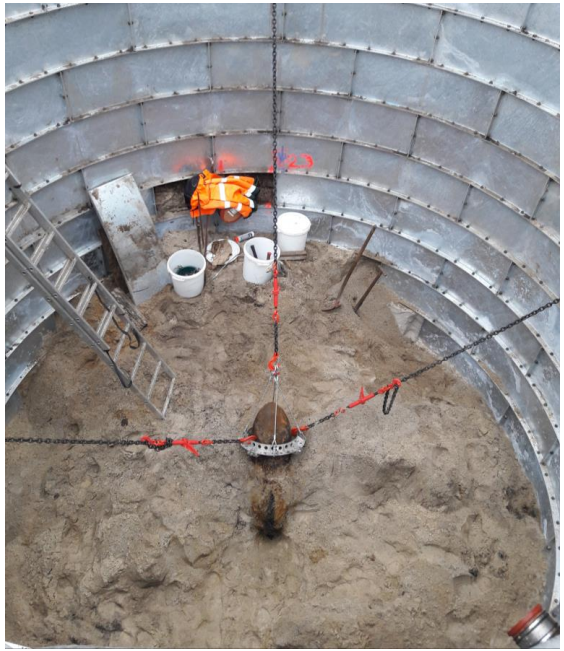
# Classification of Deep UXO with Borehole Electromagnetics

Laurens Beran, Black Tusk Geophysics



# Outline

1. WWII era UXO in Oranienburg, Germany
2. Advanced Geophysical Classification (AGC) with Borehole Electromagnetics
3. Examples

Black Tusk GEOPHYSICS

# Allied bombing: Germany

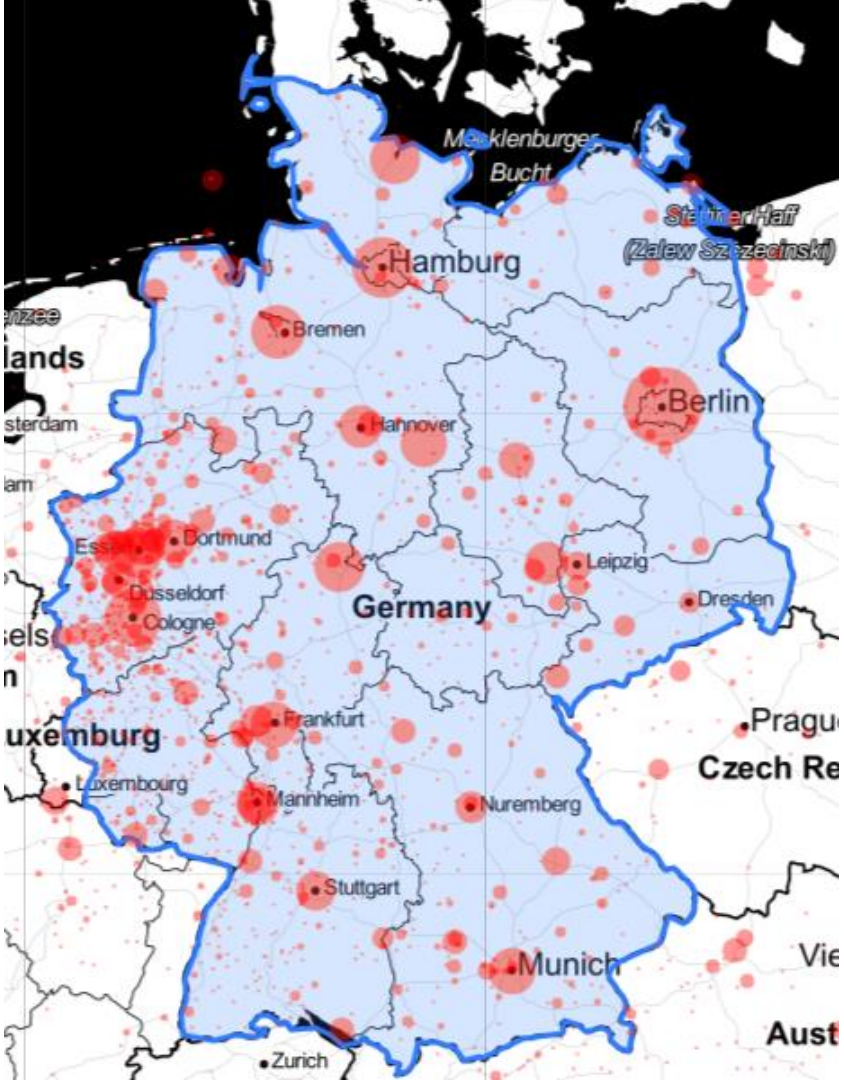
(1939-1945)

Tons dropped (000s)

10

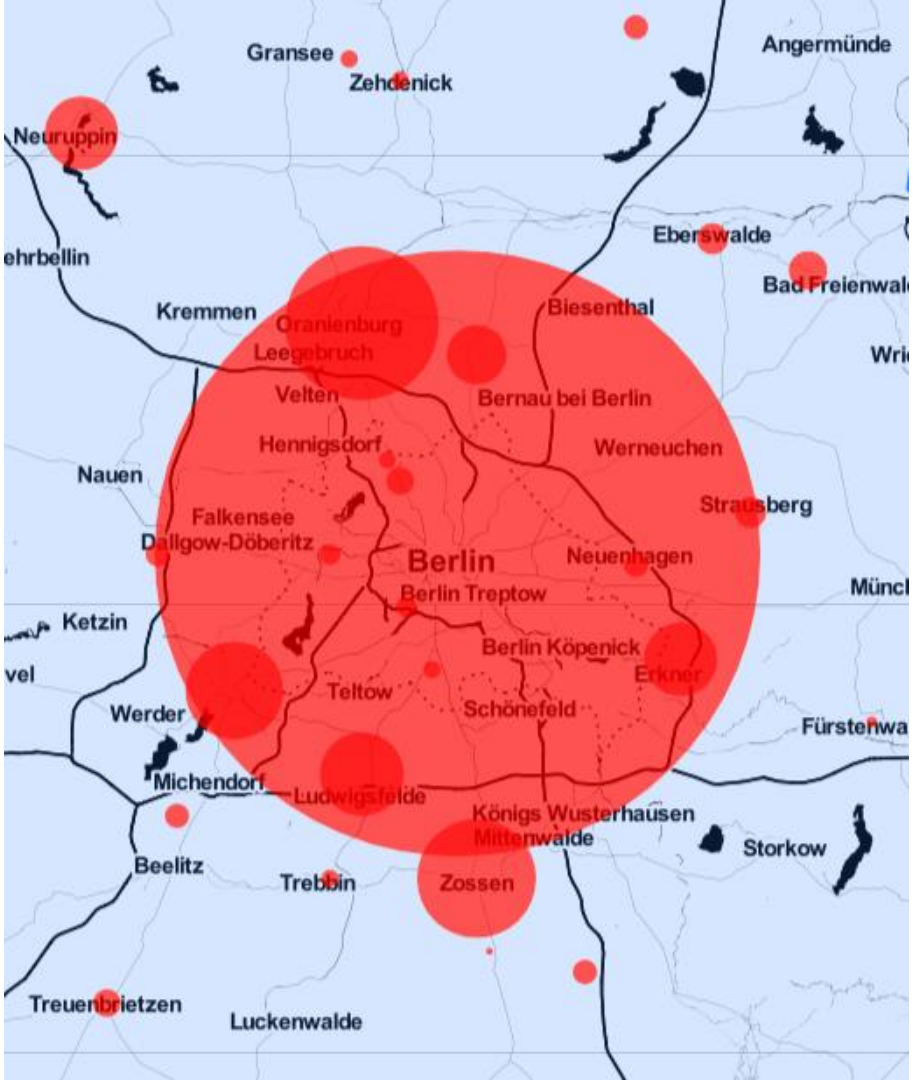
50

100



# Allied bombing: Berlin

(1939-1945)



