Developing Vicarious Calibration for Microwave Sounding Instruments using Lunar Radiation

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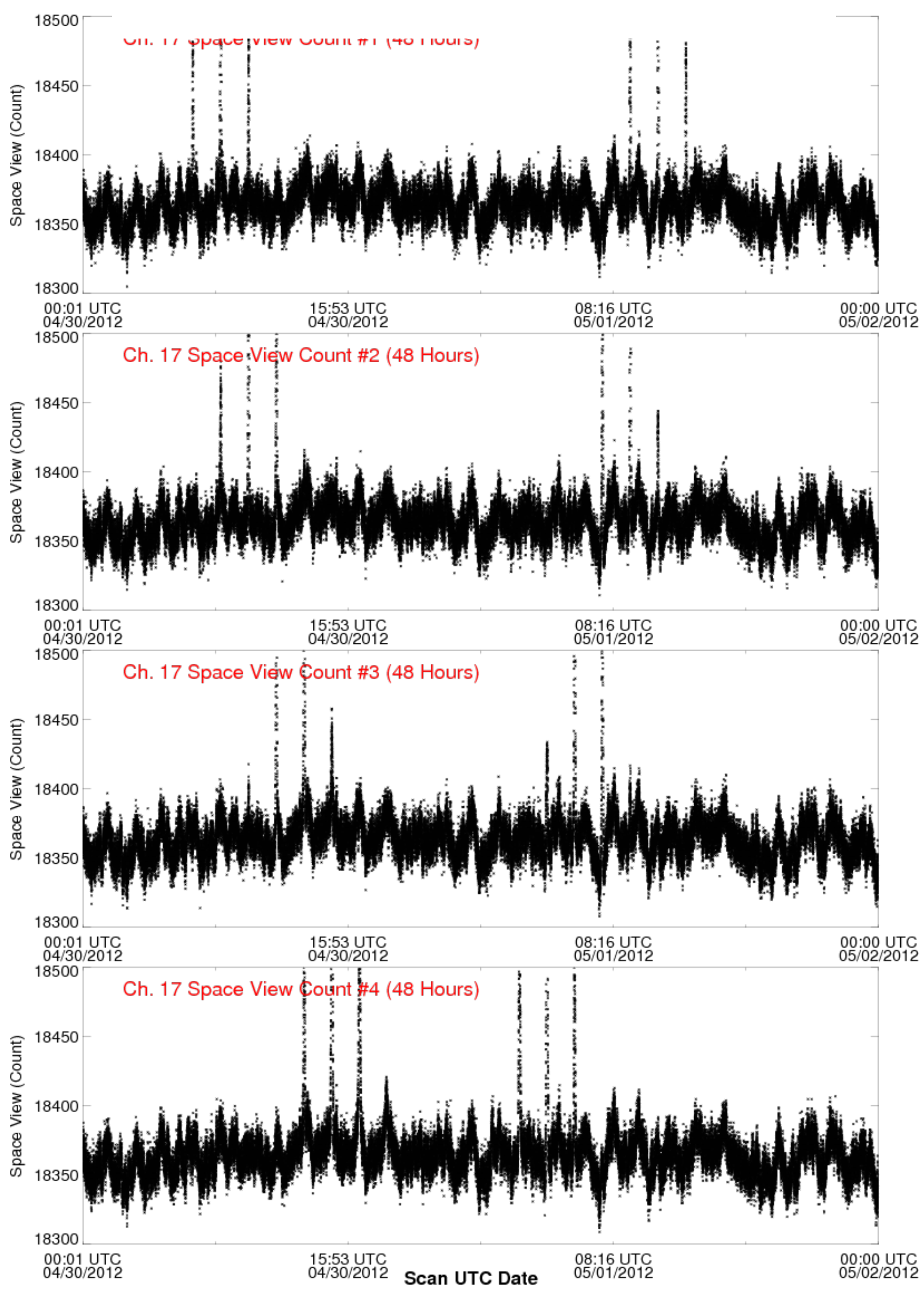
Outline

- Dual characteristics of lunar radiation in microwave remote sensing
- Lunar observations from microwave sounding instruments
- Lunar microwave brightness temperature model development and validation
- Application of lunar observation in long-term gain stability monitoring
- Conclusion and discussion

NOISE

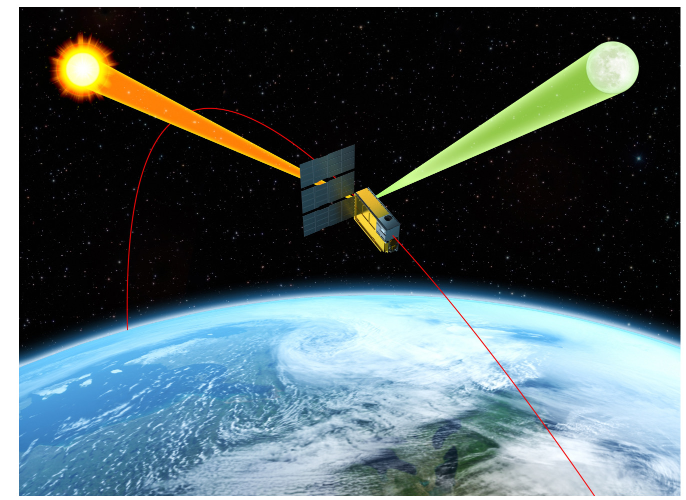
Lunar radiation as a noise need to be corrected

