SHARAD Workshop – 45th LPSC

– FINDING DIELECTRIC PROPERTIES –

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Preamble

Interaction of SHARAD happens in diverse ways:

- ionosphere - conductivity
- at the surface and other interfaces – contrast in permittivity, roughness
- through a given subsurface volume – conductivity, volume scattering

Here, I examine in this presentation a simplified case:

- smooth surface with a given dielectric contrast
- signal loss due to conductivity through a given volume

Disregarded in this presentation are the effects arising from:

- ionosphere
- surface roughness

Basic Principles and Vocabulary:

Permittivity – describes how charge migration and dipole re-orientation occurs in a medium submitted to an electric field.

$$\varepsilon_0 = 8.85 \times 10^{-12}\ \mathrm{F} \cdot \mathrm{m}^{-1}$$

Relative Permittivity – the ratio between the permittivity of a material and that of vacuum

$$\varepsilon_r = \varepsilon / \varepsilon_0$$

(or 1 for vacuum/free-space)

Dielectric Constant – another name to relative permittivity

Conductivity – describes how easily the flow of charge (current) occurs in a medium submitted to an electric field.

$$\sigma = J / E$$

(current density/electric field).

Basic Principles and Vocabulary:

Complex permittivity – $\varepsilon = \varepsilon' + i\varepsilon''$ or $\mathrm{Re}(\varepsilon) = \varepsilon'$, $\mathrm{Im}(\varepsilon) = \varepsilon''$

- the real portion relates to the dielectric constant, which we have already seen

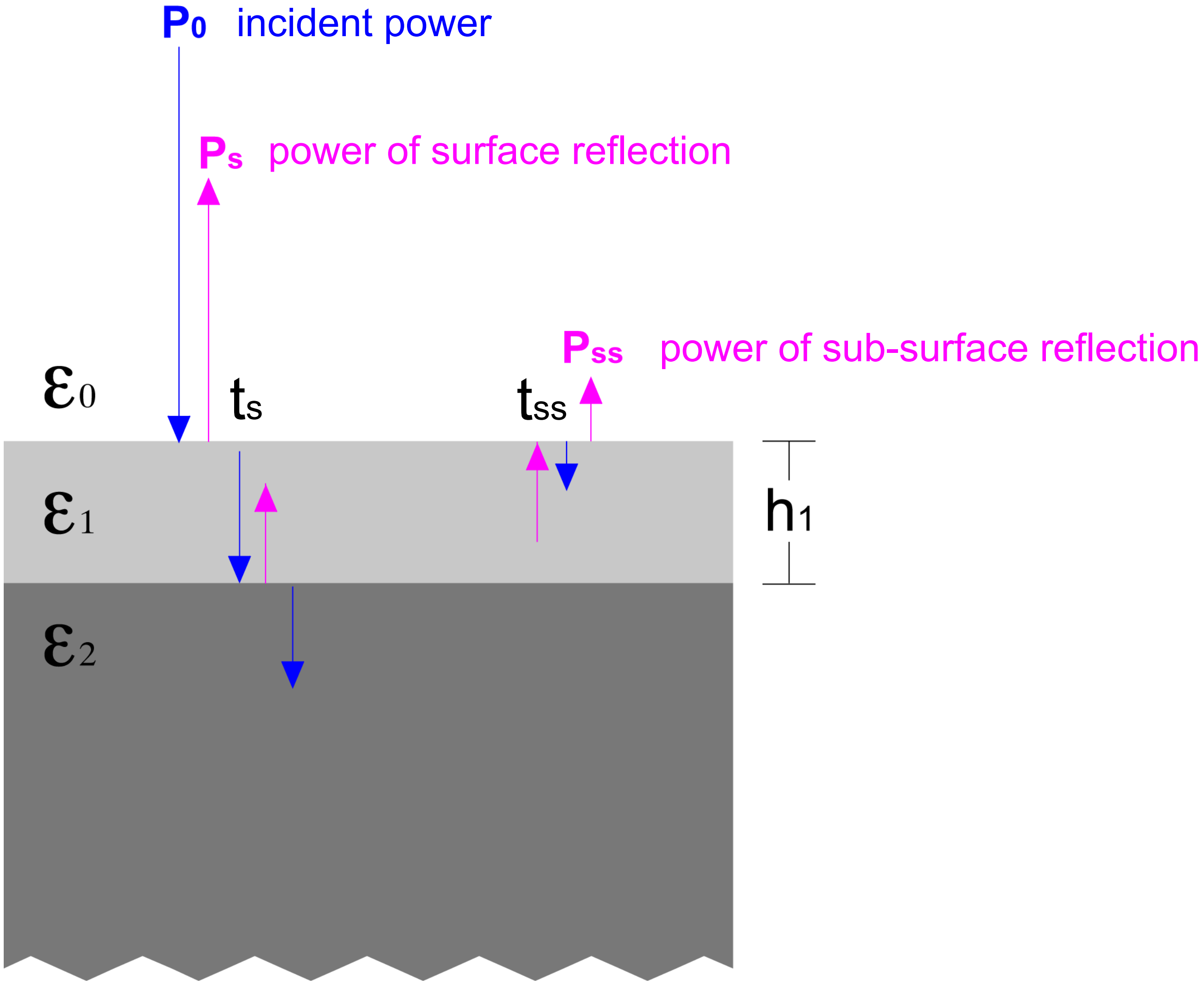
- the imaginary portion relates to the conductivity…

$$\varepsilon'' = \frac{\sigma}{\omega}, \qquad \omega = 2\pi f$$

Loss tangent – the ratio between the real and imaginary portions of the complex permittivity and a measure of the lossiness of a material (the lossier a material is, the more attenuated a signal becomes as it travels through the medium).

