AN INVESTIGATION OF RADAR SCATTERING FROM FRACTURE IN EUROPA'S UPPER ICE SHELL. Y. S. Aglyamov[1], D. M. Schroeder[2], M. S. Haynes[3] and S. Vance[4], [1]California Institute of Technology, 1200 E California Blvd, Pasadena, CA 91125, [2]Stanford University, 450 Serra Mall, Stanford, CA 94305, [3]Jet Propulsion Laboratory, 4800 Oak Grove Dr, Pasadena, CA, 91109.

Introduction: Ice-penetrating radar potentially offers an attractive means of sensing the deep subsurface of icy satellites. In particular, the planned Europa Mission is set to include REASON, an radar instrument on two frequencies (9 and 60 MHz), with the intent to study the subsurface, and in particular sense the existence of a subsurface water ocean. Moreover, the JUICE mission to Ganymede, Callisto, and Europa is set to include its own ice-penetrating radar.

Although ice-penetrating radar has been successfully used on Earth and Mars, a number of potential obstacles to the detection of such an ocean on Europa have been posited; in particular, the ice-water interface is expected to be many kilometers below the surface, possibly much deeper than the Antarctic ice sheet. The radar signal might be lost over that distance either from bulk properties or from scattering off minor interfaces. This study considers the latter case.

In particular, concerns have been raised regarding the porous regolith expected in the upper part of Europa's icy shell (1), with the spectre of total loss of signal. Additionally, the tectonic faulting known to be common on Europa might be cause for concern. Here, these two sources of loss are considered for the case of Europa, along with a brief comparison of the regolith case with Enceladus and Ganymede.

Regolith Losses: Europa is believed to contain an impact-generated regolith near its surface, but such a regolith is believed to be limited to its top few meters (2). This is insufficient to cause significant attenuation. However, Europa may also contain a tidally generated regolith. If such a regolith exists, a volume-scattering model can be used to estimate scattering losses from it, given regolith depth, pore size, and porosity (1).

Pore size can be constrained based on existing radar observations of Europa's surface. Black *et al.*'s model of the impact regolith based on those suggests a maximum pore size of 20 cm, with most pores being smaller (3). Tidal regolith is expected to be significantly less fractured than impact regolith, so we expect a smaller typical pore size.

Maximum regolith depth can be constrained based on thermal conductivity and heat flow (5). Ice will creep to close any pores at sufficient pressures and temperatures, and the part of the ice crust above this line (approximately 170 Kelvin) will be cold, conductive, and not dissipate tidal energy (2). Using the Luikov *et al.* model for thermal conductivity of porous media (4), along with known constraints on ice creep (6), a temperature profile can be generated and closure depth determined. Assuming tidal regolith extends to this full depth, scattering losses can then be estimated.

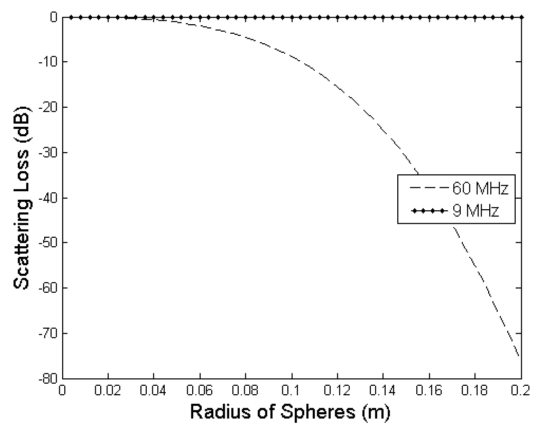

Figure 1. Dependence of scattering loss on characteristic pore radius at 30% porosity for the 60 MHz and 9 MHz radars, using a simple volume-scattering model.

Fault Losses: The surface of Europa is known to contain numerous strike-slip faults, and it would not be unexpected for a radar signal to encounter several of those on its path. Galileo observations suggest that, in some areas, a typical distance between visible faults is 5 km (8).

However, these fault zones would be unlikely to contain vacuum, nor would they be able to retain liquid water. The fault zones could be distinguishable by a variation in ice crystal fabric; but the associated dielectric contrast would be small, around 1% (9).

Assuming fault zones 2 meters wide (wavelength-scale), randomly spaced faults were input into a one-dimensional full-wave model for multiple values of dielectric contrast. Faults were spaced on average 250 meters apart. For a contrast of 1%, two-way losses were well under 1 dB.

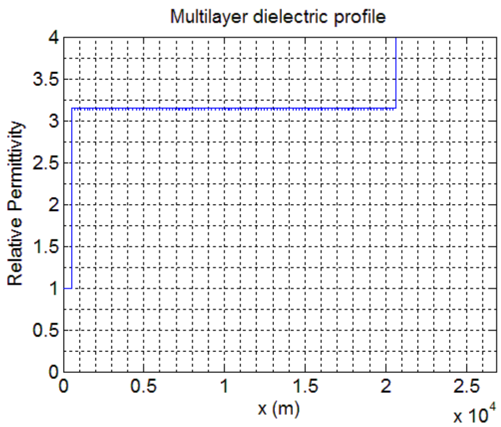

Figure 2. Sample dielectric profile used, with 1% dielectric contrast.

Conclusion: For the range of physical processes and material properties observed or hypothesized for Europa, scattering losses are unlikely to play a significant role in determining radar signal penetration and performance. Losses are expected to be dominated by bulk properties of the ice such as temperature (warm ice is known to scatter radar signals more) and impurities. This is as for ice on Earth. Physical processes with no direct Earth analogue might alter this conclusion.

Crevasses, another possible source of scattering losses, were not examined in detail, due to lack of constraining data. However, crevasses in any case require tensile stresses, and therefore half of Europa's surface will tend to close them instead of opening them.

Ganymede and Enceladus both have more favorable conditions than Europa for the maintenance of a deep tidal regolith. Enceladus has a far smaller surface gravity than Europa, while Ganymede has a far lower surface heat flux; both factors lead to creep becoming dominant only at a greater depth. However, because scattering depends so strongly on scatterer size, the critical scatterer size remains similar for those satellites at tens of centimeters.

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