Updates On Microwave Lunar Geolocation and Calibration

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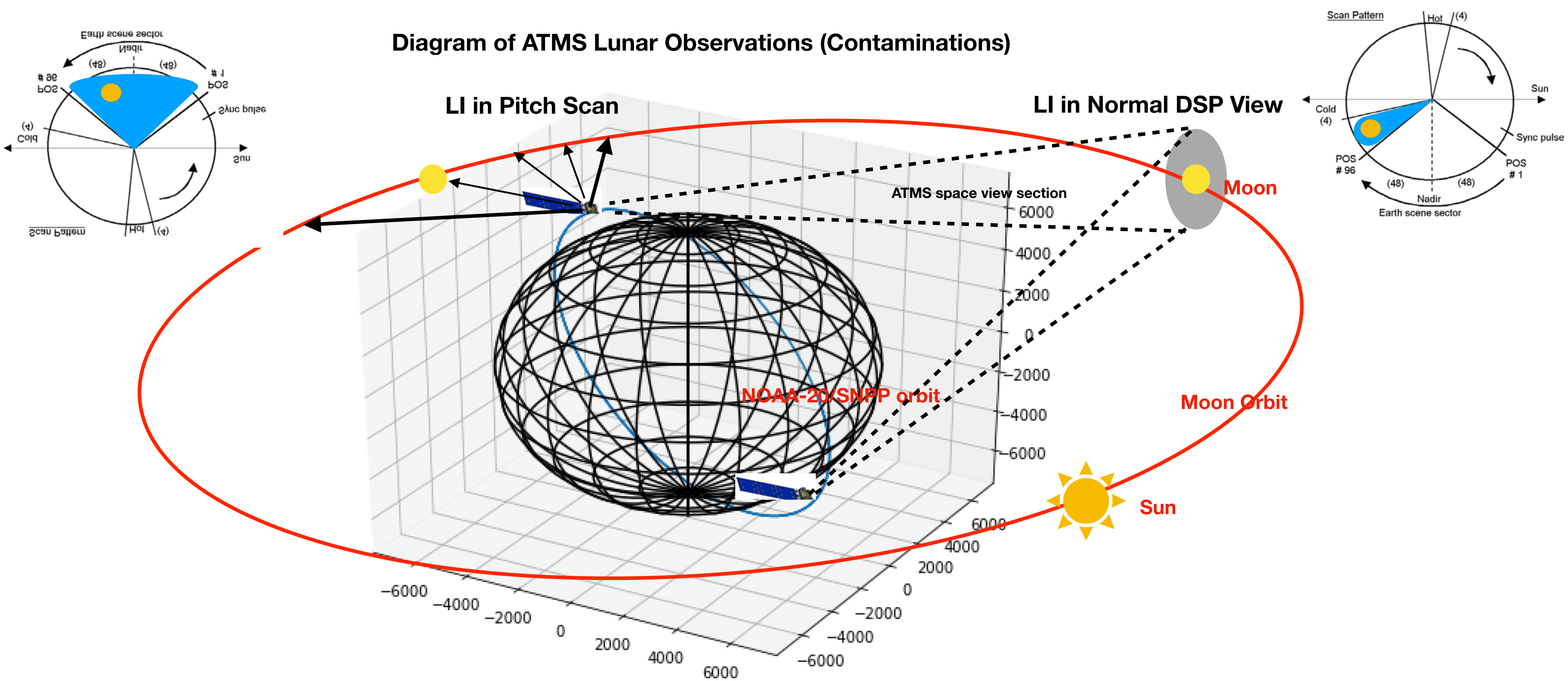
Outline

