

ECOLE ET OBSERVATOIRE DES SCIENCES DE LA TERRE

Institut de Physique du Globe de Strasbourg (ULP-CNRS UMR 7516)

Equipe Rifts et Dorsales

Marc Munsch Physicien des Observatoires

Daniel Boulanger, Patrice Ulrich,

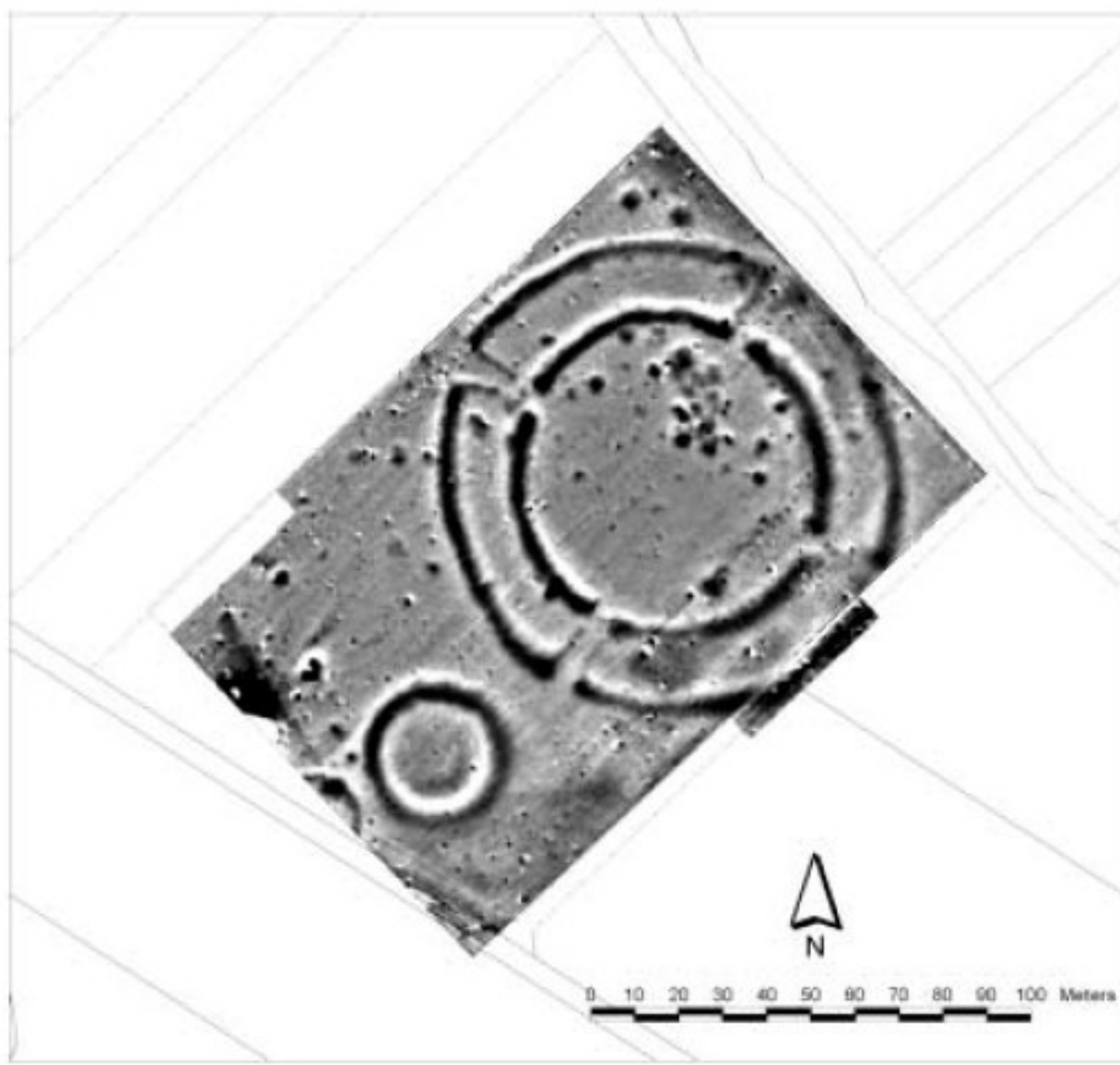
Mohamad Baala, Mustapha Bouiflane,

Kaouthar Ben Azouz, Alexis Mainault,

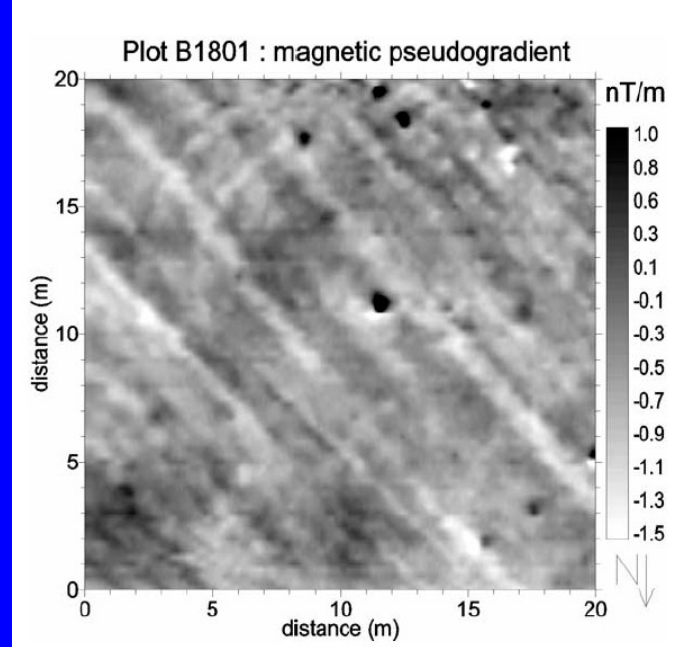
Francois Ledrappier, Romaric Limacher

Apport du magnétisme à la connaissance de la sub-surface

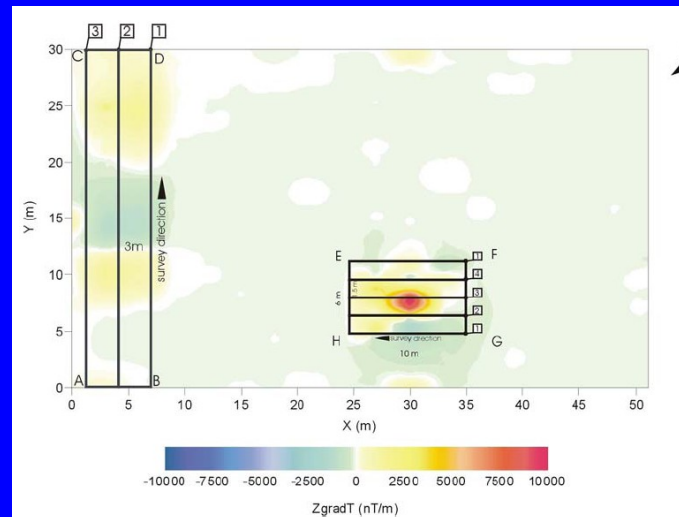
Marc.Munschy@eost.u-strasbg.fr



Neubauer, 2001



Mathé et Lévêque, 2003



Chianese et al., 2006

❑ Mesure magnétique et traitement

❑ Outils d'interprétation et particularités de la méthode magnétique

❑ Exemples anthropiques

- ✓ Dépollution de sites industriels
- ✓ Archéologie

❑ Exemples naturels

- ✓ Cartographie magnétique multi-échelles dans la région de Colmar
- ✓ Lithologie de la Bruche

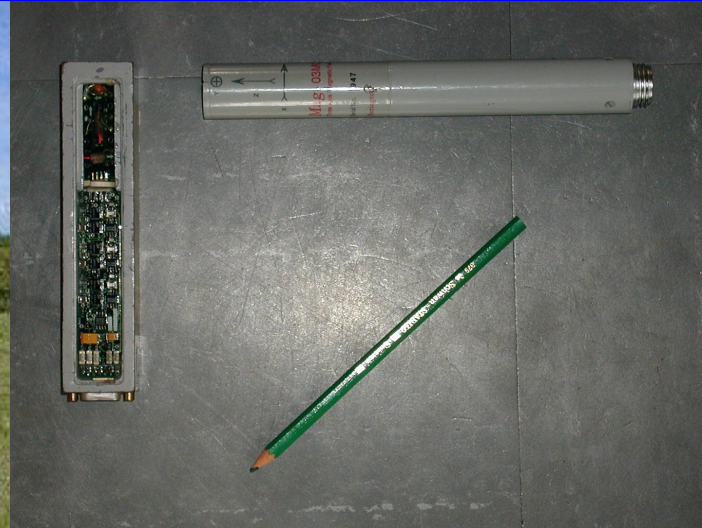
Capteurs scalaires
à protons



pompage optique



Capteurs vectoriels
fluxgate

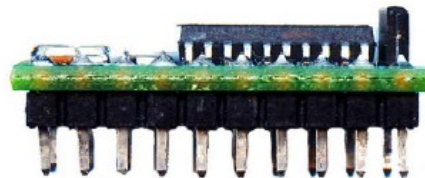
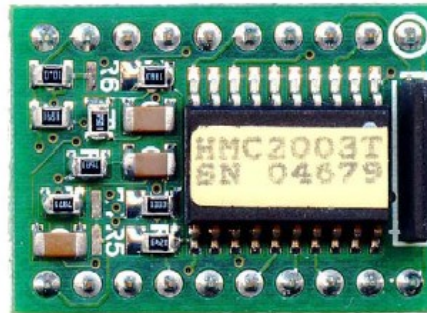


