MELT DETECTION BENEATH CHAOS TERRAINS ON EUROPA USING ICE PENETRATING RADAR.

F. Di Paolo[1], B. Cosciotti[2], S. E. Lauro[2], E. Mattei[2], E. Pettinelli[2] and L. Bruzzone[3]
[1]MobyGIS Srl, Via Guardini, 24, 38121 Trento, [2]Mathematics and Physics Dept., Roma Tre University, Via della vasca navale, 84, 00164 Rome, Italy, [3]Department of Information Engineering and Computer Science, University of Trento, Via Sommarive, 9, 38123 Povo (TN).

Introduction: Due to the low attenuation of radio frequencies in ice, Ice Penetrating Radars (IPRs) will be hosted onboard the next ESA and NASA missions to explore the icy crust of the Jupiter moon Europa [1], [2]. [3] suggested that Europan chaos terrains, like Conamara Chaos and Thera Macula, formed above lenses of liquid water placed at a depth of 3 km inside the icy crust of the moon; the authors suggested that if the water lens below Thera Macula was liquid at the time of the Galileo encounter, we are probably witnessing the resurfacing due to active chaos formation. [4] proposed that, even if the resurfacing ended a long time ago, a time of $2.85 \cdot 10^5$ y is necessary for a 3-km liquid water lens underneath Thera Macula to freeze completely, evidencing the possibility to have still some melt material at present. Similarly, also Conamara Chaos has been described as an area where intense diapirism disrupted a brittle surface overlying ductile ice, causing ice blocks floating over partial melted zones and exposing subsurficial materials (e.g.,[5]).

We explore different thermal and dielectric scenarios to evaluate the possibility to detect such a water lens and other geological structures in the shallower part of the Europan crust. Radar performances are expressed in terms of signal-to-noise ratio (SNR) along the vertical coordinate at the two relevant frequencies of RIME and REASON IPRs (9 and 60 MHz). An analysis of the basal SNR in presence of volume scattering associated to a surficial layer of fragmented ice has been performed to evaluate the effect of such a phenomenon at 60 MHz.

Geologic scenarios:

The temperature profiles used have been taken from the thermal scenarios proposed by [4], supposing that the ice beneath Thera Macula was liquid 0, 30, 300, 3,000, 30,000 or 150,000 years ago. The dielectric scenarios considered here are reported in Table 1.

#	Ref.	Material
1	[6]	Pure ice
2	[7]	Salty/acid ice
3	[8]	Salty ice
4	[9]	Dusty ice
5	[6]	Porous pure ice

Table 1. Considered dielectric scenarios.

For Scenarios 4-5, the effective relative permittivity of a two-phase mixture is considered, using a mixing rule for spherical inclusions [10].

Fig. 1 shows the value of the attenuation as a function of temperature for the considered dielectric scenarios. It is noticeable that, for Scenario 4, the attenuation results frequency dependent.

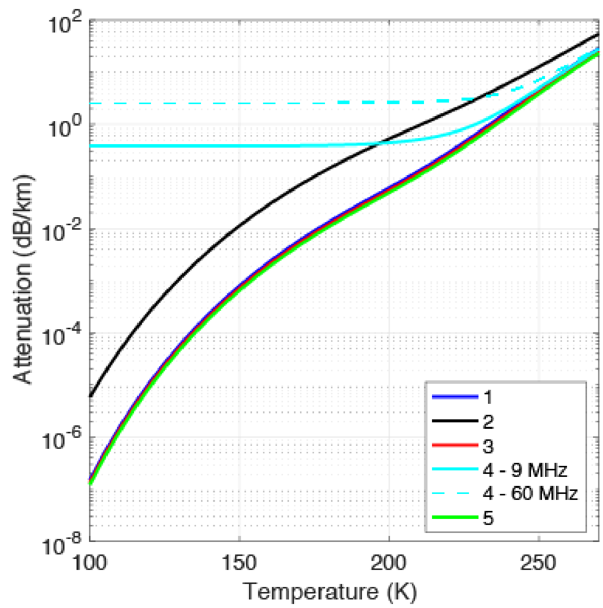

Fig. 1. Temperature-dependent attenuation for the considered scenarios.

Two-way attenuation and SNR:

Following [11], we use a one-dimensional transmission line model, considering the far field condition, normal incidence and the propagation of a plane wave into a layered structure. Such a condition can be reasonably assumed comparing the magnitude of the spacecraft altitude (400 km) to the thickness of the icy crust of Europa. An interface of liquid water is located at the bottom of the layered structure. We consider two end-members for the permittivity of the basal layer (water lens): the value of 80 for pure water, and the value of 30 for a salted water.

For Scenario 5, we evaluate the effect of volume scattering on SNR for the 60 MHz antenna in a reasonable range of parameters: a 0-20% porosity, and a pore radius of 0.1-1 m The regolith thickness has been fixed in each thermal scenario considering the depth associated to the critical temperature (170 K) of the pores close off. For our thermal scenarios, such depth assumes the values of 0, 30, 140, 480, 1350, 1880 m, going from the 0 y scenario to the 150,000 y thermal scenario. Since for the 0 y thermal scenario no regolith is predicted, the evaluation of volume scattering in the Mie regime is performed only in the other 5 thermal scenarios, whose regolith layer is significative with respect to the antenna resolutions.

