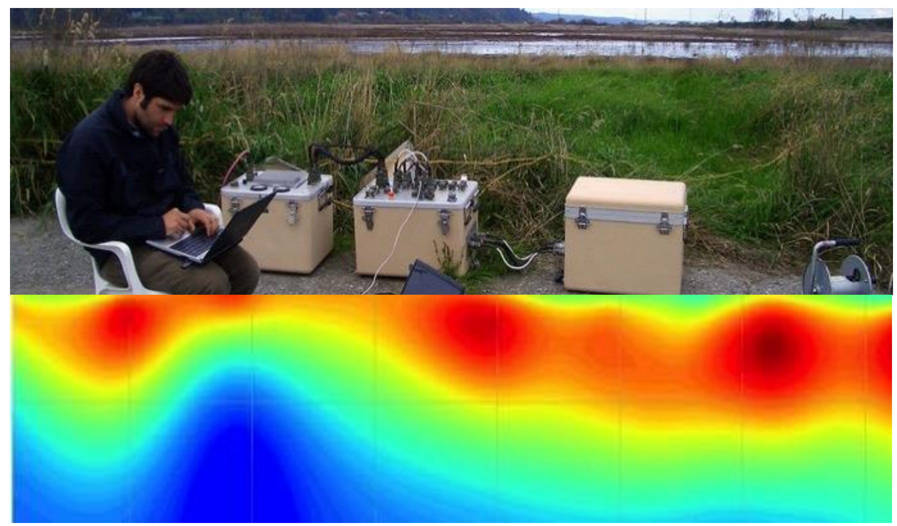
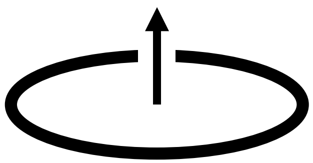
EOSC 350 : Environmental, Geotechnical and Exploration Geophysics I

EM EM-31

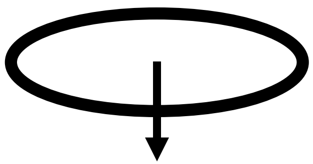


September – December, 2017

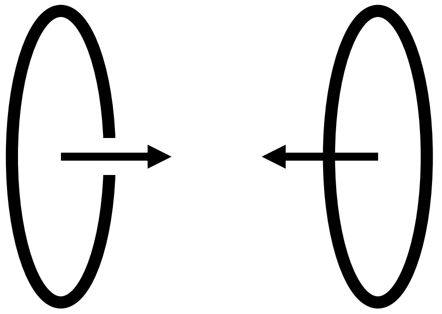
How to draw 3D loops and field lines on a 2D paper



