# Test with ImpulseRadar Raptor GPR array at Gisacum (Vieil-Évreux, France), and comparison with MALÅ MIRA

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**Abstract**
The ImpulseRadar Raptor-45 GPR array was tested. The instrument achieves a high signal-to-noise ratio, also at high survey speed. Lifting the sensors off the ground introduced multiple reflections. 3-D migration can enhance these multiples in profiles and time-slices. Fast data acquisition by lifting the sensors should be balanced against data quality.

**Keywords**
air-launched vs. ground-coupled; groundpenetrating radar; multi-antenna array; multiple reflections; 3-D migration

## Introduction

On 7 September 2022, a test was carried out with an ImpulseRadar Raptor-45 groundpenetrating radar (GPR) array instrument at the Gallo-Roman sanctuary of Gisacum, near Évreux, Normandy, France (Guyard 2005). The test was conducted over the western *fanum*, where electrical resistance, magnetometry and GPR surveys have previously taken place (Dabas 2009; Novo et al. 2012). A hitherto unpublished survey with a MALÅ MIRA GPR array, carried out in August 2012, provided suitable data for comparison.

## Instruments, data acquisition and processing

The ImpulseRadar Raptor-45 was deployed in two configurations (Tab. 1) by René Ruault (Georeva, France). The first one consisted of 18 channels (10 transmitters and 9 receivers with centre frequency 450 MHz), and was mounted behind a small van, 5–10 cm above the surface. This allowed fast data collection: an area of 1.3 ha was covered in 1 hour and 40 minutes. A manually pushed, ground-coupled, 8 channel ImpulseRadar array was used to survey an adjacent area. The results were compared with data collected in 2012 by Mike Langton (Guideline Geo, Sweden) with a ground-coupled MALÅ MIRA towed by an ATV, consisting of 8 channels with frequency 400 MHz.

For all three surveys, cross-line spacing was 0.08 m. An estimation of the dielectric permittivity by means of migration velocity analysis resulted in a slightly higher value for the 2012 MIRA survey (Tab. 1). The moisture content, and its possible influence on conductivity and attenuation, can therefore be assumed to be somewhat higher for the 2012 data, complicating exact comparison with the 2022 ImpulseRadar survey. All data were processed using the same workflow, including dewow (1-D high-pass filter which from each temporal sample in the trace subtracts the mean of a window of 20 samples (4 ns) centred around the sample to be corrected), time zero alignment, gain, band-pass filtering, background removal and 3-D phase-shift migration.

## Results and discussion

Due to the high data acquisition rate, enabling the stacking of multiple traces also at high survey speed, the ImpulseRadar data show little random noise (Fig. 1a) and a somewhat larger penetration depth (~1.8 m) than the

| Instrument | No. of channels | Frequency (MHz) | Inline spacing (m) | Crossline spacing (m) | Deployment | Area (ha) | Duration (min) | average wave velocity (m/ns) | average relative dielectric permittivity |
|---|---|---|---|---|---|---|---|---|---|
| **Impulse Radar Raptor** | 18 | 450 | 0.03 | 0.08 | lifted off the ground | 1.29 | 100 | 0.1107 | 7.3 |
| **Impulse Radar Raptor** | 8 | 450 | 0.05 | 0.08 | ground-coupled | 0.06 | 30 | 0.1145 | 6.9 |
| **MALÅ MIRA** | 8 | 400 | 0.08 | 0.08 | ground-coupled | 0.62 | 200 | 0.1021 | 8.6 |

