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EARTHSHINE OBSERVATIONS FROM SOFIA

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ABSTRACT

The Earthshine Project re-invigorated a method that holds the potential to observe our planet on a global scale, as it would be viewed from a very distant point. By measuring the light reflected from the bright and dark sides of the Moon, we can observe the Earth by means of astronomical techniques. More than six years of sustained observations from Big Bear Solar Observatory (BBSO) in California, have enabled us to determine annual changes in the Earth's global reflectance, in the 0.4-0.7μm range, with an accuracy of 1.0%. These data are significant inputs for climatic global circulation models (GCM). Spectroscopic earthshine measurements have also been undertaken from Palomar. Now we aim to extend these observations to the infrared. In this presentation, we will discuss the importance of doing photometry and spectroscopy of the infrared earthshine from the stratosphere, and the different scientific goals intended through these long-term observations.

INTRODUCTION

Our climate has varied as the Sun has evolved since the formation of the solar system. In more recent eons, climate changes have also being attributed to variations in the Earth’s orbital parameters along with geological events that naturally modify the concentration of greenhouse gasses. However, the physical mechanism(s) responsible for the increase of the globally averaged Earth’s surface (and sea) temperature during the last century remains unclear. The Sun's irradiance has been precisely measured from space for more than twenty years, and although some fluctuations have been detected, they are insufficient to explain the temperature increase of about half a degree centigrade. However, the changes in Earth’s reflectance and emission at global scales, critical regulators of the Earth’s energy balance, have not yet been accurately determined.

BACKGROUND

We have been measuring Earth’s reflectance with a 15 cm telescope attached to the 65cm Solar Telescope in BBSO since 1998 (Goode et al., 2001). The advantage of measuring terrestrial albedo by observing the light of the Earth reflected from the Moon arises from the capability of obtaining long-term global-scale information, difficult to acquire by any other way. These measurements have allowed us to determine seasonal variations in the global albedo (Palle et al. 2003), to establish a relationship between the albedo and observed clouds properties from ISCCP satellite data, and to construct from the latter a proxy measure of the Earth’s global reflectance in the visible range (Palle et al., 2004b). We have determined from this proxy large albedo variations with important implications for climate change.

Besides optical imaging, routine spectroscopic observations, covering approximately from 0.4 to 0.8 μm, have been taken at Palomar Observatory with the 60-inch telescope (P60") from January 1999 to present. The spectral resolutions of these data, 0.2 and 5.0 Å/pix, enables the study of wavelength-dependent albedo and also global measurements of atmospheric greenhouse gasses. In order to do this, we compare our observed molecular bands with synthetic spectra modeled using standard atmosphere codes and the High-Resolution Transmission Molecular Absorption (HITRAN) database. Inside our spectral range, a few molecular bands are available, including oxygen A (7620-7720 Å), oxygen B(6920-6860 Å) and several water bands. From the moonshine images, we first determine the properties of the local atmosphere, which are then used as input in the analysis of the earthshine data. We have determined the averaged column density of O_2 and H_2O, as well as the mean averaged atmospheric temperature, for both the local and global atmospheres (Montanes Rodriguez et al.,2004, Palle et al, 2004b and Montanes Rodriguez et al., in preparation).

SCIENTIFIC GOALS.

The climate of Earth is driven by the redistribution of the Sun's energy over the Earth's surface. Variations in the incident energy over time, or variations in the balance of this energy, will have consequences for the Earth's climate. By measuring the terrestrial reflectance and emission in the infrared region we will obtain relevant information with implications for climate sciences, and, in addition, these results will provide a better understanding of possible biomarkers, supporting future bioastronomy missions.

Near Infrared.

Firstly, as a complement to our photometric albedo measurements from BBSO, we aim to extend these observations to the near infrared region (1-5μm). As climate evolves, these measurements may be able to identify significant changes due to processes such as cloud feedback and therefore lead to a better understanding of the Earth's energy budget.

