GPR simulations for pipeline oil drainage detection

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Abstract

Introduction

Pipeline detection and investigation of leakage and fluid drainage play a major part in geophysics applied to downstream problems. Oil drainage may have impact in contaminating subsurface environment, and by consequence, affect socially and economically the nearby population. When that hazard occurs, it could be mapped by geophysical techniques. The strong contrast in electrical properties between oil (or gas), metallic pipes and sediments, makes GPR (ground penetrating radar) one of the best techniques to be used for mapping oil drainage and for pipeline detection.

In this paper, a 2-D GPR forward modelling algorithm was used to create simulations of a several drainage situations.

The resulting images can help geoscientists in the interpretation of simple cases.

Method

Ground penetrating radar (GPR), also known as geo-radar, has become, in recent years, a popular geophysical technique to study shallow subsurface sediments, as it allows for fast acquisition of high-resolution images of the sedimentary architecture. GPR is based on the reflections of electromagnetic waves, transmitted from a point at the surface through the subsurface. These reflections are caused by changes in the electromagnetic properties of subsurface features, which can be associated to changes in lithology or variation in the water content. Good references for this method can be found in Annan (1992) and Davis & Annan (1989).

2D Forward Modelling

A 2D forward modelling algorithm called GPRMAX2D (Giannopoulos, 2002) was used to simulate GPR surveys. That algorithm is based on finite difference time domain (FDTD) method, whose approach to the numerical solution of Maxwell's equations is to discretize both the space and time continua. It allows model building derived from simple geometric shapes as rectangles, circles and triangles, such a way that the combinations of those shapes can reproduce some complex geological models. To reduce computational requirements, some suppositions are assumed by GPRMAX2D algorithm in order to simplify the models, like:

- All media (layers) are considered to be linear and isotropic.
- The GPR transmitting antenna is modelled as a line source.
- The constitutive parameters are, in most cases, assumed not to vary with frequency.

The parameters choice was the key step for model building. The area was chosen as a rectangle with 10 m width and 3 m high. DC relative permitivitty and conductivities values were based in Annan (1992) and Porsani (1999) tables.

The examples were idealized in a way to reproduce several situations that can be founded in GPR surveying for mapping contamination extension caused by oil drainage of a metallic pipeline.

In these examples the metallic pipe was described as a cylindrical perfect conductor (Giannopoulos, 2002). Its cross-section is shown in all the examples. The other media used in these simulations have the electrical properties shown in Table 1.

Lithology	Relative Permittivity	Conductivity (mS/m)
Dry Sand	4	0.02
Wet Sand	20	0.2
Concrete	6	0.0
Oil	2.8	0.01

Table 1 – Electrical Properties of the lithologies used in the forward simulations.

We also choose a 600 MHz central frequency for antennas, 0.1 m for station spacing, 0.25 m for antenna offset and a 50 ns time window. Acquisition was supposed to be common-offset using GPRMAX2D scan mode.

Free space layer was used only for computational purposes. Antennas were supposed to be laid down on solid environment (concrete or sand). Oil lithology described in Table 1, means sand contaminated with oil.

Examples

#1 – A cylindrical metallic pipeline with 1 m diameter, buried in a dry sand layer (Figure 1). No oil drainage is carrying out of the pipe.

A hyperbola can be seen in the radargram showed in Figure 1. That's the classical GPR signature used for pipe detection.

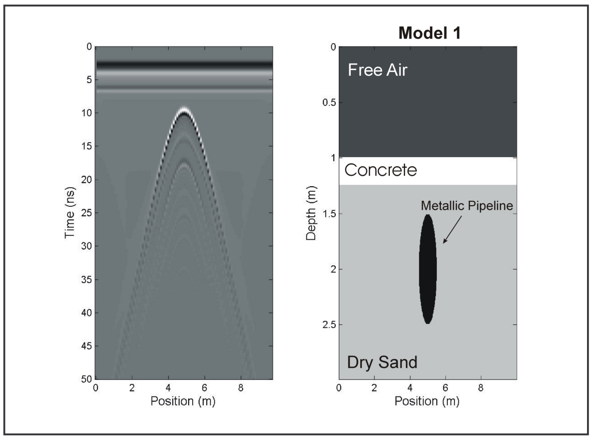

Figure 1 - Right: Model 1. Left: GPR simulation obtained using model 1.

#2 – A cylindrical metallic pipeline with 1 m diameter, buried in a dry sand layer (Figure 2). Oil drainage is carrying out of the pipe.

Despite of low contrast, the drainage can also be observed as shown by white arrows.

