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Earthshine measurements with automated telescopes

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Abstract. Earthshine is sunlight reflected by the Earth visible as a dim image of dark portion of the Moon's disk. The earthshine intensity relates to the Earth's albedo, which relates to the Earth's effective temperature. Temporal variations of the earthshine intensity provide information on the variations of the Earth's albedo and global effective temperature. We will build a global ground-based network of automated telescopes to measure the earthshine intensity to study the short-term and long-term variations of the Earth's albedo.

Key words. Moon – Earthshine – Earth's albedo – Global temperature

1. Introduction

Earthshine is is sunlight reflected by the Earth which is visible as a dim image of dark portion of the Moon's disk. The intensity of earthshine relates to the Earth albedo, which is an important parameter in the Earth's global energy budget. The idea of measuring earthshine to determine the variations of Earth's albedo and effective temperature was first proposed by Danjon (Danjon 1928, Danjon 1936, Danjon 1954). He used the ratio of the intensity of the dark portion to the intensity of the bright portion to reduce the effects of the atmosphere and solar intensity. However, the error bar of his measurements, about 5%, is too large to determine the variations of the Earth's effective temperature. The recent earthshine measurements at the Big Bear Solar Observatory show that the error bar of albedo can be as small as 1% Goode et al. (2001). It indicates that measuring earthshine with modern technology becomes a promising method to measure the variations of the Earth's albedo. The goal of this project is to build a network of automated telescopes to measure the variations of earthshine intensity to study the variations of the Earth's albedo and effective temperature.

2. Earthshine and Albedo

The Earth's albedo is a weighted average of the local reflectivity over the areas illuminated by sunlight. Its typical value is about 0.3 though it varies with time. The incident sunlight is reflected by air, clouds and the surface. The surface reflectivity varies widely depending on the surface type and physical condition, ranging from values as low as 5% for oceans to as high as 90% for snow Hartmann (1994). The local reflectivity changes with time; it leads to a temporal change in the global albedo. The reflectivity of clouds is high. The variations of the cloud coverage and thickness have a significant contribution to the variations of the Earth's albedo. The earthshine intensity relates to the Earth's albedo (Koonin et al. 1996, Goode et al. 2001). Thus measuring the variations of the earthshine intensity provides information on the variations of the Earth's albedo.

3. Albedo and Effective Temperature

The Earth's albedo and effective temperature are related. If the Earth's albedo (Bond albedo) is a, a fraction a of the incident solar energy is reflected back to space, and the rest, $1-a$, enters the Earth system. The solar energy entering the Earth, E_i, can be expressed with the Earth's albedo a as

$$E_i = \pi R_e^2 \cdot (1-a) \cdot F \quad (1)$$

where F is the solar energy flux and R_e the Earth's radius. The energy entering the Earth is converted into heat and re-radiates into space in infrared wavelengths. The reradiated energy E_o can be expressed in terms of an effective temperature of the Earth T_e as

$$E_o = 4\pi R_e^2 \cdot \sigma T_e^4 \quad (2)$$

where σ is the Stefan-Boltzmann constant. Averaging over a period long enough, the input energy E_i and the output energy E_o balance. Thus T_e can be expressed in terms of albedo a

$$T_e = \left[\frac{(1-a)F}{4\sigma}\right]^{1/4} \quad (3)$$

If a equals to the typical value 0.3, from equation (3) $T_e = 255°$K. It is noted that this value is lower than the average Earth's surface temperature, about 270°K. This is due to the green-house effects (e.g. see Hartmann 1994).

From equation (3), the variations of albedo relate to the variations of global effective temperature as

$$\frac{\delta T_e}{T_e} \approx -\frac{1}{4} \cdot \frac{\delta a}{a} \quad (4)$$

An increase of 1% in albedo results in a decrease of about 0.6°K in T_e. Equation (4) also tells us that if albedo can be measured with an accuracy of 1%, T_e can be determined within about 0.6°K.

4. Global Network

Since earthshine measurements at one site provide information on the reflectivity averaged over only part of the Earth, it needs several identical telescopes at appropriate longitudes to obtain a good coverage of averaging area to provide more complete information on the albedo. It is of scientific importance to study the long-term variations of the global temperature, and equation (3) is valid only in a long term. Thus long-term measurements of earthshine are important. To make long-term observations feasible with a low cost, automated telescopes are necessary. Our plan is to establish a global network of identical automated telescopes to make long-term earthshine observations. We have built a prototype automated telescope (see Figure 1). The first telescope will be set up at Lulin Mountain (altitude 2700 M) in Taiwan in 2003. The second and third telescopes will be set up in Midanak, Uzbekistan and Tenerife, Spain.

