Assessing the Ability of Radar Sounders to Discriminate between Corner-Reflections and Point Scatterers: Application to Europa's Chaos Terrains R. J. Michaelides[1] and D. M. Schroeder[1], [1]Stanford University, Department of Geophysics, rmich@stanford.edu.

Introduction: The Europa Clipper Mission's primary objective is to detect and characterize the three-dimensional distribution of liquid water within and beneath Europa's icy shell [1]. Several models have been proposed that hypothesize the subsurface distribution of liquid water in Europa's ice shell, from discontinuous perched aquifers [2], to vertical water-filled conduits that link the surface to aquifers at depth [3]. Discrimination between these types models would shed light on the subsurface distribution of liquid water in Europa's ice shell, and inform models of planetary surface and subsurface evolution.

Background: REASON (Radar for Europa Assessment and Sounding: Ocean to Near-surface) is a dual frequency radar that can operate with a center frequency of 9 MHz (HF) and 60 MHz (VHF), suitable for sounding terrestrial and planetary ice bodies kilometers thick [4],[5]. Airborne radar sounding has been successfully employed to categorize the internal ice structures, subglacial and englacial interfaces, and surface elevations over a range of terrestrial ice bodies [6],[7], [8]. Peters et al. identified bottom crevasses at the base of terrestrial icebergs and ice shelves based on their characteristically long echo tails, and categorized these features based on the presence or absence of water within the fractures [7]. We demonstrate that similar analyses of radar echo morphology and azimuth spread with REASON can be used to discriminate between different subglacial scattering regimes, and could be used to characterize the subsurface ice structure and water distribution within Europa's ice shell.

Previous studies have demonstrated that Europa's chaos terrains may represent regions of complex ice deformation and freeze-out overlying shallow perched water lenses in Europa's ice shell [2]. Notably, this model suggests that significant bottom crevasses and fractures would form at the boundary of the water lens and the overlying ice shell, allowing briny water to be injected into the overlying ice. As these crevasses fill with water, hydrofracturing will initiate crack tip propagation, breaking up the overlying ice into steep-sided blocks of ice akin to terrestrial icebergs. Analysis of the aspect ratios of floating blocks in Conamara Chaos suggest a minimum depth to the subglacial water lens of only 2.8 km, suggesting that REASON could directly image the ice-water interface in chaos terrains. Furthermore, characterization of the water distribution at the ice/water interface could constrain formation mechanisms for chaos terrain. Characterization of Europa's chaos terrains is a primary mission objective of the Europa Clipper Mission, which will necessitate a proper interpretation of REASON data over these regions.

Methods: Several terrestrial radar ice-sounding studies have noted that tabular icebergs and ice sheet bottom crevasses exhibit corner reflector behavior [6], [9]. Specifically, corner reflectors exhibit much larger radar cross sections (RCS) compared to standard point reflectors, but, in comparison to point reflectors, the geometric nature of corner reflectors restricts the range of solid angles over which corner reflections can be received by an active radar. We evaluate whether this can be exploited to constrain subsurface water distribution and/or basal water state for radar sounding observations. For the chaos terrain model described in [2], chaos terrain can be modeled as a series of floating ice blocks overlaying either a liquid subglacial water body, or a granular ice/water matrix. In either case, the inter-

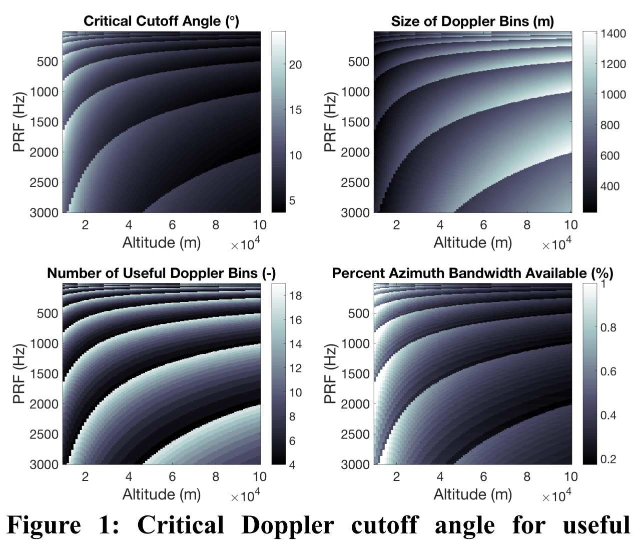

Figure 1: Critical Doppler cutoff angle for useful Doppler bins, Dimension of Doppler bins, total number of useful Doppler bins, and percent azimuth bandwidth available, as a function of the radar PRF, and spacecraft altitude. Robustness of radar target discrimination is quantified with these parameters for a range of expected flyby geometries and subsurface water distribution scenarios.