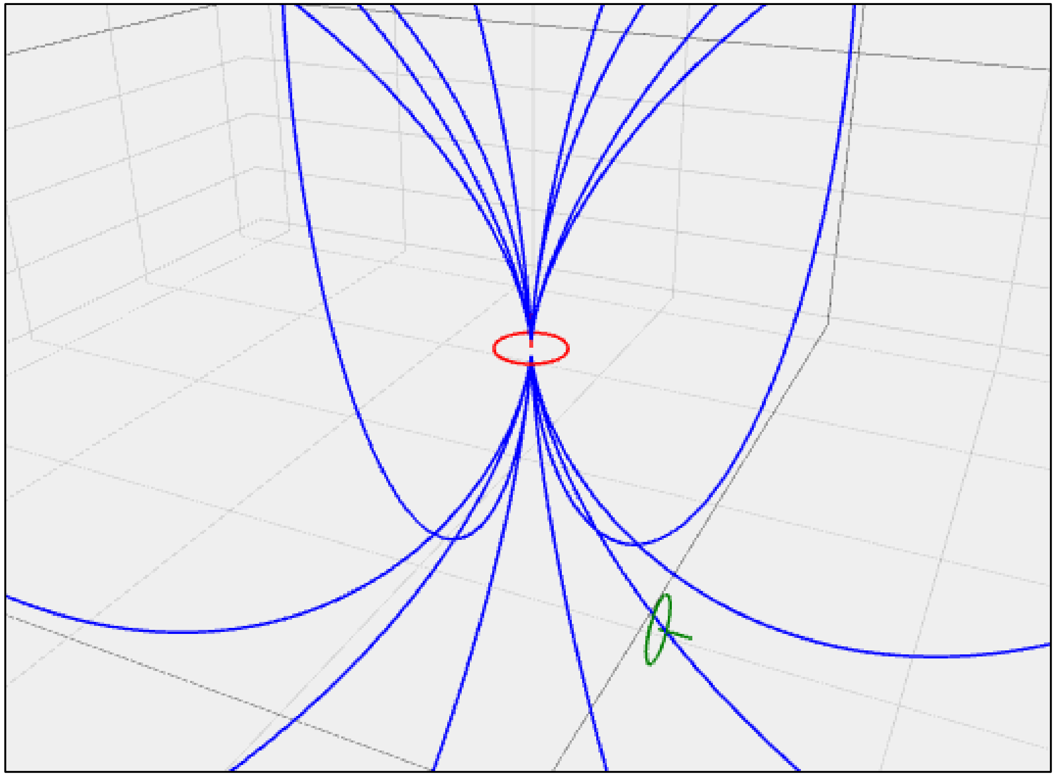
Viewing from above
Dipole upwards



Viewing from above
Dipole downwards

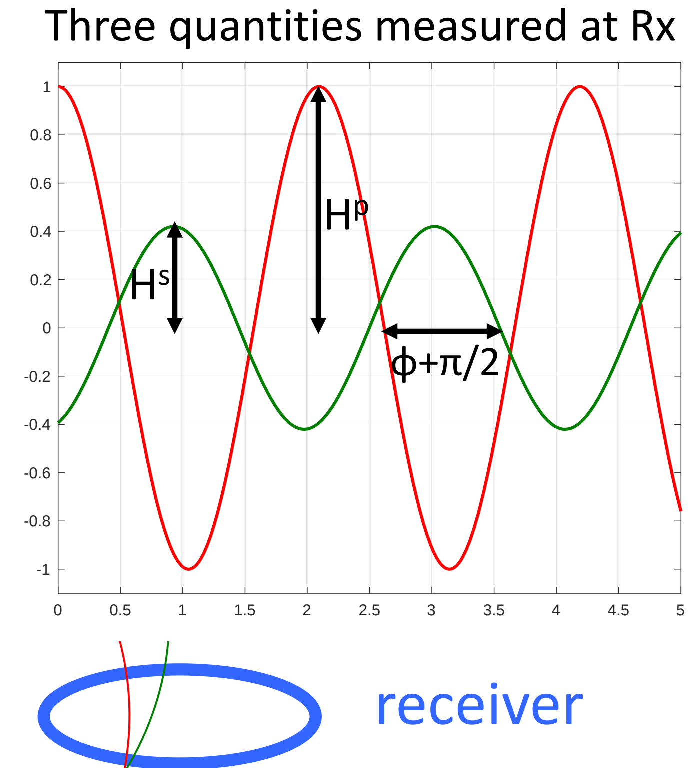


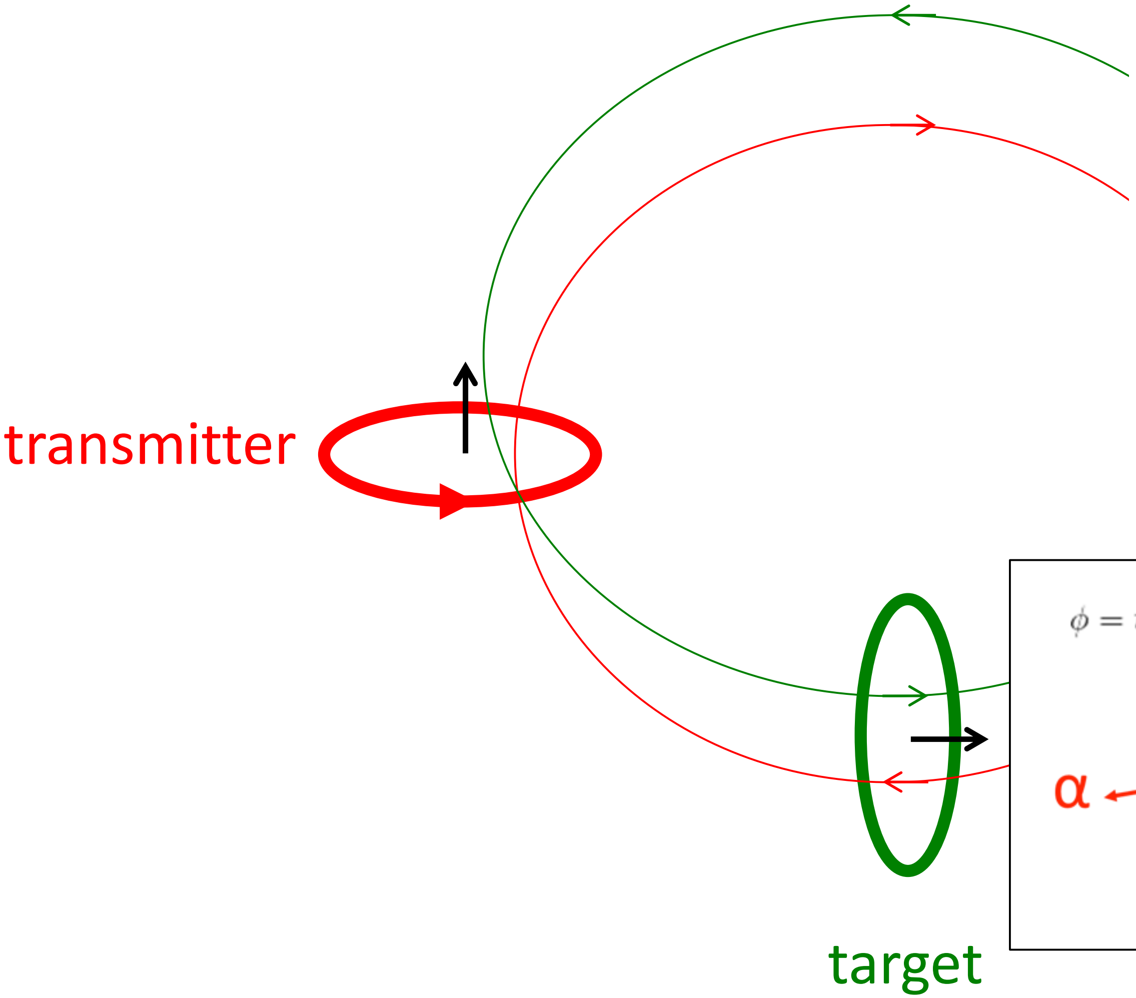
Viewing from right side

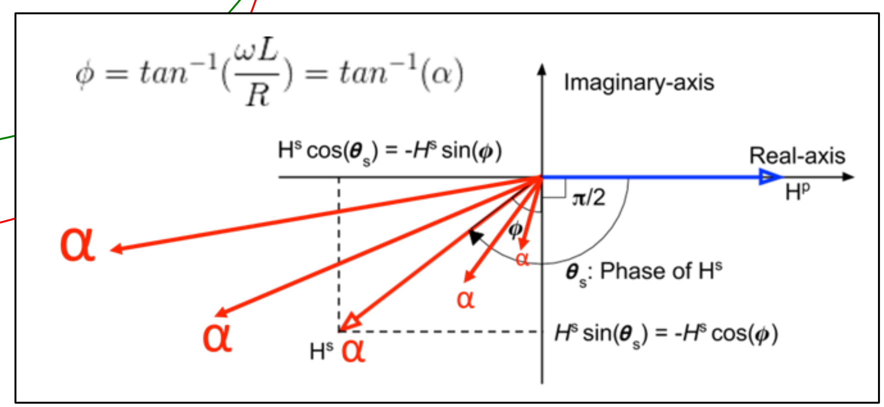


Interactive 3D visualization in “MagDipoleLoops3D.ipynb”
clone from https://github.com/yangdikun/magLab.git

3-loop Model

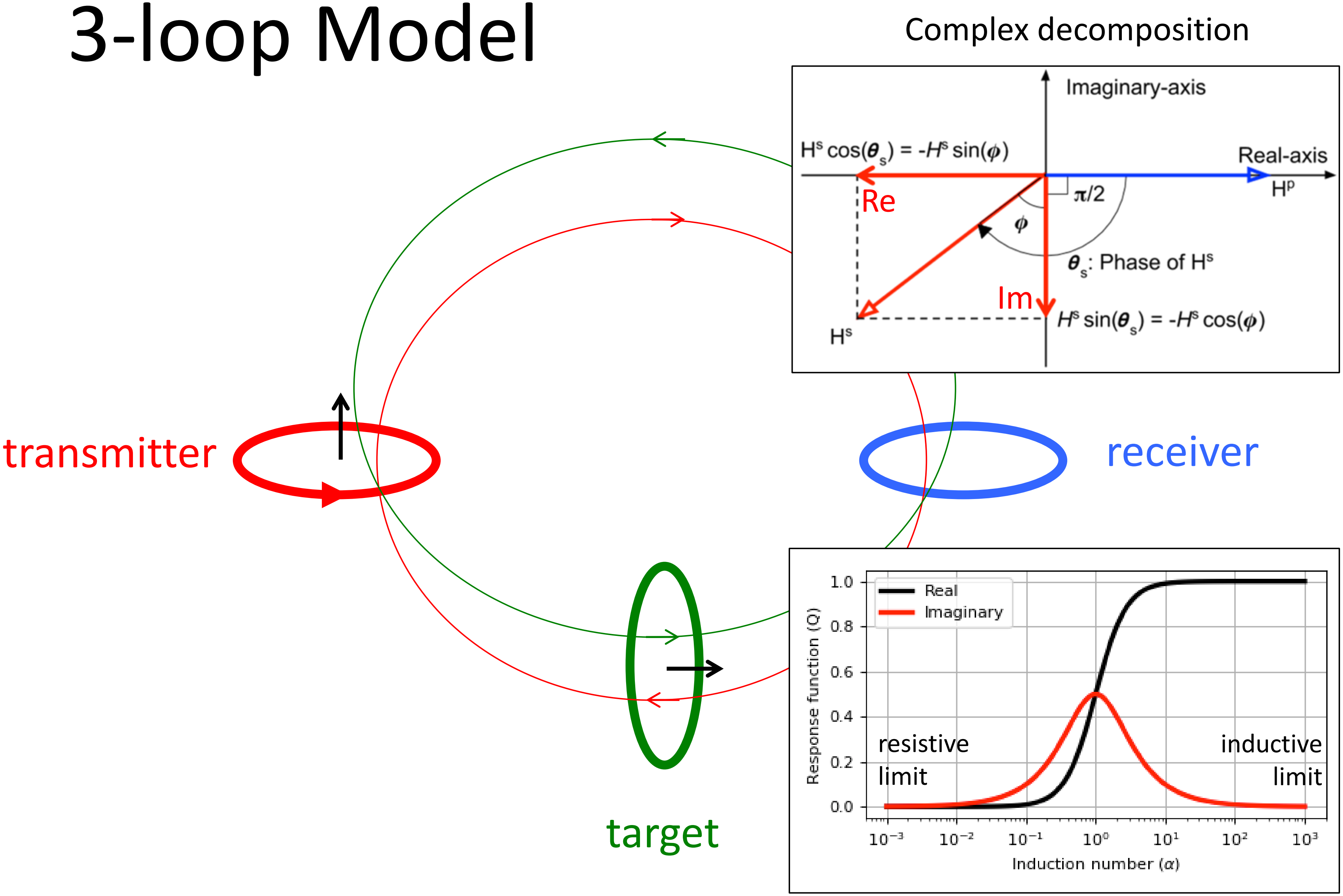






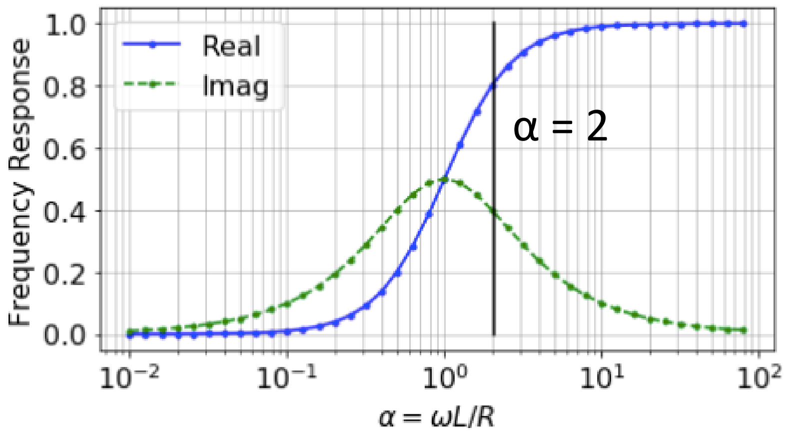
- $\mathbf{H^s}$ and $\boldsymbol{\phi}$ depend on $\boldsymbol{\alpha}$
- $\boldsymbol{\alpha}$ depends on $\boldsymbol{\omega}$, **L**, **R**

3-loop Model

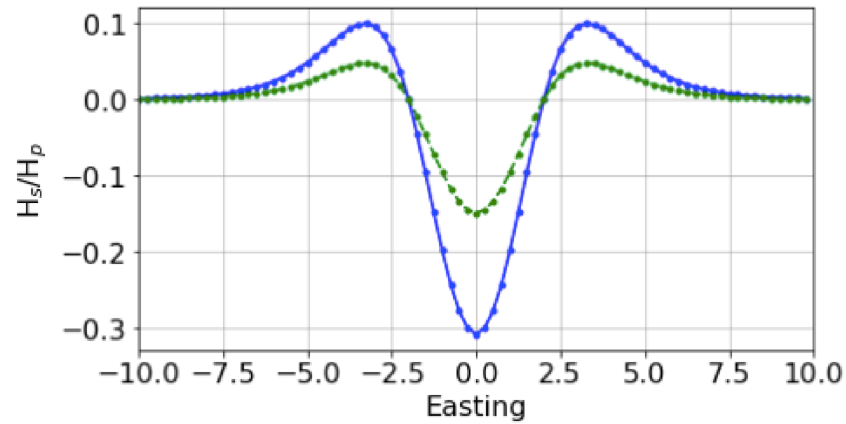

Complex decomposition
Imaginary-axis
H^s cos(θ_s) = -H^s sin(φ)
Real-axis
H^p
Re
π/2
φ
θ_s: Phase of H^s
Im
H^s sin(θ_s) = -H^s cos(φ)
H^s
transmitter
receiver
target
Real
Imaginary
Response function (Q)
resistive limit
inductive limit
Induction number (α)
1.0
0.8
0.6
0.4
0.2
0.0
10^-3
10^-2
10^-1
10^0
10^1
10^2
10^3

Data along a Profile

Response function of different α



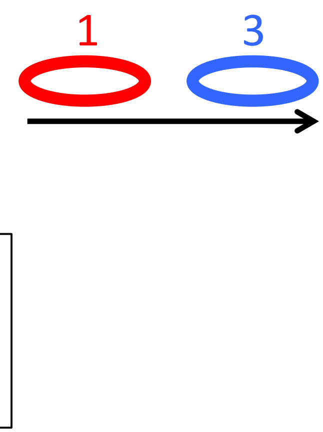
Data along a profile for α = 2



$$\frac{H_3^s}{H_3^p} = -\frac{M_{12}M_{23}}{M_{13}L}\left[\frac{\alpha^2 + i\alpha}{1+\alpha^2}\right]$$

Coupling
- location, orientation
- overall magnitude

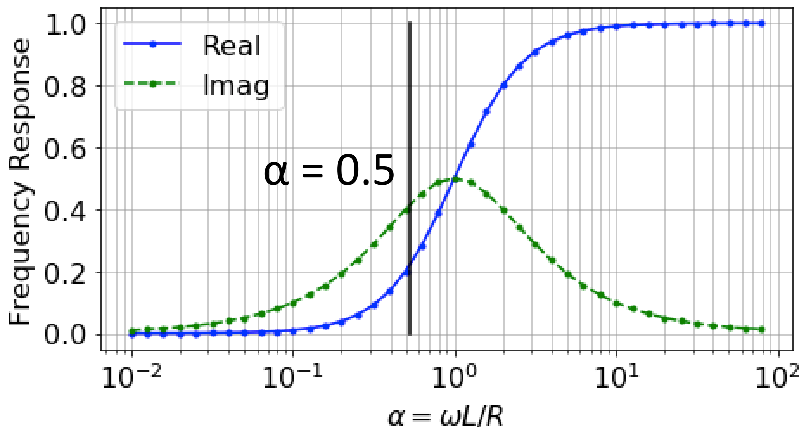
Induction
- properties of loop 2
- how much in Re & Im