$$\tan\delta = \frac{\varepsilon''}{\varepsilon'}$$

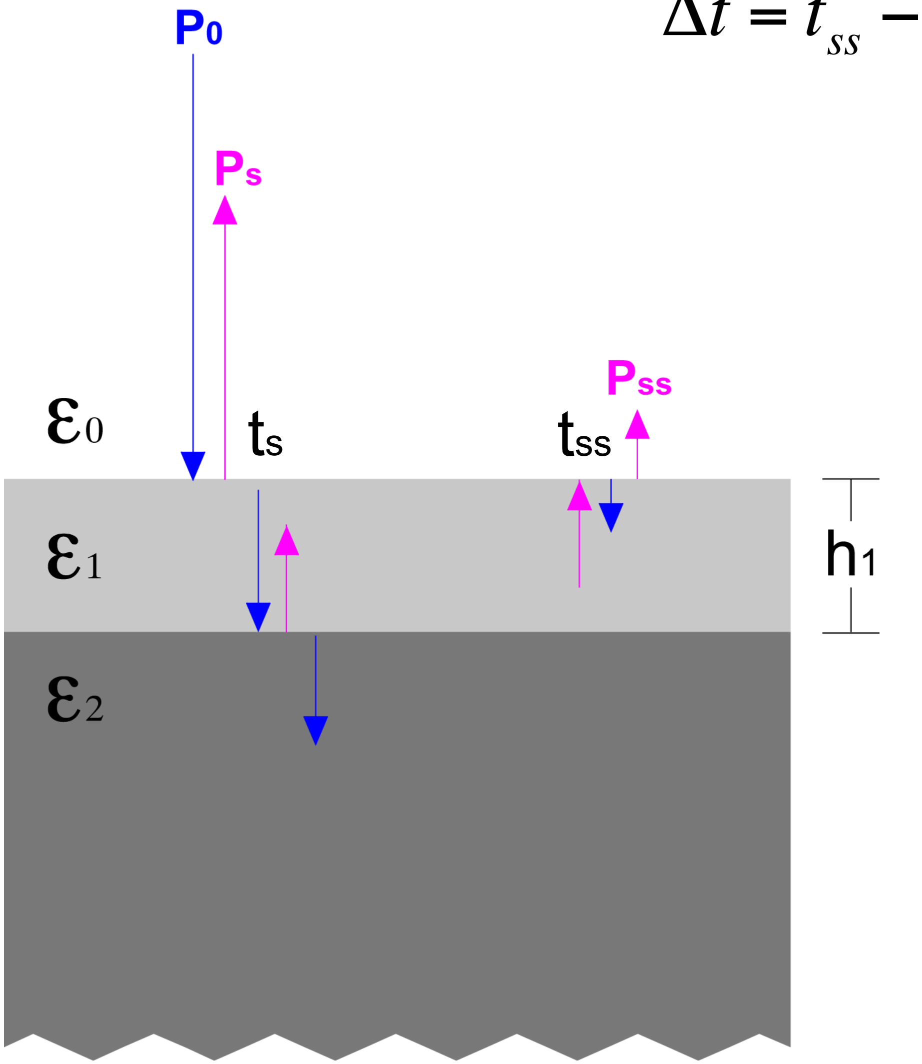
Propagation I



Propagation I

Delay between surface and subsurface reflections

$$\Delta t = t_{ss} - t_s$$



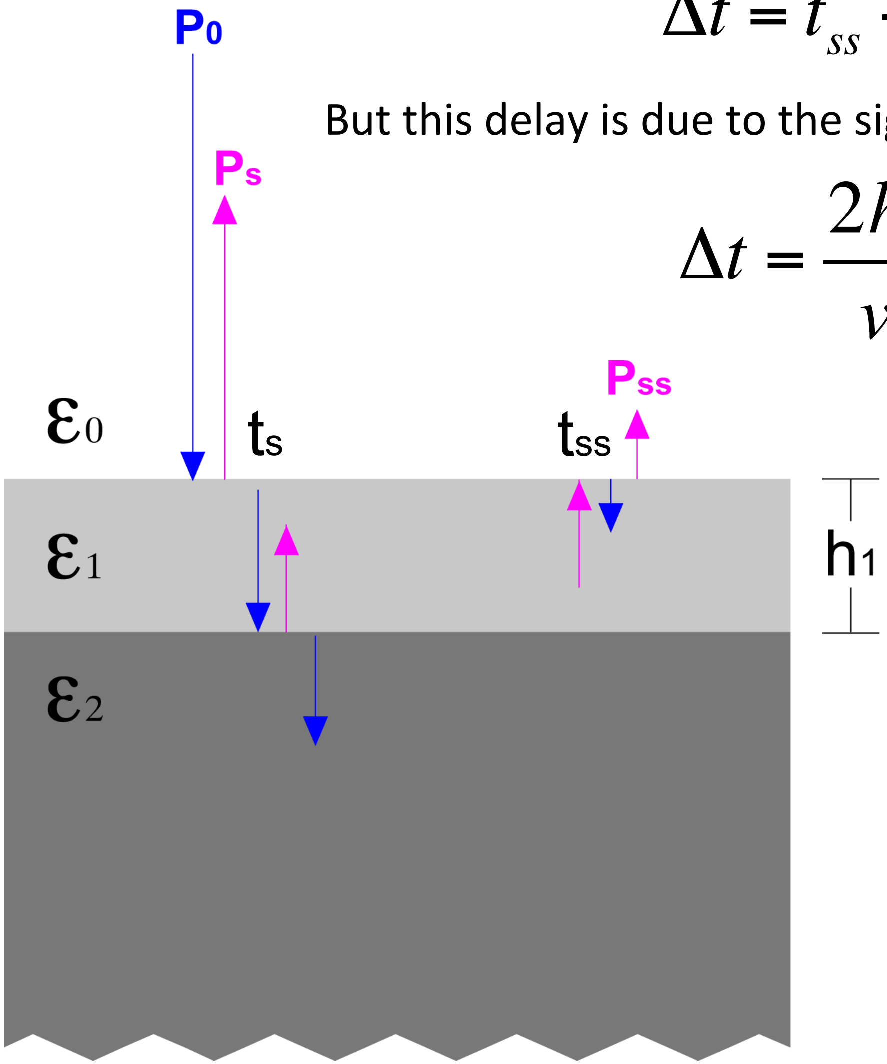
Propagation I

Delay between surface and subsurface reflections

$$\Delta t = t_{ss} - t_s$$

But this delay is due to the signal travel time

$$\Delta t = \frac{2h_1}{v}$$



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$$v = \frac{c}{\sqrt{\varepsilon_1'}}$$

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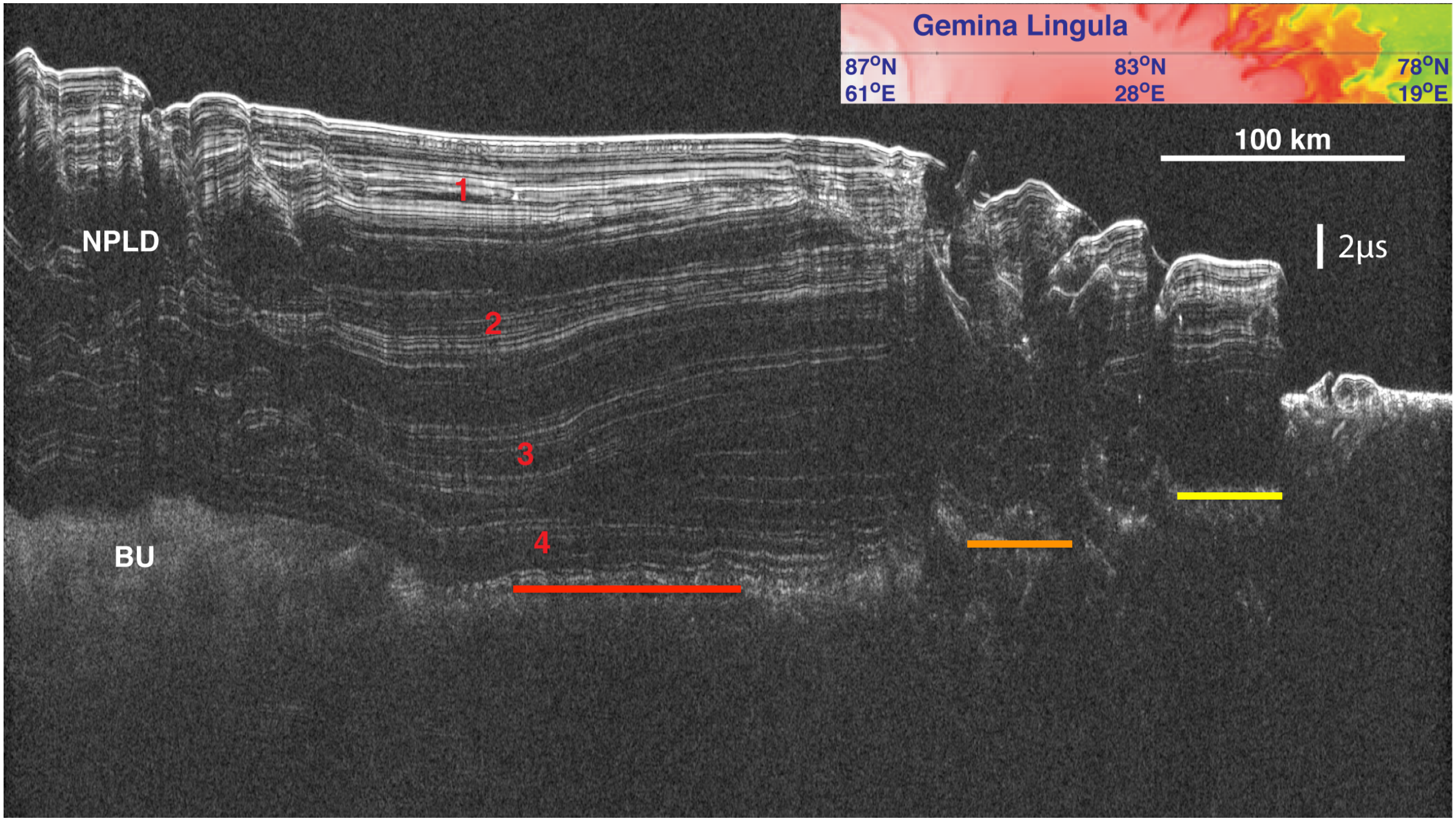
$$v = \frac{c}{\sqrt{\varepsilon_1'}}$$

c is speed of light in vacuum

If h_1 is known and Δt measured, then the last two equations can be combined and rearranged into

