A Study of Martian Mid-Latitude Water Ice Using Observations and Modeling of Terraced Craters

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I. Introduction
- There is abundant evidence for excess water ice (ice that exceeds the pore space of the regolith) in the mid-latitudes: ice exposed in recent impact craters, scallops, thermokarstically expanded craters, and ice at the Phoenix excavation site.
- Understanding the distribution and composition (pure, dirty or porous) of this ice will lead to a better understanding of the mechanism(s) and climate that emplaced this ice.
- Craters and SHARAD radagrams are independent mechanisms for probing the subsurface to study this ice and both show extensive layering (presumably of this ice) across Arcadia Planitia.
- We constrain the depth of a widespread interface using HiRISE Digital Terrain Models of the terraced craters. Knowledge of its depth allows the radar data to be interpreted in terms of dielectric properties and constrain the composition of the layer.
- Comparing models of crater formation to crater topography allows us to test a variety of properties for the subsurface layers (thicknesses, porosities, strengths) as well as projectile sizes and speeds for insight into impact conditions.

II. Observations

SHARAD Radar
- Radar reflections indicate sharp change in the dielectric constant (relative dielectric permittivity) \( \varepsilon_r \) of the material.
- The dielectric constant is a measure of how effectively an EM wave can move in a material.
- Dielectric constants of common materials:
  - Vacuum, Air: \( \varepsilon_r = 1 \)
  - Ice: \( \varepsilon_r \approx 3.15 \)
  - Basalt: \( \varepsilon_r \approx 6 \)
- We have mapped a subsurface reflector (originally detected and mapped by Paut et al. LPSC 2009) in 277 SHARAD tracks across Arcadia Planitia by comparing the radiograms to clutter simulations (which simulate reflectors due to off-nadir topography).
- The reflector likely corresponds to the same interface as the floor terrace in the craters. The wall terrace is too shallow to be detected by SHARAD.

III. Combining Observations
- The dielectric constant is related to radar propagation velocity in the equation below.
- We can use delays to crater terraces with SHARAD delay times to constrain the dielectric constant and thus the properties of the ice assuming the terrace corresponds to the same interface causing the radar reflector.
- Floor terrace depths:
  \[ \Delta T = c \varepsilon_r \Delta \varepsilon \]
  \[ V = \frac{\Delta \varepsilon}{\Delta T} \]
  \[ \varepsilon_r = \frac{1}{v^2} \varepsilon_{rock} \]
- \( c \) is the propagation velocity in vacuum.
- The dielectric constant of the subsurface layer is given by:
  \[ \varepsilon_r = \frac{1}{v^2} \varepsilon_{rock} + \frac{1}{v^2} \varepsilon_{ice} + \frac{1}{v^2} \varepsilon_{air} \]

IV. Modeling Crater Formation

iSale (Simplified Arbitrary Lagrangian Eulerian) Model
- Allows multiple materials and rheologies
- Modified from the SALE hydrocode [Amsden et al. 1980] to account for three target materials, various equations of state, various constitutive models and a porous-compaction model [Collins et al. 2004; Wünnemann & Ivanov 2003; Wünnemann et al. 2006].
- Is well tested against other hydrocodes [Pierazzo et al. 2008].

Components of the Model
- Differential equations established through conservation of momentum, mass and energy describe the dynamics of a continuous medium.
- Equation of State describes thermodynamic state (pressures, internal energies and densities).
- Strength Model describes response of a material to stresses that induce deviatoric deformations or changes of shape using elasticity, plasticity and fluid flow.

V. Conclusions
- By combining crater terrace depths and SHARAD subsurface reflector delay times, we calculate the full expected range of dielectric constants (\( \varepsilon_r \)) for this layer to be between \( \approx 2 \) (corresponding to a maximum of 55% ice if mixed only with air) to \( \approx 75\% \) ice if mixed with lithic material) and includes the value of 3.15 corresponding to 100% ice.
- Using the radar delay times closest to each crater gives \( \varepsilon_r \) estimates of 3.3-3.6, which suggest a water-ice-rich (80%) layer decameters thick with ~20% lithic material (either mixed into the ice or as a regolith layer on top) or no porosity. The layer is ~60% ice if 20% porous.
- Modeling of impact crater formation into an icy layer target demonstrates a water ice layer (covered by a layer of basaltic regolith) is likely responsible for the doubly-terraced crater morphology. The best fits are obtained when the ice has porosity <30%.

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- Additional questions on the modeling can be directed to Dr. Elena Martellato: elena.martellato@esr.it