Absolus
0,1 nT

pseudo-absolus
0,01 nT

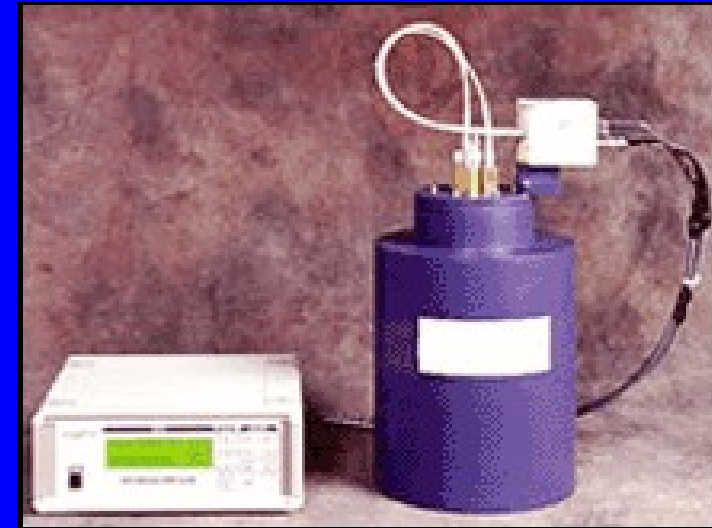
relatifs
1 nT

Résistances magnéto strictives

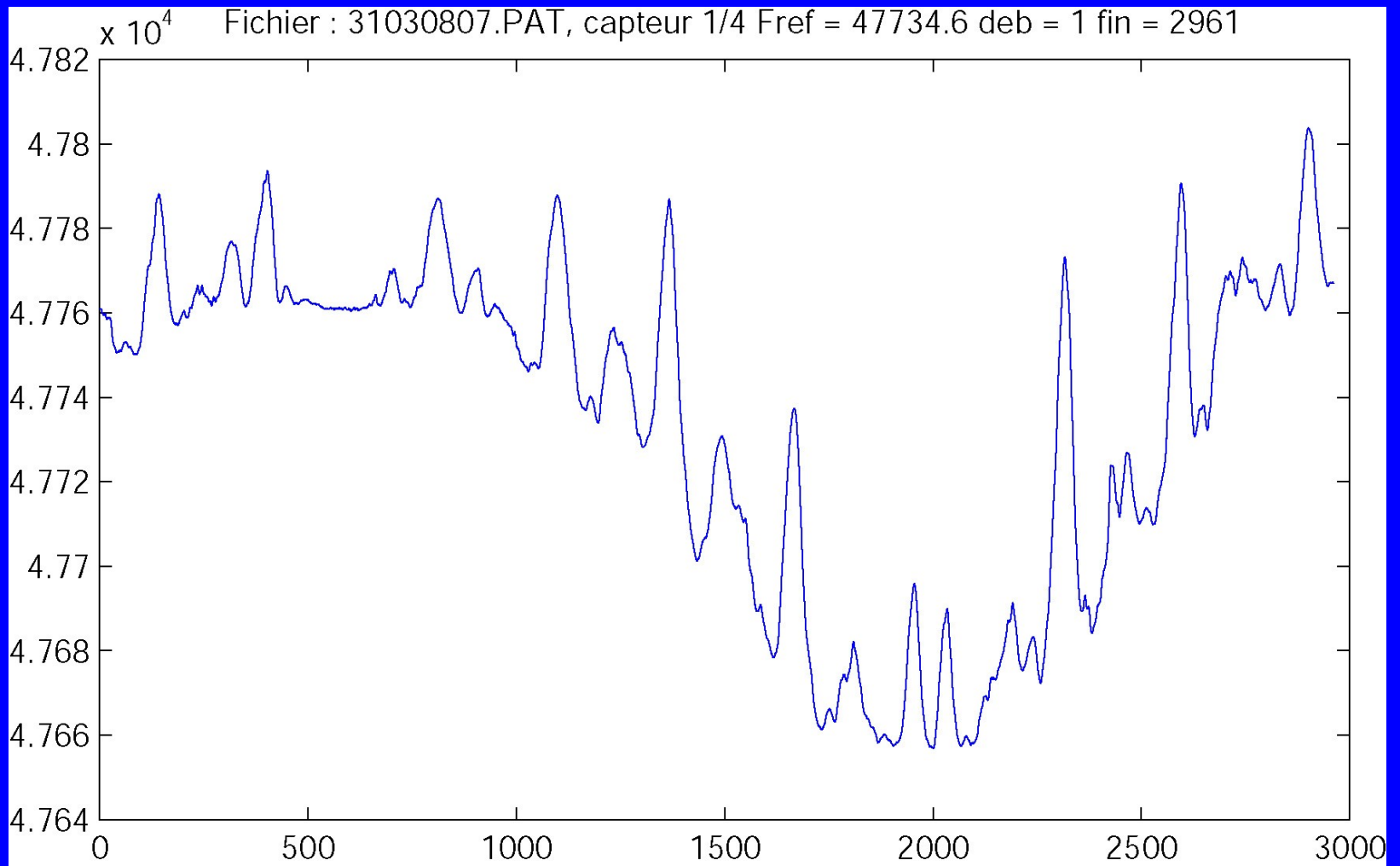


SQUID

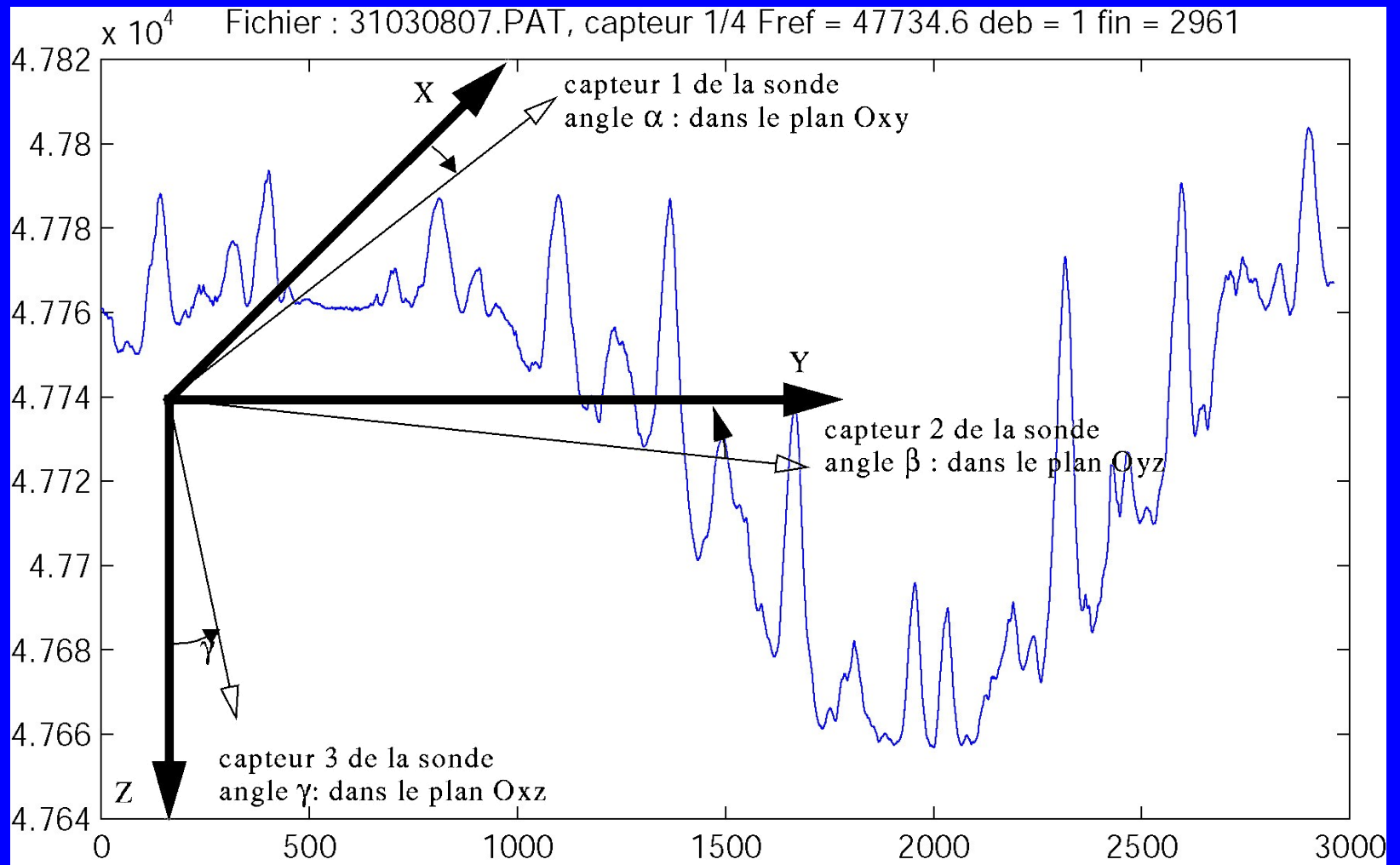
Superconducting Quantum
Interference Device



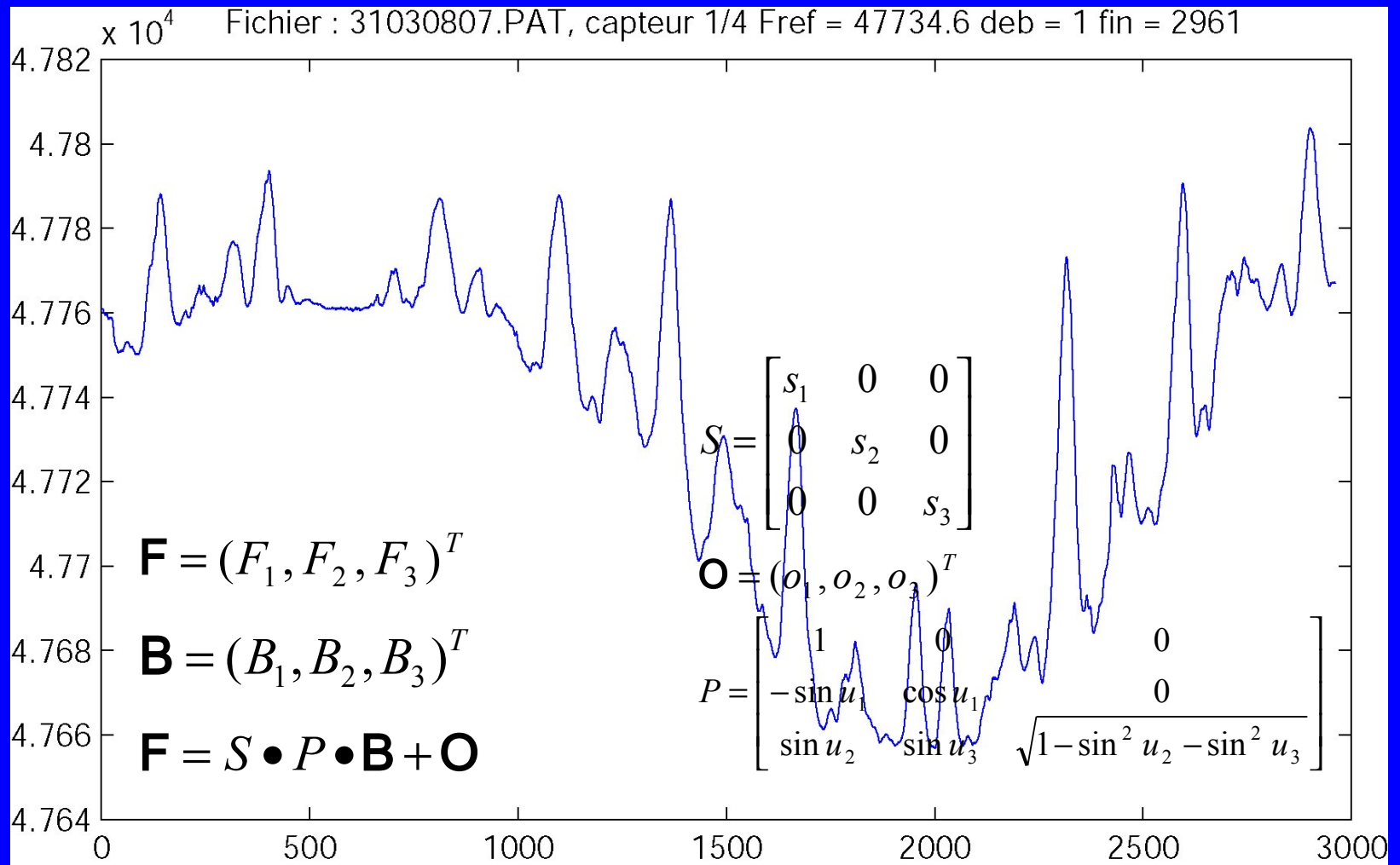
Tenseur magnétique



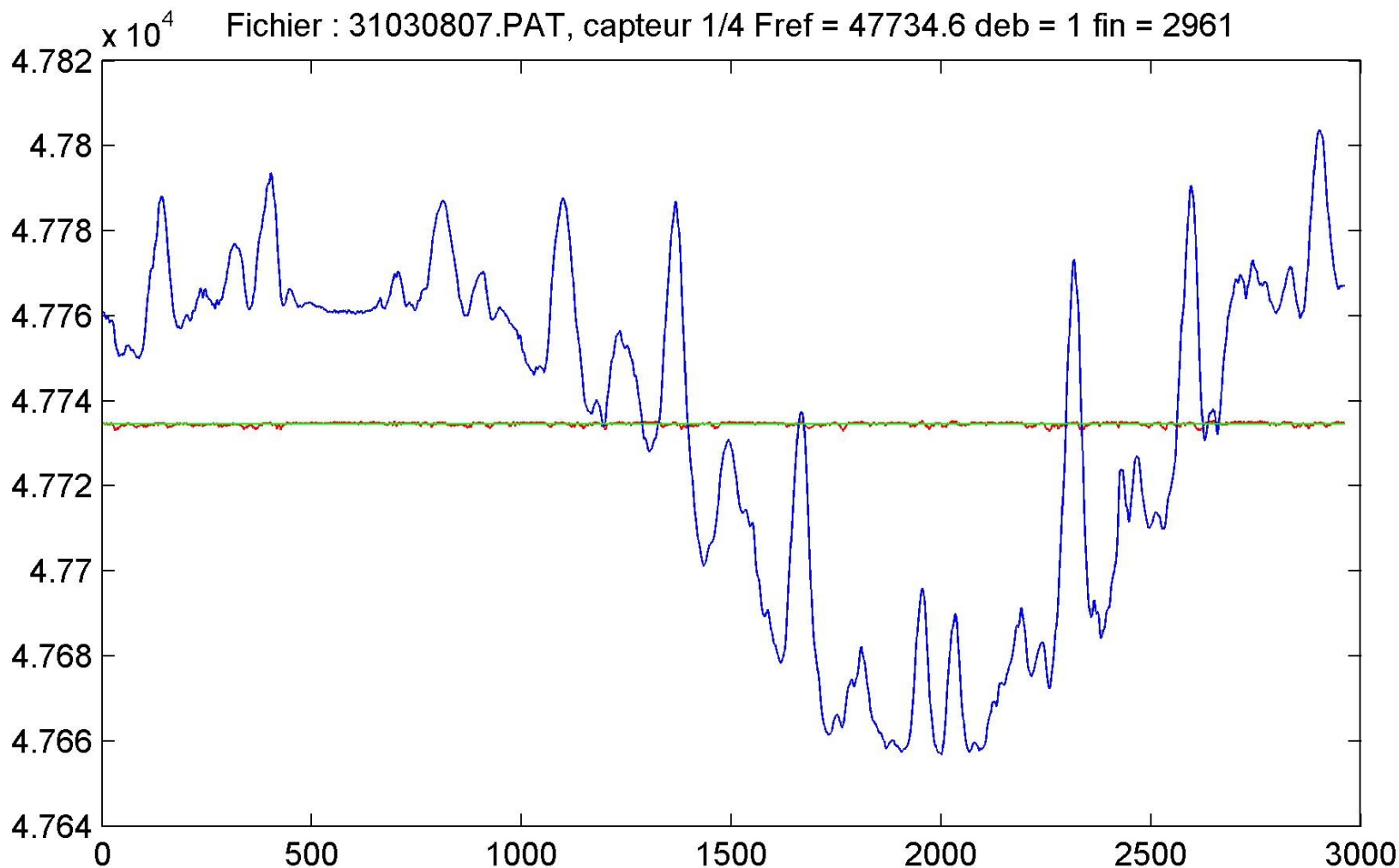
Etalonnage d'un magnétomètre vectoriel fluxgate



