EVALUATION OF DIFFERENT RECEIVER ORIENTATIONS AND RECEIVER SEPARATIONS IN MAGNETIC GRADIOMETER METHOD

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Introduction

The recent magnetic measurements are now faster and more sensitive

Gradient measurements are more popular than total field measurements in near surface researches.

Introduction

Vertical gradient measurement is a common technique.

In this study

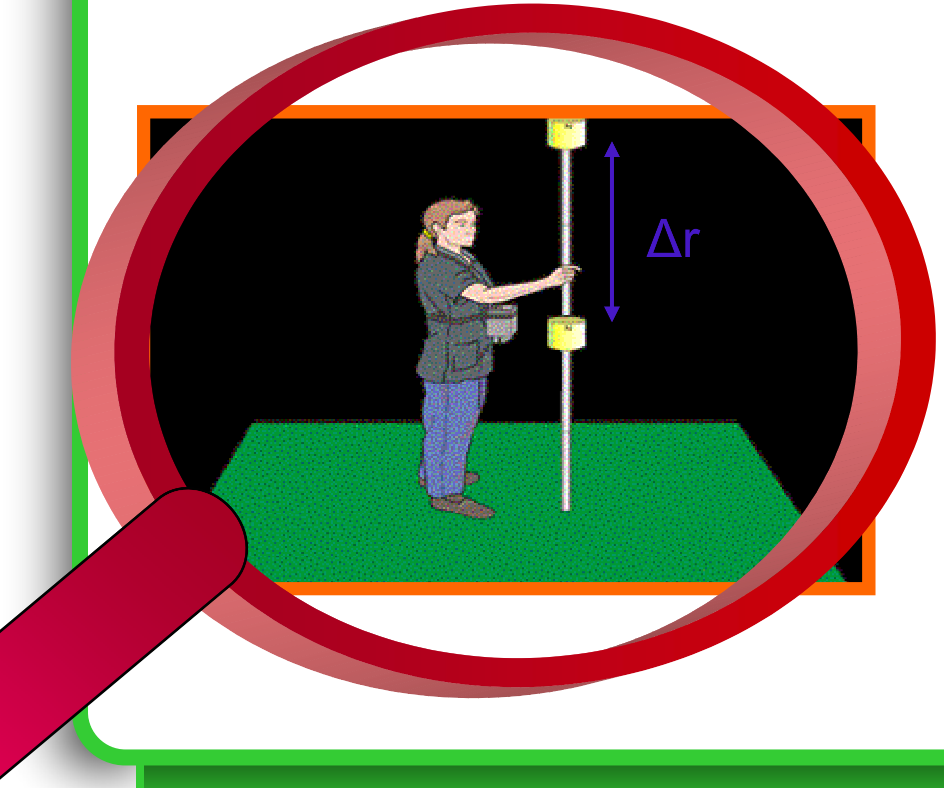
horizontal receiver orientataion

and

different receiver seperations were considered

The Magnetic Gradiometer Method

The basis of Gradiometer method is to measure the total field with two magnetometers in different levels at every measurement point.

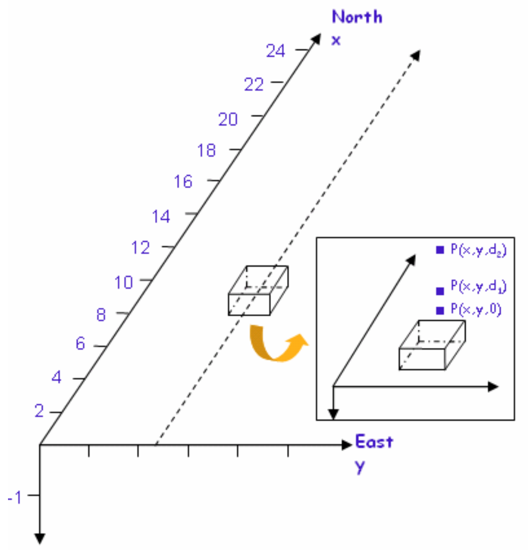


Vertical Gradient

$$\frac{A_T}{\Delta r} \approx \lim_{\Delta r \to 0} \frac{T_r - T_{r+\Delta r}}{\Delta r} = \frac{dT}{dr}$$

The measurements are done through S – N lines.
Then,
the recordings are distributed to measurement points according to selected time interval.

The Magnetic Gradiometer Method



3D Iron plate Model

EI = 1.5 CGS

Iθ = 55

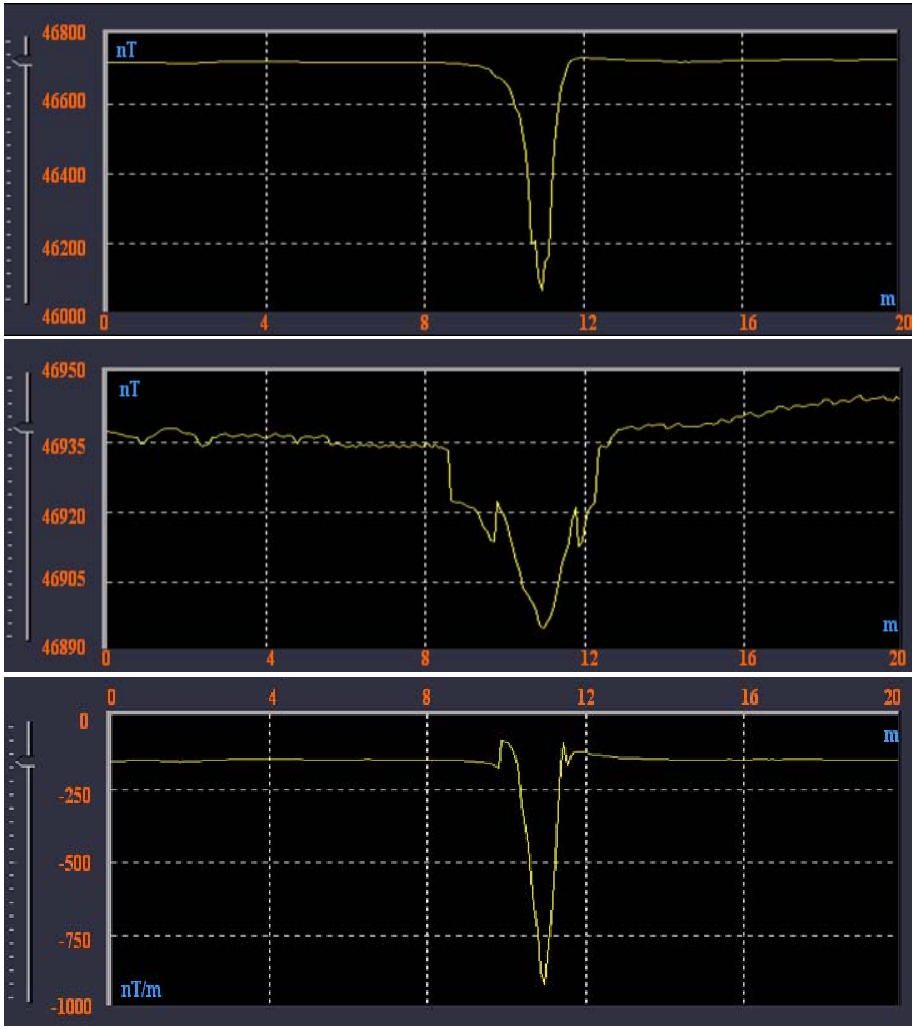
dθ = 4

Con. Reg. Field = 46000

$P(x,y,d_1)$

$P(x,y,d_2)$

$$\frac{P(x,y,d_2) - P(x,y,d1)}{(d_2 - d_1)}$$



Observed Data

Advantages of Magnetic Gradiometers

- There is no need of time correction
- Two readings are being taken simultaneously.
- Local effects are being removed automatically from data.

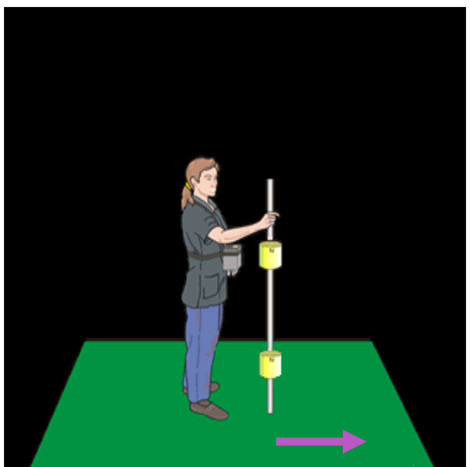
Advantages of Magnetic Gradiometers

- The gradiometer method has a higher sensitivity comparing to total field measurements for small objects that are very close to surface.
- The measurement point spaces may reduce to a few cm's.
- The measurement procedure is very fast, larger fields can be evaluated faster than other methods.

Different Receiver Orientations and Receiver Seperations in Magnetic Gradiometer Method

