Validation of the Calibrated Microwave Lunar RTM Model by Using N20 and N21 Two-Dimension Moon Observations

Hu (Tiger) Yang
CISESS, University of Maryland
Mar. 14, 2024

Summary of the Work

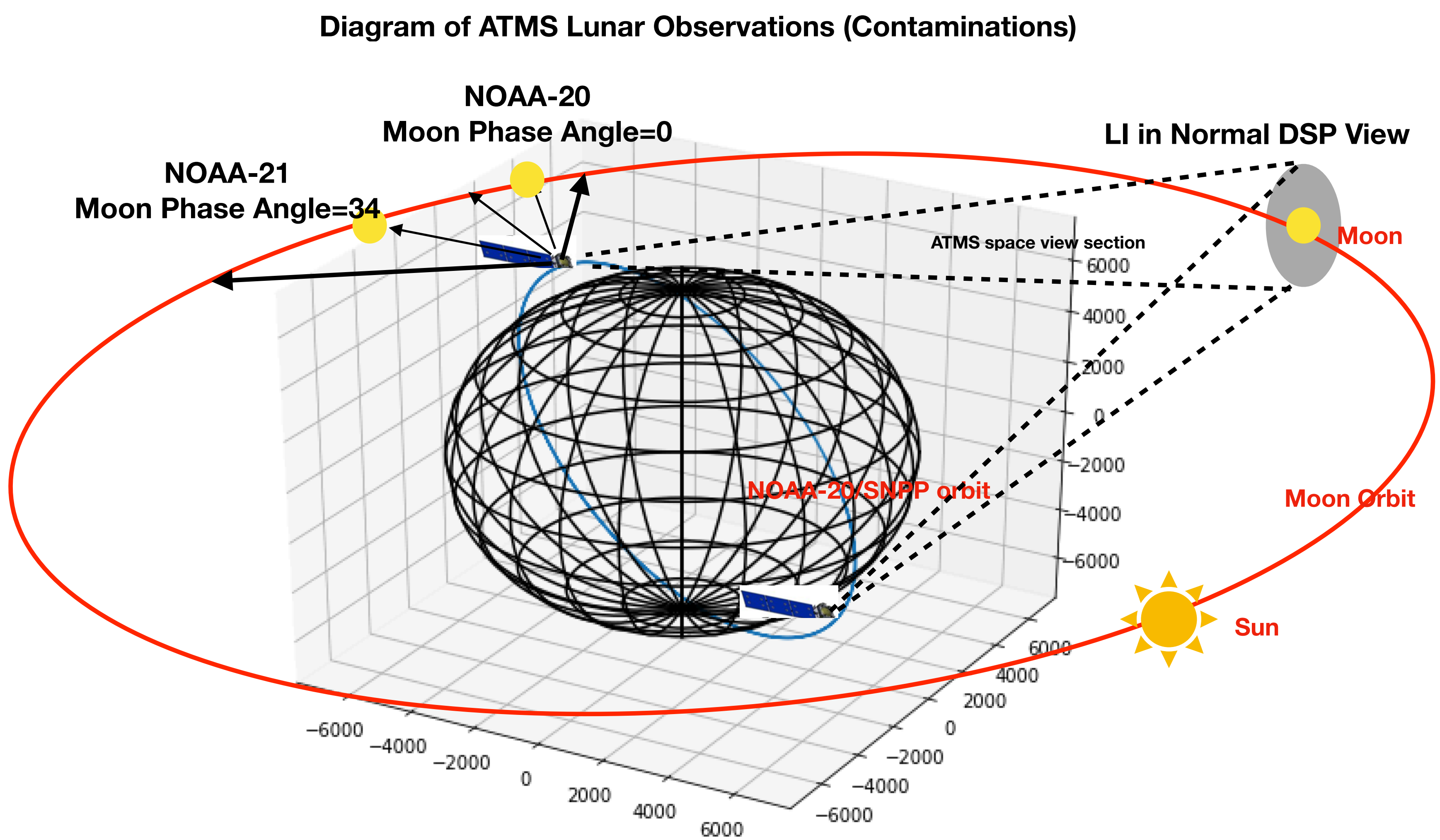
- 2D Moon scan observations from NOAA-21 was collected on 03/10/2023 during PLT, when the Moon phase angle was around 34 degree after the full Moon (0 deg)

- The original Moon observations were processed and calibrated in MiCalPS, with reflector emission correction and satellite near-field correction included

- It is found that due to the different data sampling rate, the NOAA-21 Moon antenna response is generally lower than NOAA-20, and the difference need to be addressed in Lunar Tb calculations

Two-Dimension Lunar Scan Observations from NOAA-20/21 ATMS

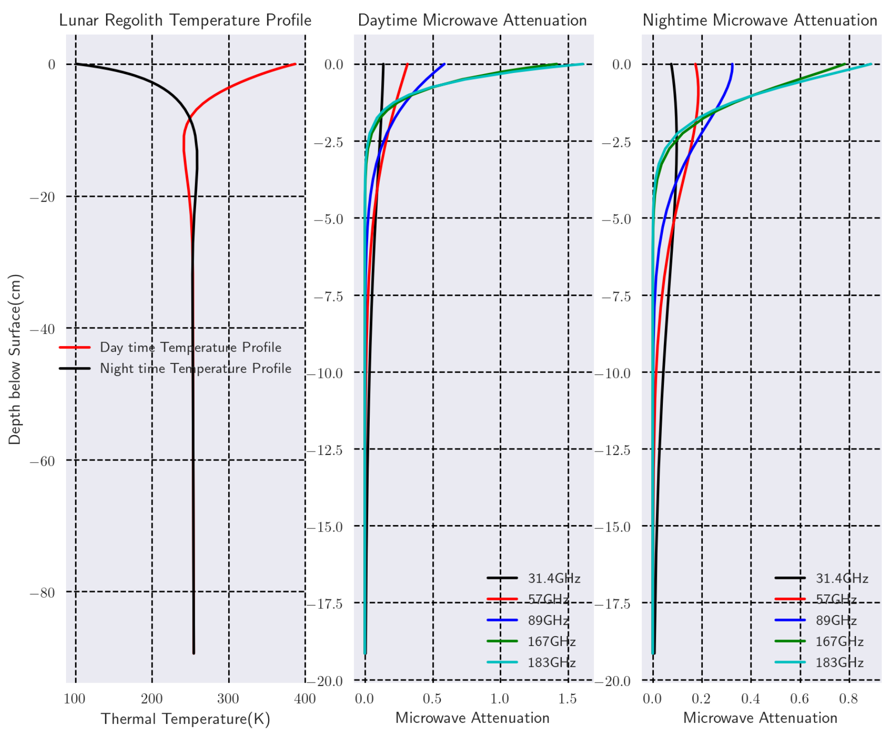
- For normal operation of JPSS ATMS, the Moon can be captured by space view when LI happens, and the Moon phase angle generally varies between 80 to 110 deg due to the stable orbit of JPSS satellites
- During pitch maneuver, the Moon can be captured for a wide range of Moon phase angles around the full Moon phase. For NOAA-21 ATMS , the Moon was captured between FOV20 and 40, around 3 days after the full moon when the Moon phase angle was 34 deg.
- For NOAA-20 ATMS, the Moon was captured between FOV60 and 80, on the day of the full Moon



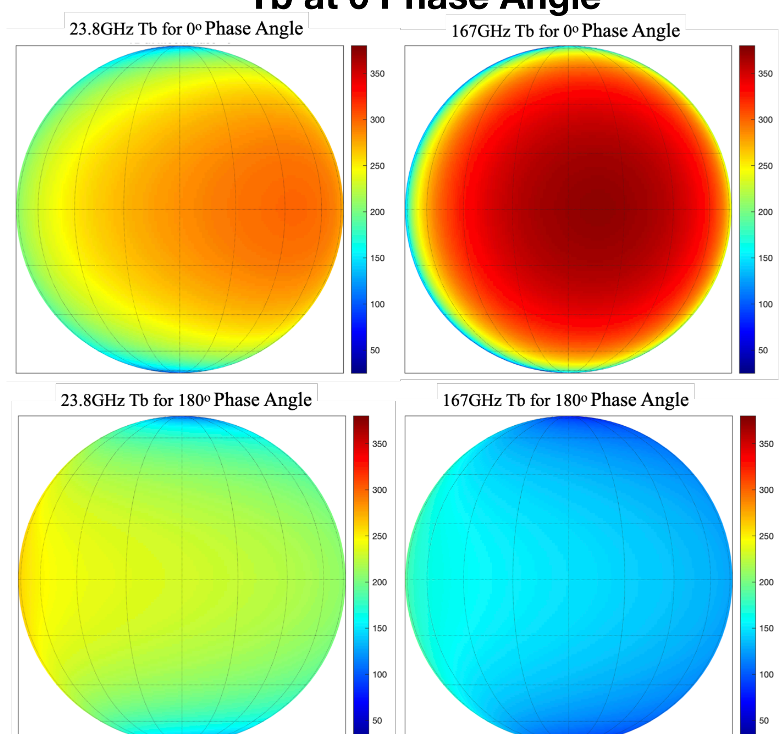
RTM Model Simulation for Lunar Microwave Emission

Yang H, Burgdorf M. A Calibrated Lunar Microwave Radiative Transfer Model Based on Satellite Observations. Remote Sensing. 2022; 14(21):5501. https://doi.org/10.3390/rs14215501

