# REMOTE SENSING OF SUBSURFACE ELECTROMAGNETICALLY PENETRABLE OBJECTS

# LANDMINE AND IMPROVISED EXPLOSIVE DEVICE DETECTION

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# Contents

# The Worldwide Landmine Problem

| Regions | (1999-2008) Casualties |
|---|---|
| Africa | **33,627** |
| Asia-Pacific | **16,390** |
| Americas | **8,558** |
| Russia | **7,202** |
| Europe | **4,628** |
| Middle East and North Africa | **3,171** |
| **Total** | **73,576** [9] |

Since 1975, more than **500,000** civilians (50% children) have been killed or maimed by landmines [8]

# The Worldwide Landmine Problem

- Tens of millions of live mines remain buried in

  ***70 countries***
  - Most of these countries make up ⅔ of the world's poorest nations [8]
  - Removal costs:

    **$300–$1000 per mine** [11]

    Cheap removal is extremely important
- Solution:

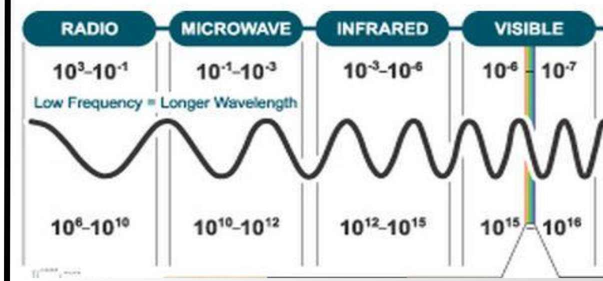
**SUBSURFACE SENSING**

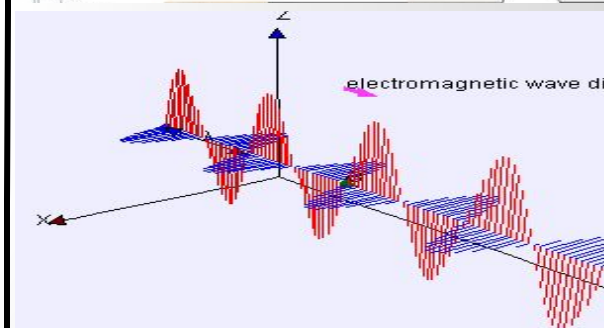

Afghanistan 10,000,000; Angola 15,000,000; Azerbaijan 100,000; Bosnia and Herzegovina 3,000,000; Cambodia 6,000,000; Chad 70,000; China 10,000,000; Croatia 3,000,000, Cyprus 16,942, Denmark 9,900, Ecuador 60,000, Egypt 23,000,000, El Salvador 10,000; Eritrea 1,000,000; Ethiopia 500,000, Falklands Islands (Malvinas) 25,000; Georgia 150,000l Guatemala 1,500l Honduras 35,000 Iran, Islamic Republic of 16,000,000 Iraq 10,000,000 Korea, Republic of 206,193 Latvia 17,000 Lebanon 8,795 Liberia 18,250 Mozambique 3,000,000 Namibia 50,000 Nicaragua 108,297 Rwanda 250,000 Somalia 1,000,000 Sudan 1,000,000 Ukraine 1,000,000 Viet Nam 3,500,000 Yemen 100,000

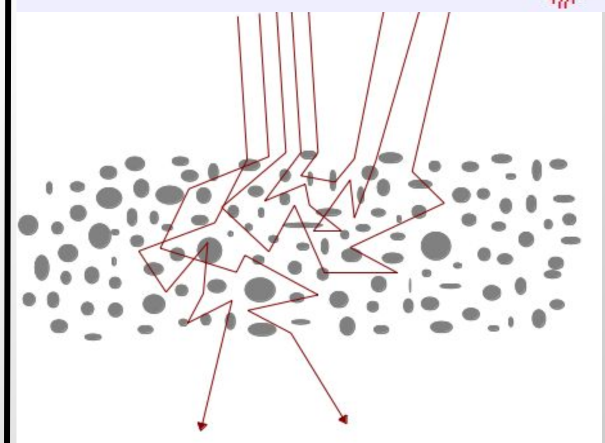
[10]

# Subsurface Sensing

- ***Detecting*** and ***identifying*** underground objects
- Transmission, **Scattering**, & Absorption of **Electromagnetic Waves (EMW)**
  - Scattering dependent on *microphysical properties* of individual materials involved
    - ex: landmines, soil, air
    - relative permittivity, permeability, conductivity
  - **Radio waves**: longer waves = optimal detection wavelength for landmine sizes; greater scattering effects

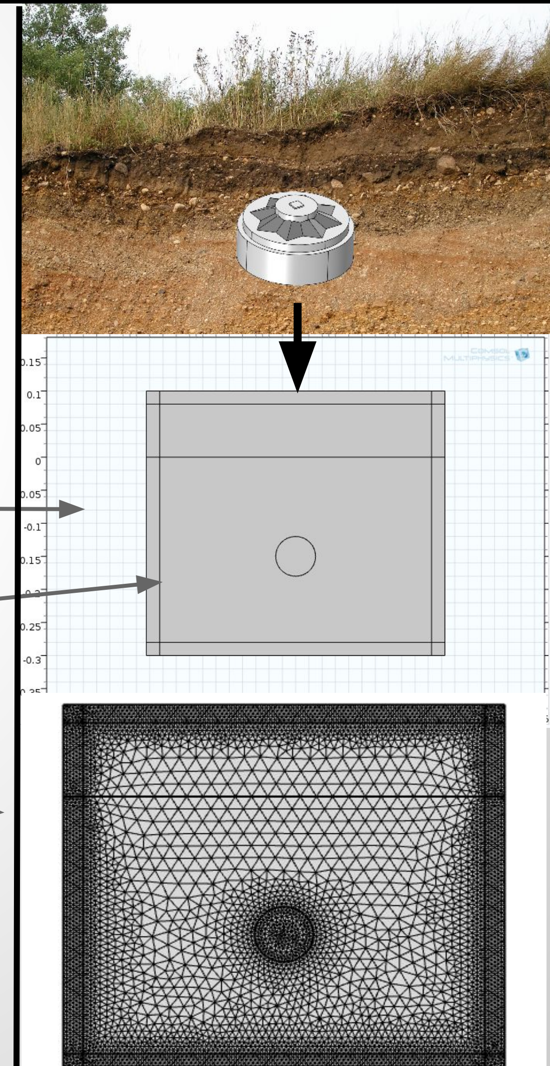




# Simulating the Real World Problem in COMSOL Software

- **Comsol Multiphysics** Software allows modal creation and an accurate *computational simulation* of a subsurface sensing scenario
- **Sequence of Simulation Creation**
  - Geometry Creation
  - Defining Materials
  - Defining Boundaries
  - Meshing
  - Specify Solver Equations
  - Post Processing



# Real Problem for Simulation

- Landmines can be embedded under many layers of the ground
- Deminers can not accurately know which layer the mine lies in or what the layers are made of
  - wet soil, dry soil...
- Simulating all situations > **TEMPLATE**

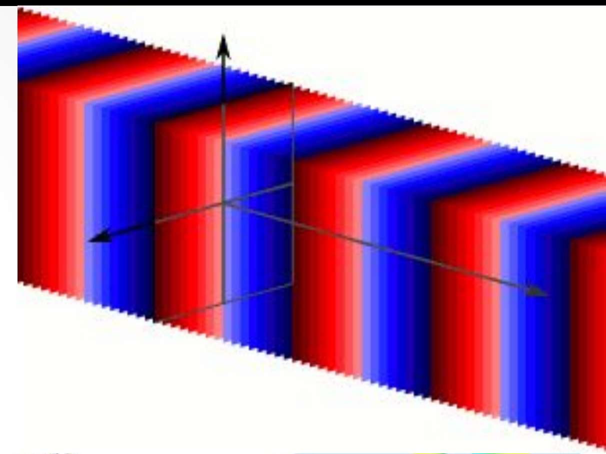
# Distinguishing Landmines from Other Anomalies

