Radar Sounding of Temperate Permafrost in Alaska: Analogy to the Martian Mid-Lattitude ice-rich Terrains

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Study of the distribution and state of the Martian subsurface water is one of the priority goals of the Mars Exploration Program, as it has important implications on the hydrogeologic and climatic evolution of Mars and on the possible development of life on the red planet.
In order to constrain the ambiguities regarding the distribution and state of subsurface water, two low-frequency sounding radars, MARSIS (Mars Advanced Radar for Subsurface and Ionosphere Sounding) [1] and SHARAD (SHAllow subsurface sounding RADar) [2] are probing the Martian subsurface.
The identification of volatiles signatures in the GPR data is constrained by our understanding of both dielectric and scattering losses mechanisms that are generated by the dielectric complexity and the heterogeneities of the Martian subsurface. Although some GPR investigations have examined Mars analogs volcanic terrains [3,4], radar sounding on Mars analog frozen terrains (like permafrost) remain poorly investigated.
To address this issue, we conducted ground penetrating radar and resistivity investigations on Mars analog permafrost terrain, in the area of Fairbanks (Alaska, USA). We used four frequencies antennas (40, 270, 400 and 900 MHz) along a same profile allowing us to study the frequency dependence of attenuation mechanisms over a wide frequency band.

Geophysical settings

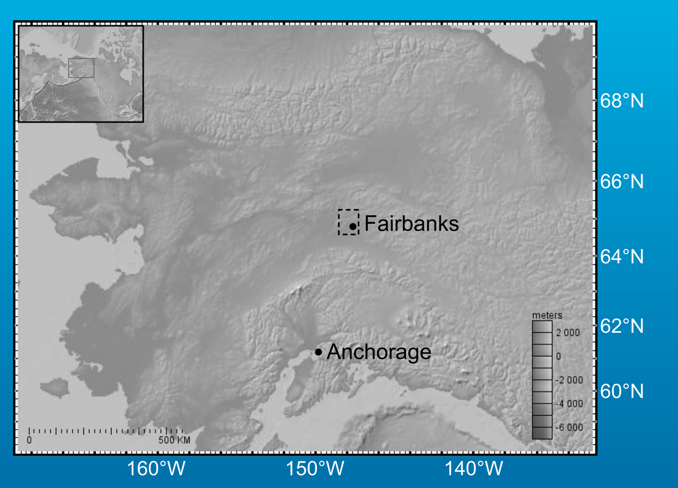


Figure 1 : Location of the Fairbanks area (Vault Creek site is at ~20 km North of Fairbanks).