# Oranienburg in WWII

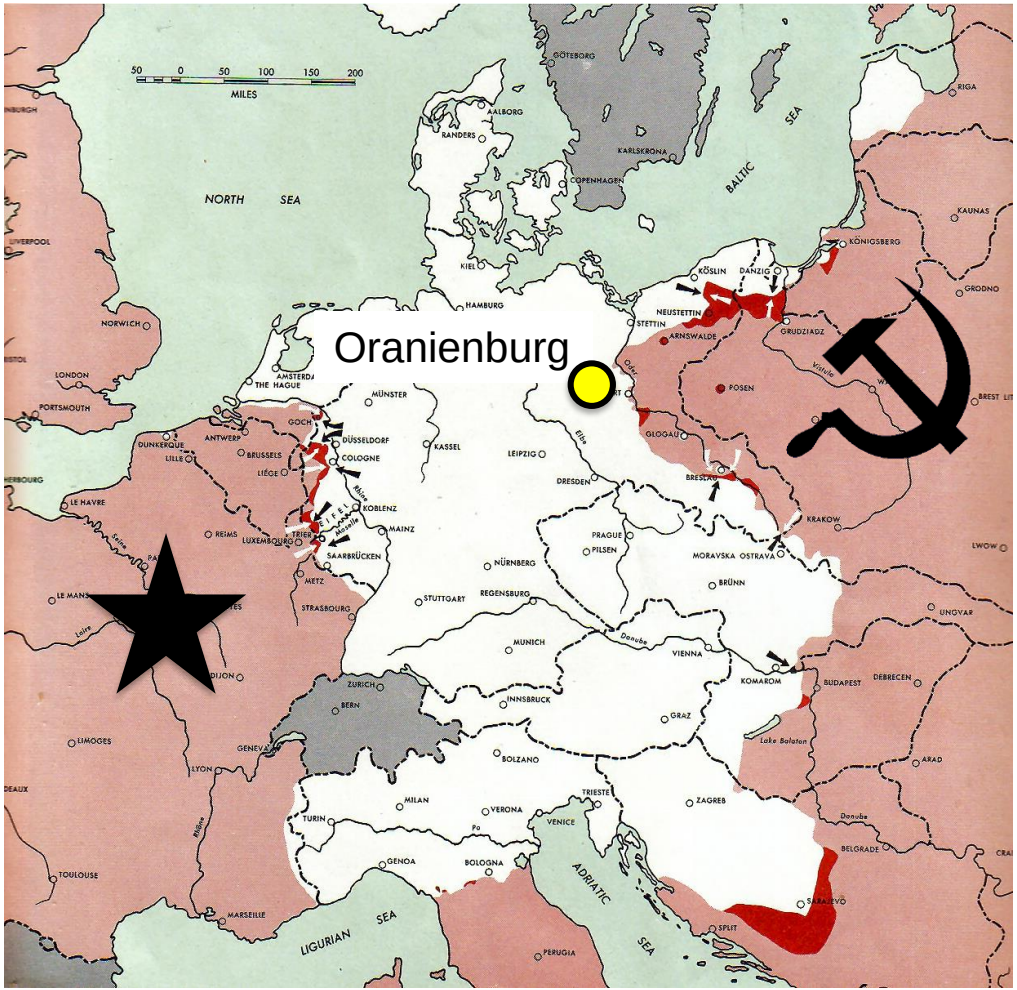
- Heinkel Aircraft Factory
- Byk Pharmaceuticals
- Uranium processing for German nuclear program

Heinkel He-111

Byk Pharmaceuticals Factory

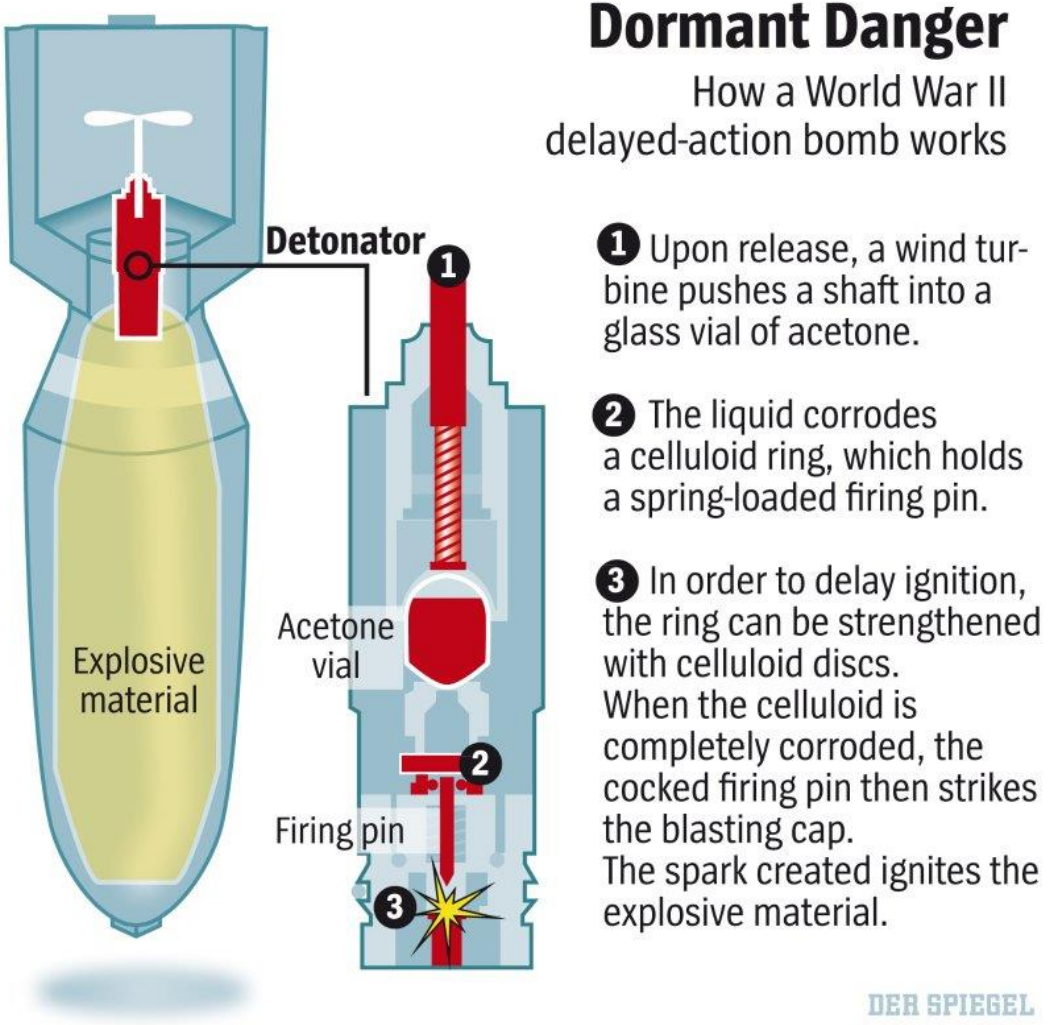
# Oranienburg
## March 15, 1945

“612 B-17 Flying Fortress bombers of the Eighth Air Force dropped 1,506 tons of high-explosive and 178 tons of incendiary bombs on the plant”



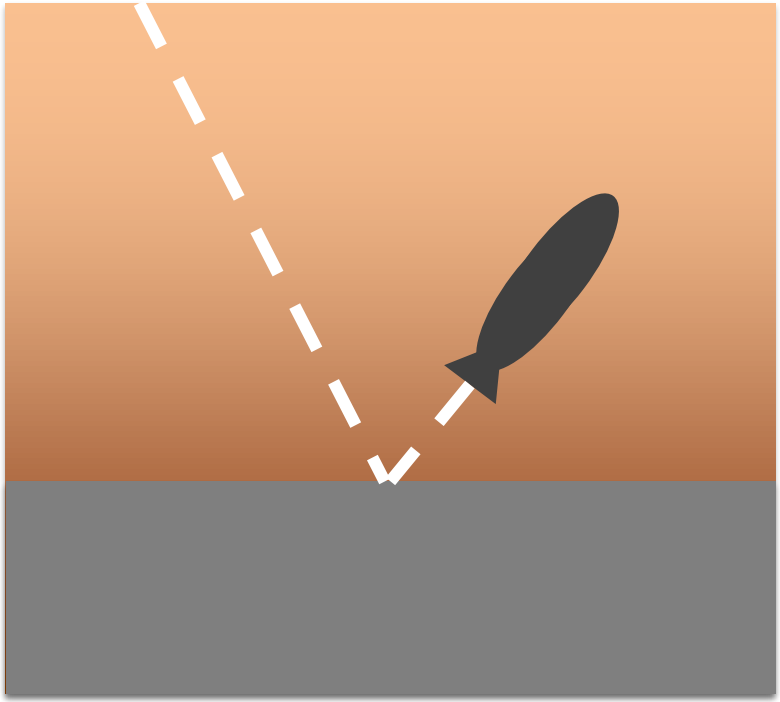
Ein amerikanisches Luftbild aus dem Jahr 1945 zeigt Bombentrichter vom Angriff auf die Oranienburger Auer-Werke. Links im Bild ist der Havelbogen zu erkennen, weiter rechts die Bahnlinien und der Bahnhof. REPRO: HAJO