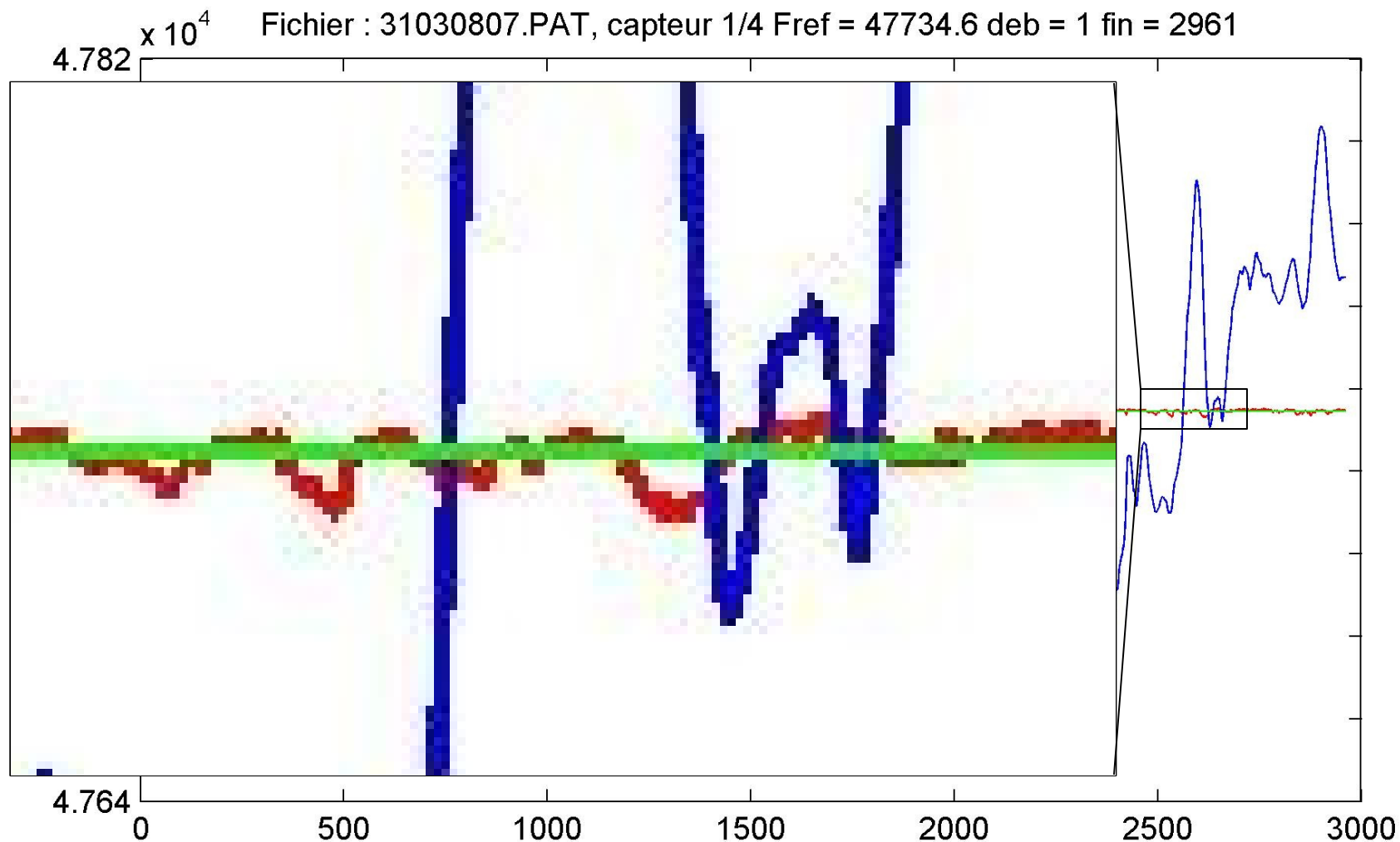
3 erreurs de sonde 3 erreurs de zéro et trois erreurs d'orthogonalité



$$B = |\mathbf{B}| = \sqrt{\mathbf{B}^T \bullet \mathbf{B}} = \sqrt{\left[\mathbf{P}^{-1} \bullet \mathbf{S}^{-1} \bullet (\mathbf{F} - \mathbf{O}) \right]^T \bullet \mathbf{P}^{-1} \bullet \mathbf{S}^{-1} \bullet (\mathbf{F} - \mathbf{O})}$$



	Calibration	Offset	Angle (°)
Sonde X	0.749521 (+/-0.000031)	12.2 (+/- 1.1)	-0.216229 (+/- 0.000031)
Sonde Y	0.749817 (+/-0.000063)	3.5 (+/- 3.0)	0.057745 (+/- 0.000304)
Sonde Z	0.751838 (+/-0.000026)	20.9 (+/- 0.3)	-0.022778 (+/- 0.000617)
T° Elec = 16.0 0.0 T° Capt = 136.5 0.0 moy = 47734.5 ect = 0.4			



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T° Elec = 16.0 0.0 T° Capt = 136.5 0.0 moy = 47734.5			ect = 0.4

Effet d'une aimantation parasite sur la mesure vectorielle

Leliak, 1961 – Leach, 1980

Aimantation rémanente

$$\mathbf{G} = (g_1, g_2, g_3)^T$$

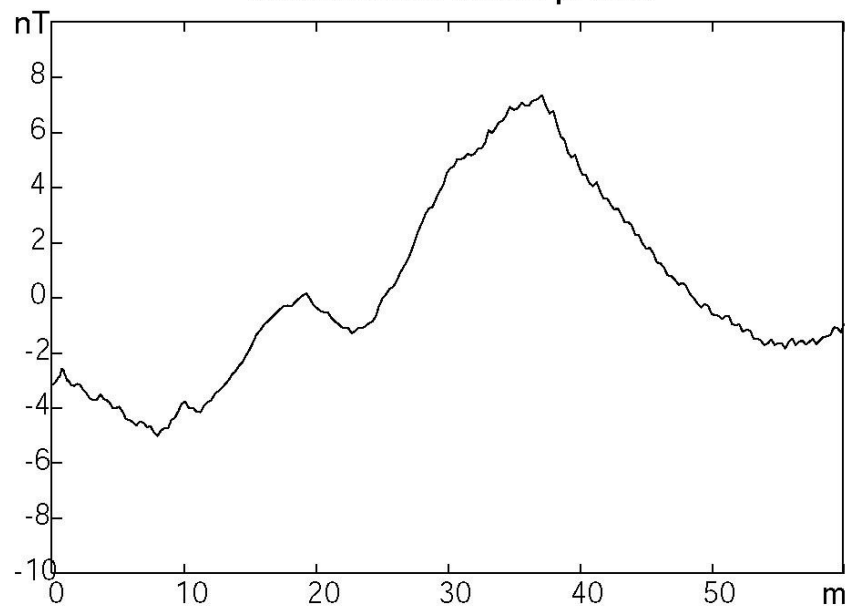
Aimantation induite

$$\mathbf{H} = \mathbf{Q} \bullet \mathbf{B}$$

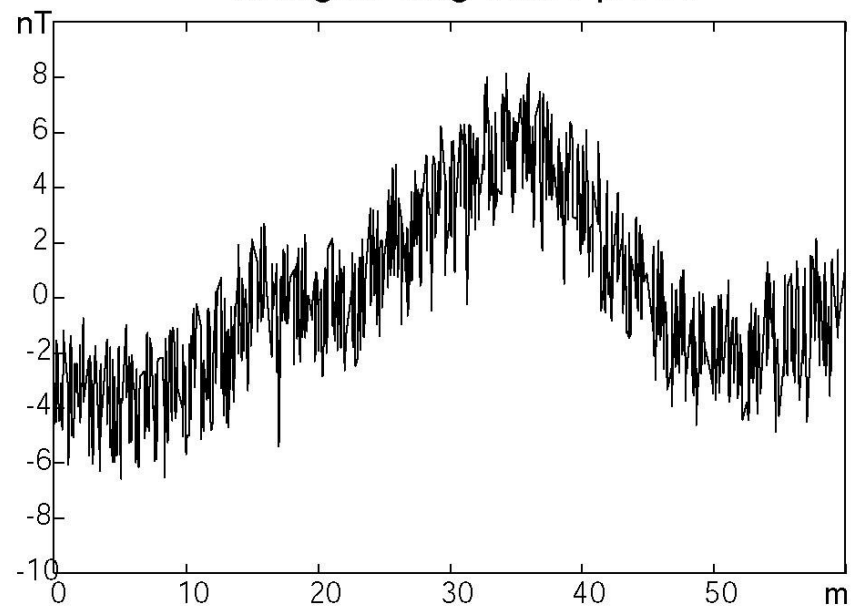
Matrice triangulaire
Inférieure à
six inconnues



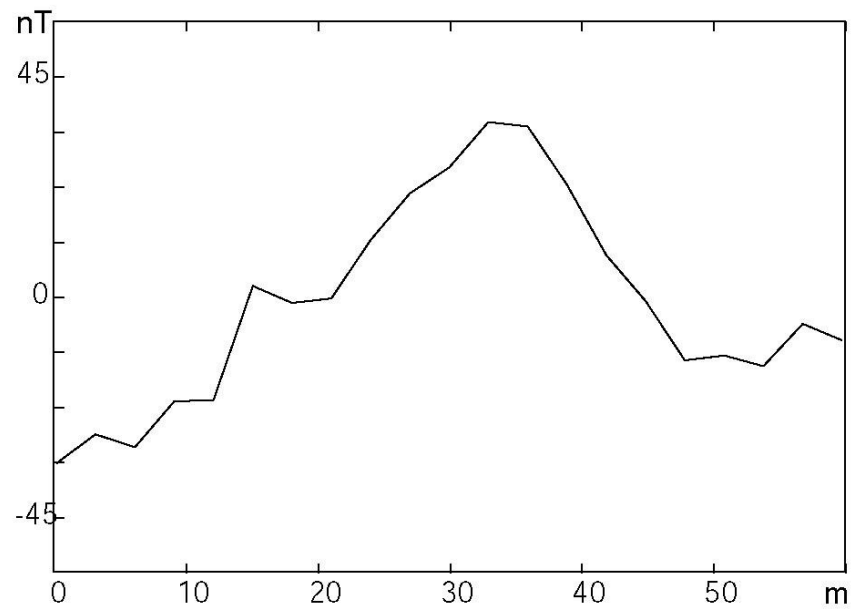
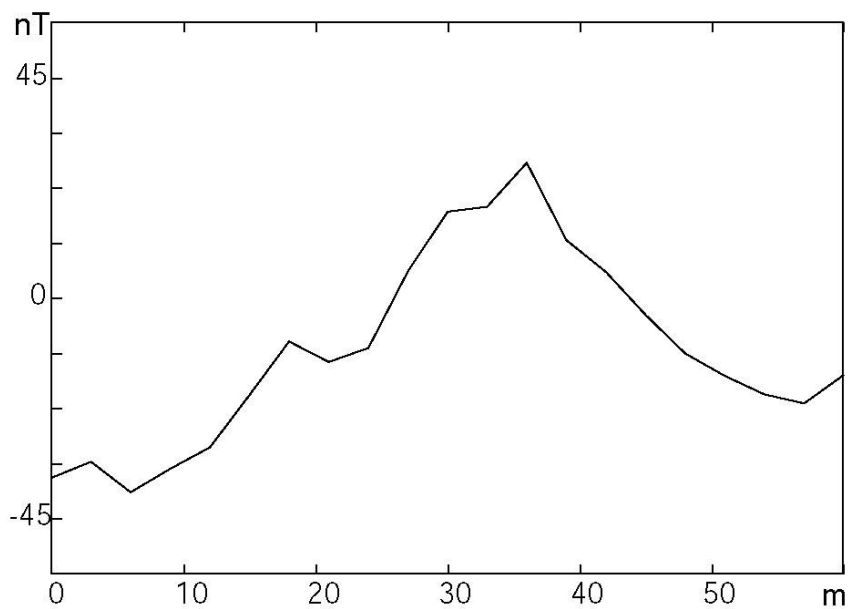
Geometrics G858 profile



