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Active Infrared Technique for Landmine Detection: Numerical and Experimental Results

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The silent tragedy of antipersonnel mines

Landmine Monitor has identified in the past 10 years:

- 73,576 casualties of landmines
- 119 states
- cost was more than 3 billion of dollars

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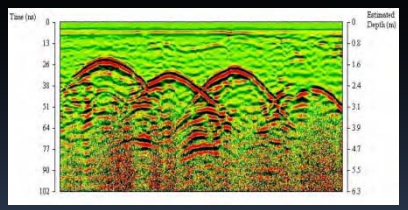
The mine detection challenge

New generation landmines have low metal content !!

Metal Detector (simple and cheap) is no more sufficient

Ground Penetrating Radar is expensive and complex to use



New *Multisensor Devices* and *Data Fusion* techniques

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LABORATORIO di SMINAMENTO UMANITARIO

COMSOL CONFERENCE PARIS 2010

Humanitarian Demining Lab (HDL)

The HDL researchers have developped a new and cheap thermal technique based on soil heating and IR probing by a pyrometers array

The remote and contactless detection of buried mine, or similar object, is simply based on the measure of thermal contrast due to a different value of material parameters the heat meets during warming and next cooling of ground (soil, air inside the mine, explosive, mine plastic bulk, detonator..)

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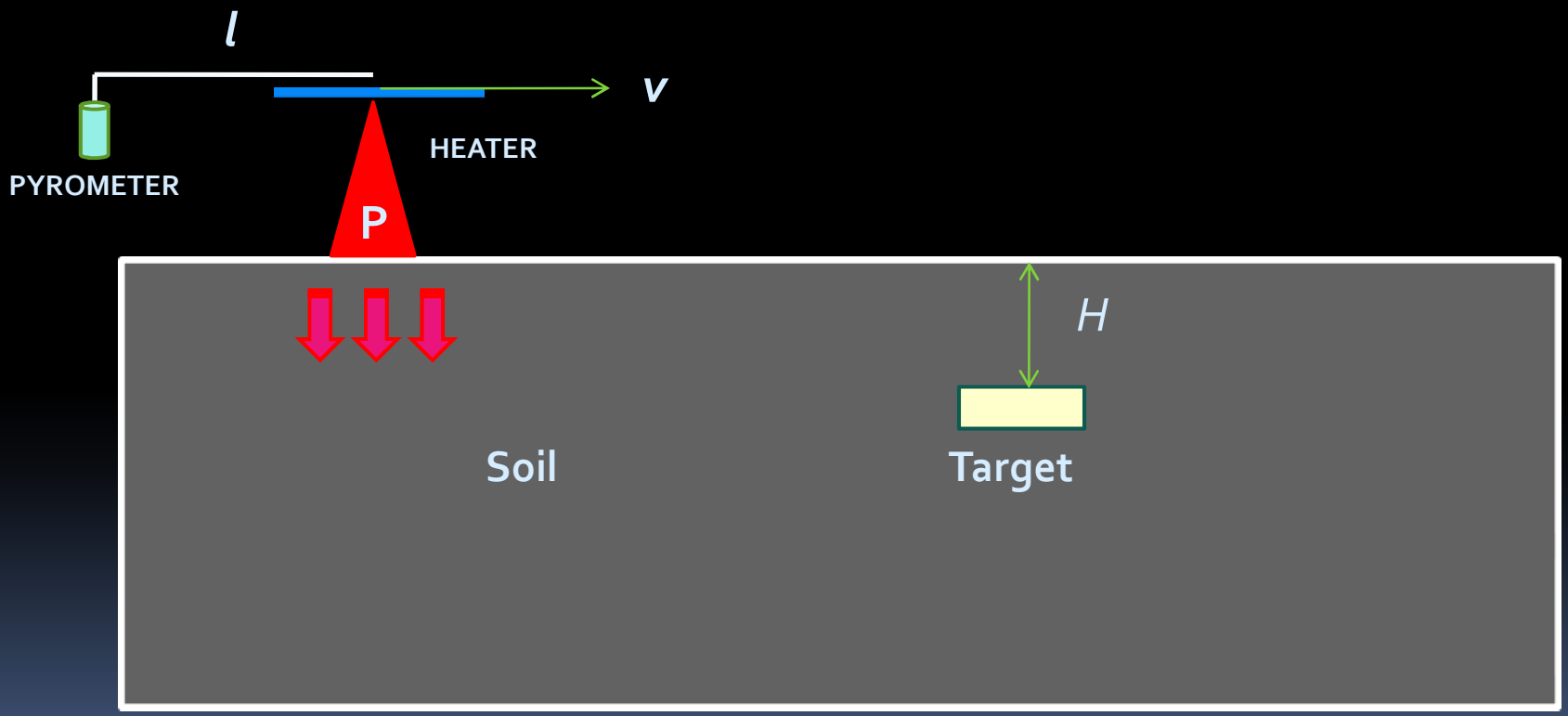
The detection system