face between solid ice and liquid water or a water/ice matrix would exhibit a difference in dielectric constant significant enough to produce reflections of incident radar signals. Vertically oriented crevasses and water-fractures within the overlying ice shell (which are expected at the ice shell/water body boundary in [2]) could appear as corner reflectors and diffractors to the REASON instrument, analogous to terrestrial iceberg crevasses as in [7]. If a corner reflection from a crevasse and the ice/water body interface can be unambiguously identified in REASON data, the thickness of the ice shell overlying a perched englacial water body could be determined precisely. Furthermore, englacial water distribution could be constrained, and correlated with surface ice shell topography.

In this work, we discuss the range of operating regimes for SAR processing of REASON radar data, and relate these operating regimes to the problem of target discrimination. The effects of both Snell's Law diffraction and off-nadir doppler returns are discussed and quantified. We derive a discrimination threshold that is dependent upon the effective usable azimuth bandwidth of the radar; we then construct a maximum-likelihood estimator using this threshold, and apply it to simple simulations of point target and corner reflector radar scattering data processed for a range of REASON operating regimes. Finally, we comment on the range of REASON operating regimes most conducive towards target discrimination, and the various radar operating regimes that allow for successful target discrimination.

Results: The smallest tilting ice blocks at Conamara Chaos are reported as ~2 km wide (with an inferred thickness of ~2.8 km from an aspect ratio analysis, [2]). Unfocused SAR processing for a flyby VHF (60 MHz center frequency) sounding observation at a 10 km altitude and a 1 kHz PRF yields the following design parameters:

wavelength	5 (m)
altitude	10 (km)
velocity	1428 (m/s)
PRF	1 kHz
range resolution	2.5 (m)
azimuth resolution	223.6 (m)
Number of pulse per burst	16 – 64 (bins)
Doppler Bin size	1094 – 273 (m)
critical angle	4.7 – 19.2 (∘)
Number of Useful Doppler bins	1 – 12 (bins)

Choosing 64 pulses per burst results in a doppler bin size of ~273 m, which means this example ice block can be resolved by 7 azimuth pixels. Furthermore, FFTs of length 64 should be adequate to discriminate between a one-sided (corner reflector) and two-sided (point target) distribution of returned energy. Of course, this is the smallest ice block observed by [2], and larger blocks can be even more readily imaged and characterized.

The above analysis is conducted for a range of radar operating regimes and models of expected subsurface water distribution.

Conclusion: A primary science objective of the Europa Clipper Mission is to characterize the surface and subsurface water content and distribution of Europa's ice shell. Using several existing models of Europan ice-shell water distribution and geometry, we discuss a range of possible radar operating regimes, and quantitatively discuss the tradeoffs between target discrimination and radar system performance. Finally, we demonstrate that for certain radar operating regimes and flyby geometries, discrimination between different subsurface radar scattering behaviors can be achieved, and subsurface water distribution in Europa's ice shell can therefore be constrained.

References: [1] Europa radar feasibility [2] B. E. Schmidt, D. D. Blankenship, G. W. Patterson, and P. M. Schenk, Nature, vol. 479, no. 7374, pp. 502–5, 2011. [3] E. S. Kite and A. M. Rubin, Proceedings of the National Academy of Sciences, vol. 113, no. 15, pp. 3972–3975, 2016. [4] C. F. Chyba, S. J. Ostro, and B. C. Edwards, LPSC,Mar. 1997. [5] Kalousová, K., D. M. Schroeder, and K. M. Soderlund J. Geophys. Res. Planets, 122, 524–545 , 2017 [6] M. E. Peters, D. D. Blankenship, and D. L. Morse, Journal of Geophysical Research B: Solid Earth, vol. 110, no. 6, pp. 1–17, 2005. [7] M. E. Peters, D. D. Blankenship, D. E. Smith, J. W. Holt and S. D. Kempf, *IEEE Geoscience and Remote Sensing Letters*, vol. 4, no. 1, pp. 142-146, Jan. 2007. [8] D. M. Schroeder, D. D. Blankenship, and D. A. Young, Proceedings of the National Academy of Sciences, vol. 110, no. 30, pp. 12225–12228, 2013. [9] R. W. Jacobel, K. Christianson, A. C. Wood, K. J. Dallasanta, and R. M. Gobel, Annals of Glaciology, vol. 55, no. 67, 2014.