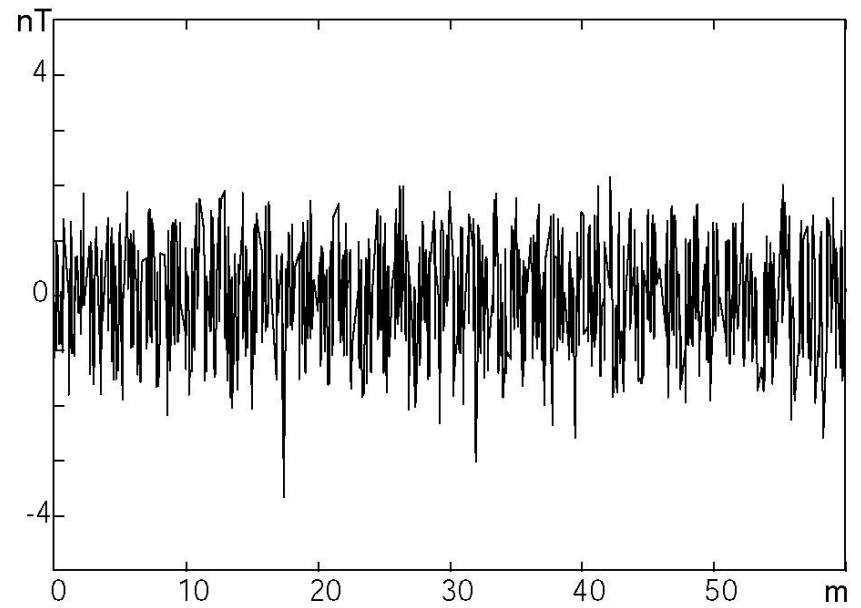
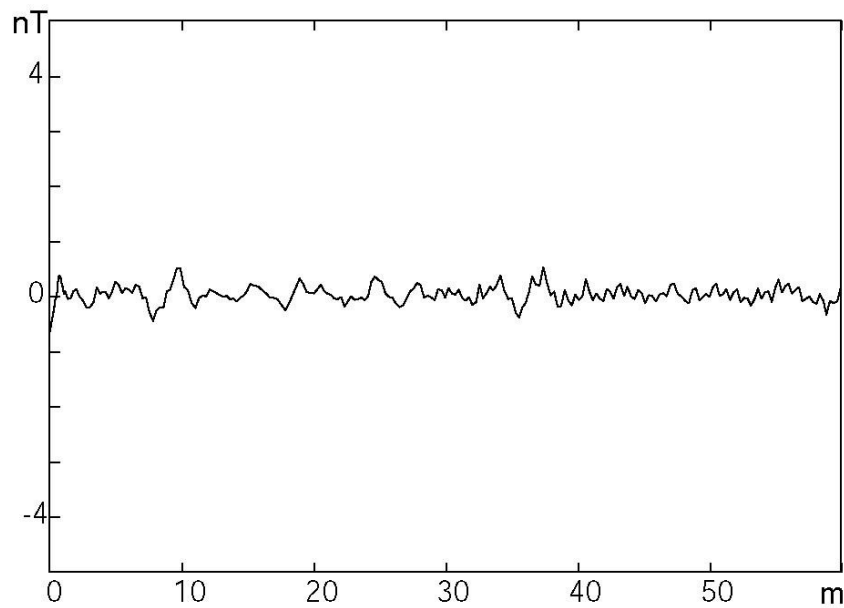
Bartington Mag-03MC profile



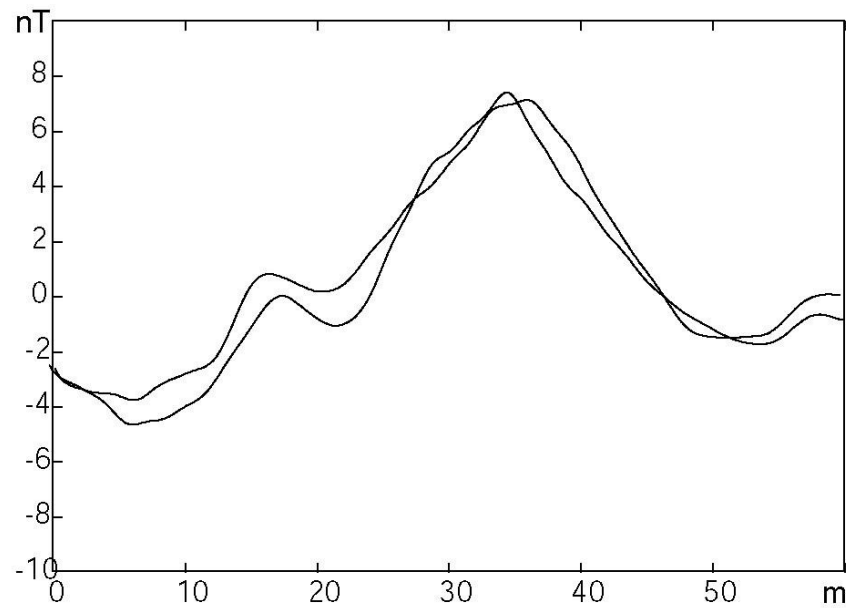
Magnetic anomaly



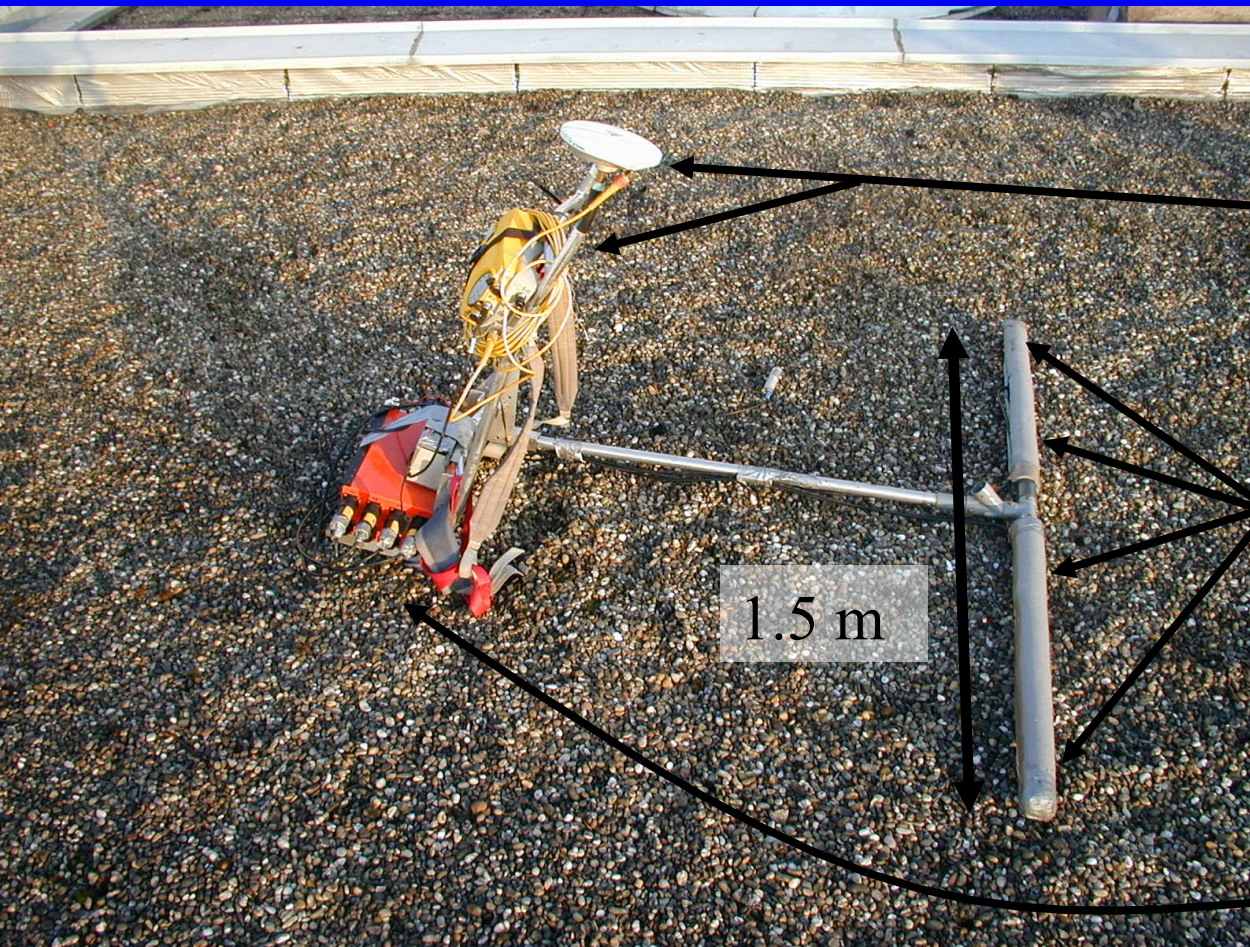
Magnetization of the equivalent layer in magnetic field unit



Noise : difference between the magnetic anomaly measured and the magnetic anomaly of the equivalent layer



Magnetic anomalies of the equivalent layer deduced from Geomtrics G858 and Fluxgate Mag-3MC profiles



Antenne et récepteur GPS

4 capteurs magnétiques

1.5 m

Electronique

Aéromagnétisme



❑ Mesure magnétique et traitement

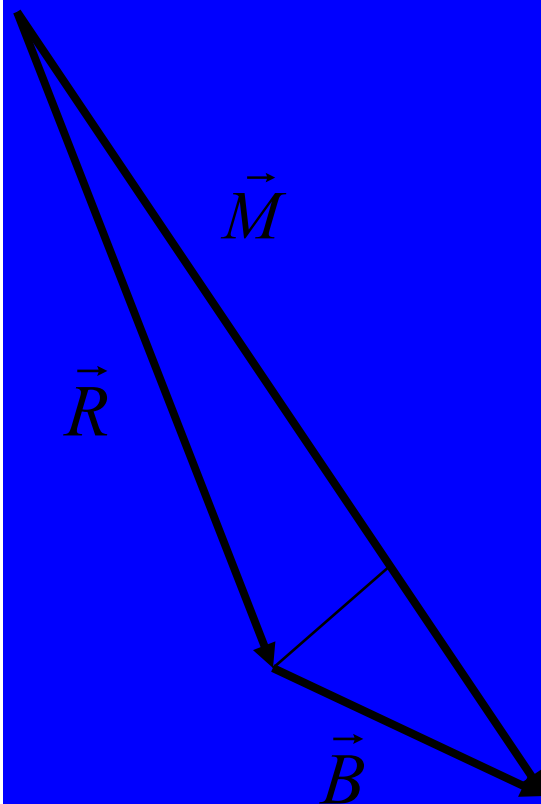
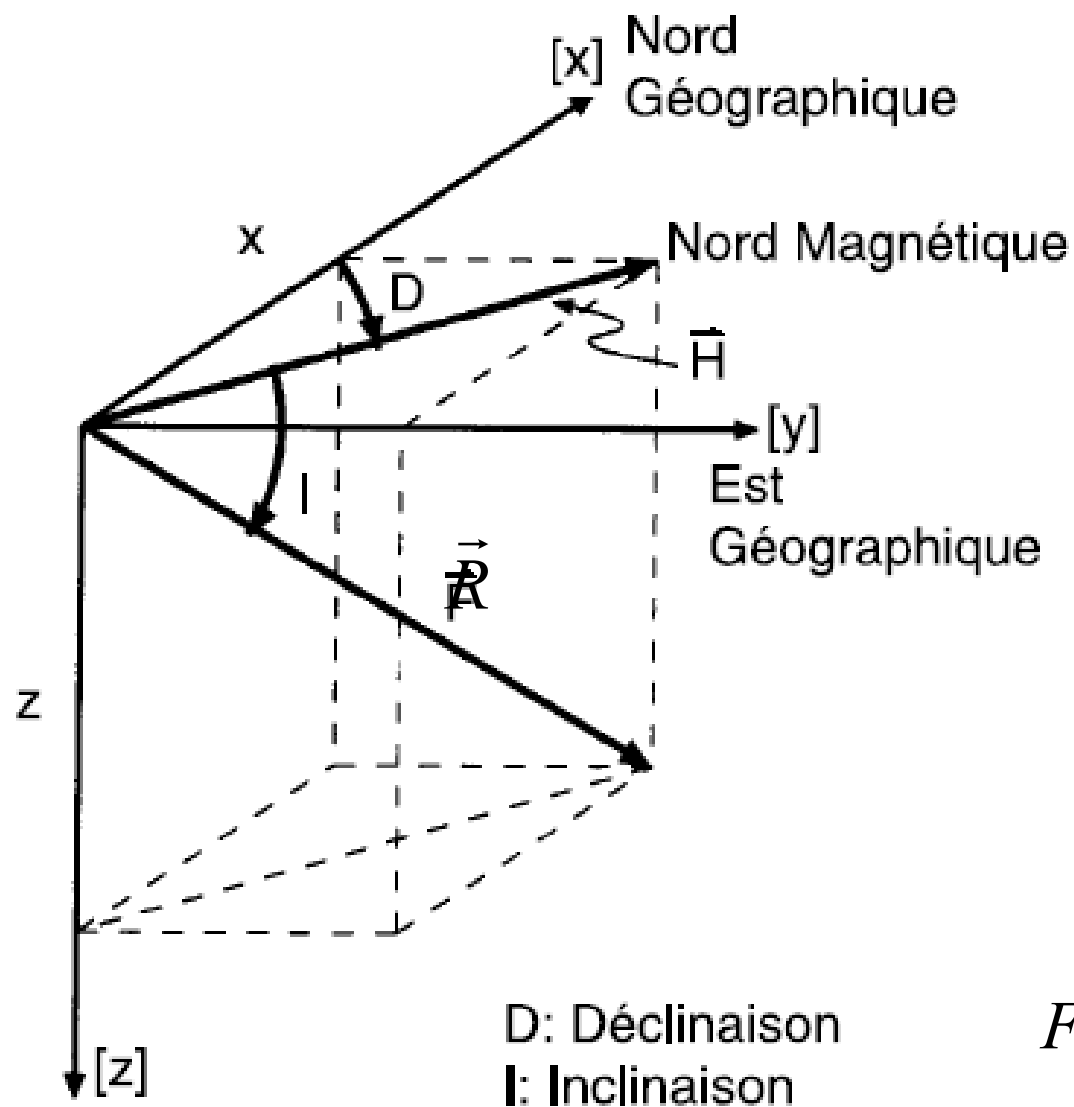
❑ Outils d'interprétation et particularités de la méthode magnétique