# UXO in Oranienburg



# UXO in Oranienburg

- Undetonated bombs in nose-up orientation
- 100s of delayed-action bombs remain



# Advanced Geophysical Classification in Germany

Challenges:

1. UXO are deeper (5-10 m) than can be detected or classified with AGC EM arrays
2. UXO are present in urban environments where there is a significant background response from infrastructure

# Detection of Deep UXO

- Historical records
- Aerial photography
- Surface geophysics (large loop EM)
- Borehole geophysics (magnetics, radar)

# AGC borehole surveys

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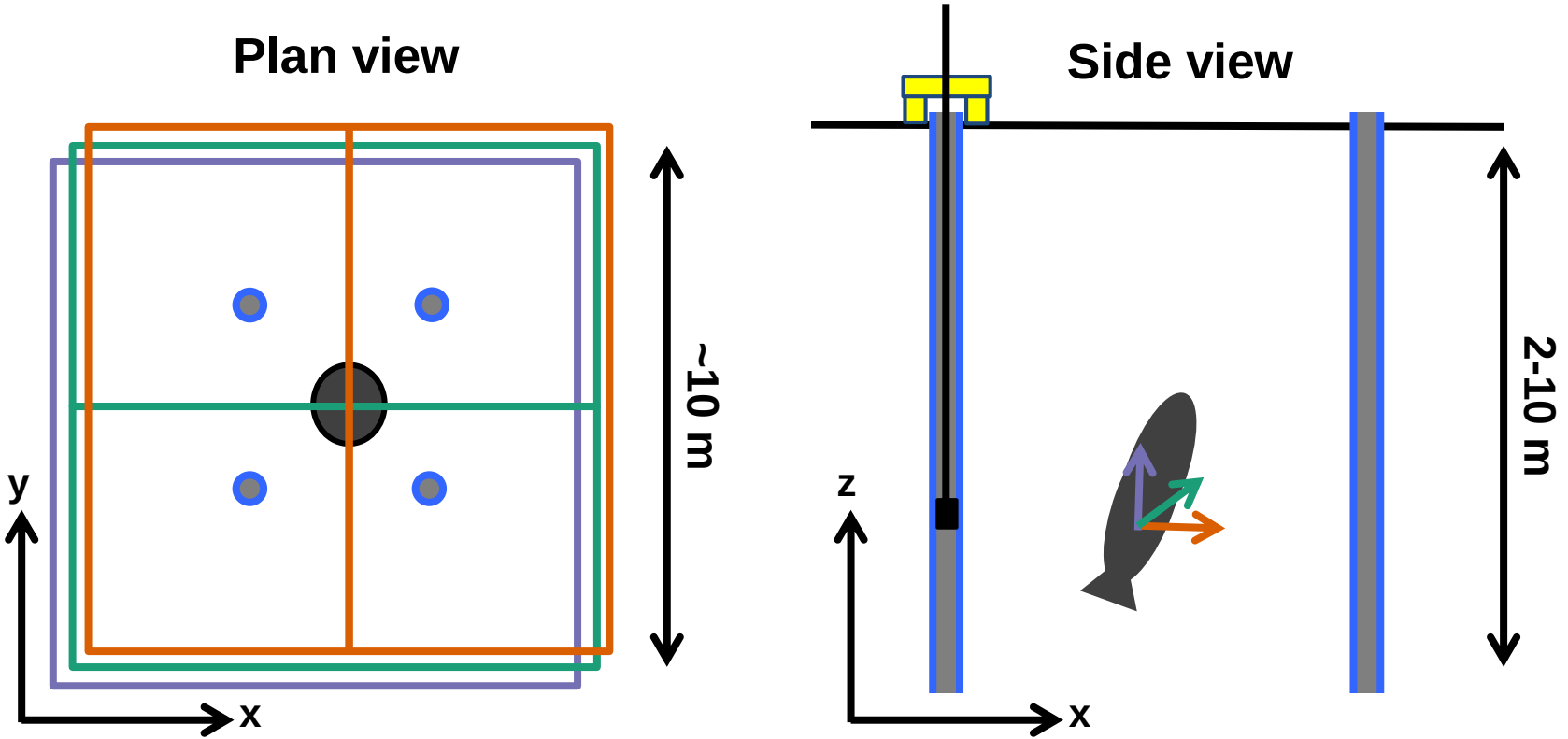
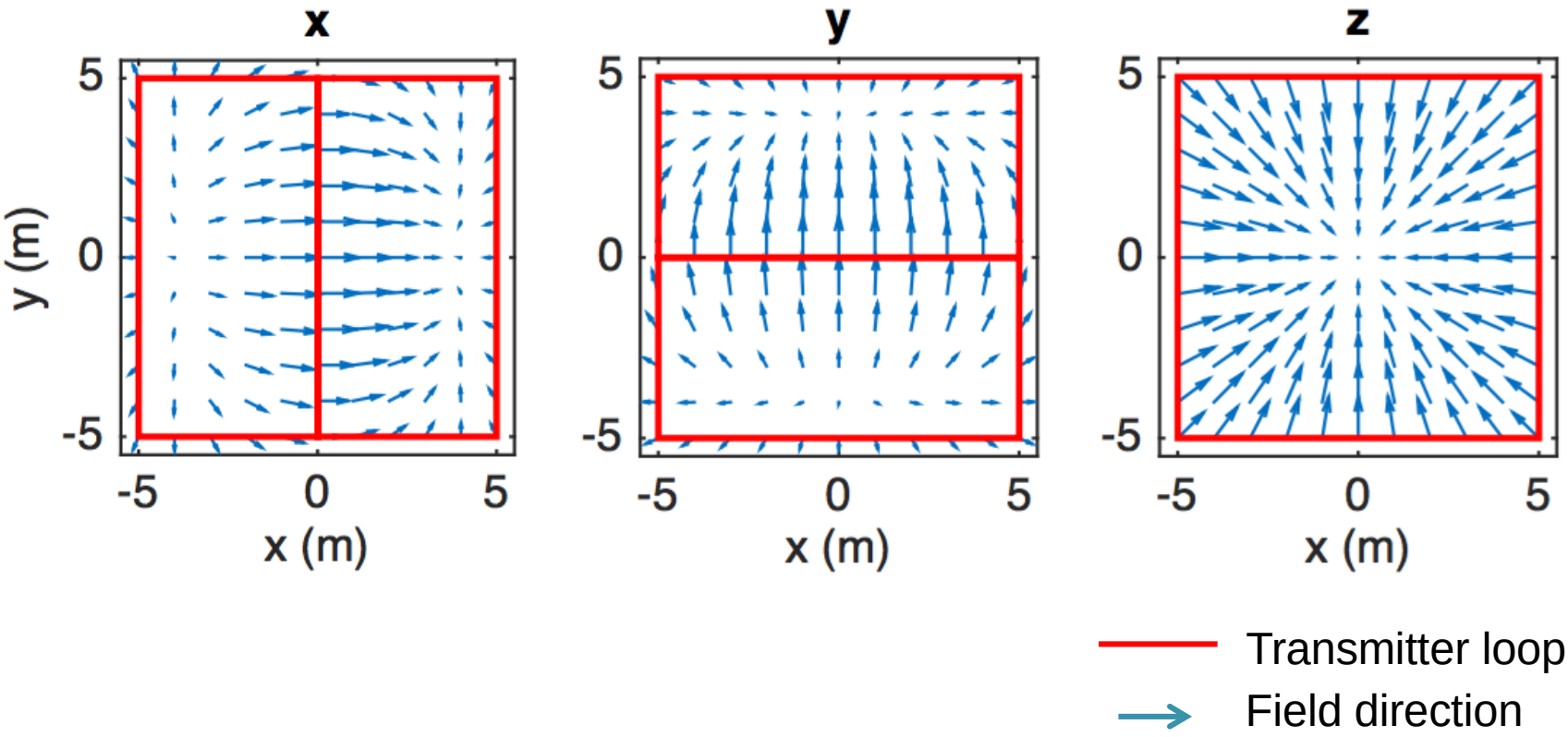
# AGC with borehole electromagnetics