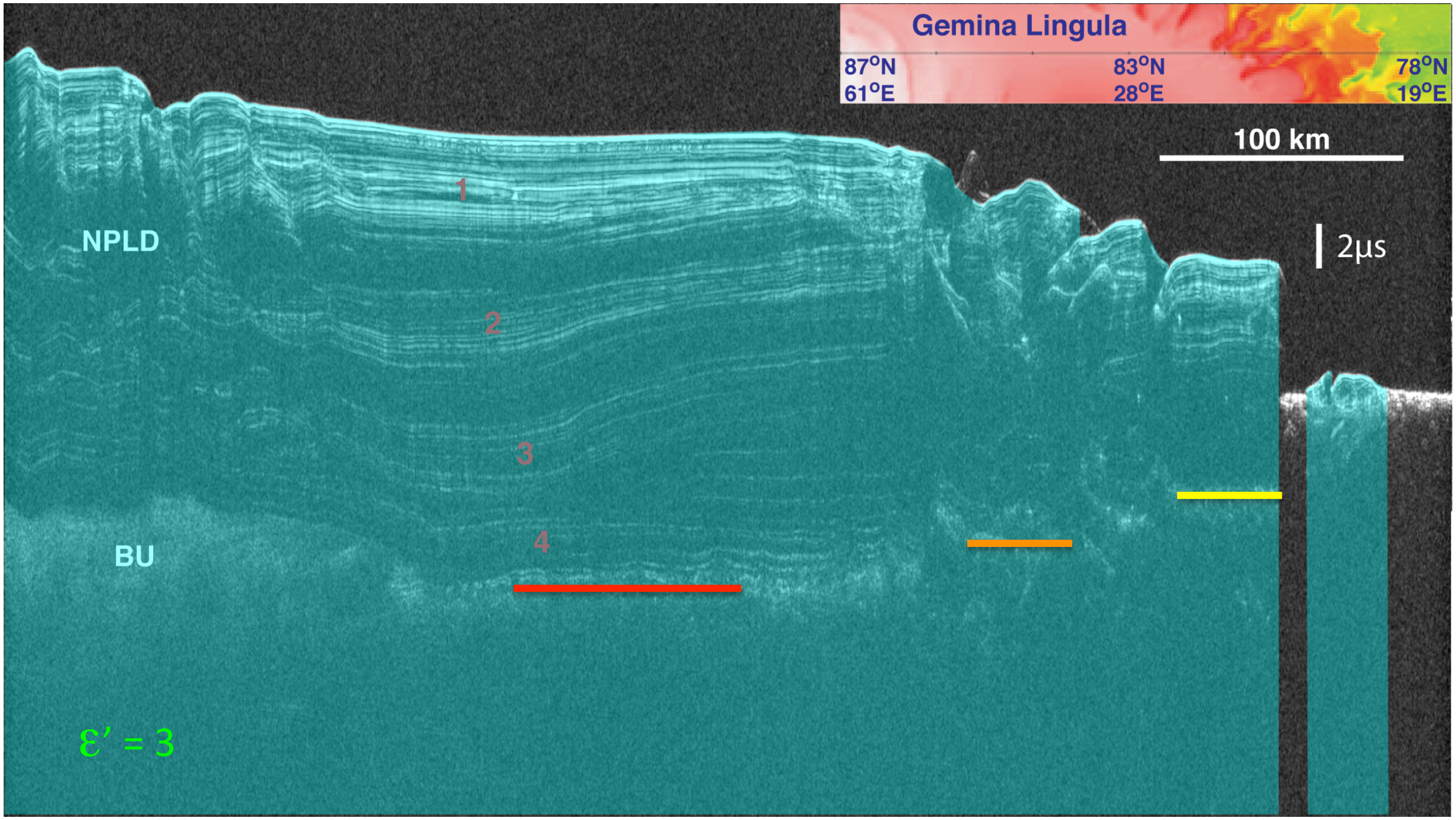
$$\varepsilon_1 = \left(\frac{c\Delta t}{2h_1}\right)^2$$

Finding Dielectric Constant – Case 1: NPLD



Finding Dielectric Constant – Case 1: NPLD

Need to define the domain to which the dielectric constant (>1) will be applied



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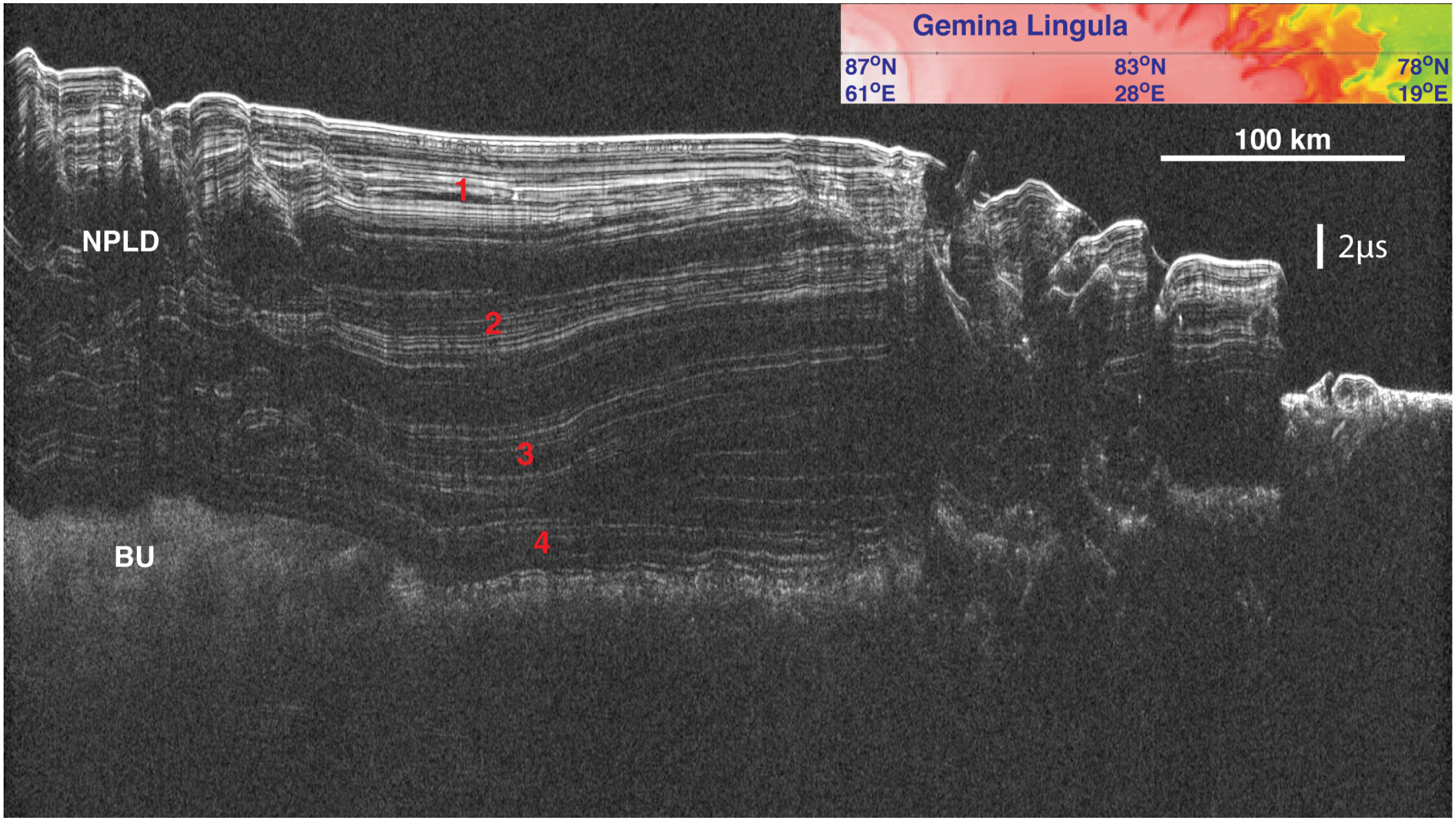


