Enceladus' Brilliant Surface: RADAR Modeling

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INTRODUCTION

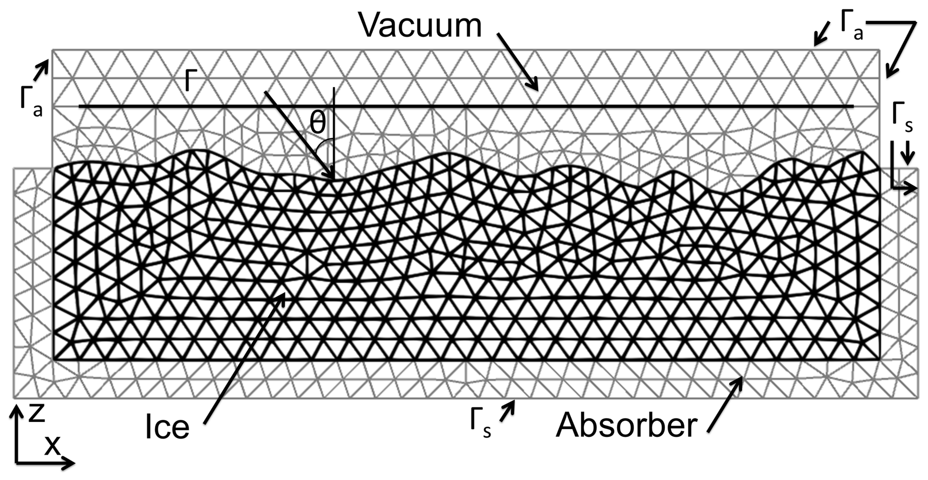
Icy satellites of the outer Solar system display unusually bright Radar albedo [1,2,3]. In November 2011, the Cassini spacecraft was able to image the surface of Enceladus with its synthetic aperture radar at high resolution [4]. It found that most of the satellite showed a very high radar backscattering cross-section. Further, this backscatter was only weakly dependent on incident angle.

We investigate geologically plausible scattering configurations of the icy surface using a rigorous, fully-coherent electromagnetic scattering tool based on the finite element method (FEM) [5].

Past work on this subject has involved the use of "exotic" scatterers embedded inside an icy substrate to explain high backscatter [6,7]. In our analysis, the only material we use is ice and demonstrate that high backscatter is possible under this constraint.

METHODOLOGY

The Finite Element Method is a general purpose tool for the solution of differential equations. A geometry of interest is specified, from which the radar scattering cross-section is calculated.



- Tessellated 2D computational domain.
- Incident radar wave at specified angle. Incident wave is "tapered" in amplitude to reduce numerical edge diffraction effects [8].
- One "realization" of a rough surface. To get a convergent ensemble average, many (50–100) realizations must be considered [9,10].
- Absorbing boundary layer to terminate computational domain [11,12].

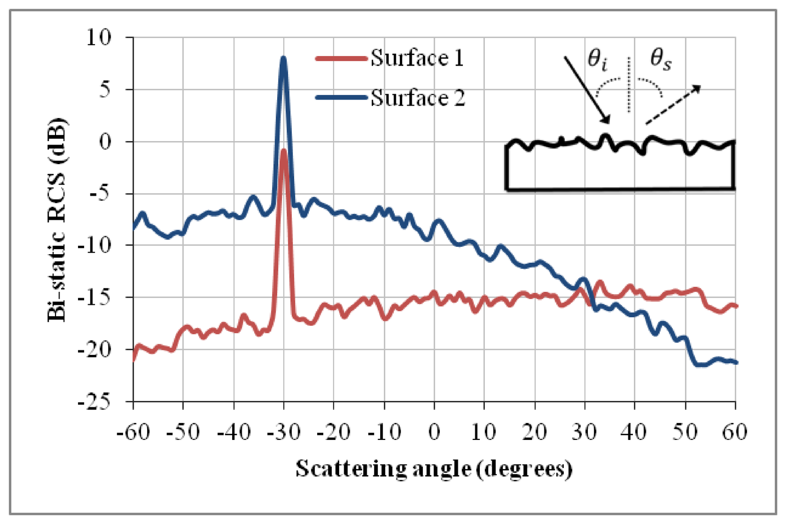
Important Caveat: 2D simulations, i.e. third dimension is homogeneous and physics invariant in that direction. But, big computational advantage gained.

RESULTS

• Bi-static Radar Scattering Cross-section

Shows ensemble averaged scattered radar power as a function of angle for a given incident radar beam.

Surface 1:
h = 0.25 cm, c = h
Surface 2:
h = 0.25 cm, c = 5 h
h: mean surface height
c: surface correlation length
[Surface modeled as a Gaussian random process.]



Surface statistics determine the nature of scattered radar power when the substrate is homogeneous.

• Rough surfaces: Homogeneous substrates

Variation of radar backscatter (in dB) as a function of incidence angle for the two types of surfaces considered above:

Incidence angle	Surface 1		Surface 2	
	H-pol	V-pol	H-pol	V-pol
50	-13.0	-13.3	-24.9	-22.5
40	-13.7	-12.8	-19.9	-17.8
30	-13.4	-14.8	-13.3	-13.3

Clearly, the backscatter is very sensitive to surface statistics.

