

Introduction: Earth's relatively clear thermal infrared (TIR) atmospheric windows correspond to the wavelength region of maximum emitted energy for the global average temperature (8-12 μm) as well as the temperature of most volcanoes/fires (3-5 μm). Furthermore, a majority of minerals have diagnostic emissivity spectra in the 8-12 μm region, making it excellent for the study of surface composition [1].

TIR spaceborne imaging has been used for thermal anomaly detection (e.g., volcanic eruptions, wildland fires, anthropogenic sources) for over three decades [2]. Volcanological applications of remote sensing have always been constrained by numerous factors including instrument performance, data availability, and revisit frequency. Thermal anomaly detection, plume chemistry, mass flux, lava composition, textural properties, interaction of ash with the natural and human environment, and the mitigation of hazards are but a few of the topics being addressed with these data sets [3-6]. However, the use of satellite data to detect and monitor transient thermal and climatological events (e.g., volcanic eruptions, forest fires, and large dust emissions into the atmosphere) relies on high temporal resolution data sets (typically, on the time scale of minutes). This frequency does not exist consistently for the entire Earth's surface from current LEO and GEO satellites.

A lunar-based thermal infrared instrument used for Earth observations would have several advantages over current datasets, as well as being constrained by several drawbacks. If a suitable location on the moon were established for an Earth observatory, a TIR instrument could be deployed in stages as the manned presence increases in duration and infrastructure.

Background: Most current spaceborne TIR systems have been designed mainly for weather monitoring and include GEO instruments (i.e., GOES) and LEO instruments (i.e., AVHRR and MODIS). These have temporal scales on the order of 0.5 – 6 hours and spatial resolutions on the order of 0.5 – 8.0 km. Each provides hemispherical to near global coverage with the wavelength bands necessary to detect the onset of thermal hazards in near real-time [3-5]. Although not designed for volcanic eruption monitoring, approaches have been implemented that automatically scan the data to detect and map these thermal anomalies. For example, MODVOLC is a non-interactive algorithm

that applies a simple set of mathematical expressions to the MODIS data stream for evidence of thermally-anomalous pixels. Once a hot spot has been identified, its time, location, emitted spectral radiance, and the satellite observation geometry are cataloged [4]. Thermal flux records over particular volcanoes provide important long term data for use in monitoring and modeling. Furthermore, synergistic approaches are also now in use that employ the low spatial resolution satellite data from the AVHRR and MODIS instruments as quick response detectors, which trigger a observation of LEO instruments with much higher spatial resolution (e.g., ASTER or Landsat ETM+) [6].

However, these monitoring protocols suffer from several important limitations. Although MODIS and AVHRR provide near global coverage, their temporal resolution (6-12 hours) is still too low in many cases for real-time response. And whereas GOES data approach the needed temporal time scales (15-30 min), views are limited to the western hemisphere and have extreme distortion nearing the poles.

A Lunar-based TIR Approach: TIR remote sensing for the lunar surface could be potentially useful for a variety of thermal monitoring and surface/atmospheric compositional mapping depending on the spatial and spectral resolution of that data. The design and implementation of instrumentation that could evolve from the simple and low cost to the more complex would be the preferred pathway in order to return data as quickly as possible. Such an implementation could include for example: (1) the deployment of a radiometer that could provide whole-Earth broadband temperature monitoring on the time scale of seconds; (2) the later addition of foreoptics and scanning for progressively better spatial resolution; and (3) the final addition of a high resolution spectrometer for multispectral capabilities. Data from such a sensor could be automatically scanned for thermal anomalies and also linked into a sensor network with instruments in GEO or LEO orbits for better feature discrimination on the surface. Such a sensor could be ideal of hazard monitoring of fires (location, progression, biomass burning) and volcanoes (new detection, eruption progression, plume tracking).

However, the deployment of such an instrument and the data returned from it will present certain challenges, not the least of which would be the ability to

provide adequate spatial resolution. This can be demonstrated by the simple thought experiment: if an instrument with a similar design/optics to the current ASTER TIR system (90 m/pixel resolution) were placed on the moon, the data would be degraded to 50 km/pixel. Clearly, larger telescopes and detector arrays would be needed for detection and monitoring of thermal anomalies. Furthermore, the average distance of the moon from the Earth is 384,400 km, however this varies by greater than 40,000 km, which would impact the spatial resolution of the data (Fig 1). Finally, although the orbital variability of the Earth-moon system would provide whole-disk views (including the polar regions), the view would migrate day to day and throughout the month (Fig 2).