Lunar Regolith Temperature Profile and MW Thermal Emission Weighting Function



Calculated Moon Surface(Earth Side) Microwave Tb at 0 Phase Angle

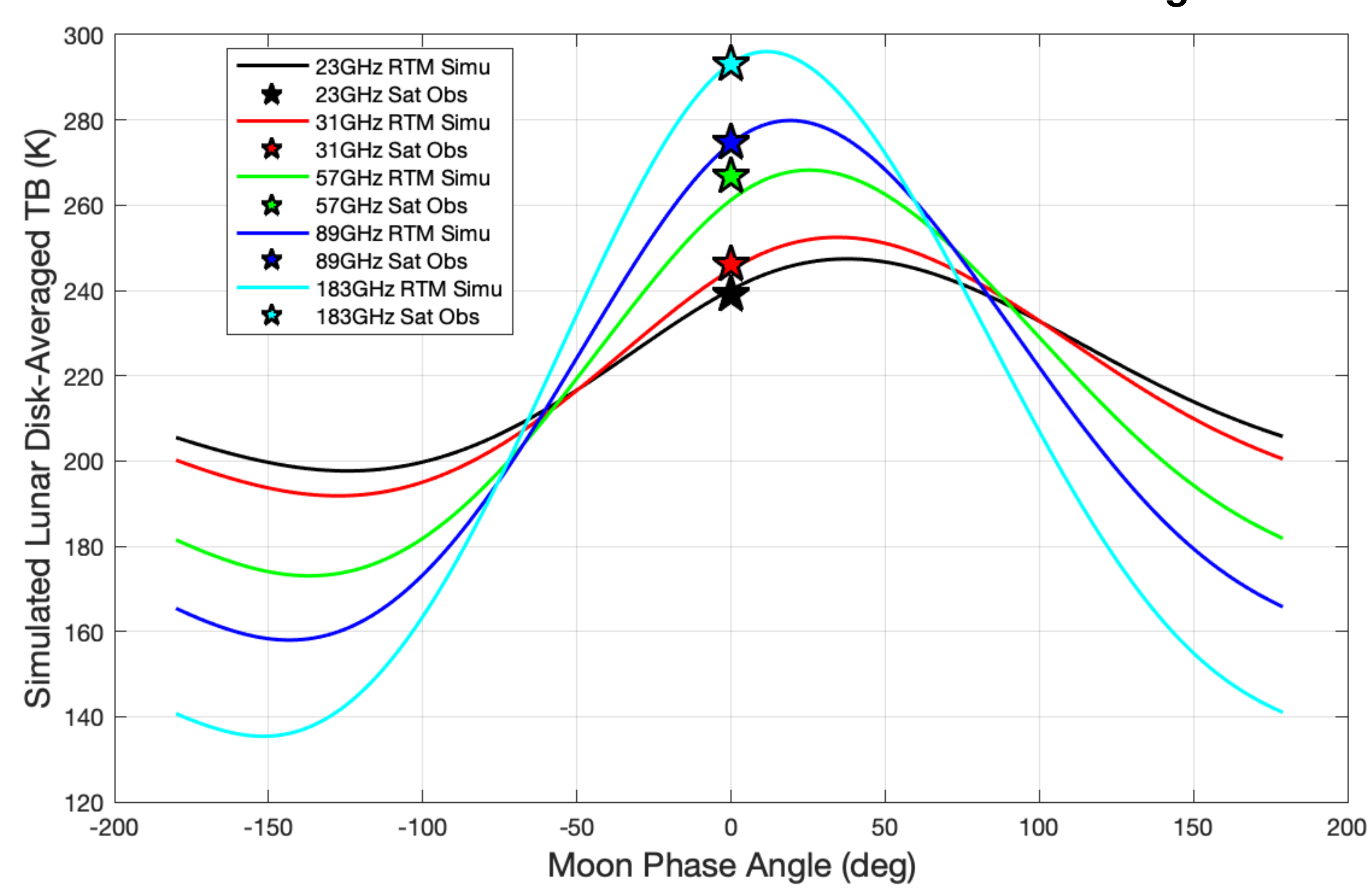


Calculation of Disk-averaged Lunar Tb

- No diurnal variation in deep layer
- More contribution from deeper layer in lower frequency band
- More contribution from deep layer during night time
- Magnitude of Phase-Lag decrease with the increase of frequency

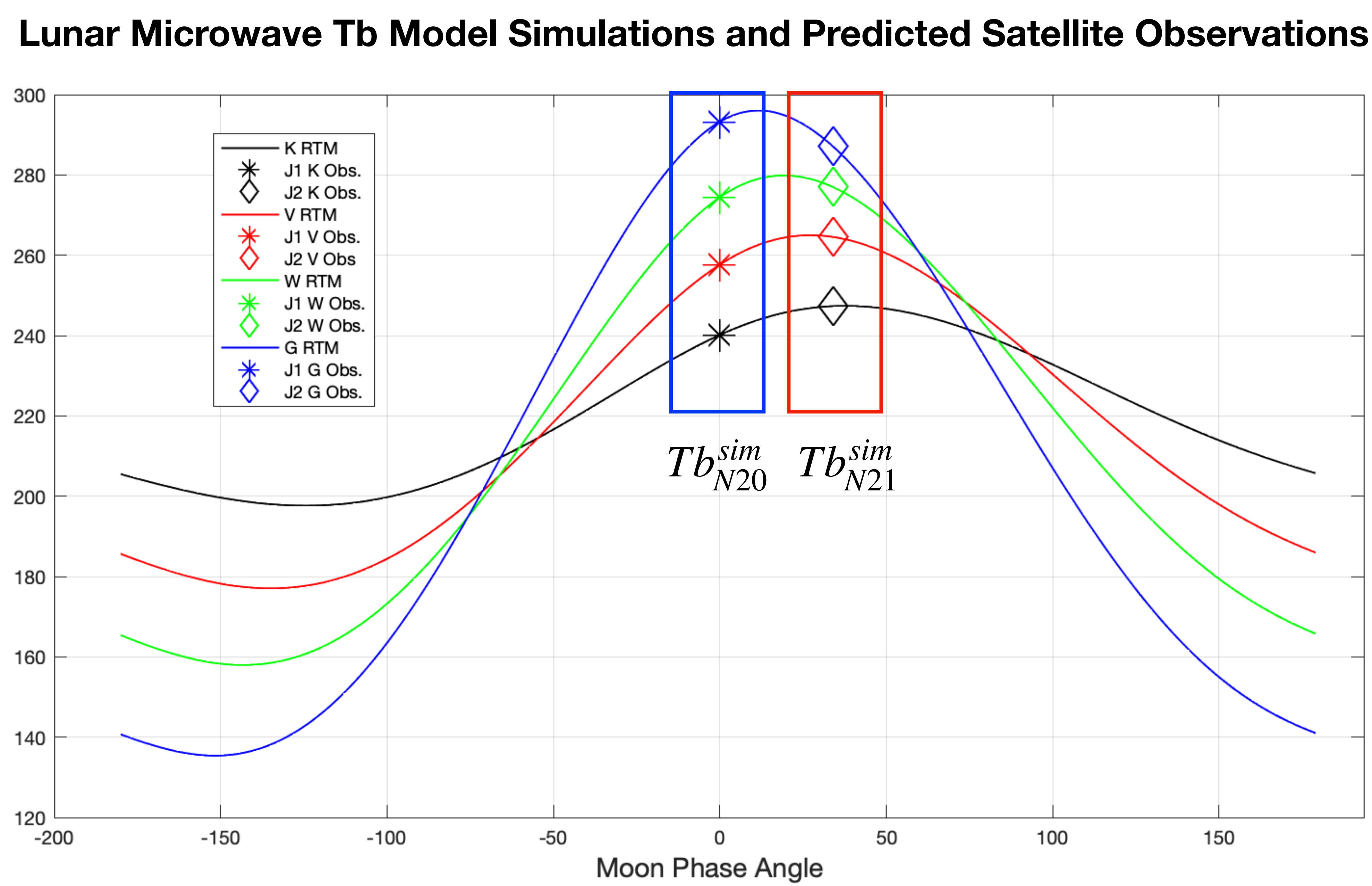
$$T_B(\lambda) = E_\lambda \int_0^\infty \kappa_\lambda \sec(\theta_i) \cdot T(z) \cdot e^{-\int_0^z \kappa_\lambda(z)\sec(\theta_i)dz} dz$$

Calibrated RTM Simulation for the Moon Disk-Averaged Tb



Prediction of the Disk-averaged Tb for NOAA-21 Lunar 2D Scan Test

- Lunar RTM simulation shows that for lower frequency channel of ATMS, the peak of the Moon disk-averaged Tb should appears around 3-days after the full moon, caused by the phase lag in lunar microwave observations
- For NOAA-21 Lunar observations, it is expected that the magnitude of lunar Tb should be higher than NOAA-20 in K to W band, and lower in G-band



