill over

$$\eta(\beta)= \frac{Ta^{Qp} - \int_0^{2\pi}\int_{esv} G_{pq}\cdot T_b^{pq}(\theta,\phi)d\theta d\phi - T_c\cdot \int_0^{2\pi}\int_{spc}(G_{pp}(\theta,\phi)}{T_b^{pp}(\theta=0,\phi=90)}$$



Projected Main beam Antenna Gain

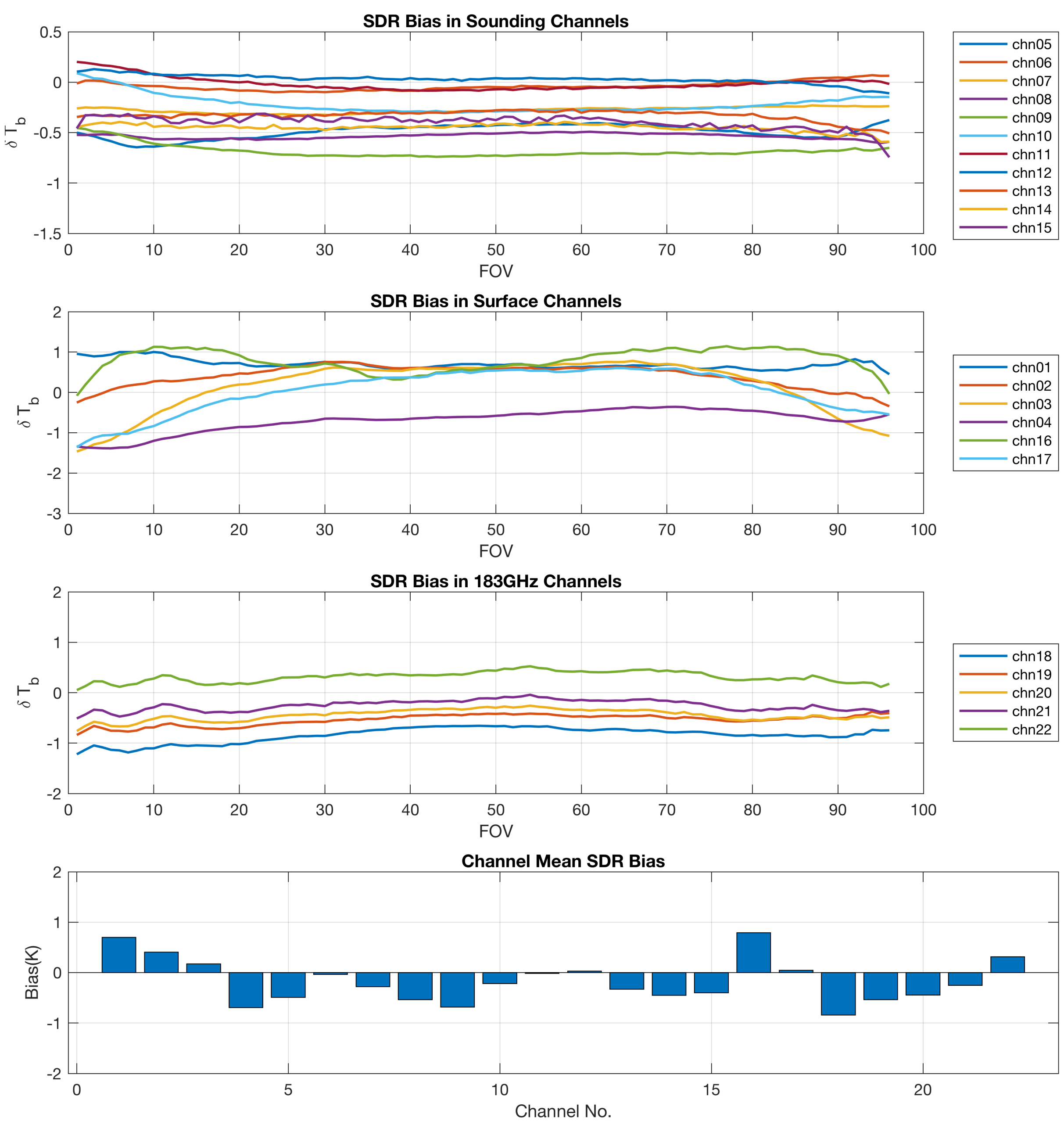
