IDENTIFYING SURFACE CHARACTERISTICS USING AN ICE PENTRATING RADAR SOUNDER AT EUROPA: POTENTIAL FOR LANDING SITE SELECTION . Cyril Grima[1], Dustin M. Schroeder[1] and Donald D. Blankenship[1], [1] Instiute for Geophysics, University of Texas at Austin.

Introduction

It is a goal of the Europa Clipper mission concept to assess potential landing sites for a follow-on lander. Such an assessment not only requires the identification of areas with the greatest potential to test hypotheses and constrain processes, but also requires insuring that the surface in those areas has topography that is suitable for lander operation. The Europa Clipper concept has a two-frequency (60 MHz and 9 MHz) and bandwidth (10 MHz and 1 MHz) radar sounding instrument that has the potential to assess the roughness of the ice surface utilizing its existing hardware and operational capabilities. Although the single-pulse range-resolution of each frequency and bandwidth (15 m and 100 m) is insufficient to directly resolve nadir topography on the sub-meter scale required by the lander, the scattering function of the surface echo will reflect the fraction-of-a-wavelength scale geometry (<< 5 m and 33 m) of the surface [1]. Here, we review a selection of approaches to measuring parameterizations of the scattering function to characterize surface roughness. We also provide an illustrative example of the application of a subset of these techniques to the surface of Thwaites Glacier, West Antarctica. We also discuss how cross- frequency comparison can help constrain the effect of uncertain surface penetration and we conclude with an initial estimate of the scale of rms deviations (on the order of 25 cm) and slopes (from less than 1 degree to a beam-pattern-limited-maximum of over 45 degrees) that we expect these techniques to be able to measure at Europa.

RMS Height from Echo Amplitude Reduction

One of the simplest methods for estimating surface roughness involves measuring the reduction in echo amplitude relative to a theoretical or calibrated specular return [8]. The scattering model behind this method is developed assuming the surface is perfectly conductive and that the reduction in amplitude is a result of the destructive interference (relative to the specular case) caused by the rms phase delay introduced by the surface roughness [1]. The amplitude reduction (given the assumption of uniform dielectric constant) is therefore directly related to the rms height of the surface. Although the development of this model assumes a perfect conductor, it has been both theoretically and empirically demonstrated to apply to surfaces with finite conductivity [1, 7]. At Europa, this technique is likely to provide a comparative estimate of rms surface heights between areas that can be assumed to have the same material properties (conductivity and dielectric) and good echo amplitude calibration. In practice, such areas may be small, of limited scientific interest, and may not exhibit an amplitude reduction signal that is detectable above the noise for comparisons between single measurements. Many or all of those limitations are mitigated or overcome by the more sophisticated approaches that follow, however, this technique does represent an improvement over an altimeter-only approach and also serves as an illustrative base-line for comparison. The assessment area for this approach is on the scale of a Fresnel Zone (kilometers) in both across-track and along-track directions.

RMS Height from Distribution of Amplitudes

A more sophisticated approach to using echo amplitudes to estimate rms height of the surface exploits the variation in amplitude from echo to echo to construct a probability density function (pdf) of echo amplitudes over a relatively small region (kilometers) and fits that pdf to a two-parameter distribution function [7]. The two parameters in that function can be related to a scattering model that describes the coherent and incoherent contribution to the measured echo amplitude, and relates those amplitudes to the rms height of the surface[3]. This model assumes that the coherent energy is dominantly returned from the nadir direction and is modulated only by the rms height, and dielectric constant (in a similar manner to the first approach) and that the off nadir energy is incoherent and determined by a combination of rms height, dielectric constant, and correlation length. By making the simplifying assumption that the correlation length is large (its effect on echo amplitude is small) the fitted coherent and incoherent power parameters can be used to estimate the rms height of the surface independent of echo calibration [3]. This approach can provide improved estimates of rms roughness compared to the single-echo-amplitude approach since its parameters are the product of a statistical fit for a large number of independent measurements and can be employed without precise echo amplitude calibration. It is also insensitive to large-scale (hundreds of kilometers) variations in material properties (conductivity and dielectric constant). At Europa, this technique is likely to produce a statistically robust measure of surface rms height that can be used to compare regions across the surface in terms of rms roughness for landing suitability (it has also been employed to successfully identify regions of distinct geology on Mars) [3].