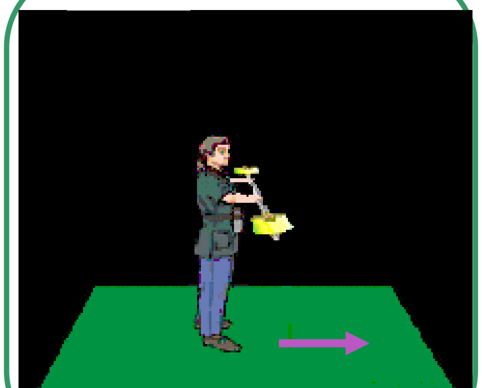
Receiver Orientations

Vertical Gradient

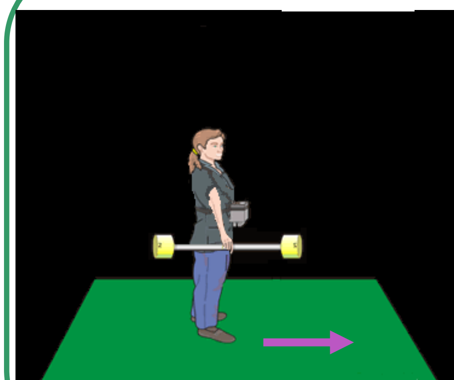


Horizontal Gradient

GPL

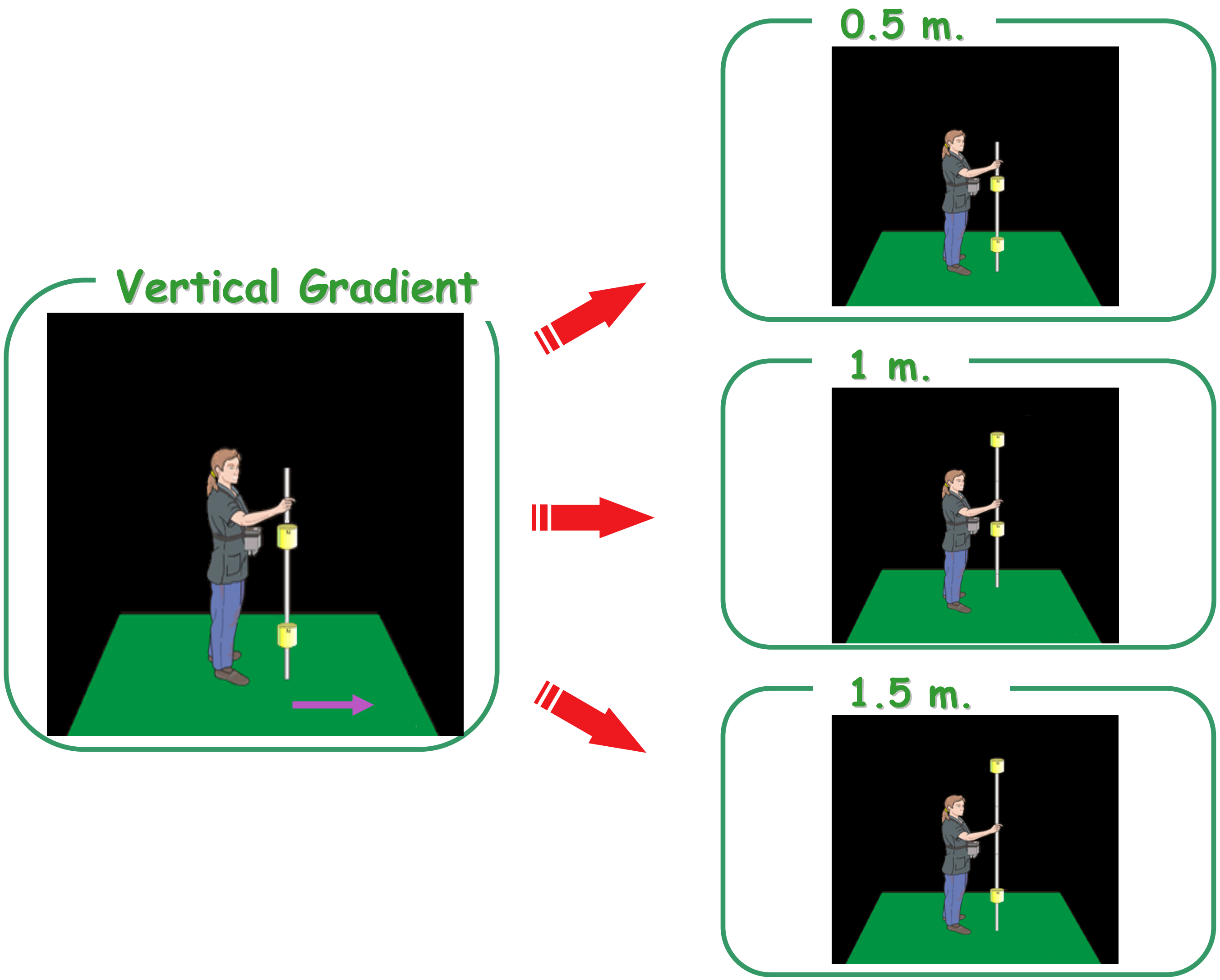


GAL

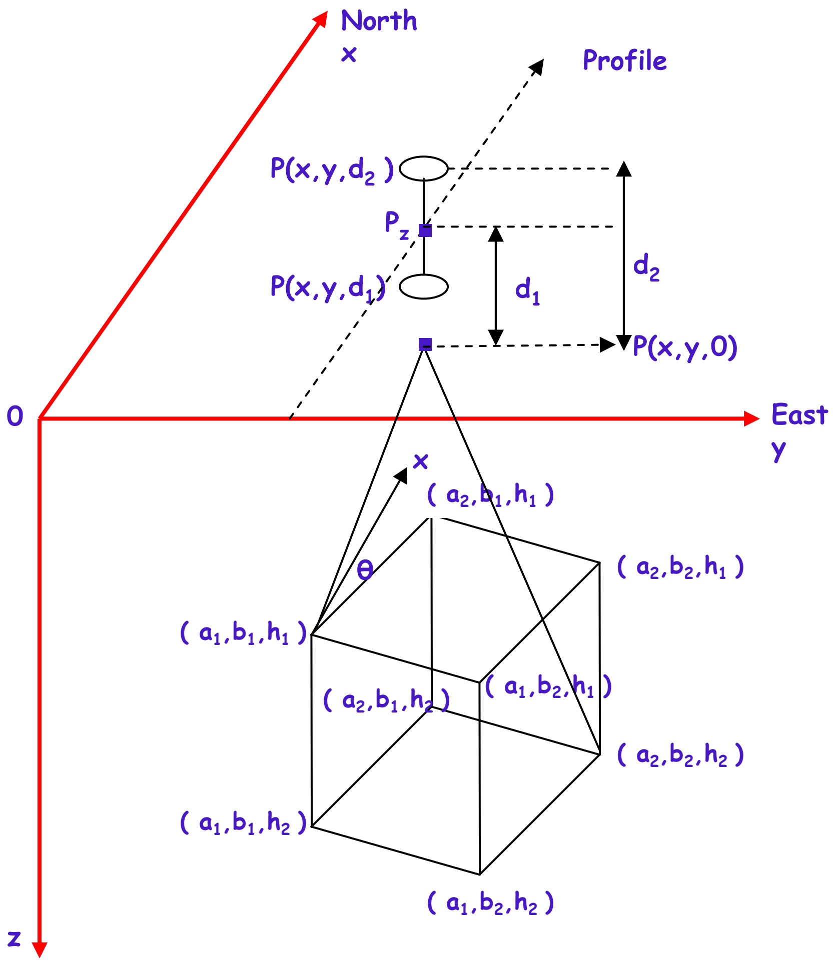


Different Receiver Orientations and Receiver Seperations in Magnetic Gradiometer Method

Receiver Seperations



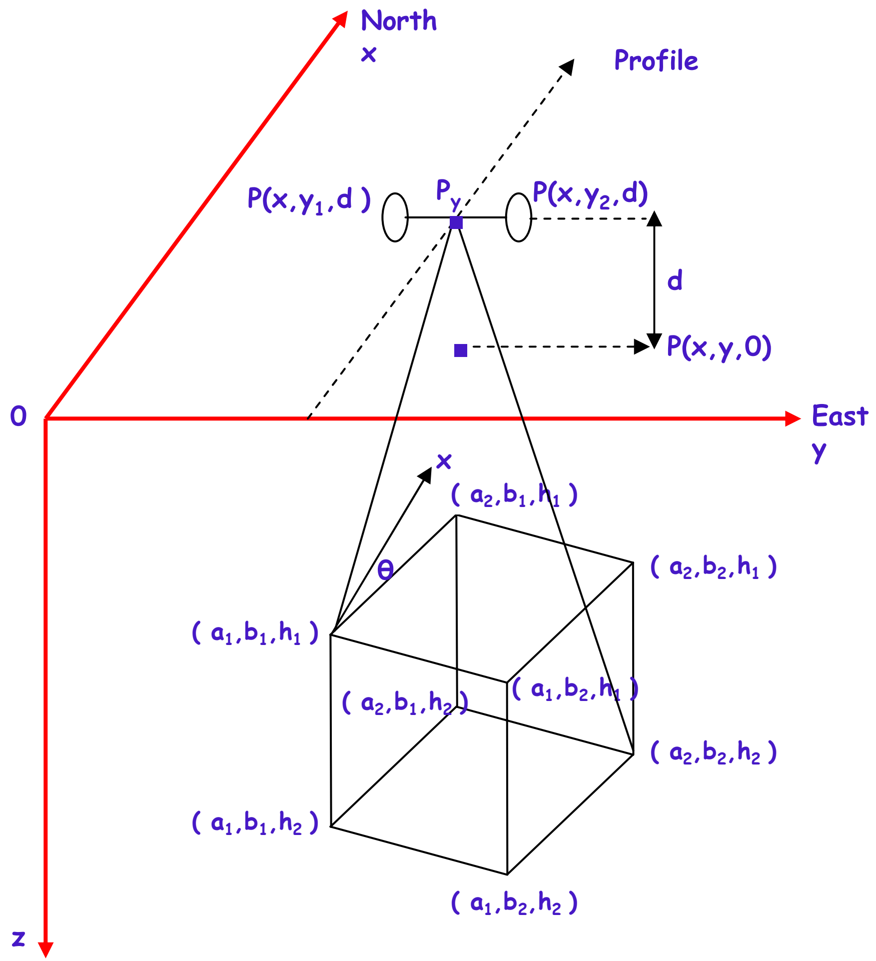
Vertical gradient measurement over three-dimensional rectangular prism



Vertical Gradient

$$\frac{T_{P(x,y,d_1)} - T_{P(x,y,d_2)}}{d_2 - d_1} = \left.\frac{dT}{dz}\right|_{P_z}$$

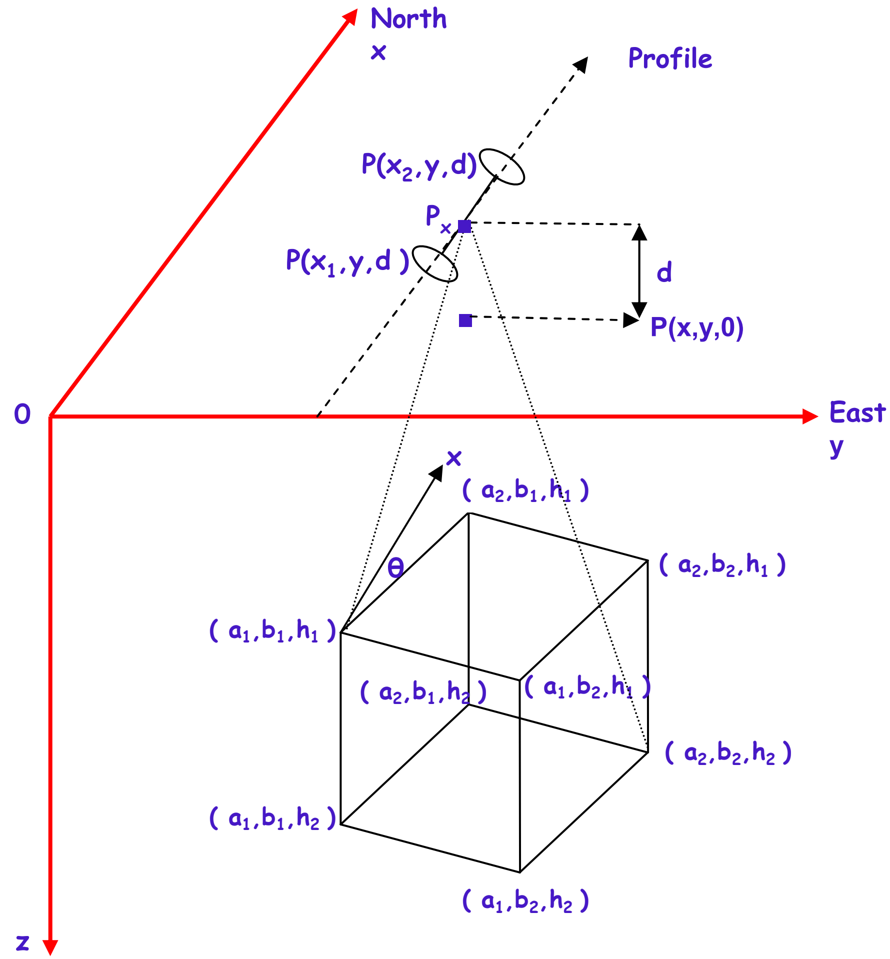
Horizontal gradient (GPL) measurement over three-dimensional rectangular prism



GPL

$$\frac{T_{P(x,y_1,d)} - T_{P(x,y_2,d)}}{y_2 - y_1} = \left.\frac{dT}{dy}\right|_{P_y}$$

Horizontal gradient (GAL) measurement over three-dimensional rectangular prism



GAL

$$\frac{T_{P(x_1,y,d)} - T_{P(x_2,y,d)}}{x_2 - x_1} = \left.\frac{dT}{dy}\right|_{P_x}$$

3D Forward Solution Cases

In the modelling of potential field data,

Forward solution is mostly used.