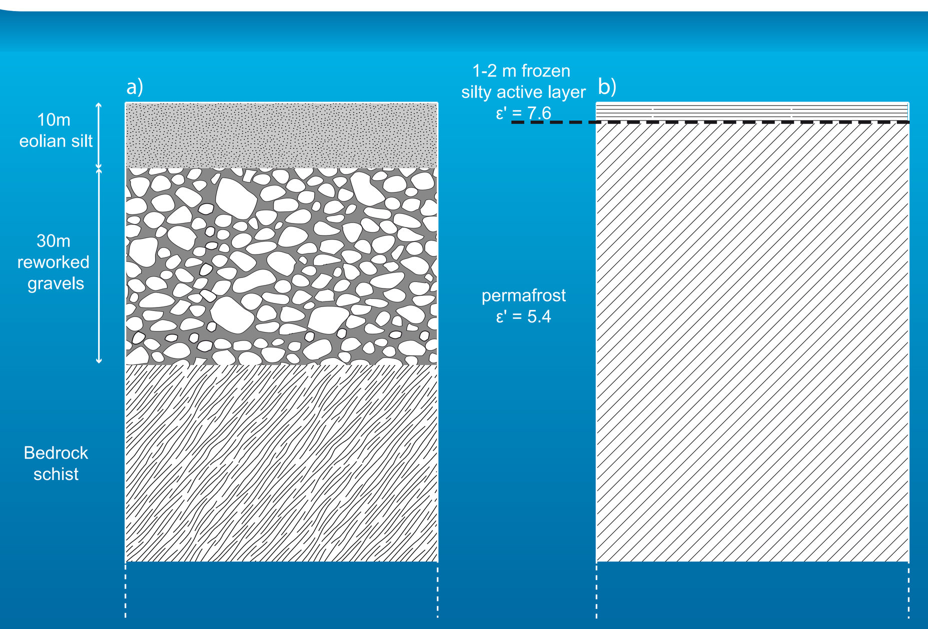


Figure 2 : Cross-sections of the Vault creek site subsurface. a) Geological cross-section [5]. b)Geoelectrical cross-section [6,7].
As the survey was led early march, the active layer was totally frozen. On the contrary, during the summer season, the liquid water present in the active layer will dramatically increase the permittivity of the silty active layer (ε' ~ 30). Thus the geoelectrical cross-section presented here is valid only for the winter season.

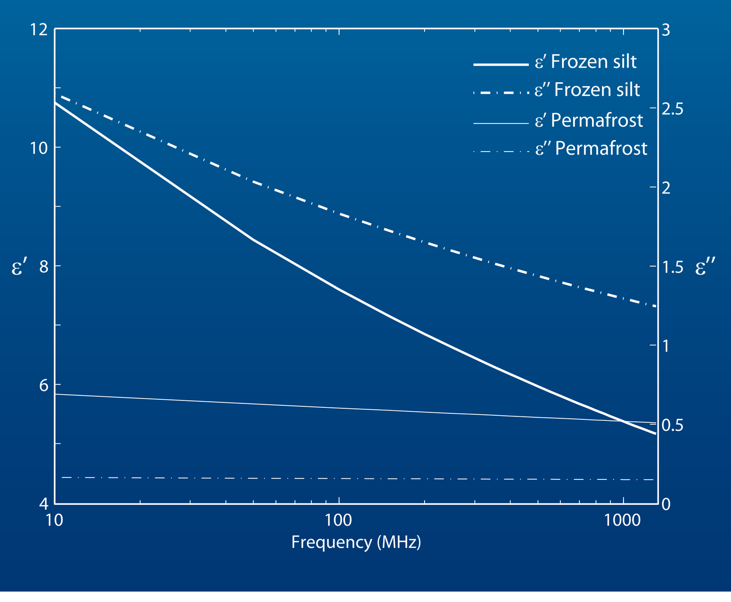


Figure 3 : Permafrost and frozen silt permittivity as function of frequency, according to the Jonscher law [8].