**Table 1:** Data acquisition parameters.

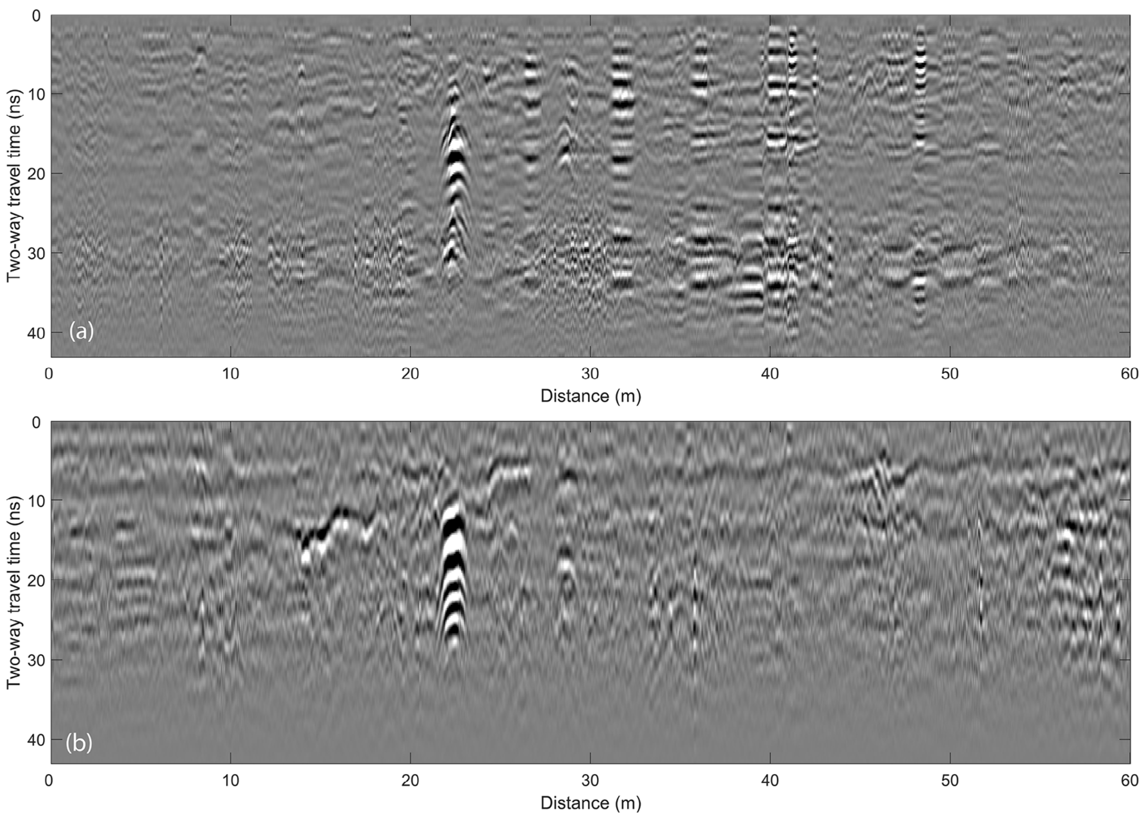


**Fig. 1:** a) Profile collected with the vehicle-mounted ImpulseRadar Raptor-45, after background removal, showing a wall reflection at 22 m, and remnants of multiples. b) Same profile, collected with the MALÅ MIRA.

MALÅ (~1.5 m, although the slightly wetter soil conditions may also play a role here). In the profiles collected with the ImpulseRadar, repetitive horizontal reflections are visible, because the waves were reflected back and forth between the slightly elevated antennae and the surface. Also after background removal (subtraction of the average of the complete profile from each trace) numerous anomalies remain, since the multiple reflections are not perfectly horizontal, but follow the uneven surface (Sala and Linford 2012). In the profiles collected with the ground-coupled MALÅ instrument, these are much less apparent (Fig. 1b).

In the time-slices, these multiples form noise stripes with higher amplitudes where shallow furrows run in N–S direction (Fig. 2a). In Figure 2 c), these are visualized in