Inverse solution can only be useful if there is sufficient preliminary information about the field.

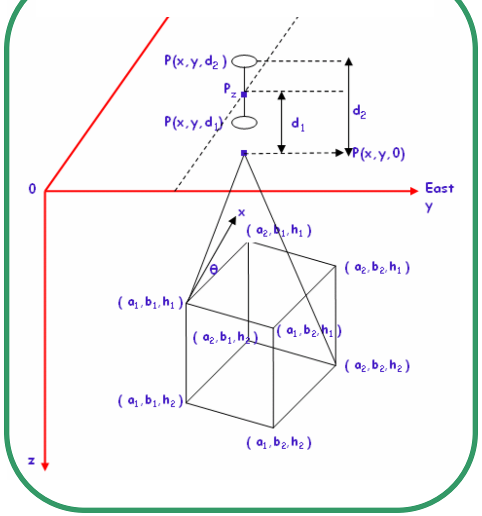
3D Forward Solution Cases

In this study, 3D modelling program, developed by Rao and Babu (1993), is used

The program is adapted to produce gradiometer data

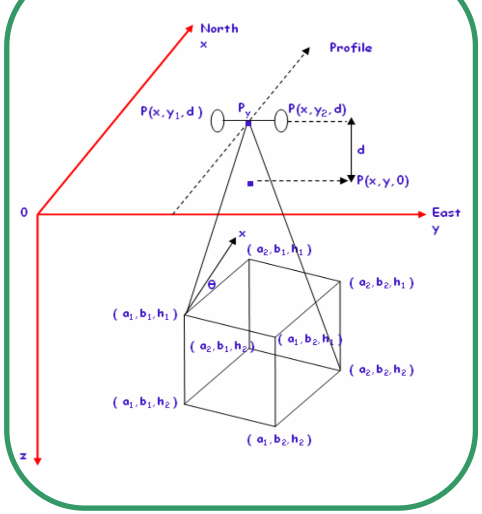
3D Forward Solution Cases

Vertical Gradient



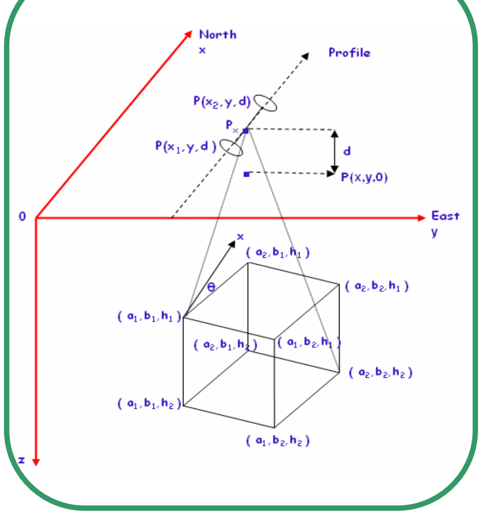
$$G(P_z) = \sum_{j=1}^{N_p} \frac{T_{P_{calc}(x,y,d_1)} - T_{P_{calc}(x,y,d_2)}}{d_1 - d_2}$$

GPL

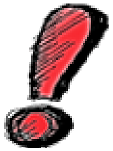


$$G(P_y) = \sum_{j=1}^{N_p} \frac{T_{P_{calc}(x,y_1,d)} - T_{P_{calc}(x,y_2,d)}}{y_2 - y_1}$$

GAL



$$G(P_x) = \sum_{j=1}^{N_p} \frac{T_{P_{calc}(x_1,y,d)} - T_{P_{calc}(x_2,y,d)}}{x_2 - x_1}$$



N_p : Number of Prisms

3D Forward Solution Cases – Vertical Gradient

Prism No.	a_1 (m)	a_2 (m)	b_1 (m)	b_2 (m)	h_1 (m)	h_2 (m)	d_1 (m)	d_2 (m)	I_θ (degree)	d_θ (degree)	θ (degree)	EI (CGS)
1	2	9	5	6	0	0.05	0.2	0.7	55	4	0	1
1	2	9	5	6	0	0.05	0.2	1.2	55	4	0	1
1	2	9	5	6	0	0.05	0.2	1.7	55	4	0	1
1	2	9	5	6	0	0.05	0.2	2.2	55	4	0	1

constant regional field (gammas) : 46000

fixed

fixed

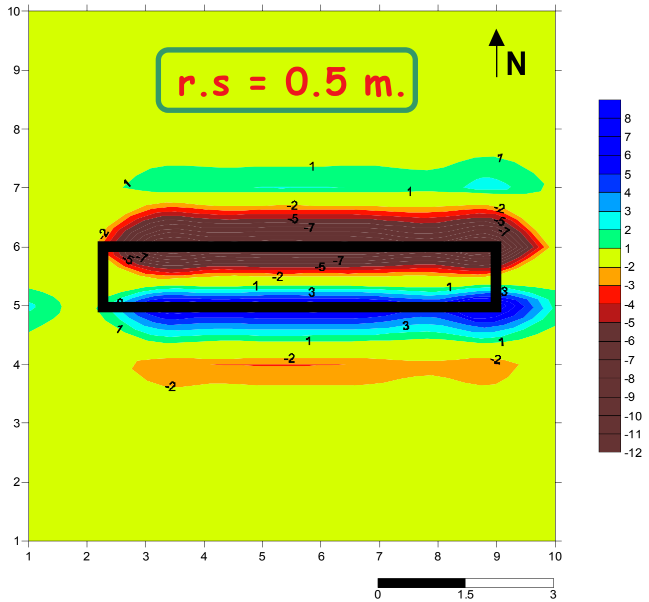
For 0.7 r.s = 0.5 m.

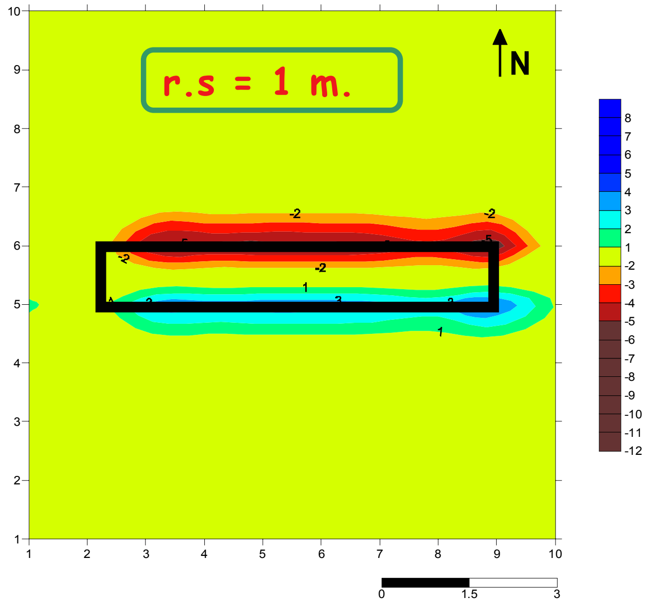
For 1.2 r.s = 1 m.

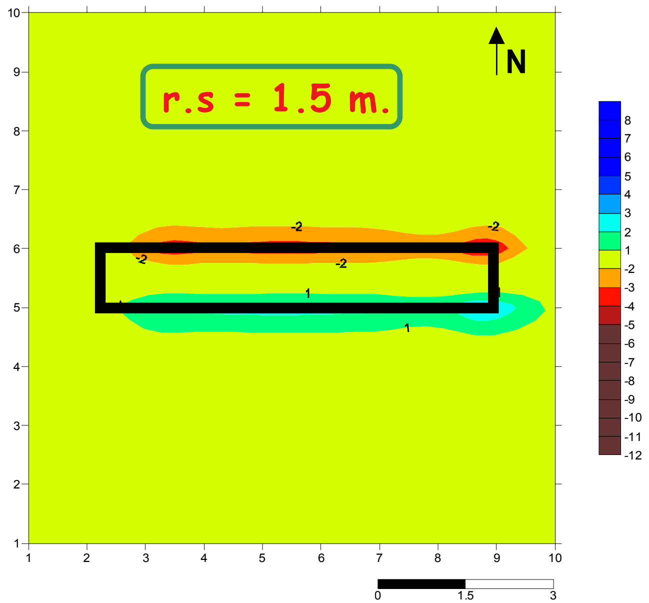
For 1.7 r.s = 1.5 m.

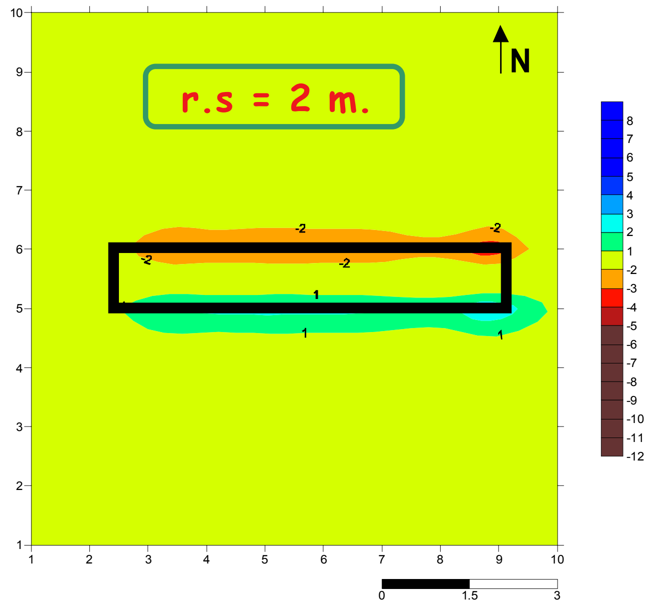
For 2.2 r.s = 2 m.