ICVS Monitoring of CV Anormaly

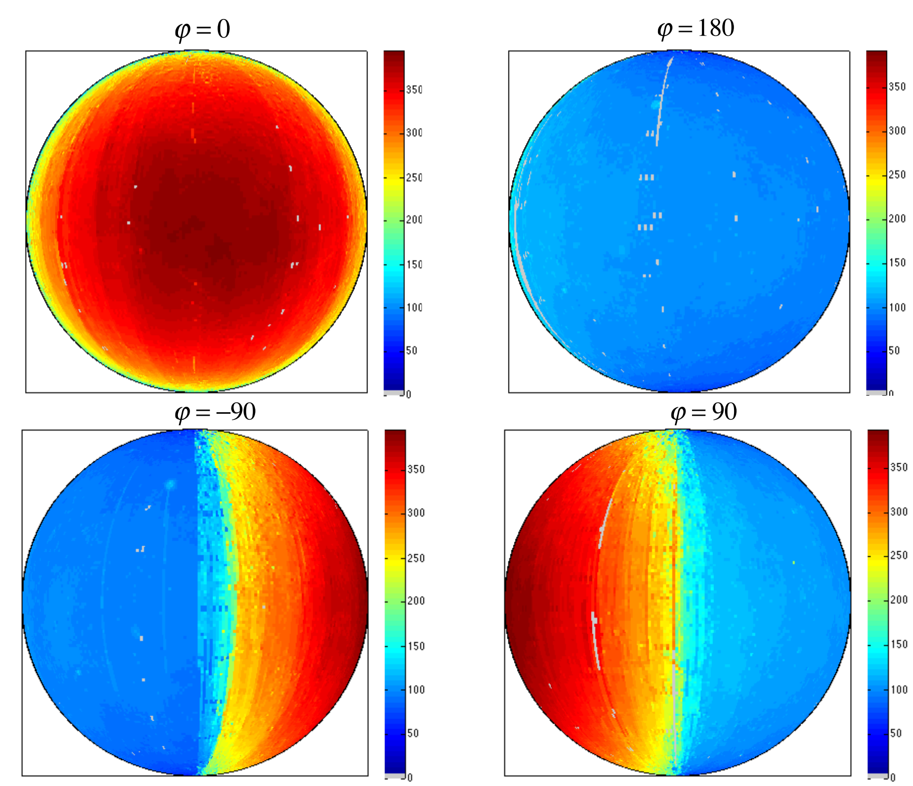


INFORMATION

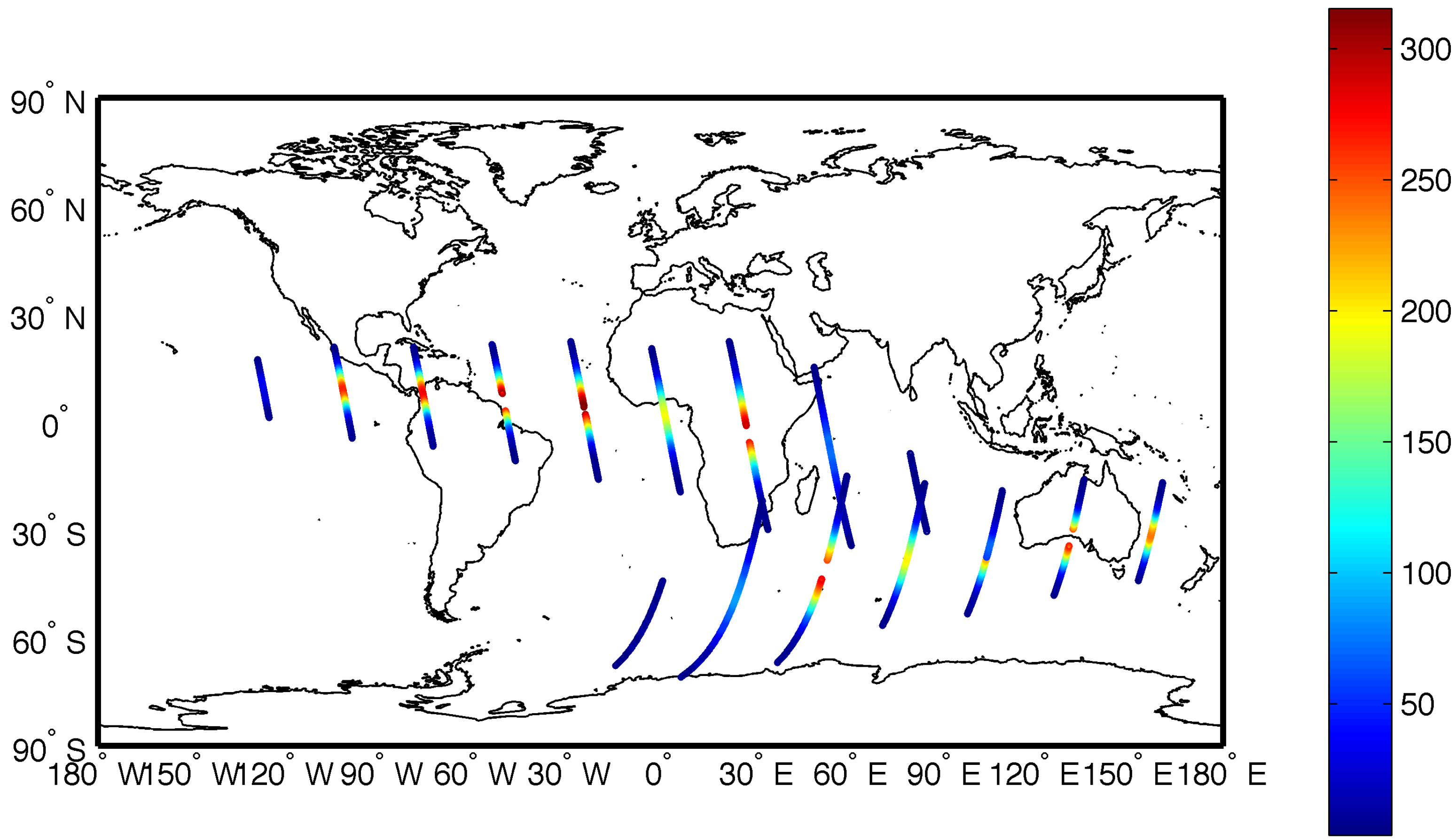
Lunar radiation as an important information need to be retained



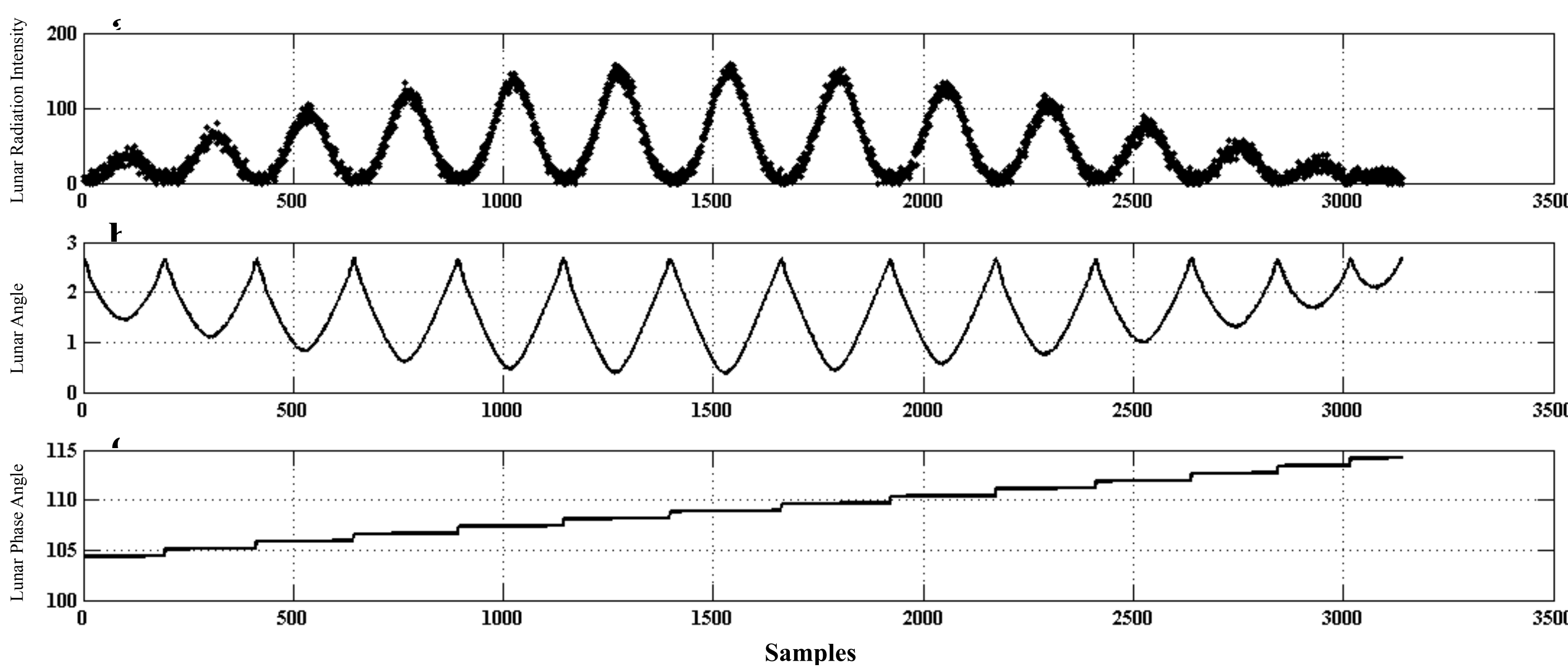
- Accessible for all spacecraft in earth orbit
- Wide dynamic range in brightness temperature
- Highly stable radiation in microwave band