Resistivity sounding

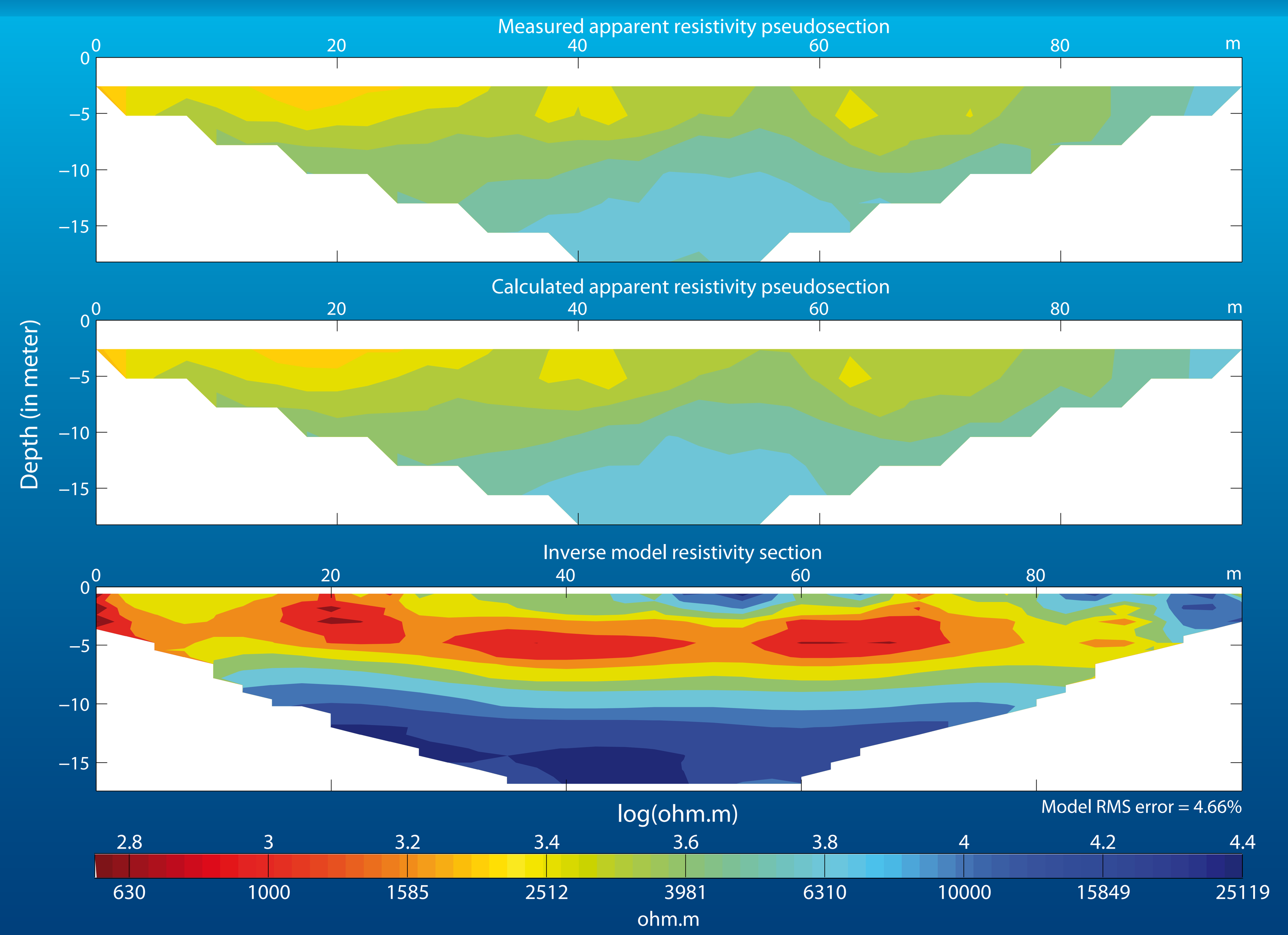