1. Large, high current (150A) transmitter loops
2. Long off-time fluxgate magnetometer receiver at depth

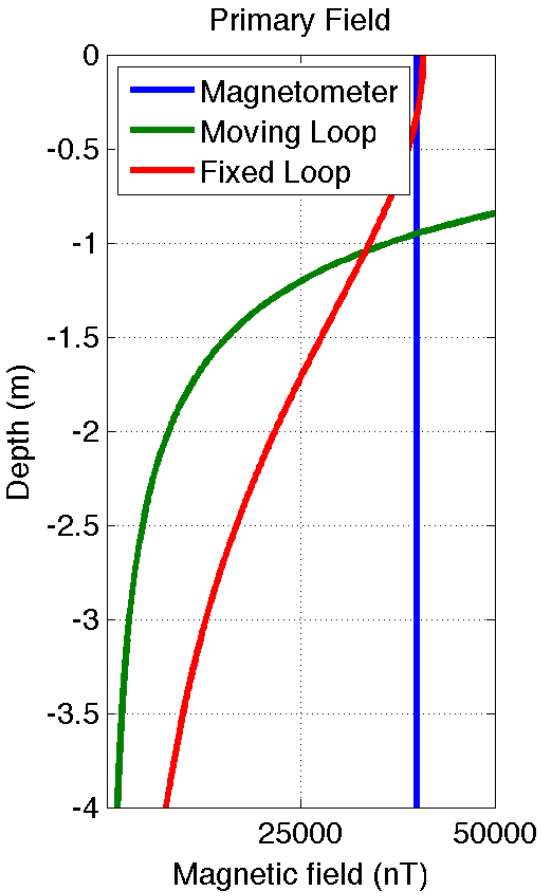
# AGC with borehole electromagnetics

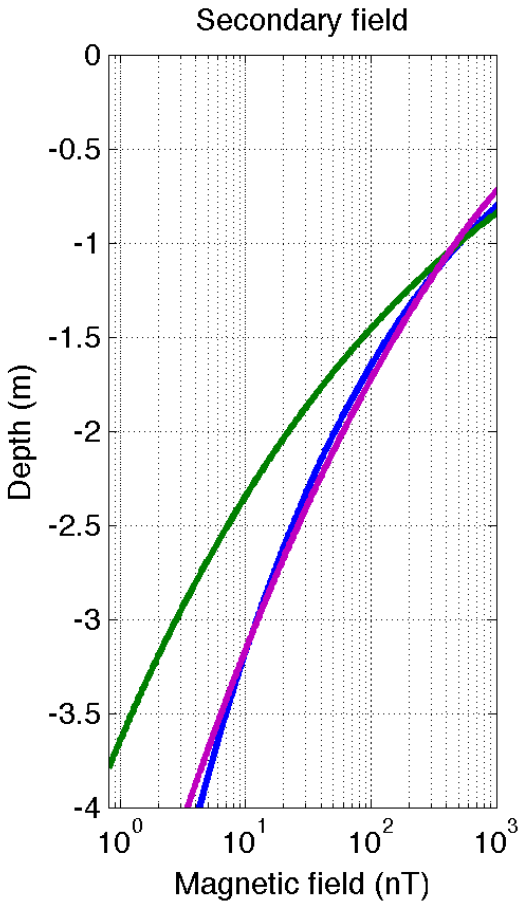


# Borehole EM transmitters



# Borehole EM transmitters




Mag gradiometer ~ $z^{-4}$

Small loop EM ~ $z^{-6}$

Large loop EM ~ $z^{-4}$

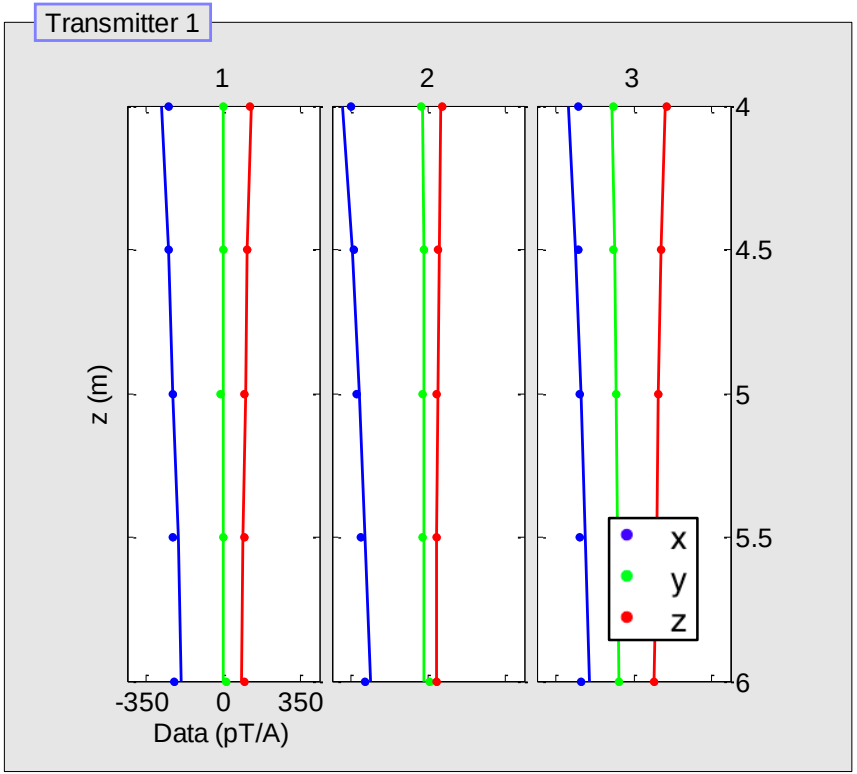
# Borehole EM receiver

Fluxgate magnetometer

1. Low noise
2. Long measurement window (~50 ms)
3. x,y,z components of fields measured

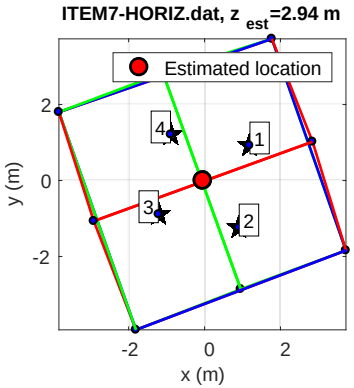
# Forward modeling and inversion

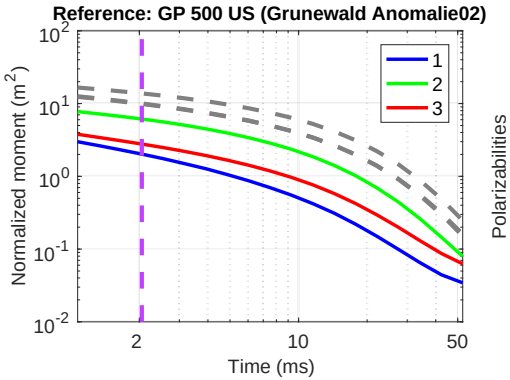
- Wandering dipole: solve for induced moments at each channel, allowing location to vary.
- Background (due to infrastructure) modeled as halfspace response.

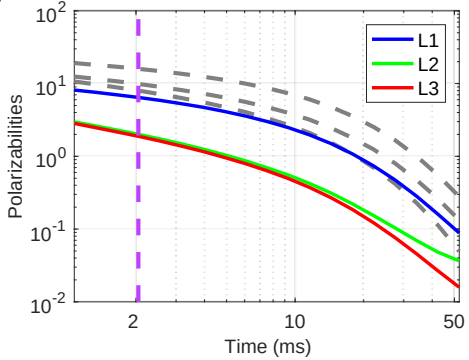


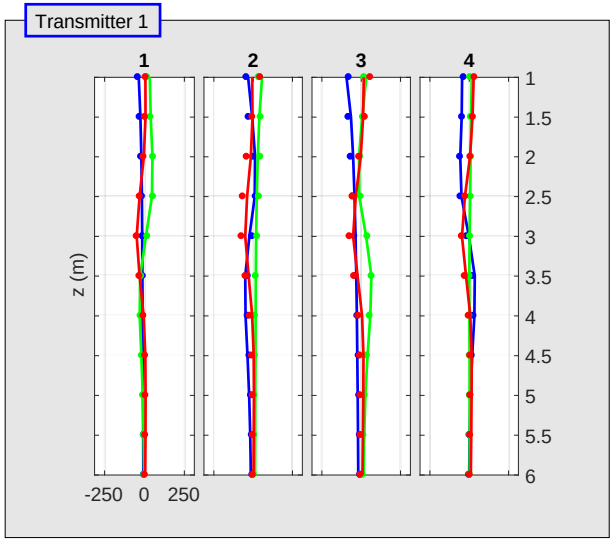
# Library measurements: 250 lb bomb (horizontal)

