Developing vicarious calibration for microwave sounding instruments using lunar radiation

Hu(Tiger) Yang

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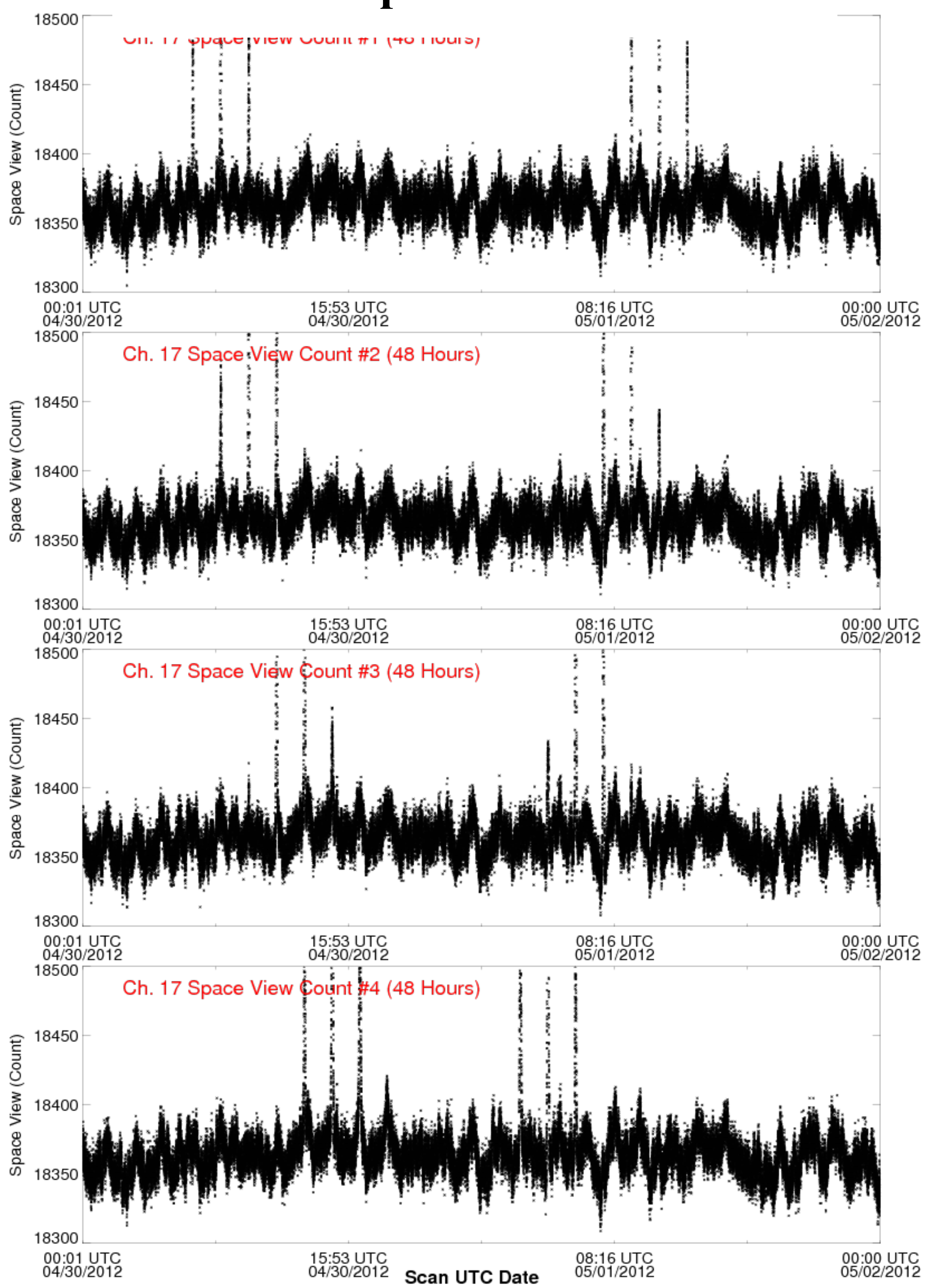
NOISE

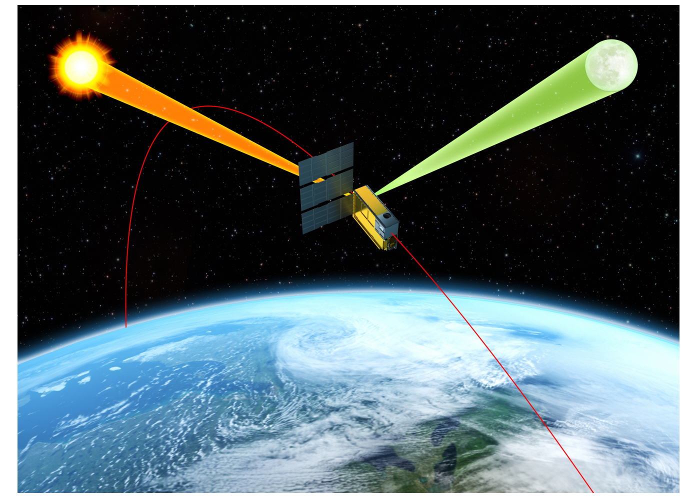
Lunar radiation as a noise need to be corrected

Lunar Intrusions Observed in ATMS Space View Counts

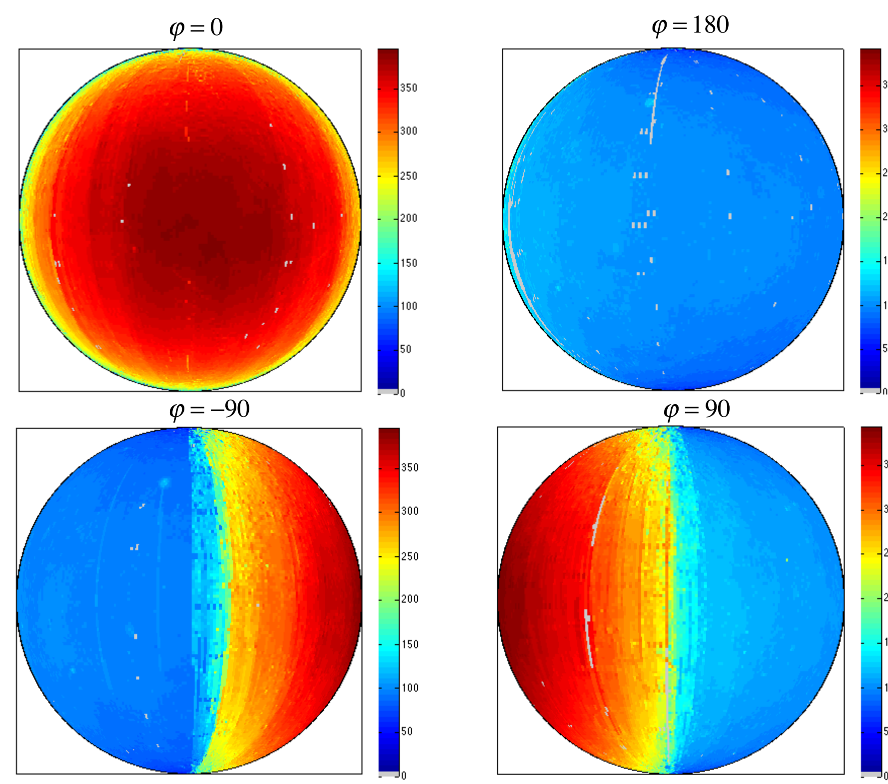


INFORMATION

Lunar radiation as an important information need to be retained



- Accessible for all spacecraft in earth orbit
- Wide dynamic range in brightness temperature
- Highly stable radiation in microwave band