3D Forward Solution Cases – Vertical Gradient

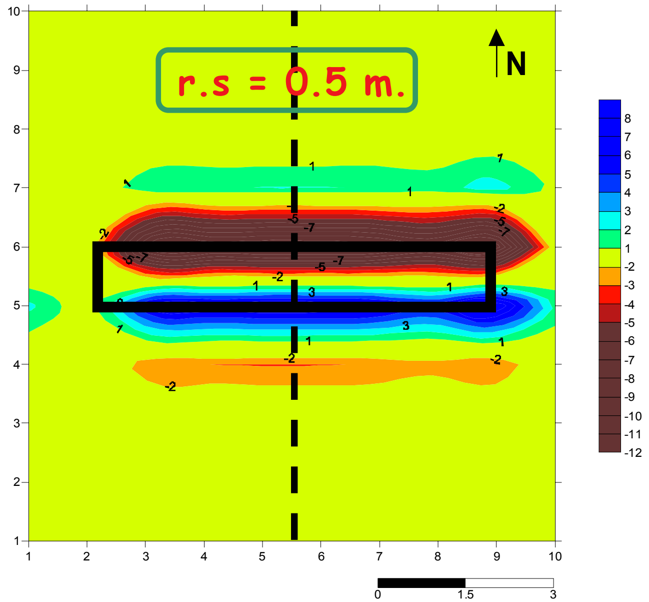


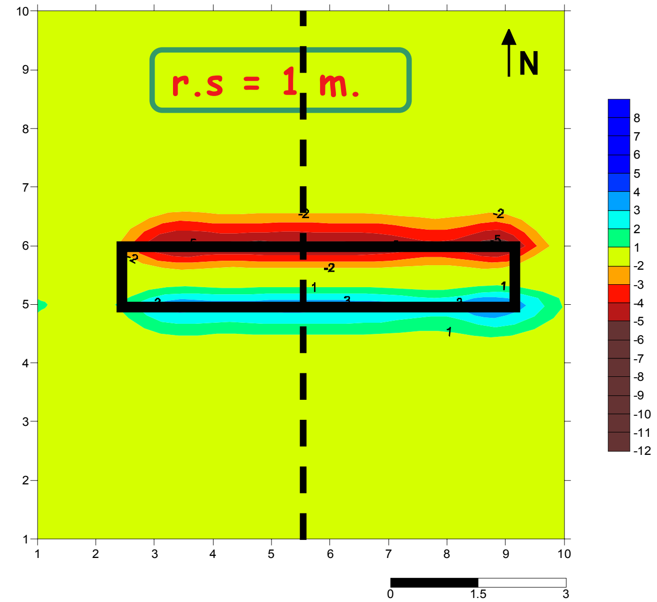


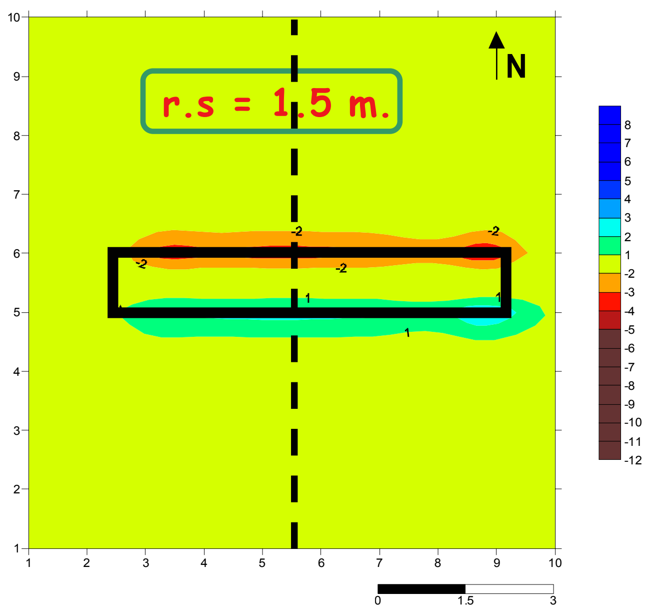


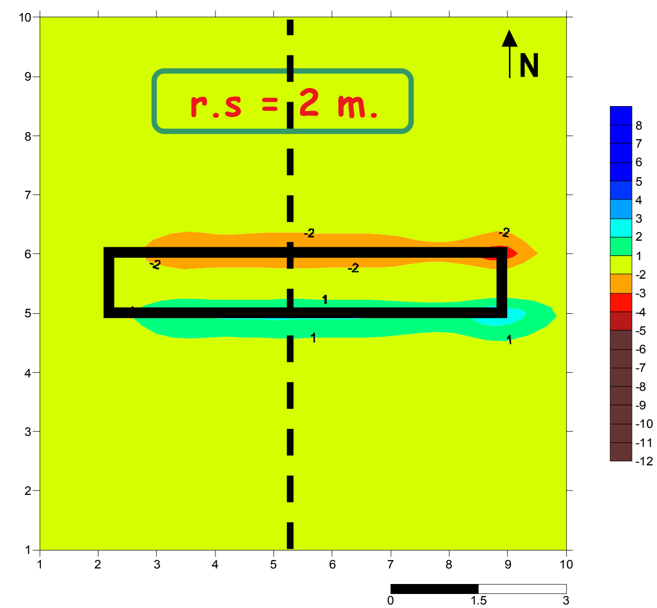


3D Forward Solution Cases – Vertical Gradient

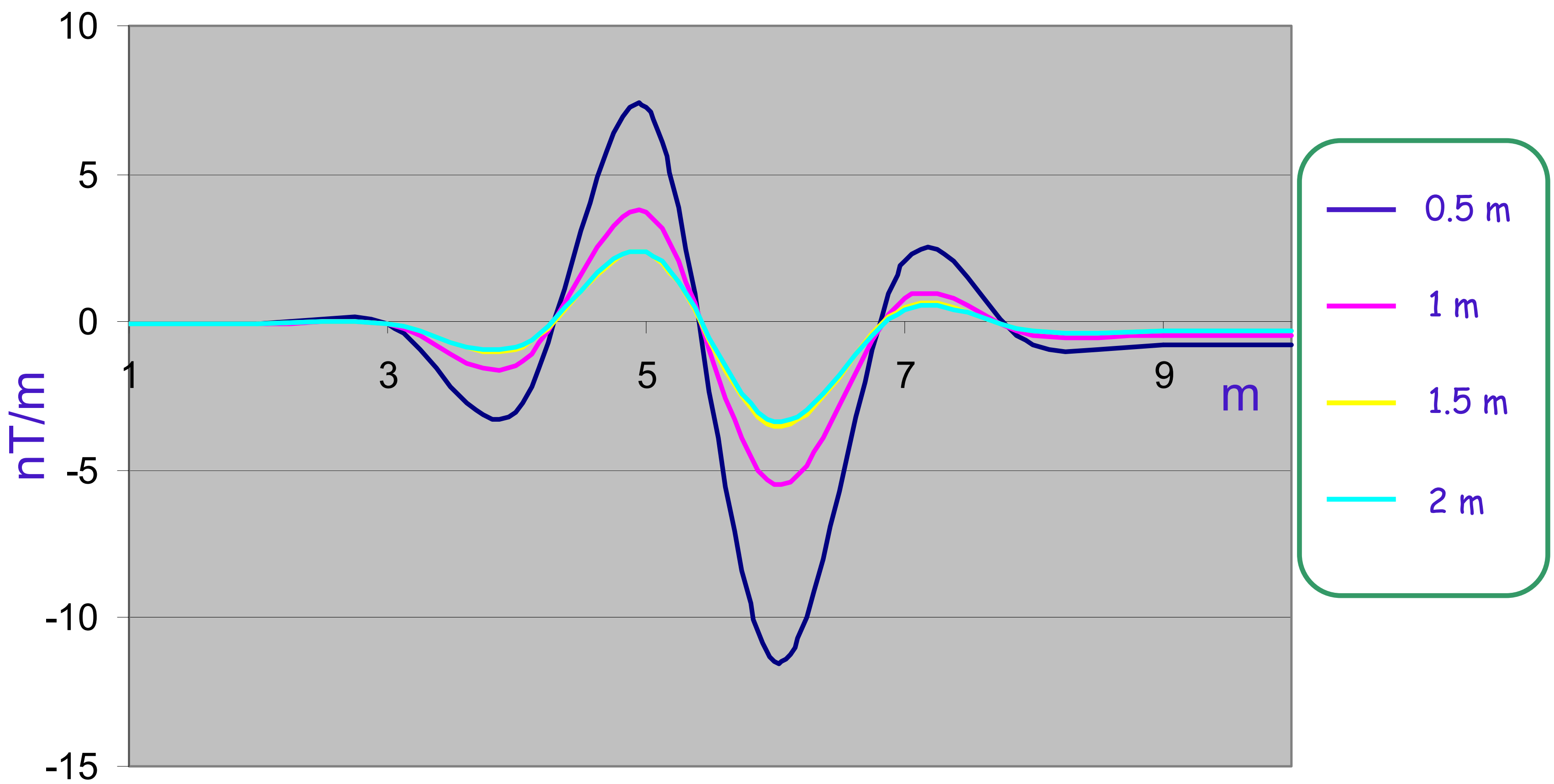








3D Forward Solution Cases – Vertical Gradient



3D Forward Solution Cases – Horizontal Gradient (GPL)

Prism No.	a_1 (m)	a_2 (m)	b_1 (m)	b_2 (m)	h_1 (m)	h_2 (m)	d_1 (m)	d_2 (m)	I_θ (degree)	d_θ (degree)	θ (degree)	EI (CGS)
1	2	9	5	6	0	0.05	0.7	-	55	4	0	1
1	2	9	5	6	0	0.05	0.7	-	55	4	0	1
1	2	9	5	6	0	0.05	0.7	-	55	4	0	1
1	2	9	5	6	0	0.05	0.7	-	55	4	0	1

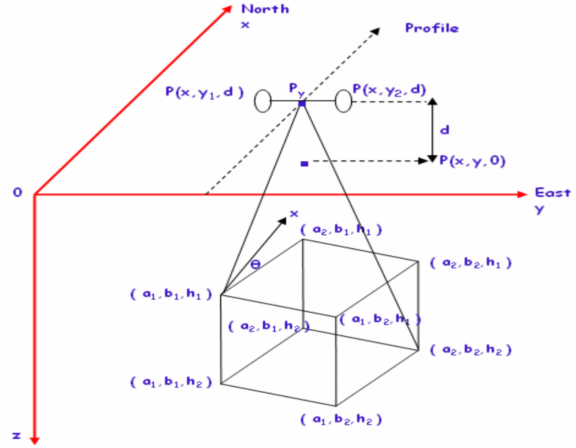
constant regional field (gammas) : 46000

$y_2 - y_1 = r.s = 0.5$ m.