Lunar Observations from SNPP ATMS



Year of LI	Dates of Lunar Intrusion Events
2011	Dec.03-05
2012	Jan.2-4, Mar.31, Apr.1-2,29-May. 01,Nov.22-23,Dec.21-23
2013	Jan.21, Mar.20-22, Apr.19-21, May.18-20,Nov.12, Dec.10-12
2014	Jan.9-10, Feb.8-9, Mar.9-11, Apr. 8-10, May.7-9, Nov.30, Dec. 01-02, 29-31
2015	Jan.28-29, Feb.27-28, Mar.28-29, Apr.26-28, May.26-28, Sep.23, Nov.20-21, Dec.19-21
2016	Jan.17-19, Feb.16-17, Mar.16-17, Apr.14-16, May.14-16, Jun.13, Dec.8-9



$$0 \leq \beta' \leq 1.25 \cdot \theta_{3dB}$$

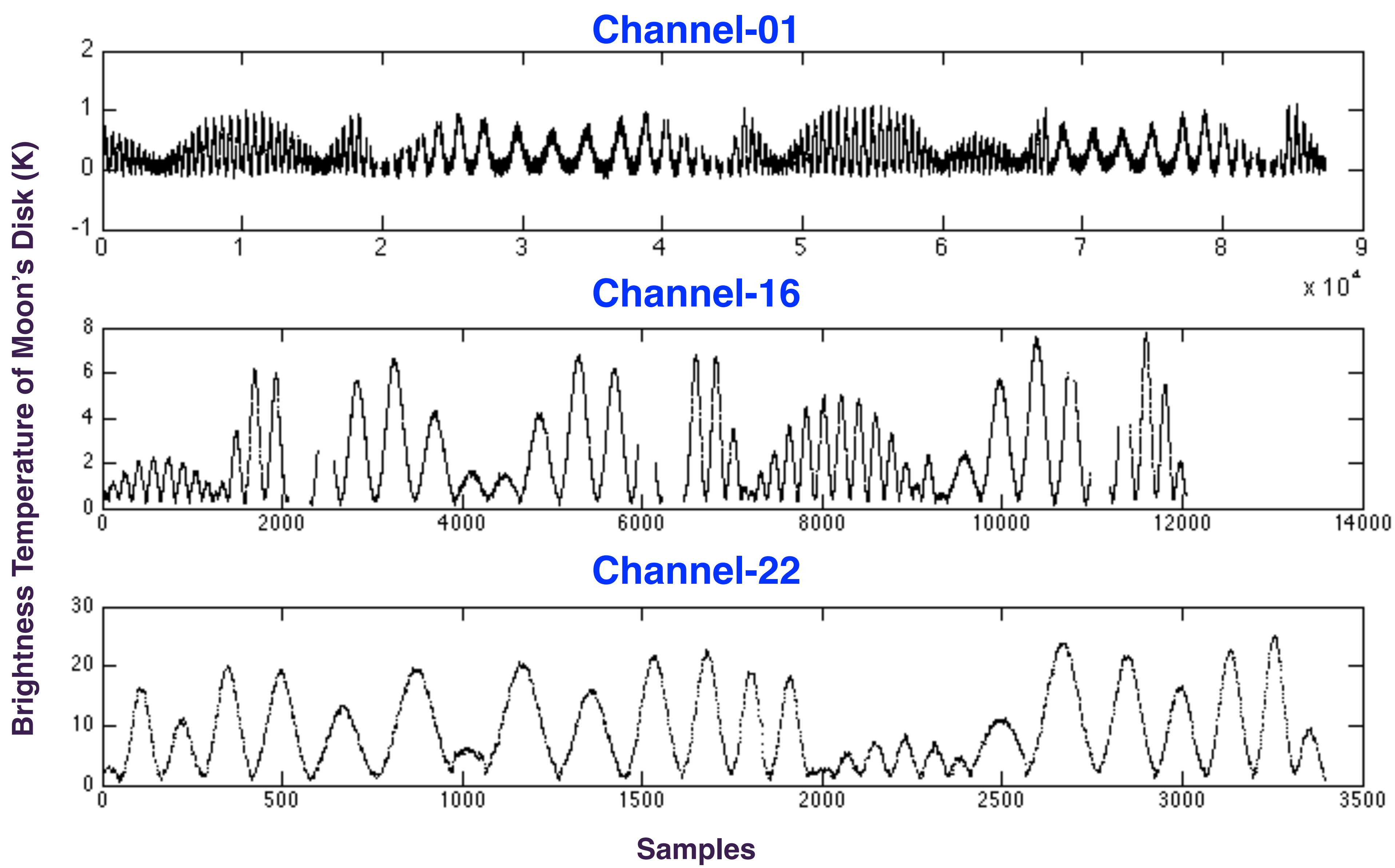
$$\beta' = |\beta + \alpha_1|,$$

$$\alpha_1 = \frac{r_{moon}}{d_{moon}}$$

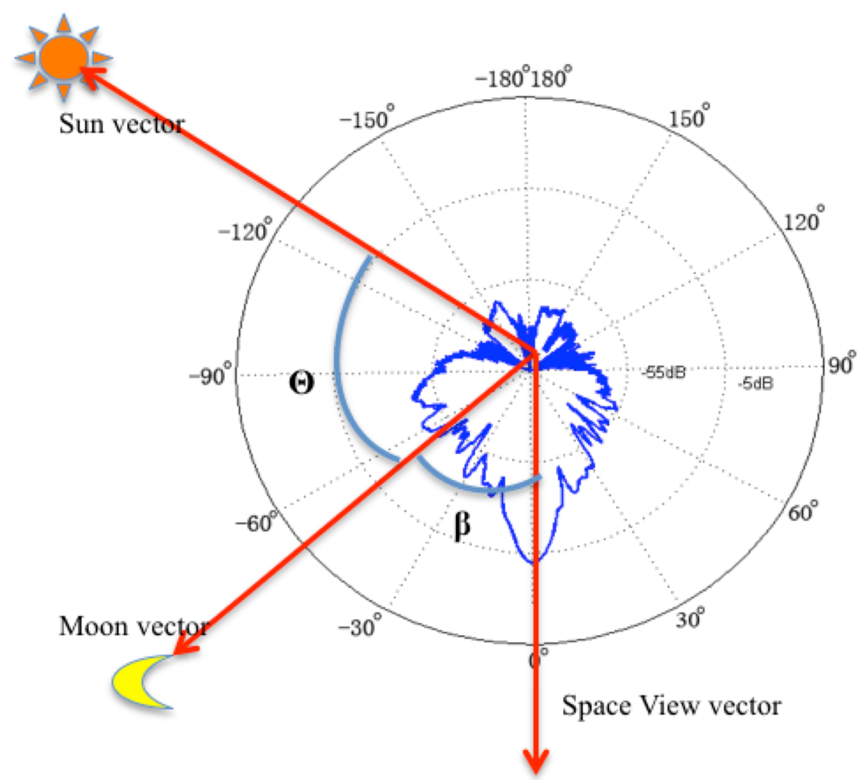
Lunar Disk Microwave Brightness Temperature Calibration