N20/N21 Post-Launch Pitch Maneuver Test

NOAA-20 Pitch, 01/31/2018

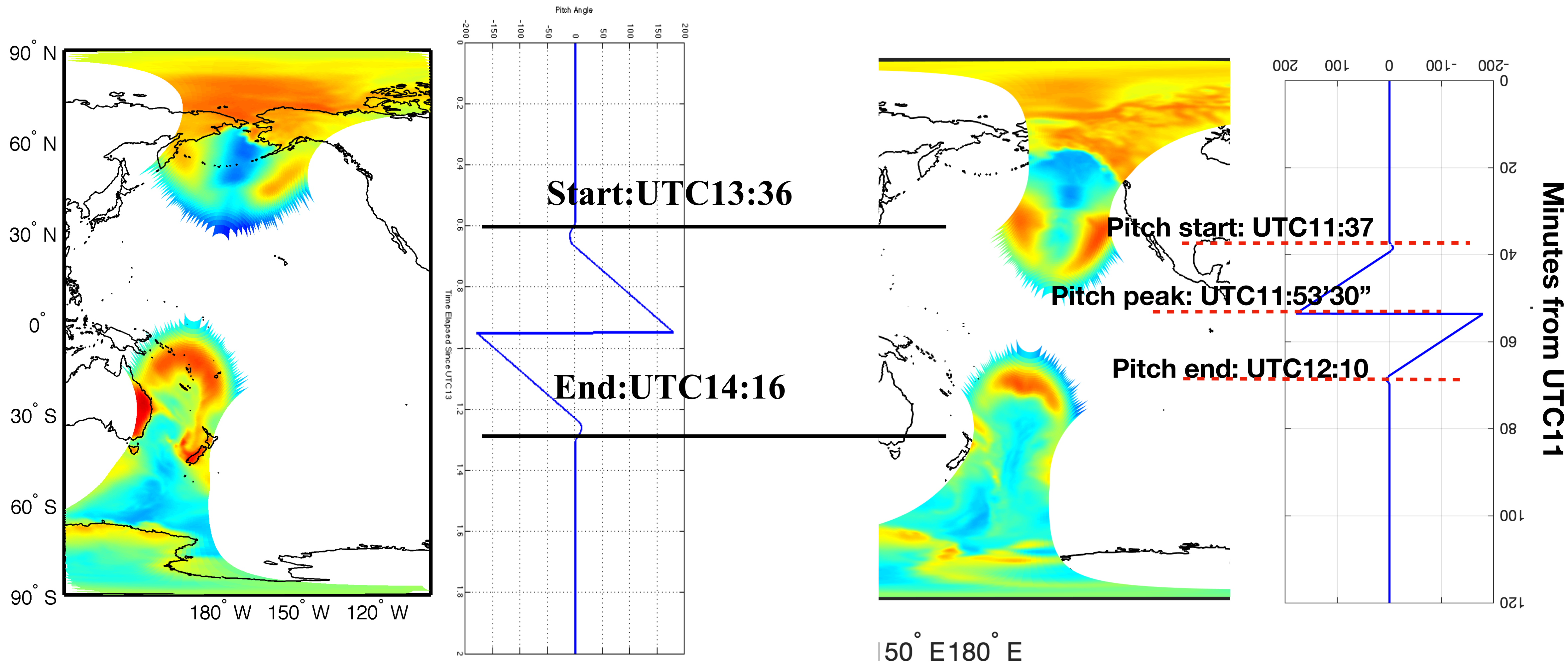
Satellite pitch slew rate: 0.1785 deg/sec

Moon Phase Angle=0°

NOAA-21 Pitch, 03/10/2023

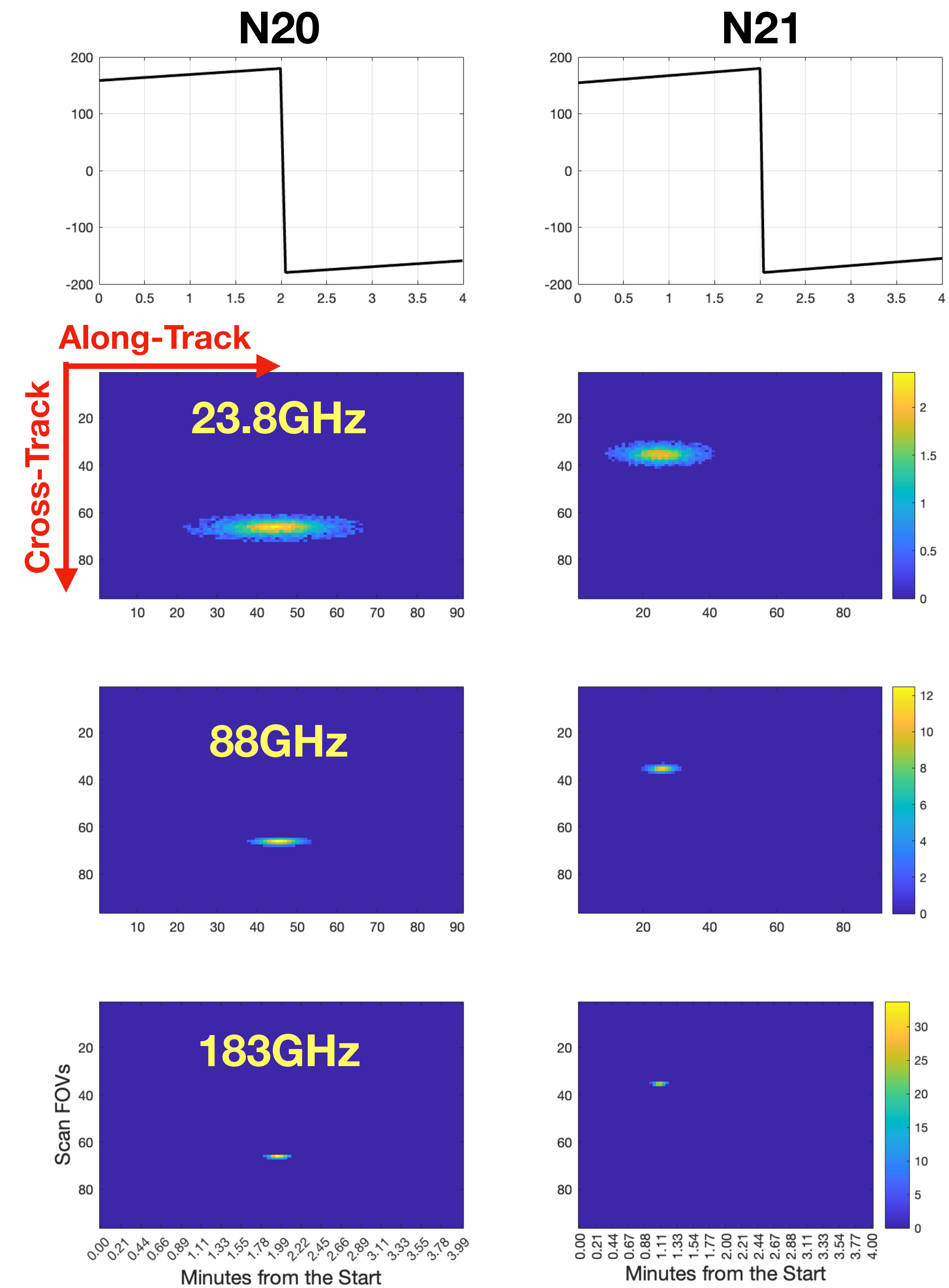
Satellite pitch slew rate: 0.2114 deg/sec

Moon Phase Angle=34°



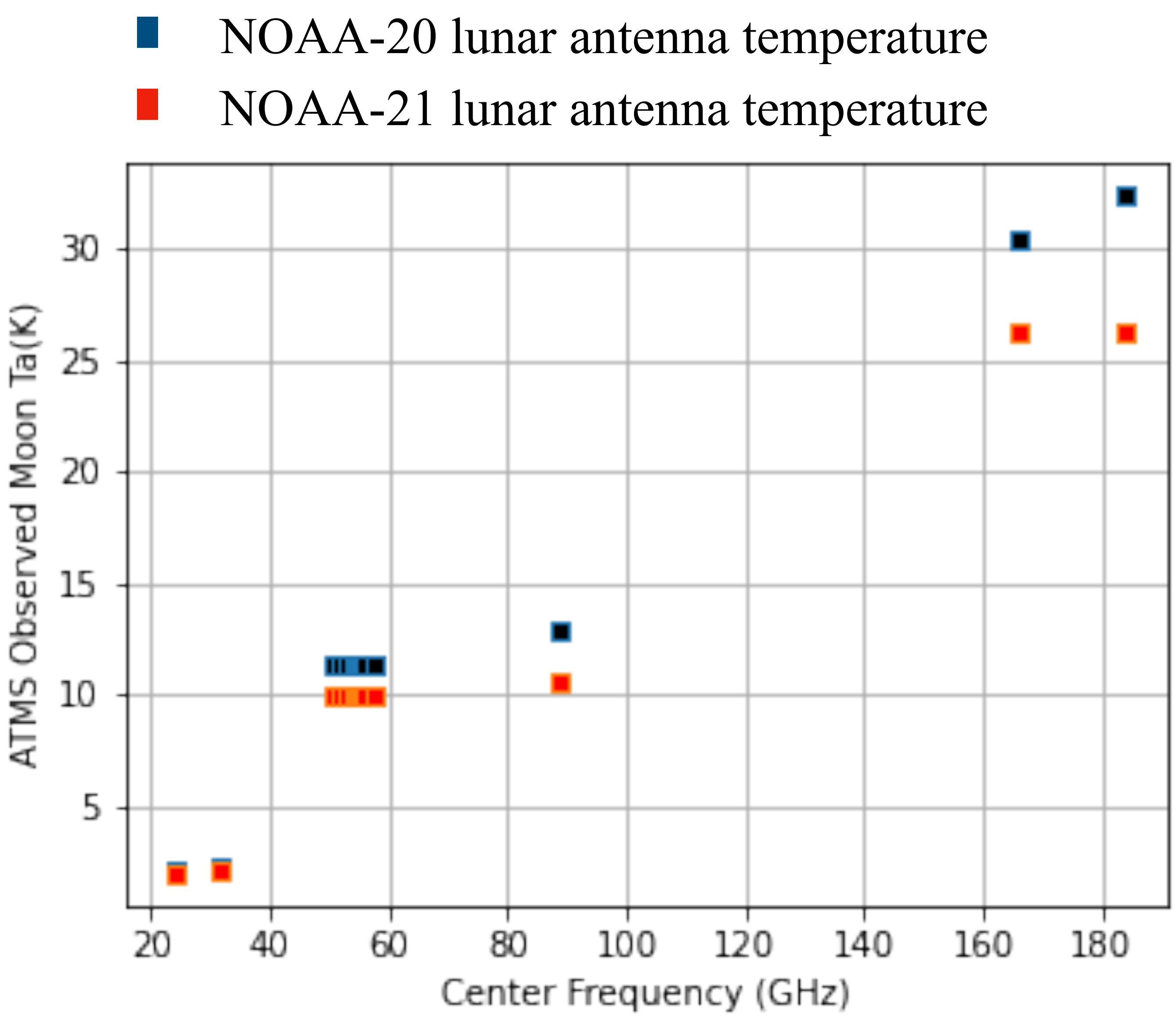
Calibrated Antenna Temperature for ATMS Lunar Scan