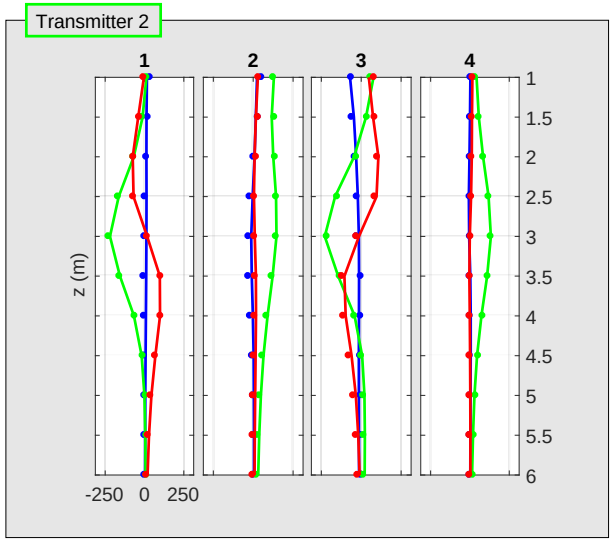
**(2/2) Dipole+background model**
**Channel 15 (2.05 ms)**

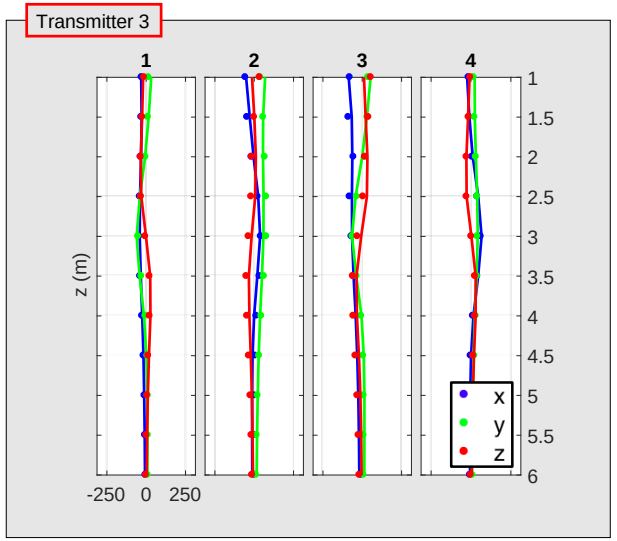


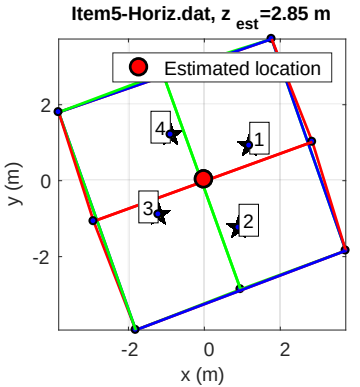



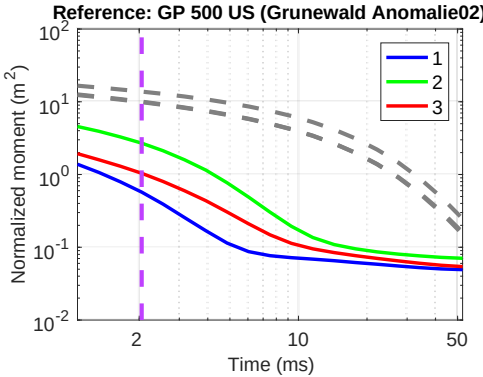



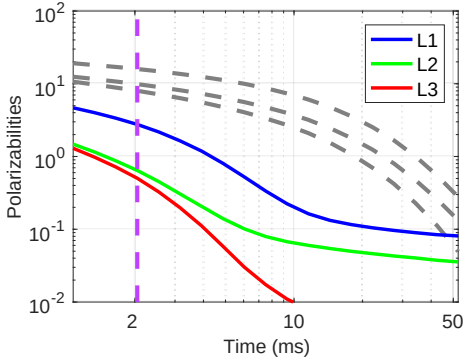



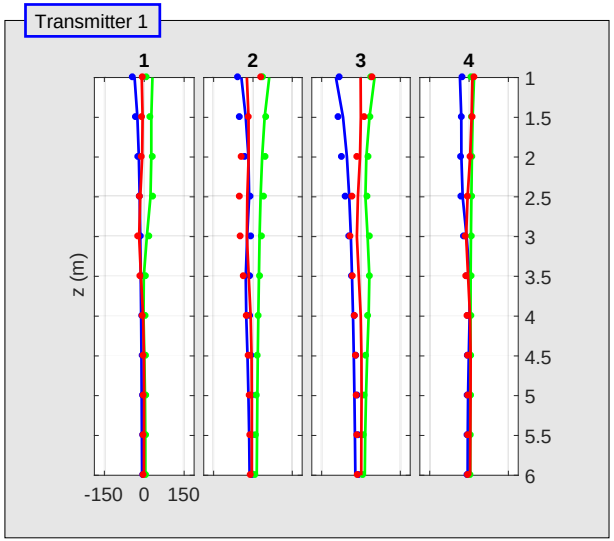
# Library measurements: 100 lb bomb (horizontal)

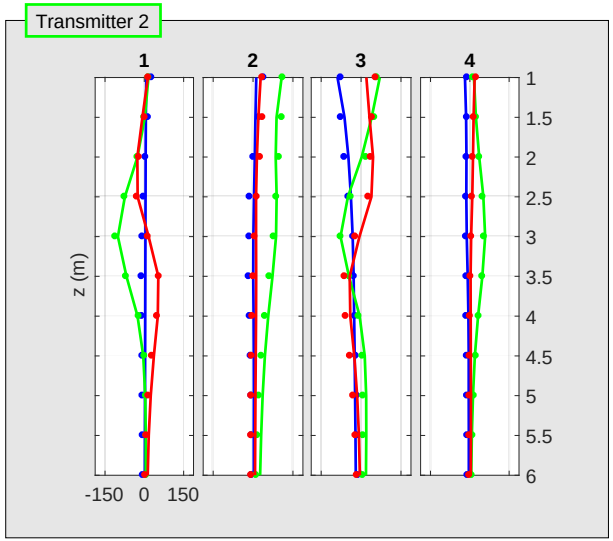
**(2/2) Dipole+background model**
**Channel 15 (2.05 ms)**