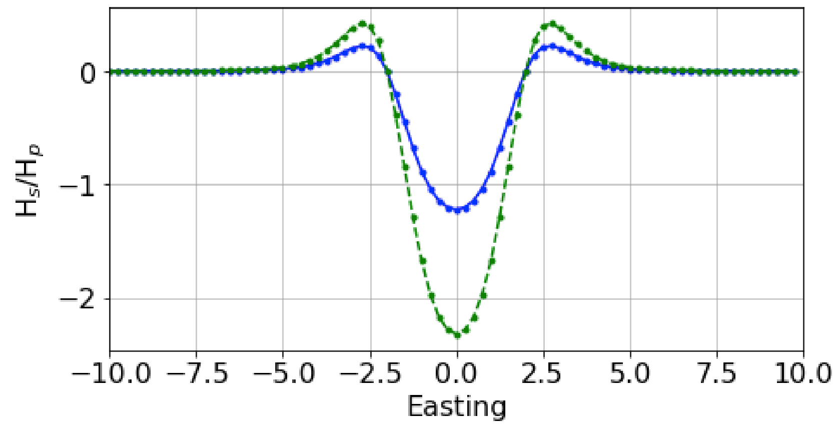
Interactive demo in “EM_ThreeLoopModel.ipynb”, clone from https://github.com/geoscixyz/gpgLabs.git

Data along a Profile

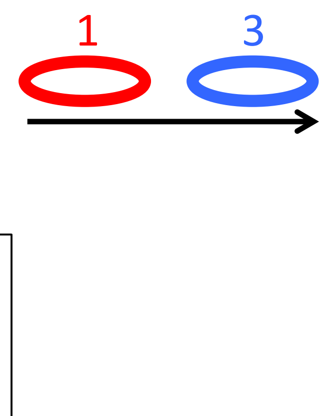
Response function of different α



Data along a profile for α = 0.5



$$\frac{H_3^s}{H_3^p} = -\frac{M_{12}M_{23}}{M_{13}L}\left[\frac{\alpha^2 + i\alpha}{1+\alpha^2}\right]$$

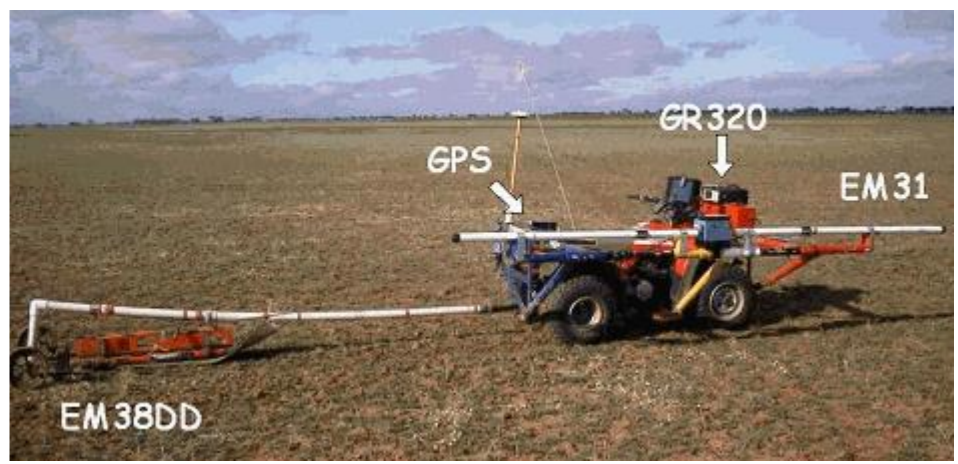


Coupling
- location, orientation
- overall magnitude

Induction
- properties of loop 2
- how much in Re & Im

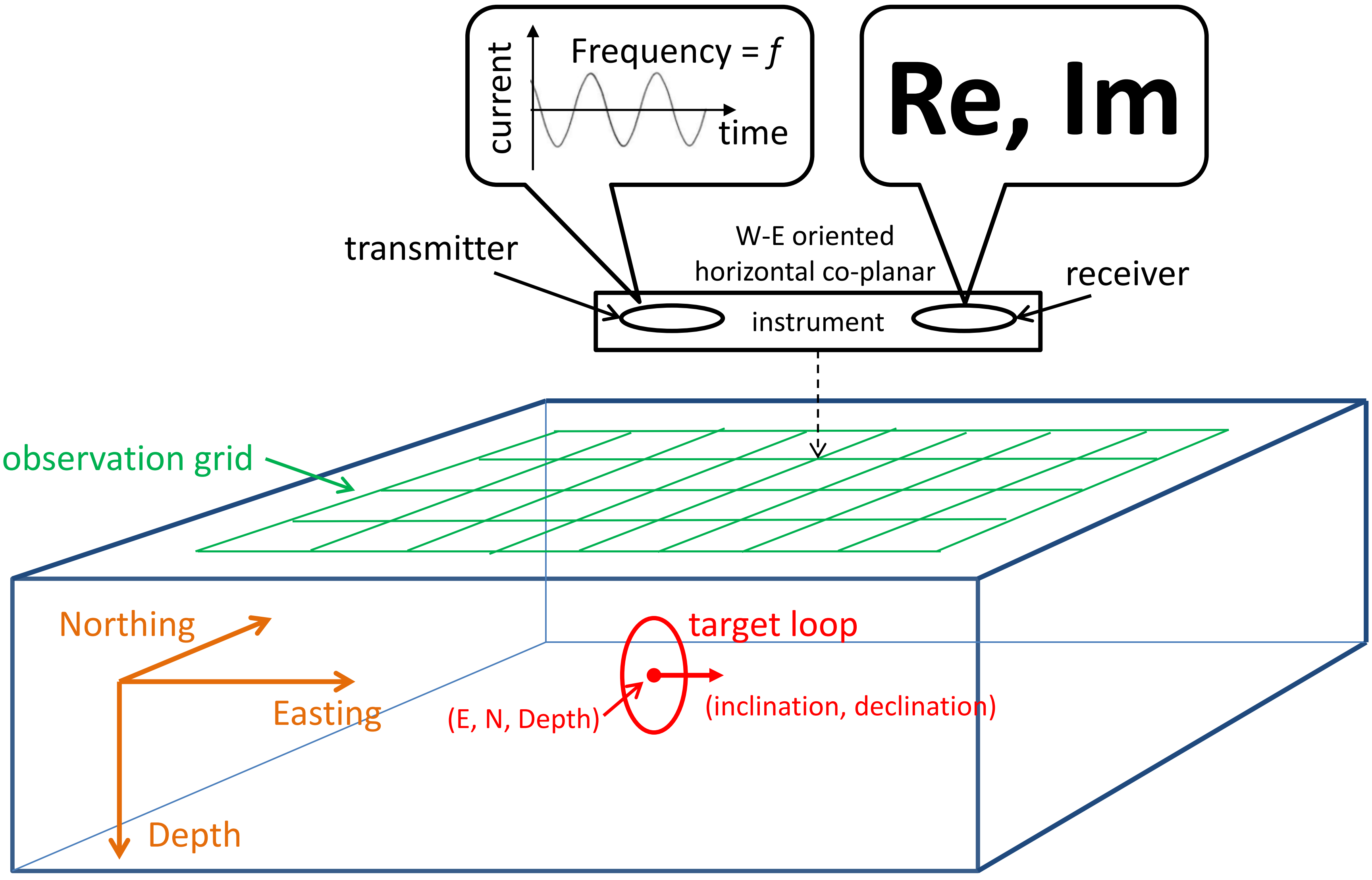
Interactive demo in “EM_ThreeLoopModel.ipynb”, clone from https://github.com/geoscixyz/gpgLabs.git

EM-31

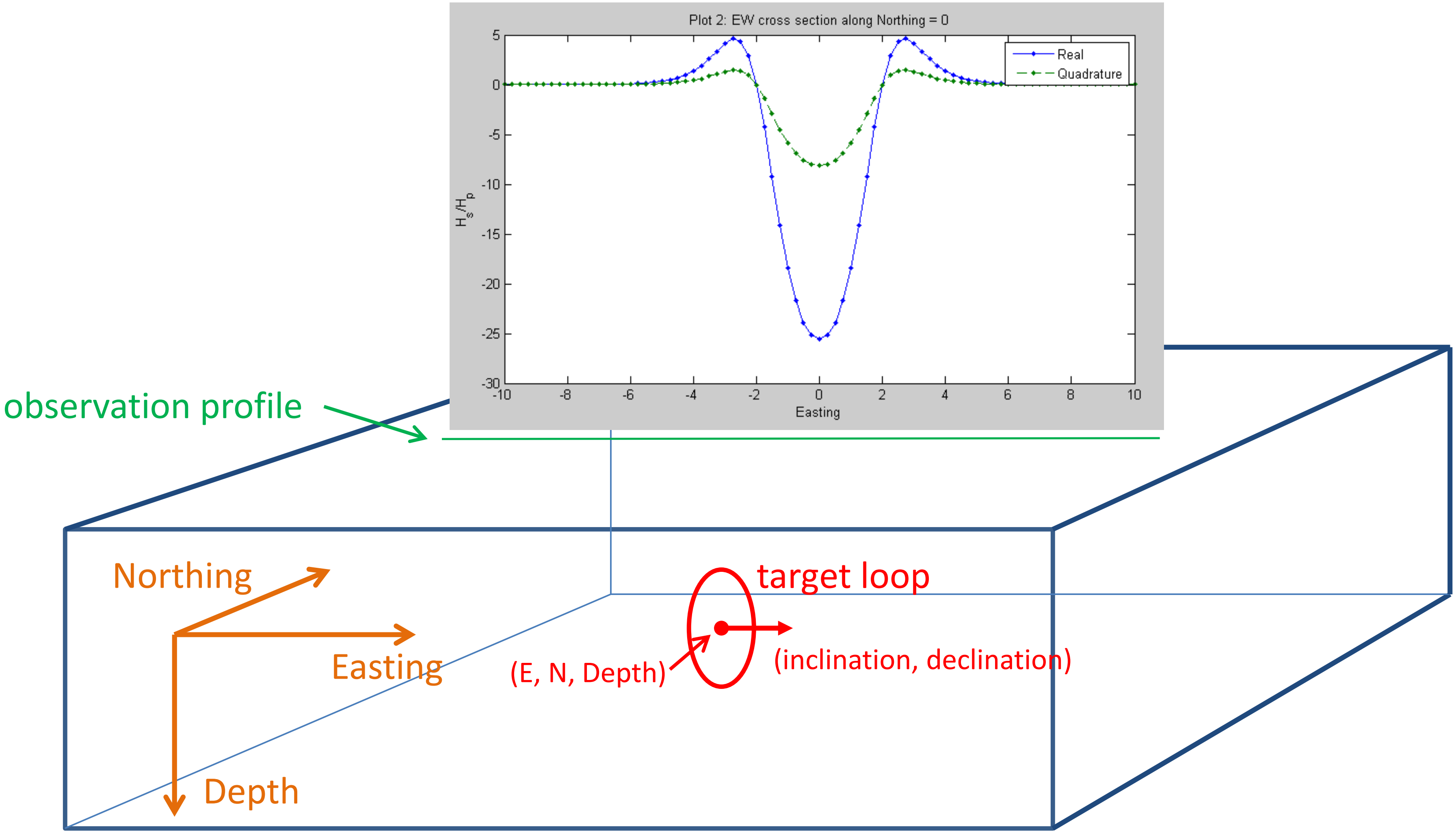


- Frequency = 9.8 kHz
- Tx-Rx spacing = 3.66 m
- Horizontal or vertical coplanar
- “Ground conductivity meter”