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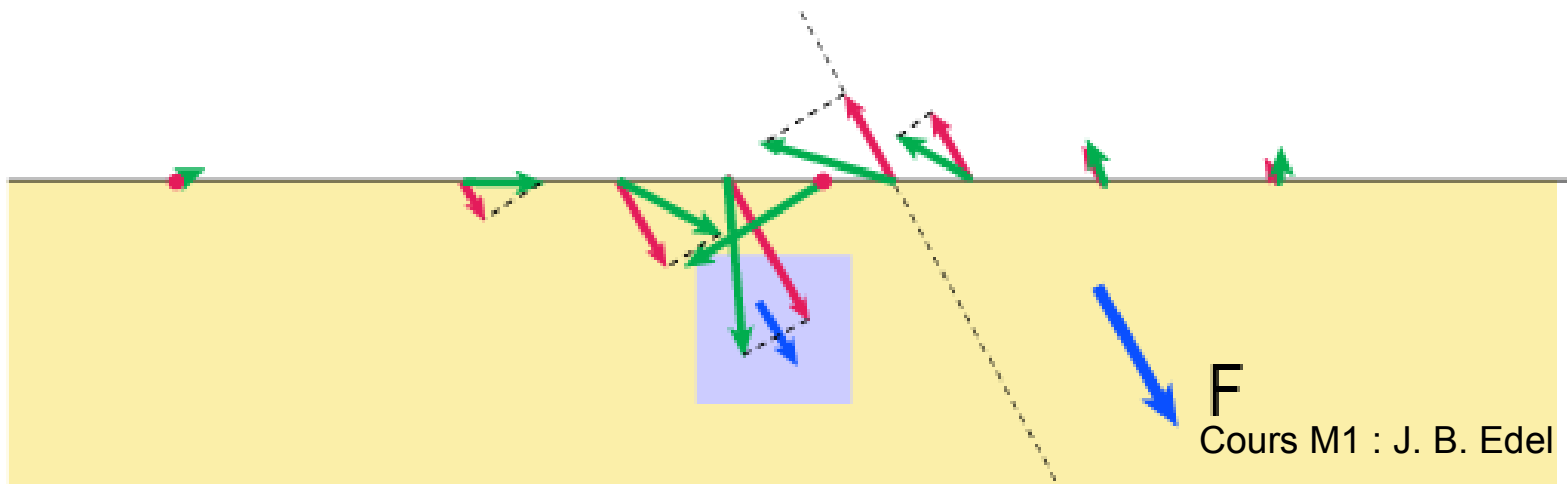
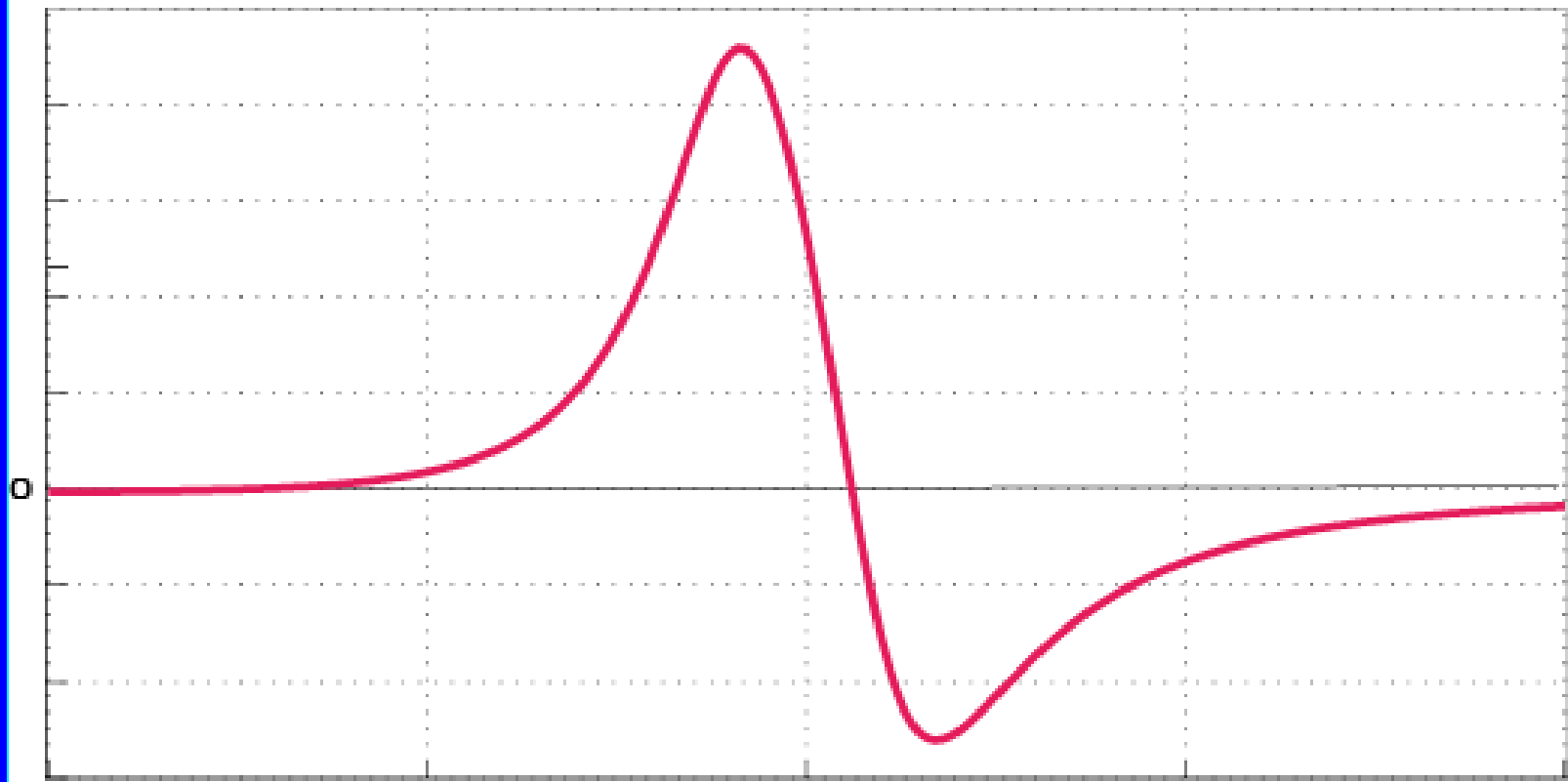
❑ Exemples naturels

- ✓ Cartographie magnétique multi-échelles dans la région de Colmar
- ✓ Lithologie de la Bruche