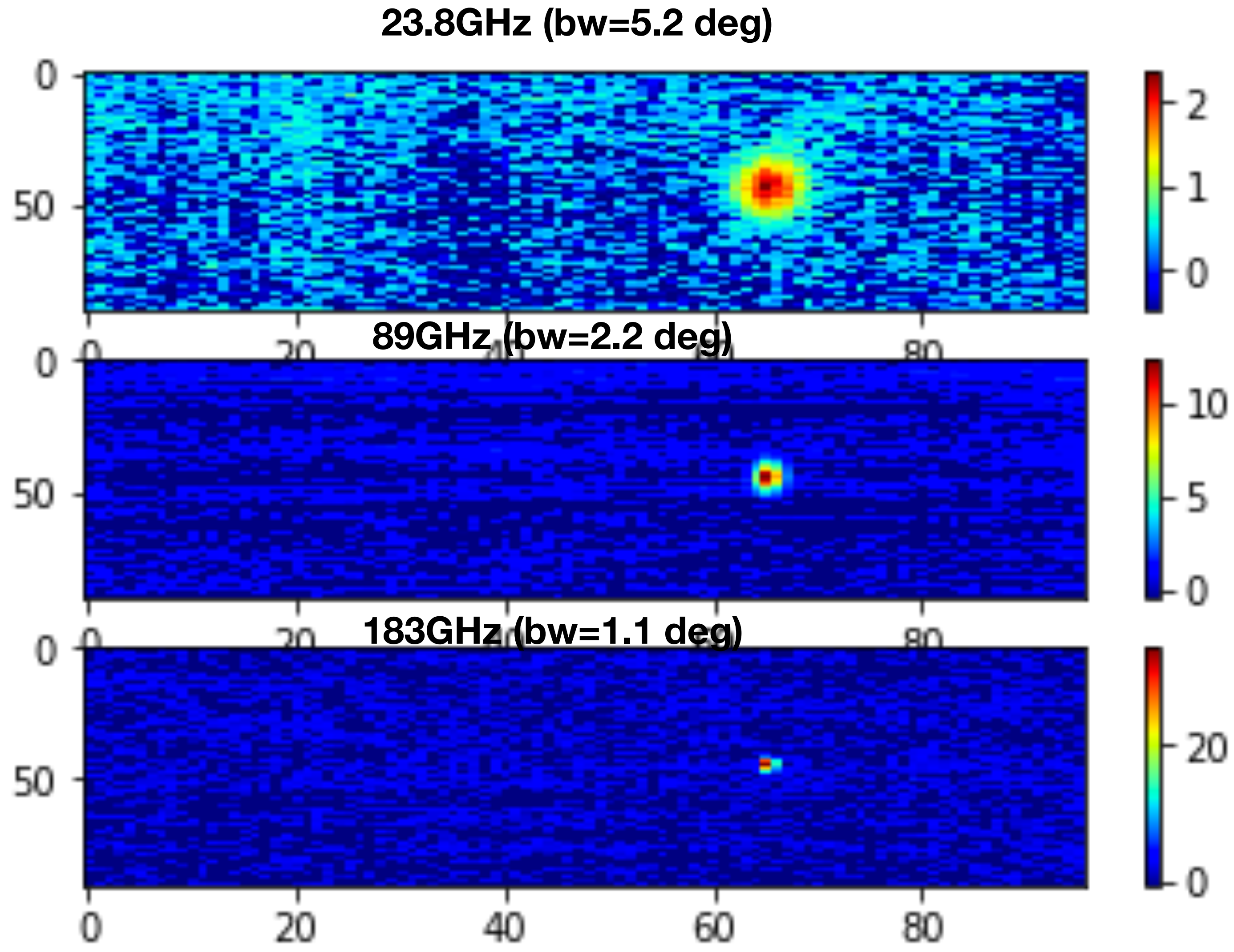
- Evaluation of NOAA-20 ATMS on-orbit geolocation error by using 2-D lunar observations
- Retrieval of Lunar Microwave brightness temperature spectrum from satellite observations
- Validation of satellite derived unresolved lunar disk Tb spectrum with model simulations
- Conclusion and Future work

Two-Dimension Lunar Scan Observations from NOAA020 ATMS

The NOAA-20 satellite was successfully launched on 18 November 2017. On January 31, 2018, the spacecraft performed a pitch-over maneuver operation, during which the two-dimensional lunar scan observations were collected. Due to the orientation of NOAA-20 orbits, radiation from a full Moon disk with closely to 180 deg phase angle were collected when the Moon passing through the antenna beam



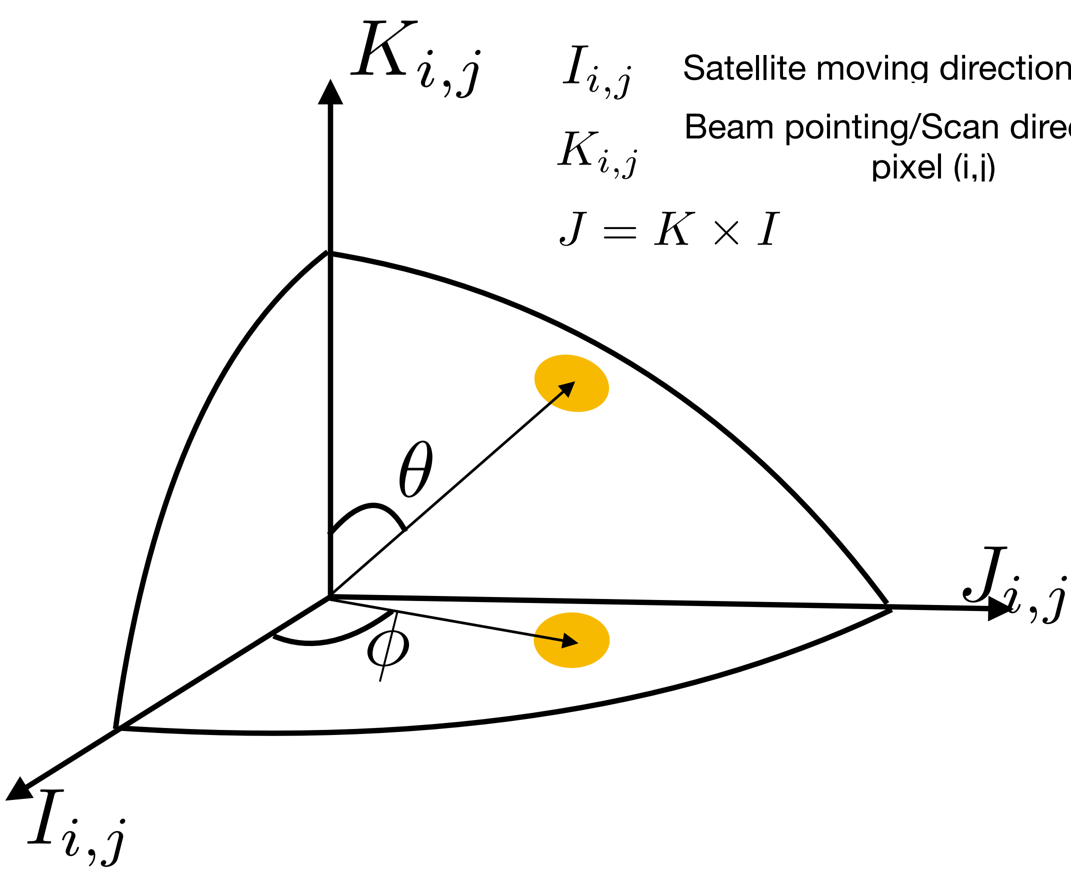
- The observed raw data counts were transferred to brightness temperature by using the calibration equation with the warm load and cold space observations.
- Further corrections for warm bias, earth side lobe contamination, as well as the reflector emission contamination are needed.
- To derive the pure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