EM-31 Data

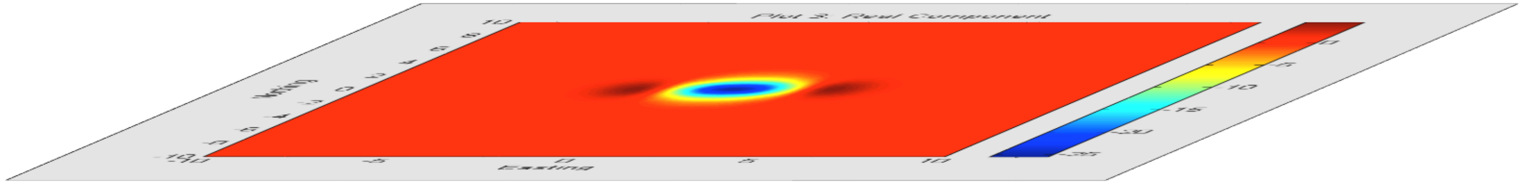

current
Frequency = f
time
Re, Im
transmitter
W-E oriented
horizontal co-planar
receiver
instrument
observation grid
Northing
Easting
Depth
target loop
(E, N, Depth)
(inclination, declination)

EM-31 Data

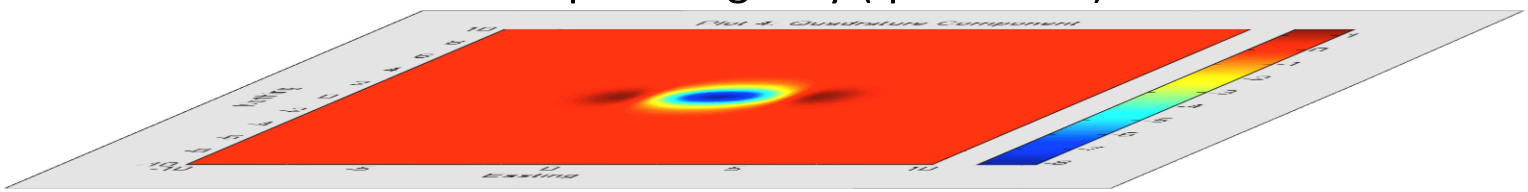

Plot 2: EW cross section along Northing = 0
Real
Quadrature
H_s/H_p
Easting
5
0
-5
-10
-15
-20
-25
-30
-10
-8
-6
-4
-2
0
2
4
6
8
10
observation profile
Northing
Easting
Depth
target loop
(E, N, Depth)
(inclination, declination)