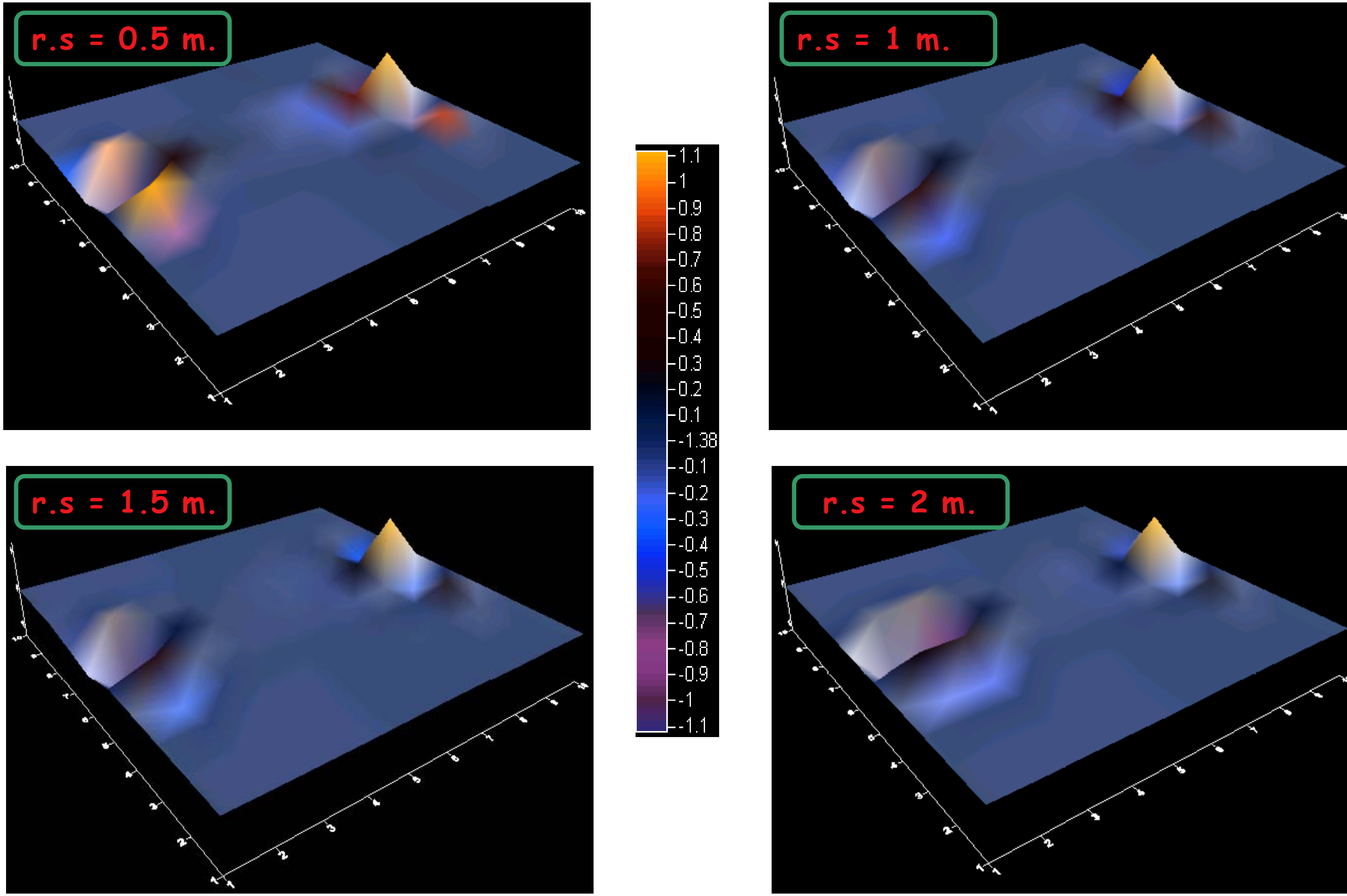
$y_2 - y_1 = r.s = 1$ m.

$y_2 - y_1 = r.s = 1.5$ m.

$y_2 - y_1 = r.s = 2$ m.



3D Forward Solution Cases – Horizontal Gradient (GPL)



3D Forward Solution Cases – Horizontal Gradient (GAL)

Prism No.	a_1 (m)	a_2 (m)	b_1 (m)	b_2 (m)	h_1 (m)	h_2 (m)	d_1 (m)	d_2 (m)	I_θ (degree)	d_θ (degree)	θ (degree)	EI (CGS)
1	2	9	5	6	0	0.05	0.7	-	55	4	0	1
1	2	9	5	6	0	0.05	0.7	-	55	4	0	1
1	2	9	5	6	0	0.05	0.7	-	55	4	0	1
1	2	9	5	6	0	0.05	0.7	-	55	4	0	1

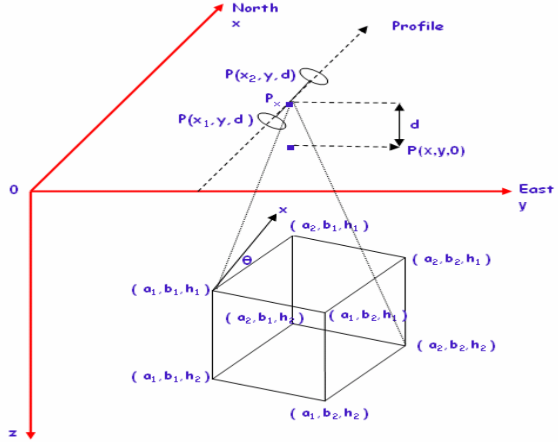
constant regional field (gammas) : 46000

$x_2 - x_1 = r.s = 0.5$ m.

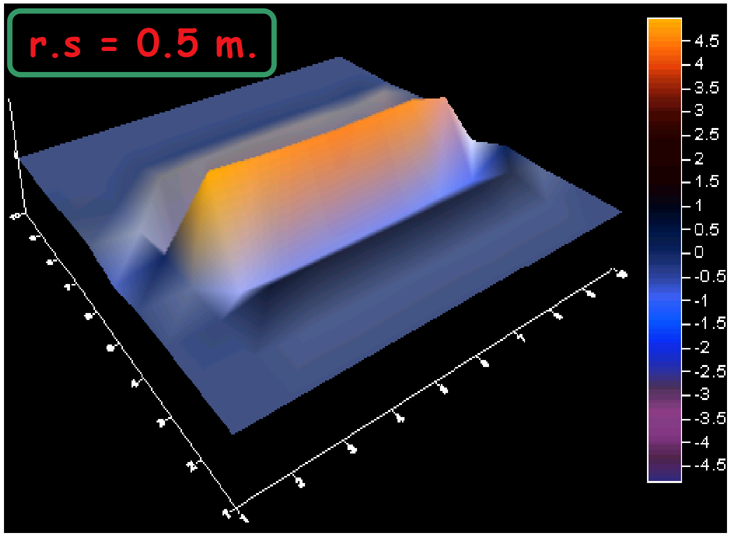
$x_2 - x_1 = r.s = 1$ m.

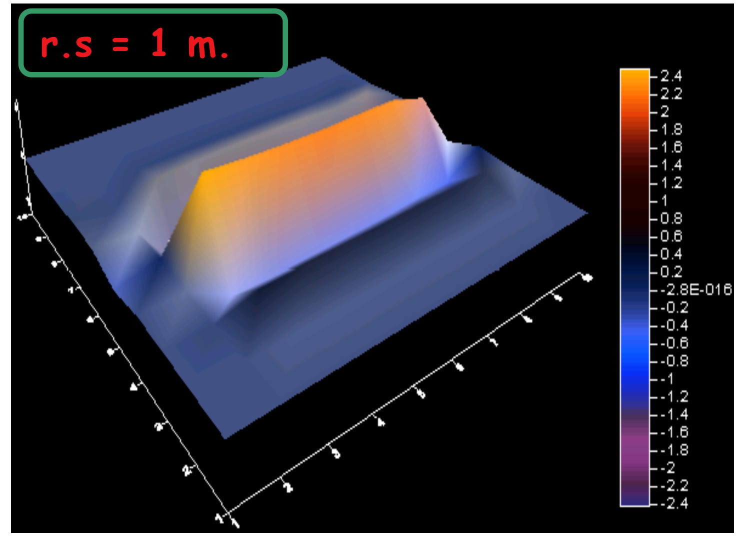
$x_2 - x_1 = r.s = 1.5$ m.

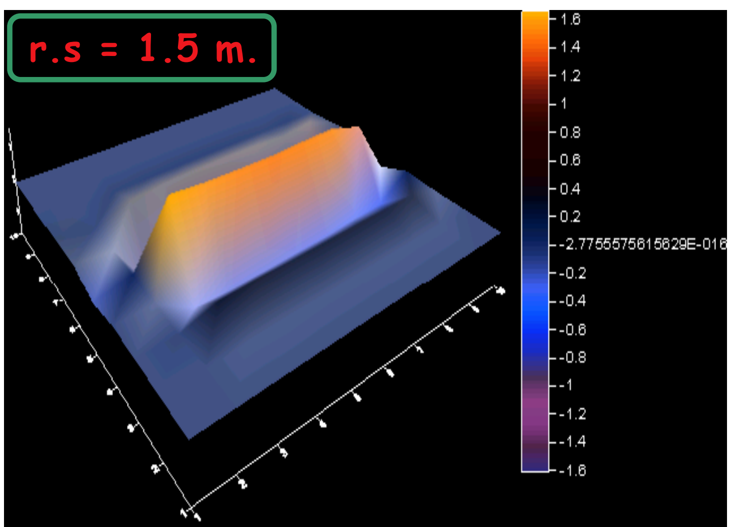
$x_2 - x_1 = r.s = 2$ m.