Finding Dielectric Constant – Case 1: NPLD

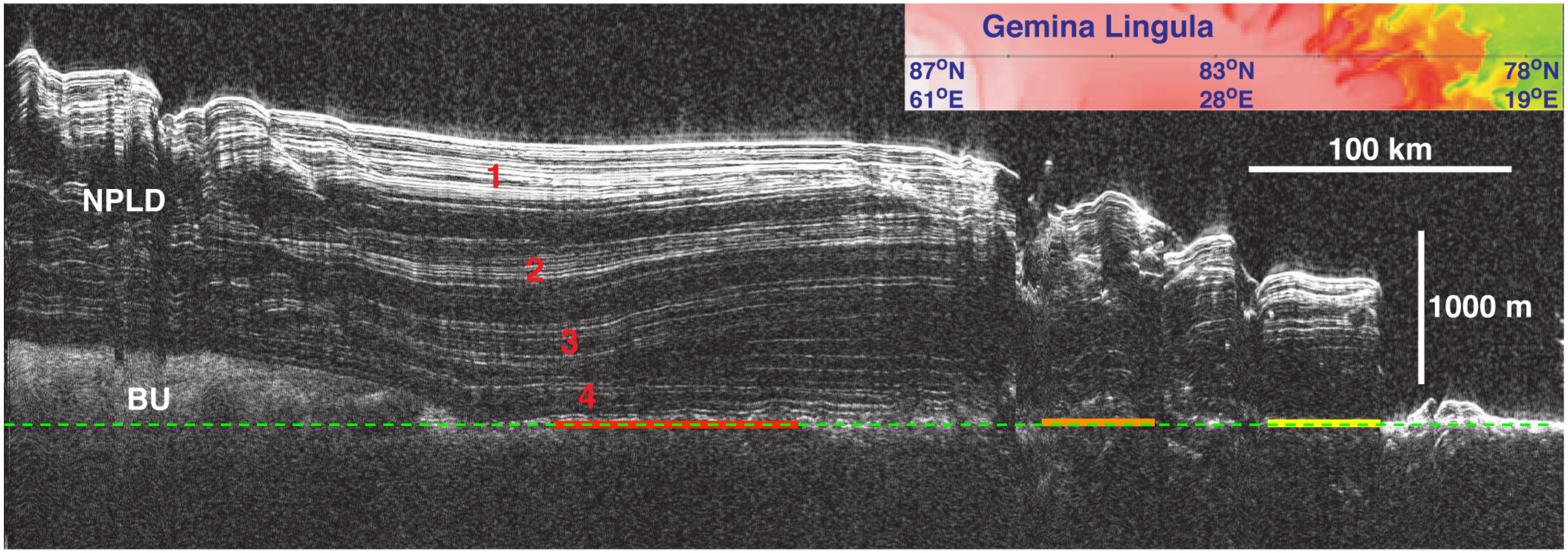
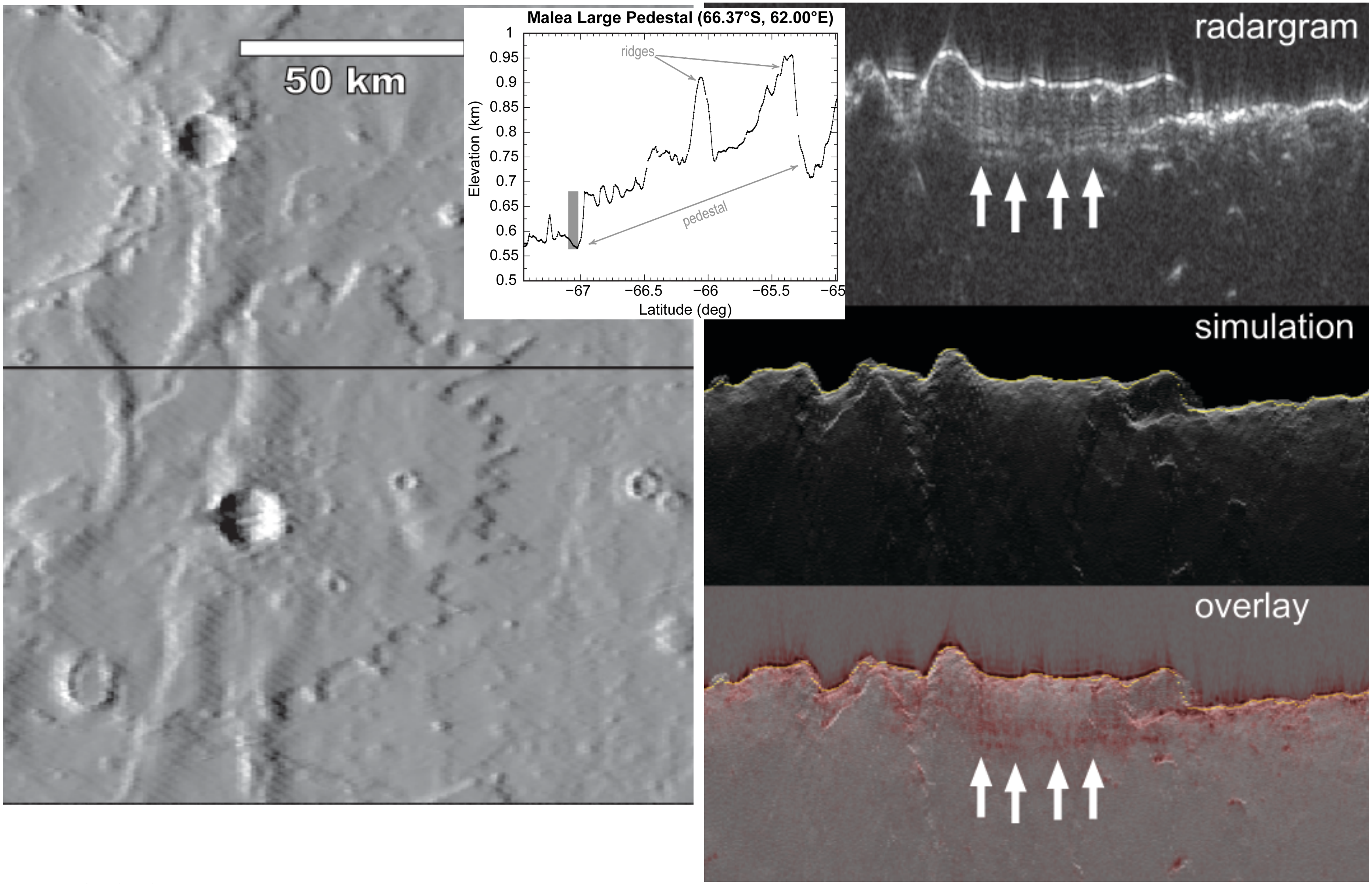