Advantages of Lunar Calibration

- Accessible for all spacecraft in cubic satellite constellation
- Time and location of lunar observations are highly predictable
- Highly stable radiation in microwave band

Challenges of Lunar Calibration

- Accurate antenna pattern measurements
- Knowledge of Lunar brightness temperature spectrum in microwave frequencies
- Knowledge of lunar phase lag in lunar surface brightness temperature model

Outline

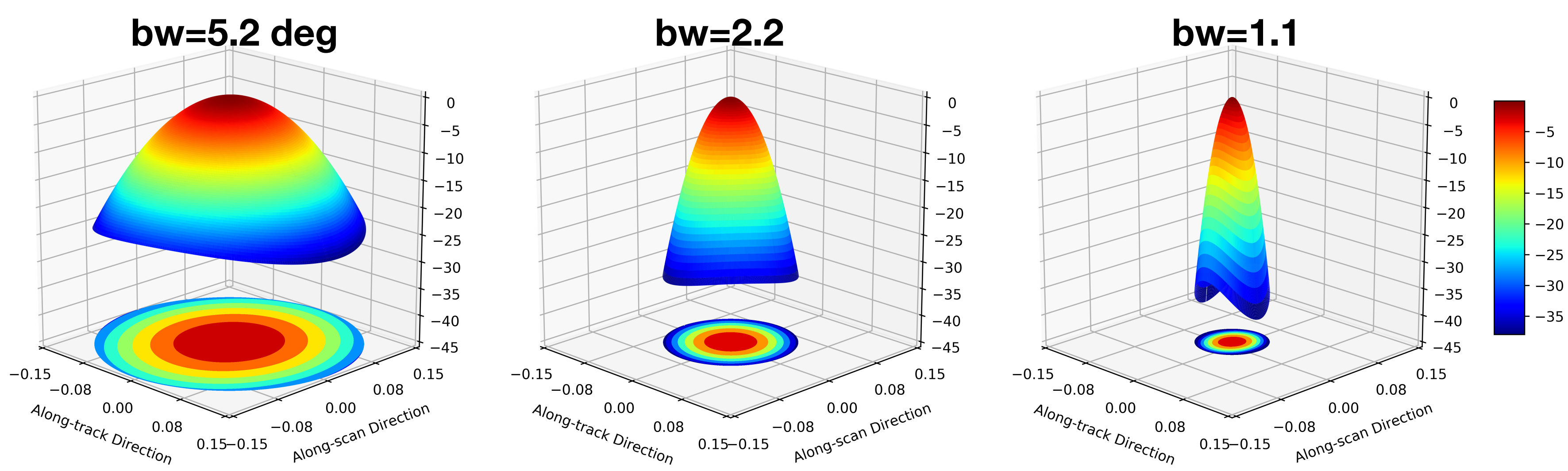
- Simulation of lunar observations from satellite orbit
- 2-D lunar scan observations from NOAA-20 ATMS
- Microwave brightness spectrum of Lunar's disk derived from ATMS
- Lunar model for ATMS calibration
- Application examples of lunar calibration for ATMS instruments

Antenna Response Obtained from ATMS 2-D Lunar Scan

when apparent angle of Moon's disk is much smaller than antenna beam width, the data sampling at each FOV represents the integration of normalized antenna response over Moon's disk and averaged over integration time

$$G(\theta,\phi)=\frac{1}{\tau}\int_{\frac{-\tau}{2}}^{\frac{\tau}{2}}dt\oiint\limits_{\Omega_{moon}}G'(\theta',\phi')sin\theta' d\theta' d\phi'$$

Normalized Antenna Response After Interpolation by Using 2-D Gaussian Function

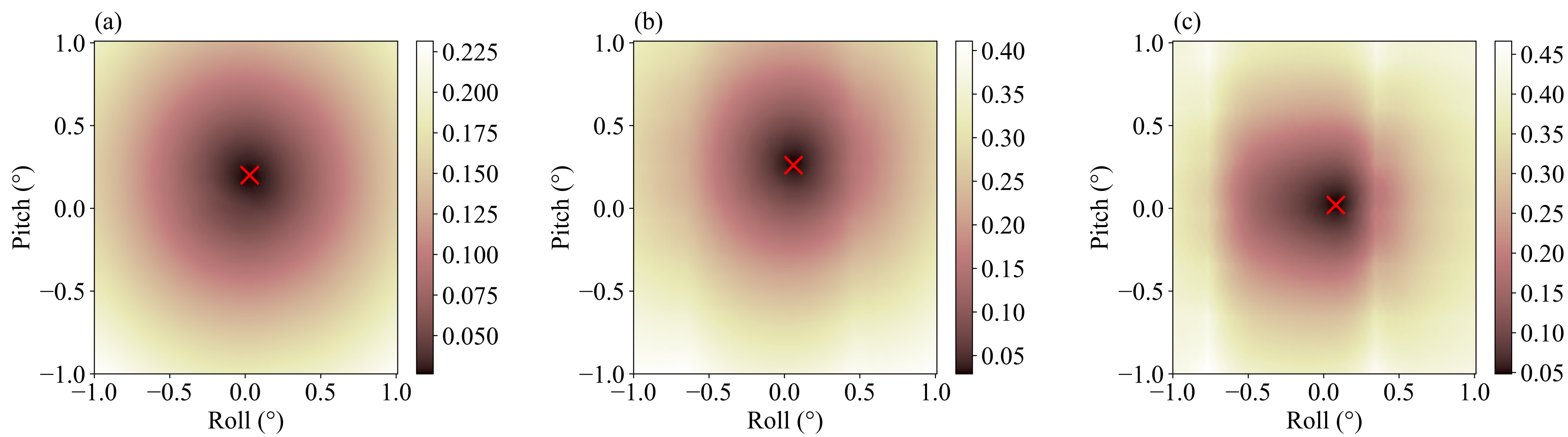


Method for Beam Pointing Error Assessment

Considering the facts that the magnitude of antenna response is very sensitive to position of Moon's center in the Field of View of antenna beam on observing direction. Especially when lunar appears at the center of FOV, where the gradient of antenna response reaches its maximum. Therefore by comparing simulated antenna response of lunar scans with the observation truth, the displacement of beam center can be identified.

