LUNAR SURFACE SCATTERING FROM NEW 3-CM POLARIZATION AND PHASE RADAR DATA

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Introduction: As part of an effort to interpret the meter- to kilometer-scale surface properties of the moon, we have analyzed new 3-cm wavelength radar images of several lunar surface sites collected by Zisk in 1987 [1]. By collecting the amplitude and relative phase of two orthogonal polarizations at the radar, we can extend our description of scattering mechanisms beyond those suggested by earlier amplitude-only radar data. In particular, we can now separate coherently scattered energy in both the polarized and cross-polarized echoes from energy which is incoherently scattered (unpolarized). In addition, the high spatial resolution of these new images permits study of the scattering behaviors of sub-kilometer-scale geologic features. These same techniques are applicable to earth-based radar sensing of Venus. The moon's dry surface provides a useful analog to the type of environment we imagine exists on the venusian surface. It is hoped that by studying specific lunar targets such as crater ejecta deposits, lava flows of varying composition, and pyroclastic deposits we will be able to make useful comparisons to similar materials on Venus.

Dataset: Previous radar backscatter measurements of the lunar surface at 3.8-cm wavelength [2] had a spatial resolution of 1-2 km. Two orthogonal polarizations were mapped simultaneously, but phase-difference information was not obtained. The new 3-cm wavelength radar data for the moon have a range resolution of 15 m [1], and the phase difference between the two receiver polarizations was retained in the data recording. This relative phase term allows us to construct a Stokes vector for each radar pixel. The 4 elements of a single Stokes vector represent the wave-state of the reflected wave [3]; a wave expressed in this manner can be visualized as the superposition of two sinusoidal waves with orthogonal polarizations and a given phase difference.

In reality, the backscattered wave from a natural surface is not a monochromatic sinusoid (fully polarized), and a single Stokes vector cannot describe the complete statistical nature of the wave. The echo can be fully described, however, by decomposing it into a fully-polarized, or monochromatic, part, and a random, narrow-band unpolarized component. The unpolarized portion contains equal power in both orthogonal modes, with random phase between them [3]. The randomness can be measured by observing several successive Stokes vectors from the same pixel. Alternately, we may assume spatial homogeneity and average Stokes vectors for several adjacent cells. The result is a set of three independent quantities: (1) polarized and (2) depolarized "coherent" power, and (3) unpolarized, or incoherent, power. The phase information measured for each look thus allows us to separate scattered power produced by coherent mechanisms, such as specular facets or dihedral corner reflectors [4], from that produced by random (or diffuse) scattering. The applications to scattering studies are obvious; lunar scattering theories have previously been forced to ignore the possible existence of coherently-cross-polarized echoes, even though the radar data for the icy Galilean satellites show very strong coherent cross-polarization effects from these natural surfaces [5].

Copernicus Crater: We have studied the 3-cm radar data recently acquired for Copernicus crater in order to test the utility of the above technique for identifying scattering mechanisms, and to provide supplemental geologic information to that obtained by Howard [6] and Pieters et al. [7]. These radar data were obtained in July, 1987 at Haystack Observatory. For each of the radar cells (resolution 120m x 30m), we constructed a Stokes vector from the measured echo powers and phase. We then averaged the vector elements over 3-pixel square boxes of data. This yielded a "9-look" average Stokes vector for each pixel. The unpolarized power was calculated for each vector, as were the coherent polarized and depolarized echo strengths [3]. The relative strengths of each type of power were displayed on separate video display color channels, which allowed rapid comparison of the inter-unit differences in scattering.

We can simplify the interpretation of backscattered echoes by using some simple radar scattering models. Coherent polarized backscatter could be produced most easily by specular reflections from radar-facing facets (quasi-specular return) [4]. Coherent depolarized return (for circular illumination) could be produced by a dihedral corner reflector, whose double-reflection path returns an echo with identical handedness to the illuminating wave. Unpolarized energy is most probably due to random surface roughness on the scale of a wavelength or less [8]. If we assume that these three models are the dominant mechanisms for the production of their respective backscatter echoes, then we can compare the radar-implied surface geometry to that seen on Lunar Orbiter photographs of the Copernicus area.

It is immediately obvious that the floor, central peaks, terrace blocks, and perched impact melt ponds can be discriminated with the radar data. Much of the Copernicus crater floor displays a speckle pattern of coherent and incoherent returns. This is in keeping with a model of the surface morphology which predicts random cm to m-scale roughness elements, in the form of rocks or sculpted regolith. The rock faces can produce quasi-specular [4] backscatter, while their intersections with the regolith surface may act as dihedral reflectors. There are few areas of the crater floor in which a single type of backscatter dominates; there are, however, consistent pairings of mechanisms. Radar-facing hillsides in the floor tend to be low in coherent depolarized return, but high in coherent polarized and incoherent returns. The obvious model is that of a rough slope, whose flat areas act as specular reflectors for the illuminating energy.

The crater wall is broken up into many scarps and terraces, ranging from 800-1500 m high and 3-10 km wide. Some of the terraces have perched ponds of impact melt draped across them. These ponds are 2-4 km wide and up to 10 km in horizontal extent. There are several types of observed backscattering behavior over the range of the wall units. Scarp walls which are oriented normal to the illuminating energy display the same behavior seen for the central peaks and large hills in the crater floor; their echo consists of coherently polarized energy and incoherent power, with little coherent depolarization. The scarp faces not oriented normal to the radar (inferred by their continuity with the radar-facing slopes) tend to be dominated by incoherent scatter. This is in keeping with a rough-surface model viewed at large angles of incidence; the quasi-specular (coherently polarized) return is minimal. If we compare the signatures of these slopes with those of the radar-facing hillsides or scarps, we find that in general coherent depolarization is not a common scattering mechanism on such surfaces.

The echoes from areas between the scarps, interpreted from Lunar Orbiter 5 images to be rocky terraces and ponded impact melt, tend to be strongly dominated by coherently depolarized backscatter. Little incoherent or coherent polarized return is seen. This is consistent with a model of many meter-scale dihedral reflectors on the surface of these terraces. One suggested mechanism for this geometry is a small-scale fold or fracture pattern on the surface of impact melt ponds not visible in the Lunar Orbiter images. Further analysis of this phenomenon, and the differences between the perched impact melt ponds and the floor of Copernicus, are expected to yield new insights into the post-emplacement deformation of the crater floor and the quenching of the melt sheet [cf. 9,10].

<u>Summary:</u> The preliminary analysis of 3-cm polarization and phase information for Copernicus demonstrates the utility of high-resolution radar images. At 3-cm wavelength, the wall, floor, and terrace units of Copernicus can be distinguished, and their backscatter characteristics can be explained by simple geometry models. The relationship between the geometric models and the detailed geologic structure of the areas remains to be established. We therefore intend to pursue these analyses for other areas of the moon, and to refine our ability to identify particular combinations of scattering behaviors and relate them to local geology.

<u>References:</u>

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