- P : Heater Power
- v : Cart Velocity
- l : Heater-Pyrometer Distance
- H : Depth



Thermal Contrast: **T(mine soil)-T(free soil) =*f(P/v , l/v , H)***

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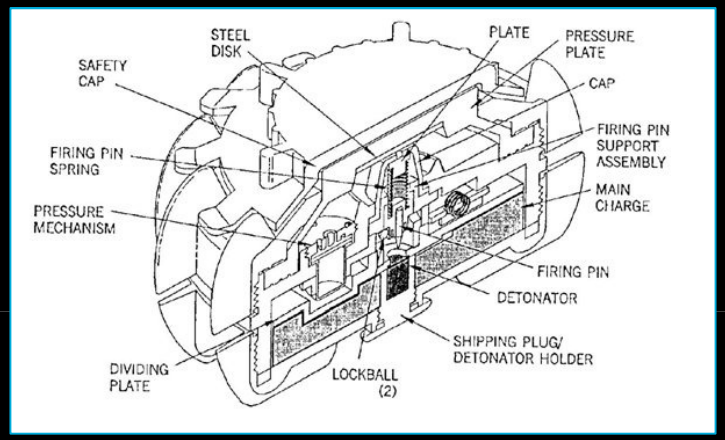
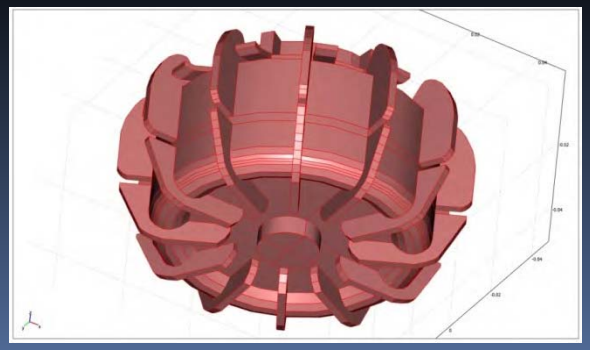
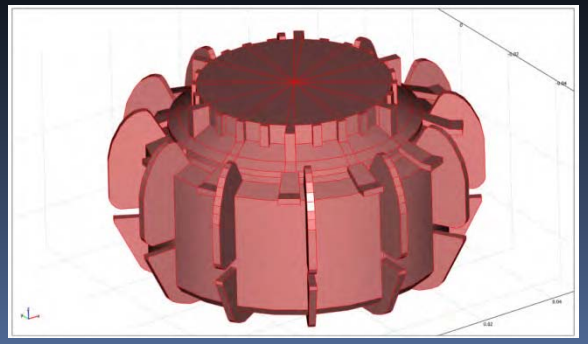
Comsol Multiphysics comes in the lab…



from Ordata website

Starting from this image found in the web, we have been able to perform a complete 3D reconstruction of real mine **only using** Comsol Multiphysics CAD Editor





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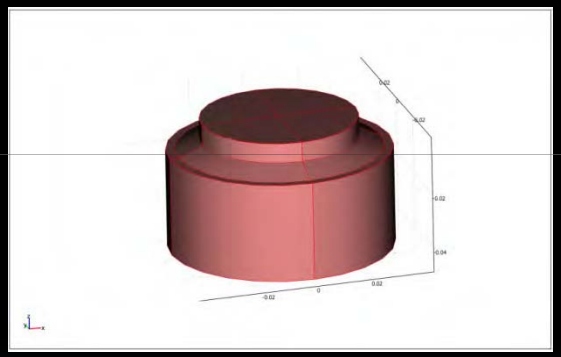
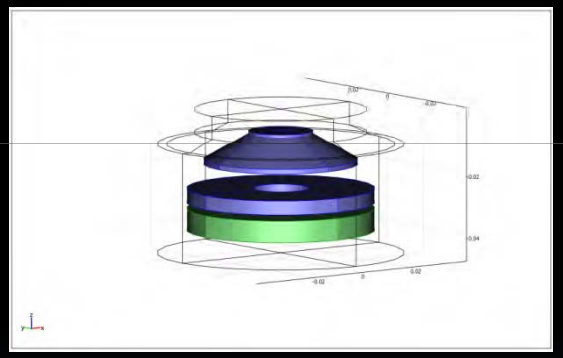
The Comsol model (reduced complexity)