Given (ξ_r, ξ_p) are roll and pitch Euler angles error in ATMS geometric calibration, the optimum (ξ_r, ξ_p) value can be determined by finding the minima of the function below:

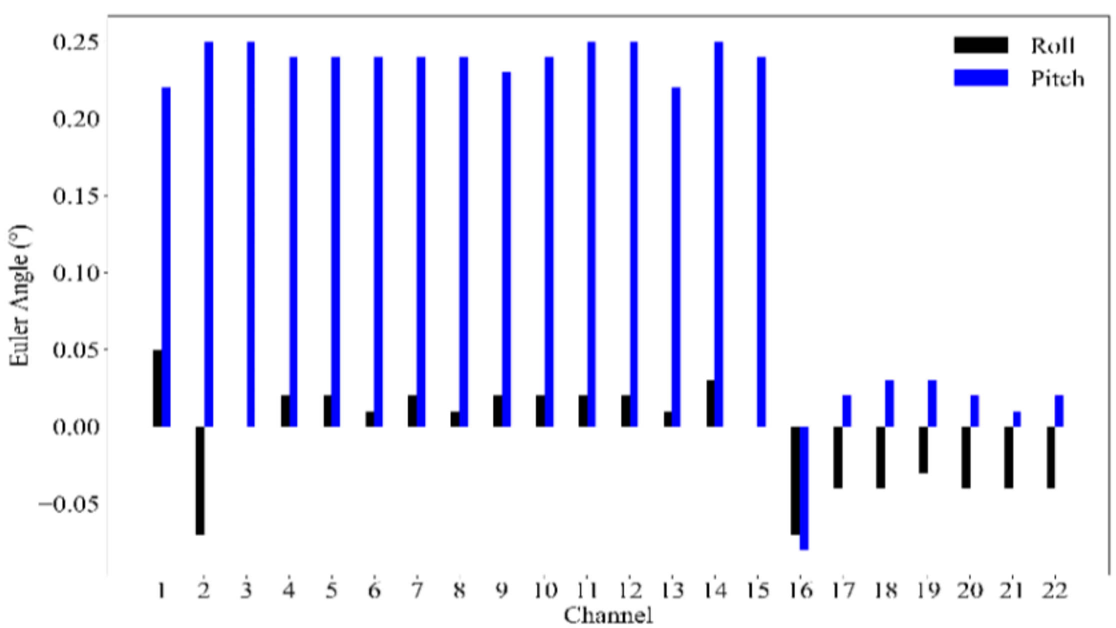
$$\sigma(\xi_r, \xi_p) = \frac{1}{N-1}\sqrt{\sum_{i=1}^{N}(G(\xi_r, \xi_p) - G_{obs})^2}$$



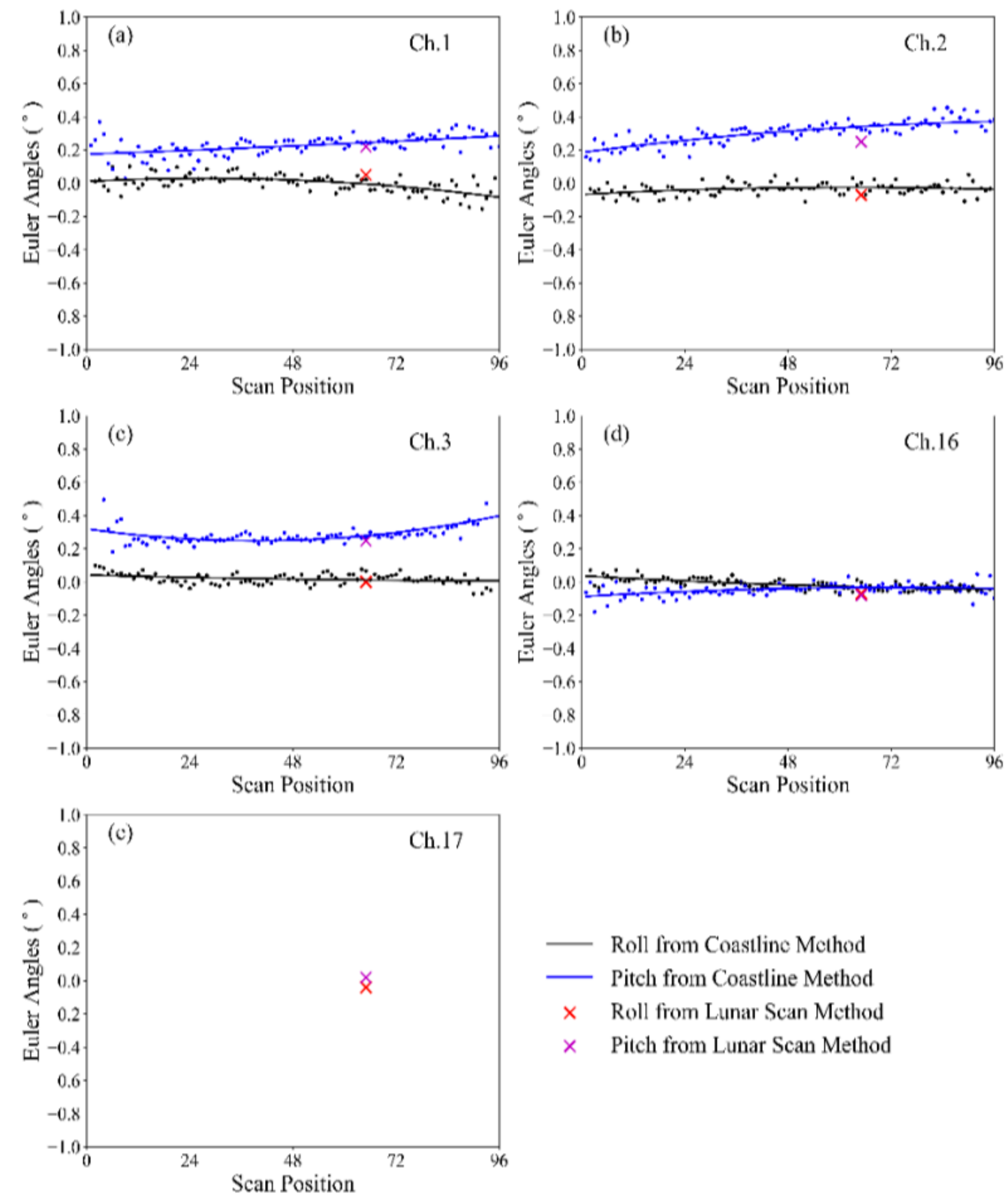
Retrieving Results and Validation

- 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

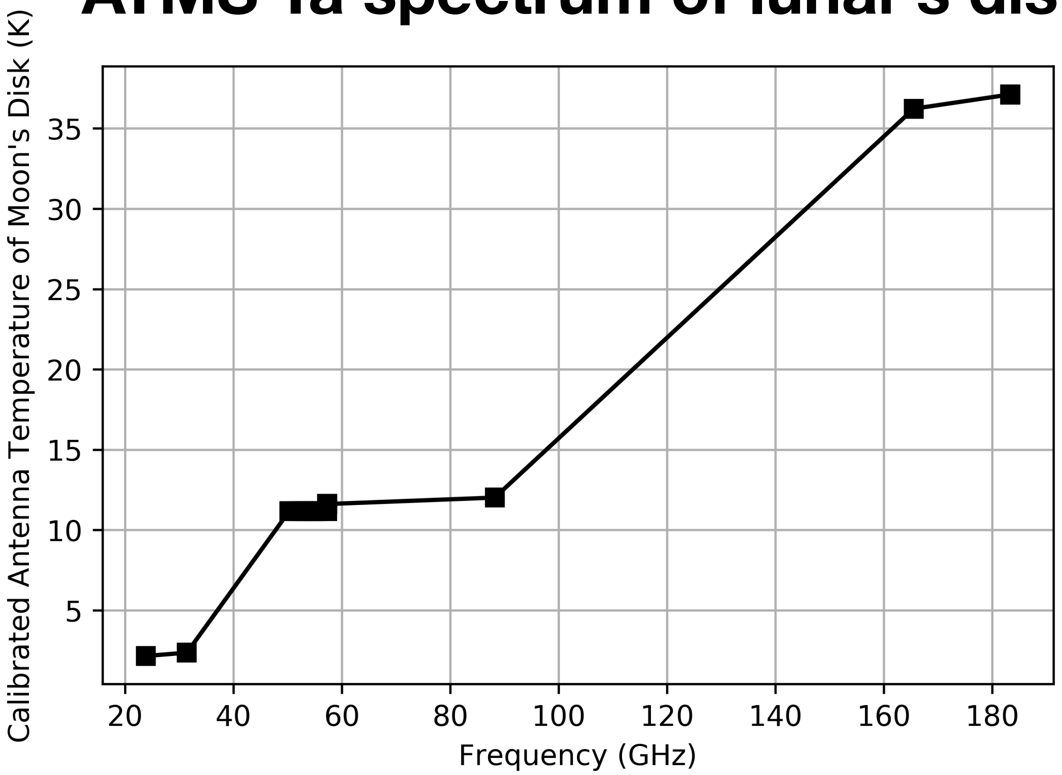


Validation with Results from Coastline Method

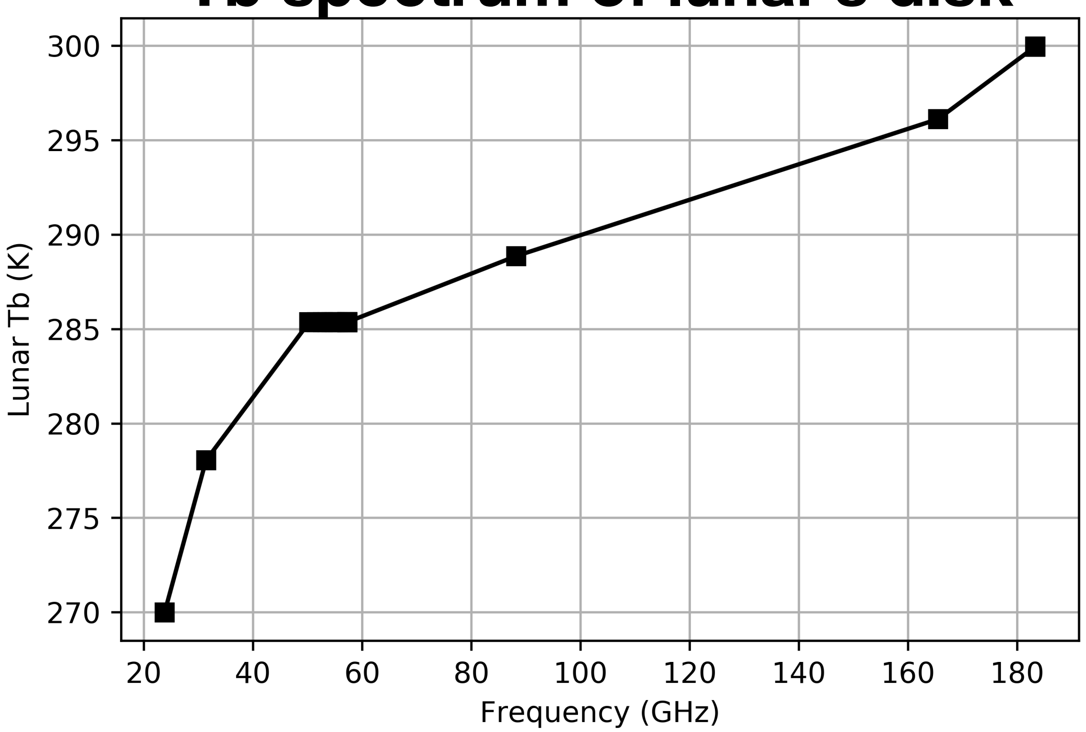


Retrieving Model for Lunar Microwave Brightness Temperature Spectrum

ATMS Ta spectrum of lunar's disk



Tb spectrum of lunar's disk



original lunar observations were calibrated to radiance, with instrument nonlinearity, cold background radiation, as well as the thermal emission from antenna reflector were corrected and removed from observations

