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Subsurface properties retrieval from the ExoMars WISDOM GPR data

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Abstract

The "Water Ice Subsurface Deposits Observation on Mars" Ground Penetrating Radar (GPR) is selected to be part of ESA's 2018 ExoMars Rover payload. This instrument has been designed to characterize the shallow subsurface of Mars in terms of electromagnetic properties and to lead the drill to locations of interest. WISDOM is a polarimetric step frequency radar operating from 0.5GHz to 3GHz, which allows a vertical resolution of a few centimeters over a few meters depth [1].

The aim of this study is to retrieve the top layer permittivity and the location of buried scattering objects. WISDOM will be operated 30 cm above the surface, inducing wave refraction at the transition between air and ground. We show that, given the expected precision of the instrument [1] the impact of this air layer cannot be neglected when one estimates the permittivity value. An adjustment by a 2D model based on ray-tracing, developed in LATMOS, which takes into account WISDOM properties and configuration, will lead to better permittivity and reflectors positions estimations. Another approach, based on the deconvolution between the surface echo signal and a reference can also be used to obtain a top layer permittivity estimation.

1. Introduction

WISDOM has been designed to achieve a vertical resolution of a few centimeters. Here we are discussing the accuracy of the depth estimate we can obtain. The instrument measures delays that can be converted into distance once the permittivity value is known.

The scattering objects signature on radargrams for a traditional GPR is an exact mathematical hyperbola whose shape allows the perfect retrieval of the medium permittivity and reflectors locations. In WISDOM configuration, it is not the case anymore due to the refraction at the transition between air and ground (Fig.1). However, the signature obtained still allows an estimation of these two parameters, but induces errors.

A 2D simulation tool based on ray-tracing which takes into account the 30 cm air layer between the antennas and the surface has been developed at LATMOS. This tool allows the study of the impact of different parameters (such as the permittivity value and the depth of the scatterer), the radargrams interpretation, and, since it provides simulated data, it can be used to test simple methods as hyperbolic adjustment.

Another approach that draws advantage of WISDOM configuration can also be considered : since the antennas are above the surface, it is possible to deconvoluate the surface echo with a reference, typically acquired above a totally reflective plate (such as mettalic) at the same distance. In the frequency domain, this amounts to calculate the amplitudes ratio of the surface echo to the reference considering the environment as a linear filter. The ratio obtained represents an estimation of the top layer permittivity.

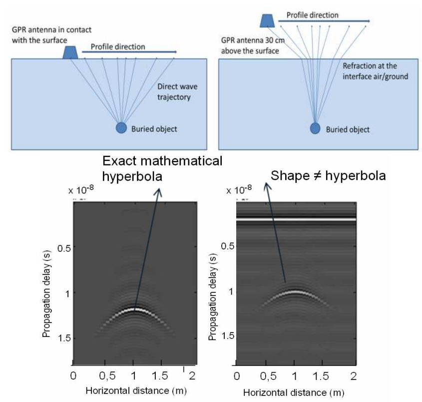

Figure 1 : Illustration of wave propagation difference between the usual use of GPR and WISDOM configuration

2. Adjustment by an analytical hyperbola

2.1 Method

We first apply an adjustment by a hyperbolic function on data simulated via the 2D ray-tracing model to retrieve the refractive index of the medium and the locations of the scattering objects. Due to the fact that WISDOM is operated at a distance above the surface, this method induces errors that we can evaluate to quantify the precision obtained. This method is tested for 3 types of data sets : a homogeneous medium, homogeneous with an additive white noise and with induced inhomogeneities in the subsurface (Fig.2).

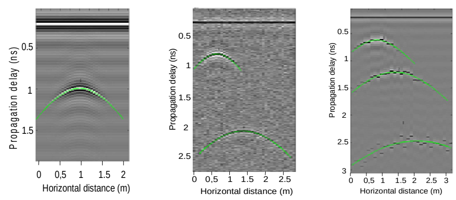

Figure 2 : Adjustment by an hyperbolic function on simulated radargrams : a) In a homogeneous medium; b) With additive white noise; c) With induced inhomogeneities in the subsurface

2.2 Results

In case of a homogeneous medium (Fig.2.a), the permittivity value retrieved by a mere hyperbola adjustment is, as expected, reliable (error<10%) for low permittivity values and deep targets in the subsurface. A refractive index of 1.8 (typically ice medium) can be well estimated for targets depths larger than 2 meters (Fig.3.a). The precise location of buried reflectors can also be estimated : if they are below the radar path, the horizontal position corresponds to the top of the hyperbola and can be easily retrieved. The reflector depth is more difficult to obtain. However, for materials with a high porosity having thus a low permittivity value (<1.7), it is possible to retrieve the depth with less than a 5 cm error. For higher permittivity values, the uncertainty remains between 5 cm and 11 cm with better results for targets buried deep enough in the soil (Fig.3.b).

This adjustment method remains reliable in presence of an additive white noise (Fig.2.b) : with a SNR of 10 dB, the statistical dispersion of the results is negligible, around 0.1% of the value. However, it is sensitive to the inhomogeneities in the subsurface (Fig.2.c) : with a standard deviation distribution of 10% around the mean refractive index value, the statistical dispersion of the retrieved permittivity value is around 10%.

3. Discussion and conclusion

The preliminary results shows that even if the hyperbolic adjustment method can be used for any data set, the validity domain for which this method is precise enough according to the instrument's expectations are beyond the domain aimed by WISDOM [1]. A systematic correction of the air layer can be applied, improving the precision, but remains insufficient. Preliminary results of inversion based on the use of the direct model, rather than the hyperbolic adjustment, will be presented. The principle is to obtain a first estimation by an hyperbolic adjustment and to run simulations with entry parameters around the pre-estimated values. The best fit is obtained by searching the minimum of the RMS between simulated and original radargrams (Fig.4).

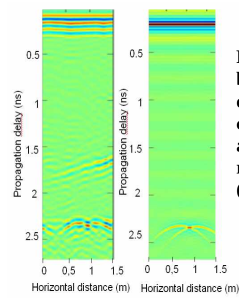

Figure 3 : Comparison between a radargram obtained in an Alpine ice cave in Dachstein, Austria and a simulation with 2 reflectors buried in the ice (n~1.8) at ~2m depth

This method allows a better precision on both permittivity and scattering objects location estimation. We can also compare the permittivity obtained by this method and by the deconvolution of the surface echo with a reference. Results obtained on data collected on well documented environments will be presented too.

Acknowledgements

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References

[1] Ciarletti V et al : WISDOM, a GPR designed for shallow and high resolution sounding of the Martian subsurface, 0023-SIP-PIEE, 2010