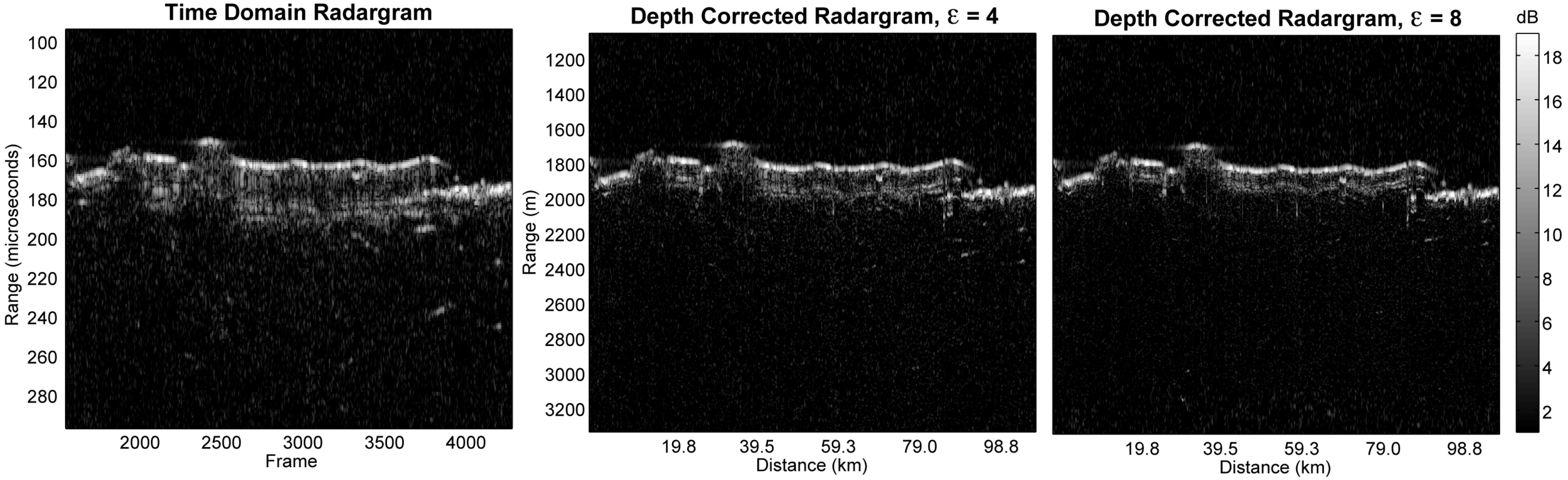
Fig. 3. Radargram from SHARAD orbit 5297 with time-to-depth algorithm applied for ε' = 3 (Phillips et al., 2008)

A dielectric constant of 3 will cause the basal reflections to lie in the same level as the surrounding Vastitas Borealis. Nearly pure ice is a good solution for the NPLD.

Finding Dielectric Constant – Case 2: Pedestals



Finding Dielectric Constant – Case 2: Pedestals

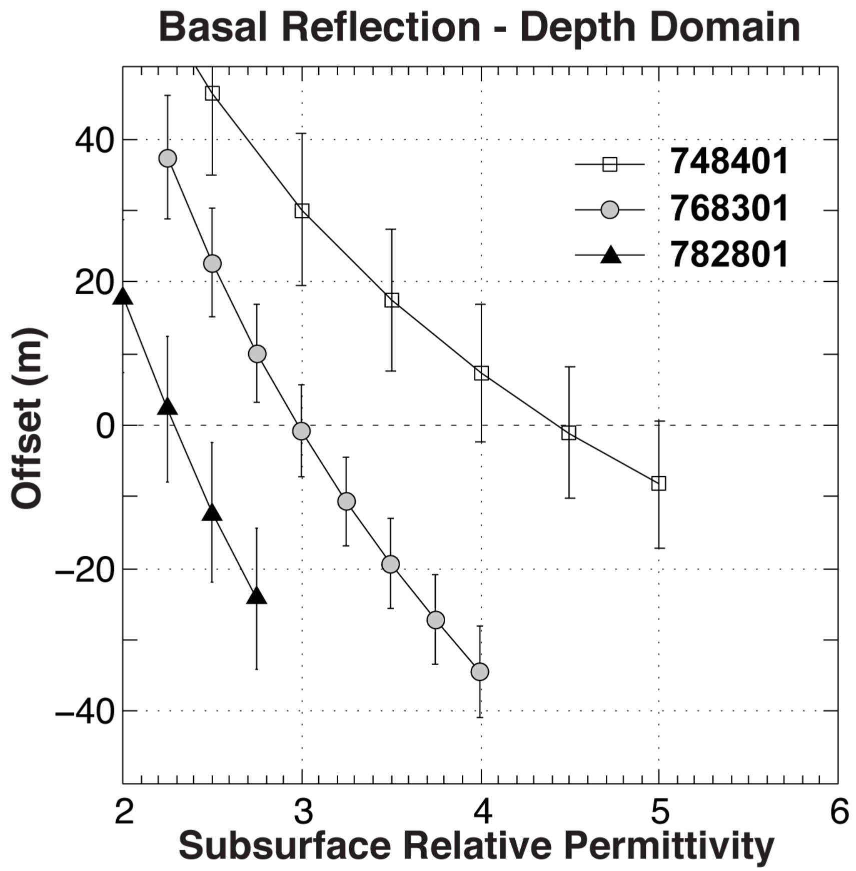


One may test different values for dielectric constant and test the behavior.

water ice : $\varepsilon' = 3$

most rocks : $4 \leq \varepsilon' \leq 9$

Finding Dielectric Constant – Case 2: Pedestals



- Measure vertical offset between depth of basal reflector and the surrounding terrain

- Zero offset gives the dielectric estimate for the material.

- In this case, multiple radargrams give different answers!

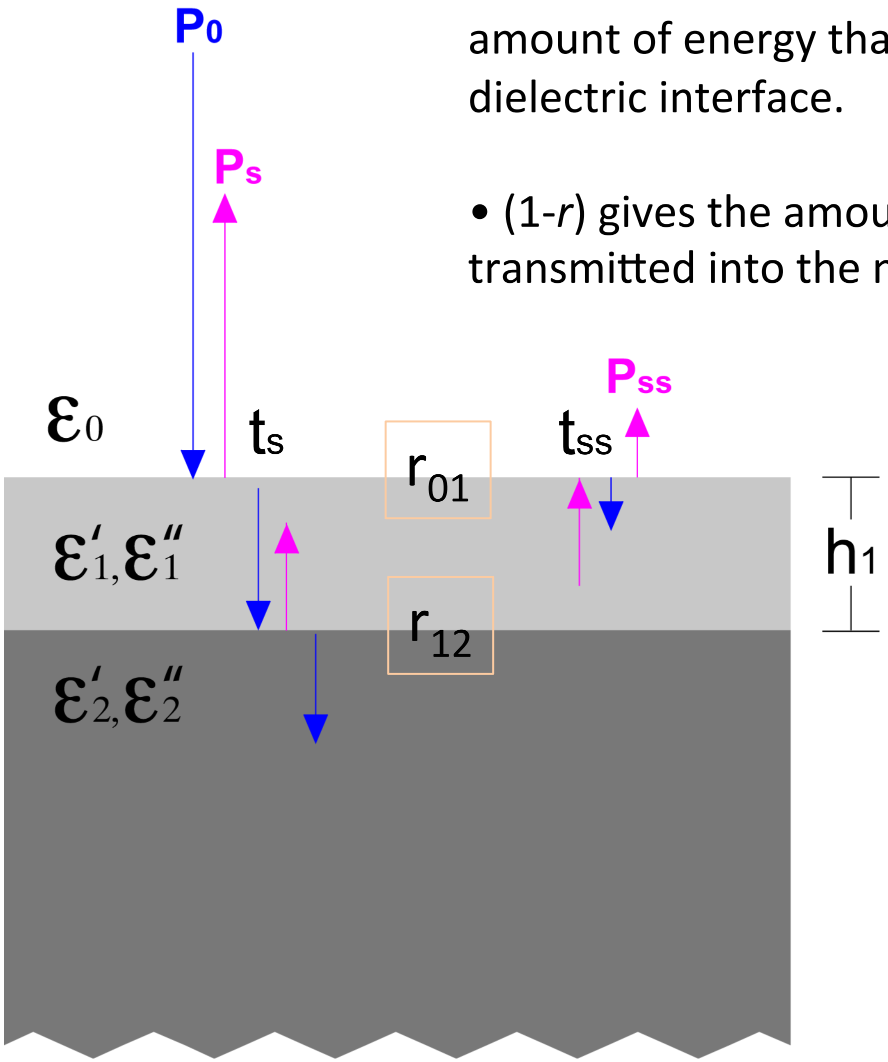
  - material is heterogeneous

  - interface roughness/topography add uncertainty to the offset

  - “basal” reflector is not so “basal”

