Uncertainty and phase angle dependency of SELENE/SP Lunar Reflectance Model for Lunar calibration

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Introduction: Reliable and stable quality control of data products for Earth observations is a key factor to maintain the product reliability, and thus the long-term radiometric calibration is indispensable for the Earth observation missions. Because of harsh space environmental conditions, instrument performances may degrade at launch and during on orbit. Since Moon radiometric properties are extremely stable for a very long term (> 1 Million year [1]), Lunar calibration is one of useful calibration methods on orbit in which Moon is treated as a known brightness light source. Spectral Profiler onboard SELENE, a Japanese Lunar orbiter, has provided a new hyperspectral Moon reflectance and photometrical model, which enables to simulate any Moon observation. Comparing observed and simulated Moon images, sensor degradations will be validated. Since the issue is the uncertainty of the model and the appearance of Moon varies with time due to waxing and waning (= phase angle variation) and Moon libration effect, it is required to understand the model accuracy and its photometrical characteristics depending on incident, emission and phase angles.

Hyperspectral Lunar Reflectance Model based on SELENE/SP data: Multi and hyper-spectral sensors onboard Earth observing satellites usually have lots of spectral bands and ability to obtain high spatial resolution images and thus requires enough spectral bands and high spatial resolution for Lunar reflectance models.

A new lunar reflectance model based on hyperspectral data of Spectral Profiler (SP) onboard SELENE, which was a Japanese Moon satellite operated in 2007 – 2009 [2], covers a wavelength range from 500 nm to 1600 nm with 6-8 nm spectral sampling interval and involves lunar surface photometric properties depending on incident, emission and phase angles. The model resolution reaches 0.5 x 0.5 degree in longitude and latitude and the model has totally 720 x 360 grids. Both high spectral and spatial resolutions are comparable to resolutions of a lunar image obtained by a planned hyper-spectral imager such as Hyperspectral Imager Suite (HISUI), a Japanese next-generation Earth observation project involving a hyperspectral imager with the ground sampling distance of 30 meters [3].

Figure 1. Examples of simulating Moon observations using SP lunar reflectance, photometric function model. (a) Lunar image taken by ASTER/Band 2 on Apr. 13, 2003 and (b) its simulated lunar image.

Figure 1 shows an example of simulating a Moon observation using SP model following previous studies [4] [5]. We simulated an observation by Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) onboard Terra using Band 1 (centered at 560 nm), Band 2 (660 nm) and Band 3 (810 nm) [6] conducted on April 13, 2003, considering photometric properties of SP model to simulate the Moon observation.

Evaluation of SP Model Uncertainty: The well spatial resolution enables to compare radiance between observed and simulated images at every pixel. Figure 2 shows a scatter plot of observed and modeled radiance of Band 2 and its frequency distribution of observed radiance normalized by modeled radiance. Table 1 summaries mean ratios (observed radiance / simulated radiance), their standard deviations and standard errors

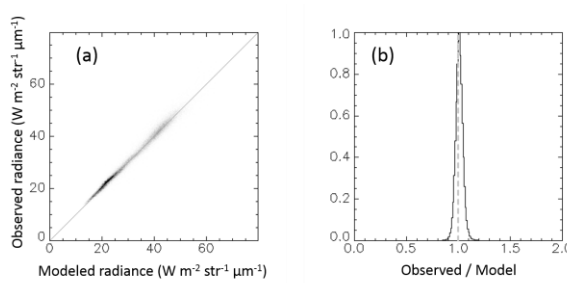

Figure 2. (a) Scatter plot comparing observed and simulated Moon radiance for ASTER/Band 2. Grey lines represent the position where both radiance are same. (b) Frequency distribution of observed radiance divided by simulated radiance at each pixel.

Table 1. Mean ratios, standard deviations, standard errors and correlation coefficients between observed and simulated radiance at each pixel.

	Band 1	Band 2	Band 3
Mean ratio (Obs./Model)	1.20	1.01	0.95
Std. dev.	0.03	0.03	0.04
Std. error	0.0002	0.0002	0.0002
Correlation	0.992	0.993	0.993

and correlation coefficients for all bands. To estimate the standard errors we consider the number of pixels (70,000) we can use for the brightness comparison. It should be noted that observed radiance was estimated using ASTER radiance correction coefficients version 2.1.2 which covers the period involving ASTER Moon observation date (version 2.1.2 is based on only onboard calibration results).

From mean ratios of observed/simulated radiance, we can find somewhat large biases, that means at this time it is difficult to use SP model to evaluate "absolute degradation" of sensors. One possible reason of this bias is the calibration issue of SP sensor according to SP calibration reports comparing other Lunar observation sensors [8] [9]. On the other hand, magnitudes of standard errors show the order of 0.01 % in all bands, this indicates the uncertainty of the mean value is only less than 0.1 % (of course we should consider the bias). Because of this small uncertainty, the lunar calibration has a good ability to evaluate "relative degradation" of sensors in which we can cancel the bias.

Phase angle dependency of SP Model comparing with ROLO Model: Because SP observed Moon surface with various solar incident angles and phase angles, it can be expected that SP model basically well descrives variation of Moon irradiance (= disk integrated brightness) with various phase angle condtions, although SP observed with restricted emission angle condtion (always nearly 0 degree).

To evaluate the phase angle dependency, we compare Moon irradiance (= disk integrated Moon brightness) from SP model with that from ROLO model [10] using model correction parameters. Figure 3 shows the irradiance ratios between SP model and ROLO model using parameters for 745 nm wavelength in the time period from January 1 to December 31 in 2013, this means we tested with more than12 cycles of Moon waxing and waning. Data at phase angle range smaller than five degrees is omitted because the current SP model cannot treat such small phase angle range. In this comparison we consider not only phase angle variation but also the libration effect of Moon.

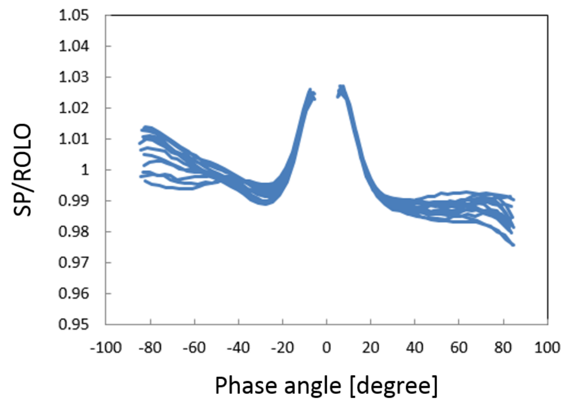

Figure 3. Irradiance ratio (745 nm) between SP model and ROLO model as a function of phase angle in the time period from Jan. 1 to Dec. 31 in 2013. Negative signed phase angles indicate waxing lunar phases.

The curves in Figure 3 are not flat curves and the standard deviation is 1.1%. However if we consider the phase angle range less than 50, the irradiance ratios are stable in 12 cycles. On the other hand at large phase angle range irradiance ratios shows relatively large deviation in 12 cycles, and this may cause the evaluation error even for relative degradation. Thus at least in the phase angle range less than 50, and if we chose an enough restricted phase angle range, it can be expected that Lunar calibration with SP model provides a reliable result for relative degradation.

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