- LI cases with at least one clean cold space view without lunar contamination were selected.
- Effective brightness temperature of the Moon's disk can be derived from calibration equation
- Bias caused by earth sidelobe contamination and antenna emission are need to be corrected for cold space Tb in calibration

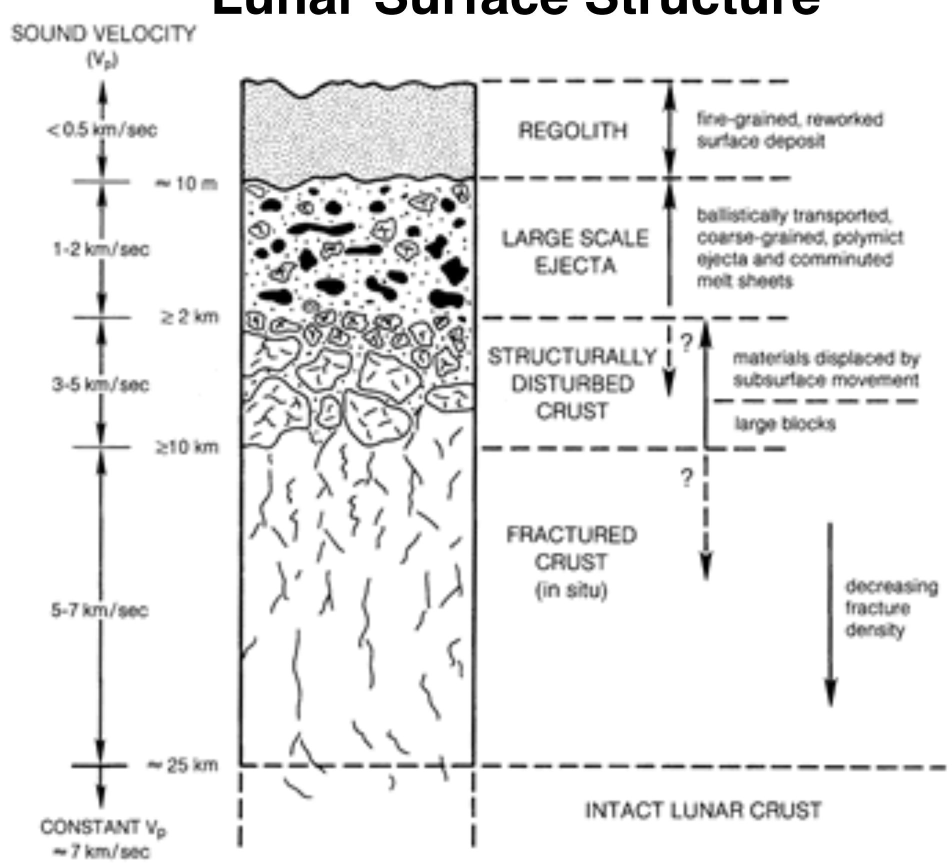
$$TB_{moon}^{eff} = \left[\frac{T_w - T_c}{C_w - C_c^{min}}\right] \Delta C_{moon}$$



Lunar Model Development



Lunar Surface Structure



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 :

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

Assuming the azimuthal asymmetry is insignificant, the antenna response within the mean beam range can then be accurately simulated by one dimension Gaussian function:

$$G_{ant}(\beta') = e^{-(\beta' - \alpha_0)^2 / 2 \cdot \sigma^2}$$

where β is the separation angle between antenna boresight and Moon-in-View vector, α_0 is the beam pointing error angle. The normalized solid angle of moon is calculated as a solid angle of moon disk normalized by the beam solid angle, :

$$\Omega_{moon} = \frac{\pi\left(\frac{r_{moon}}{D_{moon}}\right)^2}{\Omega_A}$$

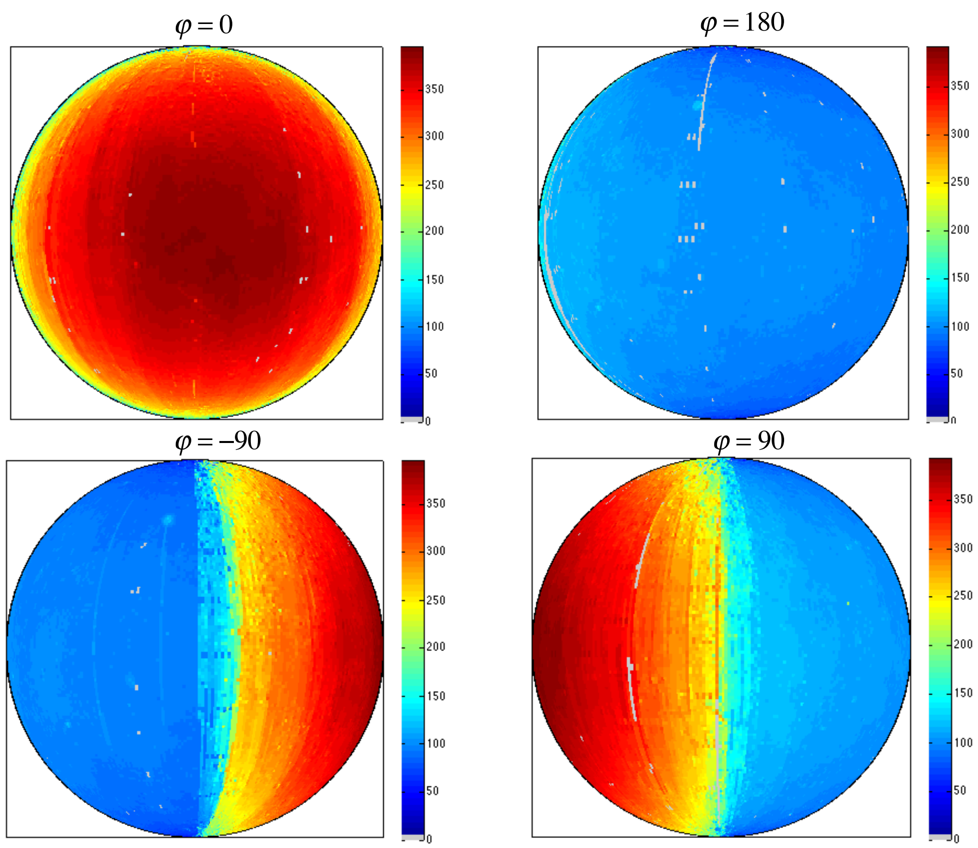
Beam solid angle can be calculated from ground measured antenna pattern data as:

