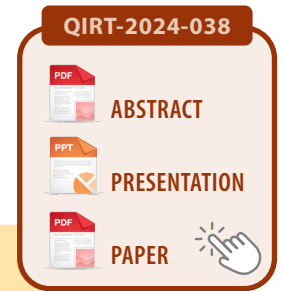




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THERMOGRAPHIC DETECTION OF UNDERGROUND CAVITIES. THERMAL MODELLING AND EXPERIMENTAL RESULTS

The search for underground cavities, and possibly their characterization, is a problem encountered in various fields:

- transport security (e.g. search for cavities due to land subsidence around pipes or under asphalt surfaces: roads, airport runways)
- military applications (caches and tunnels)
- monitoring of a network of buried pipes, particularly for district heating
- geological prospecting (caves, caverns).

We will focus here on the observable “thermal infrared signal” as a vector of information on the surface temperature, the spatio-temporal variations thereof being likely to provide information on the presence of a buried structure or cavity, or even allow characterization such as, for example, lateral dimensions and depth. Infrared thermography is indeed a good option for an easy and rapid evaluation of the spatial distribution of surface temperature and, if needed, its temporal variations during a diurnal cycle. However, the question to answer is whether the disturbances induced by the buried structure to heat transfer in the ground print a sufficiently significant signature on the surface temperature field to be reliably detected by thermal infrared remote sensing. To this end, we will present the results of the thermal modelling of the temperature field near an underground cavity in natural conditions (typical sun and atmosphere radiative flux, convection).

The cavity, through the volume of air it presents in the upper part, offers a significant thermal barrier to the vertical heat flow induced by natural atmospheric forcing (solar irradiance and atmosphere infrared down-welling flux). In the temporal phase where the conduction flow is downward (essentially diurnal phase) the diffusion of heat is thwarted, which leads to a rise in temperature above the structure. Additionally, some of the heat bypasses the structure; this 2D/3D lateral diffusion depends on the ratio between the lateral dimensions of the upper part and the distance to the free surface.

Ultimately, a temperature contrast appears on the surface above the structure. However, due to lateral diffusion, the representation of the cavity in the infrared image presents a blurred contour. The surface temperature field therefore offers an altered image of the upper part of the structure.

The modelling makes it possible to quantify these phenomena, in particular to determine the spatio-temporal evolution of the contrast during a day/night cycle, and to study the influence of the determining parameters (depth, lateral dimensions, thermal properties of the ground, heat exchanges with the atmosphere, etc.). This analysis will allow us to answer questions such as:

- what is the preferred moment in the diurnal cycle to maximize the probability of detection?
- what are, depending on the nature of the soil (i.e. the thermal properties) the detection limits in terms of depth and lateral dimensions?

A 2D numerical model was developed with either Cartesian or cylindrical geometry. The chosen method is based on the finite volume approach with variable mesh size and time progression according to the alternate-direction-implicit method (ADI). Typical results are reported regarding the temperature field under the soil surface, the spatial profile of the temperature contrast at two optimal times, the temporal evolution of the contrast during a 24h cycle for different values of the depth of the cavity top.

A thorough parametric analysis will be presented together with experimental results obtained with a series of cylindrical barrels buried at different depths. Measuring the optical properties of the surface (spectral reflectance, emissivity), the thermal properties of the soil at different depths (effusivity according to the hot plane method, and conductivity according to the hot wire method), and the water content at different locations made it possible to interpret the recorded infrared images and identify the effects that could hinder the detection of the buried barrels.