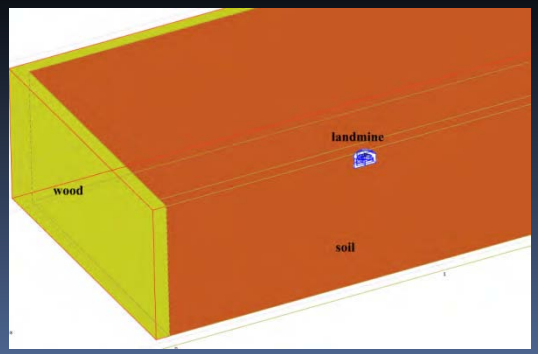
The large size of soil box compared to small objects inside the mine, suggested to reduce the mine complexity to avoid an huge number of degree of freedom



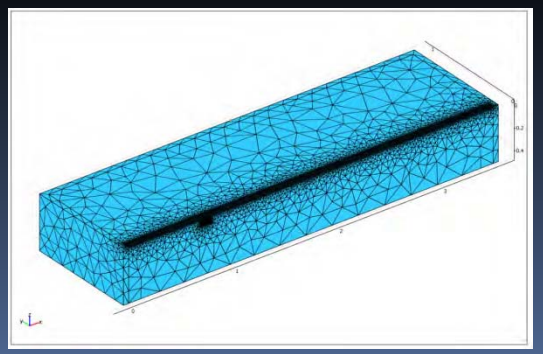
The more simple model adopted



Air (blue) and explosive (green) volumes



Soil, wood and mine section



The tetrahedral mesh

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The Comsol model

- Heat Transfer Module (Conduction, Convection, Radiation)

$$\rho c_p \frac{\partial T}{\partial t} + \nabla \cdot (-k \nabla T) = q + h(T_\infty - T) + \varepsilon \sigma (T_{amb}^4 - T^4)$$

- Boundary Conditions:
  - Thermal continuity in the whole mine
  - Assigned temperature on the external sides of the wooden box (T ambient)
  - Boolean conditions for heat flux over soil surface simuling moving heater

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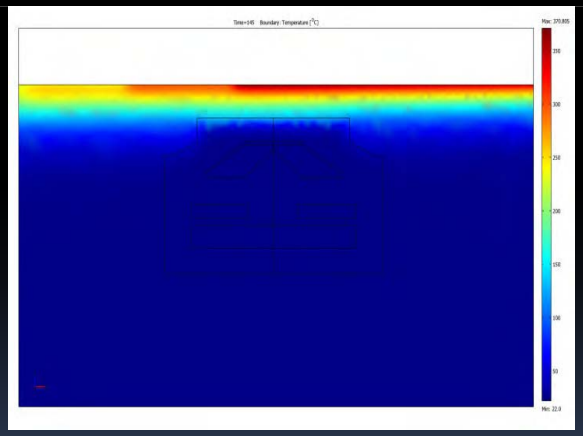
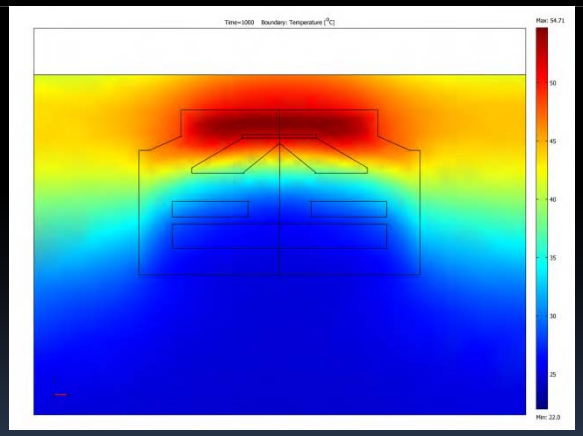
The transient analysis solution