2-D Geometry Model for Microwave Moon Observations

Dynamic Antenna Coordinate System for Lunar Scan

- Satellite's motion in along-track direction
- Instrument scanning in cross-track direction
- Moon's displacement during the observing time



$I_{i,j}$ Satellite moving direction at pixel (i,j)

$K_{i,j}$ Beam pointing/Scan direction at pixel (i,j)

$J = K \times I$

2D Satellite Lunar Observation Model

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

$Ta_{moon}(\theta_{ifov}, \phi_{ifov})$ observed antenna temperature of Moon

Tb_{moon}^{Disk} Disk integrated brightness temperature of lunar surface

Ω_{moon} Solid angle of Moon at observed antenna beam width

Ω_p Antenna solid angle

$G(\theta_{ifov}, \phi_{ifov})$ Antenna response of lunar observations at specified scan positio

$$G(\theta, \phi) = \exp -[\frac{(x - x_0)^2}{2\sigma_x^2} + \frac{(y - y_0)^2}{2\sigma_y^2}]$$

$$x = sin\theta \cdot cos\phi$$

$$y = sin\theta \cdot sin\phi$$

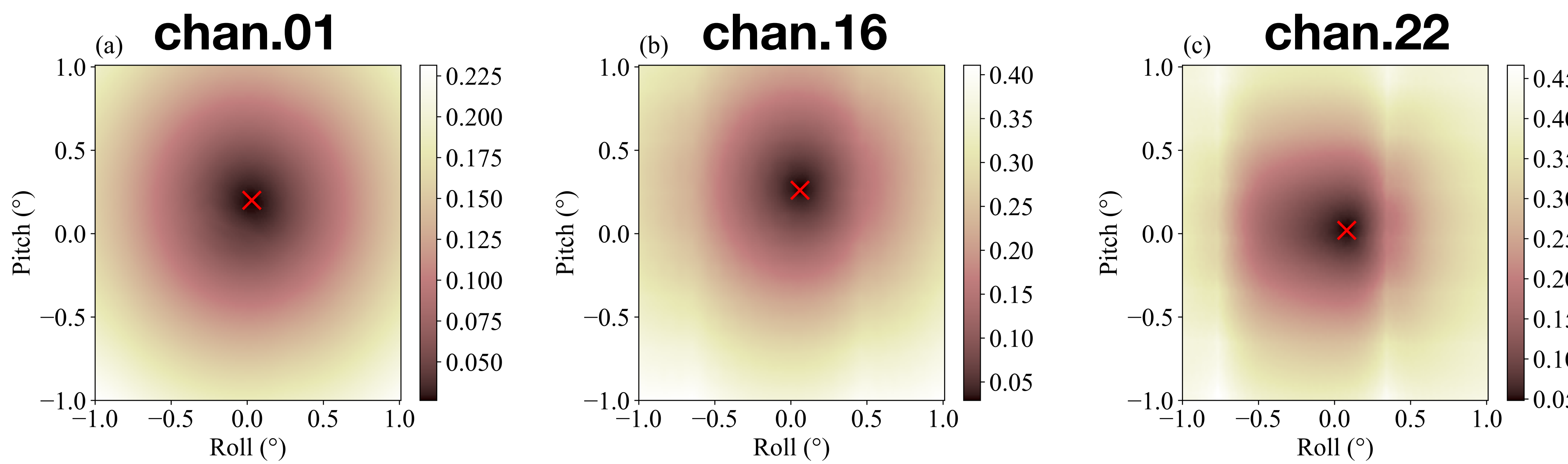
Geolocation evaluation by using 2D scan lunar observations

*Zhou, J. and **Yang, H***., "A study of a two-dimensional scanned lunar image for Advanced Technology Microwave Sounder (ATMS) geometric calibration", Atmospheric Measurement Techniques, vol. 12, no. 9, pp. 4983–4992, 2019. doi:10.5194/amt-12-4983-2019.*