  - uncertainties dominate in the case of thinner deposits

Propagation II

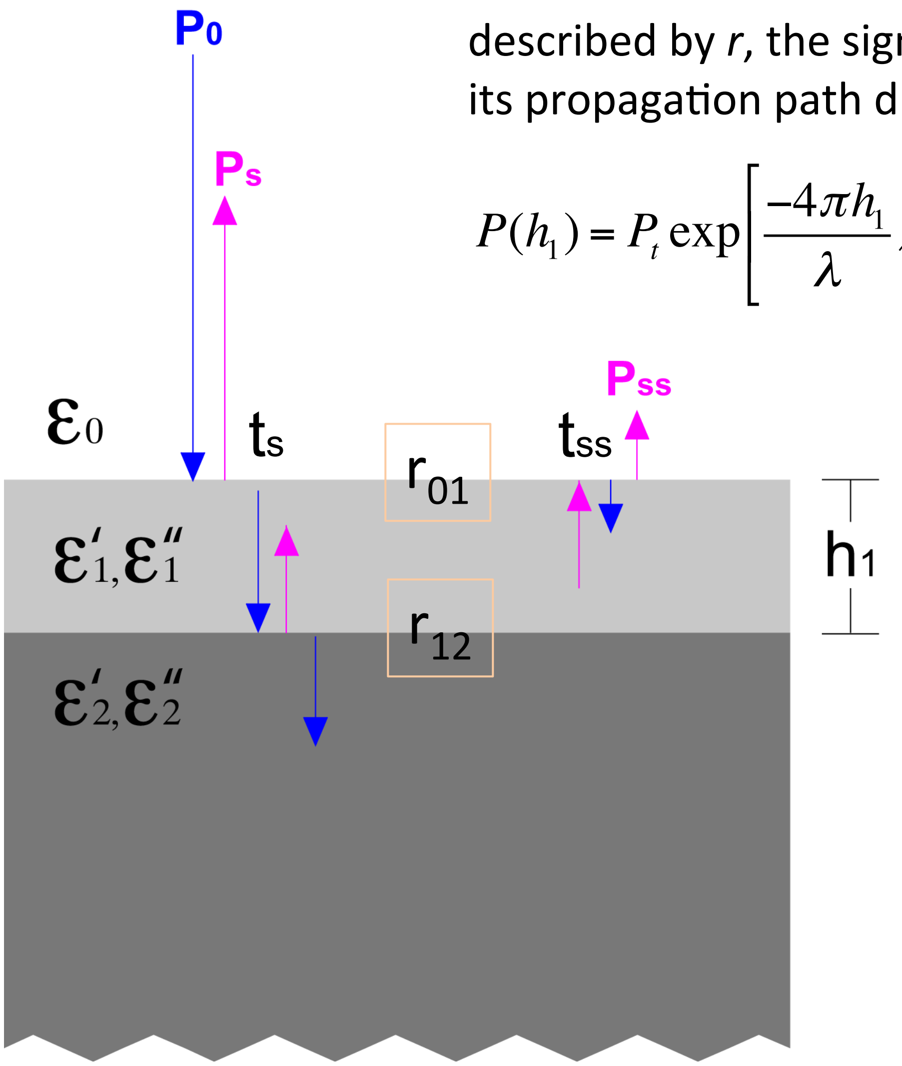


- A reflection coefficient (*r*) describes the amount of energy that is reflected off a dielectric interface.
- (1-*r*) gives the amount of energy transmitted into the next medium.

Normal incidence case:

$$r_{01} = \frac{\sqrt{\varepsilon'_0} - \sqrt{\varepsilon'_1}}{\sqrt{\varepsilon'_0} + \sqrt{\varepsilon'_1}}$$

Propagation II

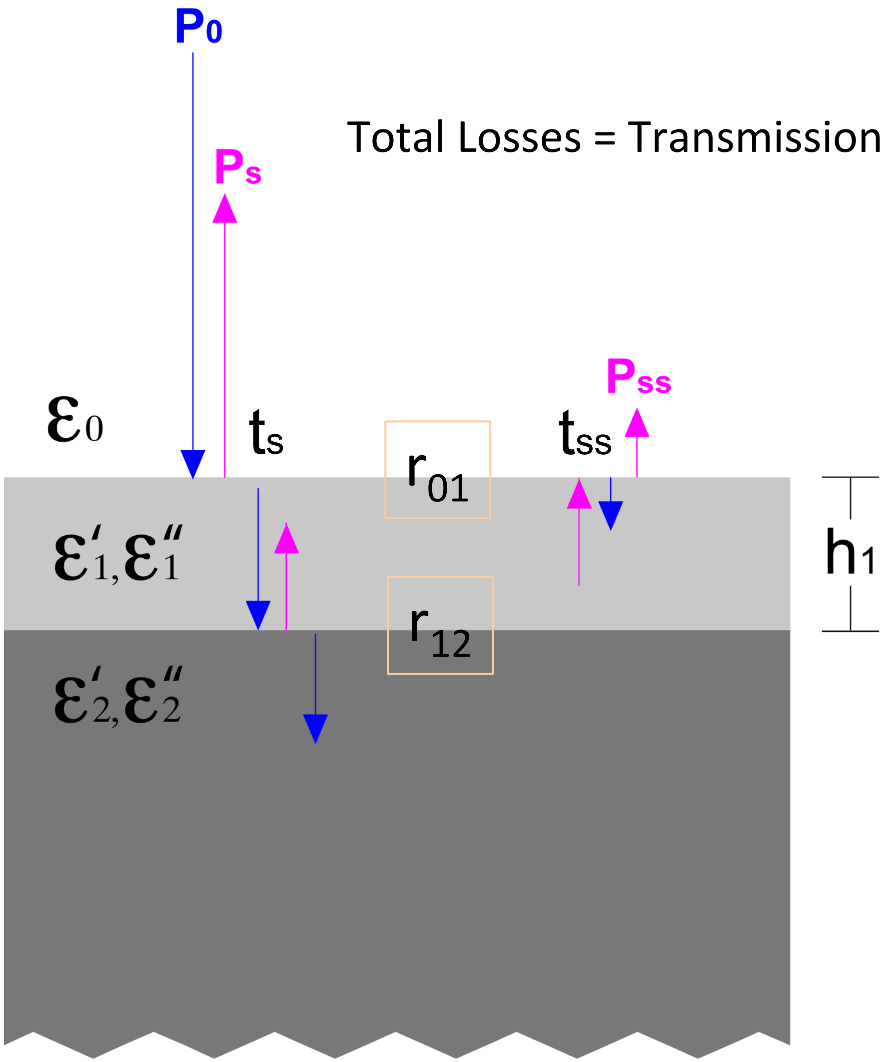


- In addition to transmission losses described by *r*, the signal is attenuated along its propagation path due to the loss-tangent:

$$P(h_1) = P_t \exp\left[\frac{-4\pi h_1}{\lambda}\sqrt{\frac{\varepsilon_1'}{2}\left(\sqrt{1+(\tan\delta)^2}-1\right)}\right]$$