- Only ±45 scan lines around the peak pitch angle were used for the study to reduce the impacts from the Earth contamination
- Reflector emissivity determined from OMPS pitch maneuver was used to make the reflector thermal emission correction for lunar calibration
- Satellite near-field contamination determined from the full-cycle pitch observation was used to make the near-field contamination correction for lunar calibration
- Due to the higher slew rate of N21 pitch maneuver, the sampling rate of N21 ATMS lunar is lower than N20, fewer Moon scan samples were obtained from N21



Comparison of ATMS Lunar Ta spectrum between NOAA-20 and NOAA-21

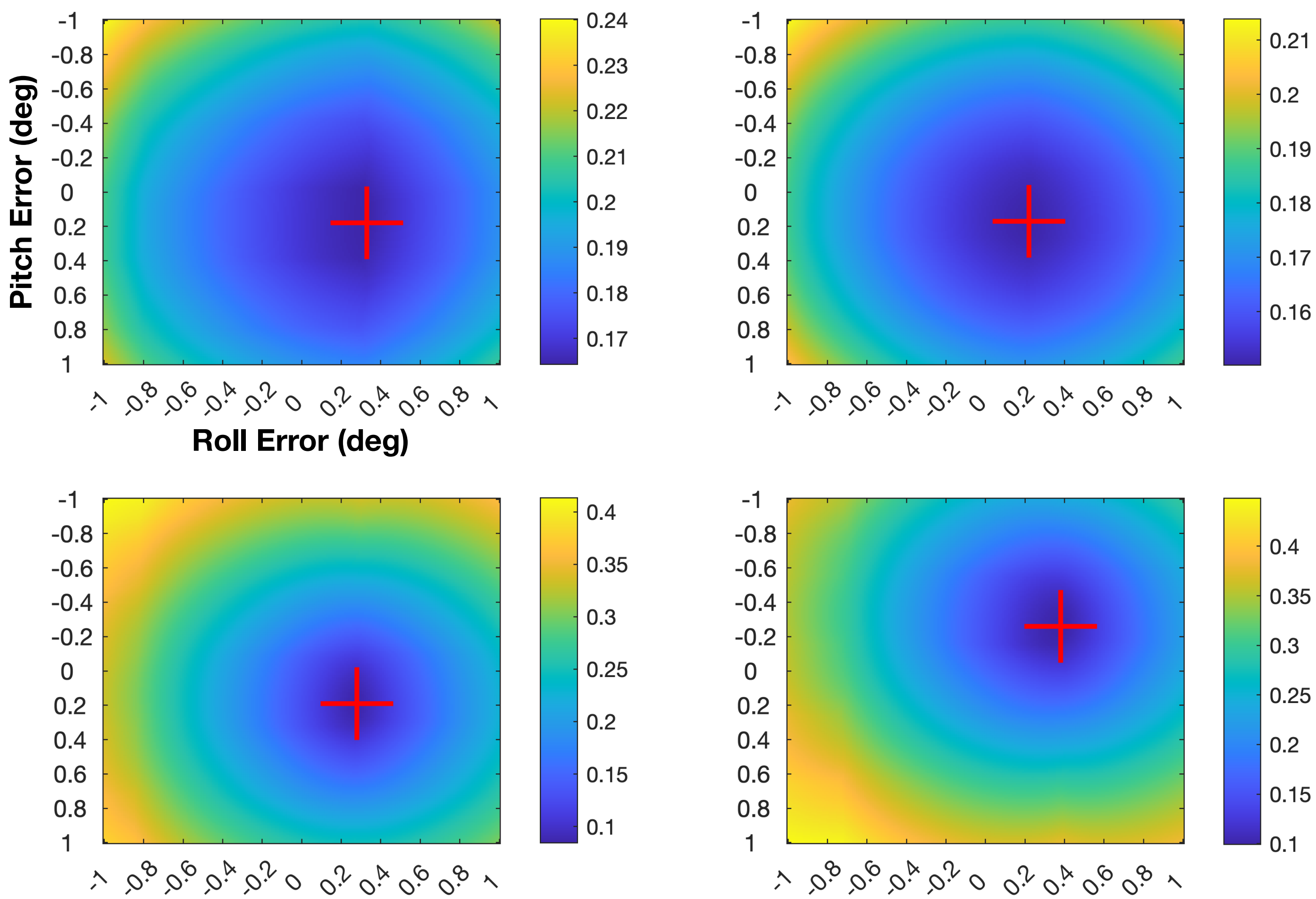
- Antenna temperature calibration results show that NOAA-21 lunar Ta is generally lower than NOAA-20, and the difference increase with frequency
- Note that to derive the Moon disk-averaged Tb, the antenna should be corrected separately for NOAA-20 and NOAA-21

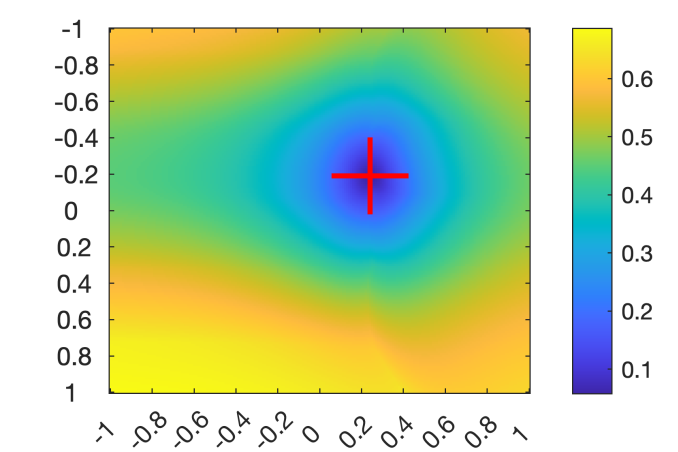


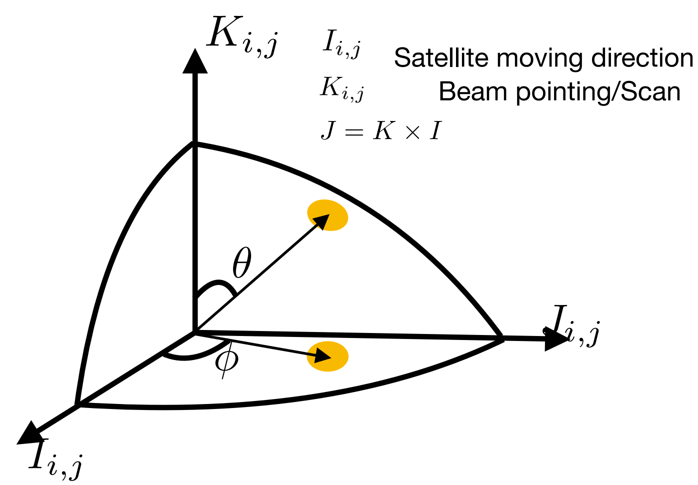
Band/Frequency (GHz)	NOAA-20	NOAA-21
K(23.8)	2.14	1.99
V(50~57)	11.39	9.45
W(88)	12.88	10.68
G1(166)	30.40	26.25
G2(183)	32.41	26.30

Beam Pointing Error Evaluation

NOAA-21 Lunar Geolocation Error Evaluation







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.

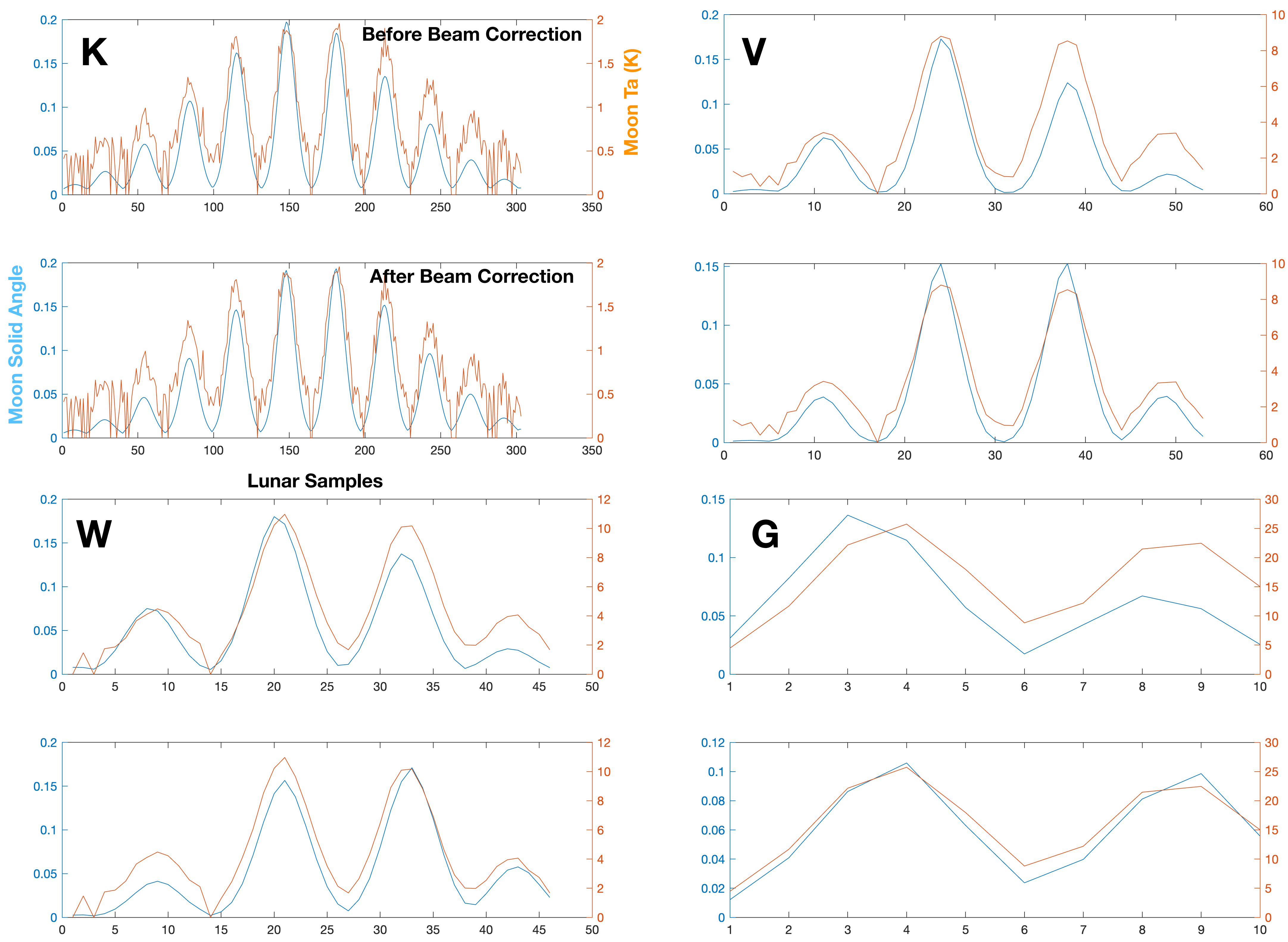
$$\sigma(\xi_r, \xi_p) = \frac{1}{N-1}\sqrt{\sum_{i=1}^{N}(G(\xi_r, \xi_p) - G_{obs})^2}$$