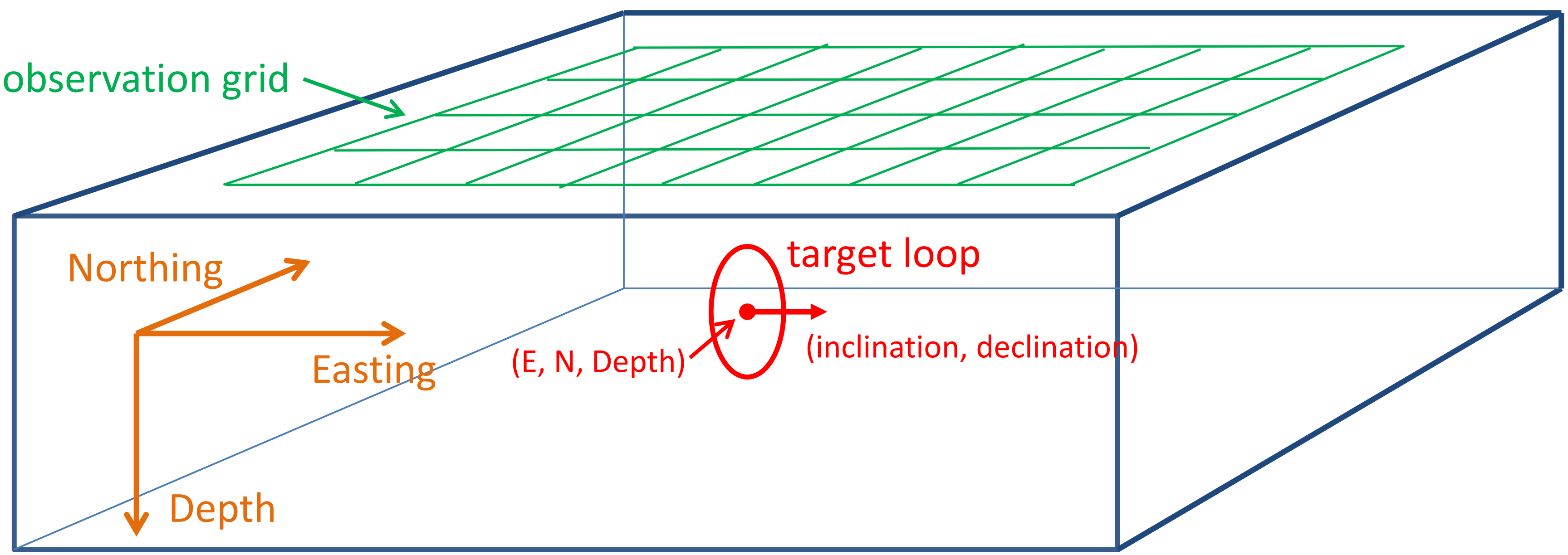
EM-31 Data

Map of real (in-phase) data

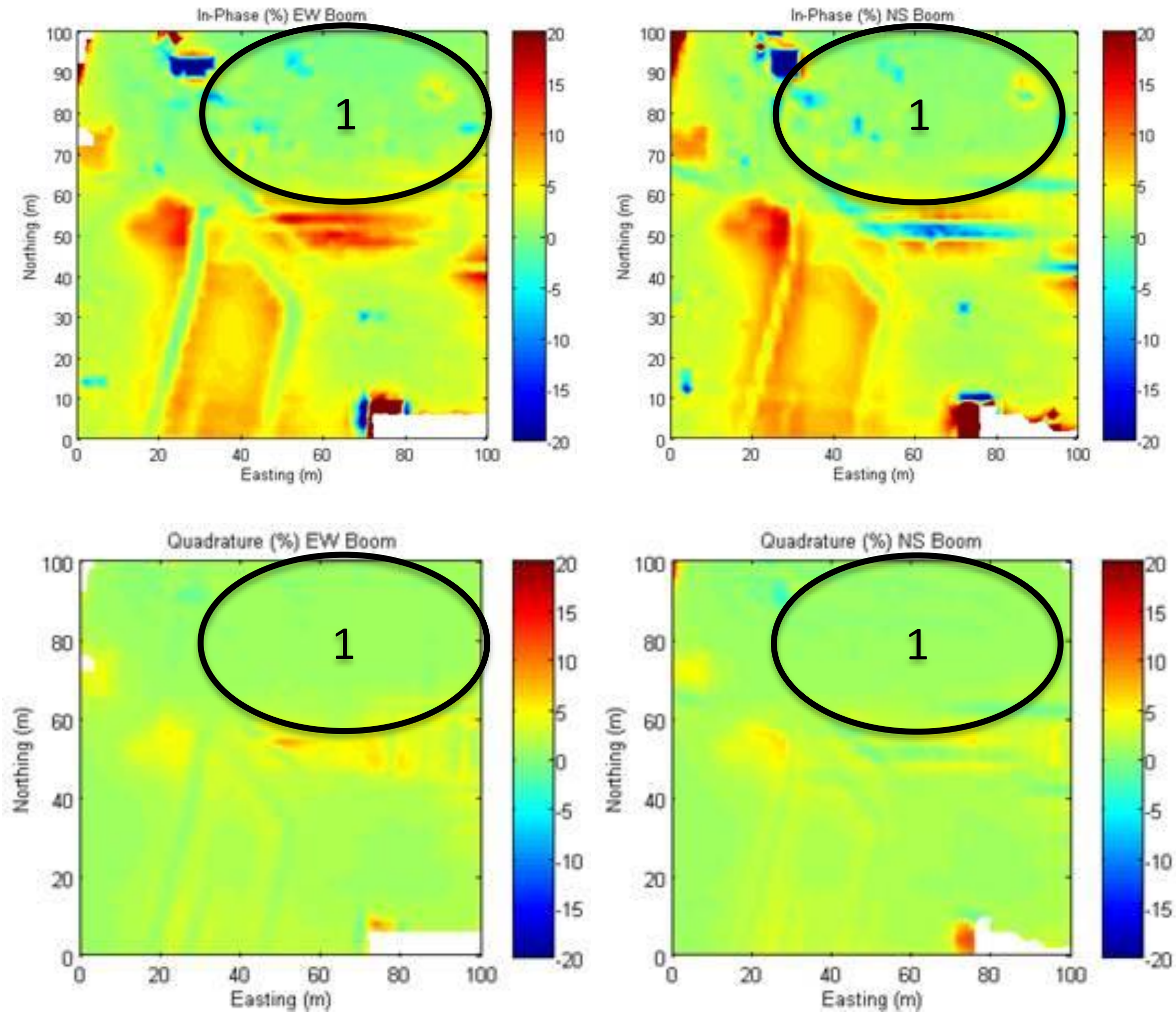


Map of imaginary (quadrature) data



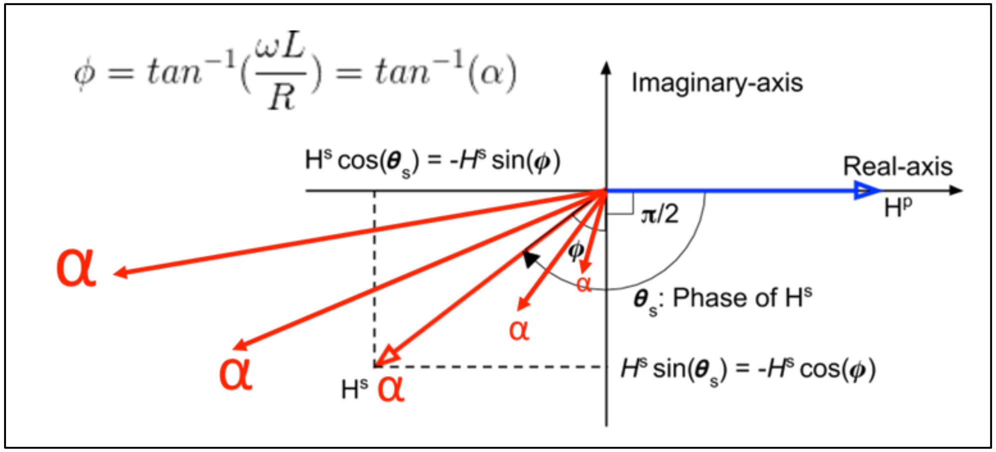


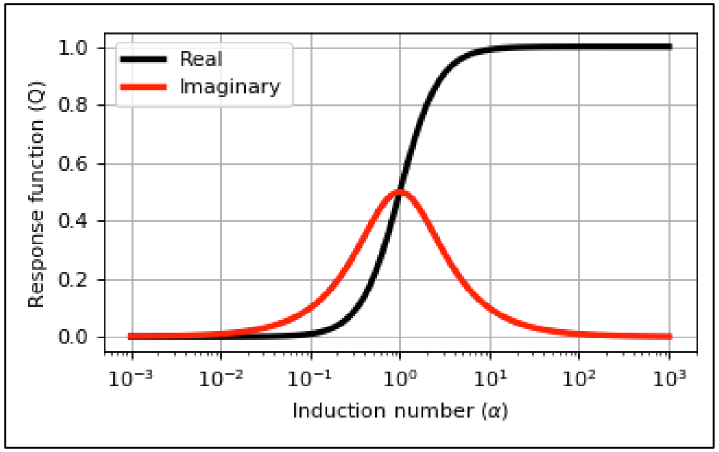
EM-31 Data Interpretation



Data Feature 1:
Uniform, smooth and small

EM-31 Data at Low Induction



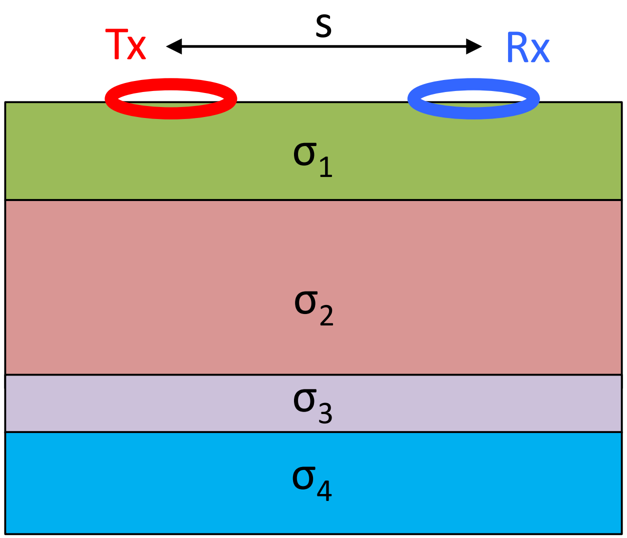


Small **Re** and small **Im** on the data maps, **α** big or small?

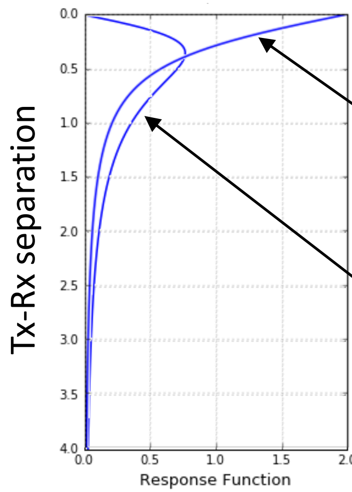
Low induction number:

- **H^s** data mostly in quadrature, **Im** > **Re** ≈ 0
- Very small induced current
- Subdivide the earth into many pieces; each piece interacts with Tx-Rx independently without interaction between any two pieces (**recall low induced magnetization in magnetics, easy calculation using superposition!**)

Apparent Conductivity



Sensitivity ϕV



Vertical coplanar (VCP)

- only sensitive to σ_1

Horizontal coplanar (HCP)

- mostly sensitive to σ_1
- also sensitive to σ_2

If $\sigma = \sigma_1 = \sigma_2 = \sigma_3 = \sigma_4$ (half-space)

$$\mathbf{Re} \approx 0 \qquad \mathbf{Im} = \frac{\omega \mu_0 \sigma s^2}{4}$$

Derive apparent conductivity

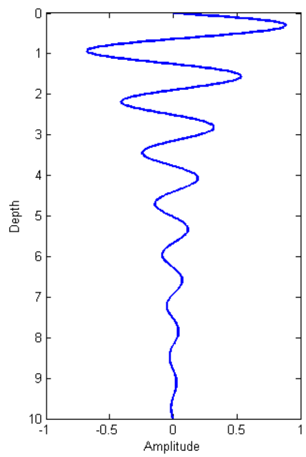
$$\sigma_a = \frac{4}{\omega \mu_0 s^2} \mathbf{Im}$$

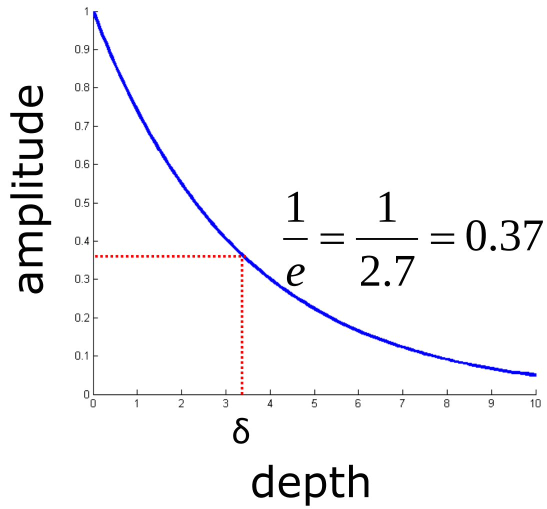
If $\sigma_1 \neq \sigma_2 \neq \sigma_3 \neq \sigma_4$ (layered earth), apparent conductivity (transformed **Im** data) is weighted sum of contributions from each layer.

$$\sigma_a = \int_0^\infty \phi_V(z) \sigma(z) dz$$

For instrument not on the surface, $\sigma_1 = 0$.