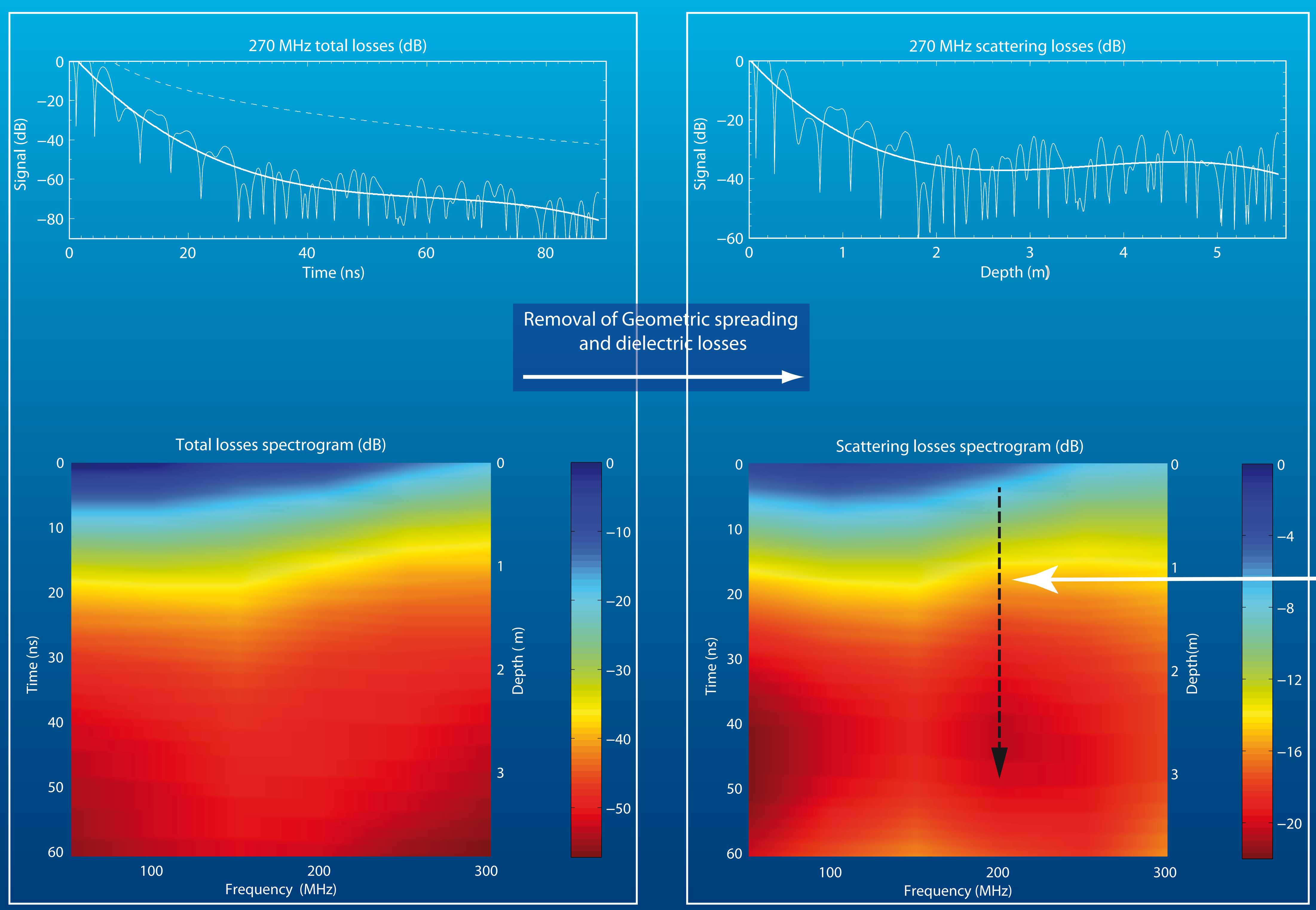