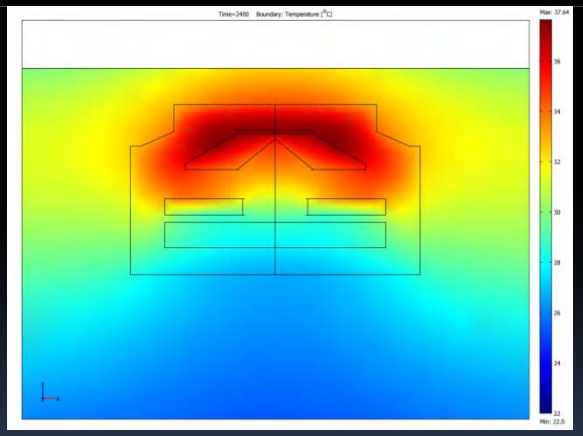
Comsol permitted us to discover and see the effective internal transient heat flow we just theorically supposed



The radiator is passing over the buried mine



The cooling phase after 1500 sec.



2400 seconds after warming (color scale expanded)

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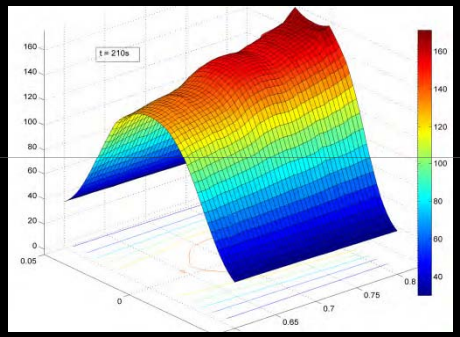
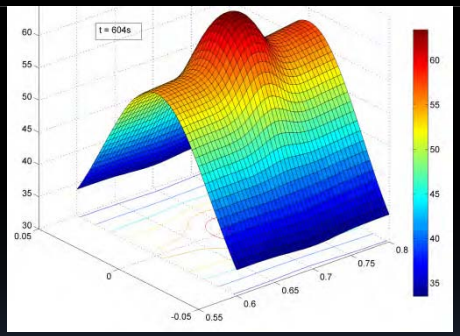
Thermal contrast evidence

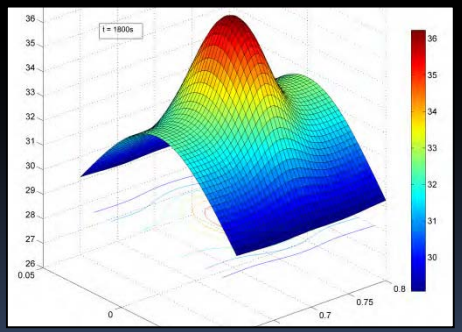
During the cooling phase, the warm collected inside the mine's volume rises up in the soil surface and permits the mine IR detection



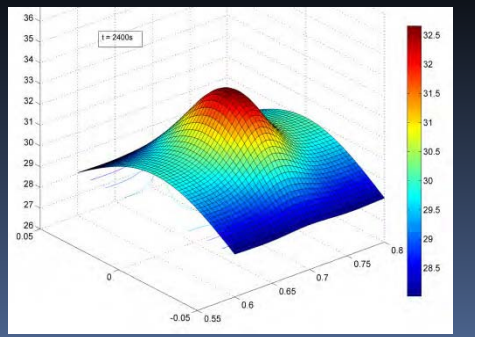
210 seconds after warming…



… 604 seconds



… 1800 seconds



… 2400 seconds

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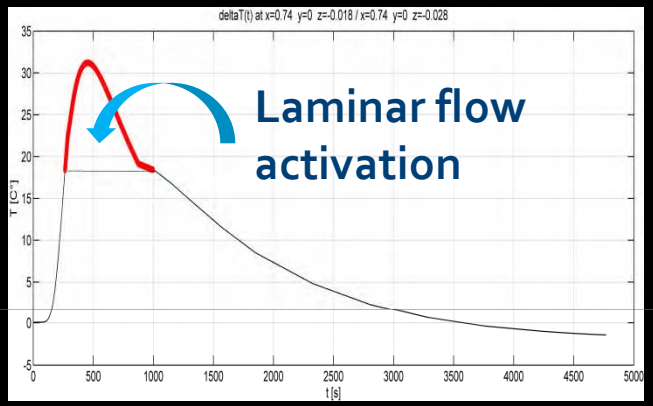
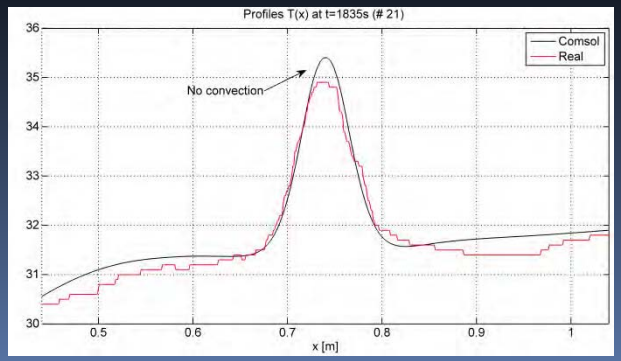
Laminar air flow and high model accuracy