To calculate the antenna gain of the moon, the smearing effects need to be taken into account

$$G(\xi_r, \xi_p) = \frac{G_{imoon}}{G_{imoon}^{max}}$$

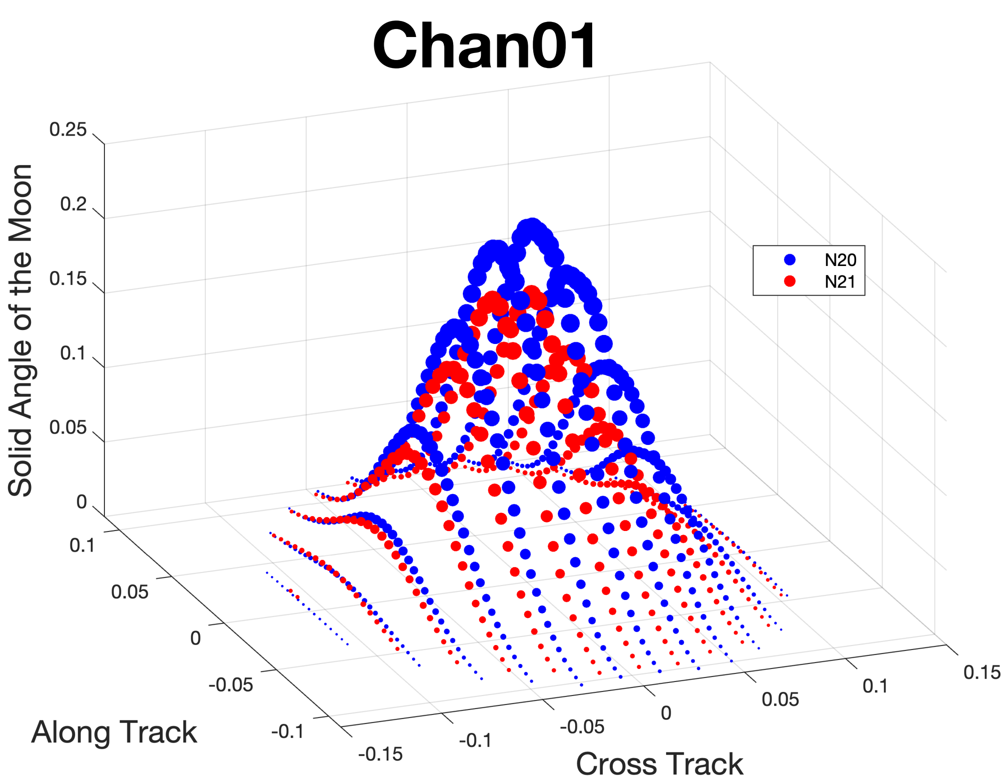
$$G_{imoon} = \frac{1}{L}\int_{\frac{-\tau}{2}}^{\frac{\tau}{2}} dl \int_0^{2\pi}\int_0^{\alpha_{moon}} G^{'}(\theta^{'}, \phi^{'}) sin\theta' d\theta' d\phi'$$

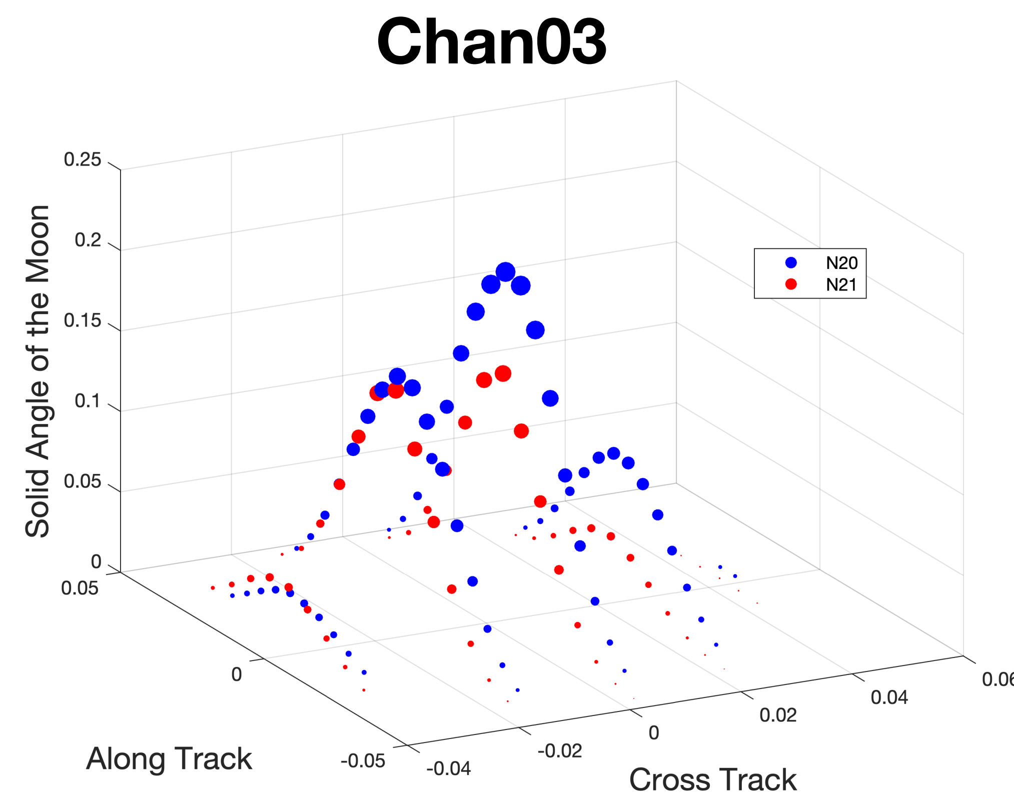
Impact of Beam Pointing Corrections on Moon Observations

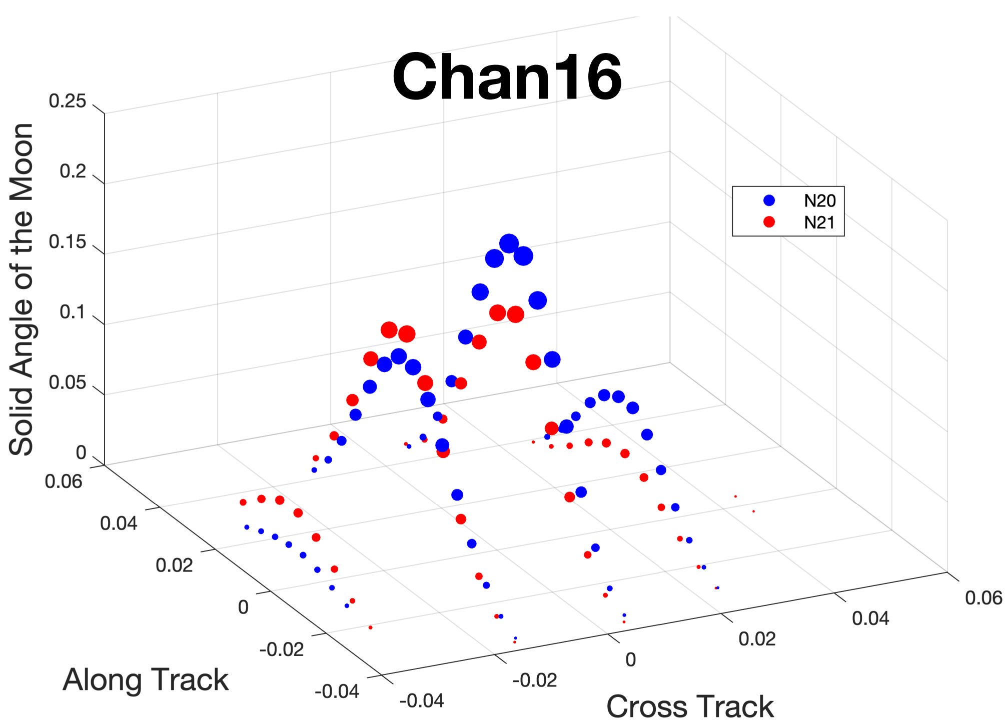


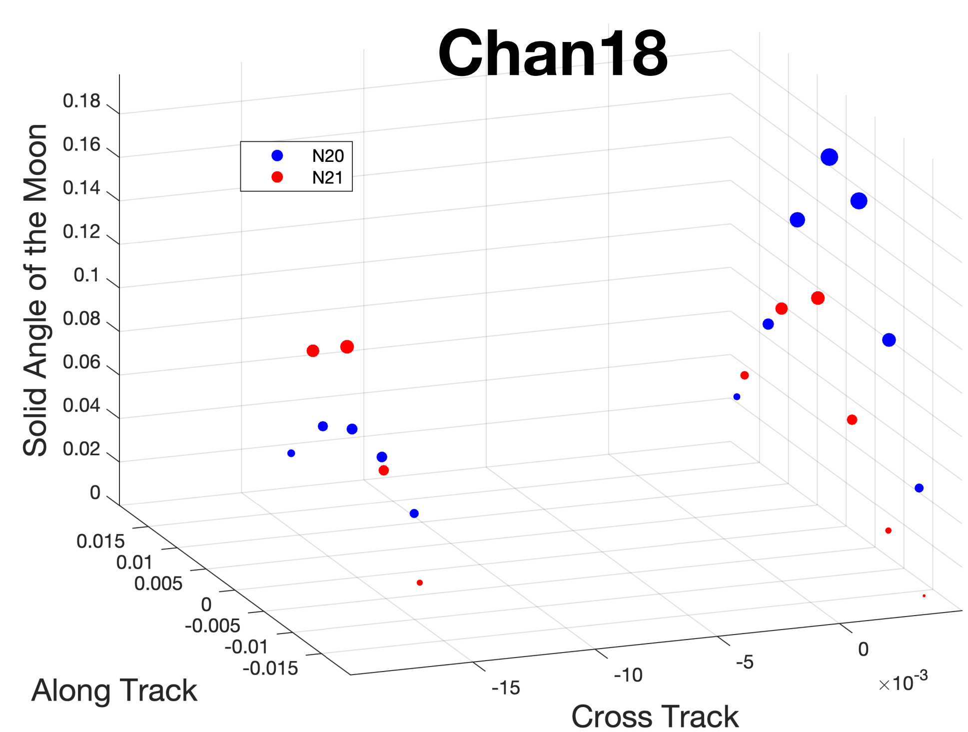
Difference in Antenna Responses for Moon Observations between N20 and N21