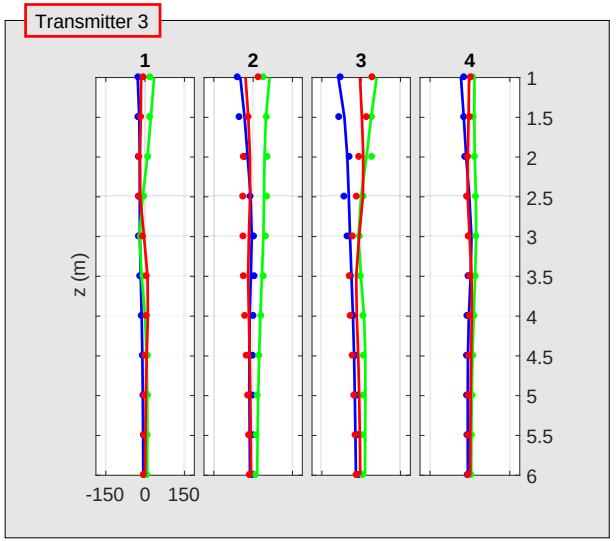


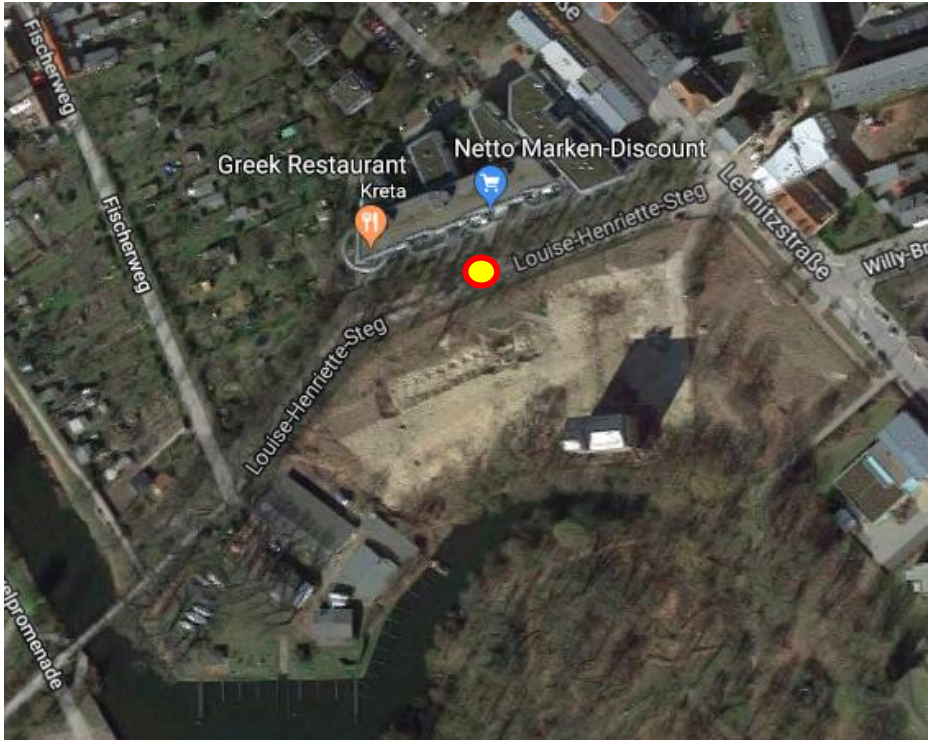



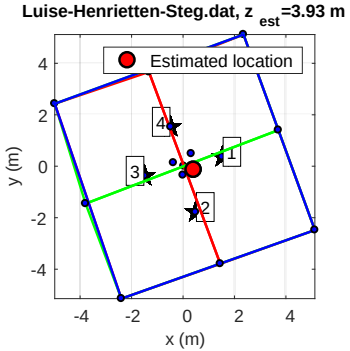



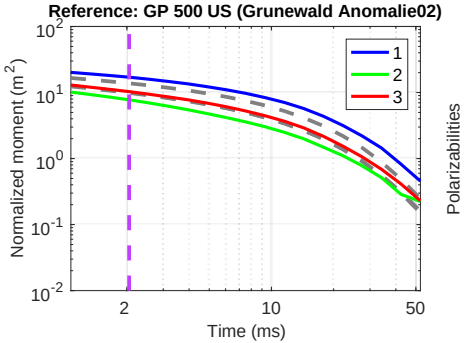
# Field example - Oranienburg

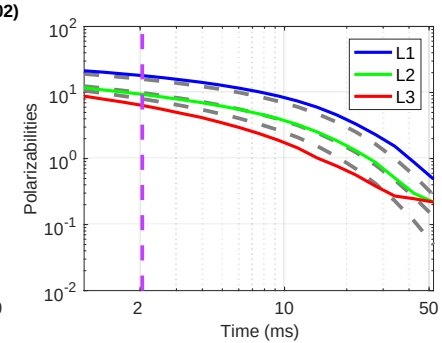


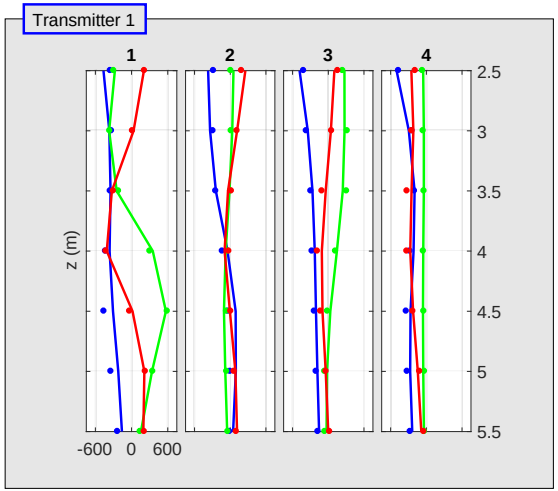

# Field example - Oranienburg

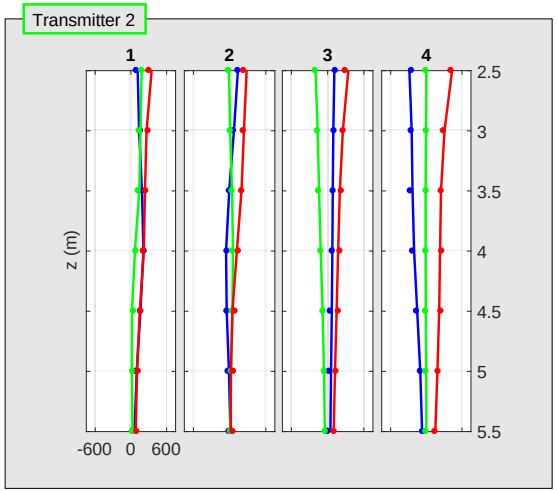
(1/1) Dipole+background model
Channel 15 (2.05 ms)

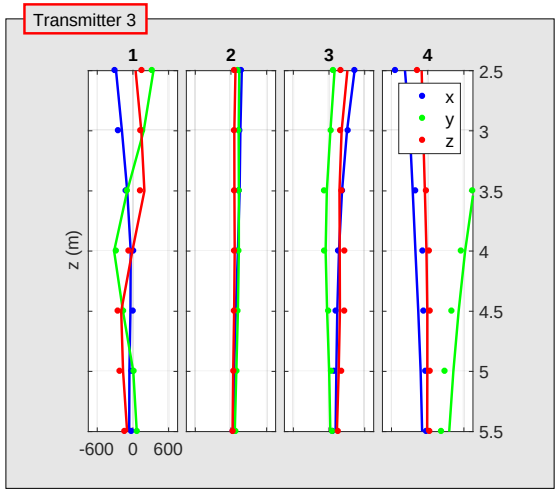


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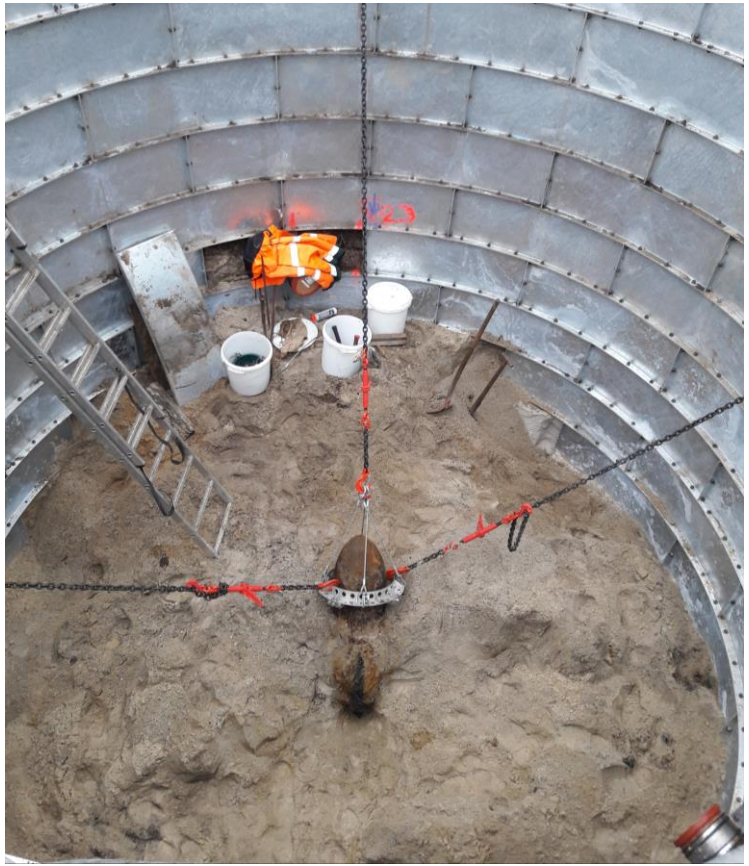
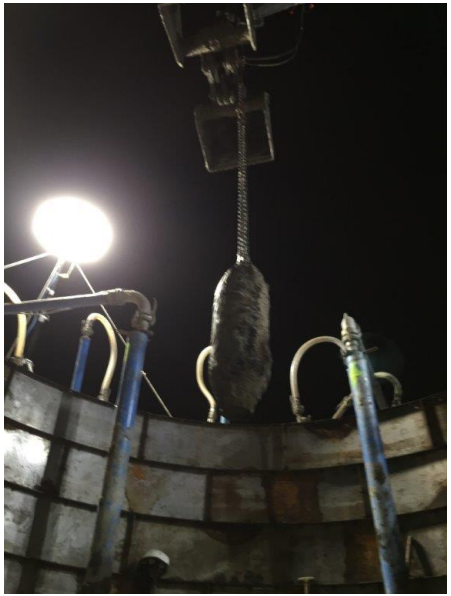
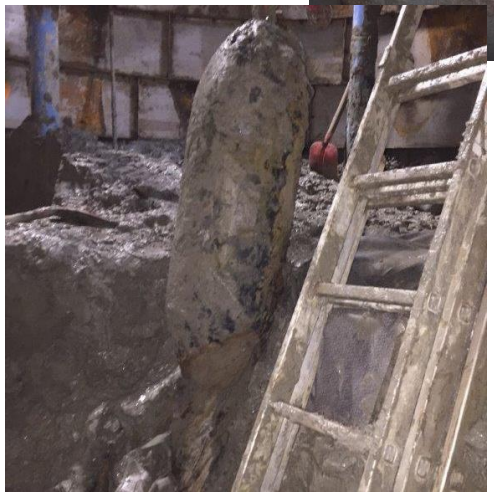


