SOLID STATE GREENHOUSES: APPROACHES FOR TEMPERATURE MEASUREMENT

Dennis L. Matson and Robert Hamilton Brown, Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109

We have introduced the term 'solid-state greenhouse' to refer to the direct, subsurface heating of a regolith by absorbed insolation (Brown and Matson, 1987; Matson and Brown, in press). Such an effect has been recognized in terrestrial snows for over fifty years (Niederdorfer, 1933). The effect is significantly enhanced for regoliths of the icy satellites because of their lower thermal conductivities and absence of significant convective transport of heat. The solid-state greenhouse effect is important both for understanding the near surface thermal structure of the regolith and because the maximum (as a function of depth), diurnal-mean, greenhouse temperature is the correct upper boundary condition to use for geothermal and temperature history calculations for satellite interiors. The present limits upon the temperature enhancements possible by solid-state greenhousing range from one degree Kelvin to more than 100K. Exact temperatures for each body depend upon the thermal and optical properties of the upper several centimeters of each regolith.

For terrestrial snows, the greenhouse temperatures are measured directly; to date these temperatures have not been determined by remote sensing methods. However, for icy satellites in the solar system remote sensing is presently the only feasible approach. We have examined theoretical approaches to determining greenhouse temperatures. Presently, this problem is not entirely tractable because many of the icy regolith properties are not known and because some of the processes are intrinsically difficult to model.

Several remote sensing approaches have been identified for the purpose of determining greenhouse temperatures. Two are ground based: (1) radiometry of the infrared thermal emission before and after eclipse emersion and reappearance, and (2) comparison of brightness temperatures inferred by infrared and microwave radiometry of thermal emission. Two spacecraft approaches are: (1) infrared radiometry of thermal emission throughout a diurnal cycle, and (2) microwave radiometry maps of the surface.

To understand why these approaches may work, let us consider the vertical temperature structure in a hypothetical regolith. An extreme case studied by Matson and Brown (1988) is shown in Fig. 2. The microwave approaches work because they are sensitive to radiation from depths of up to ten wavelengths or so. Thus, observations at wavelengths of 3 cm and longer should be able to "see" the warmer, subsurface material directly.

The approach using infrared radiometry from a spacecraft depends upon the fact that the diurnal temperature history of the surface is sufficient to recognize a solid-state greenhouse. As show in Fig. 3, the nighttime temperatures are enhanced as the greenhouse becomes warmer. Such an effect can also be due to thermal inertia, so the shape of the curves in the morning and afternoon must also be considered in order to distinguish between the two possibilities.

Observations of satellite eclipses by the planet are an attractive ground based approach. Since the sunlight is penetrating into the regolith, the effective insolation absorbed near the surface is less and the surface temperature is, at first, slower to rise. Additional heat arrives later, by conduction from depth, and eventually a steady state is reached. This warm-up signature can be compared with the cool-down signature upon emersion where insolation has been cut off and the surface temperature is dependent upon the thermal inertia and any heat conducted from the subsurface greenhouse.

REFERENCES: Brown, R. H., and D. L. Matson (1987). Thermal Effects of Insolation Propagation into the Regoliths of Airless Bodies, **Icarus 72**, 84-94; Matson, D. L., and R. H. Brown (1988). Solid-State Greenhouses and Their Implications for Icy Satellites, **Icarus**, submitted; Niederdorfer, E. (1933). Messengen des Warmeumsatzes Uber schneebedecktem Boden, **Meteor. A. 50**, 201-208.

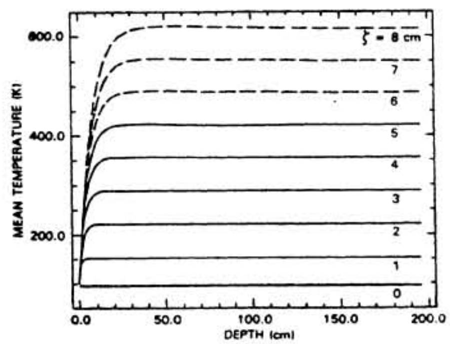

Figure 1. Average diurnal temperature versus depth for different values of the adsorption scale-lengths, ζ. The dashed curves at higher temperatures are less accurate because our model does not include thermal radiative transfer. Model parameters are those of Matson and Brown (1988, Table 2).

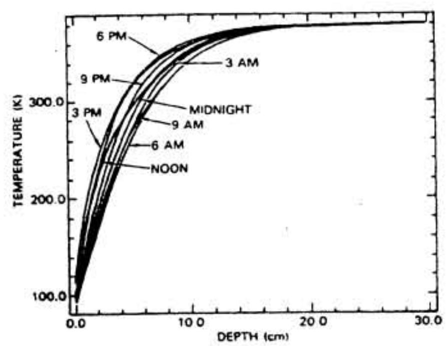

Figure 2. Plots of temperature versus depth for various times of day for ζ=5 cm.

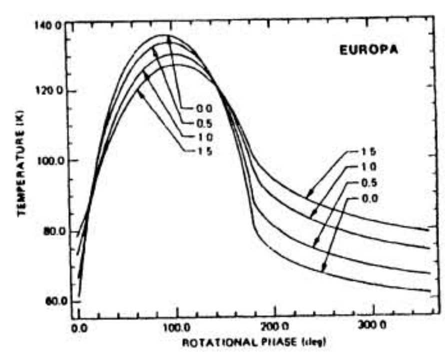

Figure 3. Europa: equatorial-diurnal curves for different sunlight absorption depth scales. A rotational phase of 0^o corresponds to the dawn terminator and 90^o is local noon. Zero obliquity, and spherical geometry are assumed. The labels are for ζ in cm.