$$\Omega_A = \iint_{4\pi} G(\theta, \phi) \sin\theta \, d\theta \, d\varphi$$

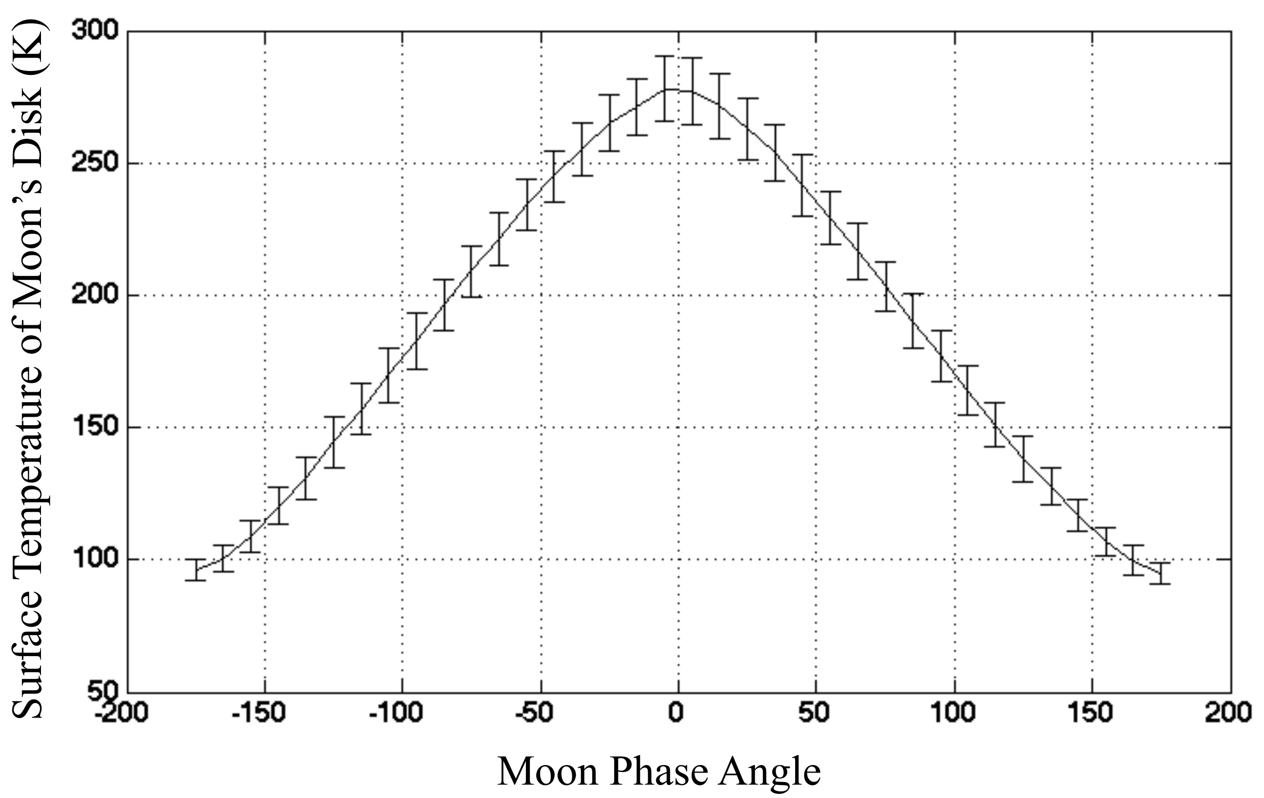
Lunar Surface Temperature

- The observations from the Diviner Lunar Radiometer Experiment instrument (DLRE) onboard the Lunar Reconnaissance Orbiter from 2009 to 2015 are used to derive average surface temperature of Moon's disk
- The average physical temperature of Lunar disk has a dynamic from 94 to 270K, with a 5~10K Std Error
- The lunar disk surface temperature model is parameterized as function of moon phase angle
- The uncertainty in lunar disk physical temperature model will raise at most 0.1K uncertainty in 5.2 deg FOV channels and 1K for 1.1deg channels

Global Distribution of Lunar Surface Temperature



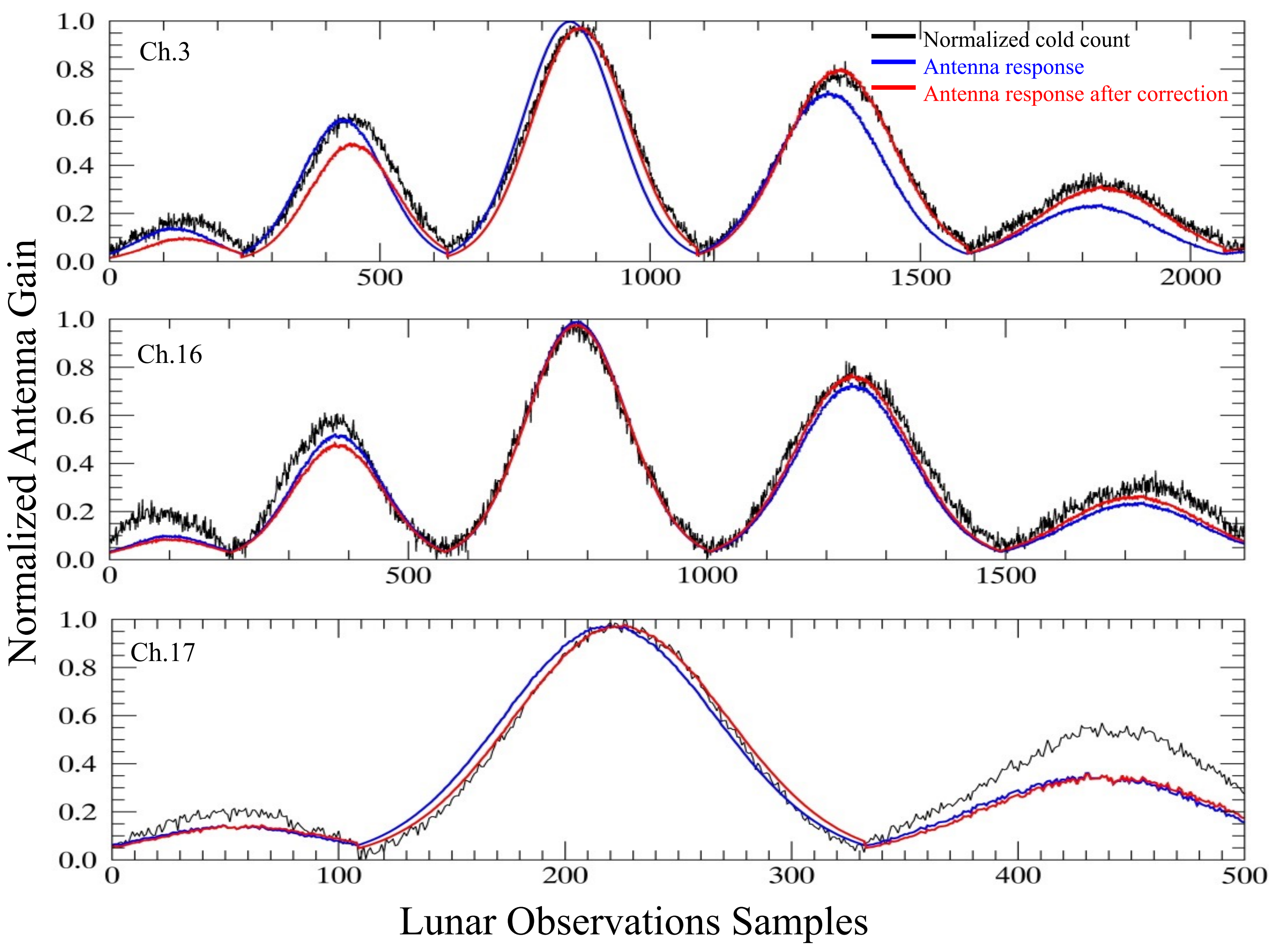
Phase Angle Dependent Average Surface Temperature of Moon's Disk