Thanks to Comsol we were able to consider the laminar air flow (inside the air-filled area necessary to explosion) to be relieved for an exact model allowing a complete agreement with real experimental data. The calculated *Grashof number* ($G_r = 1.18 \cdot 10^7$) excludes turbulent flow

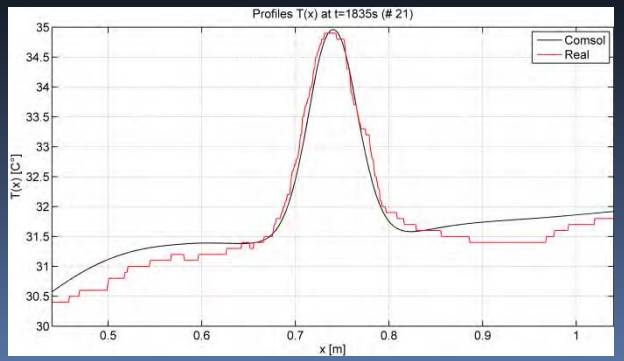
Comsol Multiphysics permitted to evaluate the temperature difference between ceiling and floor of the air cavity and estimate the laminar flow (starting only when this ΔT exceeds 18 C°)



Comparison of real data (red) to Comsol data (black)

No laminar flow

With laminar flow



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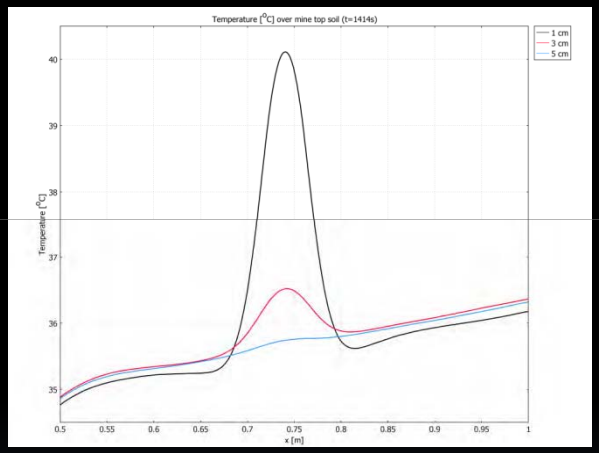
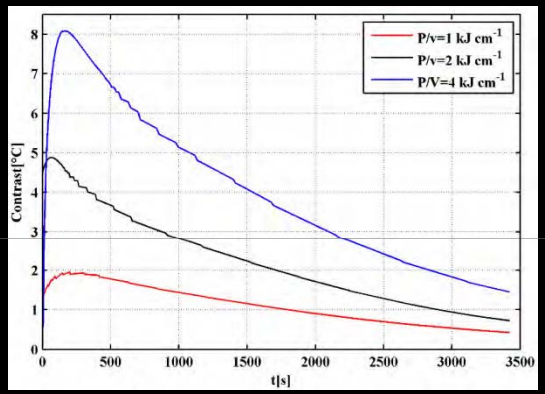
Using Comsol to carry out parametric tests

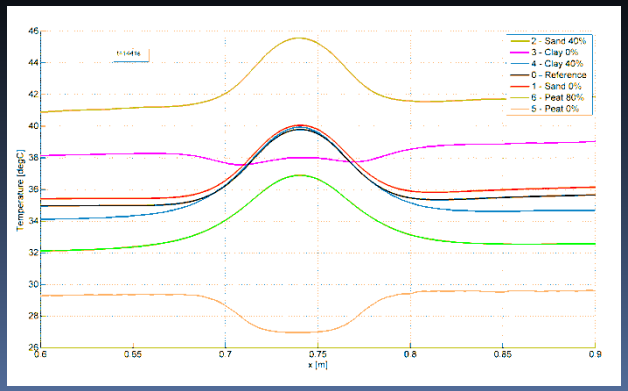
Comsol Multiphysics permitted to perform a large parametric set of tests in place of time-consuming real laboratory experiments