Low Induction: s << δ



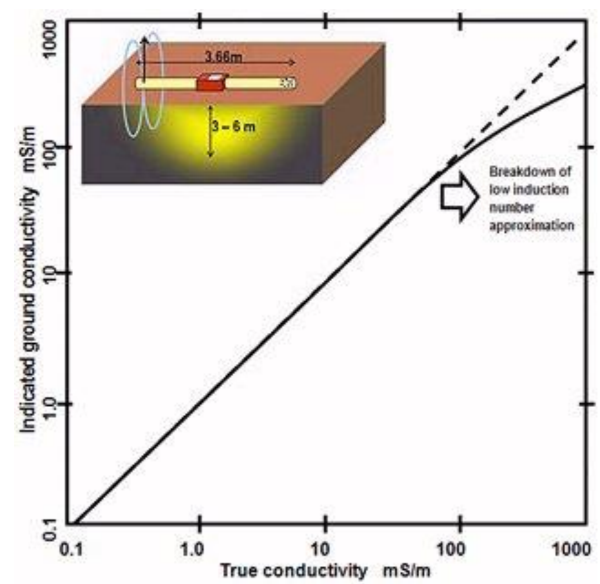


Skin depth of a uniform half-space

$$\delta = 506 \sqrt{\frac{\rho}{f}} \quad \text{meter}$$

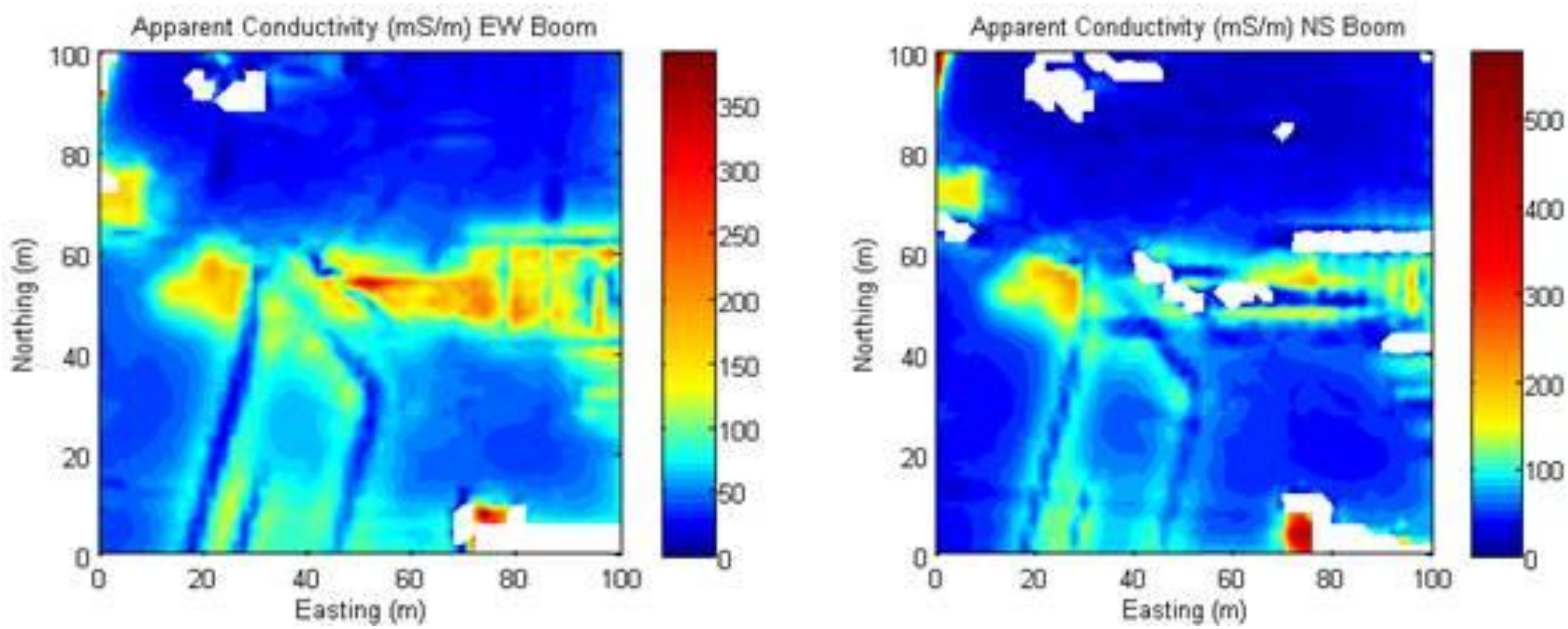
where ρ is resistivity in Ωm and f is frequency in Hz.

Back-of-envelope calculation:
For EM-31 operating at 9.8 kHz, at what resistivity would the low induction break down for a half-space?



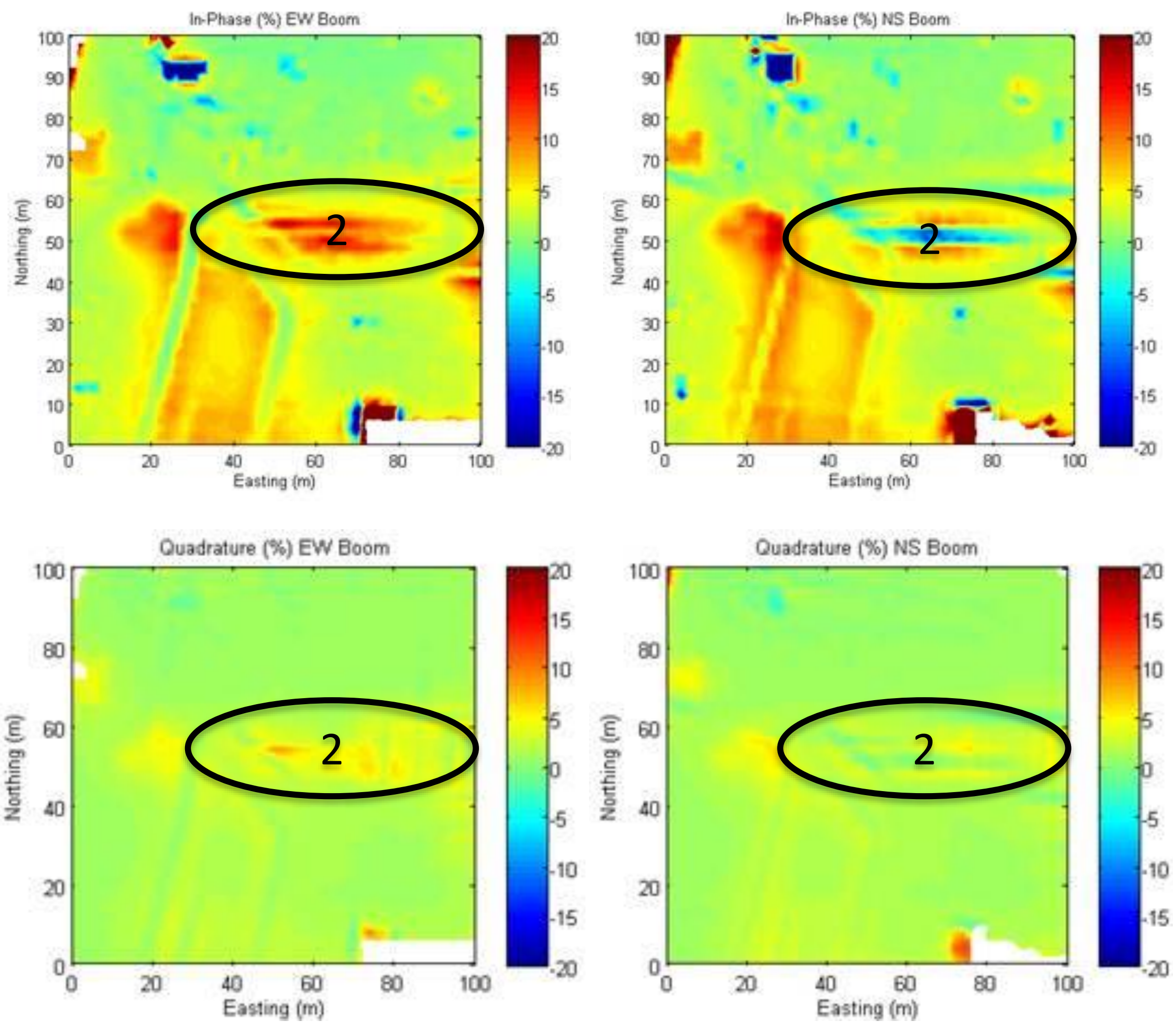
Apparent Conductivity

$$\sigma_a = \frac{4}{\omega \mu_0 s^2} \mathbf{Im}$$



Question: Which area on the maps is the most likely to have a reliable estimate of the ground conductivity?

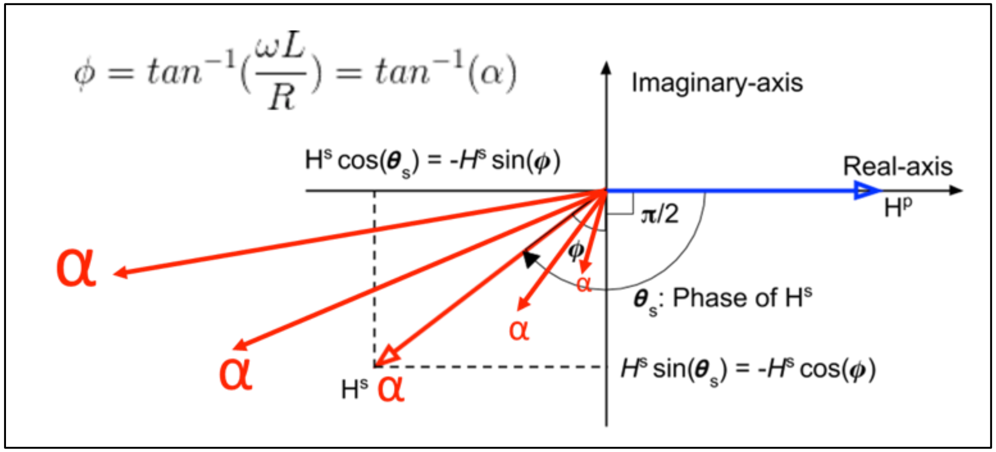
EM-31 Data Interpretation

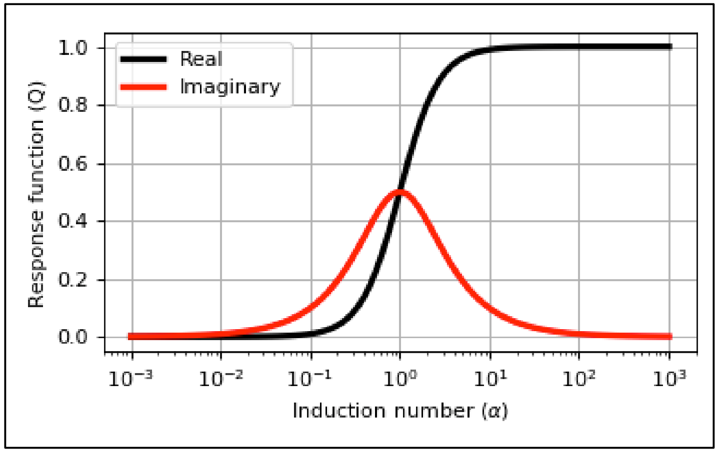


Data Feature 1:
Uniform, smooth and small

Data Feature 2:
Abrupt change
Positive and negative
Large **Re** and small **Im**

EM-31 Data at High Induction

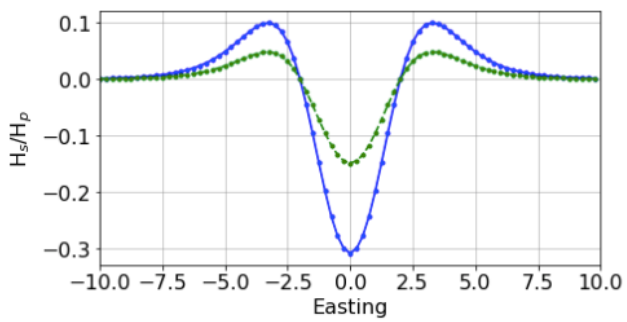




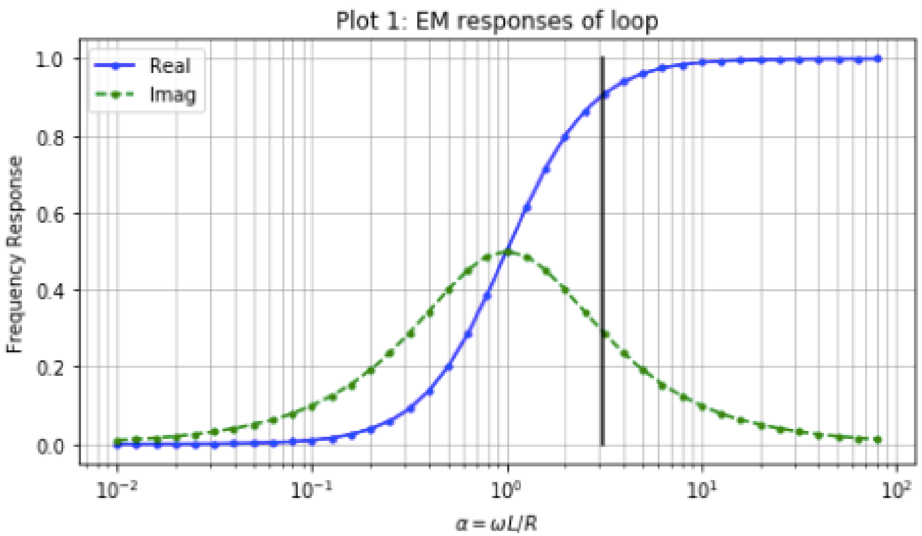
Large **Re** and small **Im** on the data maps, **α** big or small?