Antenna Pointing Error Correction

- Beam pointing error was determined in terms of Euler angles from an algorithm combined using coastline inflection point and the drift curve of lunar observations
- A correction matrix was constructed and applied in geolocation process to correct the beam pointing error in lunar observations

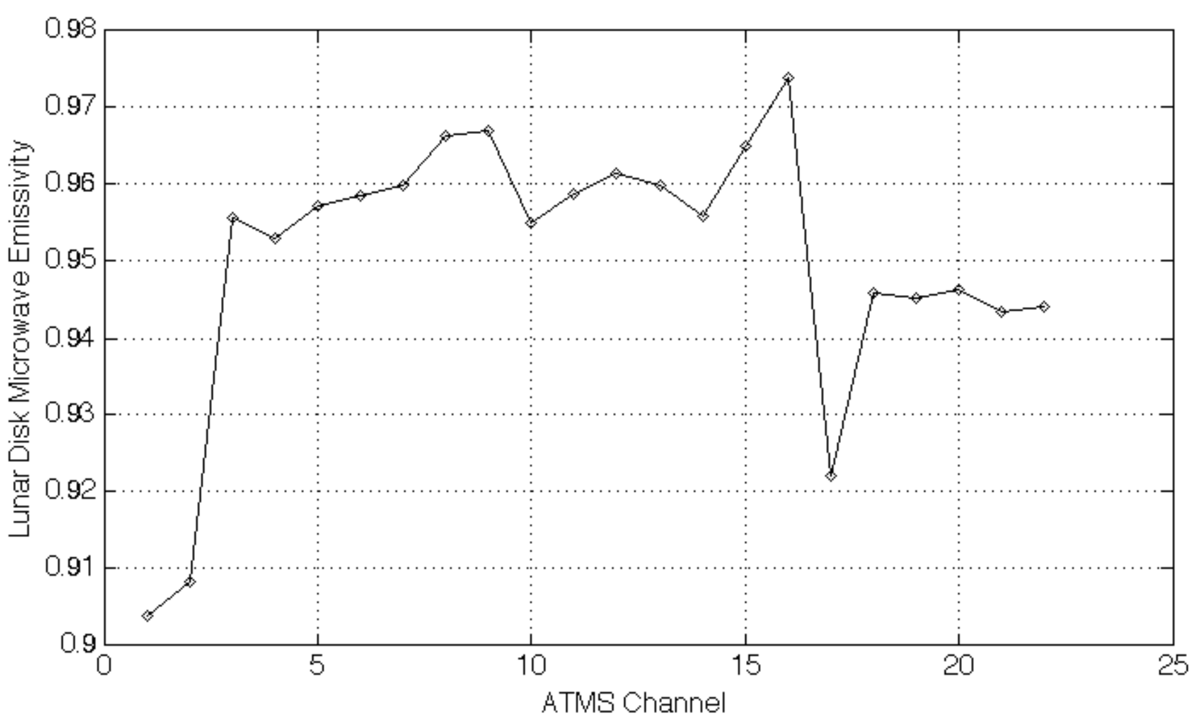
LI event observed by SNPP ATMS SPV during Jan 6-8, 2017

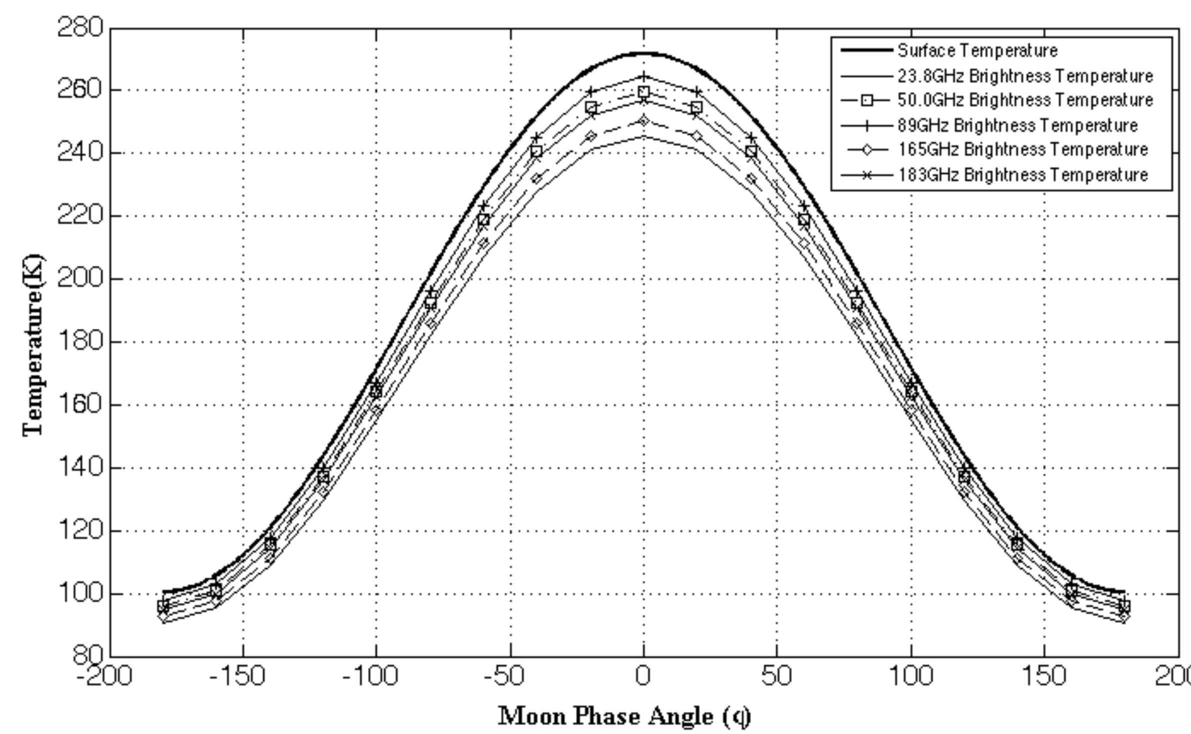


Lunar Disk Microwave Emissivity Spectrum

- Frequency-dependent emissivity spectrum of lunar disk for ATMS channels can be derived from well-calibrated ATMS brightness temperature of Moon's disk
- The retrieved average emissivity of the Moon's disk has a minimum of 0.90 at K/Ka band (23/31 GHz), and maximum of 0.97 at W band (89GHz).
- The drop of emissivity in G band is most likely due to noise in ground measured G band antenna pattern