Figure 4 : Measured (top) and calculated (middle) apparent resistivity pseudosections (in ohm.m) of the Wenner electrical survey (Vault creek site). The lowest pseudosection is the result of a least-square inversion of the ERT data after 8 iterations (RMS error of 4.66%). The contrast between the more conductive layer and the resistive layer (~8 to 10m deep) corresponds to the silt/gravels interface. We used the software RES2DINV (Geotomo Software [9]).

Ground penetrating radar sounding



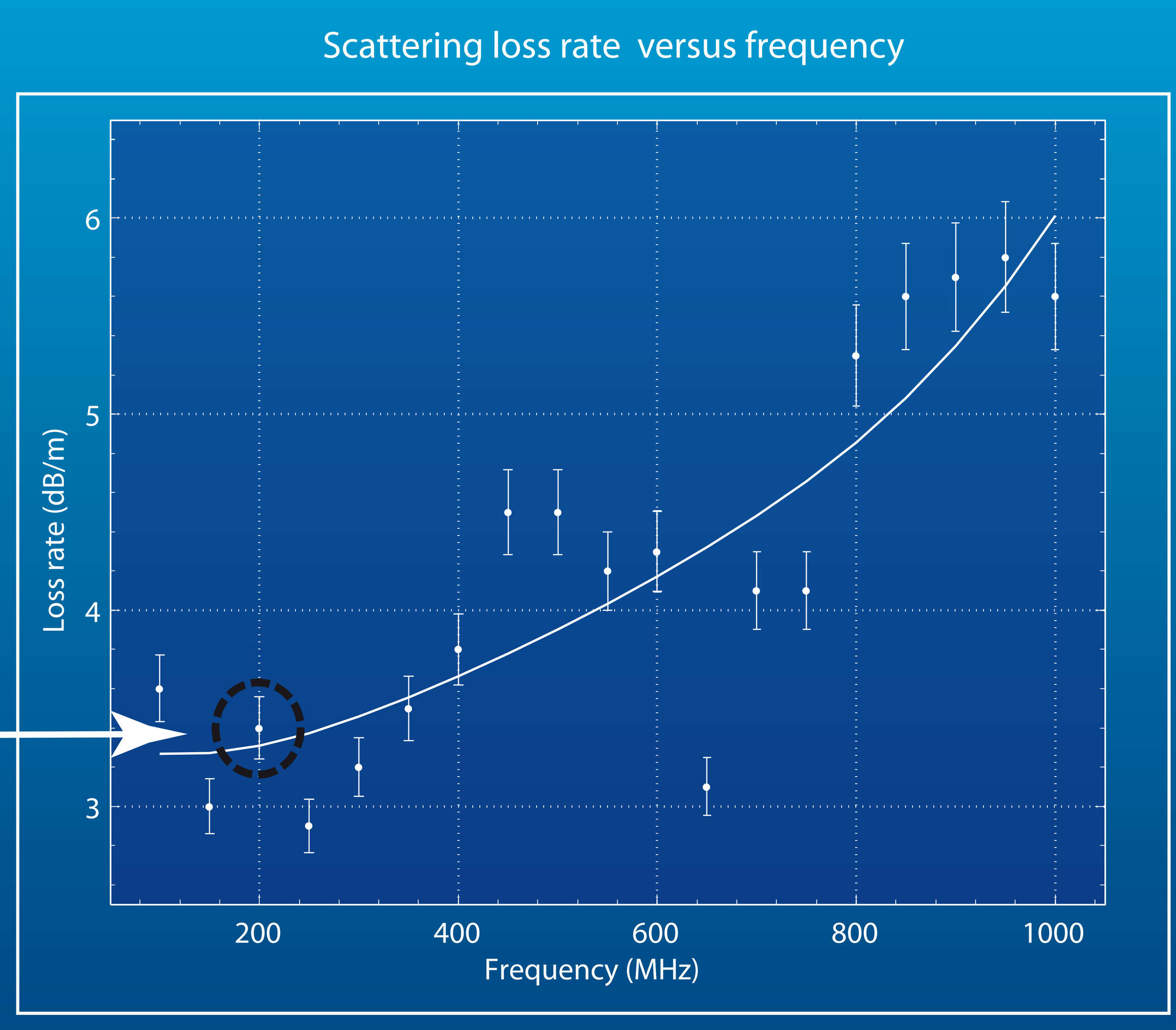


Figure 6 : Scattering loss rate (dB/m) versus frequency (MHz). The loss rate is the gradient of scattering losses observed for each frequency in the three spectrograms (270 MHZ, 400 MHZ and 900 MHZ-antenna profile frequancy analysis). For example, the point highlighted by a black dashed circle represents the loss gradient at 200 MHz represented by the black dashed arrow on figure 5 (right, bottom).

Figure 5: Frequency analysis of the 270 MHz-antenna profile mean trace. We fisrt calculated the spectrogram of the total losses (left, bottom). We then deduced the scattering losses (right) applying the radar equation. Here, we apply the radar equation formula for the case of an infinite planar target in the Fresnel zone [10]. The dashed line on the total losses graph (left, top) represents the geometric spreading and the dielectric losses obtained with this equation.
The black dashed arrow on the scattering losses spectrogram (right, bottom) represents the loss rate at 200MHz and corresponds to the encircled point plotted on the figure 6.

References

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Conclusion

This study allows to better understand and quantify the frequency behaviour of the signal losses. It is well known that the ground acts as a low-pass filter (as the low wavelenghts = high frequencies will interact with the subsurface heterogeneities). This phenomenon can be observed on the figure 6. Indeed, the loss rate increases with the frequency increasing (from 3dB/m at 150 MHz to 5.7 dB/m at 950 MHz).
This investigations will allow to better constrain the different losses observed in the Martian radar data acquired over Martian frozen terrains and thus to access to the subsurface heterogeneity informations.