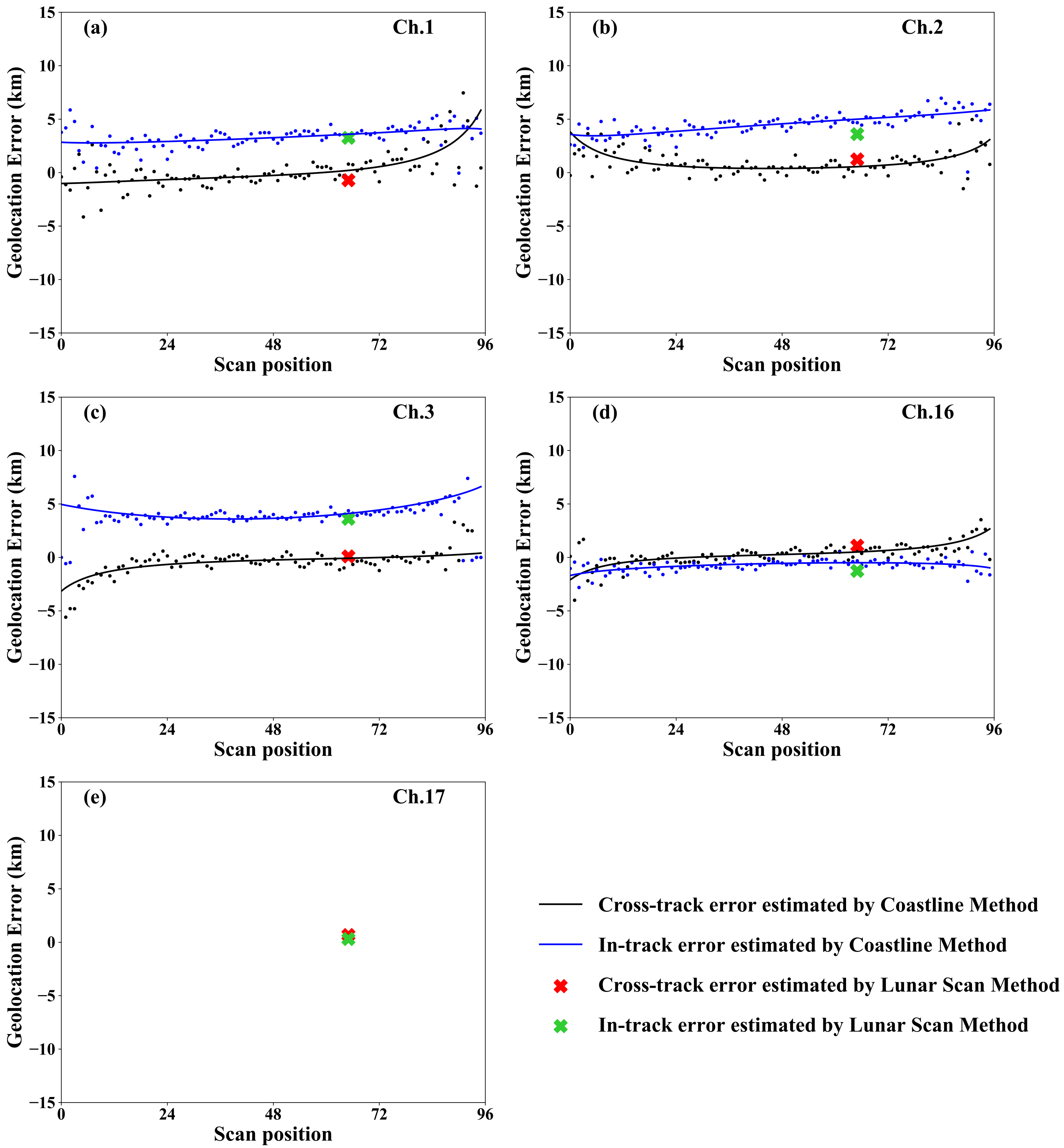
Considering the facts that the magnitude of antenna response is very sensitive to position of Moon's center in the Field of View of antenna beam on observing direction. Especially when lunar appears at the center of FOV, where the gradient of antenna response reaches its maximum. Therefore by comparing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

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



Validation of Lunar Geolocation Results with Coastline Method



Retrieving of Lunar Microwave Brightness Temperature Spectrum

H. Yang et al., "2-D Lunar Microwave Radiance Observations From the NOAA-20 ATMS," in IEEE Geoscience and Remote Sensing Letters, doi: 10.1109/LGRS.2020.3012518.

The calibrated antenna temperature of the Moon's disk of each data sample in a ATMS lunar scan, Ta_{moon}, is the radiance received from the Moon's disk integrated over a 18-ms sampling time along the moving path, which can be modeled as a function of the disk-integrated lunar microwave brightness temperature (Tb_{moon}^{Disk}), the antenna main beam solid angle (Ω_p), and the normalized antenna response (G) as follows:

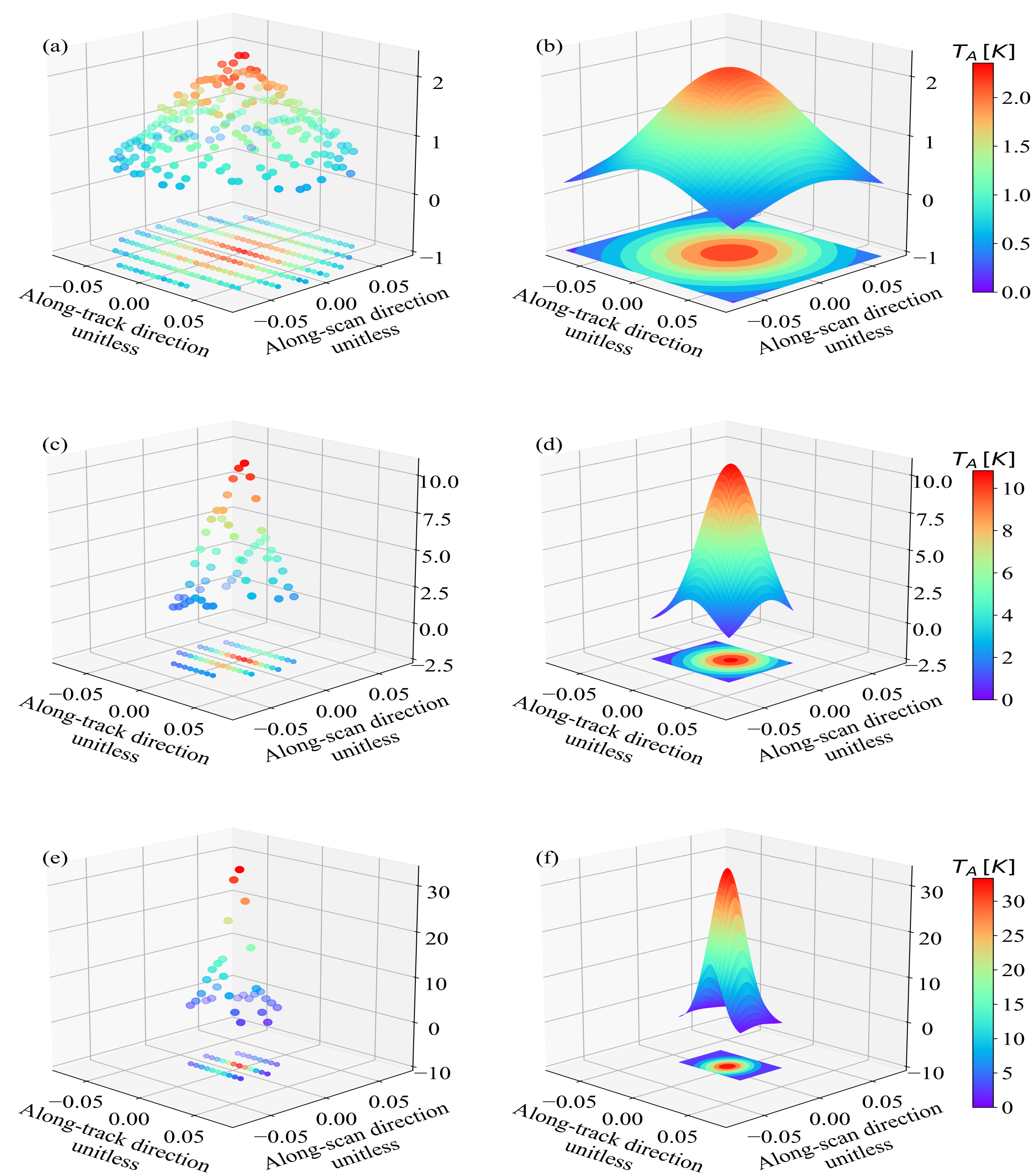
$$Ta_{moon}(\theta_{ifov}, \phi_{ifov}) = Tb_{moon}^{Disk} \cdot \frac{G(\theta_{ifov}, \phi_{ifov})}{\Omega_P}.$$