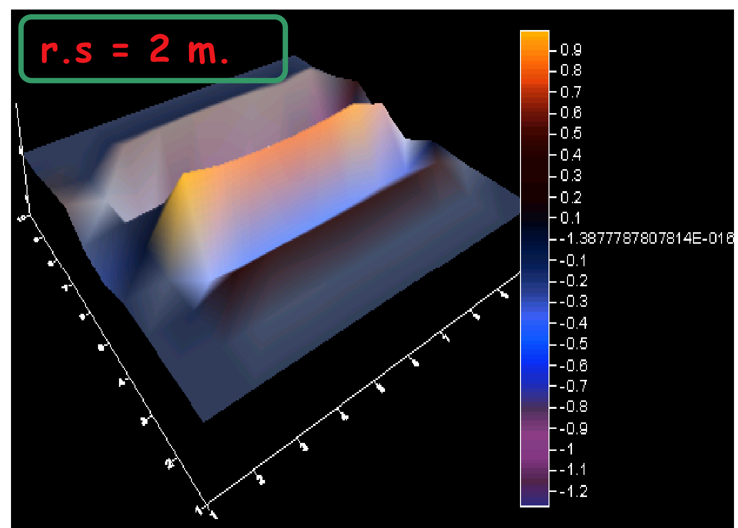


3D Forward Solution Cases – Horizontal Gradient (GAL)

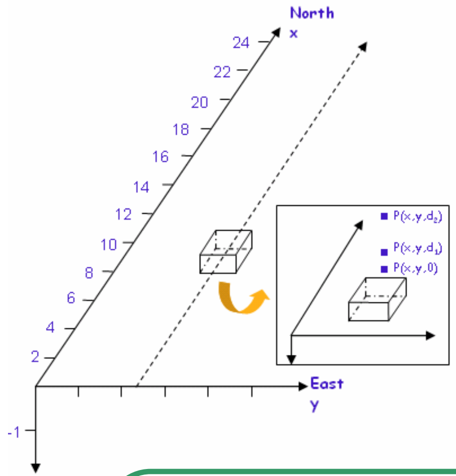






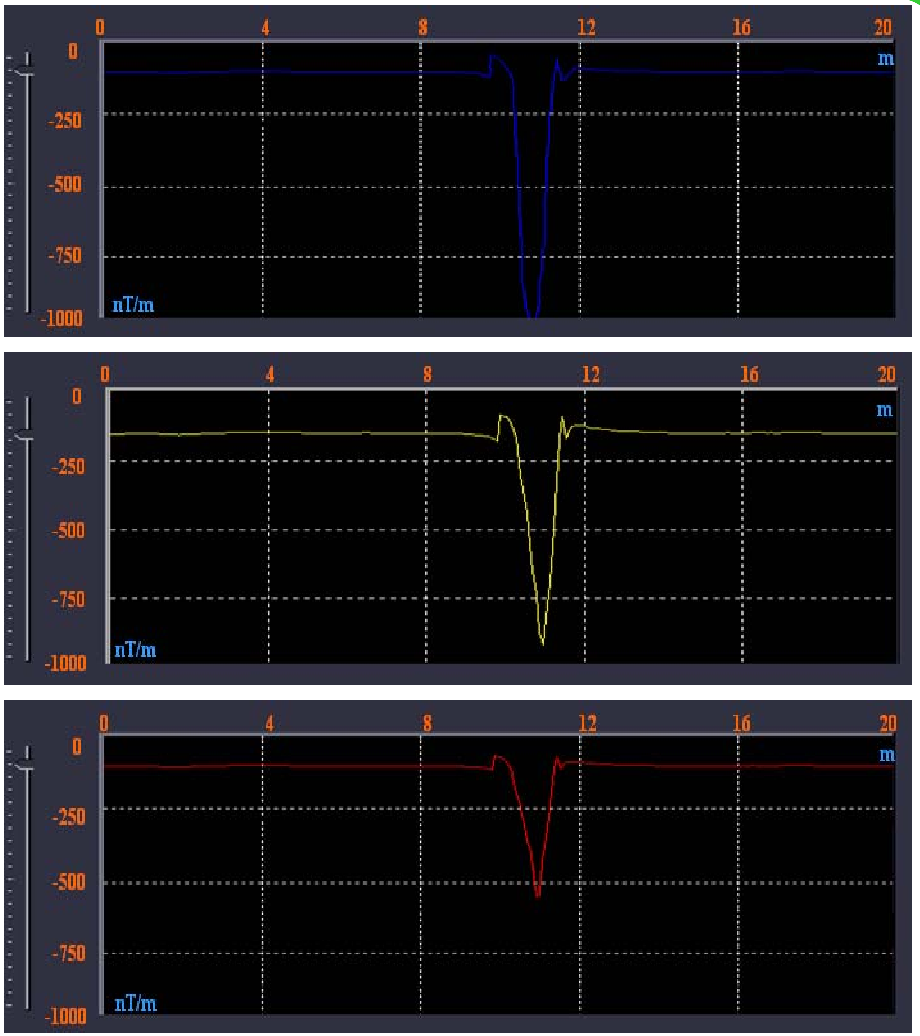


Vertical Gradient Measurement – Different Receiver Seperations



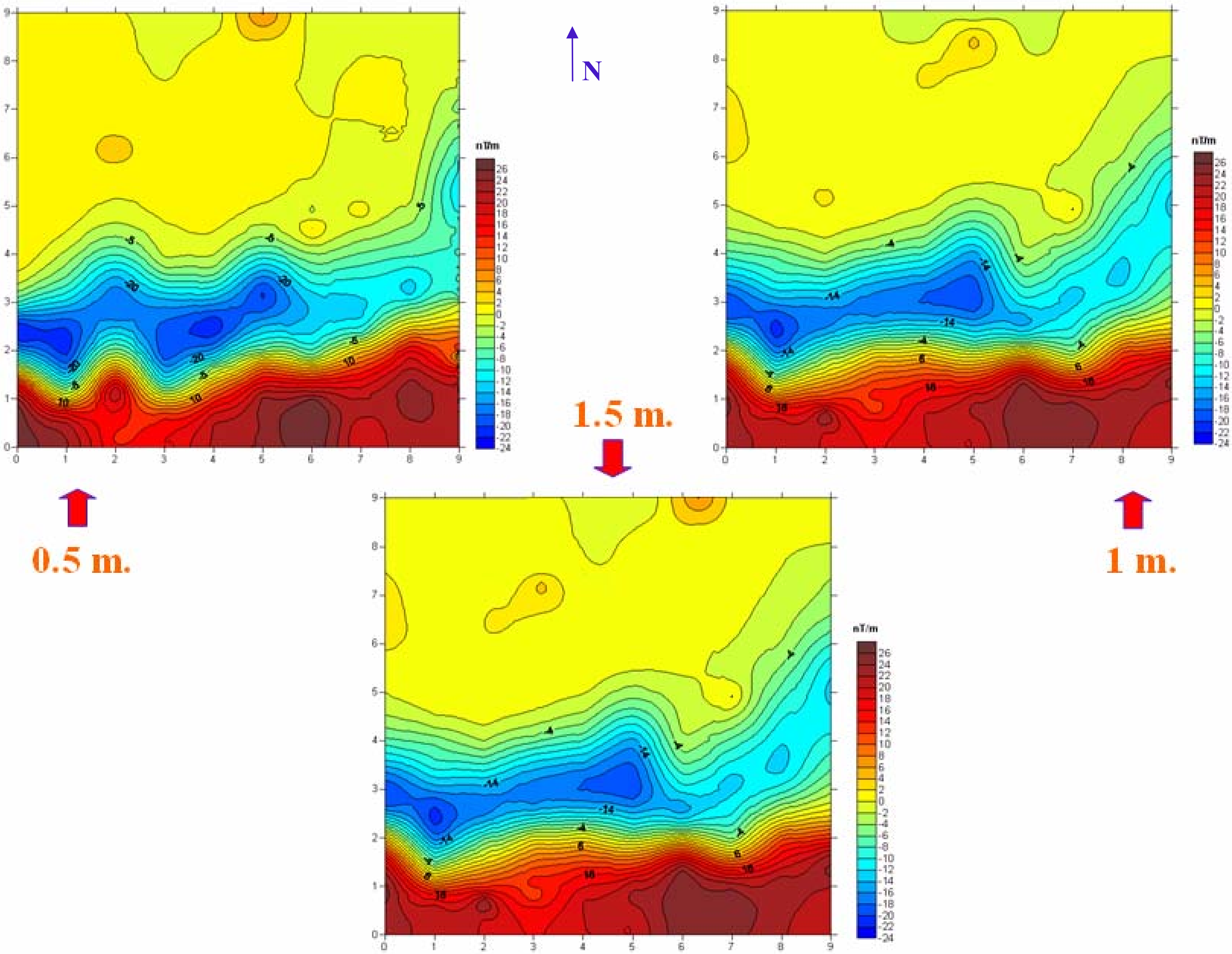
EI = 1.5 CGS
Iθ = 55
dθ = 4
Con. Reg. Field = 46000

0.5 m.
1 m.
1.5 m.

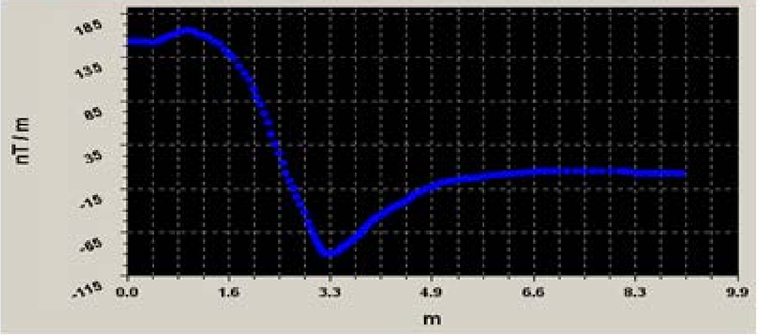


Observed Data

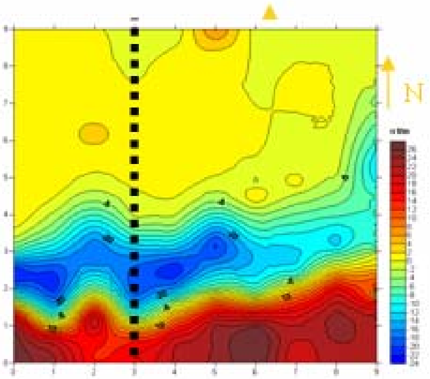
Vertical Gradient Measurement – Over an Old Sewer

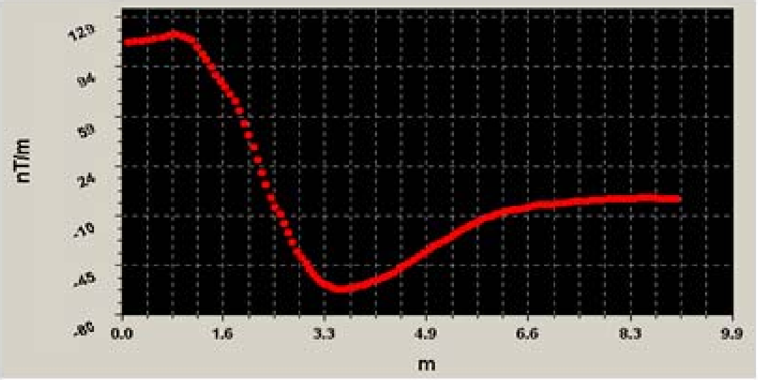


Vertical Gradient Measurement – Over an Old Sewer

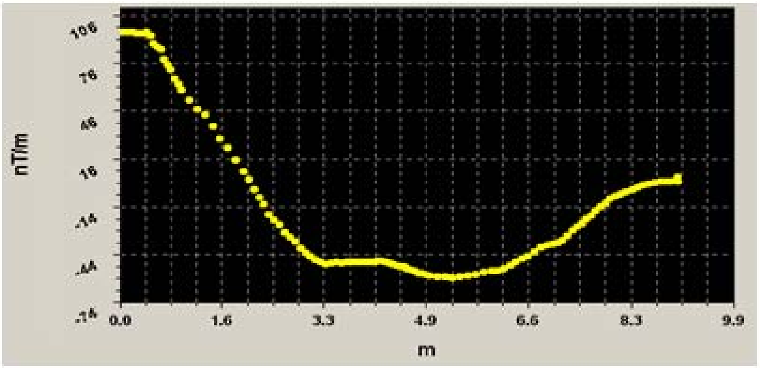


0.5 m.