5. Automated Telescopes

5.1. Optical and Imaging System

A 3.5-inch ruggedized Questar telescope (Maksutov type) and a German-type equatorial mount are used. A neutral density filter is placed near the focal plane to reduce the intensity of the bright portion of the Moon's disk such that the dark portion

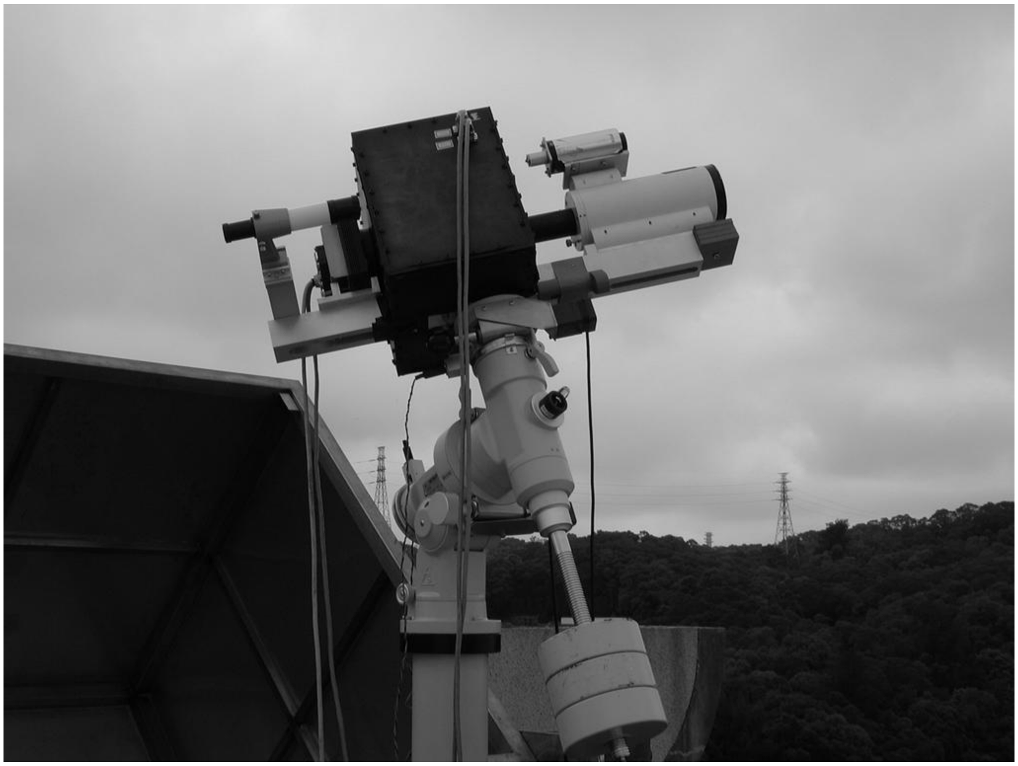

Fig. 1. Prototype automated earthshine telescope on the campus of National Tsing Hua University.

and the bright portion can be measured simultaneously. The ratio of intensities of the dark portion to the bright portion reduces the atmospheric effect. Since the fraction and position angle of the bright portion vary with time, the position and orientation of the neutral density filter need to be adjusted automatically. A mechanical device, controlled by a DSP, is used to adjust the position and orientation of the neutral density filter, based on the computed fraction and position angle of the bright portion of the Moon's disk. A 16-bit 1024×1024 air-cooled CCD is used to take images.

5.2. Tracking and Control System

Tracking the Moon is more difficult than tracking stars and the Sun for two reasons. First, the coordinates of the Moon changes with time. Second, the shape of the dominant bright portion of the Moon's disk changes with time. We use both the passive tracking (using the computed coordinates) and the active tracking (using the observed Moon's images to adjust pointing). To make the telescope robust, we minimize electronic hardware by using a digital signal processor (DSP) to control the telescope. This allows us to improve or update the control system by modifying the software of the DSP. The DSP is controlled by a Linux-based computer. A GPS is used to provide accurate time, which is required in computing the Moon's coordinates.

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