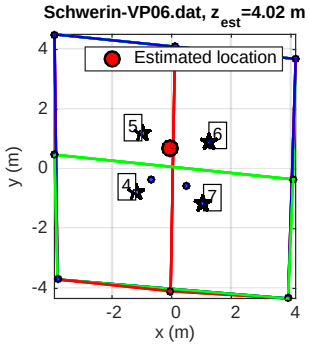
# Field example: Schwerin

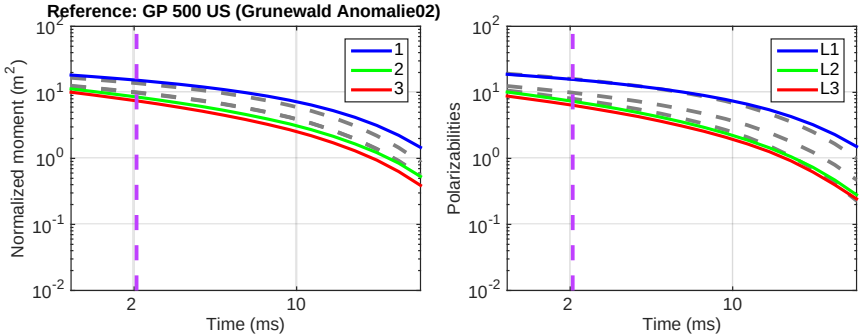


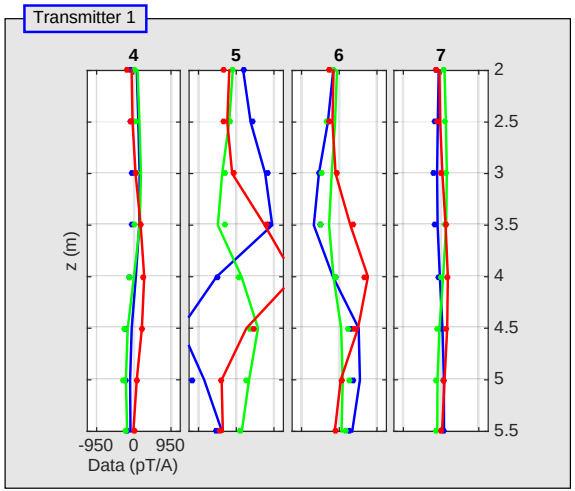


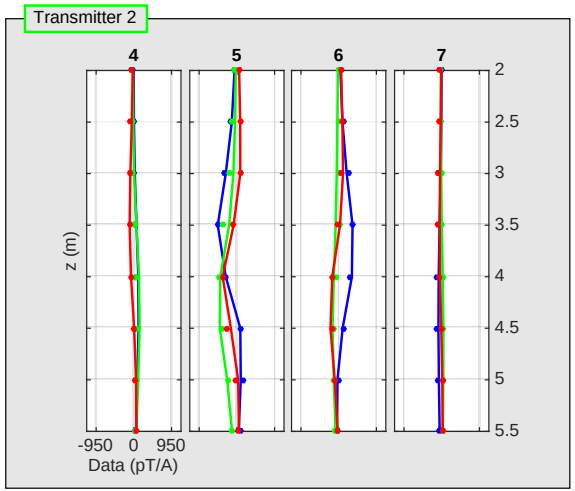
# Field example: Schwerin

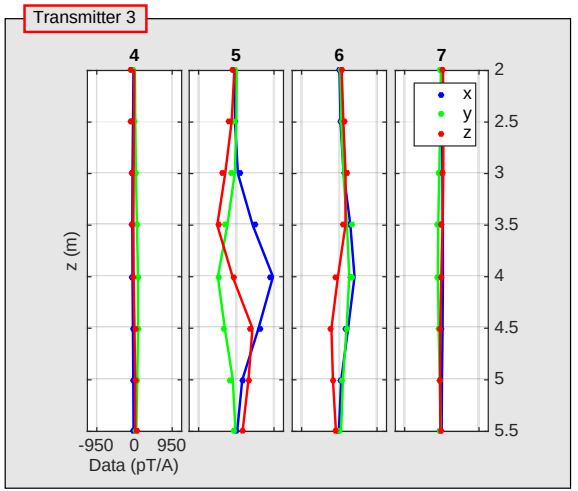
**(1/1) Dipole model**
**Channel 15 (2.05 ms)**



# QC/QA of borehole work

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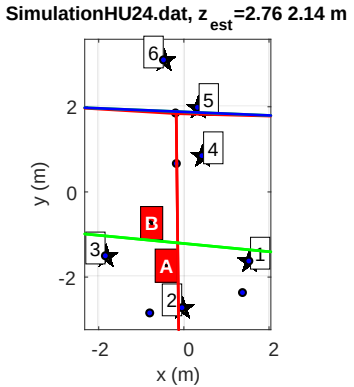
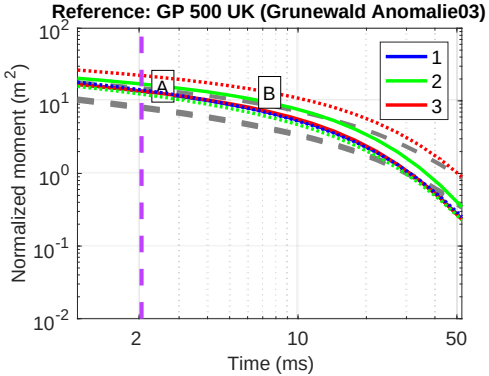
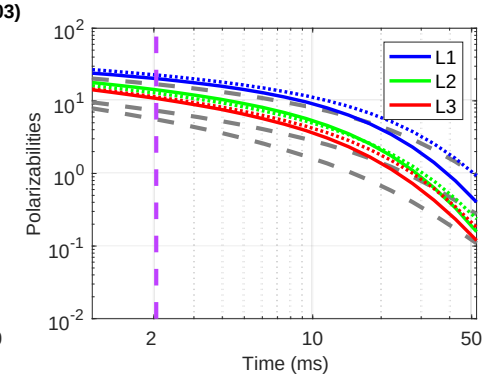
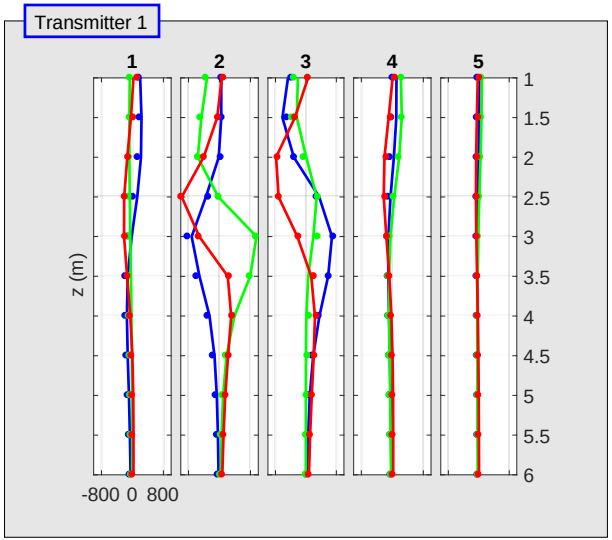
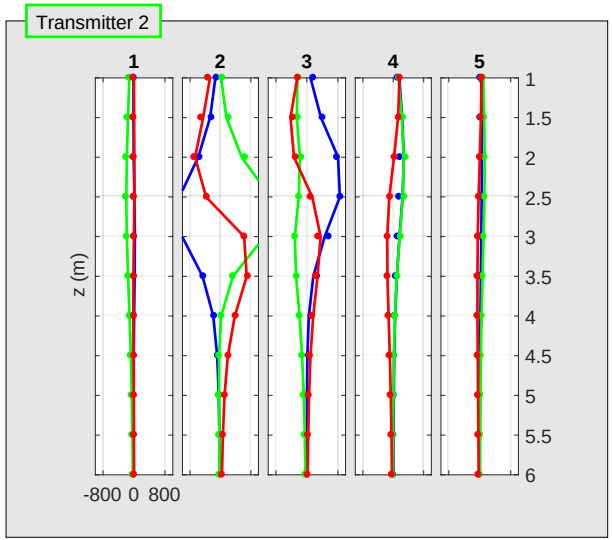
(2/2) Dipole model
Channel 15 (2.05 ms)

