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REMOTE SENSING OF PLANETARY SURFACES

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Bruce M. Jakosky

Laboratory for Atmospheric and Space Physics
UCB 392
University of Colorado
Boulder, CO 80309-0392
email bruce.jakosky@lasp.colorado.edu

I. Introduction

Our efforts have been focused on understanding the physical properties of planetary surfaces using remote sensing techniques. Specific application has been to the surfaces of the Moon and Mars. Our approach has been to use thermal-infrared emission and radar reflectance and scattering as a way of exploring the decimeter-scale structure of these surfaces. At this scale, the techniques are sensitive to physical parameters such as the average or effective particle size of surface materials, the degree of induration or physical bonding between individual regolith grains, and the abundance of rocks of different sizes resting on or admixed in to the surface. The results are relevant to understanding the geological processes that have affected the surface and, in the case of Mars, determining site safety and scientific relevance for planning upcoming lander, rover, and sample-return spacecraft missions.

Specific results are discussed below, and publications that have resulted are listed at the end.

II. Clementine observations of the lunar surface

The scientific payload on the Clementine spacecraft included a long-wave infrared (LWIR) camera with a single passband centered at a wavelength of 8.75 um. The Clementine orbit deviated by +/- 30 degrees from Sun synchronous, and for two lunar months, dayside nadir-looking images were obtained near local noon. During the systematic mapping phase of the Clementine mission, approximately 220,000 thermal-infrared images of the lunar surface were obtained. We have completed the calibration of the LWIR camera. We present the various steps involved in the calibration routine and the associated uncertainty analysis. The LWIR calibration routine can be outlined as follows: convert measured data number values to radiance via a calibration equation; subtract a zero-flux background image from each lunar image; divide by a flatfield frame; identify bad pixels; smooth over only bad pixels for cosmetic purposes; adjust radiances to reflect absolute calibration; and convert radiances to brightness temperatures via the Planck function. Observed LWIR radiances can be converted to brightness temperatures, which provide information on various physical properties of the lunar surface. We also present the global LWIR data set. The LWIR data from noontime orbits demonstrate that the Lambertian temperature model of cos 1/4 i is a fair approximation for nadir-looking temperatures, rather than the cos 1/6 i behavior observed for groundbased measurements of the full Moon. Deviations from the Lambertian model are likely due to surface roughness effects and variations in infrared emissivity. In addition, the LWIR global data set reveals the dayside lunar thermal emission to be largely governed by albedo and by the solar incidence angle.

Results are presented in Lawson 2000 and Lawson et al., 2000.

III. Lunar near-surface thermal gradients

We examined the impact of near-surface thermal gradients on lunar subsurface temperatures and thermal emission. We modified a standard airless-body surface and subsurface thermal model to include both subsurface transmission and absorption of insolation and subsurface emission, scattering, and absorption of thermal-infrared energy. The model produces significant subsurface heating, with subsurface temperatures strikingly similar to those observed by the Apollo 15 and 17 heat flow experiments. We also found that near-surface thermal gradients can have a significant impact on infrared emission, and should be considered when deriving thermal inertia from lunar infrared observations.

Results are presented by Urquhart and Jakosky 2000 and by Urquhart 1999.

IV. Lunar thermophysical properties derived from Clementine

In an effort to understand the influence of albedo and large-scale topography on remote lunar surface measurements, we have investigated the relationship between measured Clementine long-wave infrared (LWIR) camera temperatures and ultraviolet-visible (UVVIA) camera 750-nm reflectances. We compare the observed temperature-reflectance relationships with those predicted using a rough-surface numerical model with varying albedo. The lunar surface response in different highland and mare locations is explored as a function of varying phase angle. At very low phase angles, the temperature and reflectance response is primarily governed by the variation in single-scattering albedo regardless of the presence of topography. As the phase angle increases, the influence of surface roughness grows. Finally, at moderate to high phase angles, the effect of surface roughness dominates. In the absence of large-scale topography, the lunar surface temperature and reflectance response at all phase angles is governed by the variation in single-scattering albedo. LWIR-measured temperature variations yield local topographic information at high incidence angles that is unavailable via the reflectance, while UVVIA-measured reflectance variations yield local topographic information at low incidence angles that is unavailable via the temperature.

Results are presented by Lawson and Jakosky 2001 and by Lawson 2000.