$$G(\theta,\phi)$$



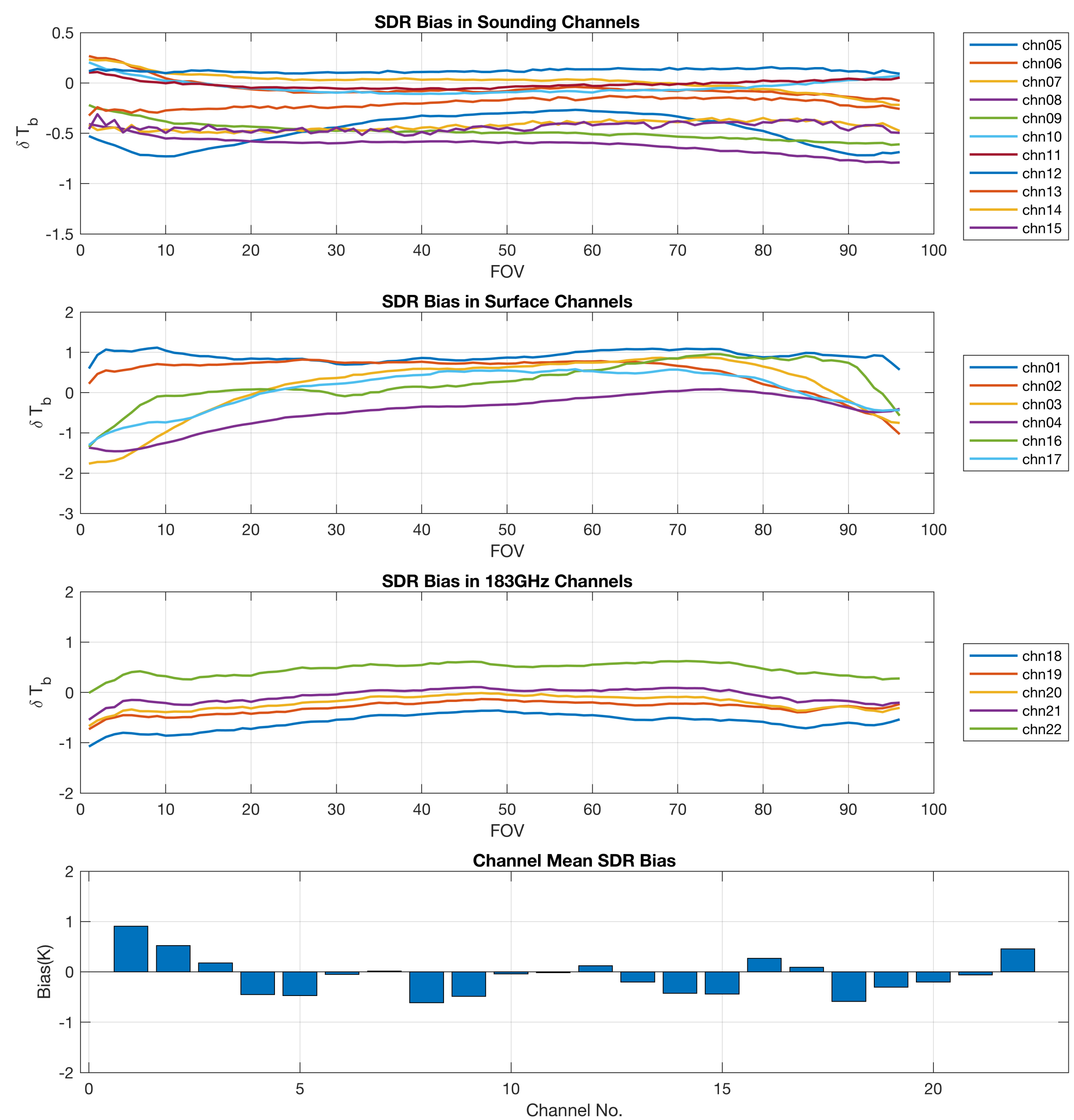
Evaluation Results for SDR Algorithm

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

N20

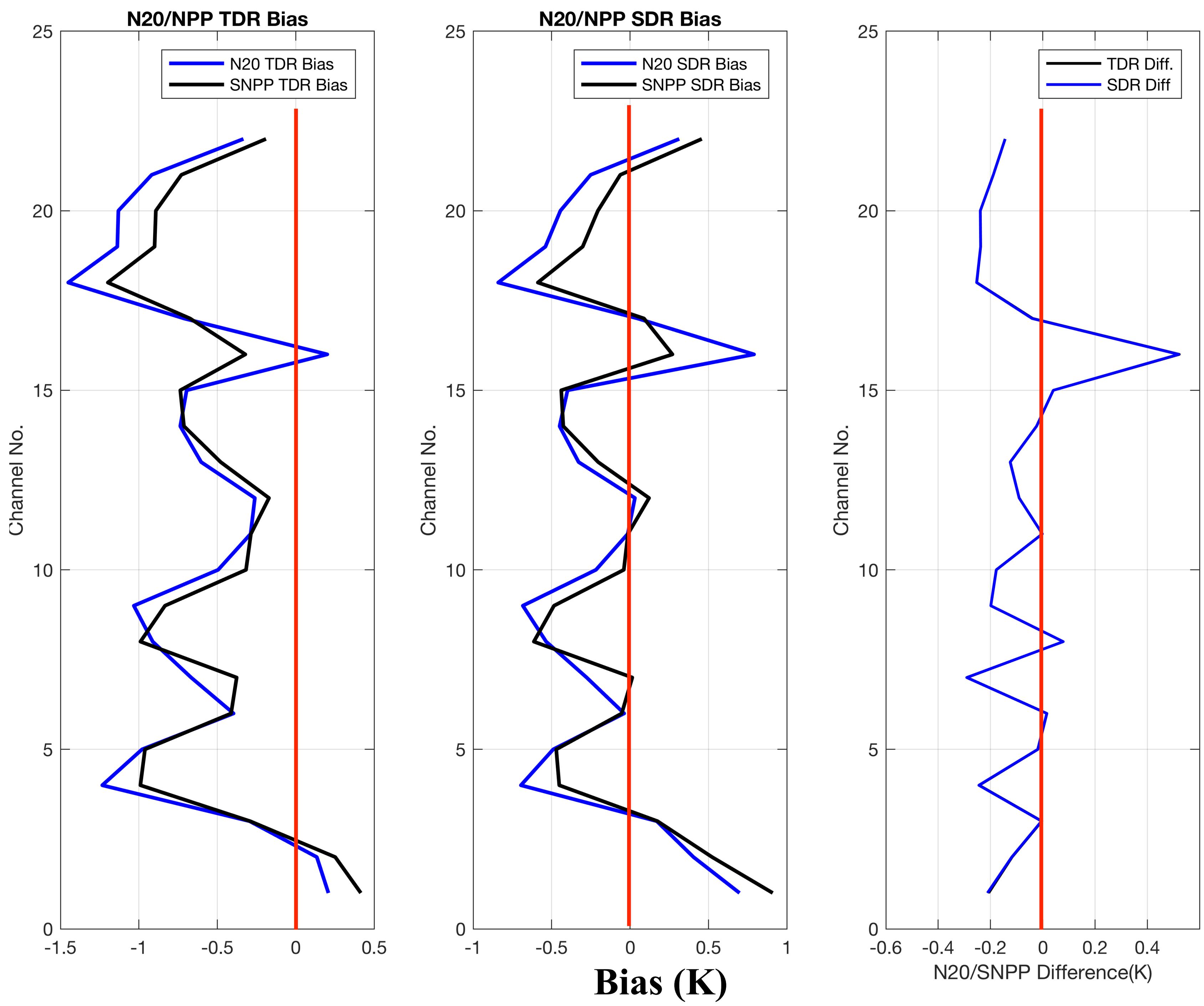


SNPP



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 channels



Conclusions and Future Work

- 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

- Future Work
  - Create hybrid antenna pattern to make further improvement on SDR
  - Develop satellite near-field radiation correction model
  - Revise SNPP ATMS SDR algorithm to keep consistent with N20