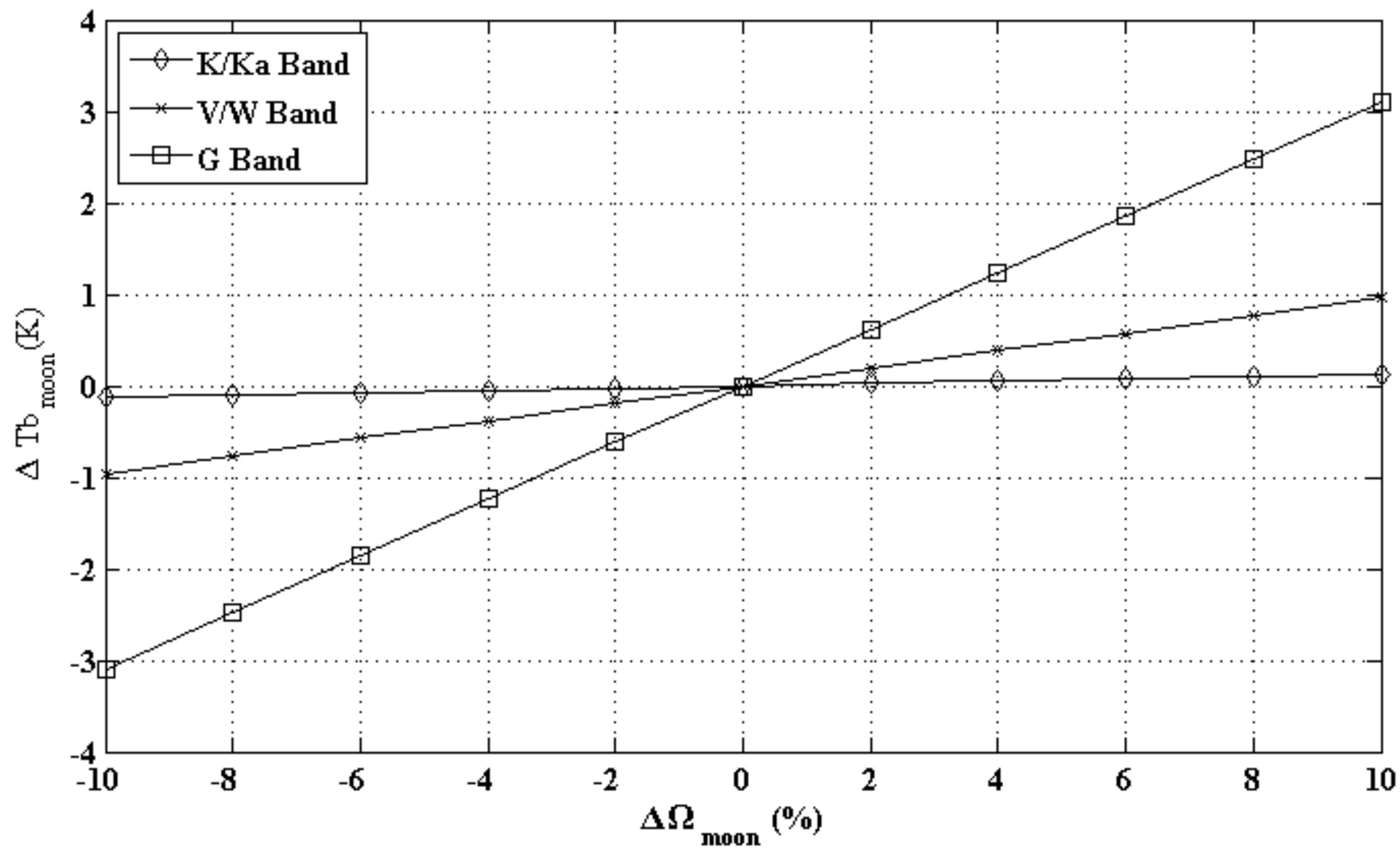
$$TB_{moon}^{disk} = \mathrm{E}_{moon}^{disk} * T_{moon}$$





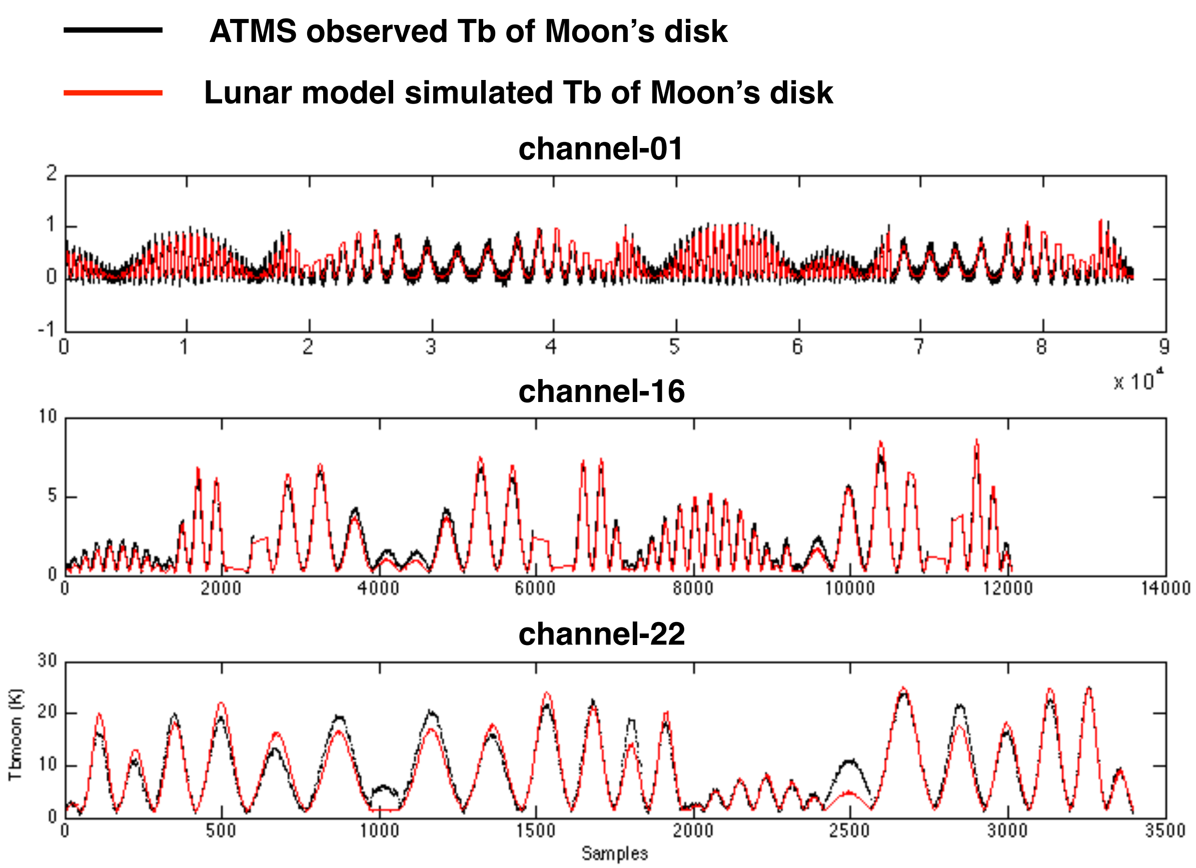
Impact of Antenna Pattern Measurement Error on Model Bias