For lunar observations at each scan position, the antenna response can be simulated as the solid-angle integration of the lunar disk over the instrument integration time along the moving path of the Moon on the surface of the normalized antenna pattern, expressed as follows:

$$G(\theta_{ifov}, \phi_{ifov}) = \Omega_{moon}^{ifov}$$
$$= \frac{1}{\mathcal{L}} \int_{\frac{-\tau}{2}}^{\frac{\tau}{2}} dl \int_0^{2\pi} \int_0^{\alpha_{moon}} G'(\theta', \phi') sin\theta' d\theta' d\phi'$$

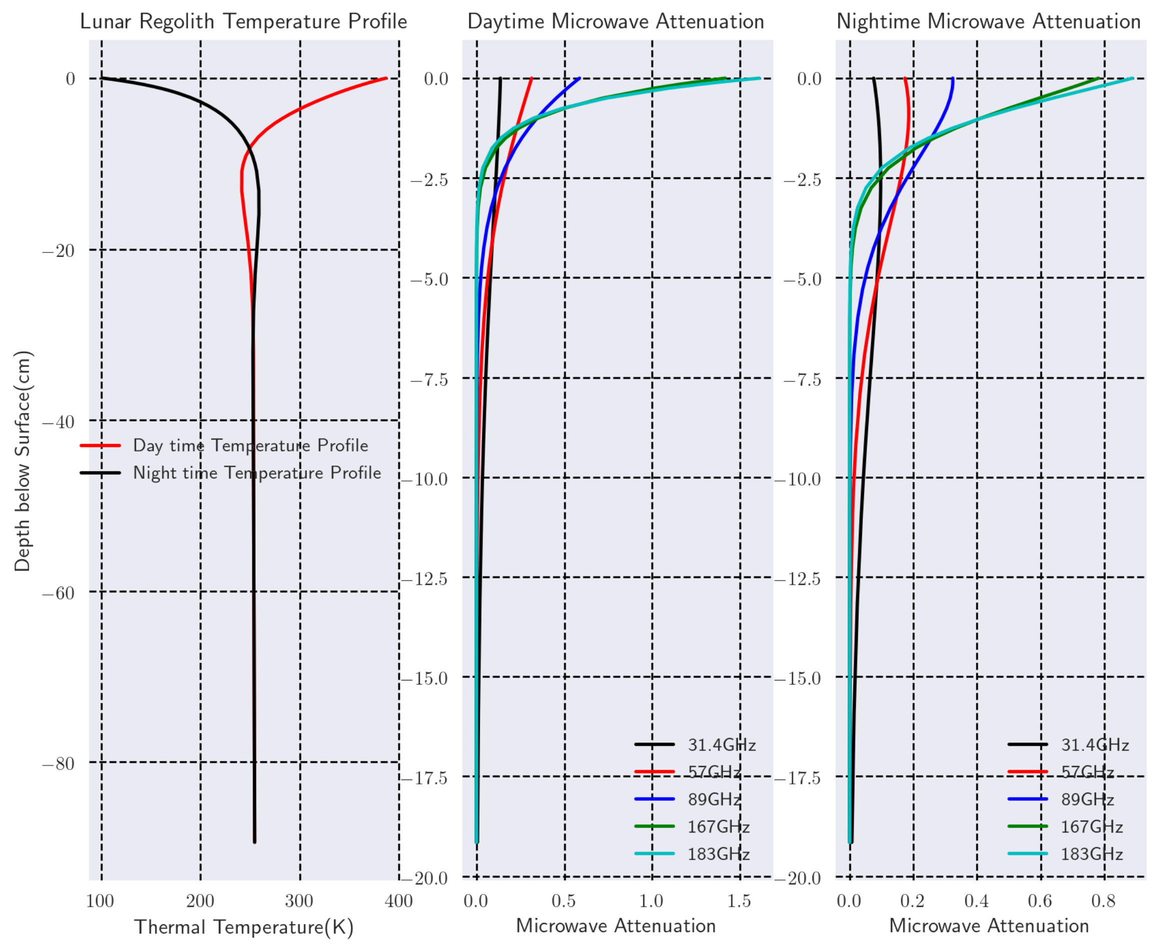
With the lunar solid angle calculated at each scan position, a linear regression model can be established to relate the calibrated lunar antenna temperature with the calculated antenna paramters as follow: For the *ith* lunar observation sample (where i=1,2,... n),