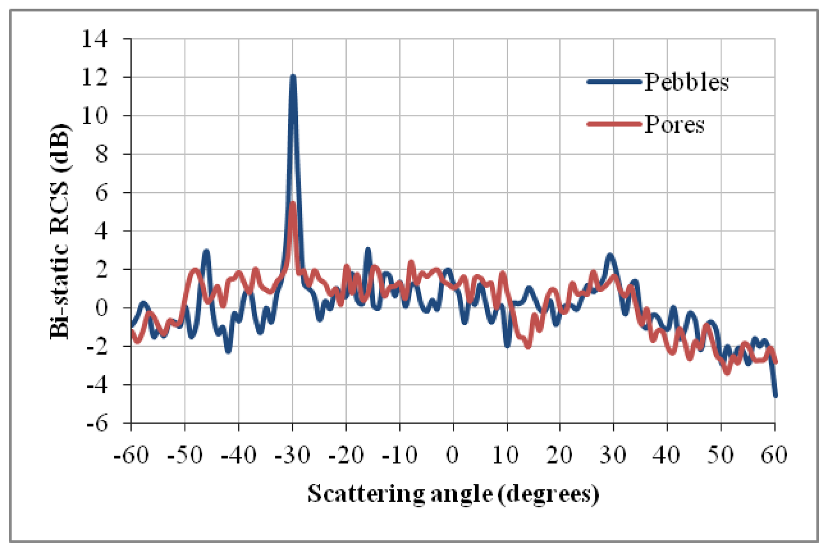
• Rough surfaces with circular pebbles atop

For the same two surfaces as above, circular ice pebbles of random radius (between 0.75λ and 1.25λ), and random spacing (between 5λ and 7λ) are sprinkled on the surface.

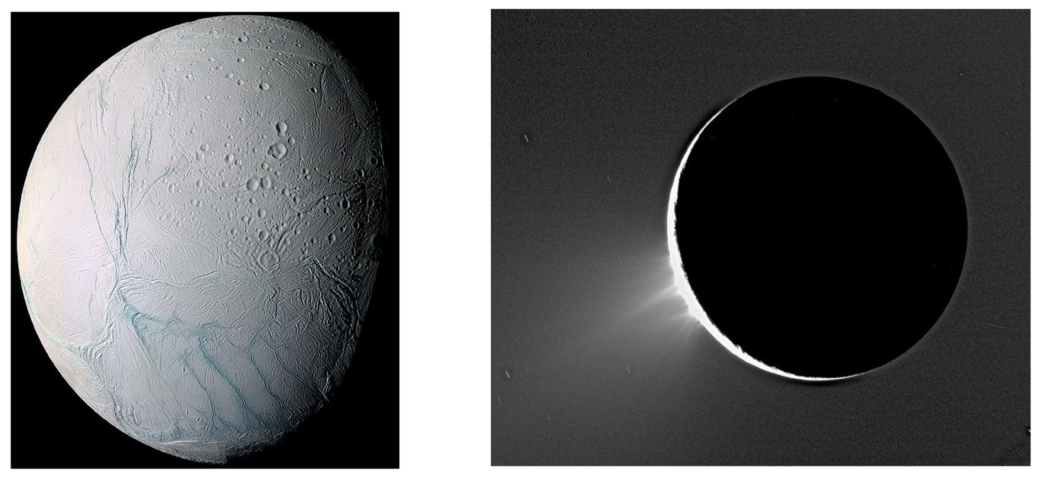
Incidence angle	Surface 1		Surface 2	
	H-pol	V-pol	H-pol	V-pol
50	1.3	1.9	0.1	0.8
40	2.3	0.9	1.1	2.0
30	2.4	1.0	3.1	2.8

Radar backscatter has now increased, and is weakly dependent on incidence angle due to retro-reflection by pebbles. Making the pebbles elliptical weakens this effect.

Bistatic radar scattering cross-section for a vertically polarized radar wave incident at 30° onto surface 2 in two possible configurations: with pebbles atop, or with an underlying porous substrate.



Where does the ice come from?



(Left) False color mosaic of Enceladus taken by the Cassini-Huygens probe in July 2005, showing the "Tiger stripes" in the South pole.
(Right) View from Cassini spacecraft of plumes seen emerging from Enceladus' South pole.
[Images courtesy of NASA/JPL/Space Science Institute]

• Rough surfaces with porous substrates

For the same two surfaces, the substrate is now made porous by randomly introducing pores. A pore is modeled by the vacuum region formed by placing three equally sized circular ice pebbles in contact. For the results below, porosity = 50% and minimum pore size is 10 mm.

Incidence angle	Surface 1		Surface 2	
	H-pol	V-pol	H-pol	V-pol
50	0.9	0.6	0.4	-1.2
40	2.0	2.5	1.4	2.0
30	3.6	2.1	2.5	2.2

As in the earlier case, the dependence of radar backscatter on incidence angle and surface statistics is gone, i.e. regardless of the surface statistics, a high backscatter is observed.
Further increase of 1-3 dB is observed by combining pebbles with porous substrates.

DISCUSSION

- The presence of coherent scattering mechanisms in addition to just rough surfaces is essential in order to get high radar reflectivity from icy substrates.
- These mechanisms give a relative increase of 10-20 dB in backscatter as compared to homogeneous rough surfaces.
- No strong geological justification for pebbled surface, but it is the preferred explanation for radar-bright channels on Titan.
- Geological justification for a porous substrate is the presence of fine ice-ejecta deposited onto the surface by the cryovolcainc eruptions. It is conceivable that the substrate is formed by the deposition of many such layers. Space weathering and sintering may play a dominant role in the creation of multiple sub-wavelength pores within the substrate [4].

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ACKNOWLEDGMENTS

This research was carried out at the California Institute of Technology, Jet Propulsion Laboratory under a contract from NASA. It was supported by the Cassini project, and a JPL R&TD Innovative Spontaneous Concept grant. We thank members of the Cassini Radar team, Steve Wall, Jakob van Zyl, and Mahta Moghaddam for discussions and support.