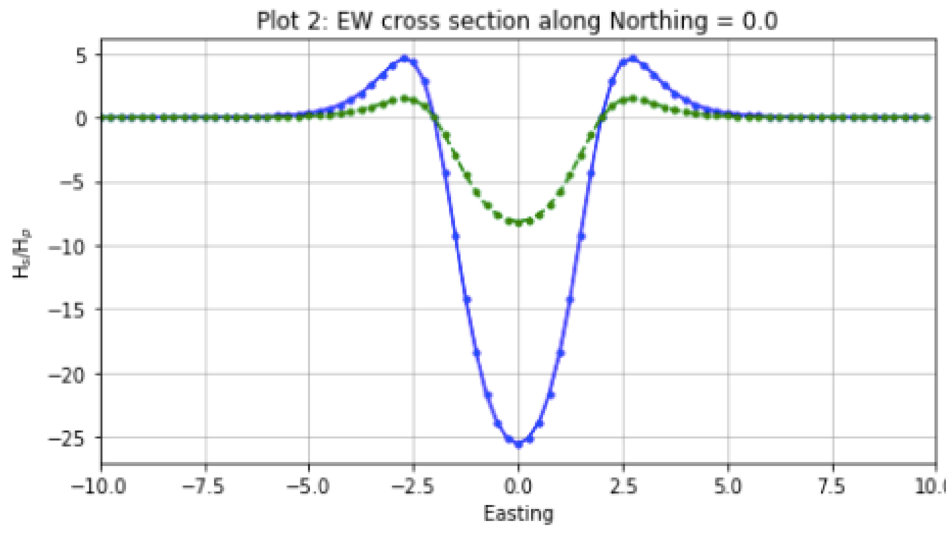
High induction number:

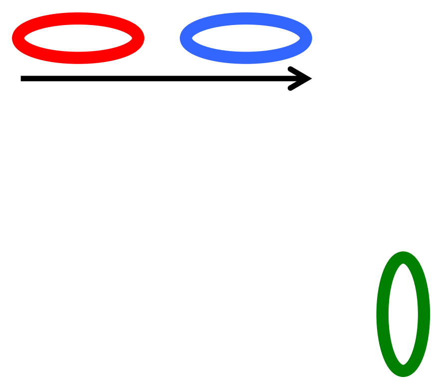
- **H**^{s} data mostly in in-phase, **Re** > **Im** ≈ 0
- Very strong induced current
- Cannot use apparent conductivity, but if the target is a good compact conductor, use the 3-loop model