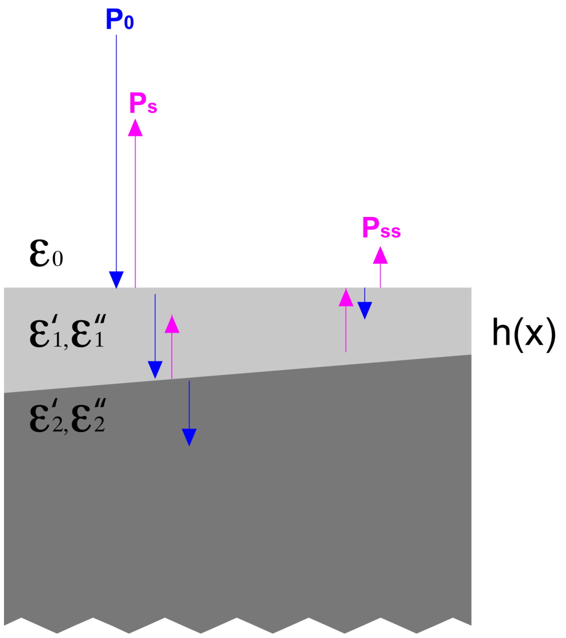
The greater the frequency or shorter the wavelength, the greater the attenuation

Propagation II



Total Losses = Transmission Losses + Path Losses

Finding Loss Tangent – Case 1: Layered Plains



- Consider the case of a sloping subsurface interface, where the layer material is assumed to be homogeneous

    - transmission losses are constant throughout

- Thickness of layer changes laterally (h(x))

    - path losses change along the slope

    - greater path loss where layer is thicker

- If any changes are seen in (P_{ss}/P_s) along slope, then $\tan\delta_1$ can be derived

Finding Loss Tangent – Case 1: Layered Plains

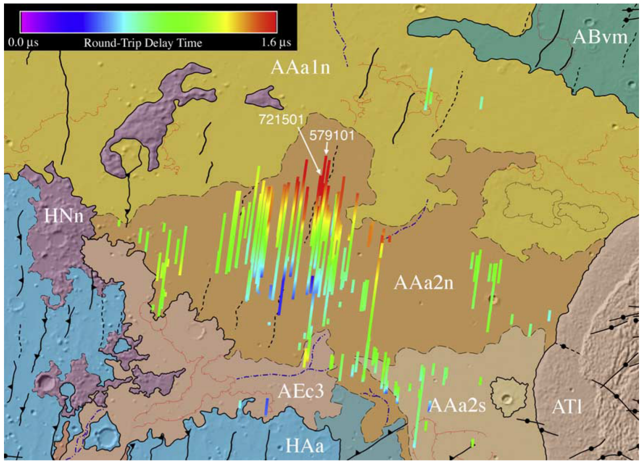


Fig. 6 - SHARAD subsurface reflections presented as color overlay for variations in round-trip echo delay on a portion of the geologic map by Tanaka et al. [2005]. From Campbell et al. (2008).

No thickness information from other data sets, therefore, no best-estimate for ε' of layer. Need to assume the plausible range for geologic materials (3-9).

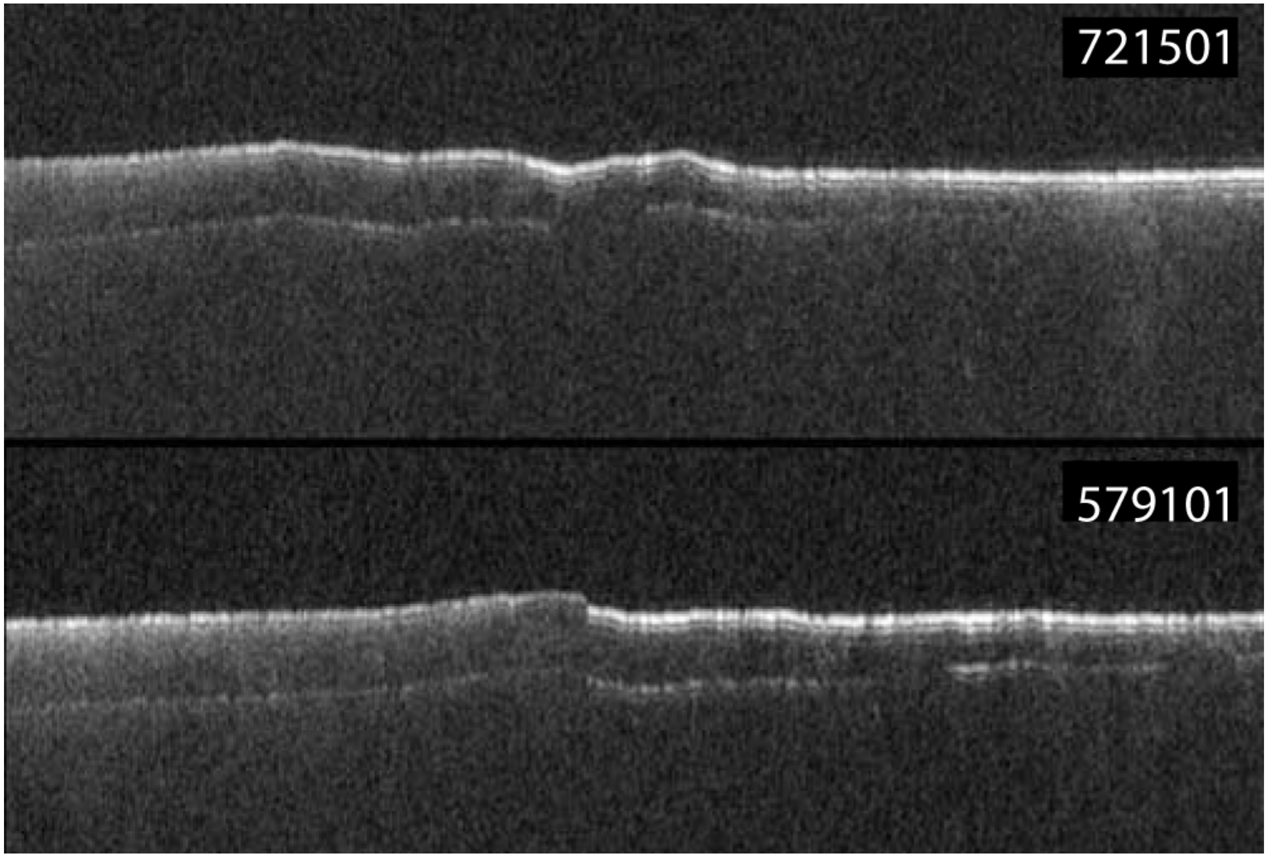


Fig. 5 - Portions of two SHARAD radargrams for in north central Amazonis Planitia (see Figures 2 and 6). North is toward the left; image width is about 315 km. Note that the subsurface reflecting horizon parallels the topography of the ridge and is continuous beneath this structure. From Campbell et al. (2008).