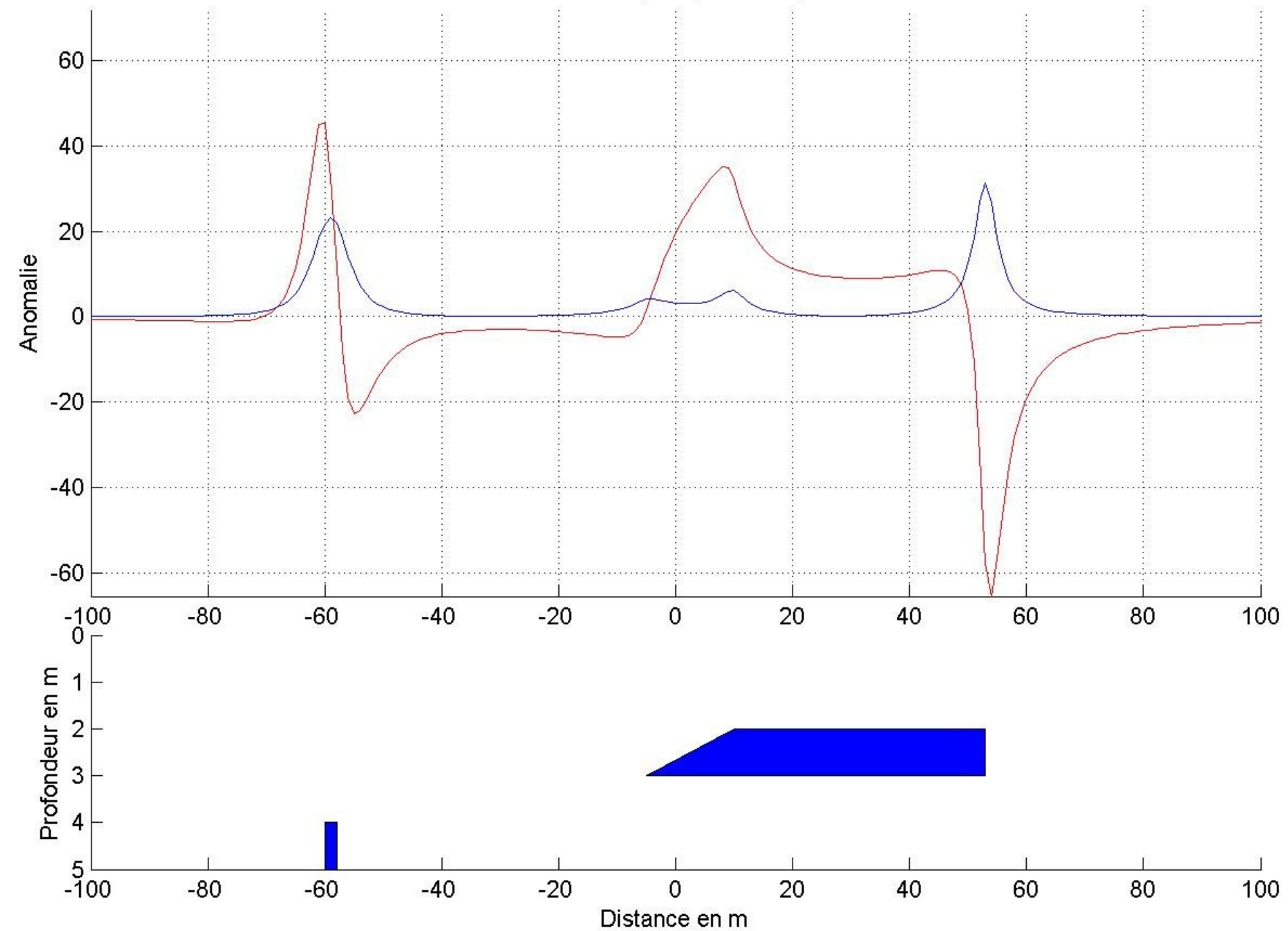


$$F = \|\vec{M}\| - \|\vec{R}\| = \|\vec{B}\| \cos(\vec{B}, \vec{R})$$

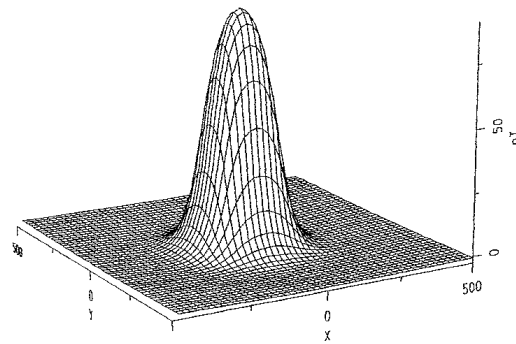
Anomalie du champ magnétique total



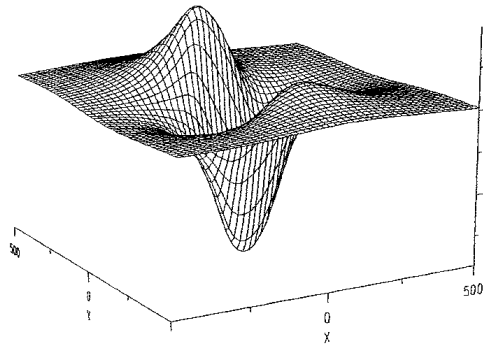
Anomalie magnétique de mag.dat



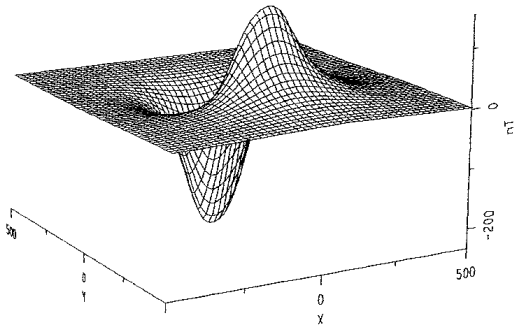
Total Magnetic Field



$I = 90^\circ$
induced only



$I = -10^\circ$
induced only



$I = -10^\circ$
induced plus
 90° remanence

Analytic Signal

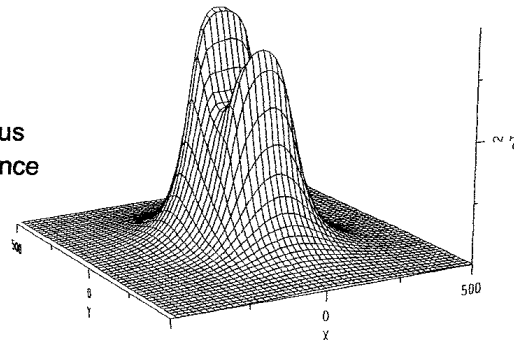
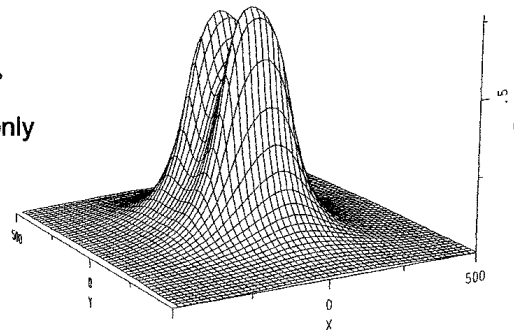
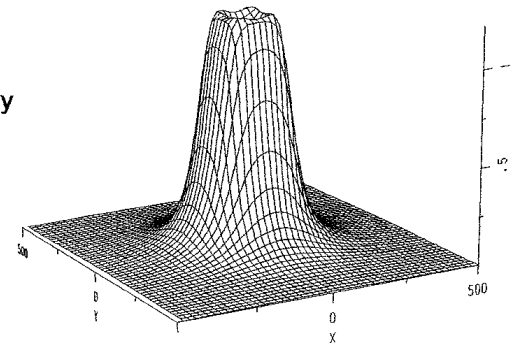
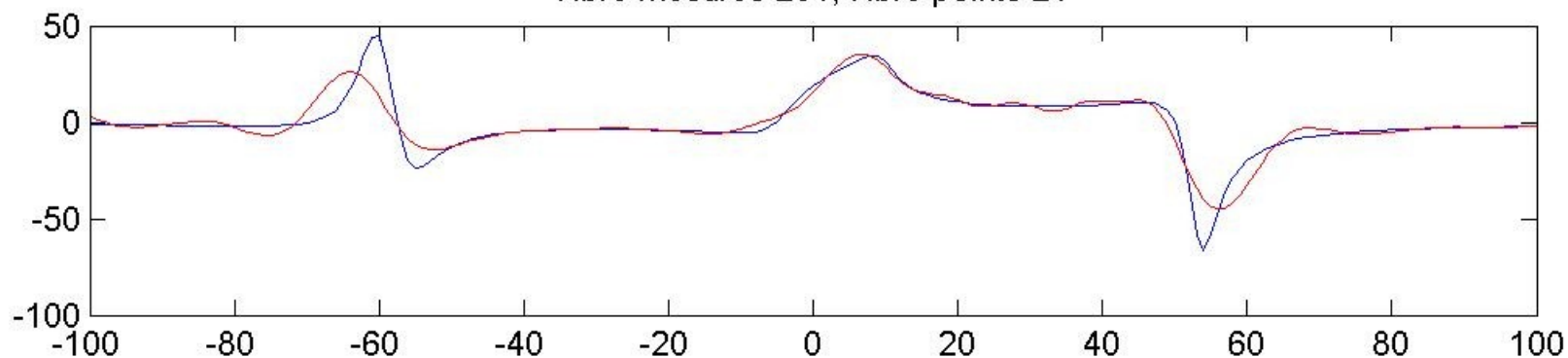
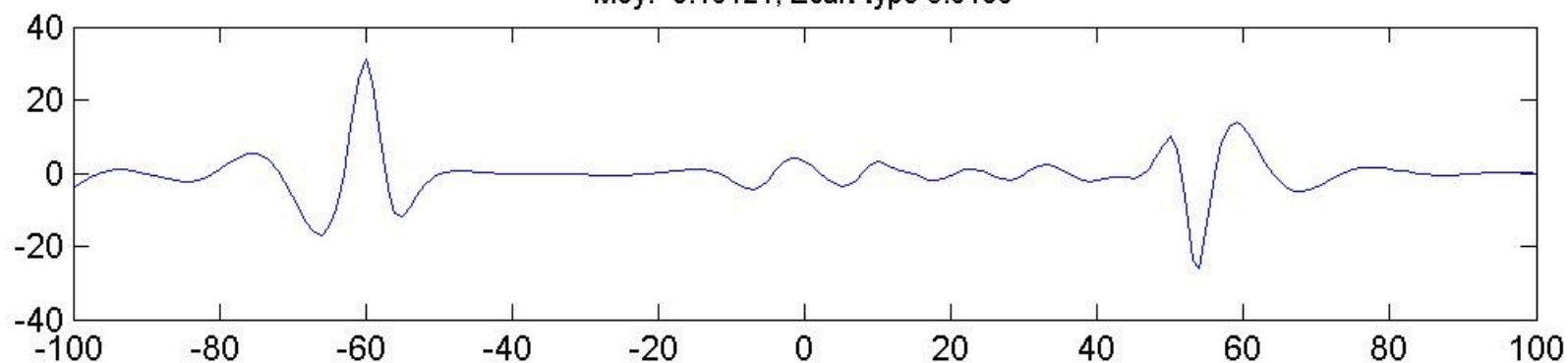


Figure 3. The analytic signal of the total magnetic field produces similar results regardless of the direction of magnetization. In this case, the analytic signal is shown for the same model used in Figure 2, under the same magnetic conditions. Note that the analytic signal peaks over the edges of the model, and the amplitude of the peak is proportional to the magnetization at that edge.