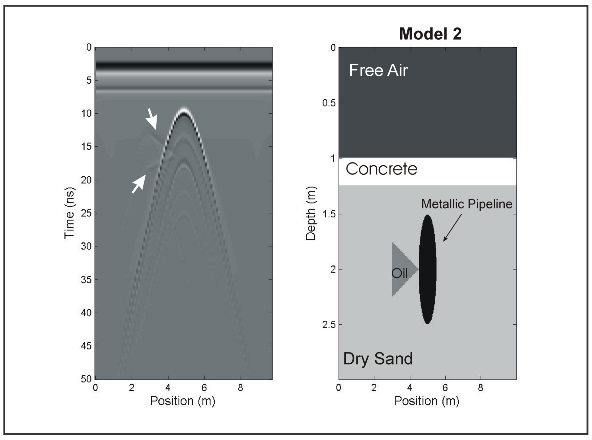

Figure 2 – Right: Model 2. Left: GPR simulation obtained using model 2.

#3 – Same features of Model 2, but drainage extension was shrinked (Figure 3).

The GPR response for this situation cannot reveal the oil drainage as easy as observed in model 2. Drainage extension might be too small, such a way its response are masked by the strong pipeline hyperbolae. The top of oil plume can be weakly observed as indicated by white arrow in Figure 3.

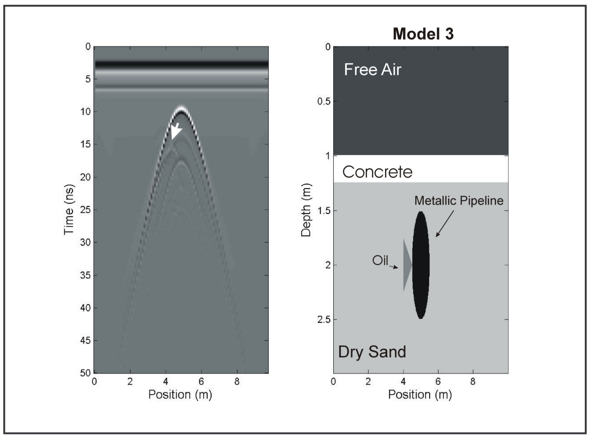

Figure 3 - Right: Model 3. Left: GPR simulation obtained using model 3.

#4 – A cylindrical metallic pipeline with 1 m diameter, buried in a wet sand layer (Figure 4). No oil drainage is carrying out of the pipe.

A strong hyperbola can be observed in this situation (Figure 4), similar to simulation shown in Figure 1. Meanwhile, the hyperbola tail for model 4 seemed to be attenuated.

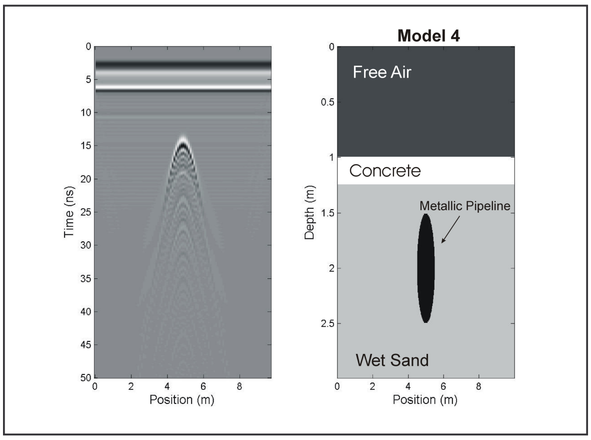

Figure 4 - Right: Model 4. Left: GPR simulation obtained using model 4.

#5 – A cylindrical metallic pipeline with 1 m diameter, buried in a wet sand layer (Figure 5). Oil drainage is carrying out of the pipe.

In this situation there is a strong contrast between oil and the wet sand environment, resulting in clearly identified signature for oil plume. The attenuation of hyperbola tail also enhances plume signature, but multiple reflections are also generated, blurring the resulting image, mainly at the bottom of the plume.

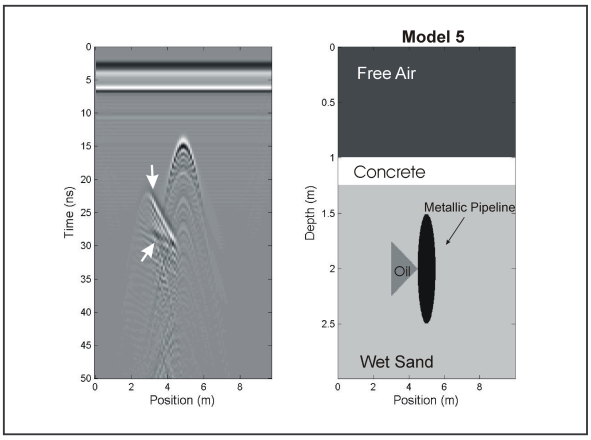

Figure 5 – Right: Model 5. Left: GPR simulation obtained using model 5.