$$y_i = \alpha + \beta x_i + \epsilon_i$$



RTM Model Simulation for Lunar Microwave Emission

H. Yang, 2021, "MILLIMETER LUNAR MICROWAVE RADIANCE: MODEL SIMULATION AND SATELLITE OBSERVATIONS", IGARSS'21

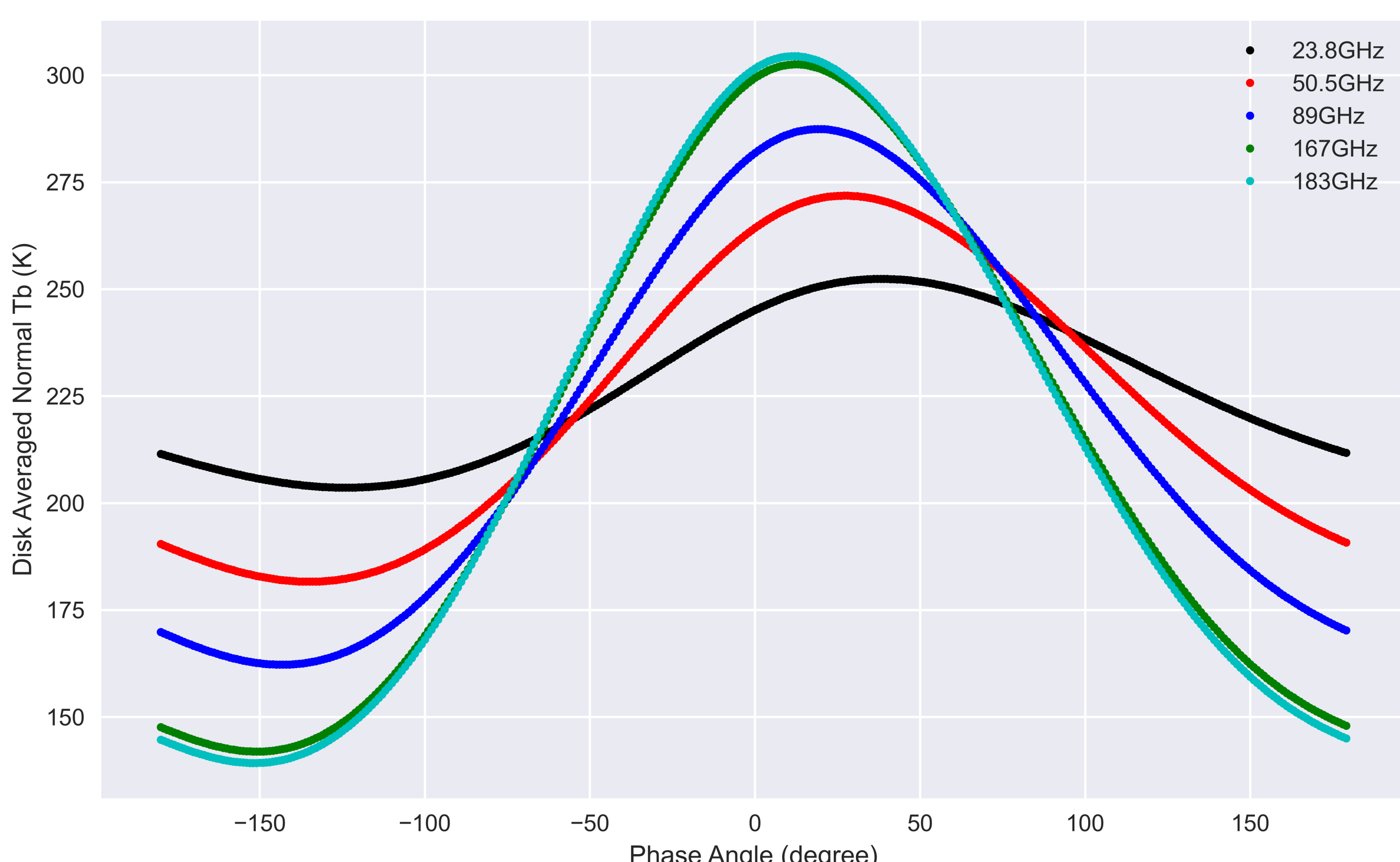


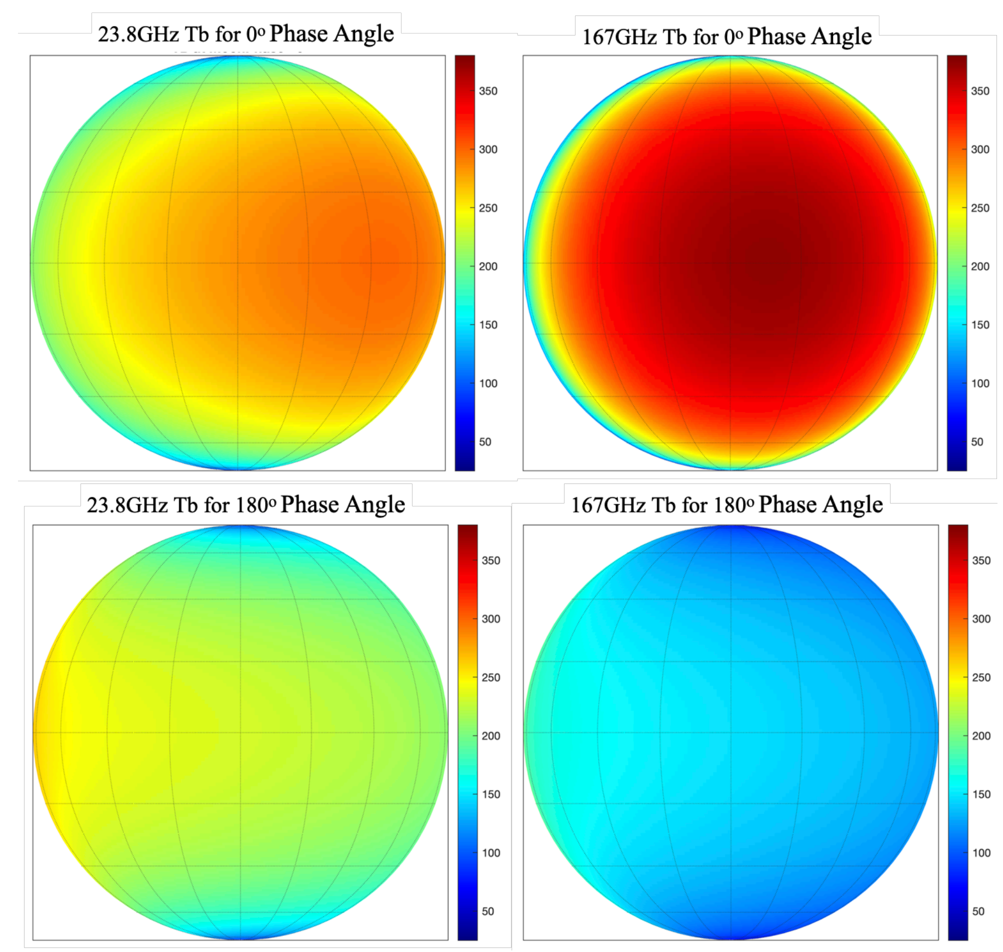
Microwave brightness temperature of lunar emission can be calculated as convolution of microwave electrical loss with