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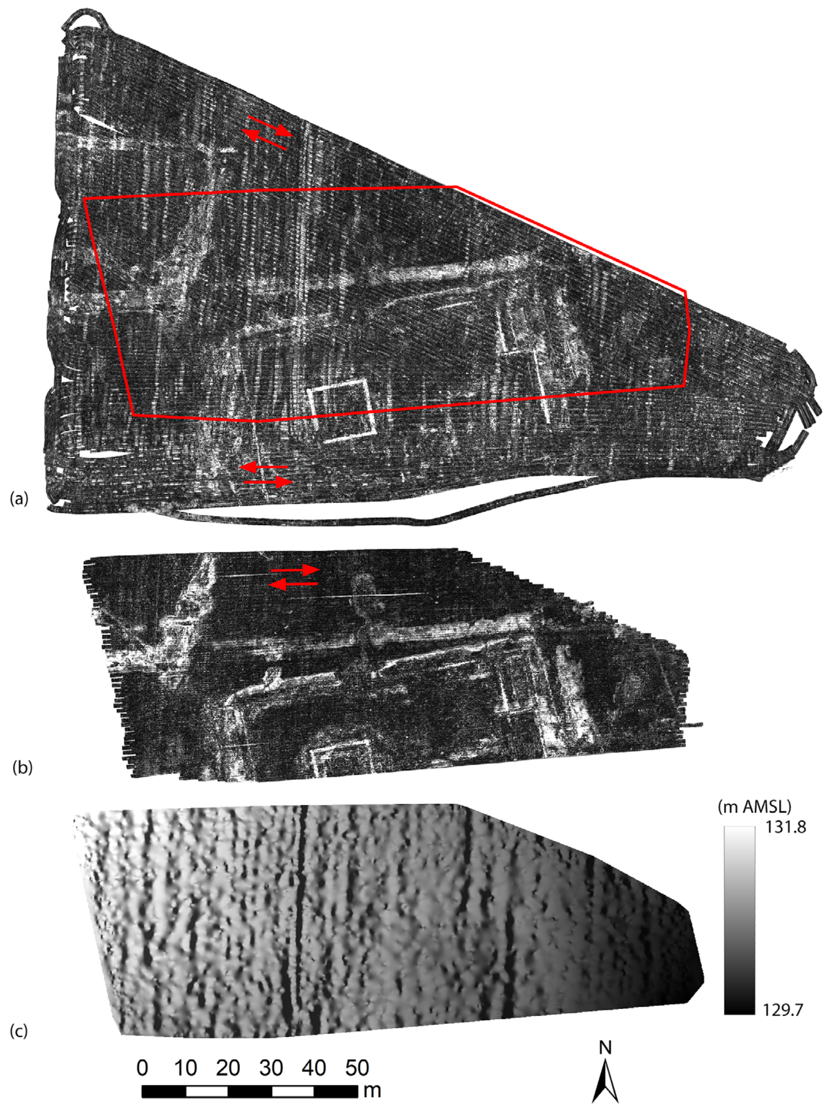


**Fig. 2:** a) – b) Time-slices at 7–8 ns, after background removal, based on data collected a) with the vehicle-mounted ImpulseRadar and b) with the MALÅ MIRA. The perimeter of the slice in b) is indicated in red in a). The arrows indicate the direction of the transects. c) Hillshade representation of the digital elevation model based on RTK GNSS measurements acquired simultaneously with the MALÅ MIRA survey.

a hillshade representation of the digital elevation model. When compared to the MALÅ data (Fig. 2b), the noise hampers the interpretation of the archaeological structures, mainly in the shallower slices. By contrast, in the data collected with the manually pushed, ground-coupled ImpulseRadar the noise patterns visible in the vehicle-mounted dataset are absent. Data quality seems affected even if the elevation of the antennae is very small (hence this deployment cannot be called 'air-launched': Diamanti and Annan 2017).

The noise found in the vehicle-mounted ImpulseRadar data can complicate 3-D migration, which improves horizontal resolution (Fig. 3a – d compares unmigrated, 2-D and 3-D migrated data). Migration cannot handle multiple reflections, which in crossline direction often appear as separate anomalies, because of the different response of the individual channels in the array (Fig. 3e). Whereas migration focuses the energy of diffraction hyperbolae, it expands multiples (Fig. 3f), so that destriping algorithms (Verdonck et al. 2013) can become less effective. For exam-