Conclusions: Very few natural hazards have the devastating impact of a large explosive volcanic eruptions or large wildland fires. Detection of the onset and progress of these hazards from space and monitoring their energy fluxes into the atmosphere has been a key facet to the NASA mission for many years. The ability to do this from a lunar-based Earth observatory is challenging, but potentially very beneficial. Science disciplines other than solid-earth hazards which could benefit include oceans (currents, ENSO events, severe storms); land surface composition (aerosol inputs, desertification, refinement of GCM's); and atmospheric chemistry/dynamics (cloud top temperatures, radiation budget, climate change).

References: [1] Christensen, P.R., *et al.* (2000), *J. Geophys. Res.*, 105, 9609-9622. [2] Friedman, J.D., *et al.* (1976), *U.S.G.S. Rep.*, 55 p. [3] Dehn, J., *et al.* (2000), *Geology*, 28, 755-758. [4] Wright, R., *et al.* (2004), *J. Volcanol. Geotherm. Res.*, 135, 29-49. [5] Harris, A.J.L., *et al.* (2000), *Geophys. Monogr. Ser.*, 116, 139-160. [6] Ramsey, M.S. and Dehn, J. (2004), *J. Volc. Geotherm. Res.*, 135, 127-146.

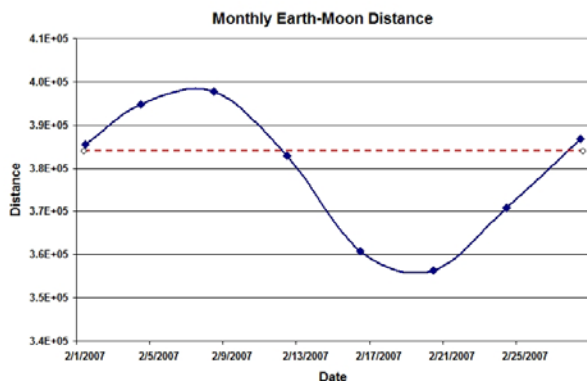


Figure 1. Variation of the Earth-moon distance from the average (dashed line) over one month (Feb., 2007).

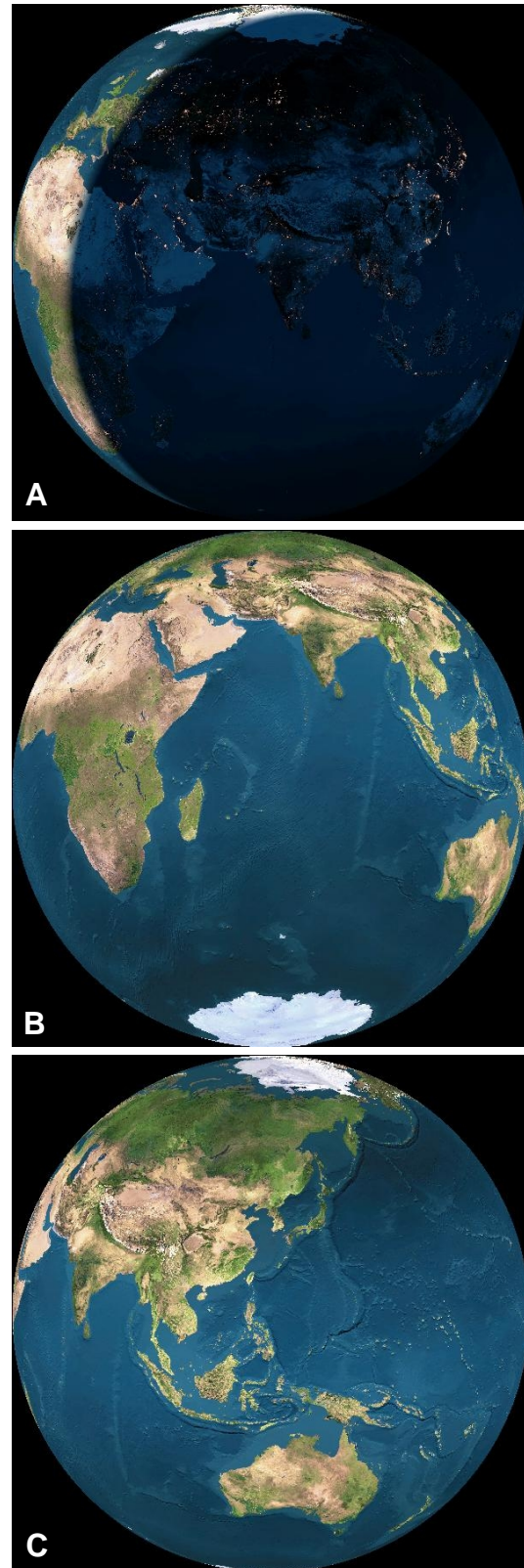


Figure 2. Views from the lunar surface of Earth on the same day throughout 2007: (A) 28 February; (B) 28 May; (C) 28 September.