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

$$R^{moon} = R - R_c - Sa$$

By combined using ground measured antenna parameters and on-orbit derived antenna responses of lunar radiation, the disk-integrated lunar microwave brightness temperature spectrum can then be derived from well-calibrated lunar antenna temperature

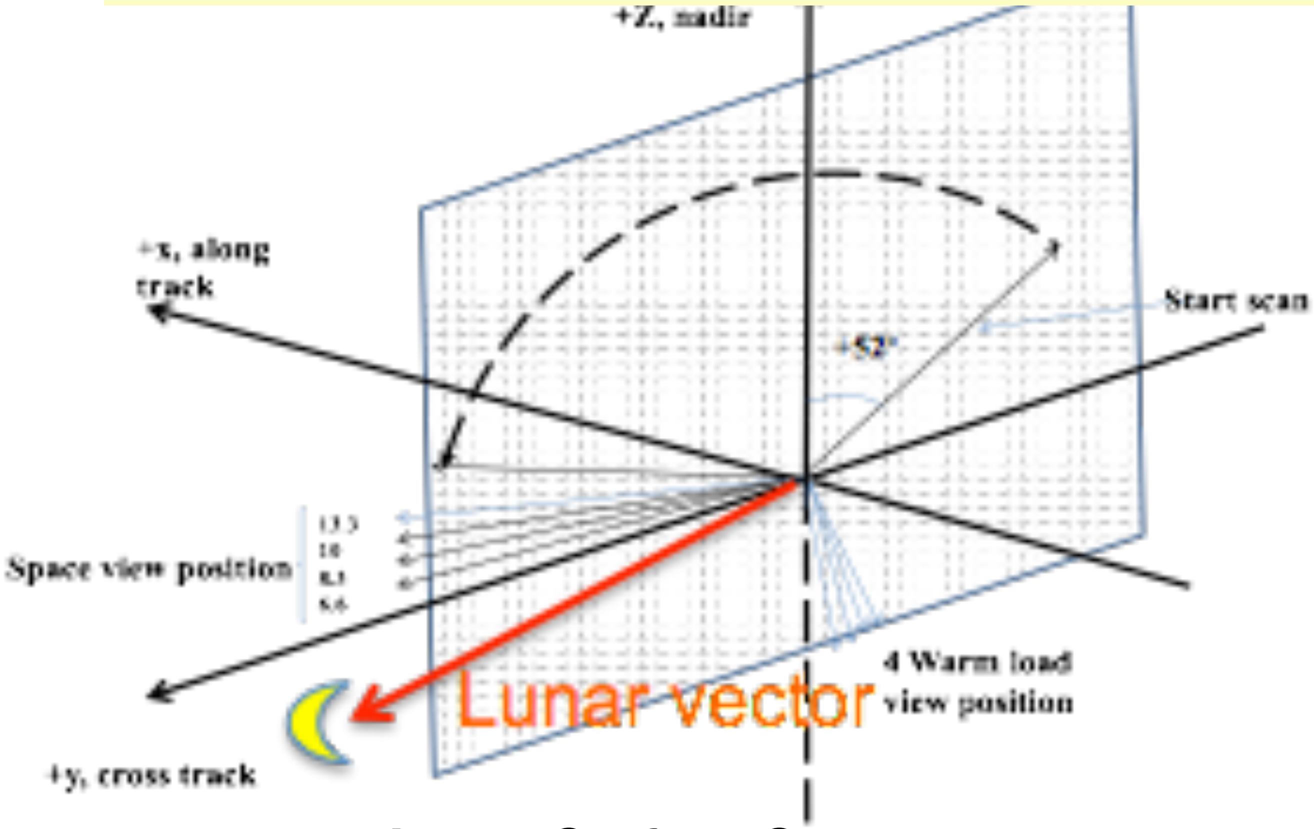
$$Ta_{moon}(\theta_{ifov}, \phi_{ifov}) = \frac{Tb_{moon}^{Disk} \cdot \Omega_{moon}^{max}}{\Omega_p} G(\theta_{ifov}, \phi_{ifov})$$