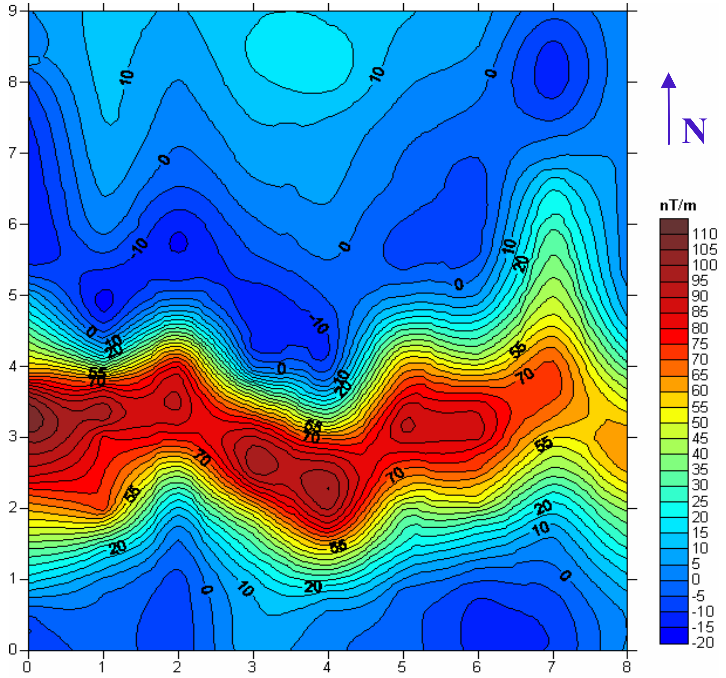
1 m.



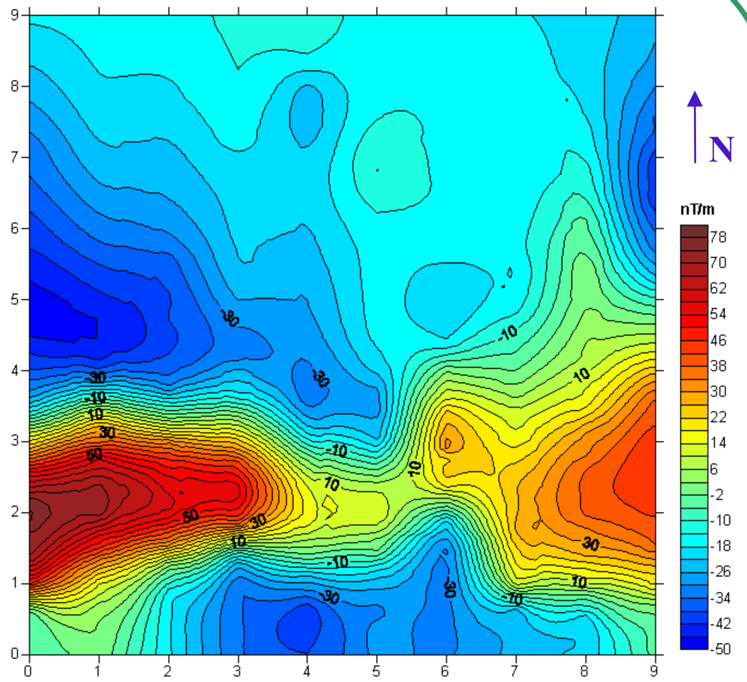
1.5 m.

Horizontal Gradient Measurement – Over an Old Sewer

GAL



GPL



3D Inversion of Magnetic Gradiometer Anomalies

Traditionally, ill-posed nature of the multi dimensional inversion of geophysical data is much severe in potential field data.

The shortage of data forces to use additional information.

Therefore, in the evaluation of potential field data, inverse solution can be only useful if there is sufficient information about the subsurface to restrict the solution space

3D Inversion of Magnetic Gradiometer Anomalies

Structural information such as extensions, locations etc are easily extracted from gradient data.

Therefore, some constraints required by the inversion procedures may easily obtained from the data set itself.

3D Inversion of Magnetic Gradiometer Anomalies

Estimation of the unknown parameters is done using of non-linear optimization technique of the Marquardt Algorithm.

Inversion procedure; starting with an initial model and iterationg on the parameters the objective function is minimized by least squares,

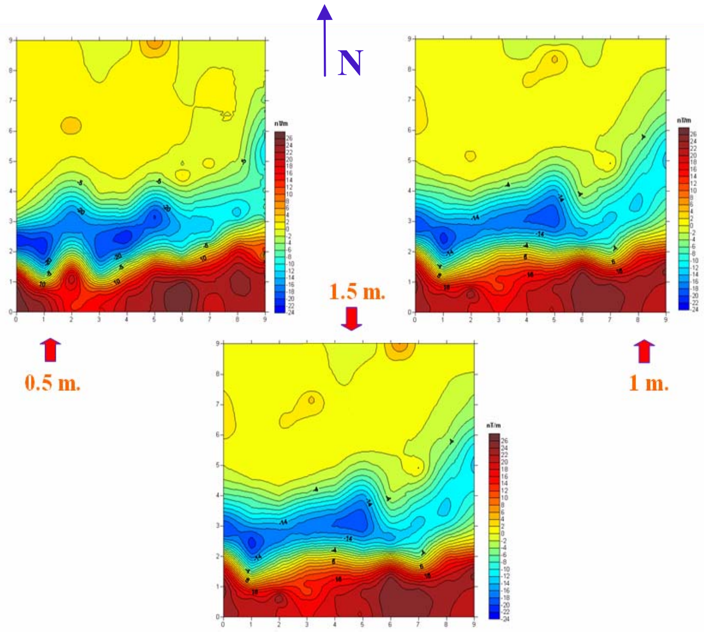
$$\kappa = \sum_{i=1}^{M_x} \sum_{j=1}^{M_y} [\, G_{meas}(i,j) - G_{calc}(i,j) \,]^2$$

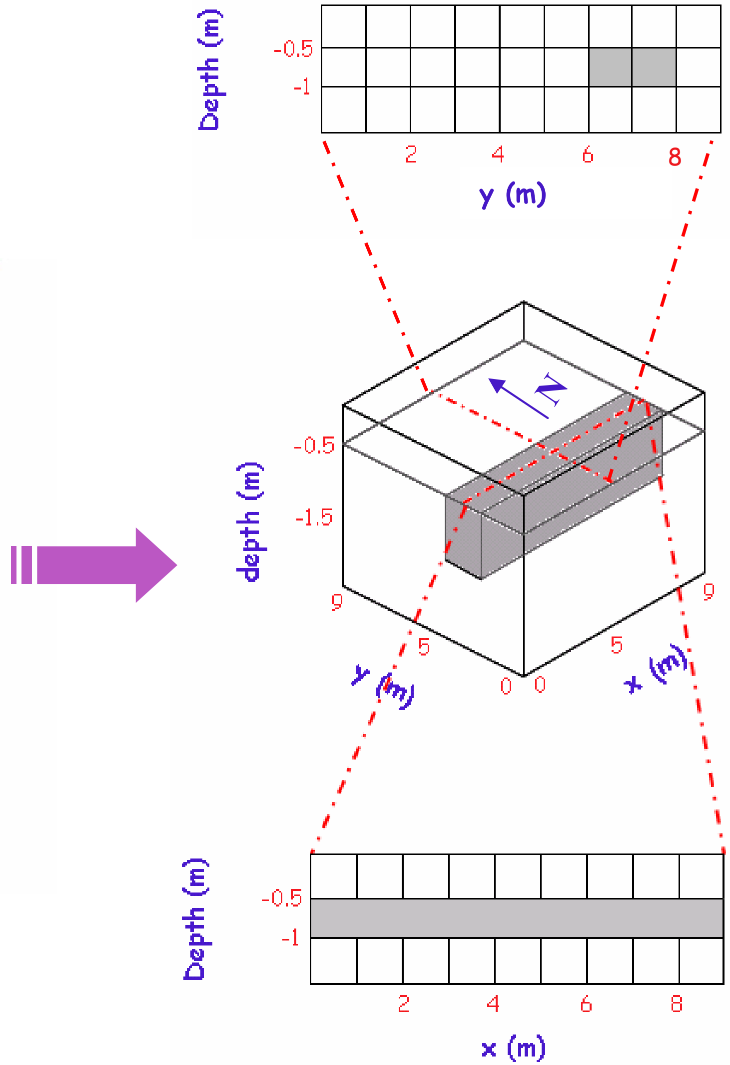
G_{meas} : Measured magnetic gradiometer anomalies