lunar regolith temperature profile over different depth(Keim, 1984)

$$TB(\lambda) = E_\lambda \int_0^\infty K_\lambda \sec(\theta_i) \cdot T(z) \cdot e^{-\int_0^z K_\lambda(z') \sec(\theta_i)} dz \tag{1}$$

The discrete form can be written as weighting sum of thermal temperature at each layer:

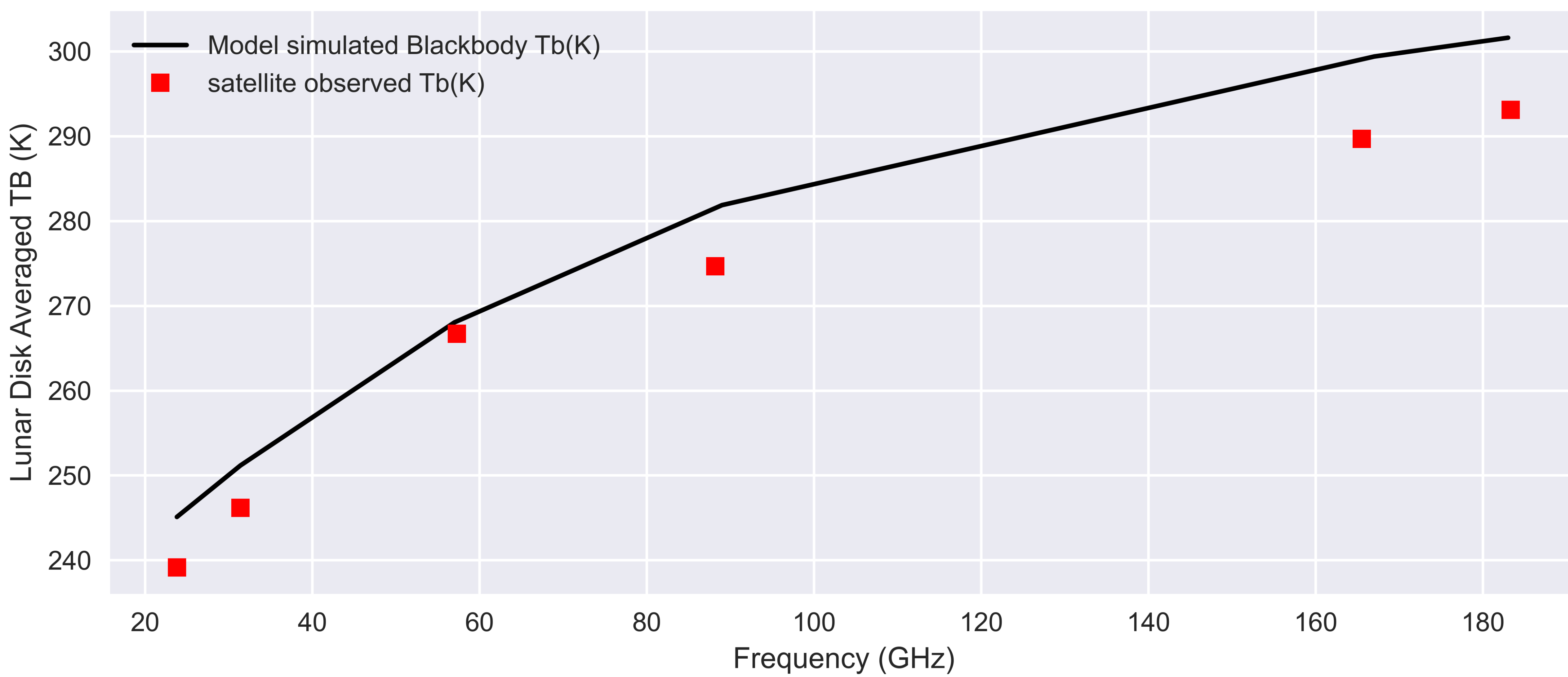
$$TB(\lambda) = E_\lambda \sum_{i=1}^{i=n} w_i * T_i \tag{2}$$