$$Ta_{moon} = Ta_{moon}^{max} \cdot G(\theta, \phi)$$

$$Tb_{moon}^{Disk} = \frac{\Omega_p \cdot Ta_{moon}^{max}}{\Omega_{moon}^{max}}$$

Lunar Model for ATMS Calibration

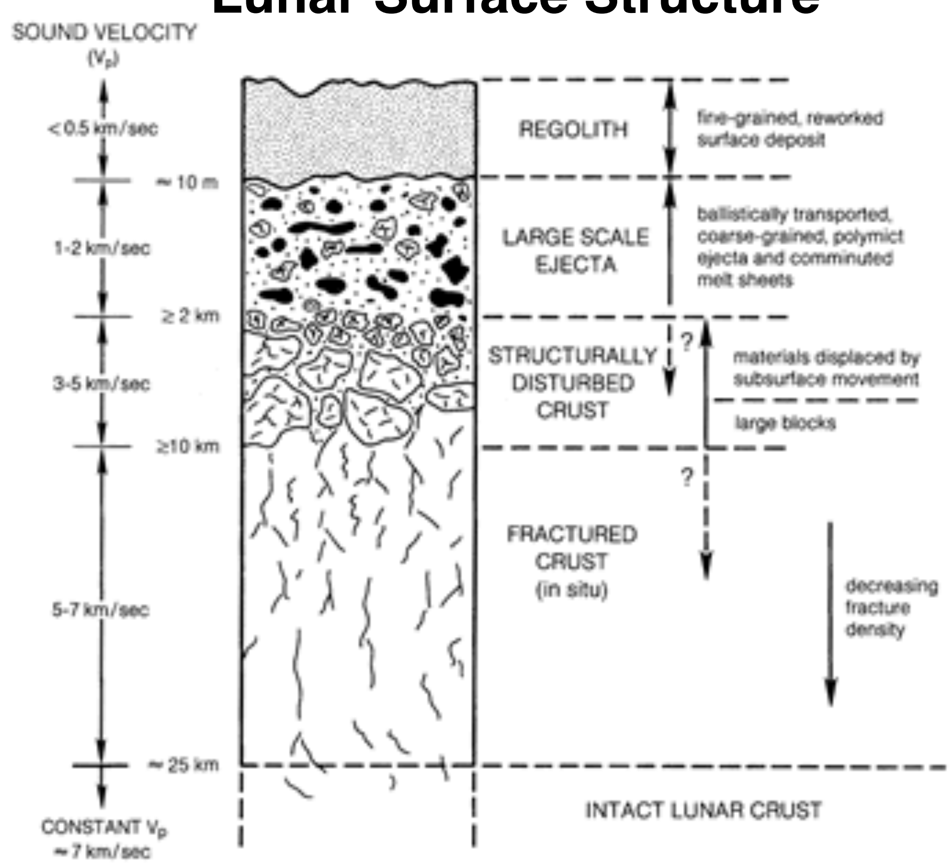
- **H. Yang and F. Weng. “Correction of On-Orbit ATMS Lunar Contamination, ” *IEEE Geosci. Remote Sens.* vol. 54, no. 4, Apr. 2016.**
- **Hu Yang, Jun Zhou, Ninghai Sun, Kent Anderson, Quanhua Liu, Ed Kim, 2018, “Developing vicarious calibration for microwave sounding instruments using lunar radiation”, IEEE Transactions on Geoscience and Remote Sensing, Vol.99, PP.1-11**



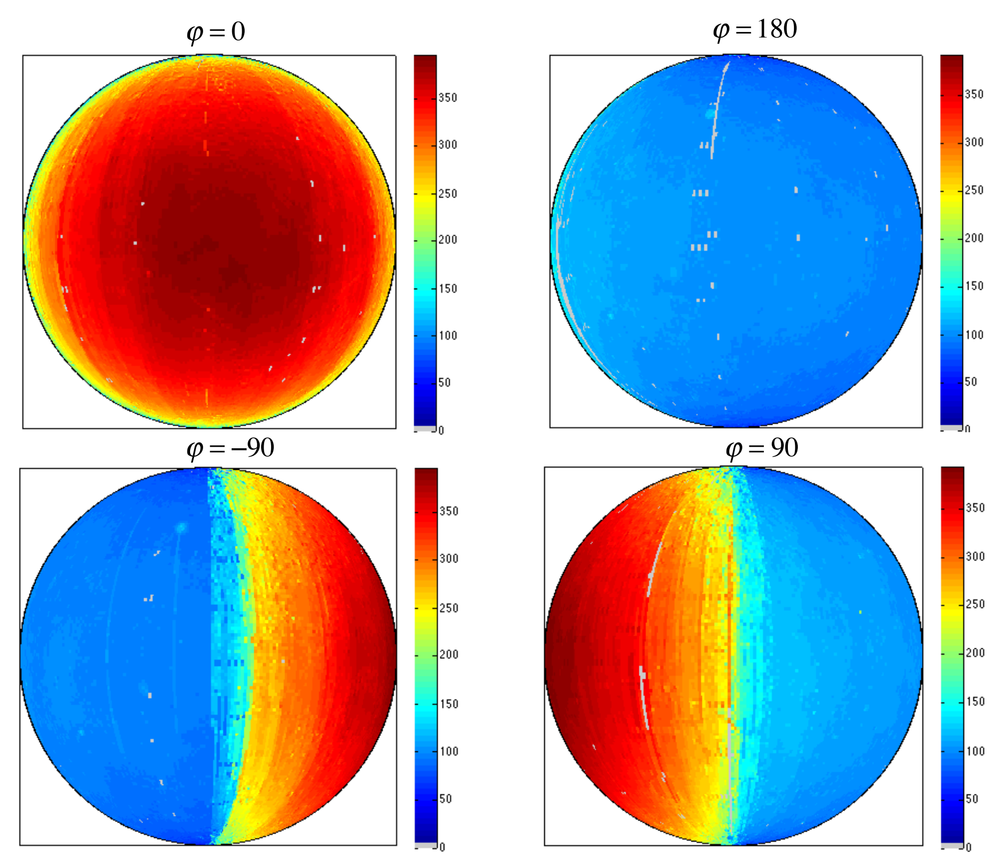
When the Moon appears in satellite observation field of view (FOV), the effective microwave brightness temperature of moon’s disk, can be expressed as function of antenna response function G_{ant}, normalized solid angle of the moon Ω_{moon}, and average brightness temperature of the moon’s disk :