Due to the lower lower sampling rate of N21 ATMS Moon scan observations, the Moon was not well captured at the beam center. As a result, the Antenna Responses from N21 is weaker than N21, which need to be addressed for the Tb retrievals.



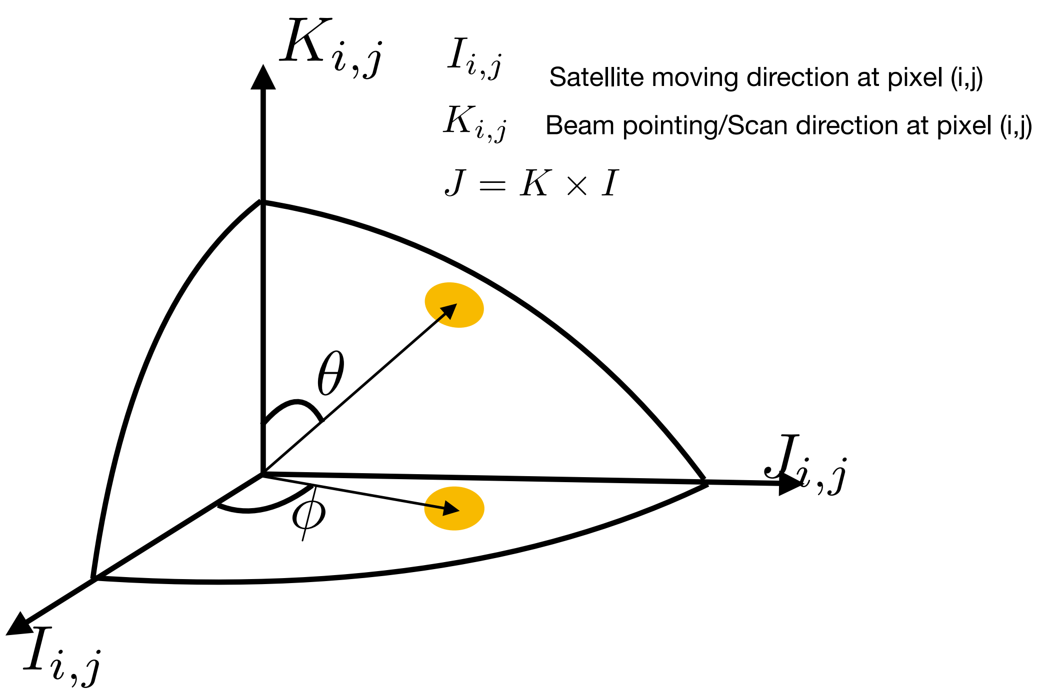






Retrieval of Disk-Averaged Moon Tb from Calibrated 2-D Lunar Observations

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 beam pointing error is corrected for the Tb retrieval
- The smearing effect has been taken into account to calculate the lunar solid angle
- Regression algorithm was used for the lunar Tb retrieval
- Observations from adjacent channels with similar frequencies were combined for the retrieval

Regression model for Tb retrieval

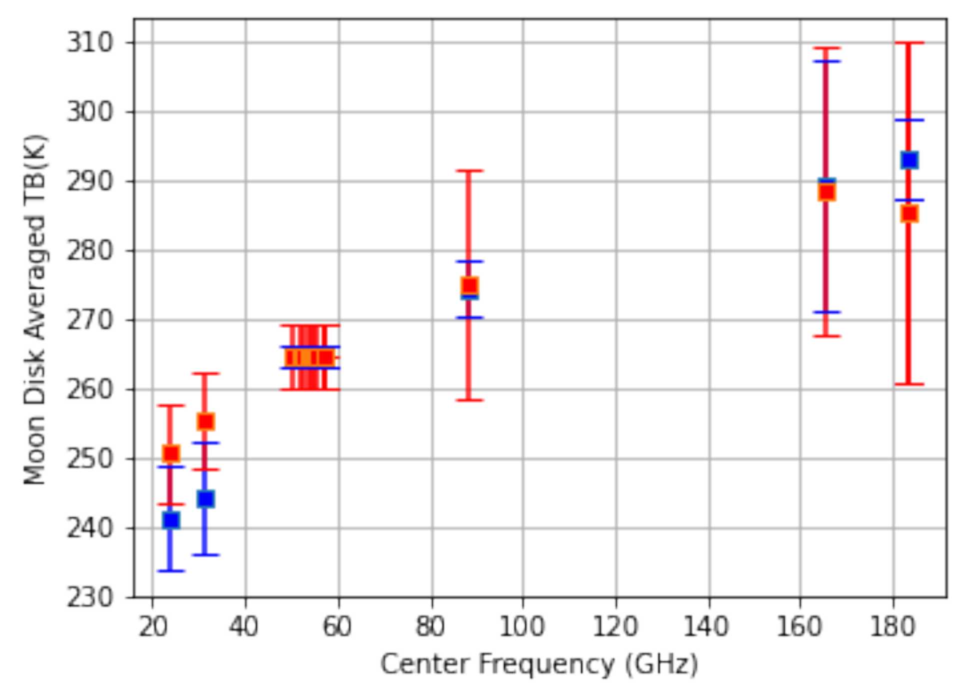
$$Ta_{moon}(\theta_{ifov}, \phi_{ifov}) = Tb_{moon}^{Disk} \cdot \frac{\Omega_{moon}^{ifov}}{\Omega_P}$$

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

Channel-Averaged Moon Tb

Band	Frequen	N20	N21
K	23.80	241.21	250.60
Ka	31.40	244.14	255.30
V	50.30	264.44	264.50
W	88.20	274.38	274.90
G1	165.50	289.19	288.50
G2	183.31	293.17	285.40

Disk-Averaged Moon Tb Spectrum from N20 and N21 ATMS

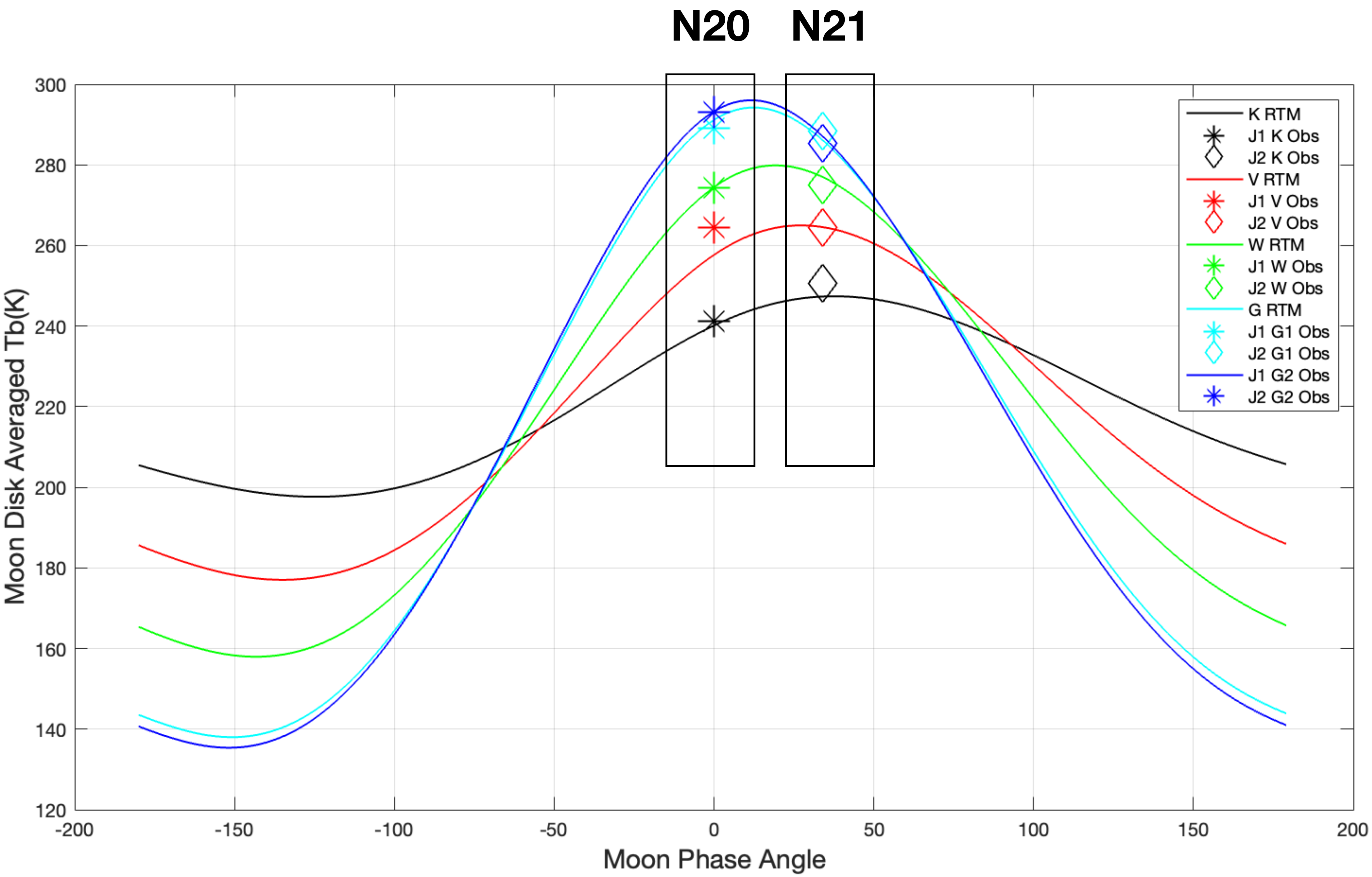


NOAA-20 lunar antenna temperature

NOAA-21 lunar antenna temperature

Retrieved Disk-averaged Tb from NOAA-20 and NOAA-21 Lunar observations

- Disk-averaged Lunar Tb retrieval results from N21 show that they match well with the calibrated Keihm RTM model
- For K-band