We present the application of this technique to airborne radar sounding data from a survey of Thwaites Glacier, West Antarctica using the University of Texas Institute for Geophysics HiCARS radar system (60 MHz Center, 15 MHz Bandwidth) in the context of the rms roughness measured by a simultaneously collected nadir- pointing laser and optical satellite image of the glacier. We can see that the rms roughness inferred by this radar analysis technique correlates strongly with roughness measured directly by the laser (exact values differ, at least in part, due to the different measurement baselines).

Another important capacity offered by an echo-amplitude-distribution fitting approach is it produces an internally generated measure of its applicability. shows the degree of correlation of the distribution of measured echoes with the function to which it has been fit for the Thwaites Glacier example. We expect regions with high correlation values (strong model/measurement agreement) to produce rms height estimates that are more reliable. At Europa, the ability of this approach to provide an internally-generated measure of its applicability would provide valuable information about the reliability of its roughness value estimates. It should also be noted that although this approach can function without calibrated echo values, should they be available, they can be utilized to estimate the dielectric value of the surface (which provides a constraint on the extent of surface penetration and its effect on roughness estimates). The assessment area for this approach is on the scale of a Fresnel Zone in both across-track and along-track directions.

RMS Slope from Energy Between Looks

An alternative and mutually cross-interpretable model for surface roughness describes a surface in terms of its rms slope rather than its rms height and correlation length [6]. For surfaces that are not extremely specular, it has been shown that the scattering function is a gaussian function of angle and can be related to rms height and correlation length [6]. Coherent radar systems (like the radar sounder on Europa Clipper) offers the possibility to process the radar data in azimuth and tag echo energy according to both delay and Doppler frequency [9]. Comparing echo energy between looks (or across different focusing windows) can be used to directly measure the scattering function of the surface [10]. The result of this cross-look comparison is a discrete histogram approximation of the gaussian scattering function. The coarseness of this histogram is a function of the Doppler frequency resolution (or the angular width of a Doppler cell), which in turn is a function of the spacecraft velocity, radar wavelength, and time span of observations included in the azimuth FFT [2]. The rms slope of the surface can be estimated by fitting the cross-look echo-energy histogram to a gaussian function of angle. For very smooth surfaces, all of the coherent energy may be contained in a single Doppler bin, which sets a limit on the smoothest surface (smallest rms slope) that can be distinguished by this approach. If combined with estimates of the rms height from one of the previous methods, the estimate of rms slope can be used to estimate the correlation length of the surface roughness as well. Like the statistical approach, the cross-look estimation of rms surface slope is not sensitive to material properties and can be used with calibrated echo strengths to estimate dielectric constants. At Europa, this approach could provide both a direct measure of rms surface slope (which may be a more appropriate measure for certain lander constraints) as well as a finer resolution compliment or alternative to the amplitude based methods described above, since its roughness estimate is performed on the scale of a Doppler bin rather than a Fresnel Zone along-track.

We attempt to demonstrate that there is a large amount of information for surface roughness characterization provided by the radar sounder in the Europa Clipper mission concept. The ability to compare radar returns for two different frequencies and to exploit the coherency of the radar system through azimuth processing to measure the scattering function across different look- angles greatly increases the richness of that information and the diversity of physical processes reflected in their estimates of roughness. When employed as an ensemble, we believe that the approaches described could be applied to data from the Europa Clipper radar sounder to identify and characterize regions of the surface that are suitable landing sites.

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