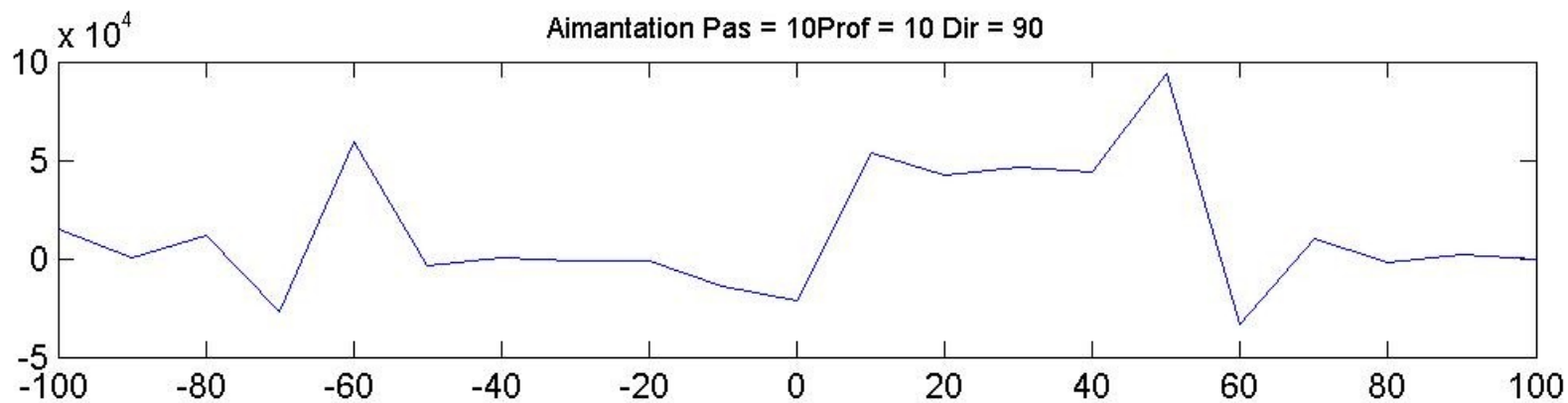
Nbre mesures 201, Nbre points 21



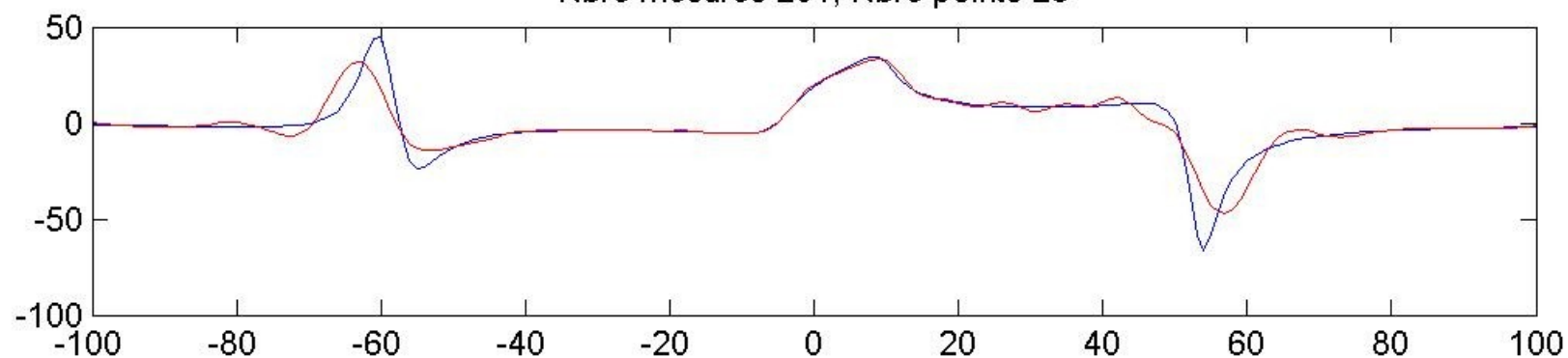
Moy. -0.19421, Ecart-type 5.9409



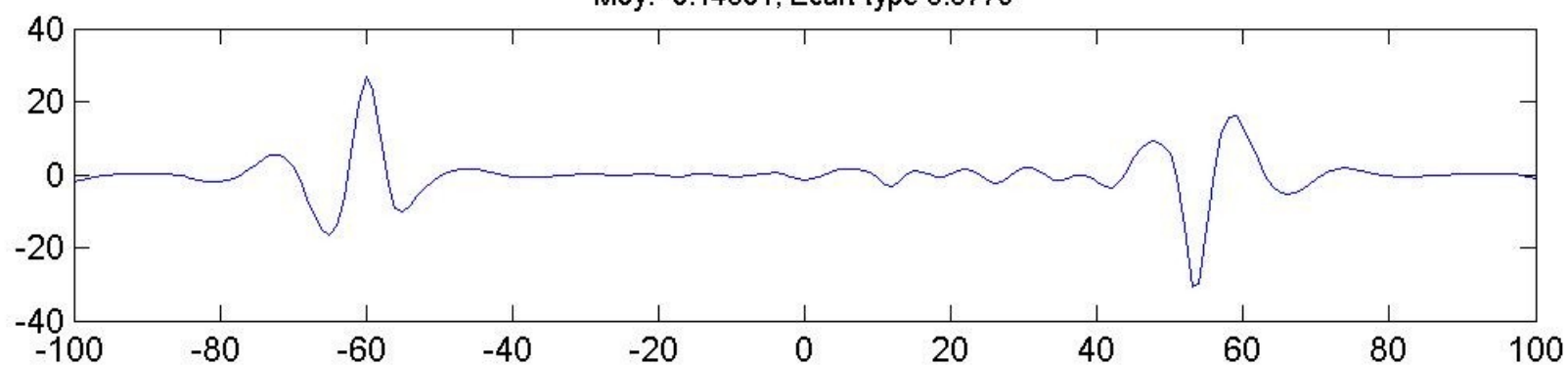
Aimantation Pas = 10 Prof = 10 Dir = 90



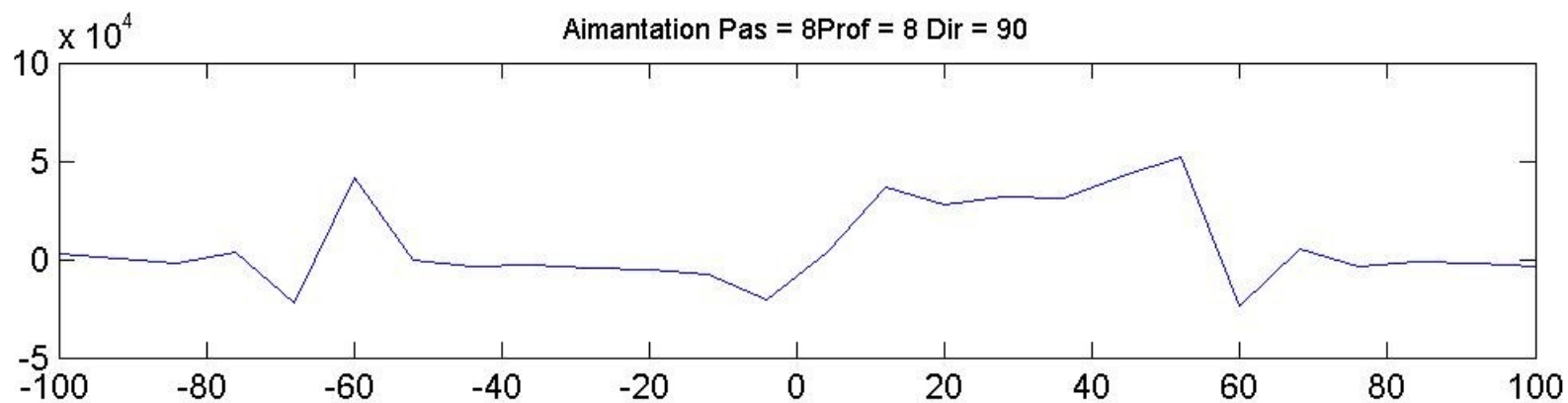
Nbre mesures 201, Nbre points 26



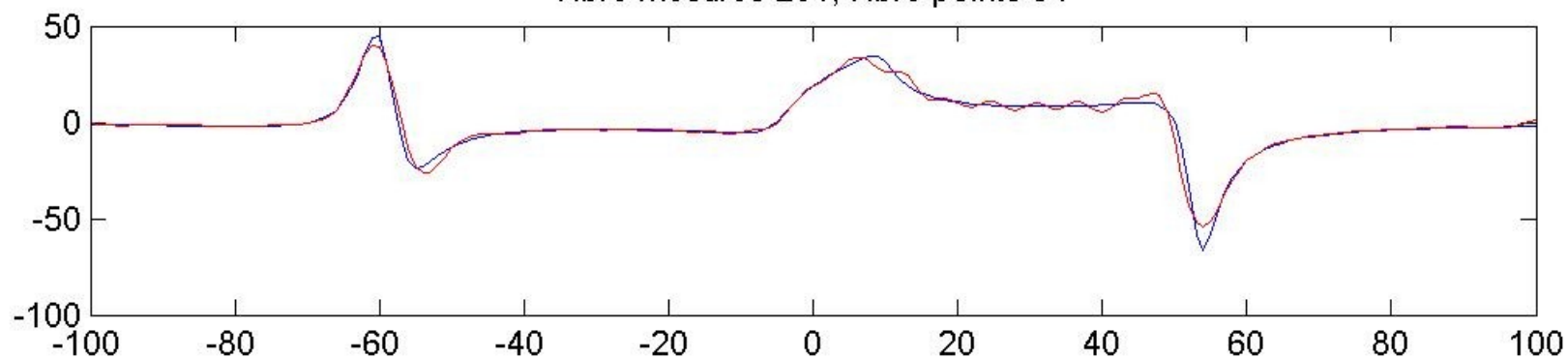
Moy. -0.14801, Ecart-type 5.8776



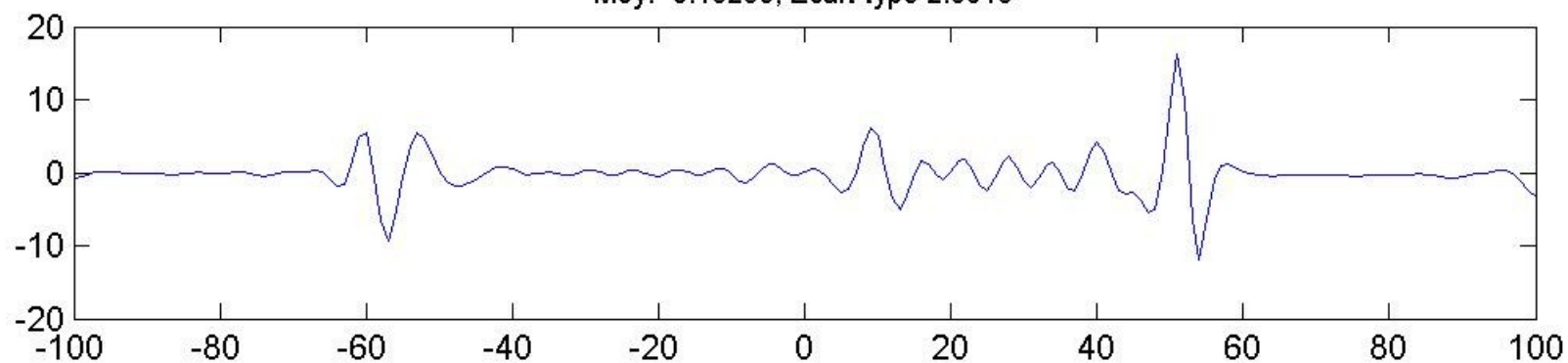
Aimantation Pas = 8 Prof = 8 Dir = 90



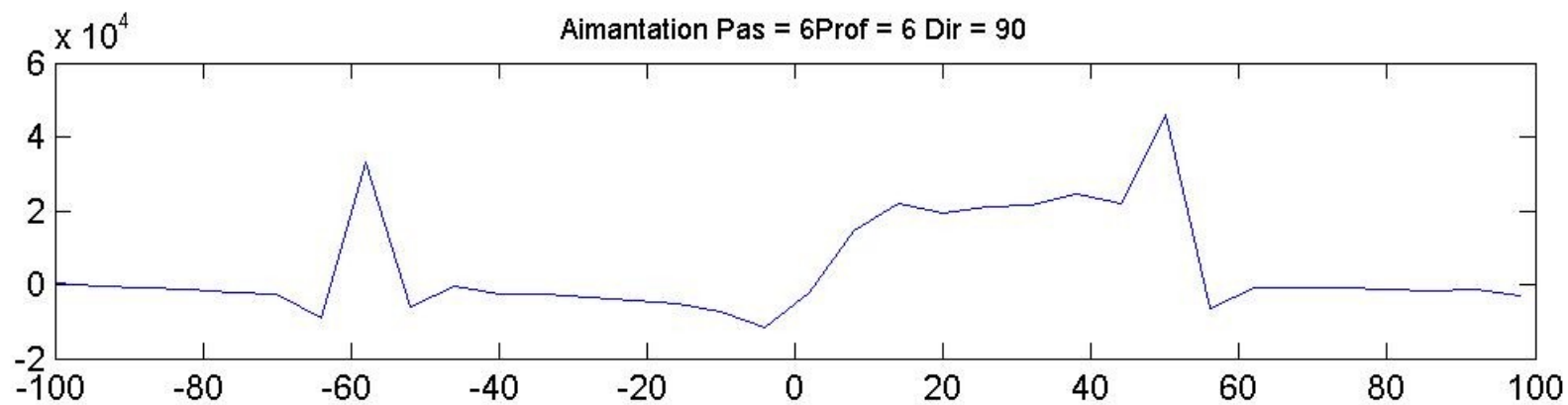
Nbre mesures 201, Nbre points 34



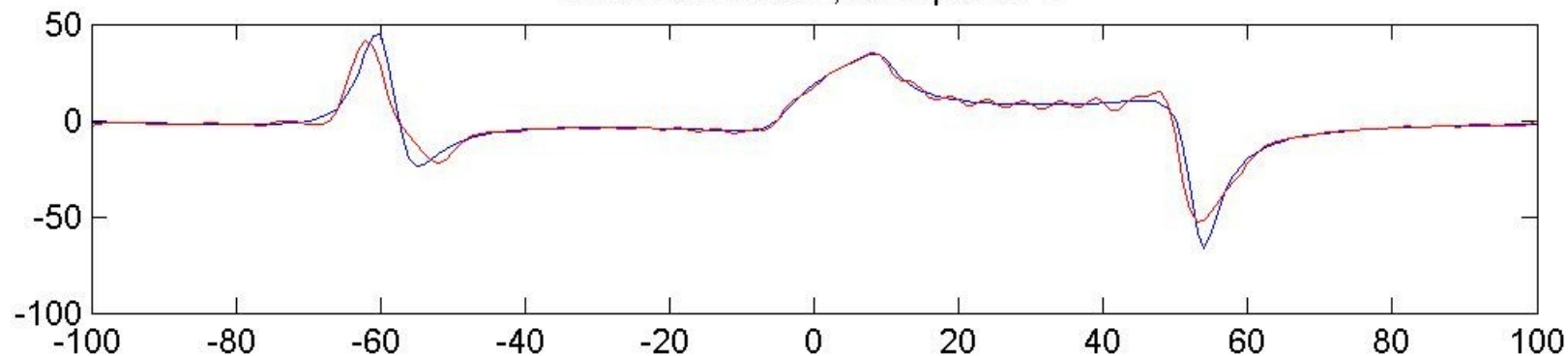
Moy. -0.15286, Ecart-type 2.5913



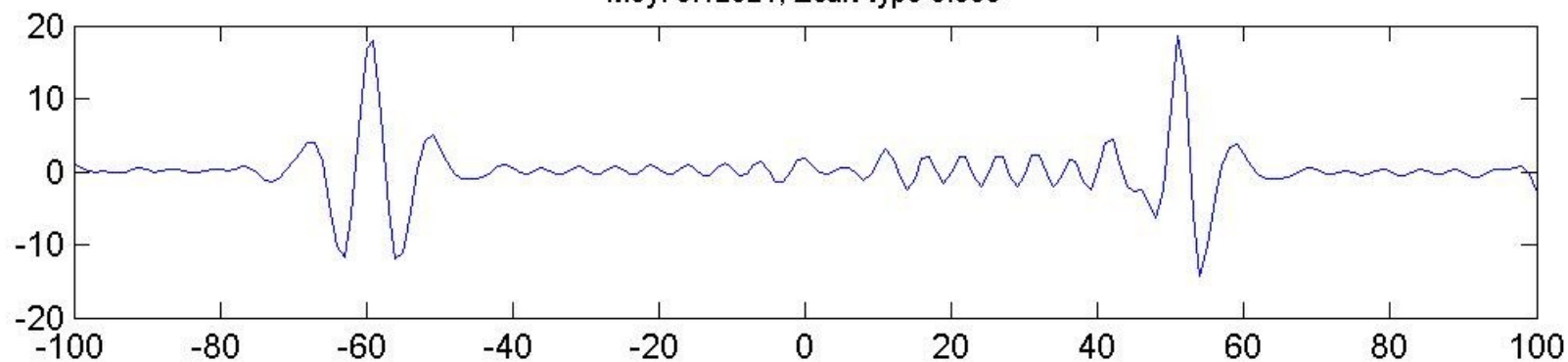
Aimantation Pas = 6 Prof = 6 Dir = 90