$$TB_{moon}^{eff} = \Omega_{moon} \cdot G_{ant} \cdot TB_{moon}^{disk}$$

Lunar Surface Structure

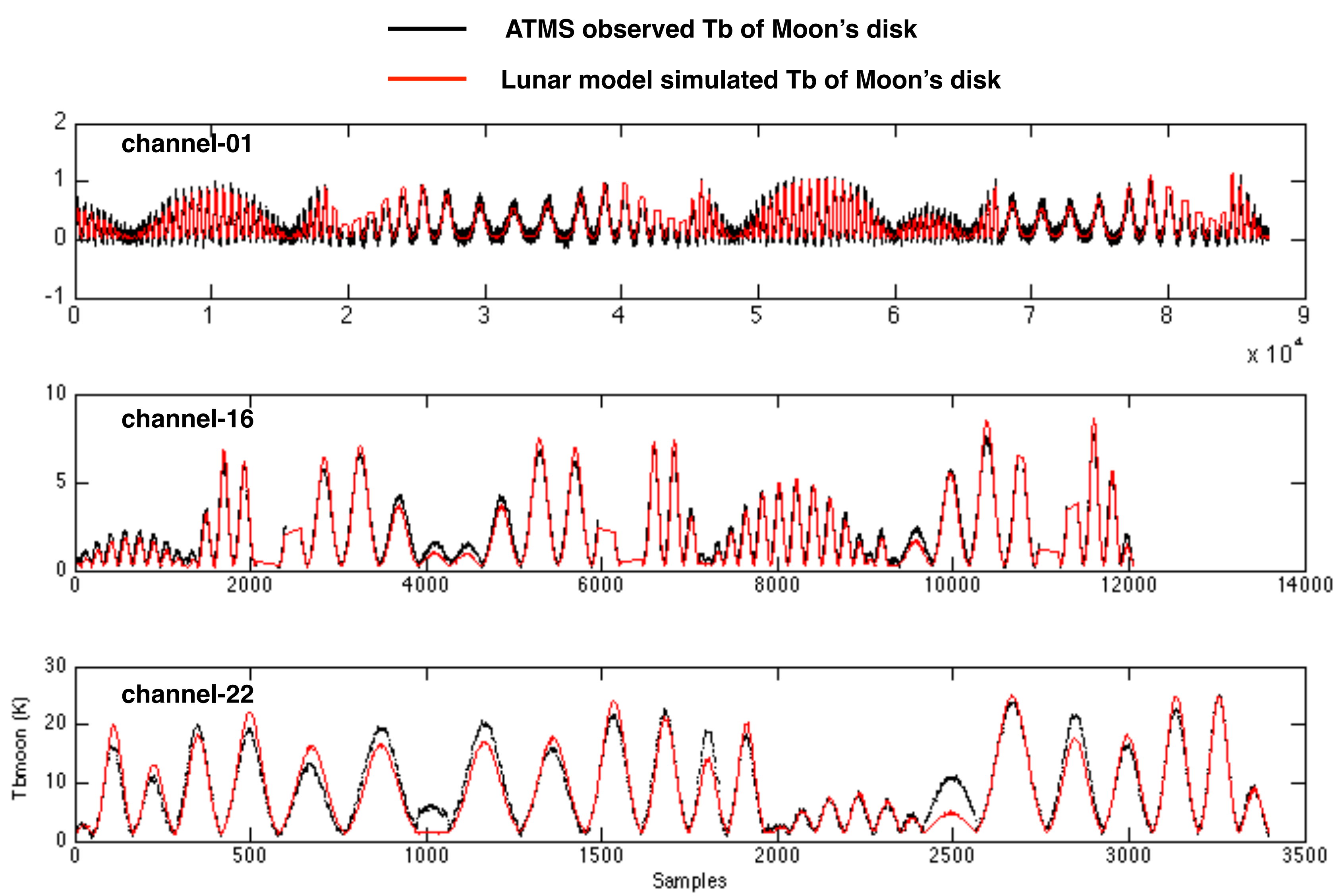


Global Distribution of Lunar Surface Temperature

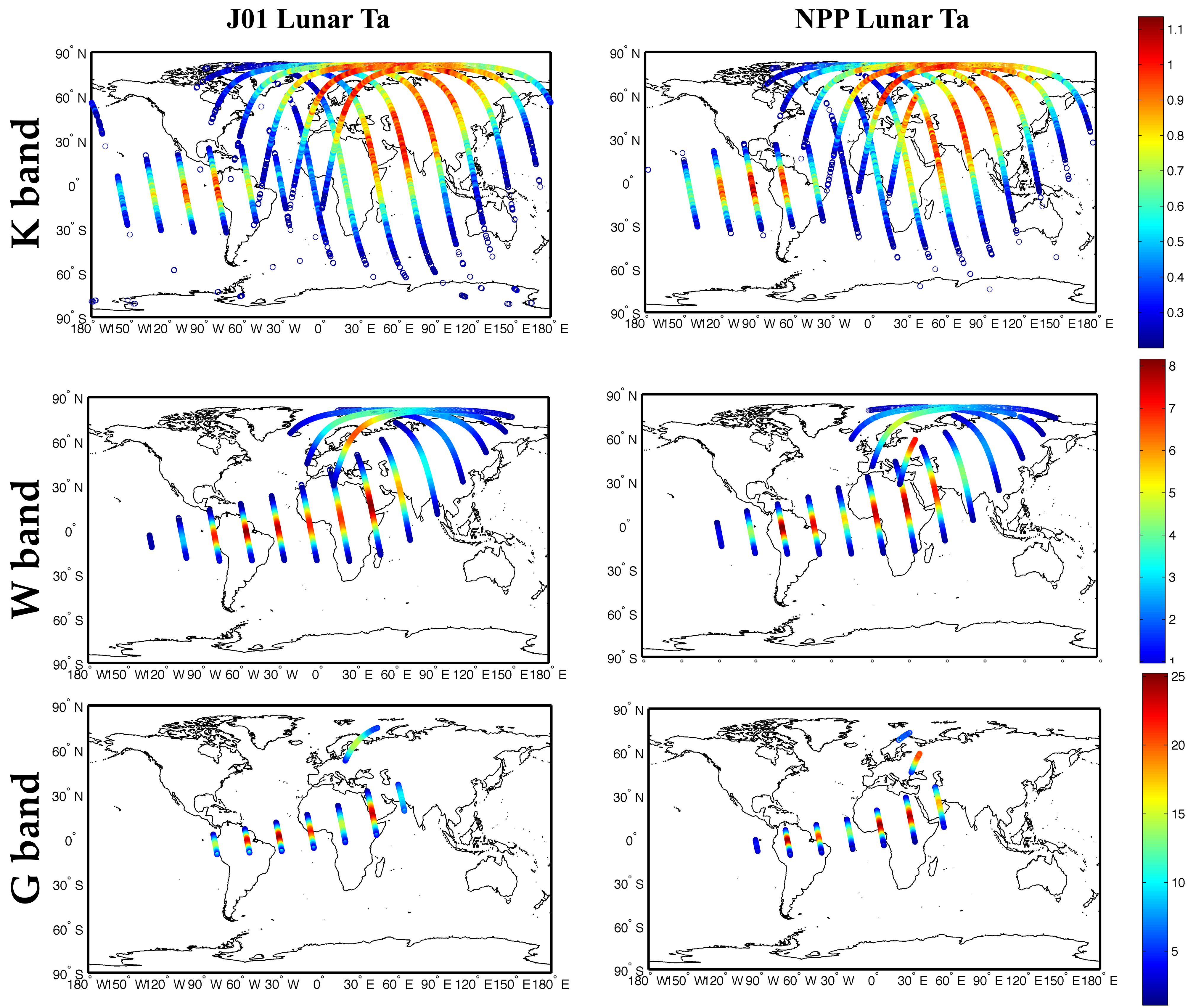


Lunar Model Validation

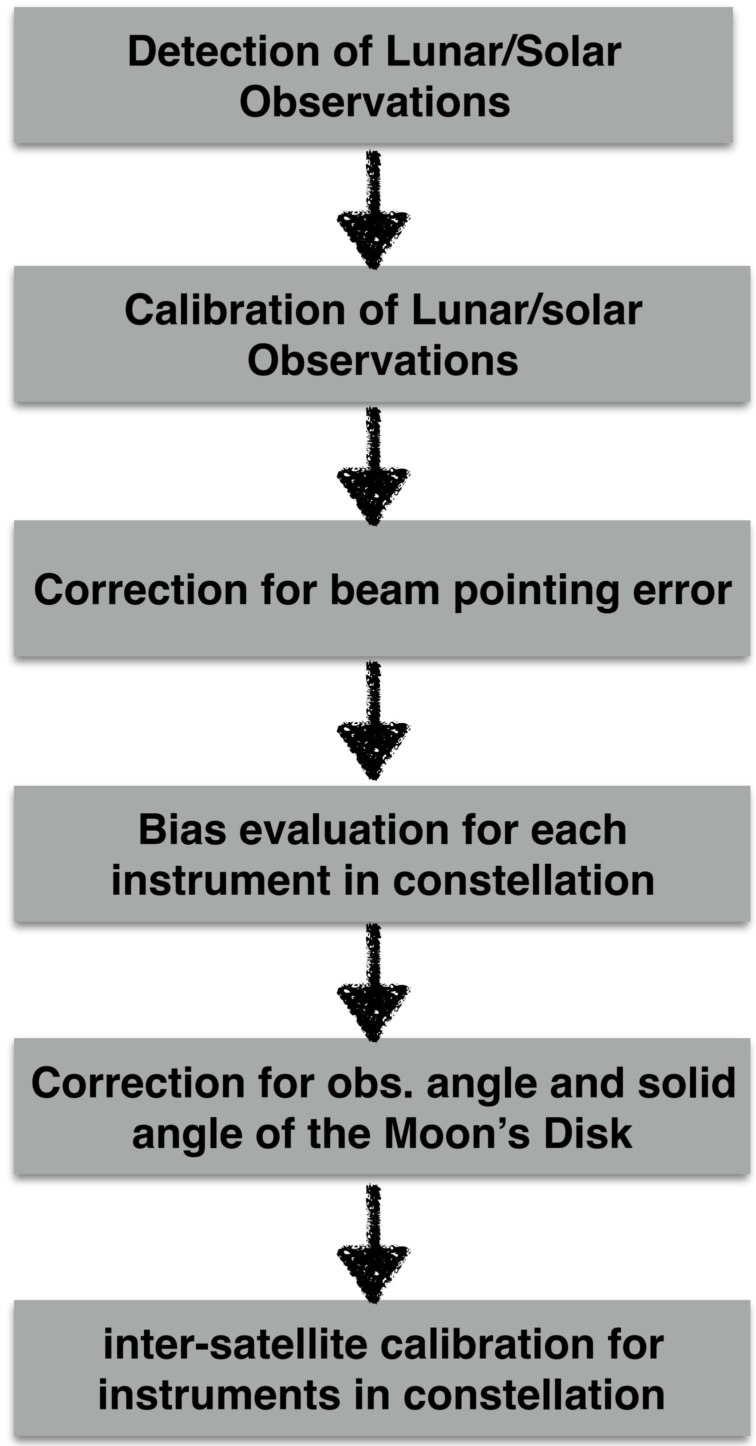
- Lunar observations from ATMS instrument from January 2012 to January 2017 are calibrated and compared with the model simulations
- The mean bias is less than 0.1K with a standard deviation around 0.2k in K, Ka, W and V bands, the standard deviation of model bias in G-band is conspicuously different with other channels and close to 1 K
- Higher model error in G bands might be explained by the much higher noise of antenna pattern measurements in these high frequency channels and therefore the larger error in lunar model as a result