Finding Loss Tangent – Case 1: Layered Plains

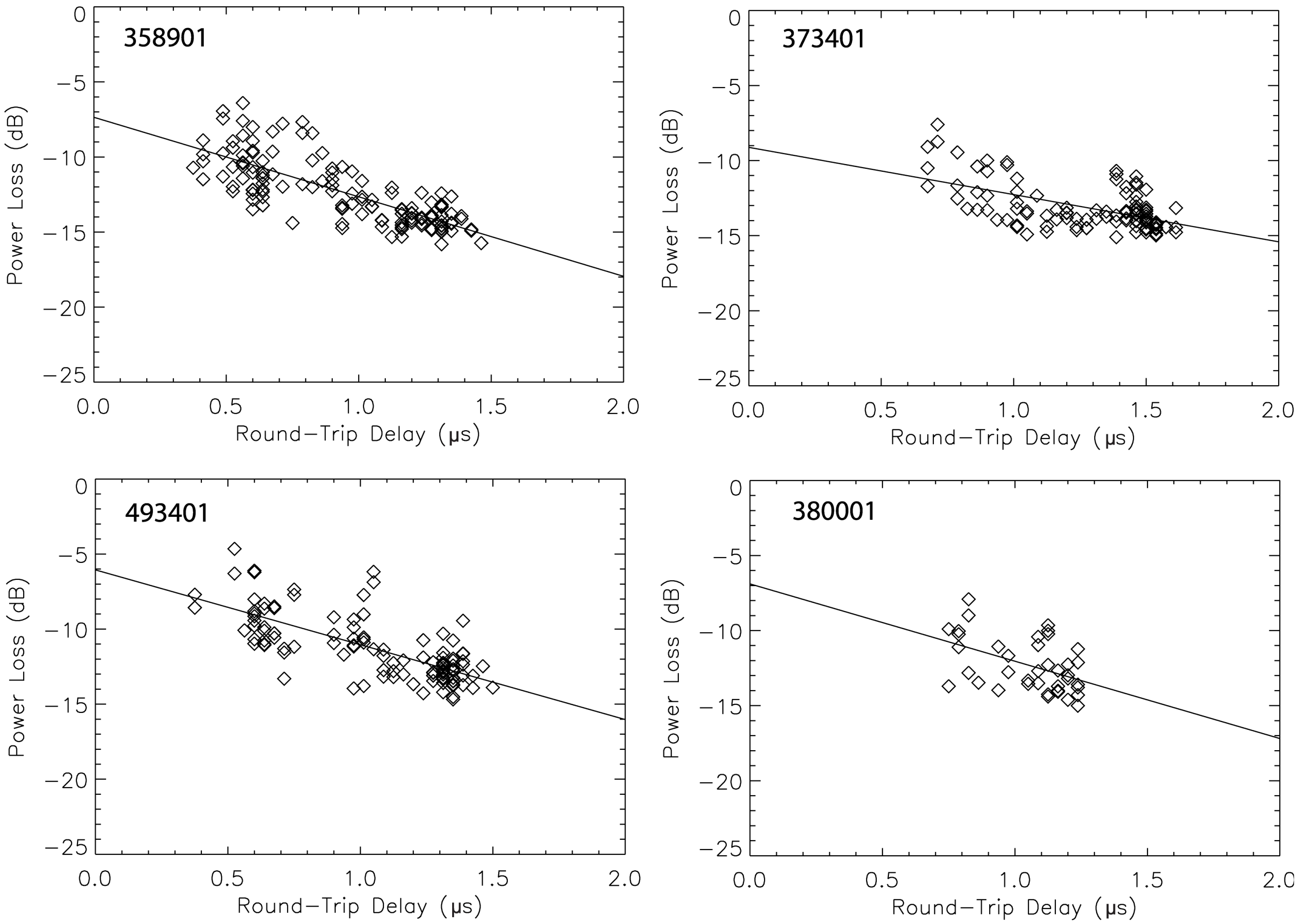


Fig. 7 - SHARAD subsurface reflector power loss (in dB) versus round-trip time delay for orbit tracks over Amazonis Planitia. Power values are normalized to the average of surface echo power along each track and fit with a simple power law (straight lines). See Table 1 for best fit slope values. From Campbell et al. (2008).

Interpretation

- There are may manuscripts and papers about dielectric properties of different materials.

- In general, H_2O and CO^2 ices have low permittivity and loss tangent, while silicates have higher permittivity and loss-tangent.

- Water, and especially salt water, have very high permittivities and loss-tangent. A putative water table would produce very strong reflections and attenuation.

- Mixtures and porosity also modulate the effective permittivity/loss-tangent.

Bulk CO_2 ice : $2.20 + i\, 2.12\times10^{-6}$
Bulk H2O ice : $3.15 + i\, 6.30\times10^{-4}$
Basalt (low) : $5.4 + i\, 1.0\times10^{-3}$
Shergottite : $8.8 + i\, 1.7\times10^{-2}$
Altered basalt : $15 + i\, 1.5$

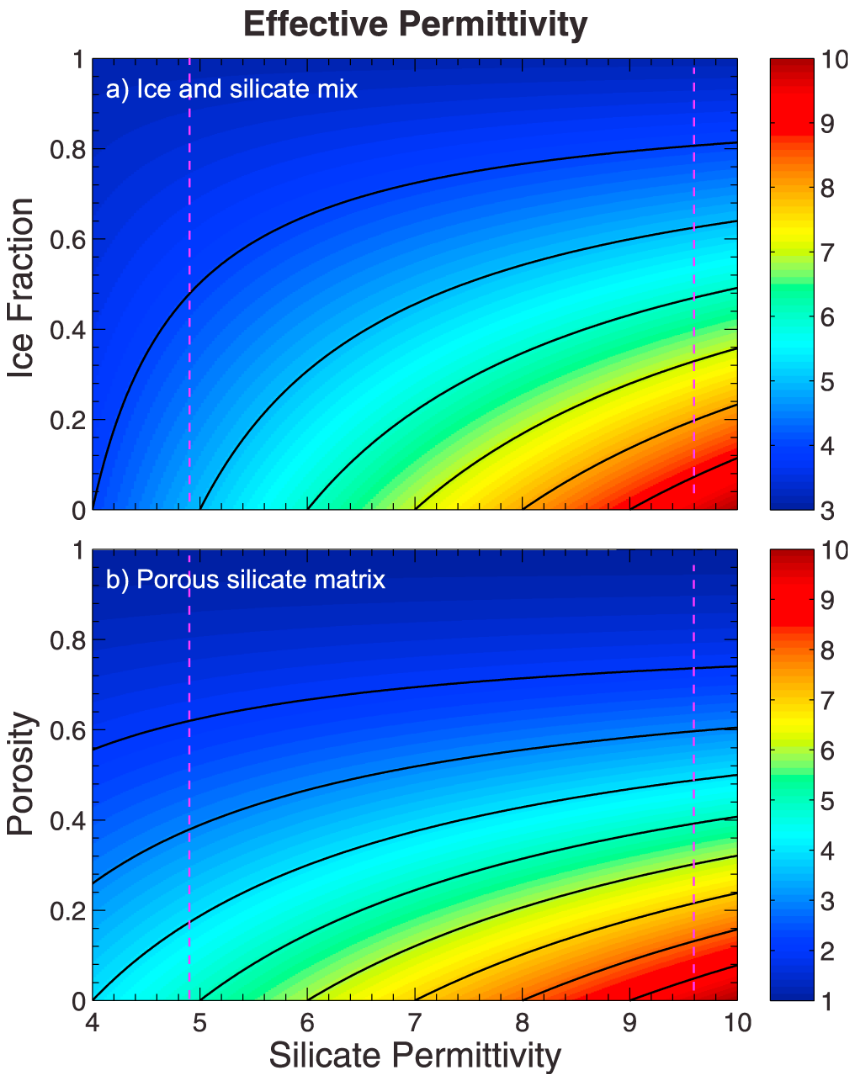


Fig. 6 - Color map showing the effective permittivity ε′mix of a mixture of water ice w/ silicates or porous silicates obtained with the deLoor mixing model, with ε′ice = 3.15. From Nunes et al. (2011).

Interpretation

- Any other independent information about composition, porosity, geologic context helps addressing the non-uniqueness aspect of radar-derived permittivities.

References

Campbell, B., L. Carter, R. Phillips, J. Plaut, N. Putzig, A. Safaeinili, R. Seu, D. Biccari, A. Egan, and R. Orosei (2008), *SHARAD radar sounding of the Vastitas Borealis Formation in Amazonis Planitia*, 12010 pp.

Nunes, D. C., and R. J. Phillips (2006), Radar subsurface mapping of the polar layered deposits on Mars, *Journal of Geophysical Research*, *111*, E06S21, doi:10.1029/2005JE002609.

Nunes, D. C., S. E. Smrekar, B. Fisher, J. J. Plaut, J. W. Holt, J. W. Head, S. J. Kadish, and R. J. Phillips (2011), Shallow Radar (SHARAD), pedestal craters, and the lost Martian layers: Initial assessments, *J. Geophys. Res.*, *116*(E4), E04006.

Phillips, R. J., et al. (2008), Mars North Polar Deposits: Stratigraphy, Age, and Geodynamical Response, *Science*, *320*(5880), 1182-1185.

Ulaby, F. T., R. K. Moore, and A. K. Fung (1986), *Microwave Remote Sensing: Active and Passive*, Artech House, Norwood, MA.