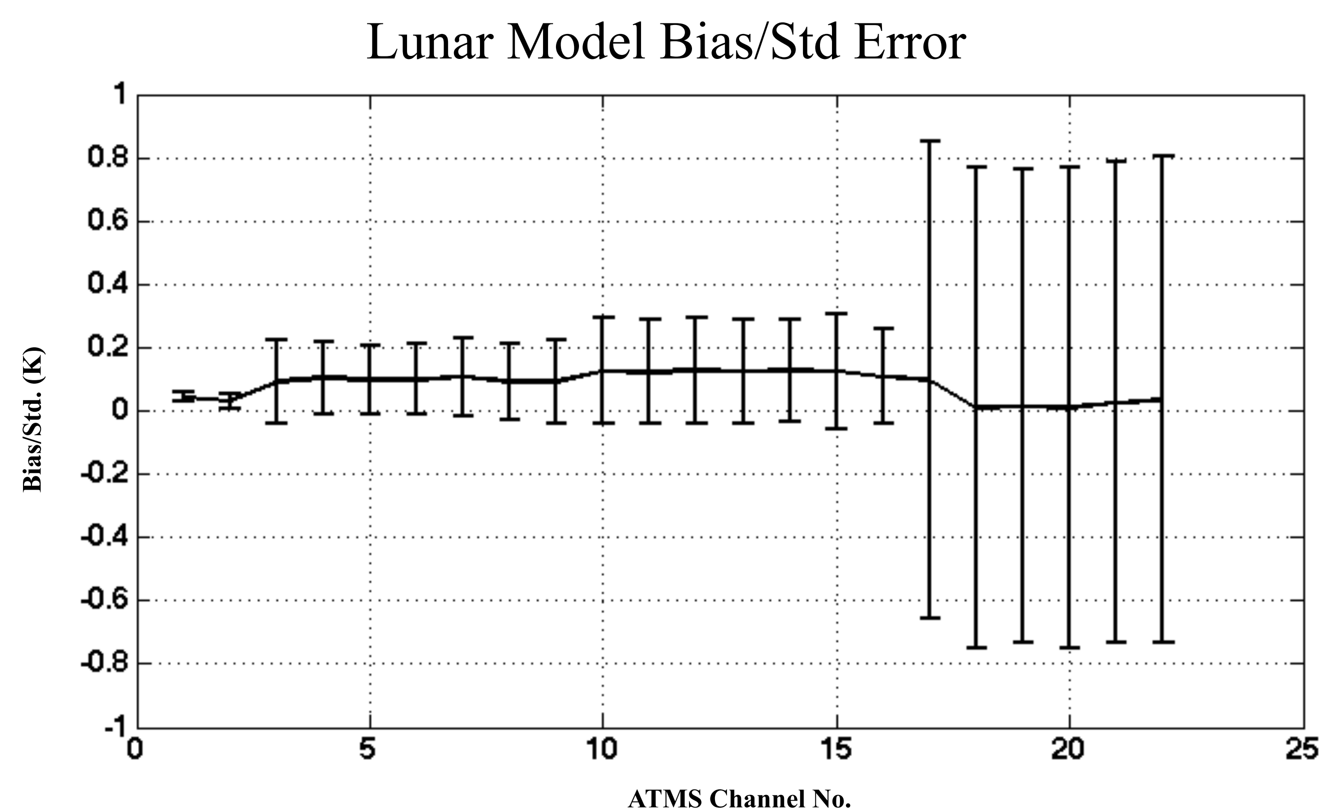
- The sensitivity of model bias to antenna beam solid angle measurement error is increase with frequency: The lower frequency channel with FOV size of 5.2^o is not sensitive to antenna beam solid angle, only 0.13K bias was observed when the uncertainty of beam solid angle is 10%, while it will introduce as large as 3K biases in G band.
- From antenna pattern ground measurements for SNPP and JPSS-01 ATMS we learned that the uncertainty in antenna beam solid angle in ATMS G bands is larger than 10%. This might explain the error in G band lunar microwave emissivity.
- Accurate information of antenna beam solid angle is very important for successful implementation of the lunar model



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

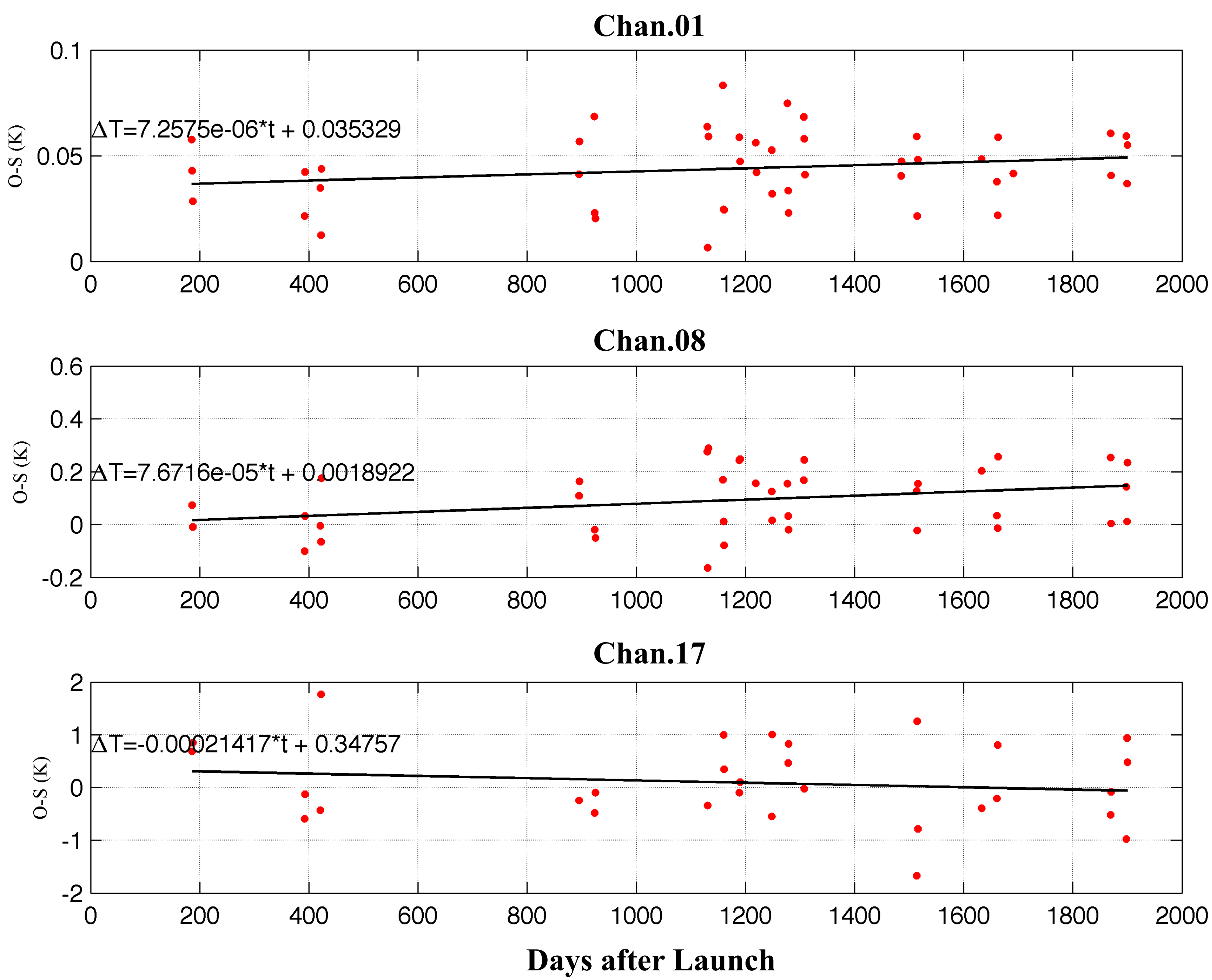




Long-term Instrument Stability Monitoring

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

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



Conclusions

- Microwave radiation from the Moon's surface is very stable and can be taken as a permanent reference target to evaluate the calibration accuracy and assess the long-term calibration stability for microwave radiometers

- A reliable lunar Tb model can be established from a well calibrated ATMS lunar observations, combined with accurate ground measurements of antenna pattern.

- In future it is possible to obtain the warm load equivalent effective lunar brightness temperature for calibration by using a finer beam width in lunar observations. This is especially important for on-orbit calibration of small and cubic satellites