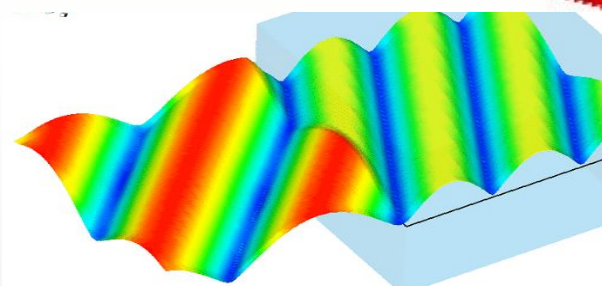
- Average Specifications
  - Diameter: 20-125 mm
  - Length: 50-100 mm
  - Weigh as little as 30g
  - Buried Shallowly
  - Various shapes
- Specific Microphysical Properties

| Material | Relative permittivity | Relative permeability | Conductivity |
|---|---|---|---|
| Air | 1 | 1 | 0 |
| Dry Soil | 2.9 | 1273+31i | 0.004 |
| Wet Soil | 4 | 1756+395i | 0.049 |
| TNT/IED Composition | 2.86 | 1256+2.26i | 2.86e-4 |


# EM Wave Physics Equations for Simulation

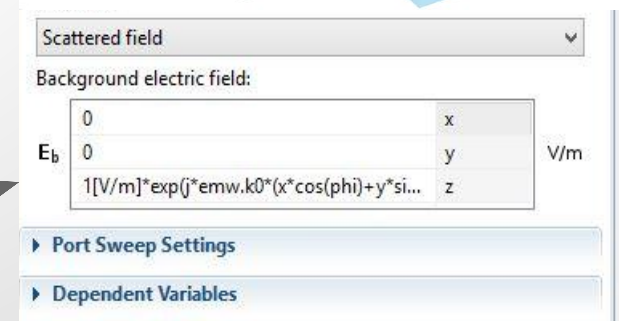
- **Plane Waves**
  - Simple 2D wave propagating in one direction
  - No variation in the Z direction and EM field
  - Propagates in the model x-y plane
- Described Using the **Plane Wave Equation**
  - This defines the plane wave's propagation
    - a linearly polarized plane wave traveling  parallel to the y-axis





E= Electric field
$E_0$ = Incident Electric Field
i = complex numbers
**k** = propagation constant
**r** = position vector

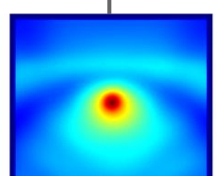
$$E_o = \left(0,0,e^{ik_0 y}\right)$$



# Scattering Physics for Simulation

**Computing Scattering**

- **Helmholtz Equation**
  - solves for individual scattering of waves based on the initial wave as well as the electromagnetic properties of the materials in the simulation



$$\nabla^2\vec{E} + \mu_r\mu_0\varepsilon_c\omega^2\vec{E} = 0$$

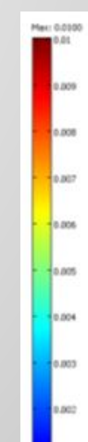
**Measuring Scattering**

- **Radar Cross Section (RCS)**
  - represents the emw scattering results from Helmholtz Equation
- **Scattering Width Equation**
  - the RCS per unit length- Results

$$\sigma_{2D} = \lim_{\rho\to\infty}\left[\frac{|E_s|^2}{|E_i|^2}\right]$$

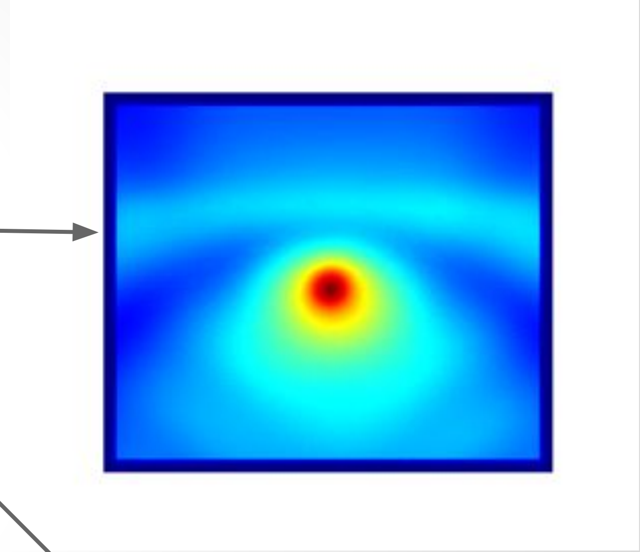
$\rho$ = distance from target to observation point

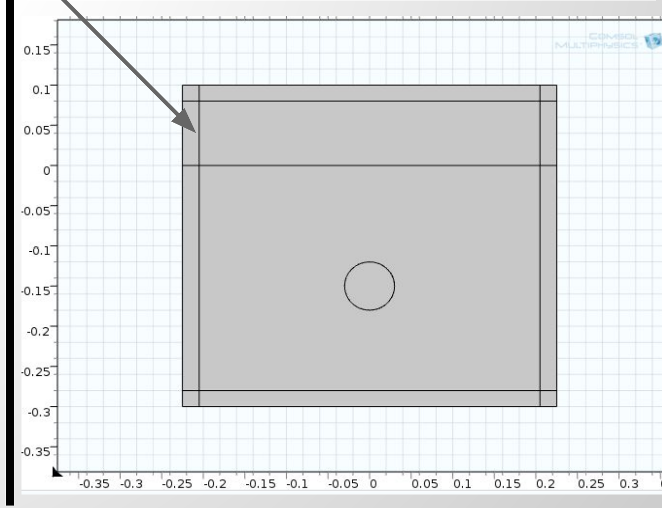
$Ei$ and $Es$ - incident and scattered electric field



# Reabsorbing Boundary Condition Physics in COMSOL

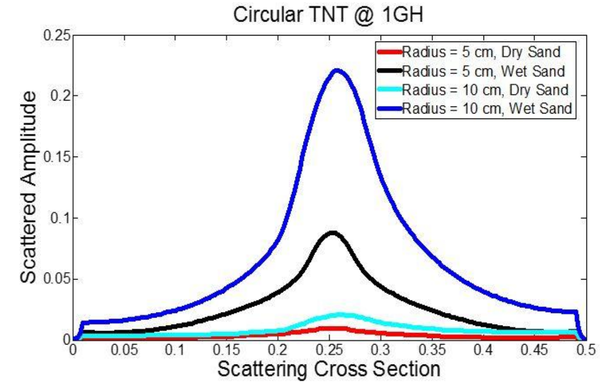
- **Absorbing Boundary Conditions**
  - non perfect absorbing layer
- Improved Results with **Perfectly Matched Layers** (PMLs)-
  - Artificial absorbing *domains*
  - Commonly used to truncate computational regions in numerical methods to *simulate problems with open boundaries*
  - Reabsorb scattered waves to eliminate reflection that causes interference
  - Size matched to wavelength