Mine depth

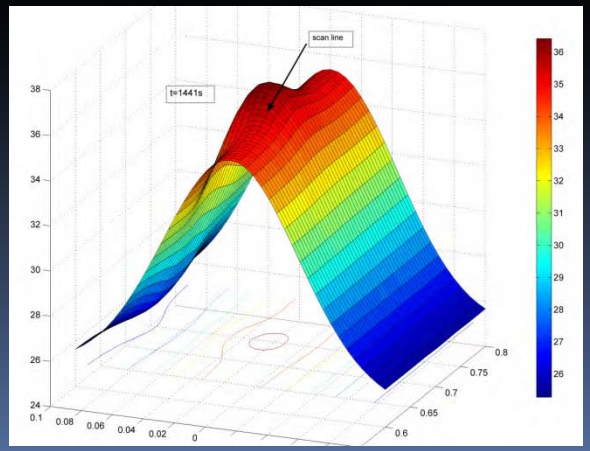
Power - Velocity ratio





Sand, clay or peat soil

Scan line misalignment



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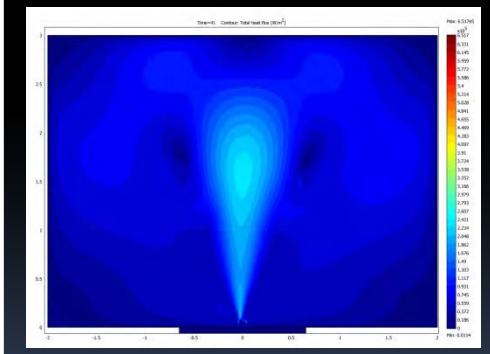
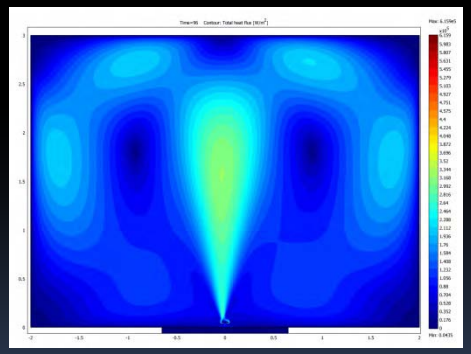
Using Comsol to improve radiator design

Comsol Multiphysics revealed also as a very usefull tool to :

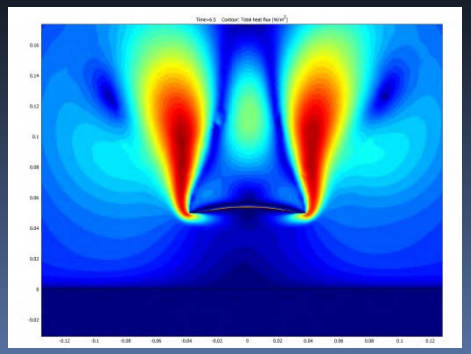
- ✓ Study and optimize the system parameters, in particular heaters shape, size, power and scanning speed
- ✓ Improve radiator shields in order to reduce heat loss by air convection over the soil surface and its flow around the laboratory room

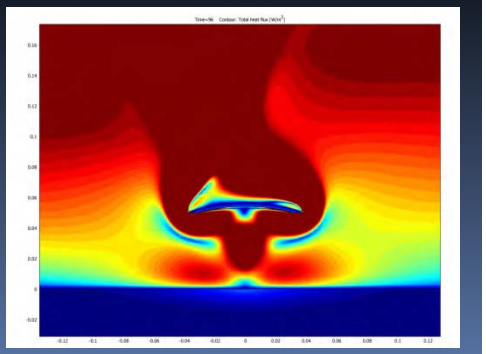




Air flow inside the room switching on the heater

Air flow around the shield switching on the heater





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Conclusions and future work

- Whole system virtualization for complete analysys
- Very low error in the system approximation (error $\rightarrow$0)
- Ability to test and verify the system directly inside Comsol

  $\longrightarrow$ no long, expensive (... and time consuming) real tests
- Understand no outside visible heat flow dynamic

- ✓ Analysis of the system for humid soil and for different landmine depth
- ✓ Analysis and study of the EM problem in order to simulate the GPR data

Never more it must happen

Thanks