We also intend to observe the near infrared earthshine through spectroscopy. We have started to explore this spectral region by observing with the Infra-Red Telescope Facility (Montanes Rodriguez et al. 2004b), but we can precisely calculate the wavelength dependent effective albedo variations by means of more regular spectral observations from the top of the atmosphere. By means of these observations, large-scale measurements of greenhouse species such as CO_2 (1.538μm), CH_4 (1.667μm), or H_2O (1.12μm) would also be possible.

By taking spectra of earthshine from above 75% of the atmosphere, we can avoid the noise introduced by the local atmosphere, mainly by the water vapor column, which is correctable in the visible region but more significant, and difficult to correct in the infrared.

Middle Infrared.

The Earth's radiation budget depends on both the Earth's reflectance and the amount of IR-radiation emitted by Earth to space. The planetary infrared emission becomes important between 5 to 30 μm, and is a function of cloud cover, large area weather phenomena, landscape, etc. Spatially resolved satellite measurements of the Earth Radiation Budget Experiment (ERBE) have found peak values of this energy in the tropical zones, and minima at the poles. Fluctuations on global scales are expected as climate change progresses, and they need to be precisely moisturized and quantified. This can be achieved by means of imaging mid-infrared observations, but cannot be done from the ground since the local atmosphere is part of energy transport mechanism. Stratospheric observations of the earthshine are needed in this spectral region. We propose to use the same method than in our albedo observations from BBSO, described in the following section, to measure changes on this energy from the Stratospheric Observatory for Infrared Astronomy (SOFIA). High-resolution spectroscopy in the middle infrared will also enable to measure greenhouse gasses (CO_2, CH_4 and water vapor) abundances.

METHODOLOGY

Measuring the Earth's reflectance and emission is not an easy task, since many corrections are needed. Our experience in the visible range will be crucial to successfully tackle the infrared data.

In our measurements from BBSO, we alternatively observe the moonshine (the light reflected from the bright side of the Moon) the earthshine (dark side) and the nearby sky. Before reaching our telescope, the moonshine light has gone through the local atmosphere above the telescope. However, the earthshine light suffers absorptions from the same local atmosphere, and also from the global atmosphere of the Earth (see *Figure 1*). The global atmosphere is defined as the portion of the sunlit Earth contributing to the earthshine. Observations of the nearby sky are required when observing from the ground to subtract the background light, scattered from the moonshine, from the earthshine data. However, this will not be necessary when observing from the top of the atmosphere. Neither will be the local atmosphere correction, although observations of the bright side will still be used for determining the incident flux.

Our observing dates are restricted by the lunar phase. A too bright moonshine produces too much scattered light, but this problem will be considerably reduced when observing from the stratosphere enhancing out temporal coverage. When the Moon is waning its time in the sky decreases, therefore our observing nights are also limited by time.

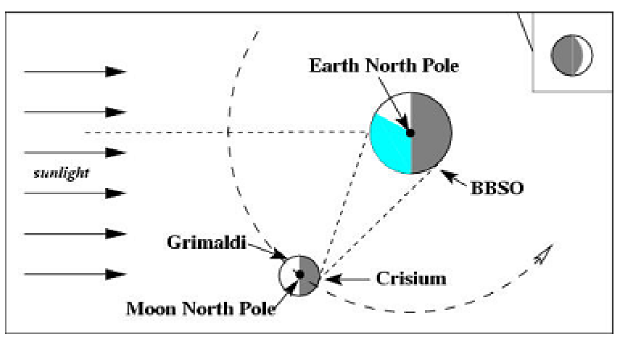

Fig.1. A not-to-scale cartoon of the sun-Earth-Moon system viewed from the pole of Earth's orbit. Crisium and Grimaldi are the fiducial points used in the observations made from BBSO. The path of the earthshine is indicated by the broken line. The Moon's orbit around the Earth and the aspect of the Moon as would be seen from BBSO for negative lunar phase angles (waxing Moon) are also indicated. The blue-shaded areas of the Earth indicate the approximate latitude range that contributes to the Earthshine. Note how for negative phase angles the earthshine contribution comes from latitudes east of BBSO.

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