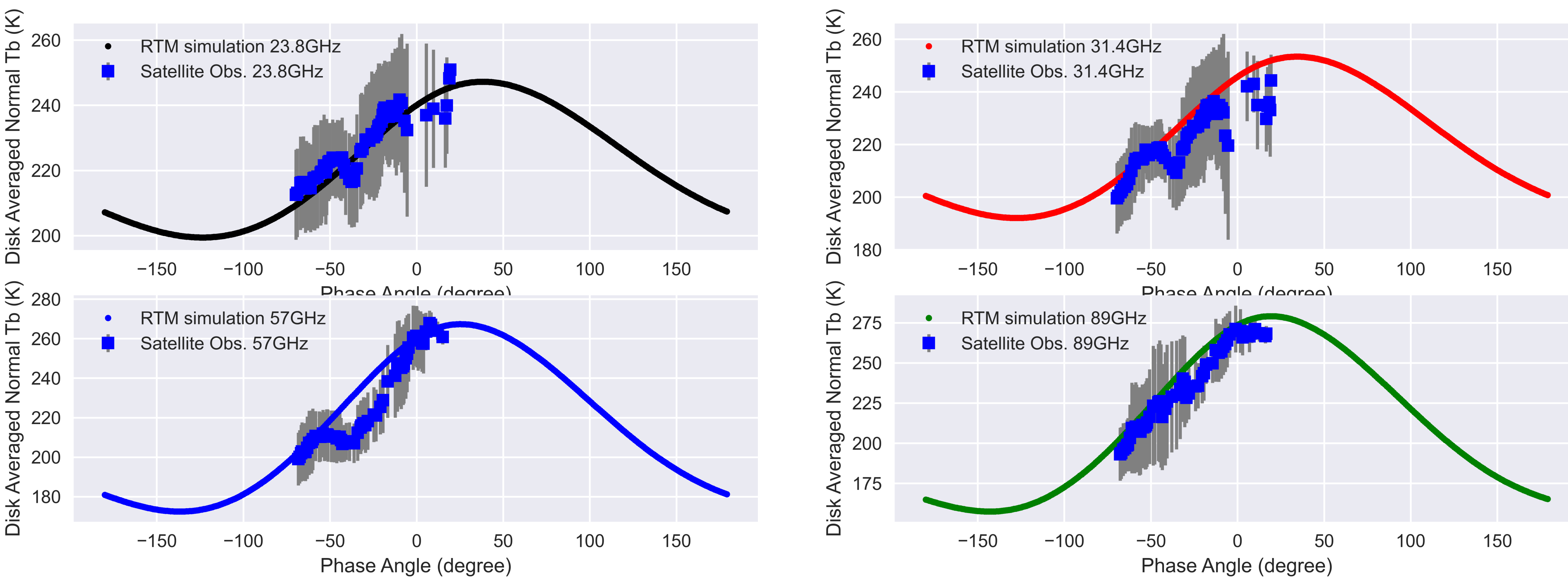
Validation of Unresolved Full-Moon Lunar Disk Tb Spectrum with Model Simulations

- In RTM simulation, only the ”black body” emission are considered to reduce the uncertainty in the simulation when Fresnel reflection function is used.
- The Lunar disk Tb is calculated based on 1^{o} by 1^{o} resolution lunar simulation, with the normalized solid angle in satellite observation direction as sum weights for each pixel
- The frequency dependent feature of satellite derived lunar Tb spectrum is consistent with model simulations, the difference can be explained by the departure of real lunar Tb with “black body” simulations



Validation with AMSU observations for different Moon phase angle

- Lunar observations from 15 years NOAA-18 AMSU instrument were collected and calibrated by using ATMS full moon lunar Tb as reference
- Peak lunar Tb at different moon phase angle were identified and compared with lunar model simulations
- Comparison results show that after corrected for the impact of lunar surface emissivity in lunar RTM model, the satellite observed lunar Tb is in highly consistency with model simulations



Conclusions and Future Work

- Unresolved Lunar disk Tb spectrum at wavelength from 1.6mm (183GHz) to 12.6 mm (23.8GHz) were derived from NOAA-20 ATMS 2-D lunar scan observations. A lunar RTM model was used to simulate the lunar microwave emission. Comparison results show that the lunar Tb spectrum derived from ATMS is highly consistent with model simulation.

- Lunar observation can be used to identify antenna beam pointing error and therefore evaluate the instrument ground geolocation error. For opaque sounding channels where surface reference can hardly been identified from the observations, lunar observation can be an alternative to evaluate and correct the on-orbit geolocation error

- Future work is to build up a more comprehensive microwave emission model for Moon's surface by combing satellite observations and model simulations.