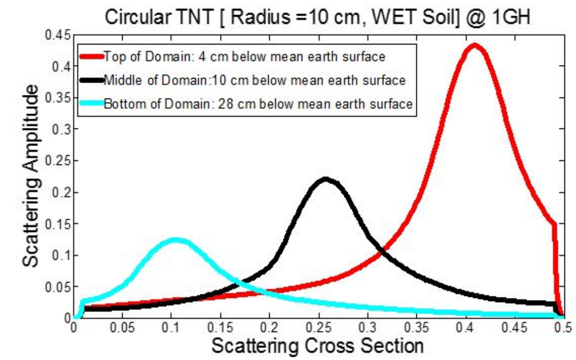


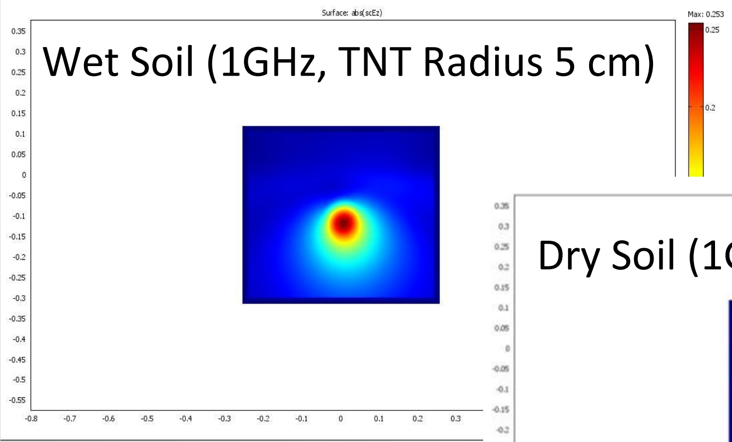


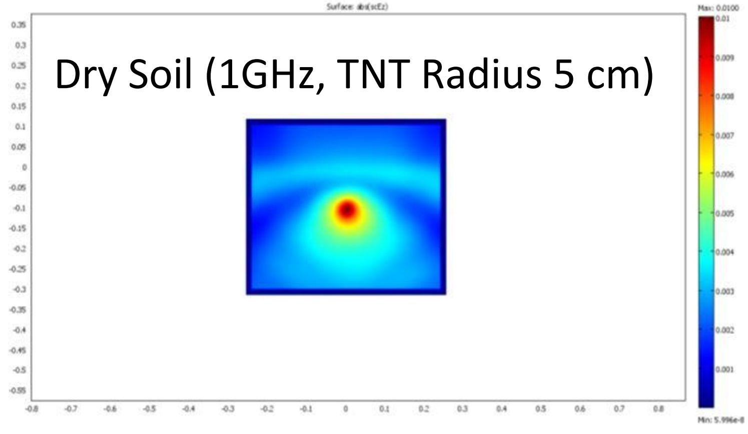
# Results and Discussion

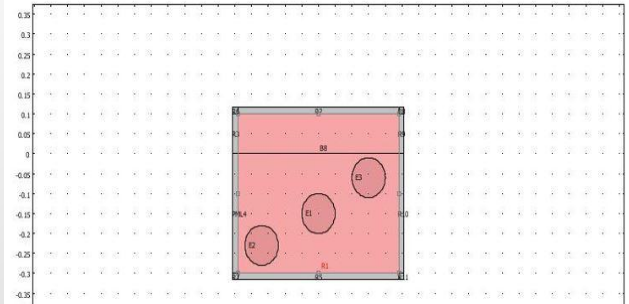
- Main independant varibales:
  - Size of Mine (radius)
  - Depth Buried
  - Soil Type and Layer Variations
  - Frequency



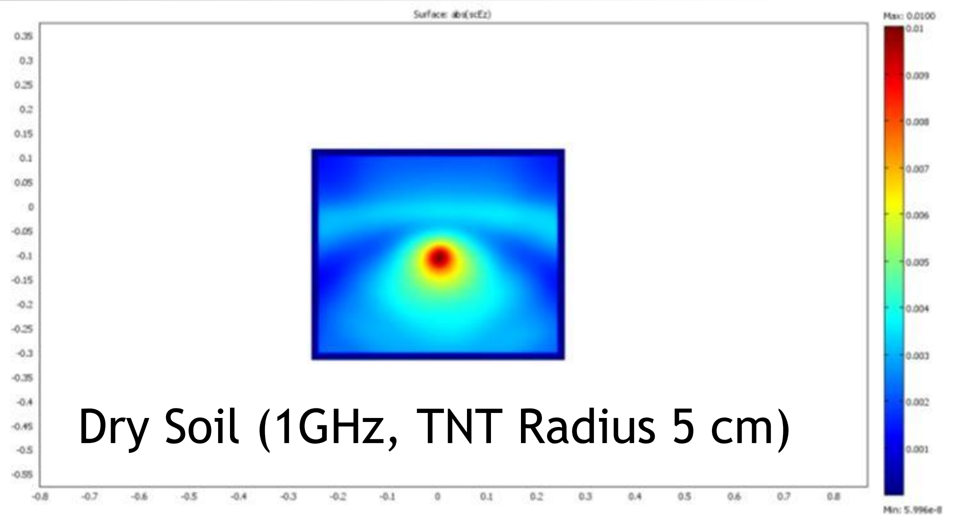



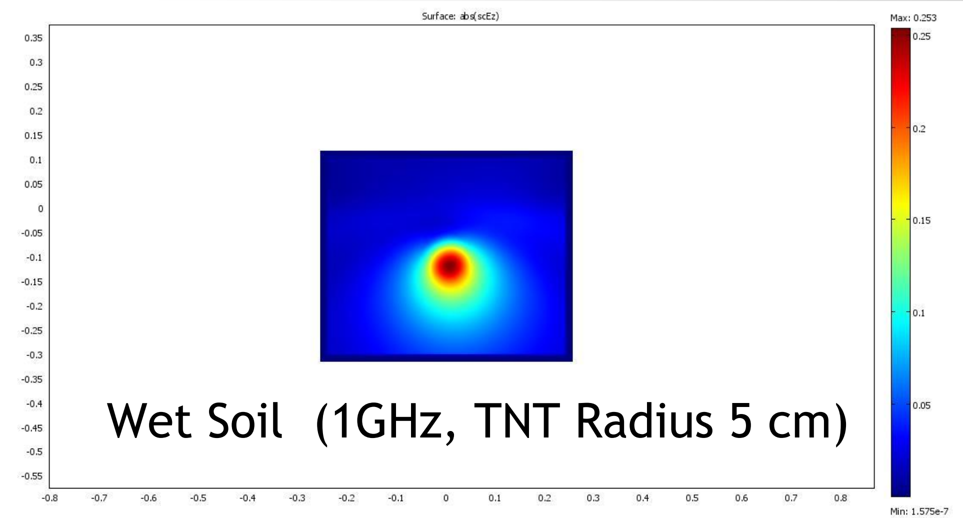



# Dry and Wet Soil Type Results



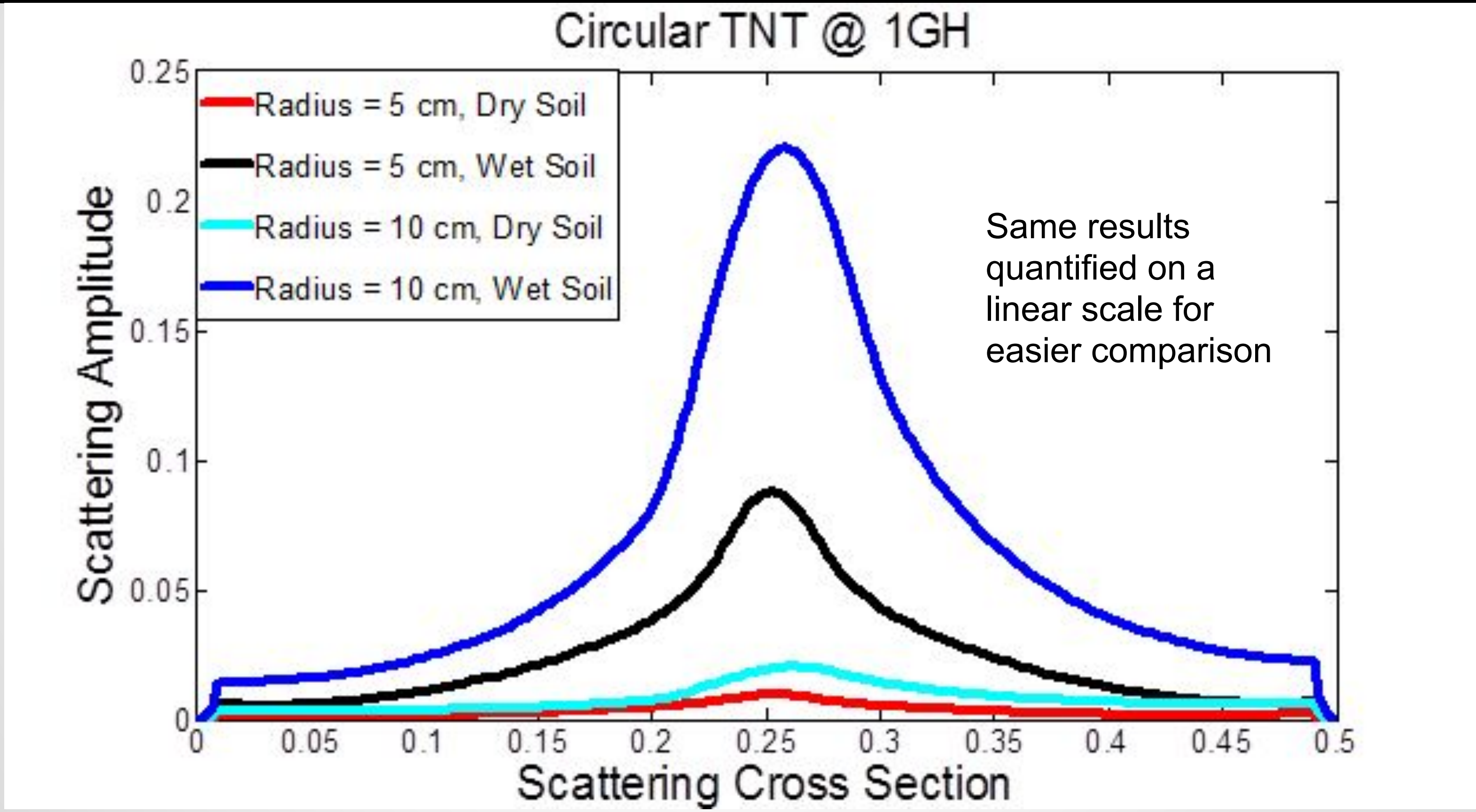

Dry Soil (1GHz, TNT Radius 5 cm)