G_{calc} : Calculated magnetic gradiometer anomalies

M_x ,M_y : Number of measurement points

3D Inversion of Magnetic Gradiometer Anomalies; Vertical Gradient



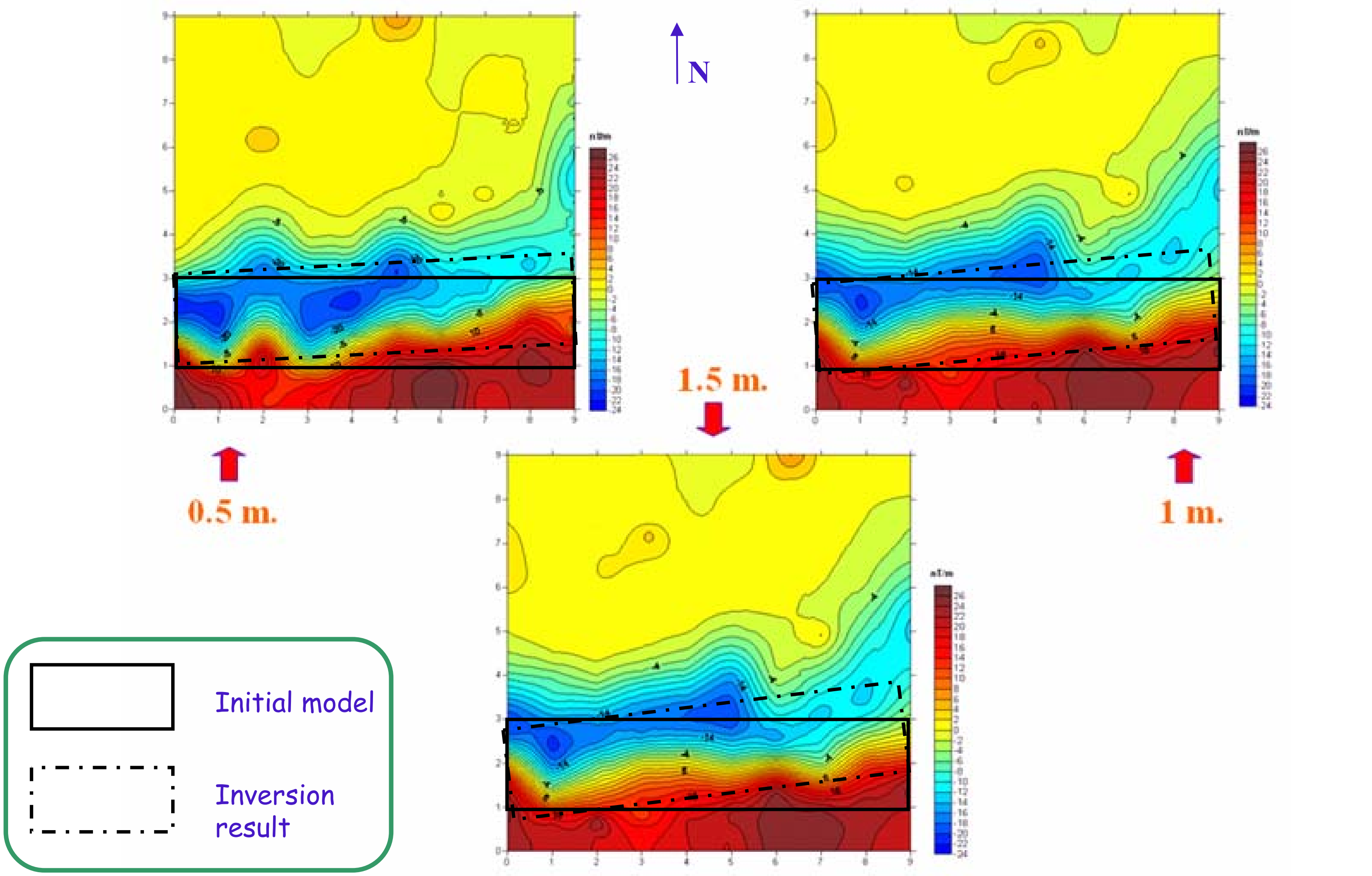


3D Inversion of Magnetic Gradiometer Anomalies; Vertical Gradient

Prism No.	a_1 (m)	a_2 (m)	b_1 (m)	b_2 (m)	h_1 (m)	h_2 (m)	d_1 (m)	d_2 (m)	I_θ (degree)	d_θ (degree)	θ (degree)	EI (CGS)
1	0	9	1	3	0.5	1	0.2	0.7	55	4	0	0.4
1	0	9	1	3	0.5	1	0.2	1.2	55	4	0	0.4
1	0	9	1	3	0.5	1	0.2	1.7	55	4	0	0.4

constant regional field (gammas) : 46000

3D Inversion of Magnetic Gradiometer Anomalies; Vertical Gradient



3D Inversion of Magnetic Gradiometer Anomalies; Vertical Gradient

Prism No.	a_1 (m)	a_2 (m)	b_1 (m)	b_2 (m)	h_1 (m)	h_2 (m)	d_1 (m)	d_2 (m)	I_θ (degree)	d_θ (degree)	θ (degree)	EI (CGS)
1	0	9	1	3	0.5	1	0.2	0.7	55	4	0	0.4
1	0.2	8.7	1.2	2.89	0.7	2	0.2	0.7	55	4	10	0.3
RMS : 3.67												
1	0	9	1	3	0.5	1	0.2	1.2	55	4	0	0.4
1	0.22	8.9	1.3	2.67	0.67	2.2	0.2	1.2	55	4	13	0.2
RMS : 4.54												
1	0	9	1	3	0.5	1	0.2	1.7	55	4	0	0.4
1	0.18	9.1	1.1	2.9	0.55	1.9	0.2	1.2	55	4	17	0.3
RMS : 3.54												

constant regional field (gammas) : 46000

Initial Model (black) — Inverted Model (red)

3D Inversion of Magnetic Gradiometer Anomalies; Horizontal Gradient

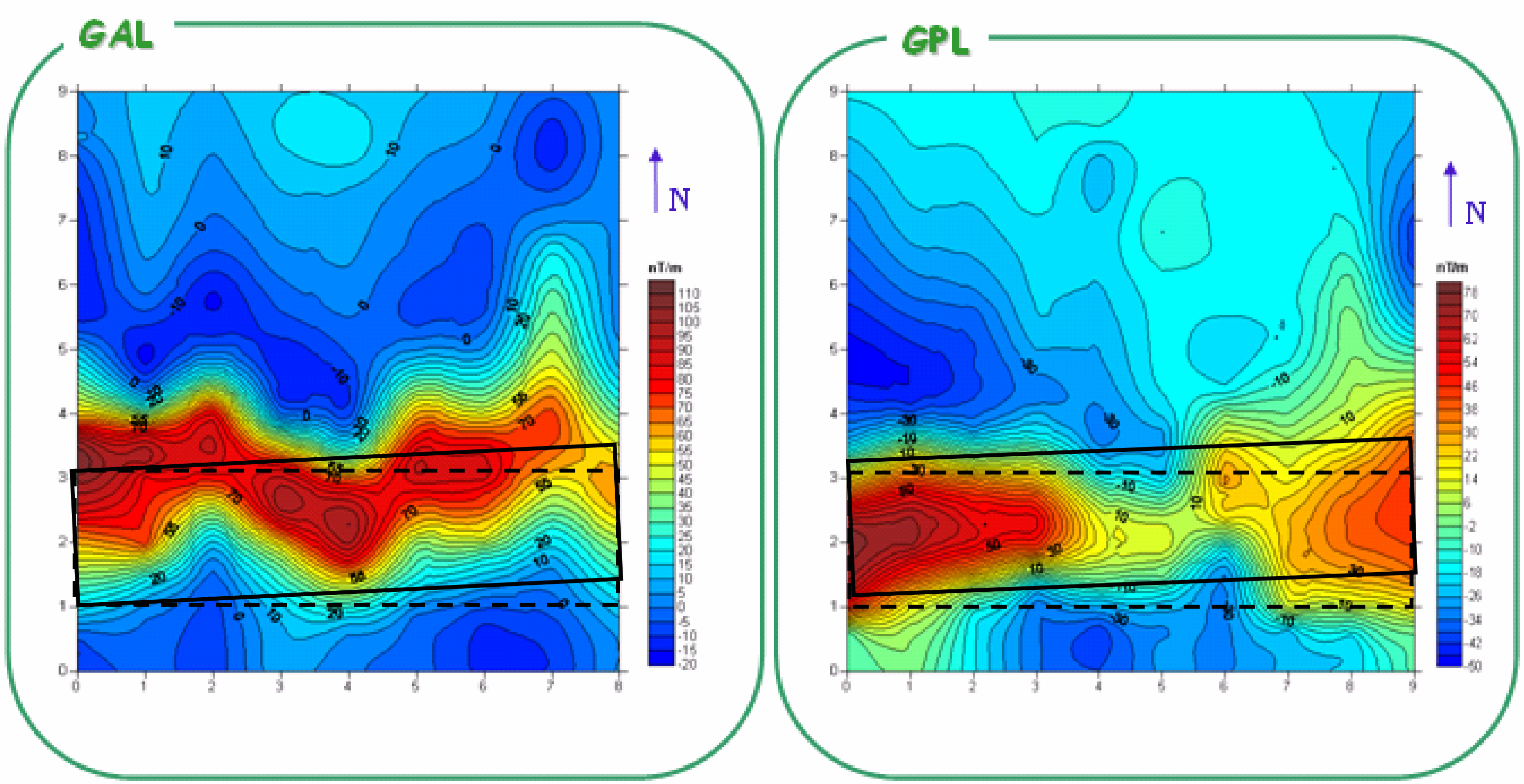
Prism No.	a_1 (m)	a_2 (m)	b_1 (m)	b_2 (m)	h_1 (m)	h_2 (m)	d_1 (m)	d_2 (m)	I_θ (degree)	d_θ (degree)	θ (degree)	EI (CGS)
1	0	9	1	3	0.5	1	0.7	-	55	4	0	0.4
1	0	9	1	3	0.5	1	0.7	-	55	4	0	0.4

constant regional field (gammas) : 46000

for GAL $x_2 - x_1 = r.s = 1$ m.

for GPL $y_2 - y_1 = r.s = 1$ m.

3D Inversion of Magnetic Gradiometer Anomalies; Horizontal Gradient



RMS = 4.12

Initial model

Inversion result

RMS = 5.78

CONCLUSIONS

- The GAL and GPL data may be produced from total field maps as a secondary output of the survey.
- In this study, direct measurements of the gradients are proposed.
- Receiver separation is important and must be chosen according to target depth, noise level and terrain conditions.
- The test results show that receiver separation should be proportional to the depth.

CONCLUSIONS

- The choice of height of the receivers from the surface as a important factor as choice of the receiver seperations.

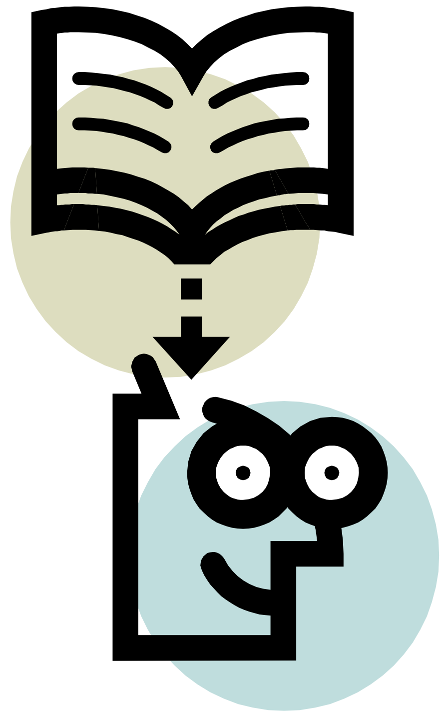
- Inversion of data obtained from different orientations increase the resolution.

- Location of the structure obtained from the gradient data and used as constraints in the inversion steps.

CONCLUSIONS

- Resolution weakness of the each gradient data set may lead earratic result in inversion.

- The result of the joint usage of gradient data in inversion will be presented in due course.



THANKS...