Conclusion and Future WORK

- NOAA-21 lunar 2D scan observations were processed and calibrated. It is found that due to a faster slew rate for N21 pitch maneuver, the Moon was not well captured at the ATMS antenna beam center

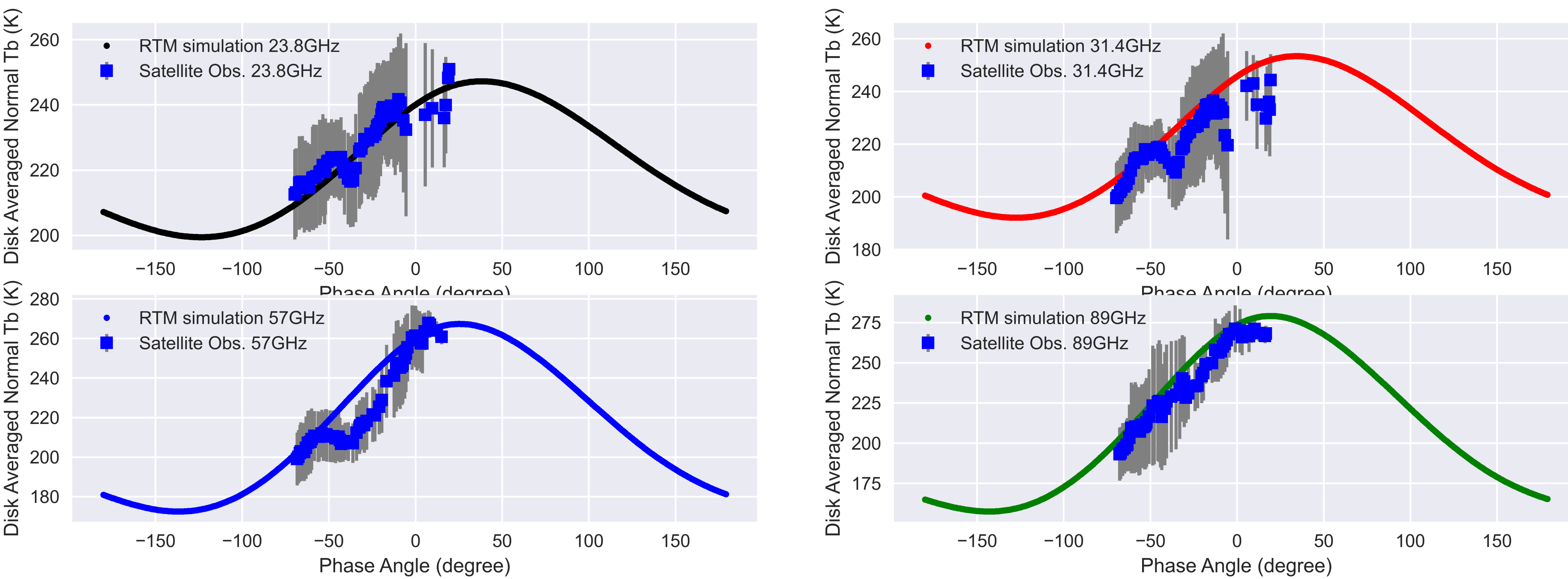
- After correction for the beam pointing error, the retrieved Moon disk-averaged brightness temperature from N21 matches well with the N20-calibrated RTM simulations

- Due to the sensitivity of the Moon observations to the beam pointing , the Moon observations at different phase angle can be used to check the beam pointing error at different beam positions

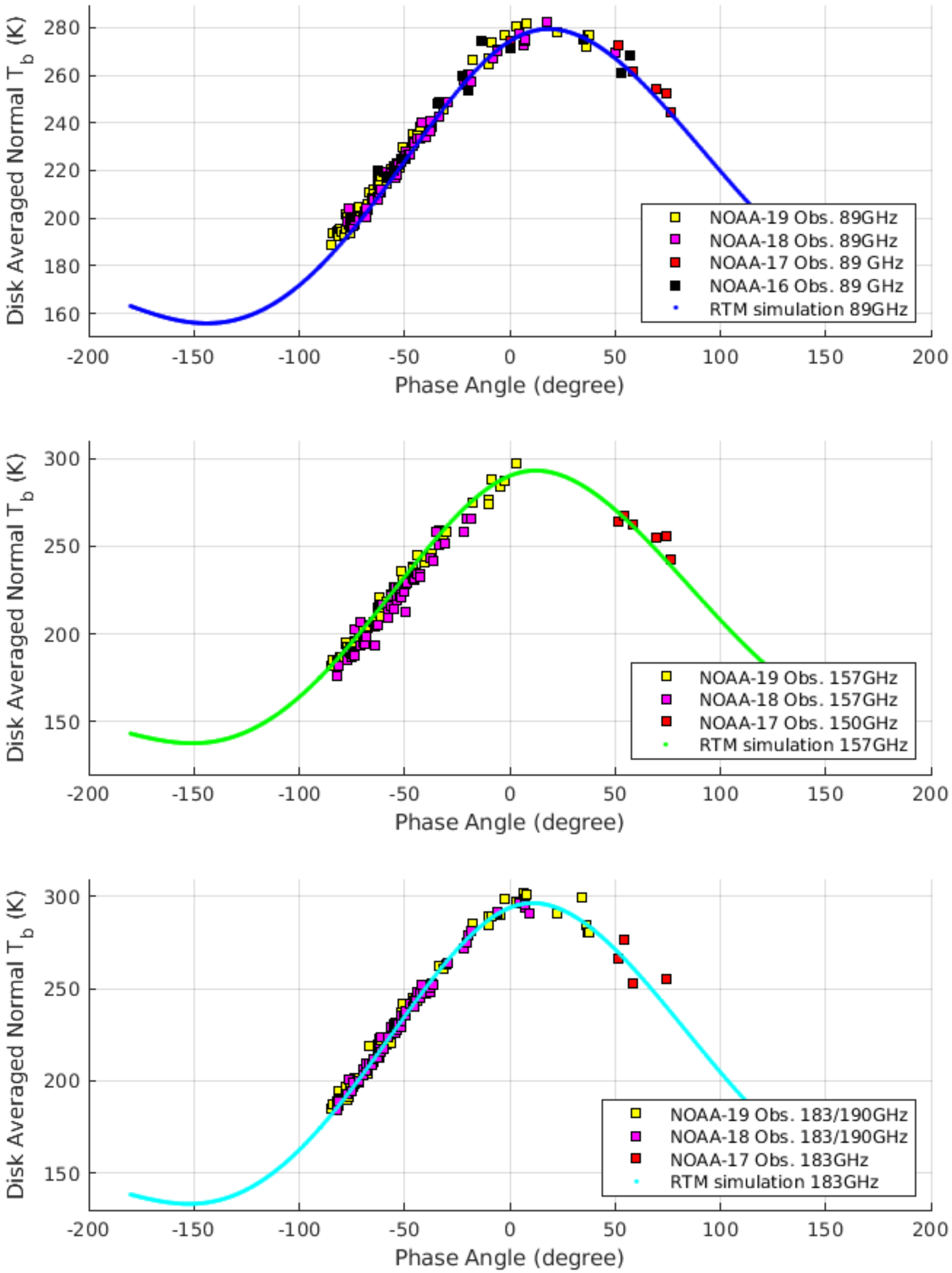
- For future, a slower slew rate of the pitch maneuver is suggested for better lunar observations

Backup Slides

comparison of simulated and observed lunar disk averaged brightness temperature at different frequencies. Solid lines are the calibrated lunar RTM model simulations, the dots are the satellite observations, and the grey bar is the standard deviation of the satellite derived lunar-disk averaged TB



(Provided by M.Burgdorf)



Comparison of simulated and observed lunar disk averaged brightness temperature at frequencies of 89~GHz and higher. Solid lines are our model simulations, the dots are the satellite observations with AMSU-B and MHS.