Wet Soil (1GHz, TNT Radius 5 cm)

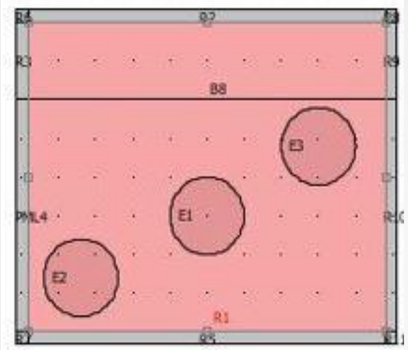
- Wet soil is more conducive to target scattering than dry soil due to its **higher conductivity** as a product of it’s *higher water concentration*
  - The higher conductivity allows the wave to stay in the medium and interfere more with the target object than the medium itself

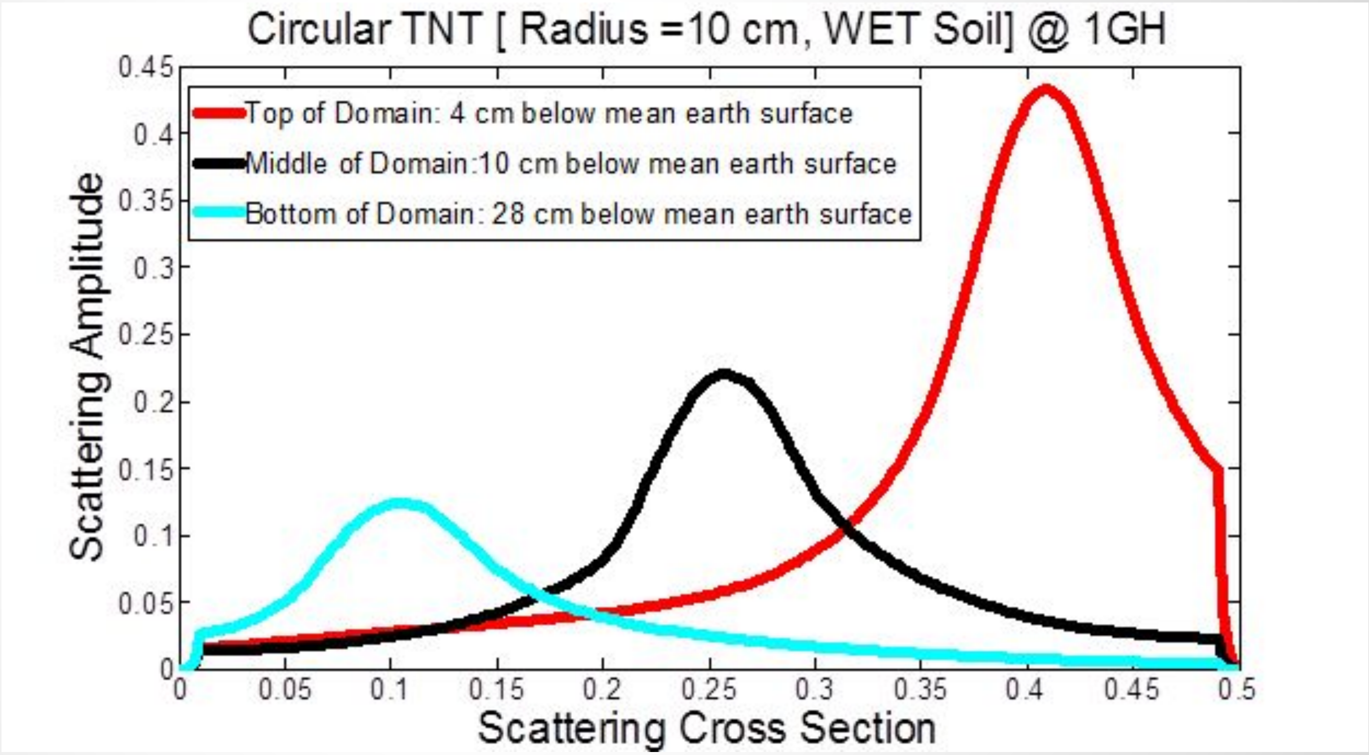
# Sizes Results




- Size of landmine directly correlates to the amount of scattering (less scattering= small object = not a mine)

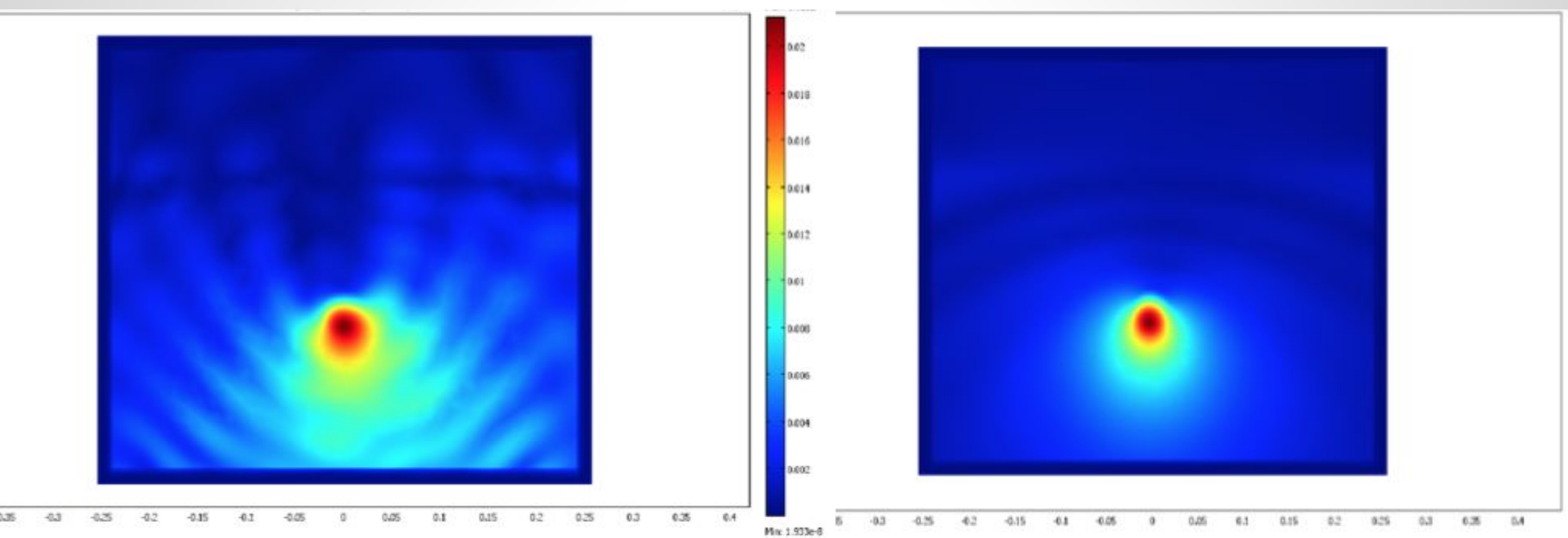
# Depth Variation Results




- TNT from higher up in the domain produces the highest amplitude of scattered waves and is most easily detected (landmines buried shallowly)

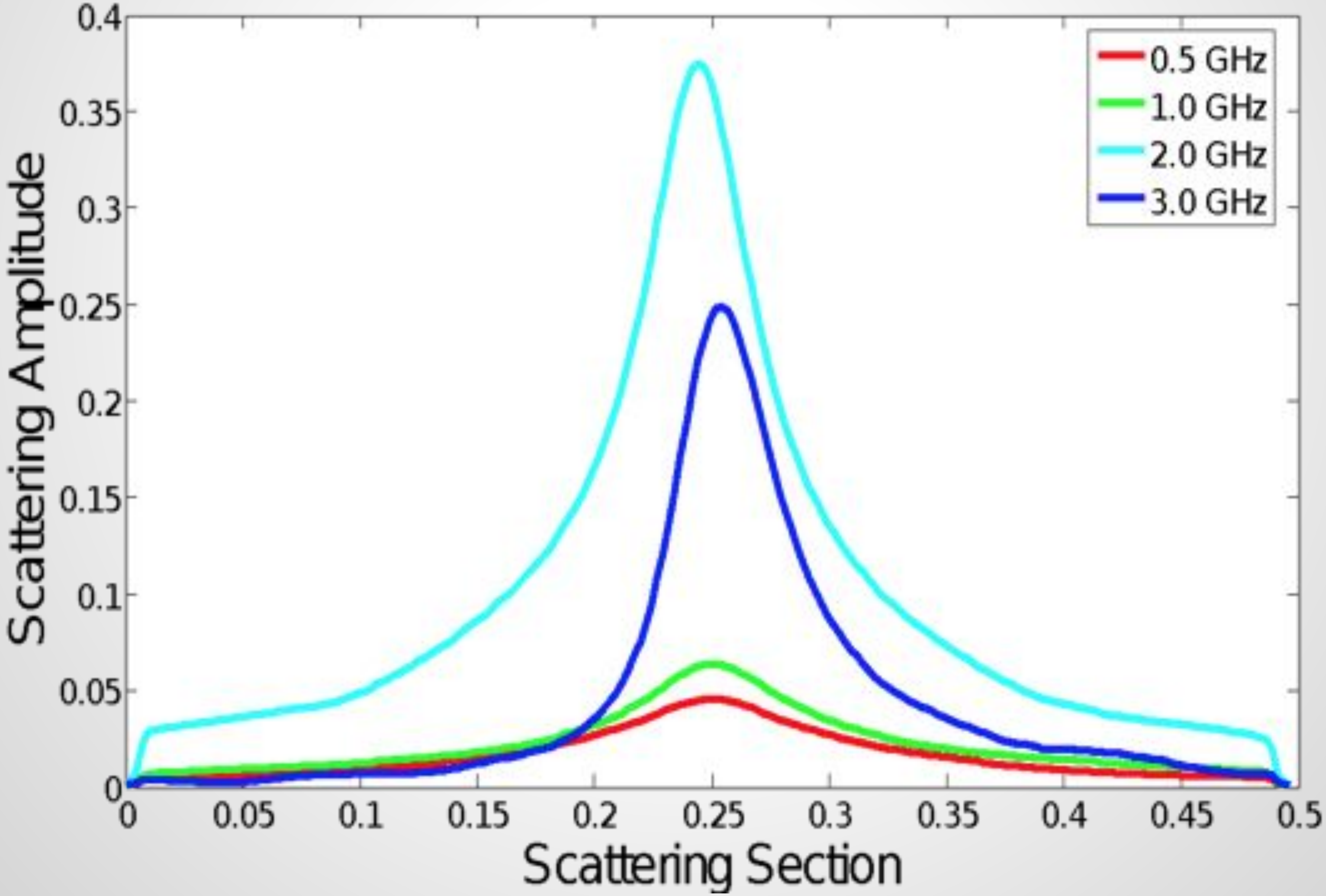
# Soil Layer Scattering Amplitudes Comparison



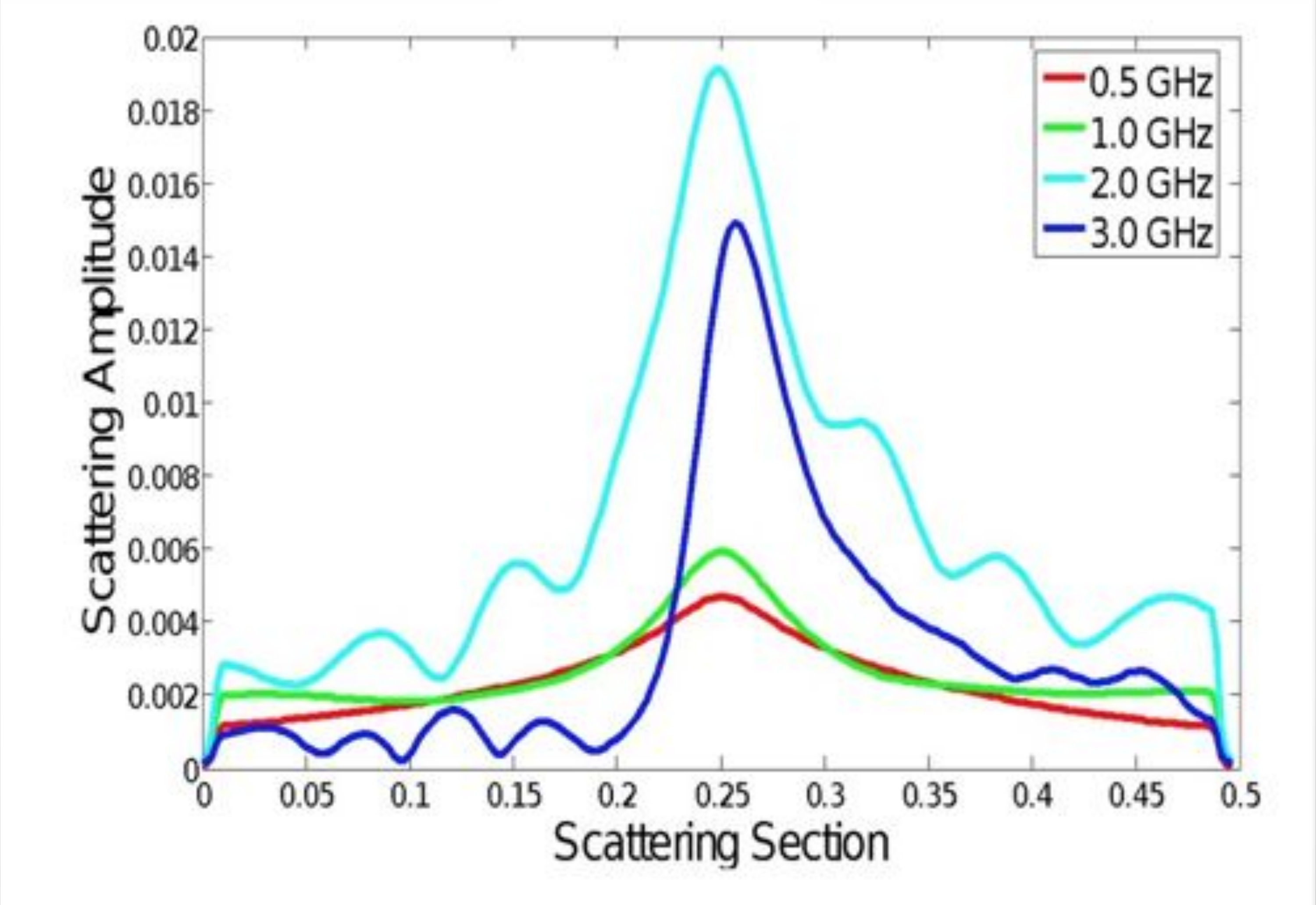
Air/Wet/Dry Soil Scattering
(1GHz, TNT Radius 5 cm)

Air/Dry/Wet Soil Scattering
(1GHz, TNT Radius 5 cm)

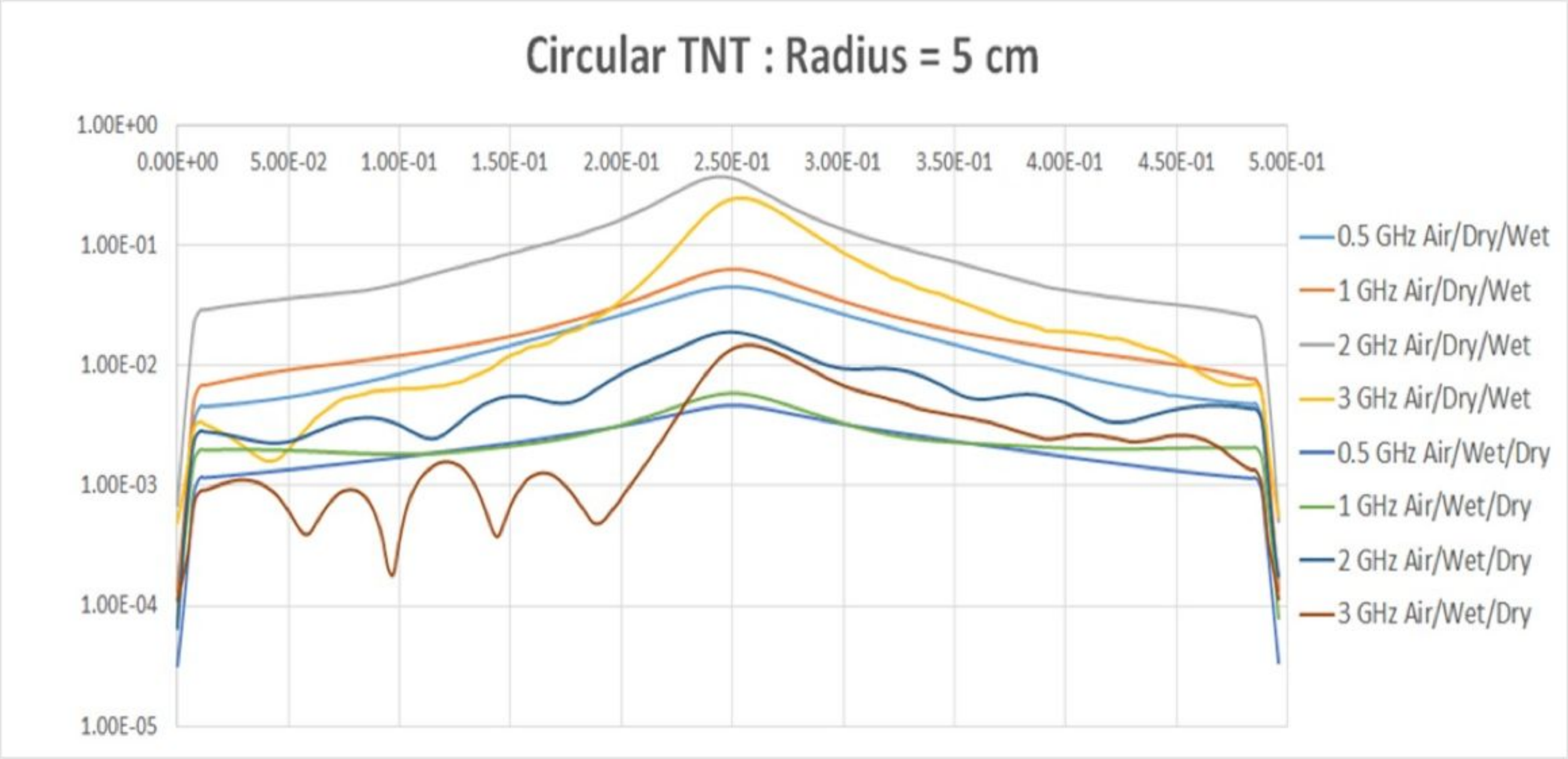
# Parametric Study- Air/Dry/Wet Soil Layers



# Parametric Study- Air/Wet/Dry Soil Layers



# Parametric Study-Wavelengths & Soil Layers



# CONCLUSION

- Successfully developed a template of various variations that may affect subsurface sensing of landmines in real world Ground Penetrating Radar situations
  - The template can also be applied to other sub-surface imaging problems with similar variations
- Future research and goals
  - Test variables of
    - other compositions of soil (clay, sand, silt)
    - different explosive types (RDX, C4, tetryl etc.)
    - variations in surface roughness