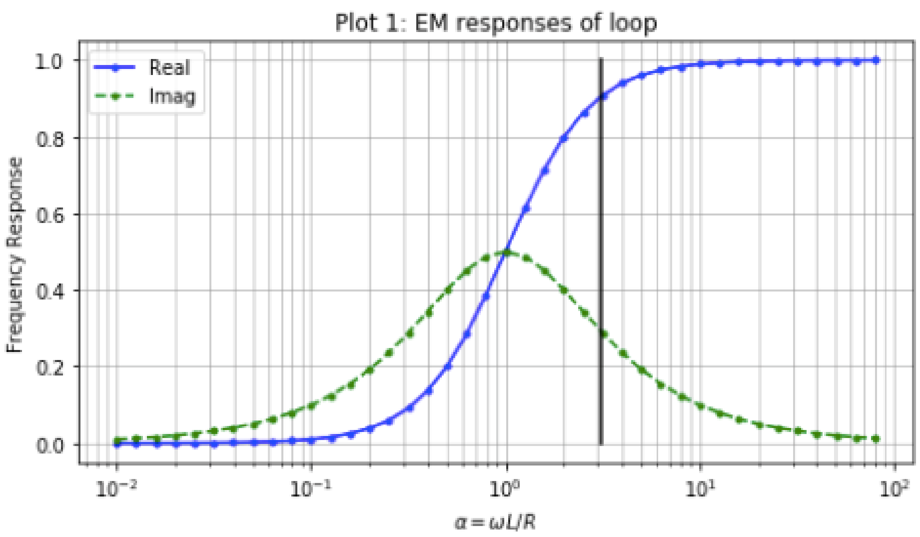
Vertical Target Loop

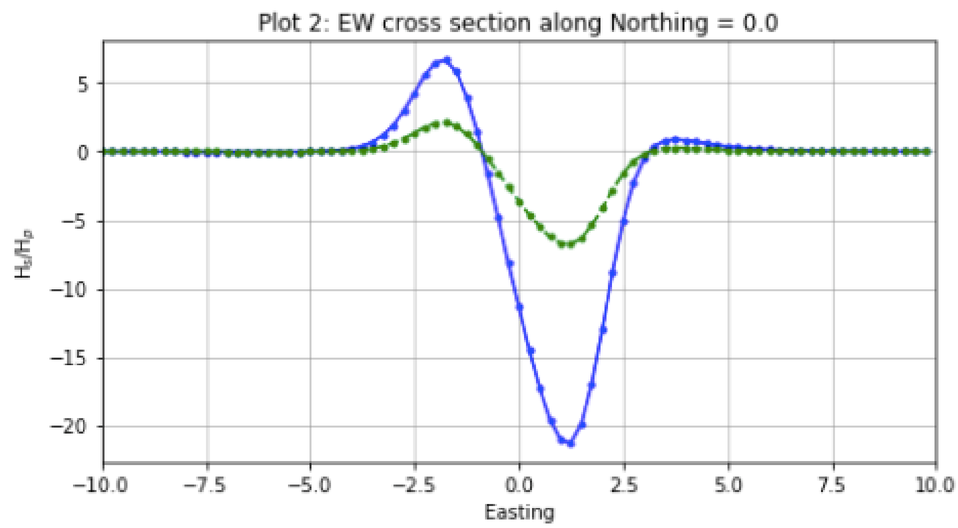


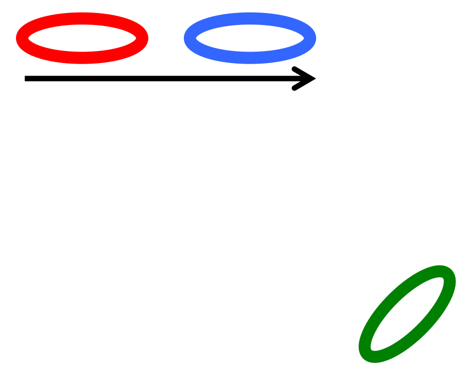




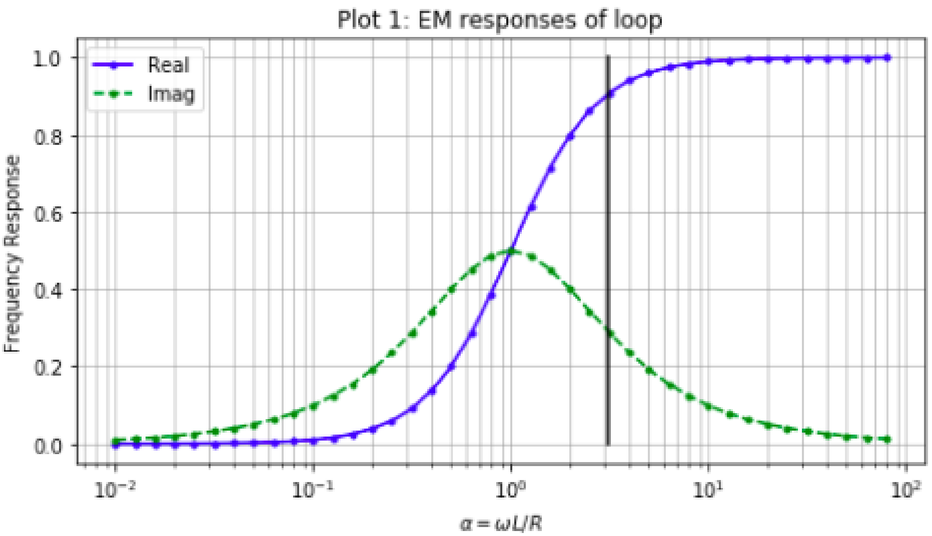
45 Degree Dipping Target Loop

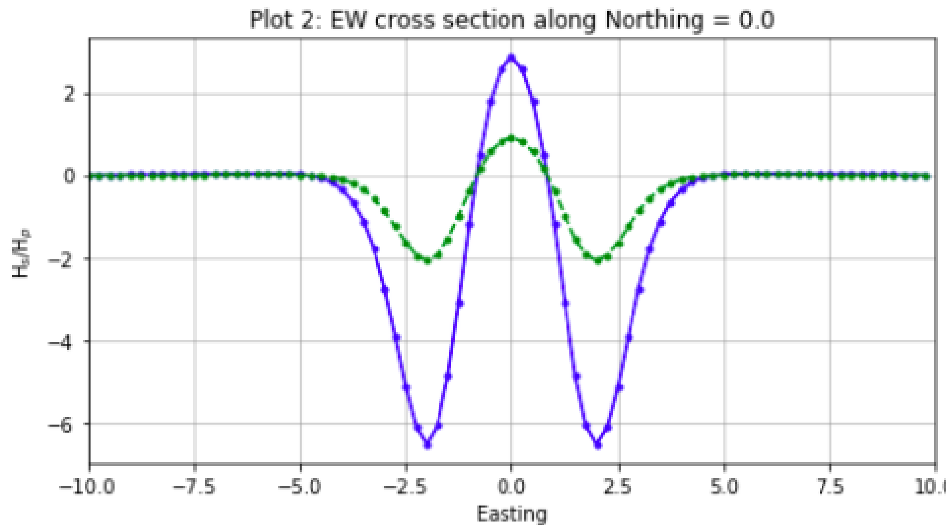


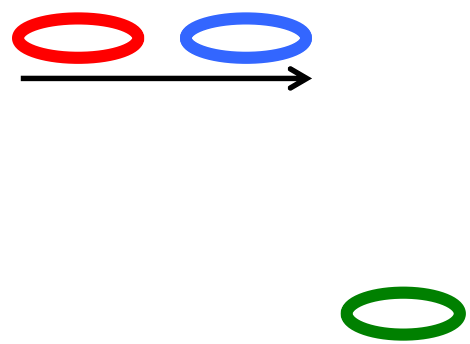




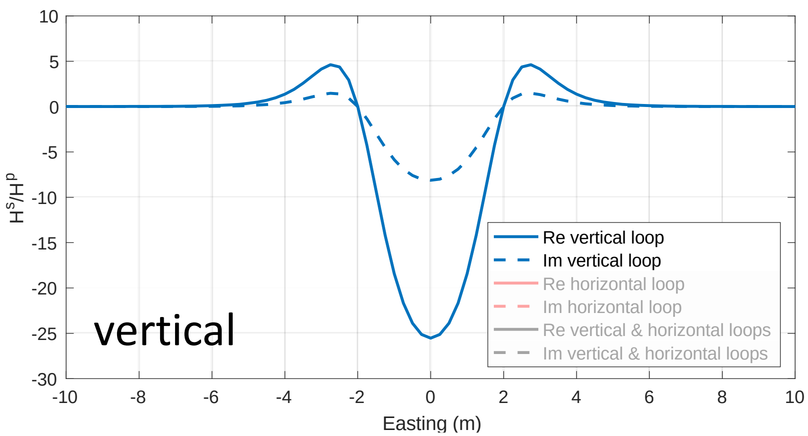
Horizontal Target Loop

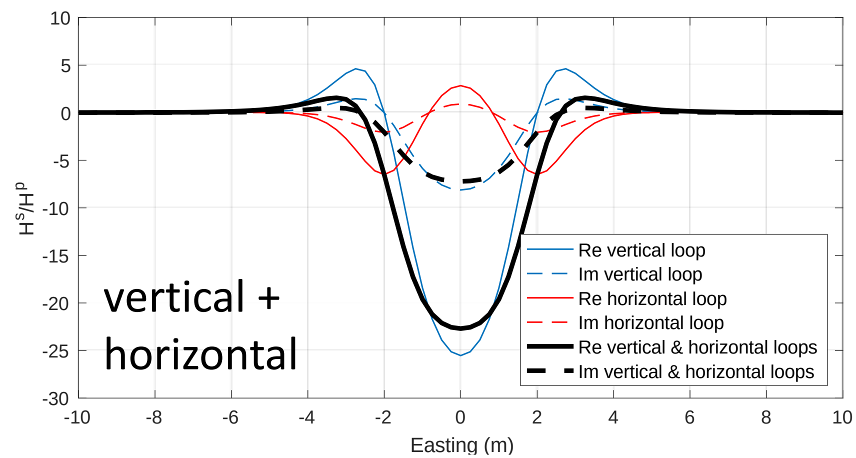


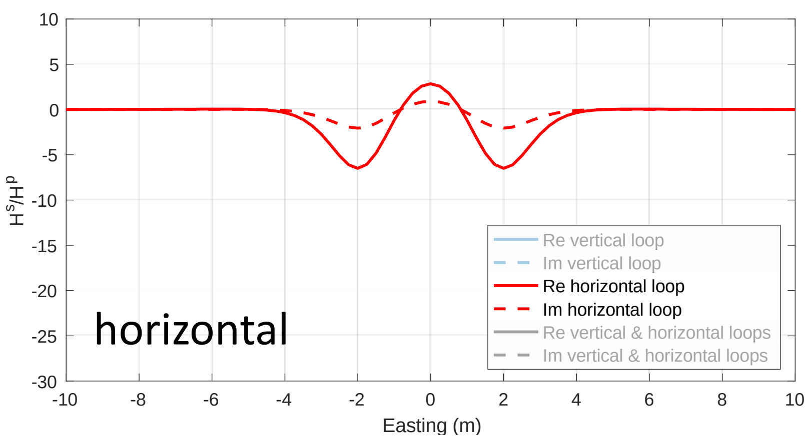


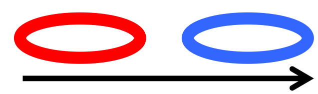


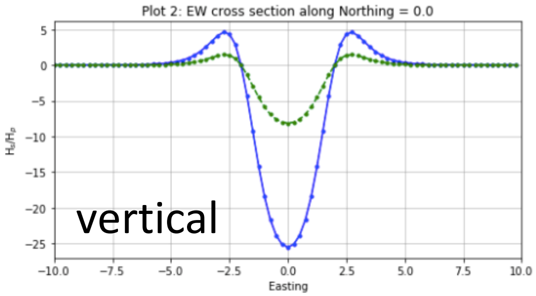
Equiaxed Target

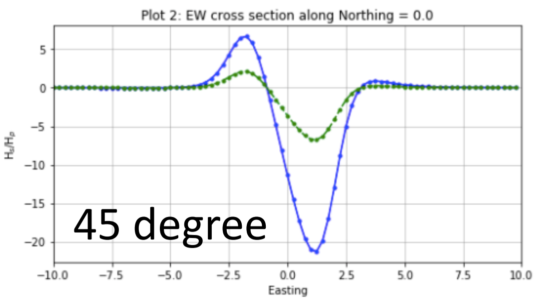


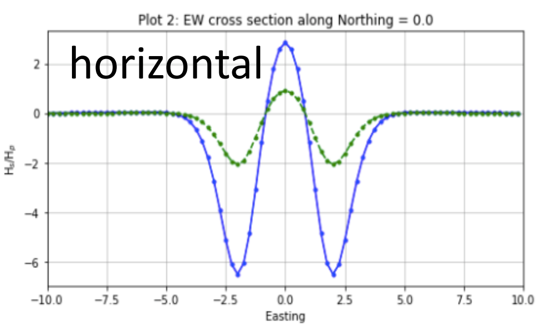


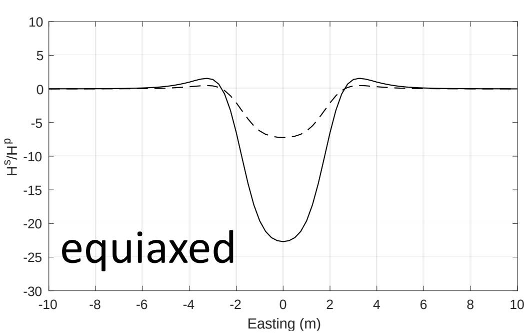


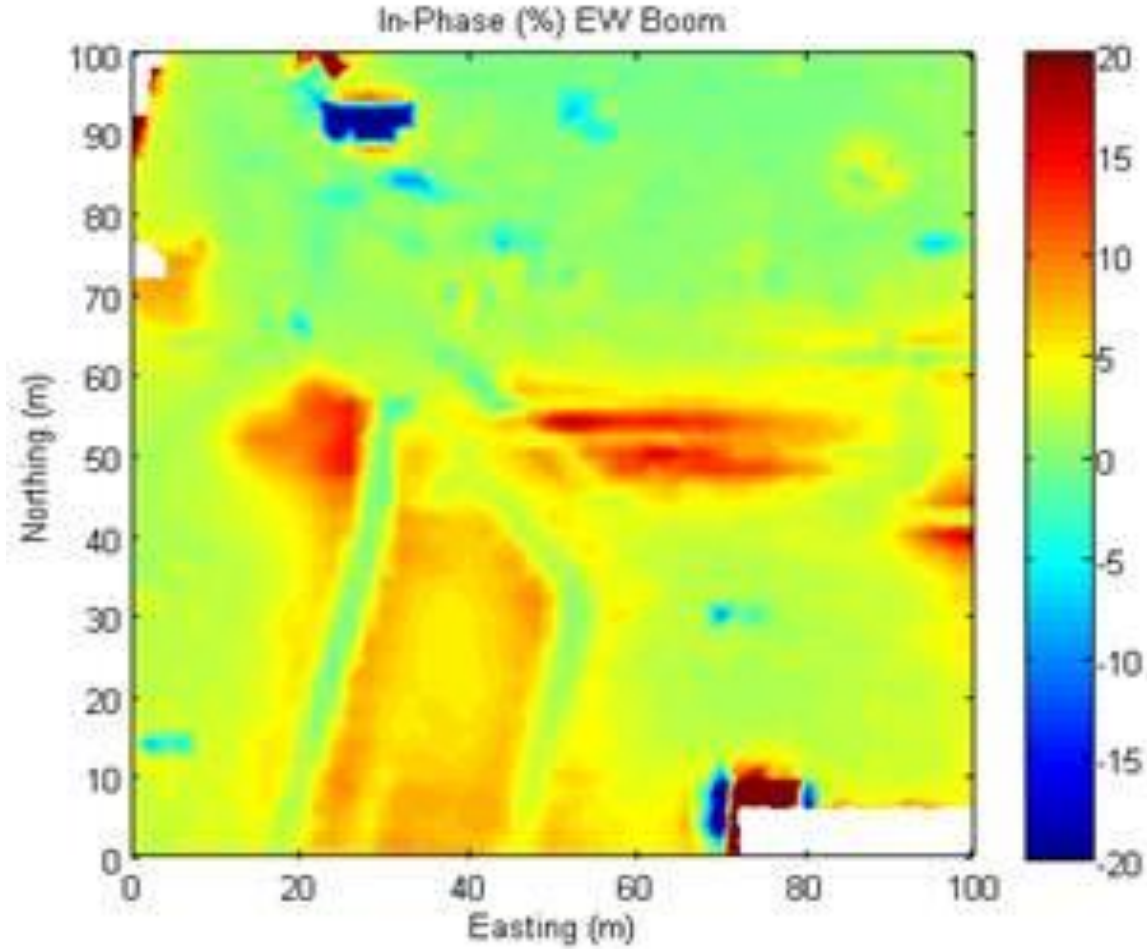












Question: Can you find those features on the data map and infer the geometry and orientations of the targets?

Summary

- EM-31 specifications
  - Frequency: 9.8 kHz
  - Tx-Rx separation: 3.66 m
  - Coil configuration: HCP or VCP
  - Boom orientation: in-line or cross-line
- EM-31 data interpretation
  - Low induction: apparent conductivity
  - High induction: compact conductors