VISIBLE/NEAR-INFRARED REMOTE SENSING OF EARTH FROM THE MOON. J.R. Johnson[1], P.G. Lucey[2], T.C. Stone[1], M.I. Staid[3], [1]U.S. Geological Survey, Flagstaff, AZ 86001 (jrjohnson@usgs.gov) [2]University of Hawaii, Honolulu, HI, [3]Planetary Science Institute, Tucson, AZ.

Introduction: The overall utility of a visible/near-infrared (0.3-3 μm) hyperspectral instrument viewing the Earth from a lunar base depends on the specific requirements of science goals. Here we provide an overview of several science objectives of Moon-based terrestrial remote sensing and discuss constraints on how relevant parameters such as spatial, spectral, and temporal resolution affect the ability to acquire useful data in the visible/near-infrared (vis/nir) wavelengths.

Science Objectives. The Earth Science Subcommittee of the NASA Advisory Council identified several Earth Observation Ojectives that would benefit from vis/nir observations: *mEO3* (atmospheric composition), *mEO6* (Earth's bidirectional reflectivity distribution function (BRDF) for climate studies), *mEO8* (synoptic surface composition), *mEO10* (ice coverage), *mEO12* (Earth shine/albedo), and *mEO13* (lightning distribution). We discuss these individually below.

mEO3. Multispectral imaging at ~1 km spatial resolution at vis/nir wavelengths would help monitor global-scale dynamics of dust storms and pollution, as well as fluxes of atmospheric constituents by examing spectral features related to H_2O (0.7, 0.8, 0.9, 1.1, 1.4, and 1.9 μm), CH_4 (0.88, 1.70, and 2.40 μm), CO_2 (1.06, 1.20, 1.60, 2.00, 2.06 μm), O_2 (0.69, 0.76, 1.26 μm), and O_3 (< 0.34 μm, ~0.60 μm) [1].

mEO6. Hyperspectral observations of Earth from the Moon using a variety of incidence, emission, and phase angles can more fully quantify Earth's BRDF. This will be useful for climate studies that require more precise radiative balance calculations than are currently available using data from low Earth orbiting (LEO) satellites.

mEO8. Hyperspectral imaging at 250-500 m spatial resolutions could provide enhanced information on and monitoring of surface mineralogy, vegetation, and atmospheric aerosol distributions at regional and global scales. In combination with multispectral data from orbiting satellites, such measurements also could provide useful data radiometric cross-calibration.

mEO10. In combination with other sensors, monitoring of regional ice masses and seasonal sea ice extent using multispectral vis/nir wavelengths would add to our understanding of the response of these features to changing climatic conditions.

mEO12. Measurements of the non-sunlit portion of the Moon illuminated by light reflected from the Earth ("earthshine") have been made for nearly a century [2-3] in attempts to quantify changes in Earth albedo and to detect biosignatures (e.g., chlorophyll or the vegetation "red edge" around 0.70-0.75 μm). Previous investigators have noted the potential benefits of acquiring disk-averaged spectra of Earth radiance to improve upon the technique [4], and others have considered similar spectroscopic techniques to investigate potential signs of life on extrasolar planets [5-6] or even the Earth, as was done using Galileo spacecraft data [7].

mEO13. Continuous monitoring of lightning would provide additional input to climate models and expand on work done by orbital sensors such as the Lightning Imaging Sensor (LIS) on the Tropical Rainfall Measuring Mission (TRMM), which investigated the dynamics and water content of tropical thunderstorms in relation to changes in climate and available buoyant energy [8]. Similarly, monitoring of volcanic activity using similar instruments in combination with sensors in orbit such as GOES, AVHRR, MODIS, Landsat, and ASTER would be possible given sufficient spatial resolution [9].

Figure 1. Apollo 11 Hasselblad 70mm camera view of Earth over Mare Smythii . Photo AS11-44-6548.

Constraints. One can consider the Moon as "a slowly rotating spacecraft….that always presents the same face to the earth" [10] (Figure 1). The advantages of a lunar-based observatory include: (1) the absence of an appreciable lunar atmosphere, which avoids atmospheric distortions and permits observations with a spatial resolution limited solely by the telescope size and without limitations on spectral coverage; (2) the lower lunar gravity and lack of wind, which permits lighter-weight support structures compared to terrestrial telescopes; and (3) two weeks of thermal stability per lunation [10-11]. The major disadvantages include: (1) dust contamination of moving parts and optical components from the lunar regolith, (2) no protection from cosmic rays or micrometeorite impacts without sufficient shielding, (3) diurnal temperature changes of 300K, (4) expensive construction and maintenance, (5) inability to observe the terrestrial poles and high latitudes at various times each lunar month due to the lunar declination, and (6) the month delay between acquisition of similar hour coverage [12].

The largest technical constraint to observing the Earth from a lunar base is spatial resolution. At the sub-Moon point, the diffraction-limited resolution (R) can be approximated (in km) by $R = \lambda/D$ where λ is the wavelength (in microns) and D is the telescope diameter (in meters). At visible wavelengths a spatial resolution of 1 km or less requires a 1 meter or larger telescope. Figure 2 shows this relation for three telescope diameters.

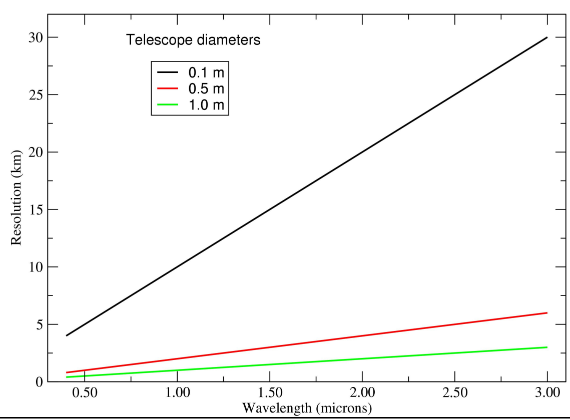

Figure 2. Spatial resolution vs. wavelength for three different telescope diameters on the Moon.

Discussion. While the arguments for Earth observations from a lunar observatory are intriguing, it is typically considered unlikely that the advantages outweigh the challenges when viewed insularly. However, as stated by [10], "a lunar astronomy program should complement the earth-orbiting satellite program." For example, one can easily imagine simultaneous observations of the Earth from instrumentation on the Moon and from geosynchronous Earth orbit (GEO) meteorological satellites in order to provide radiometric cross-calibration between instruments. The benefits of synchronized observations of planetary phenomena by multiple sensors and spacecraft have long been recognized (e.g., during the impact of comet Shoemaker-Levy 9 into Jupiter [13], or ongoing observations of volcanic eruptions on Io [14]. Synoptic observations of Earth in the vis/nir would provide additional datasets with which to monitor dynamic terrestrial phenomena such as volcanic eruptions, wind storms, and cloud cover.

By ensuring that Earth science observations are included and maintained as the lunar science architecture develops and matures, we will be able to honor the prediction of the National Research Council in 1991 that "Outstanding researchers [will] be attracted to the lunar initiative if they [can] foresee interim scientific results being obtained" [10]. This echoed the sentiment made by W. Mendell in 1985 that, "the scientific discoveries enabled by a lunar base are not predictable. Even a reasonable list of possibliities will be assembled only when a large number of minds with a broad spectrum of knowledge are made aware of the research opportunities" [15]. Once researchers and the public become aware of the capability of observing the Earth from the Moon, their interest will grow, much like how the first images of the Earth from Apollo 11 spurred a new interest in observing the Earth as a whole from the Moon (Figure 1).

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