# References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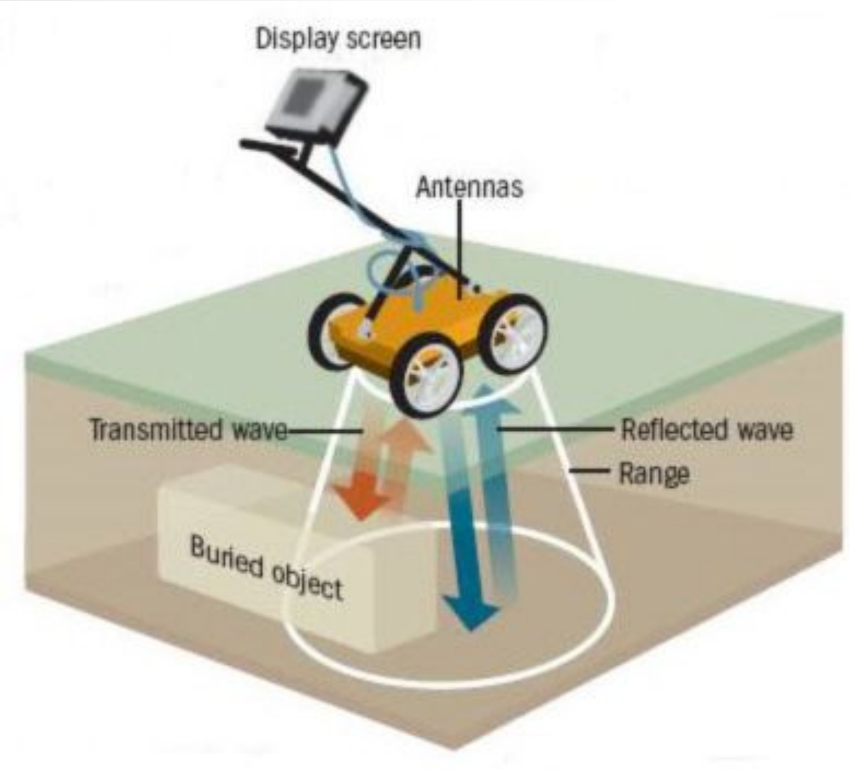
Thank You!

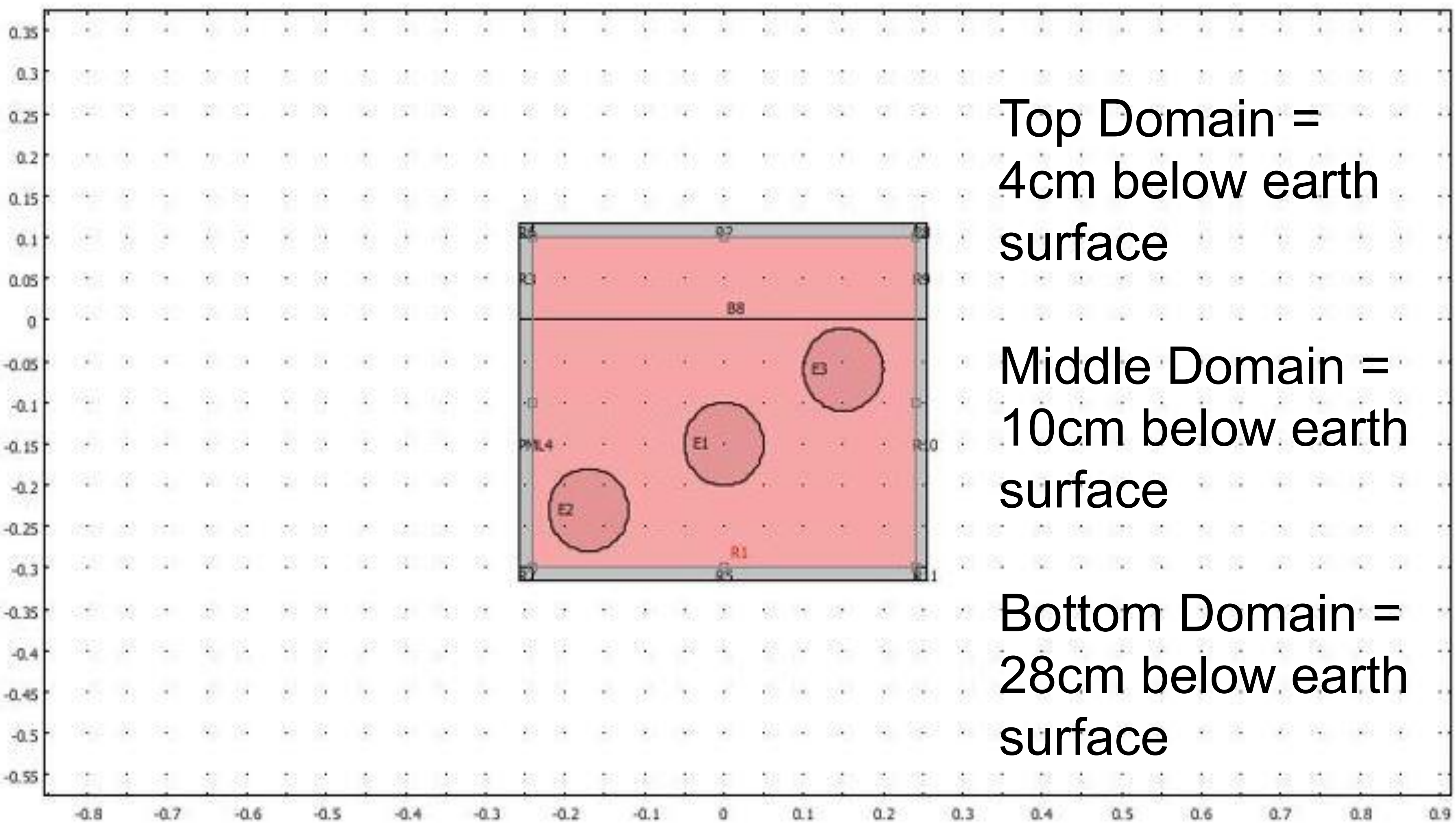
# Boundary Condition Physics In Comsol

- Boundary conditions necessary to truncate numerical domain
- Scattering Boundary Conditions
  - The boundary condition is transparent for an incoming electromagnetic waves.
  - It allows it to pass through perfectly matched layer.
  - The boundary condition are also used when we want boundaries to be transparent for scattering electromagnetic waves.
- PML- not a boundary condition in reality
  - Artificial absorbing domains
  - Commonly used to truncate computational regions in numerical methods to *simulate problems with open boundaries*
  - Reabsorb all scattered waves to eliminate reflection that causes interference
-

# Ground Penetrating Radar




# Depth Variation Modeling



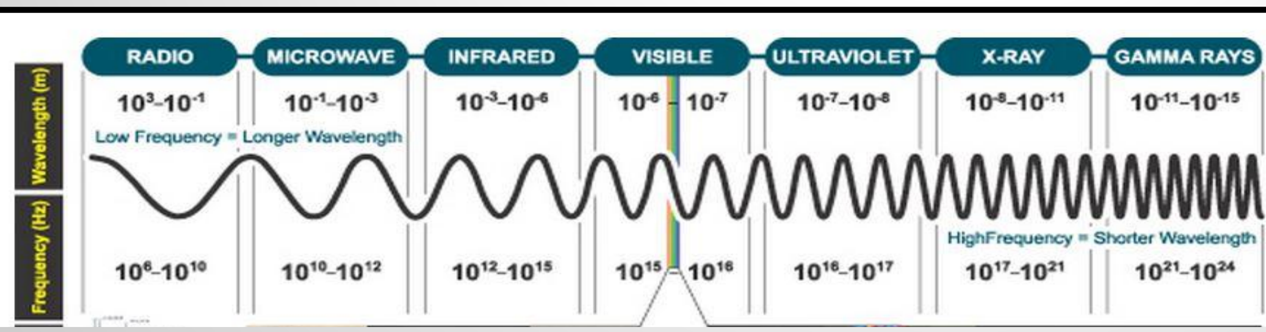

Top Domain = 4cm below earth surface

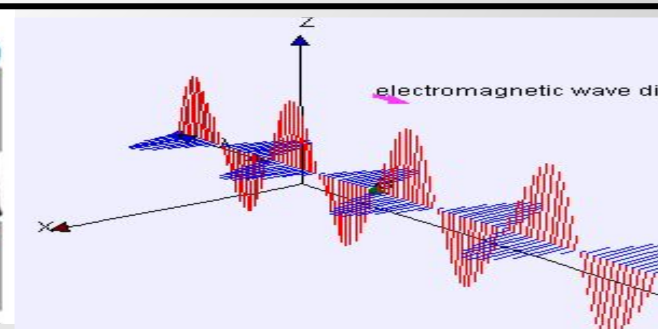
Middle Domain = 10cm below earth surface

Bottom Domain = 28cm below earth surface

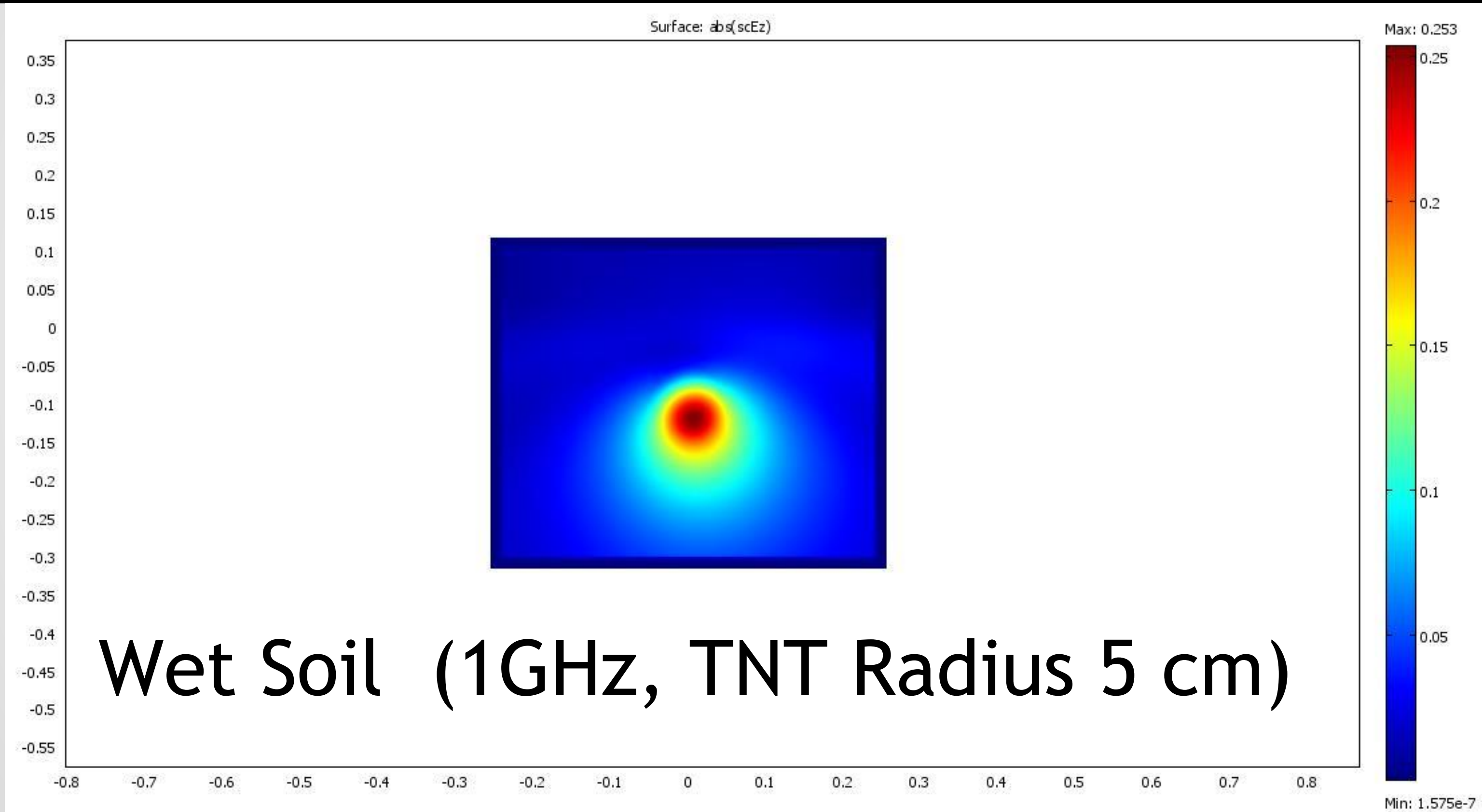
# Electromagnetic Waves

- Electric and Magnetic field vectors propagating perpendicular to each other
- Scattering dependent on microphysical properties of individual materials involved
  - ex: landmines, soil, air
  - relative permittivity, permeability, conductivity
- <u>Radio waves</u>: longer waves = optimal detection wavelength for landmine sizes



