COMPARING GOLDSTONE SOLAR SYSTEM RADAR EARTH-BASED OBSERVATIONS OF MARS WITH ORBITAL DATASETS. A. F. C. Haldemann[1], K. W. Larsen[2], R. F. Jurgens[1], and M. A. Slade[1] [1]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109, [2]Laboratory of Atmospheric and Space Physics, University of Colorado – Boulder, Boulder, CO, .

Introduction: The Goldstone Solar System Radar (GSSR) has collected a self-consistent set of delay-Doppler near-nadir radar echo data from Mars since 1988. Prior to the Mars Global Surveyor (MGS) Mars Orbiter Laser Altimeter (MOLA) global topography for Mars, these radar data provided local elevation information, along with radar scattering information with global coverage (e.g. [1,2]). Two kinds of GSSR Mars delay-Doppler data exist: low 5 km x 150 km resolution and, more recently, high (5 to 10 km) spatial resolution. Radar data, and non-imaging delay-Doppler data in particular, requires significant data processing to extract elevation, reflectivity and roughness of the reflecting surface [3]. Interpretation of these parameters, while limited by the complexities of electromagnetic scattering, provide information directly relevant to geophysical and geomorphic analyses of Mars. In this presentation we want to demonstrate how to compare GSSR delay-Doppler data to other Mars datasets, including some ideosyncracies of the radar data.

Landing Site Assessment with Radar Data: The GSSR equatorial near-nadir backscatter radar data have proven their worth in the past: radar data were critical in assessing the Viking Lander 1 site [4, 5] as well as, more recently, the Pathfinder [6, 7], and the Mars Exploration Rover (MER) landing sites [8, 9, 10]. In general, radar data have not been available to the Mars exploration community at large. We have recently completed submission to the PDS of Hagfors model fits to all delay-Doppler radar tracks obtained since 1988 in aid of landing site characterization for the Mars Exploration Program. The available Level-2 Derived data records consist of Hagfors radar scattering model fits to the delay-Doppler data with 0.1° of longitude resolution. The fit parameters are range (elevation), reflectivity (Fresnel), and surface roughness (RMS slope) for each low resolution 5km x 150km resolution cell. We are also working on delivering all the individual calibrated delay-Doppler images to the PDS.

High Spatial Resolution Delay-Doppler Data: In the 2001 and 2003 observations, the reflected radar signal was received simultaneously at four of the Goldstone Deep Space Communications Center telescopes. Delay-Doppler observations map the radar signal reflected from a target into a coordinate system based on time delay and frequency shift imparted by the planets shape and rotation, respectively. Since multiple points on the surface have the same delay and frequency coordinates, the signal from those regions are merged, and must be deconvolved by other techniques in order to create an unambiguous radar map north and south of the sub-Earth radar track. Pairs of receiving telescopes are used to create interferometric baselines. The signal from each baseline pair, both complex power-spectra, are multiplied to form a power spectrum that contains the radar reflection's magnitude and phase, due to the varied path lengths. An iterated maximum likelihood function algorithm can then unwrap the north-south ambiguity and map the radar backscatter coefficient of the surface, at a maximum resolution of five kilometers per pixel, though delay-Doppler geometry degrades the spatial resolution near the sub-radar point. The same dataset also provides the low-resolution coverage along the sub-Earth radar track without interferometric processing. Pending future funding, maps of these high resolution data will be released to the PDS next year.

Comparing with MGS Data: The low resolution data can be compared with many MGS datasets. MOLA is an obvious first choice to compare to the radar ranging estimates. The global fit is good, but we have discovered misalignments due to different reference frames, the effect of radar scattering, and our range fitting algorithm convolved with the radar ambiguity function. The error between the resolved range and known MOLA topography may be utilized in the future to better understand the performance of the radar and to define the weighting of the low resolution cell to the observed scattering behavior. The Hagfors radar cross-section parameters are compared with MGS Thermal Emission Spectrometer (TES) thermal inertia maps, Viking rock abundance data, and MOLA roughness measurements. Comparisons with global albedo, or local visible image entropy could also be fruitful.

Beyond the Conundrum of East-West slope. The fitting routines used for the Hagfors analyses of the sub-Earth delay-Doppler data do not properly account for east-west (or north-south) regional slopes. We have demonstrated in the past [11] that this has minimal effect on landing site analyses where flat areas are desired, but hampers the use of the data for analyses of rougher lava flows on volcanic flanks, where the radar geomorphology could fruitfully compare to terrestrial data. This issue for the time being also applies to the 5 km high-resolution interferometric data. Solving this problem is a high priority of the GSSR team. It will probably require iterative calculation of scattering models using regional MOLA topography, whereas our current algorithm is based on templates fit to a sphere. An additional complication in the analysis of the radar is that the near-nadir delay-Doppler backscatter signal, in addition to being ambiguously folded north-south, is multiply aliased in both the range and Doppler (frequency) coordinates mapped across the planet. Historically we have relied on the high contrast of the specular echo with respect to the diffuse echo at incidence angles greater than 10º-15º, but there are places on Mars where topography, scattering behavior, or both, can conspire to confuse the near-nadir echos. The effect is to raise the apparent “noise” of the delay-Doppler images. An approach we envisage is to use the Goldstone-Very Large Array 3.5 cm radar dataset (60 km resolution) to define the alias component. Like the east-west slope issue, aliased echo is a less important effect in large smooth regions, but it must be interpreted in particular when the terrain morphology changes over tens of kilometers, or if one intends to study single radar pixel sized features. This is precisely the case for checking the radar data with ground truth from the surface of Mars.

Checking with Ground-Truth: The results from the 2001 and 2003 GSSR interferometric observations and the MER landing sites allow an assessment of the radar slope evaluation, and may illustrate some of the caution that must be applied when extrapolating from the low resolution data. The RMS slope or roughness derived using the Hagfors model on the pre-2001 data indicated a smoother surface at Meridiani than at MPF (3.5 cm wavelength RMS slope of 1.4º vs. 4.5º) and a smoother surface at Gusev than at VL1 (12.6 cm RMS 1.7º vs 6º). Interpretation of all pre-existing radar data predicted that Meridiani Planum would be much less rocky and smoother than the VL 2 site, and that Gusev would have a combination of roughness at decimeter scales similar to or greater than VL 1 and MPF sites, but would be smoother at meter-scales. These predictions appear consistent with the generally smooth flat surfaces with moderate and few rocks observed by Opportunity and Spirit, where RMS slopes from MER Front Hazcam (FHAZ) stereo pairs average 3º at 3 m scale for both rovers, but average about 30º at 10 cm scale for Spirit and 20º for Opportunity at the same scale [12]. A small radar mystery arises from the fact that the Hagfors model analysis of the 3.5 cm 5 km x 5 km pixels that contain the MER landing sites have

$$\theta_{rms}(\text{Gusev}) = 1.6^\circ \pm 0.5^\circ$$

and

$$\theta_{rms}(\text{Meridiani}) = 2.0^\circ +1.0^\circ/-0.5^\circ$$

The Hagfors model suggests that these values represent surface roughness at scales 10λ to 100λ. Examination of the FHAZ plots shows that the "best" radar numbers undererestimate meter-scale RMS slope for Gusev, and are about right, or slightly overestimate it for Meridiani. With the plethora of MER data, Mars radar scattering modeling can proceed apace.

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Acknowledgements: This research described in this publication was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration.