



Original research article

A novel hyperspectral lunar irradiance model based on ROLO and mean equigonal albedo

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ARTICLE INFO

Article history:

Received 1 March 2017

Accepted 2 June 2017

Keywords:

Lunar calibration

Mean equigonal albedo

Hyperspectral lunar

Irradiance

ROLO model

ABSTRACT

Lunar observations are an attractive candidate for radiometric calibration of satellites in reflective solar bands (RSBs). However, our inadequate knowledge of the lunar surface's reflectance restricts the use of lunar as a standard for calibration. The uncertainty of a well-known lunar irradiance model for calibration, the RObotic Lunar Observatory (ROLO) model, is 5–10%. One of the uncertainty sources is due to the fact that the model is based on samples from the Apollo missions. To remedy this problem, we develop a novel method to improve the current ROLO lunar hyper-spectral irradiance model, which uses a mean equigonal albedo to replace the reflectance of Apollo soil samples. It is demonstrated that the 2009 Miller-Turner (MT2009) model predicts values, at wavelengths of 350–2550 nm, that are larger than the new model. Further, the irradiance of the new model is closer to that of the Moderate Resolution Imaging Spectroradiometer (MODIS) and Sea-Viewing Wide Field-of-View Sensor (SeaWiFS) than the ROLO model in the visible and near-infrared (VNIR). The mean discrepancy between MODIS measured irradiance and the ROLO values is 7.49%, between MODIS measured and the new model is 4.20%; between SeaWiFS measured values and the ROLO model is 3.93%; and between SeaWiFS measured and the new model is 2.90%.

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1. Introduction

For a fixed solar illumination and satellite observation geometry, the photometric stability of the lunar surface is about 10^{-8} per year for irradiance [10], which allows the Moon to be used as a well-defined target and an excellent radiometric reference in radiometric stability monitoring for reflective solar bands [19]. Based on the advantages of lunar data in satellite imager RSB calibration, Cao et al. [4] and Choi et al. [5] developed a Lunar Band Ratio (LBR) method which performs a relative radiometric calibration for the advanced very high resolution radiometer (AVHRR). [25] found model-based Visible Infrared Imaging Radiometer Suite (VIIRS) lunar F-factors were in general agreement with VIIRS Solar Diffuser (SD) F-factors. Eplee Jr et al. [7] illustrated the calibration biases in the cross calibration of SeaWiFS and MODIS using on-orbit lunar observations and a lunar model, indicating that there were 5% uncertainties on the absolute radiance calibration. The moon has also been used as a calibration transfer standard in the double-differencing method [21]. It is worth noting that the moon is about

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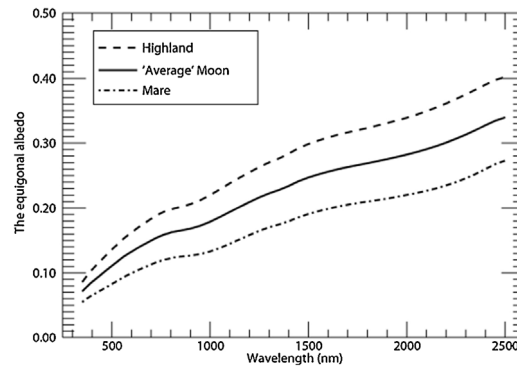


Fig. 1. The equigonal albedos of lunar highland, mare, and the 'averaged' (mean) equigonal albedo ($\bar{A}_{eq,k}(\alpha = 49.96^\circ)$).

to be used as a target for inter-calibration by the future Traceable Radiometry Underpinning Terrestrial and Helio Studies (TRUTHS) mission and Climate Absolute Radiance and Refractivity Observatory (CLARREO) mission [8,13]. In spite of the fact that all of the methods mentioned above take the Moon as a well-defined object for relative/absolute radiometric calibration or stability monitoring for RSBs, the absolute precision of hyper-spectral lunar models with respect to radiance or albedo still restricts the widespread use of lunar models in RSB calibration.

In order to utilize the Moon as a standard for calibration, the United States Geological Survey has operated the ROLO plan [17]. ROLO's raw data are acquired in 32 spectral bands between 350 nm and 2500 nm. The ROLO hyper-spectral lunar irradiance model was developed by adjusting the ROLO model reflectance using the laboratory reflectance of returned Apollo samples, which exhibit an absolute uncertainty of 5–10%. However, the reflectance of returned Apollo soil samples in the laboratory are significantly different from that in lunar observations. Because the original regolith cover on the lunar surface and gravitational forces exerted on Apollo soil samples by the Moon were significantly lower than those on the Earth, there are variations in the reflectance of returned Apollo soil samples [9,11]. Accordingly, the adjustment made is most likely to overestimate or underestimate the band strength in the ROLO lunar hyper-spectral irradiance model.

The primary objective of this study is to reduce the uncertainty in the ROLO hyper-spectral lunar irradiance model using returned Apollo soil samples for radiometric calibration. Here, we develop a novel method to improve the current ROLO lunar hyper-spectral irradiance model, which uses a mean equigonal albedo to replace the reflectance of Apollo soil samples [12]. Theoretically, this method is based on the relationship between the mean equigonal albedo and the effective disk reflectance, which is mainly attributed to a better-fitted ROLO model using the mean equigonal albedo. This paper is organized as follows: the next section briefly introduces the relationship between the mean equigonal albedo and the effective disk reflectance. Section 3 derives a new hyperspectral lunar irradiance model based on the effective disk reflectance of the ROLO model and the mean equigonal albedo. Section 4 validates the new model using Miller-Turner 2009 (MT2009), MODIS and SeaWiFS. The last section summarizes the findings and conclusions of this paper.

2. Theory and methodology

2.1. Definitions

In lunar photometry, the lunar surface has been the subject of attention for many years, and many methods to describe the characteristics of lunar photometry have been proposed. In one of the methods, the equigonal albedo of lunar was used for comparing the integral measurements of the moon (a spherical body) with the measurements of a flat laboratory sample (the lunar regolith or its analogues) or a small area on the Moon.

The equigonal albedo of the lunar surface associated with the apparent albedo can be expressed as follows:

$$A_k(\alpha, i, e) = A_{eq,k}(\alpha) D_k(\alpha, i, e) \quad (1)$$

where i is the incidence angle, e is the emission angle, and α represents the (solar) phase angle of observation geometry of the lunar surface from the observer, $D_k(\alpha, i, e)$ is the disk function in band k , which describes the brightness distribution over the lunar disk [9,27], and $A_{eq,k}(\alpha)$ is the equigonal albedo of the lunar surface. When $i = \alpha/2, e = \alpha/2$, the equigonal albedo of the lunar surface $A_{eq,k}(\alpha)$ is equal to the apparent albedo $A_k(\alpha, i, e)$ [20].

The spectral 'averaged' (mean) equigonal albedo over the lunar disk $A_{0eq,k}$ has been obtained as a linear combination of highland and mare spectra with weights of 0.57 and 0.43. The ratio of highland and mare spectra for the visible hemisphere has been calculated by [12]. For the illuminated and visible part of the lunar disk, the ratio changes with phase angle, so the averaged equigonal albedo also changes with phase angle [12,20]. As Fig. 1 shows, when the phase angle is 49.96° , the normalized mean equigonal albedo is equal to 0.1338 at $\lambda = 607\text{nm}$.

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