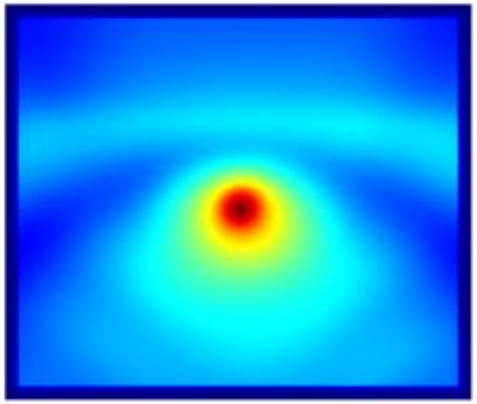
# Wet Soil Type Results

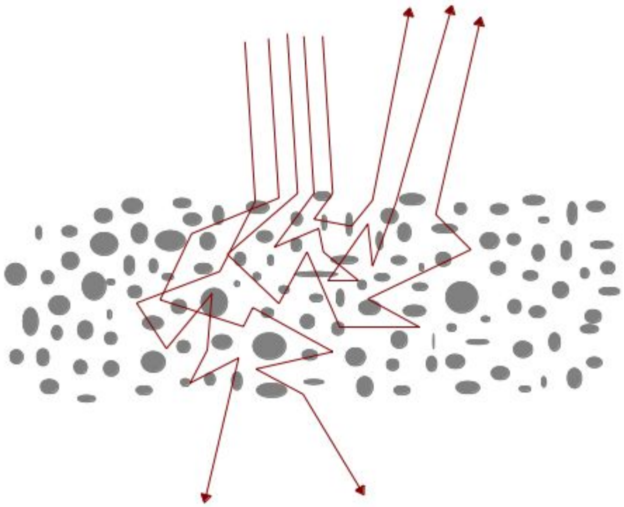



Wet soil is more conducive to target scattering due to the higher conductivity as a product of higher water concentration

# Subsurface Sensing

- ***Detecting*** and ***identifying*** underground objects
- Transmission, Scattering, and Absorption of **Electromagnetic Waves (EMW)**
- **CenSSIS-** Center for Subsurface Sensing and Imaging Systems
  - biomedical, environmental, and geophysical problems
- Problem: distinguishing the effect that the medium has on the EM wave from that of the desired object





# Thank You!

# Microphysical Parameters of Materials

| Material | Relative permittivity | Relative permeability | Conductivity |
|---|---|---|---|
| Air | 439.2 | 1 | 0 |
| Dry Soil | 1273+31i | 2.9 | 0.004 |
| Wet Soil | 1756+395i | 4 | 0.049 |
| TNT | 2.9 | 1 | 4.8e-4 |

# COMSOL

- Comsol Finite Element Method Software allows modal creation and an accurate *computational simulation of real world problems*
  - Easily allows editing and testing of various variables
- Other Finite Element Packages

  PZFlex - www.pzflex.com

  ANSYS - www.ansys.com

  AbaqusFEA – www.3ds.com

  MSC/NASTRAN - www.mscsoftware.com

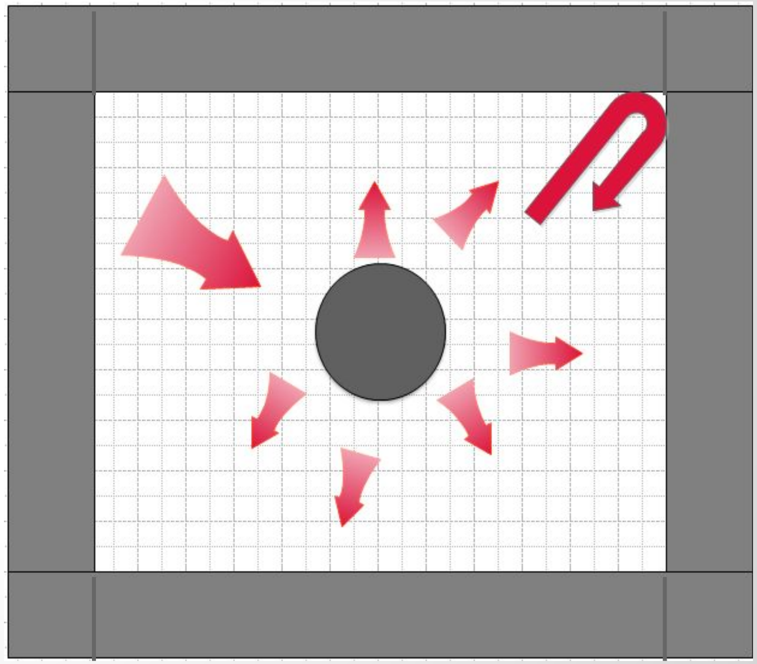
  ADINA- www.adina.com

  ALGOR – www.algor.com
- Why COMSOL?
  - Most recent FEM (Finite Element Modeling) software
  - Integrates well with MATLAB and uses MATLAB syntax
  - Allows user programing of unincluded differential equations
  - Interfaces with most CAD software and allows for import of CAD drawings

# PML (Perfectly Matched Layer)

## Importance

If we model a wave hitting some device or object, it will scatter the applied wave into potentially many directions. We don't want these scatter waves to reflect from the boundaries of the grid. We also don't want them to re-enter from the other side of the grid

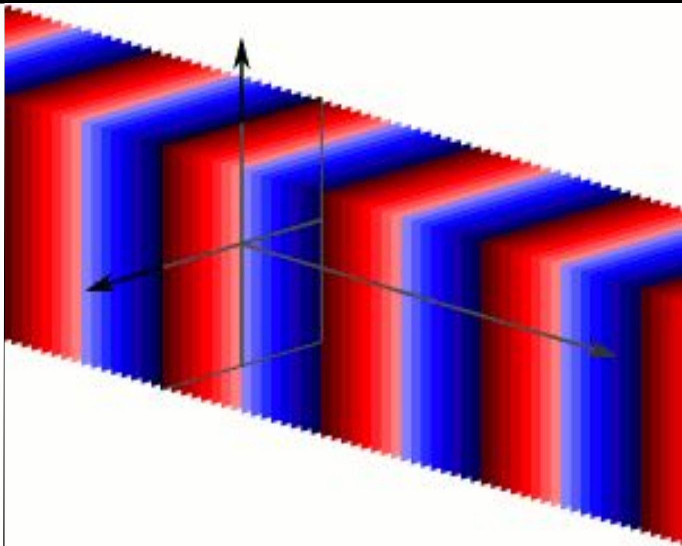


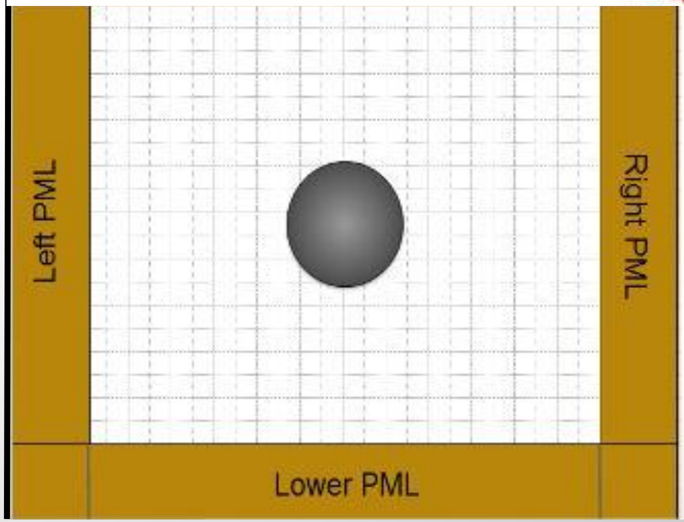
## Applications

Detecting objects underneath water surface, buried mines, pollutants, unexploded ordnance, tunnels and much more

# EM Wave Physics In Comsol

- **Plane Waves**
  - Propagating in one direction
  - Simple in computing
- **Perfectly Matched Layers**
  - Artificial absorbing domains
  - Commonly used to truncate computational regions in numerical methods to *simulate problems with open boundaries*
  - Reabsorb all scattered waves to eliminate reflection that causes interference





# Scattering Physics In Comsol

- The wave propagate from top to bottom through air and is scattered by a target in different directions
- Some waves reflects back while others enters into the medium due to continuity and refractive index
- After the wave enters into another medium and hits the target wavelength will be smaller due to refractive index