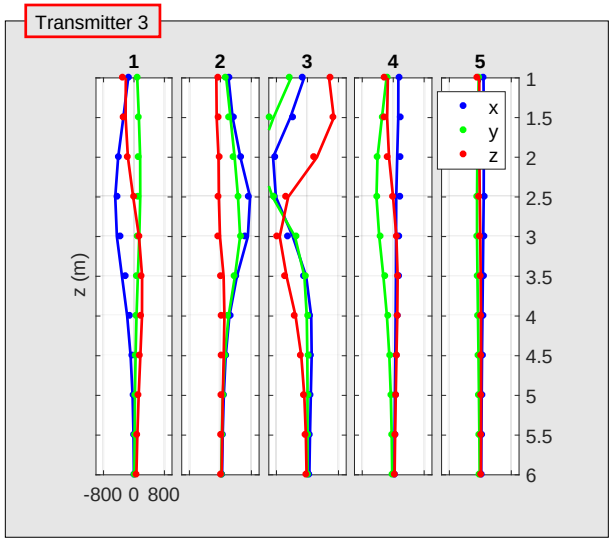


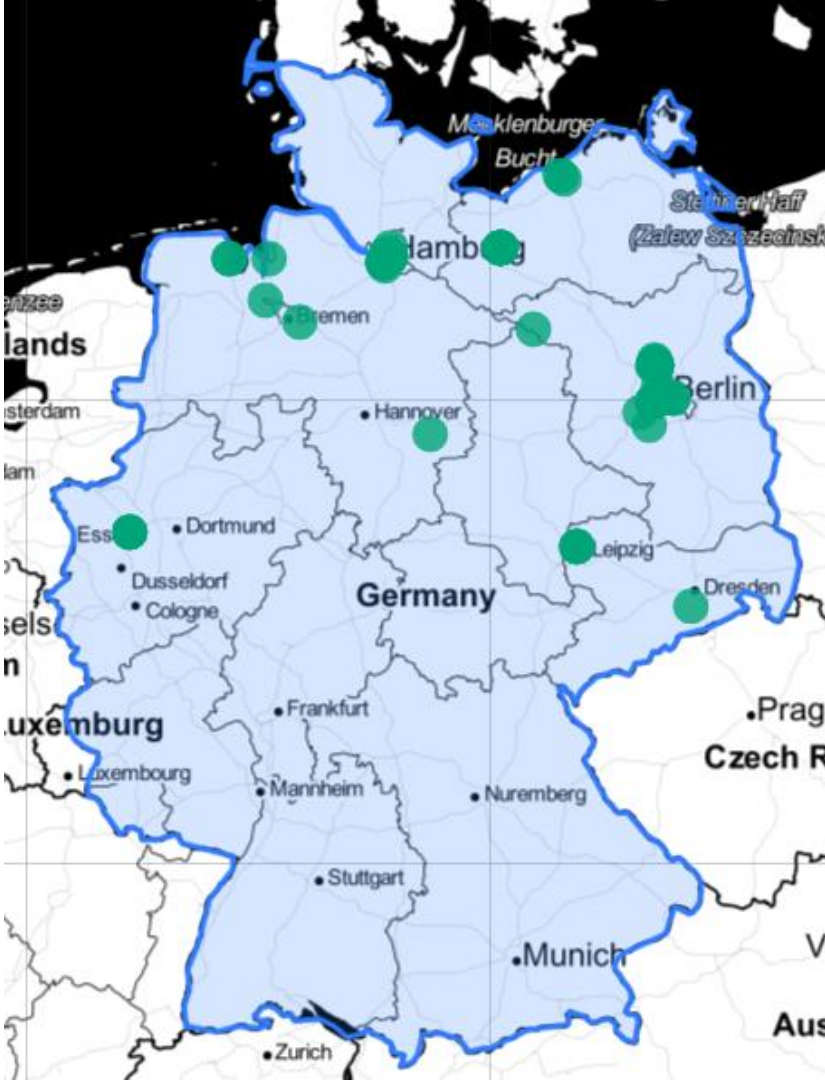



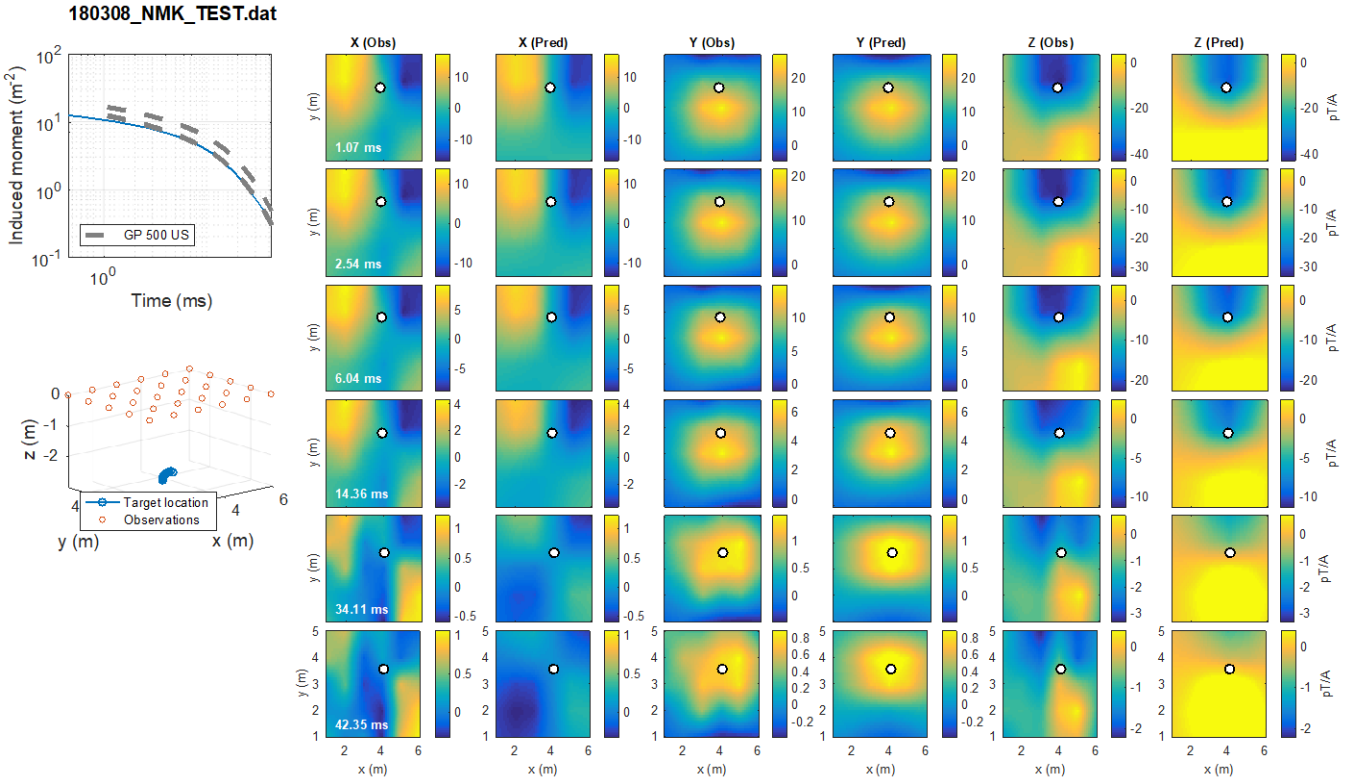
# Conclusions

- Borehole EM extends AGC to classification of deep UXO
- More than 150 surveys carried out to date



# Conclusions

- Extension to UXO classification in SE Asia



# Acknowledgements



Thorsten Leikam
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Jim Pincini


David Sinex

# Oranienburg in WWII

- Byk pharmaceuticals

# Oranienburg in WWII

- Site of uranium processing for German nuclear program


"Doramad Radioactive Toothpaste" (ca. 1940-1945)

"biologically effective" toothpaste whose radiation particles would "massage your gums"