IMPROVED KNOWLEDGE OF THE SURFACE PROPERTIES OF MARS: IMPACT OF LONG-TERM MONITORING AND HIGH-RESOLUTION DATA SET INTEGRATION.

[1]R. L. Fergason, [2]P. R. Christensen, [3]S. Piqueux [1]U.S. Geological Survey, Astrogeology Science Center, 2255 N. Gemini Drive, Flagstaff, Arizona 86001, rfergason@usgs.gov, [2]Mars Space Flight Facility; Arizona State University; PO Box 876305; Tempe, AZ 85287, [3]Jet Propulsion Laboratory, California Institute of Technology, 4800 Oak Grove Drive, Pasadena, CA 91109.

Introduction: Our understanding of the surface properties of Mars has changed dramatically over the last 10 years since the introduction of high resolution thermophysical data (i.e., the Thermal Emission Spectrometer (TES) at 3 km/pixel and the Thermal Emission Imaging System (THEMIS) at 100 m/pixel) and complementary high-resolution visible images (e.g., the High-Resolution Imaging Science Experiment (HiRISE). Building on the contributions of the Mariner 9 Infrared Radiometer, the Viking Infrared Thermal Mapper, and Termoscan, TES and THEMIS are the primary instruments used to interpret the physical surface properties of Mars, and the thermal inertia values retrieved from both the TES and THEMIS instruments broadly agree [e.g., 1]. Both instruments combined provide unprecedented spatial resolution and temporal data, allowing a broad suite of questions to be addressed. In addition, the retrieval of thermophysical properties using near-infrared Observatoire pour la Minéralogie, l'Eau, les Glaces et l'Activité (OMEGA) onboard Mars Express (MEX) thermal measurements (from 5 to 5.1 µm) has also recently been completed [2].

Our theoretical knowledge of thermophysical processes has advanced as well [3-5]. As we improve our understanding of the impact of thermal effects on surface temperature, we continually seek to integrate that capability into practical modeling applications [6]. For example, we better understand the importance of accounting for temperature dependent conductivity at lower thermal inertia values (i.e., presumably unconsolidated materials), which is essential for understanding the surface properties of the Tharsis volcanoes, unconsolidated bed forms, and other unconsolidated surfaces [5].

From improvements in thermal models, theoretical knowledge, analytical techniques, and higher-resolution data sets, four insights regarding our knowledge of surface properties of Mars have been gained: 1) thermal inertia is an effective data set for surface science studies; 2) seasonal thermophysical data provides the capability for complex surface property modeling; 3) complex modeling is not always necessary to accurately interpret the physical nature of the surface; and 4) additional advancements are needed.

Value of Thermal Inertia: Thermal inertia is the key material property controlling the diurnal and seasonal temperature variations on Mars, and this property can be directly and quantitatively related to the physical characteristics of the surface. Correctly assessing the physical properties of the martian surface is essential to all surface science studies. The derivation of accurate surface temperatures and thermophysical properties is vital for understanding past and present martian geologic processes through the definitive identification of bedrock, and the recognition of indurated surfaces, unconsolidated fines, and dust [e.g.,7-22]. Thermophysical observations are valuable for quantitatively determining the presence of and depth to buried ice at high latitudes [15-16; 23]. THEMIS-derived thermal inertia values were also critical to certify the safety of Mars Exploration Rover (MER) and Mars Science Laboratory (MSL) candidate landing sites and for selecting scientifically interesting and safe landing site locations [11; 24-27].

Seasonal Thermophysical Data: Since the earliest radiometric observations of Mars [28] measured temperatures have deviated from model-derived temperature predictions, indicating diurnal and seasonal variability in thermal inertia. Heterogeneity of the surface was considered a possible cause of this variability, based on similar studies of lunar temperature observations that incorporated models with a layered regolith [29]. In addition, studies of the thermal behavior of ground ice in the polar regions and at lower latitudes [e.g., 15-16; 30-35] and the detection of near-surface hydrogen attributed to the presence of ground ice [e.g., 36-37] have implications for near-surface heterogeneity.

Due to the longevity of both the TES and THEMIS instruments, we have a combined data set of unprecedented temporal coverage enabling many of these long-standing questions to be addressed. Seasonal variations are observed in both TES- and THEMIS-derived thermal inertia data sets and the variations observed are often larger than the data and model uncertainties [13-14; 38]. Accurately modeling and interpreting seasonal variations in temperature and thermal inertia is a powerful method of identifying surface and subsurface features that are of high scientific importance, such as determining the depth to an ice-rich layer and quantifying the thermophysical properties beneath a thin dust layer.

Advanced thermophysical modeling techniques (e.g., 2-layer systems or mixtures of surface materials) are employed to model the seasonal variations described above. These methods incorporate additional input parameters that can lead to an under-defined problem. Such techniques are thus most useful for problems that are well-defined and limited in scope. These methods can be essential for identifying the presence of and depth to subsurface ice [15-16; 23], modeling complex bed forms [10], or quantitatively assessing the surface characteristics when subsurface layering, surface heterogeneity, or significant sub-pixel-scale slopes are present.