Sat.	Instr.	GHz	Mean Error $Tb^{sat} - Tb^{effsim}$ (K)	Mean Error $Tb^{sat} - Tb^{Fresnel}$ (K)	Std.(K)
N15	AMSU-B	89	-0.7	18.5	9.2
N16	AMSU-B	89	-2.2	16.4	6.7
N17	AMSU-B	89	11	30.3	6.4
N18	MHS	89	4.9	22.5	3.6
N19	MHS	89	6.4	24.1	4.3
M-A	MHS	89	6.4	25.8	5.1
MB	MHS	89	2.8	22.2	3.4
MC	MHS	89	11.3	30.9	7.9
N15	AMSU-B	150	17	36.8	22.2
N16	AMSU-B	150	23.2	42	10
N17	AMSU-B	150	9.6	28.8	22.4
N18	MHS	157	-6.6	11.2	7.2
N19	MHS	157	1.6	19.4	5.2
MA	MHS	157	-2.7	16.8	9.1
MB	MHS	157	-6.1	13.2	4.2
MC	MHS	157	-2	17.6	8.7
N15	AMSU-B	183	10.2	30.2	16
N16	AMSU-B	183	10.4	28.6	10.4
N17	AMSU-B	183	-2.2	16.8	17.3
N18	MHS	183/190	4.4	22.1	4.1
N19	MHS	183/190	2.3	20.1	6.6
MA	MHS	183/190	4.7	24.1	6.1
MB	MHS	183/190	0.7	19.9	3.5
MC	MHS	183/190	13.3	32.8	13.7

Conclusion

- Lunar microwave RTM model developed by Keihm was calibrated with NOAA 20 full moon scan observations
- Validation results show that the calibrated RTM model accuracy is largely improved and can be used for microwave lunar calibration
- A Moon disk-averaged brightness temperature dataset has been generated from the calibrated lunar microwave RTM model at 13 frequencies range from 23 to 204GHz for Moon phase from -180 to 180 with 1 deg resolution
- The dataset and the calibrated RTM model can be accessed by requirement from Github: https://github.com/Tigeryang007/RTMlunar, contact info: huyang@umd.edu

Lunar Microwave Brightness Temperature Spectrum from NOAA-20 ATMS 2D scan Moon Observations

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^{Disk}_{moon}), the antenna main beam solid angle (Ω_p), and the normalized antenna response (G) as follows:

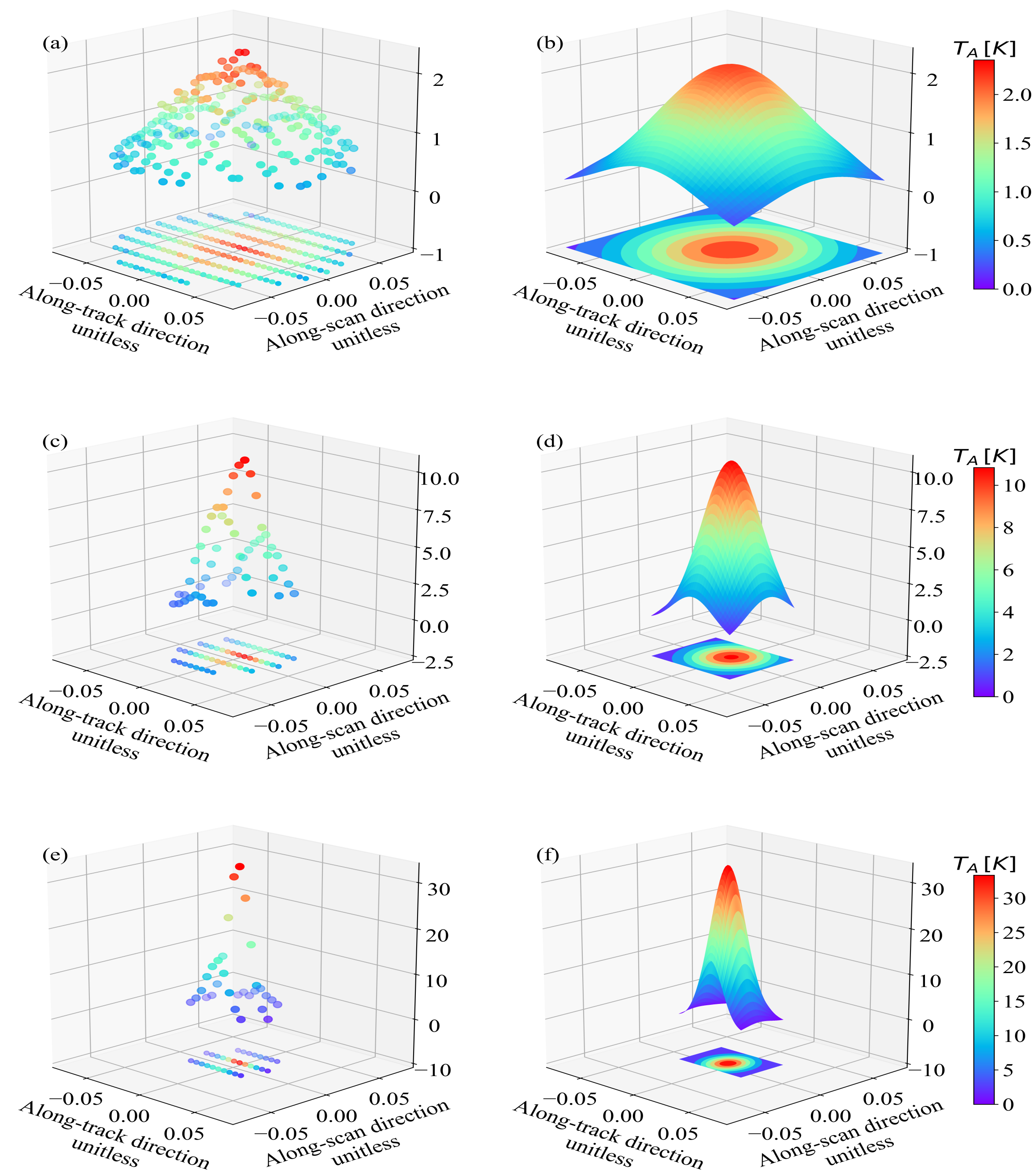
$$Ta_{moon}(\theta_{ifov}, \phi_{ifov}) = Tb^{Disk}_{moon} \cdot \frac{G(\theta_{ifov}, \phi_{ifov})}{\Omega_P}.$$

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:

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

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),

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



Theoretical Model for Microwave Emission of the Moon

S.Keihm, "Interpretation of the Lunar Microwave Brightness Temperature Spectrum: Feasibility of Orbital Heat Flow mapping", ICARUS 60, PP.568-589, 1984

Microwave brightness temperature of lunar emission can be calculated as convolution of microwave electrical loss with lunar regolith temperature profile over different depths

$$T_B(\lambda) = E_\lambda \int_0^\infty \kappa_\lambda \sec(\theta_i) \cdot T(z) \cdot e^{-\int_0^z \kappa_\lambda(z)\sec(\theta_i)dz} dz$$

Boundary Layer Condition:

$$\frac{\partial T}{\partial z} = Q/K$$ **,Q=0.018Wm-2 is the geothermal constant**

microwave absorption Term

$$\kappa_\lambda = (2\pi/\lambda)\sqrt{\epsilon'} \tan \Delta$$

Surface Emissivity is calculated with Fresnel Equation:

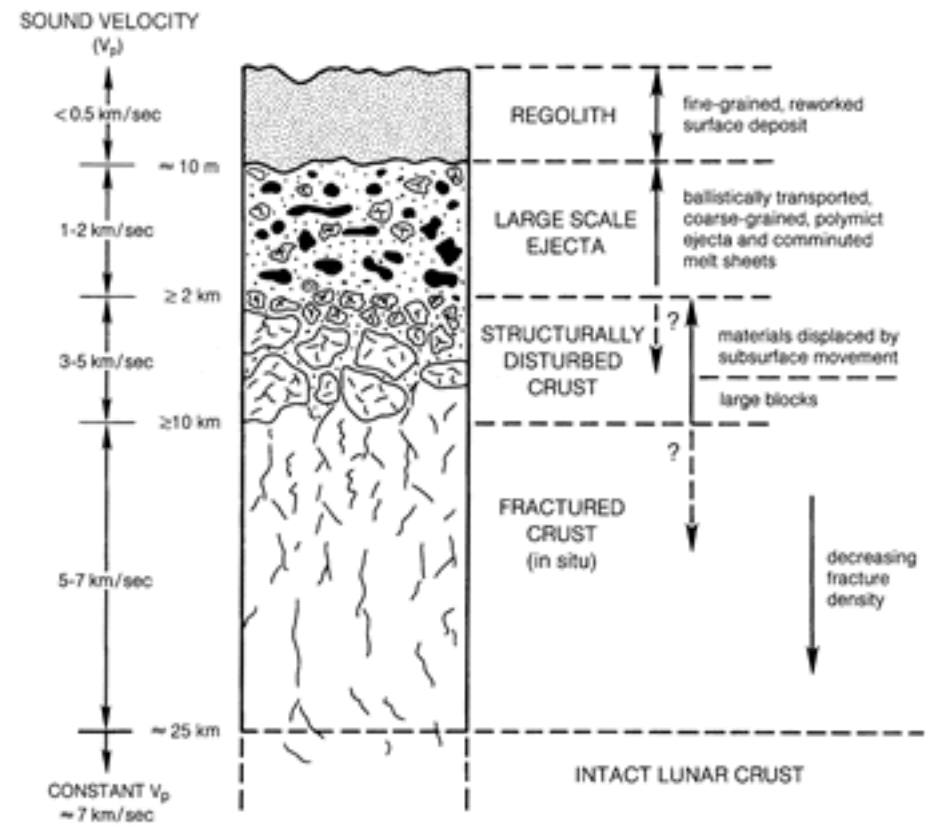
$$E_\lambda^p = 1 - R_\lambda^p$$

$$R_h = \frac{\sqrt{\epsilon'} cos\theta_i - cos\theta_0}{\sqrt{\epsilon'} cos\theta_i + cos\theta_0}$$

$$R_v = \frac{\sqrt{\epsilon'} cos\theta_0 - cos\theta_i}{\sqrt{\epsilon'} cos\theta_0 + cos\theta_i}$$

Lunar Surface Structure

Heiken, G.H., Vaniman, D.T., & French, B.M. eds, **Lunar Sourcebook**, Lunar and Planetary Institute, Houston, 1991.



- Lunar regolith temperature profile is calculated from the heat equation
- Dielectric constant calculation model is developed based on empirical fit to the Apollo sample measurements
- Parameters of thermal conductivity profile is derived based on Apollo 15 heat flow site

Validation of the Calibrated Lunar RTM Model with Lunar Observations from the Drifting-orbit Satellite