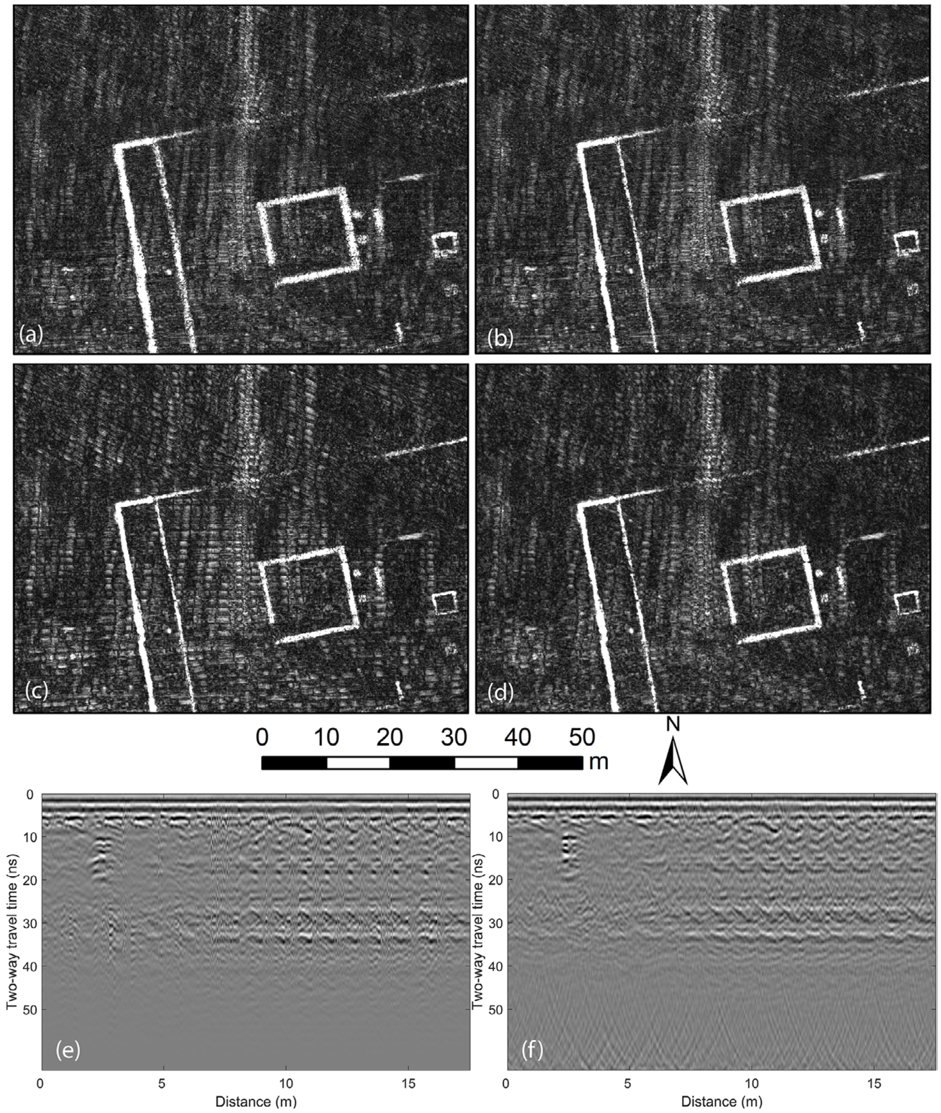


**Fig. 3:** Time-slices at 17–18 ns, showing results obtained with the vehicle-mounted ImpulseRadar, a) before migration. b) After 2-D migration. c) After 3-D migration. d) After 3-D migration and application of a destriping algorithm using a short window in the direction of the transects. e) Cross-line profile showing a buried wall (at 2.5 m) and multiple reflections, before migration. f) After 3-D migration.

ple, non-migrated and 2-D migrated data (Fig. 3a – b) were adequately destriped by balancing the channels in the array (using the median of the complete transects). However, this method proved insufficient when applied to the 3-D migrated data (Fig. 3c). A better result was obtained by using a short window in the direction of the transects. For each measurement in the window, the closest neighbours in cross-line direction were selected (not necessarily belonging to the same swath), and of these measurement series, the median was equalized (Fig. 3d).

## Conclusion

Tests with an ImpulseRadar Raptor-45 array produced data with little random noise. In the vehicle-mounted configuration, with the array slightly elevated above the surface, multiple reflections originating from the air-ground transition are visible, also after background removal. The effect of these multiples can be enhanced by 3-D migration. Therefore faster data acquisition by lifting the sensors off the ground should be balanced carefully against data quality.


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## References

Dabas M. Theory and practice of the new fast electrical imaging system ARP. In: Campana S, Piro S, editors. Seeing the unseen, geophysics and landscape archaeology. London: CRC Press; 2009. p. 105-126.

Diamanti N, Annan AP. Air-launched and ground-coupled GPR data. In: 11th European Conference on Antennas and Propagation (EUCAP); 2017 Mar 19-24; Paris, France. New York: IEEE; 2017. p. 1694-1698. doi: 10.23919/EuCAP.2017.7928409

Guyard L. Gisacum: l'originalité d'un grand sanctuaire gallo-romain. Revue Archéologique. Nouvelle série. 2005; 1:218-21. French.

Novo A, Dabas M, Morelli, G. The STREAM X Multichannel GPR system: first test at Vieil-Evreux (France) and comparison with other geophysical data. Arch Prosp. 2012;19(3):179-89. doi: 10.1002/arp.1426

Sala J, Linford N. Processing stepped frequency continuous wave GPR systems to obtain maximum value from archaeological data sets. Near Surf Geophys. 2012;10(1):3-10. doi: 10.3997/1873-0604.2011046

Verdonck L, Vermeulen F, Docter R, Meyer C, Kniess R. 2D and 3D ground-penetrating radar surveys with a modular system: data processing strategies and results from archaeological field tests. Arch. Prosp. 2013;11:239-252.