Tractable Thermophysical Problems: Advanced thermal modeling techniques are not necessary for all surface studies, and poorly constrained added parameters may leave a problem intractable and under-determined. Particularly at the equator, the combination of temperature/thermal inertia data at multiple spatial scales (e.g., 3 km, 100 meter, and rover-scale) with high-resolution visible images has proven effective in advancing our interpretation of thermal inertia data and our quantitative understanding of the surface properties at regional to local spatial scales. For example, the surface properties predicted at the MER Spirit, MER Opportunity, and MSL landing sites using 1-layer thermal inertia interpretations agreed well with the actual surfaces observed upon landing [10-11; 24-26]. In addition, thermal inertia values are typically consistent with surface properties observed in high resolution images, indicating that a simple 1-layer thermal model is likely adequate for many equatorial studies where near-subsurface ice is unlikely.

Future Advancements: Our understanding of martian surface properties has improved significantly in the past decade. We also recognize that there is tremendous science potential in integrating seasonal observation of thermal inertia with other studies, such as the investigation of active surface processes. Below are only some examples of on-going work to make advanced thermophysical problems more tractable:

1. Seasonal variations in measured thermal inertia are observed in all thermophysical data sets. An improved understanding of how the atmosphere, subsurface layers, and heterogeneous mixtures of materials affect thermophysical data is needed. This knowledge will lead to more robust and accurate interpretations of apparent thermal inertia, more confidence in the interpretation of the surface and near-subsurface materials, and is necessary for more effectively and accurately interpret the physical properties of near-subsurface materials on Mars.

2. An improved integration of current atmospheric and thermophysical modeling techniques is needed. Many seasonal variations in thermal inertia may be caused by atmospheric phenomenon, rather than physical properties of the surface and near-subsurface [39]. To effectively interpret these data, we need to first more accurately separate out the effects of the atmosphere from surface temperature measurements.

3. Additional laboratory work to measure the conductivity of grain size mixtures, duricursts of differing strengths, and layered materials under martian conditions will enable us to more effectively test our working hypotheses. These results will help us characterize the thermophysical behavior of common geologic surfaces and help to validate model results and strengthen interpretations of martian surface material.

References: [1] Fergason R. L. et al. (2006) JGR, 111, E12004. [2] Audouard J. et al. (2014) Icarus, in press. [3] Piquex S. and Christensen P. R. (2009) JGR, 114, E09005. [4] Piquex S. and Christensen P. R. (2009) JGR, 114, E09006. [5] Piquex S. and Christensen P. R. (2011) JGR, 116, E7. [6] Kieffer, H. H. (2013) JGR, 118, 452-470. [7] Titus T. N. et al. (2003) Science, 299, 1048-1051. [8] Arvidson R. E. et al. (2004) Science, 305, 821-824. [9] Arvidson R. E. et al. (2006) JGR, 111. [10] Fergason R. L. et al. (2006) JGR, 111, E02S21. [11] Fergason R. L. et al. (2012) Space Sci. Rev., 170, 739-773. [12] Greeley R. et al. (2006) JGR, 111, E02S09. [13] Putzig N. E. and Mellon M. T. (2007) Icarus, 191, 52-67. [14] Putzig N. E. and Mellon M. T. (2007) Icarus, 191, 68-94. [15] Bandfield J. L. (2007) Nature, 447, 64-67. [16] Bandfield J. L. and Feldman W. C. (2008) JGR, 113, E08001. [17] Bandfield J. L. and Edwards C. S. (2008) Icarus, 193, 139-157. [18] Edwards C. S. et al. (2009) JGR, 114. [19] Michalski J. R. and Fergason R. L. (2009) Icarus, 199, 25-48. [20] Osterloo M. M. et al. (2008) Science, 21, 1651-1654. [21] Fergason R. L. and Christensen P. R. (2008) JGR, 113, E12001. [22] Rogers A. D. and Fergason R. L. (2011) JGR, 116, E08005. [23] Putzig et al. N. E. (2014) Icarus, 230, 64-76. [24] Golombek M. P. et al. (2003) JGR, 108, 8072. [25] Golombek M. P. et al. (2005) Nature, 436. [26] Golombek M. P. et al. (2012) Space Sci. Rev., 170, 641-737. [27] Vasavada A. R. et al. (2012) Space Sci. Rev., 170, 793-835. [28] Sinton W. M. and Strong J. (1960) Astrophys. J., 131, 459-469. [29] Jaeger J. C. and Harper A. F A. (1950) Nature, 166, 1026-1028. [31] Paige D. A. (1992) Nature, 356, 43-45. [32] Mellon M. T. and Jakosky B. M. (1993) JGR, 98, 3345-3364. [33] Mellon M. T. and Jakosky B. M. (1995) JGR, 100, 11781-11799. [34] Vasavada A. R. et al. (2000) JGR, 105, 6961-6969. [35] Mellon M. R. et al. (2004) Icarus, 169, 324-340. [36] Chamberlain M. A. and Boyton W. V. (2005) LPSC XXXVI, Abstract #1566. [37] Boyton W. V. et al. (2002) Science, 297, 81-85. [38] Feldman W. C. et al. (2004) JGR, 109. [39] Fergason R. L. et al. (2014) Icarus, in prep.