V. Planning of upcoming spacecraft measurements

The Thermal Emission Imaging System (THEMIS) on board the Mars Odyssey spacecraft will determine surface mineralogy using multi-spectral thermal-infrared images in 9 wavelengths centered from 6.6 to 15.0 um. The entire planet will be mapped at 100-m per pixel resolution within the available data volume using a multi-spectral imaging approach. THEMIS will also acquire 18-m per pixel visible images in up to 5 spectral bands using a modified version of the Mars Surveyor 98 Orbiter (MARCI) and Lander (MARDI) cameras; over 100,000 panchromatic (2000 5-color) 18 x 50 km images will be acquired for morphology studies and landing site selection. The thermal-infrared spectral region contains the fundamental vibrational absorption bands that provide diagnostic information on mineral composition. Most geologic materials, including carbonates, hydrothermal silica, sulfates, phosphates, hydroxides, and silicates have strong absorptions in the 6-14 um region. Silica and carbonates, which are key diagnostic minerals in thermal spring deposits, are readily identified using thermal-IR spectra. In addition, the ability to identify most other minerals provides the proper geologic context for unique deposits. The specific objectives are: (1) to determine the mineralogy and petrology of localized deposits associated with hydrothermal or subaqueous environments, and to identify future landing sites likely to represent these environments; (2) to search for thermal anomalies associated with active subsurface hydrothermal systems; (3) to study small-scale geologic processes and landing site characteristics using morphological and thermophysical properties; (4) to investigate polar cap processes at all seasons; and (5) to provide a high-resolution link to the global hyperspectral mineral mapping from the Mars Global Surveyor TES investigation. THMEIS is designed as the follow-on to the MGS TES, which has produced a hyperspectral (143 band) mineral map of the entire planet at ~5 km sampling. THEMIS covers the same wavelength region as the TES, providing a high-spatial-resolution complement to the TES hyperspectral mapping.

Results are described in the paper by Christensen et al. 2001.

VI. Publications

A. Papers and dissertations in the archival literature

Lawson, S.L., B.M. Jakosky, H.S. Park, and M.T. Mellon (2000). Brightness temperatures of the lunar surface: Calibration and global analysis of the Clementine Long-Wave Infrared Camera data, *J. Geophys. Res.*, **105**, 4273-4290.

Urquhart, M.L. and B.M. Jakosky (2000). Impact of near-surface thermal gradients on lunar thermal emission and subsurface temperatures, submitted to *J. Geophys. Res.*

Lawson, S.L. and B.M. Jakosky (2001). Lunar surface thermophysical properties derived from Clementine LWIR and UVVIS images, *J. Geophys. Res.*, in press.

Christensen, P.R., B.M. Jakosky, H.H. Kieffer, M.C. Malin, H.Y. McSween, Jr., K. Nealson, G.L. Mehall, S.H. Silverman, S. Ferry, and M. Caplinger, The Thermal Emission Imaging System (THEMIS) for the Mars 2001 Odyssey mission, submitted for publication.

Urquhart Kelly, M.L., Thermal properties of airless planetary regoliths, Ph.D. Dissertation, University of Colorado in Boulder, Dept. of Astrophysical and Planetary Sciences, 1999.

Lawson, S.L., Brightness temperatures of the lunar surface: Calibration and analysis of Clementine Long-Wave Infrared Camera images, Ph.D. Dissertation, University of Colorado in Boulder, Dept. of Astrophysical and Planetary Sciences, 2000.

B. Selected conference abstracts

Jakosky, B.M., The martian surface revisited: Integration of Pathfinder with global remote-sensing and Viking results, Lunar Planet. Sci. Conf., Houston, 1998.

Lawson, S.L. and B.M. Jakosky, Clementine LWIR and UVVIS images: Characterizing lunar surface thermophysical properties, New Views of the Moon III Conf., Houston, 2000.

Jakosky, B.M. and M.P. Golombek, Broad perspectives on Mars landing site selection: Geological factors from centimeter to kilometer scales, Mars Landing Site Workshop, NASA/Ames Res. Ctr., 2001.

Golombek, M.P., B.M. Jakosky, and M.T. Mellon, Thermal inertia of rocks and rock populations and implications for landing hazards on Mars, Mars Landing Site Workshop, NASA/Ames Res. Ctr., 2001.

Jakosky, B.M., M.T. Mellon, and S.M. Pelkey, Physical properties of potential Mars landing sites from MGS TES-derived thermal inertia, Mars Landing Site Workshop, NASA/Ames Res. Ctr., 2001.