Lunar Observations from Tandem Pair of ATMS onboard NOAA-20/SNPP
Dec. 28, 2017

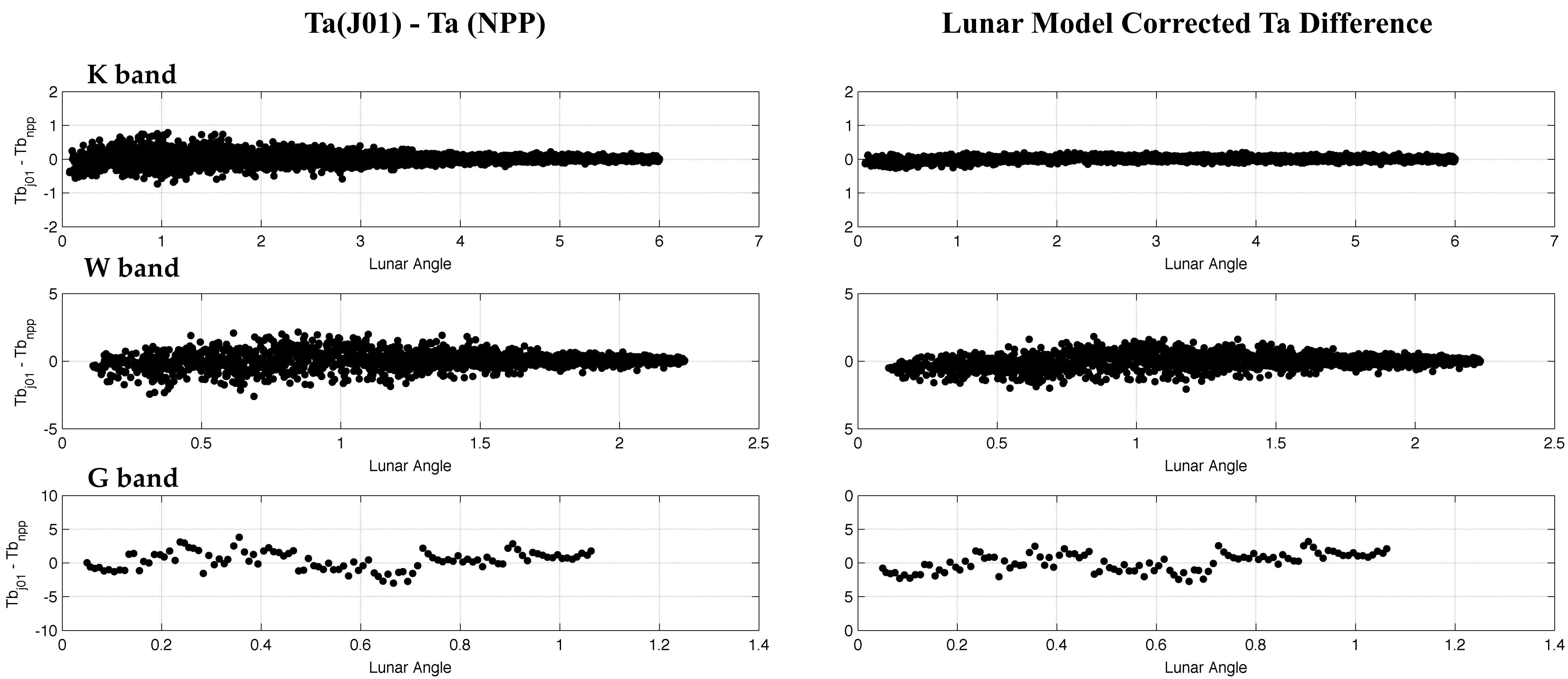


ATMS Lunar Calibration Scheme



Inter-satellite Calibration between J01 and NPP

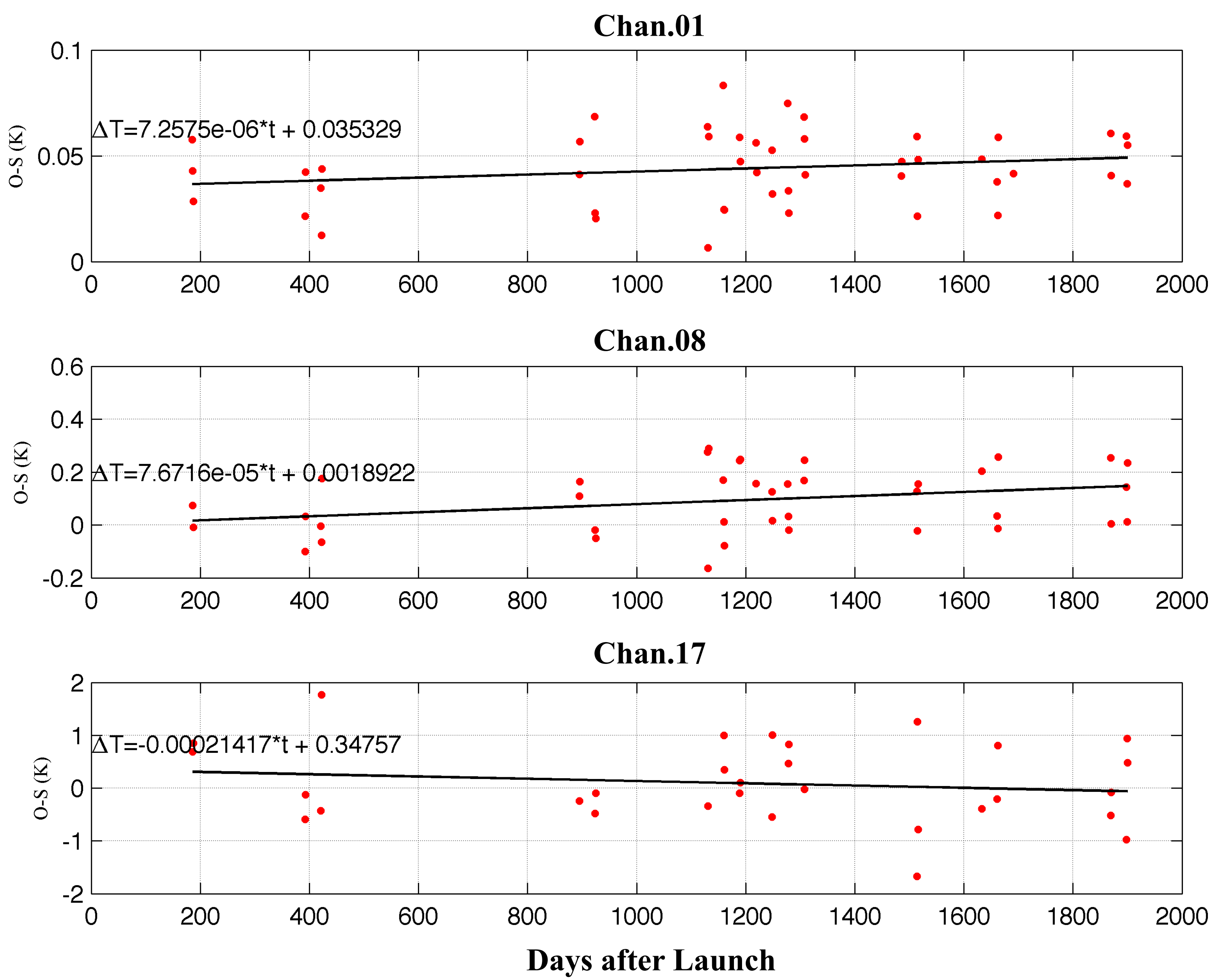
- Calibrated lunar Ta can be used to identify calibration difference between J01 and SNPP ATMS instruments
- Calibrated lunar Ta is very sensitive to pointing error at the angle near the antenna beam center
- Lunar model can be used to reduce impact of different pointing angle error in J01 and NPP



Long-term Instrument Stability Monitoring

Lunar as a Permanent Reference Target can also help to evaluate the long-term calibration stability of microwave sensors. Here, the lunar brightness temperature model developed in this work is used to simulate the effective brightness temperature of moon's disk, and then compared with the measurements from ATMS instrument. Sensor calibration stability can then be evaluated as

$$S = d(\Delta T_{moon}^{\square})/dt$$



Conclusions and Future Work

- Lunar radiation is highly stable in microwave band and can be taken as permanent calibration reference target for microwave radiometers

- 2-D lunar scan observations from NOAA-20 ATMS provide a unique opportunity to obtain knowledge of lunar microwave brightness spectrum in microwave band

- Results from ATMS lunar calibration experiment show that lunar observations from space view during lunar intrusion events are very valuable for microwave radiometer on-orbit cross-calibration and long-term instrument gain stability evaluation.

- Future work is to further improve the lunar radiation model by using newly derived Lunar disk Tb spectrum and include lunar phase lag in the model.