#6 – Same features of Model 5, but drainage extension was shrinked (Figure 6).

In this situation, the oil plume cannot be easily observed as in model 5. Another strong hyperbola signature appears, probably due to multiple reflections interference.

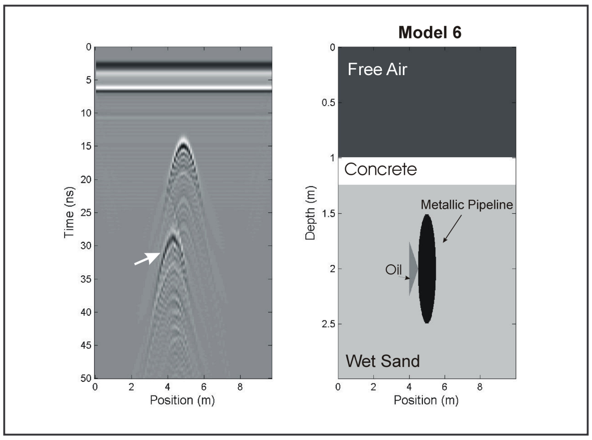

Figure 6 – Right: Model 6. Left: GPR simulation obtained using model 6.

#7 – A cylindrical metallic pipeline with 1 m diameter, buried in a dry sand layer (Figure 7). Oil drainage is carrying out of the pipe. A wet sand top layer is replacing concrete layer used in previous examples.

In this situation the conductive top layer cause horizontal ringing. Oil plume can be identified, but not so easy as shown in models 2 and 5.

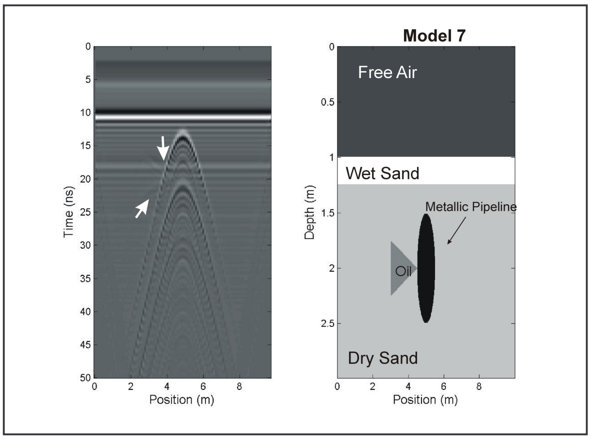

Figure 7 – Right: Model 7. Left: GPR simulation obtained using model 7.

#8 – A cylindrical metallic pipeline with 1 m diameter, buried in a wet sand layer (Figure 8). Oil drainage is carrying out of the pipe. A dry sand top layer is replacing concrete layer used in examples 1-6.

Different from model 7, in this situation the resistive top layer avoid horizontal ringing. Oil plume signature is indicated by white arrows.

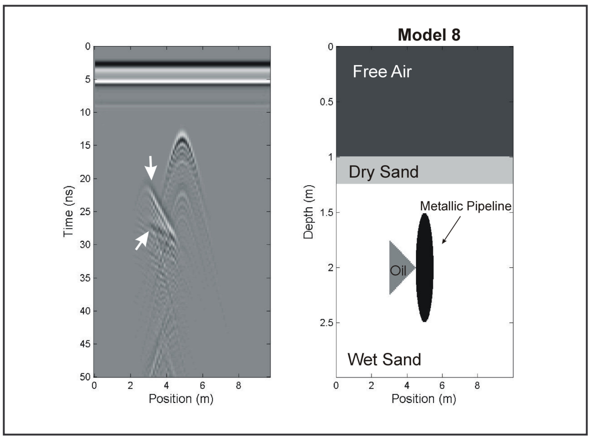

Figure 8 – Right: Model 8. Left: GPR simulation obtained using model 8.

Conclusions

GPR can be used successfully for mapping contamination plume caused by pipeline oil drainage, but that success will depend of the subsurface layering environment.

The plume can be easily mapped in a resistive environment as shown in model 2. Only few processing steps like migration and gain, will be needed to be applied to enhance plume signature.

In a conductive environment, as shown in model 5, if there is a resistive top layer, the plume can also be identified. Migration and multiple attenuation removal techniques can be applied to enhance the resulting images.

If the top layer is conductive and pipeline is placed on a resistive environment as shown in Figure 7, horizontal multiple reflections occurs. In those situations some kind special data treatment as trace difference or high-pass filtering, for example, should be applied to remove that kind of noise.

If the plume extent is not wide enough, its signature can be masked by the pipe hyperbola signal.

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