WATER AND ICE DETECTION IN THE POLAR REGIONS: THE MARSIS EXPERIMENT ON MARS EXPRESS

J. J. Plaut, Jet Propulsion Laboratory. California Institute of Technology, Mail Stop 183-501, 4800 Oak Grove Dr., Pasadena, CA, 91109. plaut@jpl.nasa.gov.

Introduction: The European Space Agency (ESA) will conduct a mission to Mars during the 2003 launch opportunity, called ìMars Express.î Much of the payload is similar to that of the failed Mars 96 orbiter, but a completely new instrument has been selected for the payload, the Mars Advanced Radar for Subsurface and Ionospheric Sounding (MARSIS). The MARSIS experiment is a joint project between the University of Rome, the Jet Propulsion Laboratory, and Alenia Aerospazio, Italy. This paper describes the science objectives of the experiment, the instrument characteristics, and applications of the MARSIS investigation to studies of the martian polar regions.

Science Objectives: The primary objective of the MARSIS experiment is to map the distribution of water, both liquid and solid, in the upper portions of the crust of Mars. Secondary objectives include subsurface geologic probing for stratigraphic and structural contacts, characterization of the surface topography, roughness and reflectivity, and ionospheric sounding. Detection of water and ice reservoirs will address many key issues in the hydrologic, geologic, climatic and possible biologic evolution of Mars, including the current and past global inventory of water, mechanisms of transport and storage of water, the role of liquid water and ice in shaping the landscape of Mars, the stability of liquid water and ice at the surface as an indication of climatic conditions, and the implications of the hydrologic history for the evolution of possible Martian ecosystems.

Instrument Description: MARSIS is a multi-frequency, coherent pulse, synthetic aperture radar sounder/altimeter. The instrument features flexibility in frequency selection for adaptation to the Mars environment, and a secondary, receive-only antenna and data channel to minimize the effects of surface ìclutterî on subsurface feature detection. The instrument will acquire echo profiles of the subsurface of Mars at a lateral spacing of approximately 5 km and a vertical (depth) resolution of 50-100 m. Four frequency channels will be available for use: 1.8, 2.8, 3.8 and 4.8 MHz. The lower frequency channels, which are likely to penetrate more deeply, will be used during night-side operations, when the ionospheric plasma frequency is lowest. The primary antenna consists of a simple dipole with a total length of 40 m. An impedance matching system will be used to improve antenna efficiency across the range of frequencies. The secondary antenna is designed with a null in its pattern at the spacecraft nadir, and will therefore primarily detect echoes from off-nadir surface structure (clutter). On-board digital processing will generate echo profiles for both the primary and secondary receive streams, at two frequencies in the nominal mode. This processing greatly reduces the data volume necessary for downlink. Post-processing on Earth will include convolution of the primary and secondary antenna profiles for surface clutter cancellation, and compilation of map products showing, for example, the depth to detected interfaces.

Detection of Subsurface Interfaces: A number of factors affect the ability of a radar echo sounder such as MARSIS to unambiguously detect a subsurface interface. A boundary must separate two materials of contrasting real dielectric constant, occur over a lateral length scale at least comparable to the sounder footprint (5 km), and over a vertical length scale smaller than the vertical resolution (50 m). The portion of the crust that lies between the surface and the interface must be sufficiently transmissive to allow a round-trip of the radar signal that is still detectable at the receiver on orbit. Scatterers comparable in scale to the radar wavelength (50-150 m) will disperse energy away from the nadir direction; these scatterers may occur at the surface, within the intervening crust, and at the subsurface interface. Larger-scale roughness (100s of m to km) of the terrain can introduce ìclutterî that can mask the echo from a subsurface interface. Such topographic undulations (e.g., crater rims, cliff faces, etc.) may contribute echoes from off-nadir positions that correspond in time-delay to the subsurface region being probed. To minimize the effects of off-nadir scattering, a synthetic aperture approach is applied to isolate echoes in the along-track direction (effectively narrowing the footprint), and the secondary, nadir-null antenna is used to identify (and subsequently remove) off-nadir echoes.

A model of surface and subsurface scattering is developed to evaluate the depths and types of interfaces that may be detected. Crustal rocks are represented by two end-members: a low-loss, moderate dielectric andesite, and a lossier, higher dielectric basalt. The porosity is assumed to be filled by one of three materials: martian atmosphere, water ice or liquid water. Near-surface porosity values of 20% and 50% are used, with an exponential decay with depth. The surface roughness is described by a two-scale model, to take into account wavelength-scale scattering and quasi-specular effects.

Model results show that substantial penetration of the signal can be expected for many reasonable cases of surface roughness, crustal composition and volatile content. The primary ìnoiseî factor above which a subsurface reflection must rise is competing signals from off-nadir. Use of the secondary antenna can lower the off-nadir clutter by 10 dB or more. At the lowest frequency (1.8 MHz), an interface between ice-saturated and water-saturated basaltic crust is detected at depths of 4 km, except for the roughest surface models. In the andesite crust, detection is expected at depths > 5 km. At the higher frequencies, detection depths are less (1-2 km in basalt at 4.8 MHz). An interface between dry rock and ice-saturated rock, which might be expected at moderate depths at low latitudes, is more difficult to detect than an ice-water interface, due to smaller dielectric contrasts between the pore-filling material. However, under favorable conditions of roughness and rock composition, such an interface should be detectable in the upper several kilometers of the crust.

If aquifers occur only at great depth (> 5-10 km) in the martian crust, they may elude detection by MARSIS. However, shallower reservoirs of liquid water, perhaps associated with thermal anomalies or an insulating upper stratigraphy, should detectable. Many other stratigraphic and structural boundaries are expected to be identified by the radar sounding, providing a view into third dimension of the geology of Mars.

Applications in Polar Regions: Data from MARSIS can potentially address several critical issues in Mars polar studies. Of particular interest is the depth and character of the ìbedî of the polar layered deposits. If attenuation of the signal by the layered materials is not too great, it may be possible to map the base of the deposit, and detect basal melting zones, should they exist. Detection of pockets of liquid water beneath the ice would be a dramatic result, with implications for possible ecosystems, and regional or global hydrologic systems. Strong discontinuities in dielectric properties may also be detected within the layered deposits, and may be indicative of major climate shifts. Properties of other high latitude terrains will be studied, including the thickness of the north polar erg, and possible subsurface stratigraphic contacts among sedimentary and volcanic units in both polar regions. Contacts between ice-saturated and ice-free crustal materials are likely to be detected in some regions. The thickness of the proposed low-latitude desiccation zone may be measurable. Detection of shallow (< 5 km) aquifers would revolutionize our ideas on the current state of water on Mars, and provide targets for future biologic searches and a possible sustained human presence.

MARSIS SOUNDING RADAR: J. J. Plaut