Results: Basal SNR for the considered thermal and dielectric scenarios are reported in Fig. 2 for the two relevant frequencies. Thresholds of 5 (critical) and 0 (detection limit) dB are evidenced in blue and red, respectively.

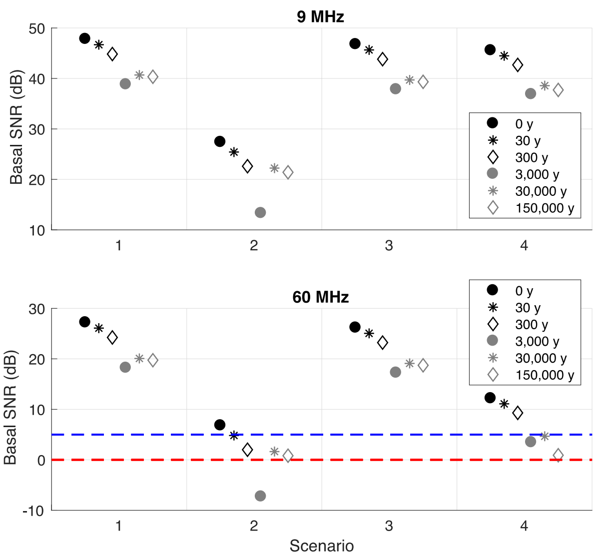

Fig. 2. Basal SNR for Scenarios 1-4 and all the thermal profiles.

Fig. 3 reports the basal SNR as a function of void radius and porosity for a porous pure ice (Scenario 5), for the 60 MHz antenna. Note that, when the detection limit (SNR = 0) is reached, the color scale is saturated in red.

Under such condition, the effect of the thermal scenario (that is actually governing the thickness of the fragmented ice) is significative. The older the crust, the thicker the scattering layer, and thus, the higher the losses associated to volume scattering. It is also evident how both the porosity and the scatterer radius affect this phenomenon, being the latter quantity more predominant.

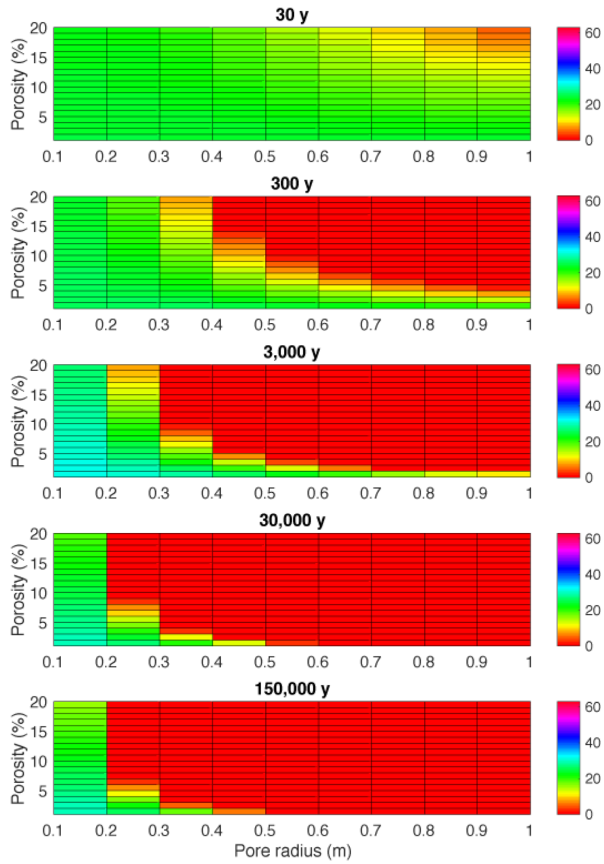

Fig. 3. Basal SNR (dB) in Scenario 5 for the thermal profiles studied and a 60 MHz antenna.

Summary: Our results demonstrate that a 9 MHz antenna is capable to detect a surficial water lens underneath the chaos terrains of Europa in all of the studied scenarios. Conversely, the performance of a 60 MHz antenna is case-specific, showing a significative signal loss in presence of a high-attenuation ice or volume scattering.

References: [1] Grasset O. et al. (2013) *Planet Space Sci., 78*, 1-21. [2] Phillips C. B. and Pappalardo R. T. (2014). *Eos, Trans. Am. Geophys. Union 95(20)*, 165-167. [3] Schmidt B. E. et al. (2011) *Nature 479(7374)*, 502–505. [4] Abramov O. et al. (2013) *Earth Planet. Sci. Lett. 384*, 37-41. [5] Carr M. et al. (1998) *Nature 391*, 363-365. [6] Kawada S. (1978) *J. Phys. Soc. Jpn., 44(6)*, 1881-1886. [7] Matsuoka K. et al. (2012) *Earth Planet. Sci. Lett. 359*, 173-183. [8] Pettinelli E. et al. (2016) *Earth Planet. Sci. Lett. 439*, 11–17. [9] Heggy E. et al. (2012) *Icarus 221(2)*, 925-939. [10] Di Paolo F. et al. (2014) *Proc. IEEE International Conference on Ground Penetrating Radar*, 362-366. [11] Di Paolo F. et al. (2016) *IEEE J. Sel. Topics Appl. Earth Observ. Remote Sens., 10(1)*, 118-129.