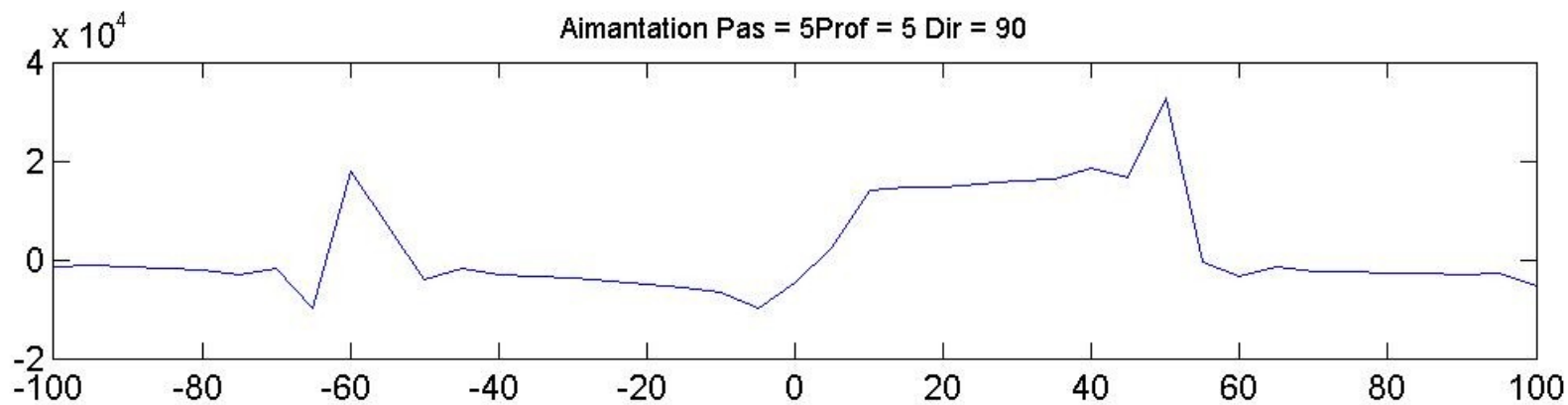
Nbre mesures 201, Nbre points 41



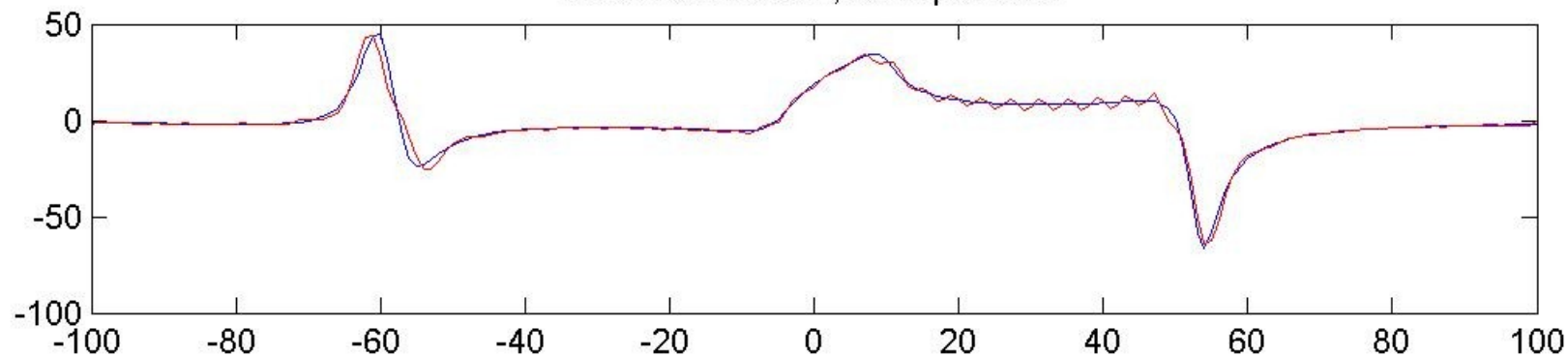
Moy. 0.12621, Ecart-type 3.636



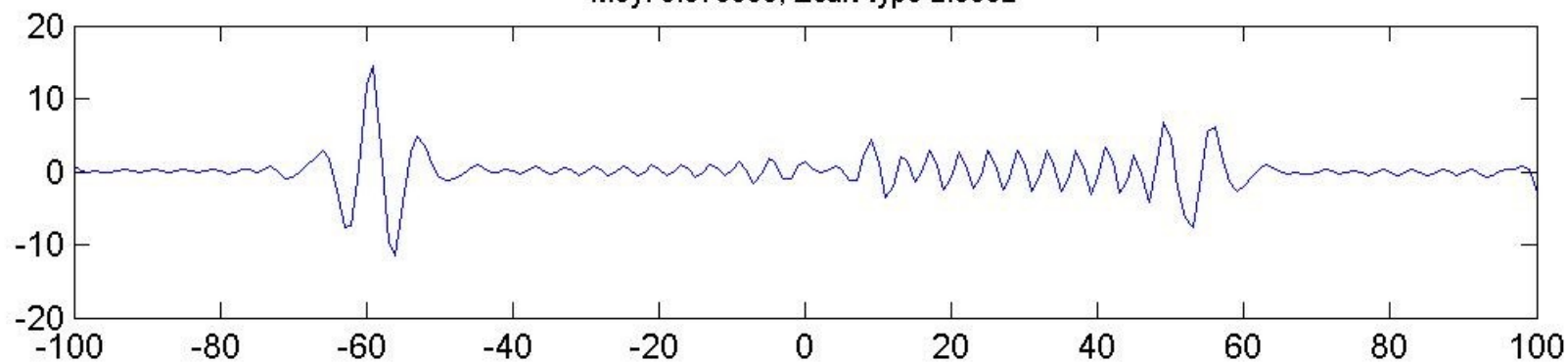
Aimantation Pas = 5 Prof = 5 Dir = 90



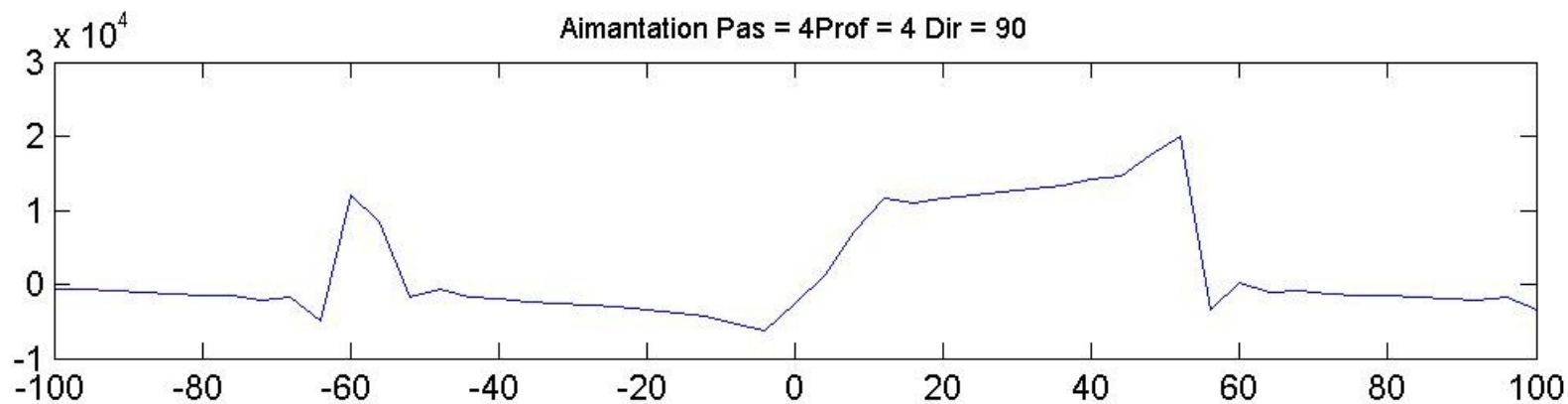
Nbre mesures 201, Nbre points 51



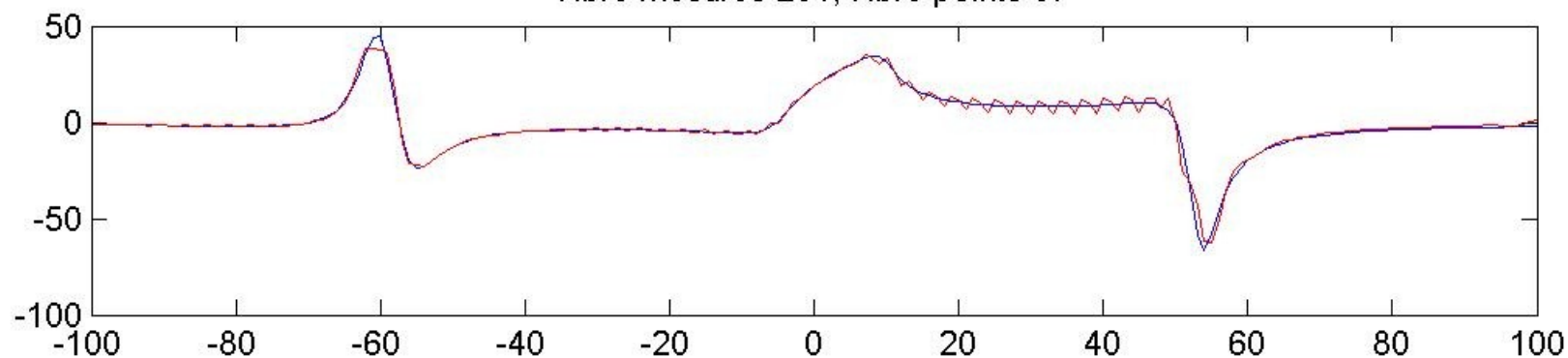
Moy. 0.070686, Ecart-type 2.5332



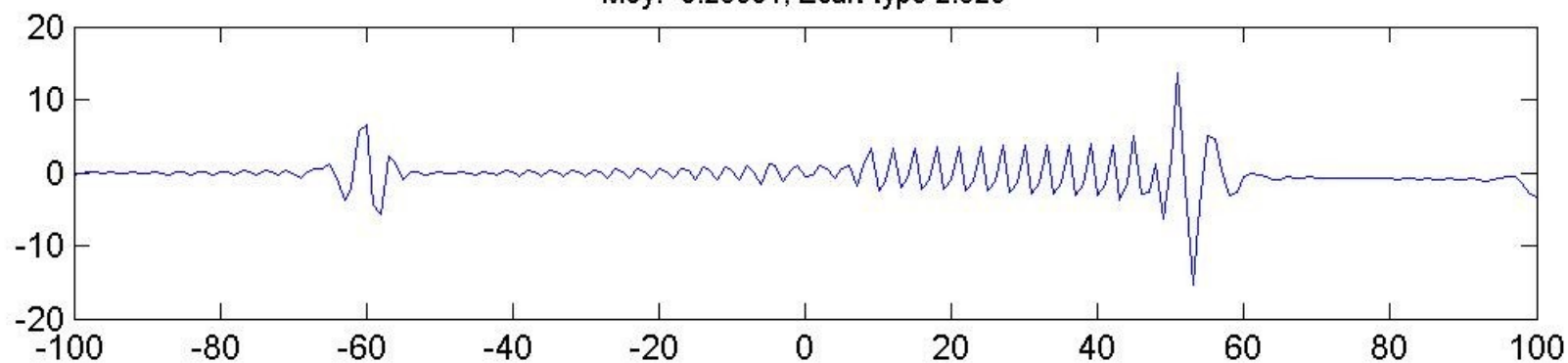
Aimantation Pas = 4 Prof = 4 Dir = 90



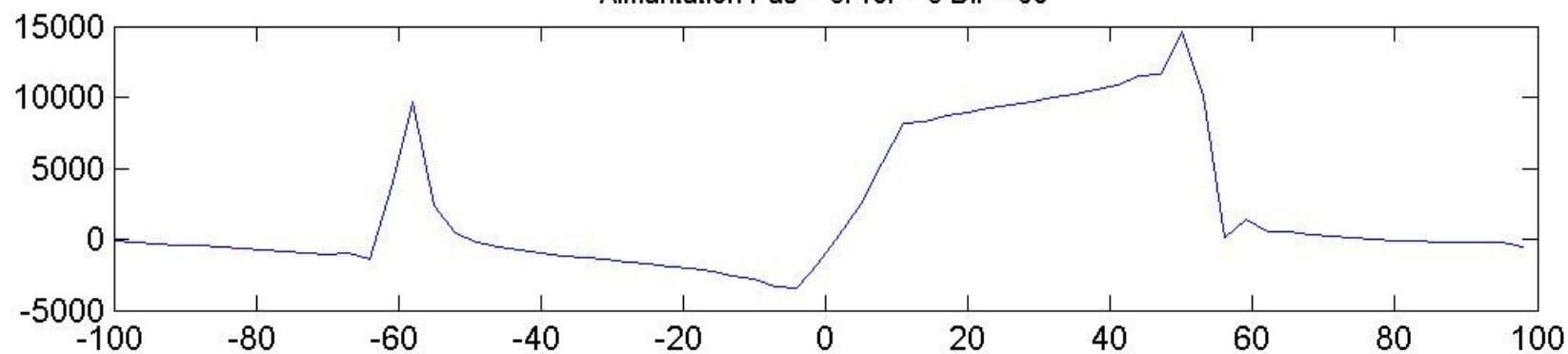
Nbre mesures 201, Nbre points 67



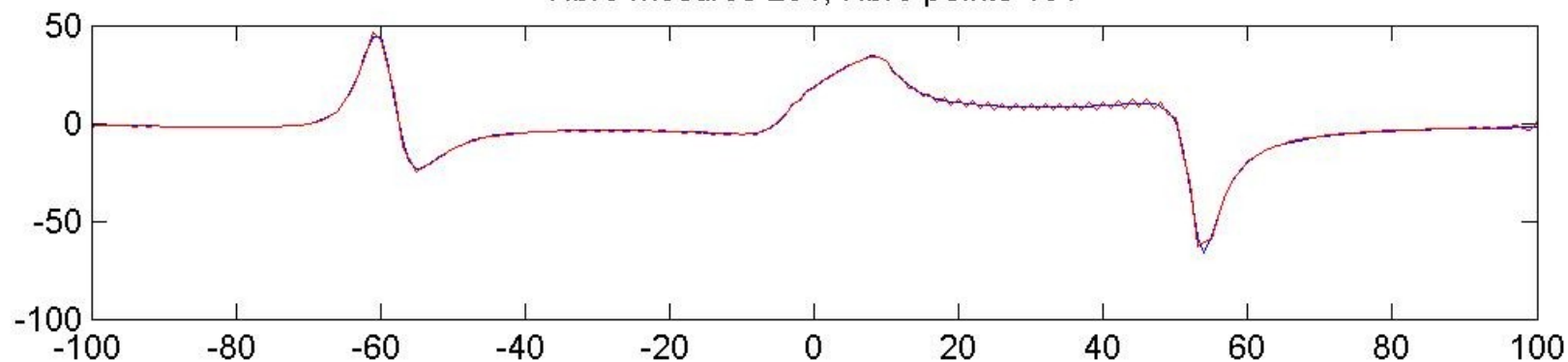
Moy. -0.25604, Ecart-type 2.326



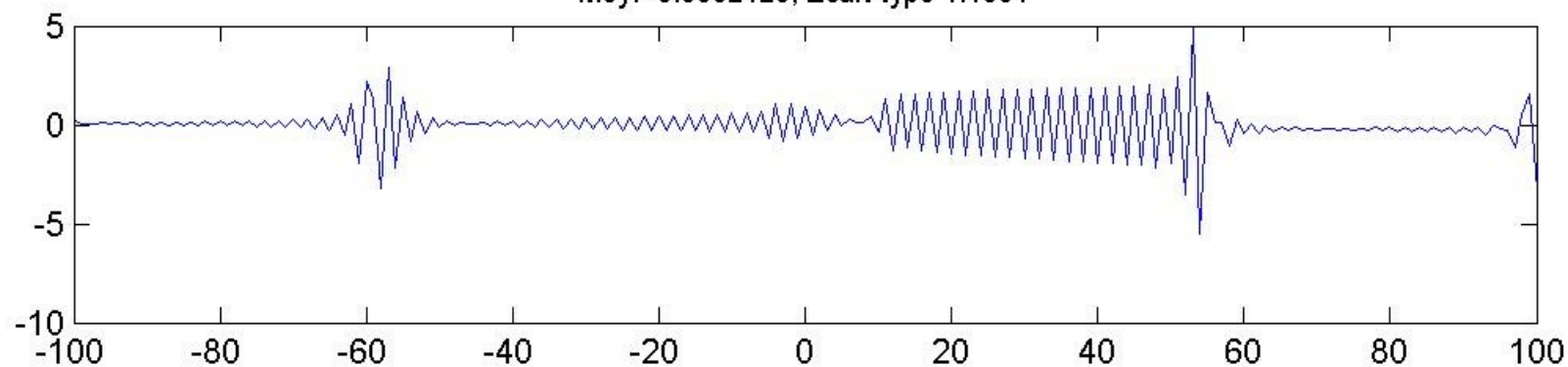
Aimantation Pas = 3 Prof = 3 Dir = 90



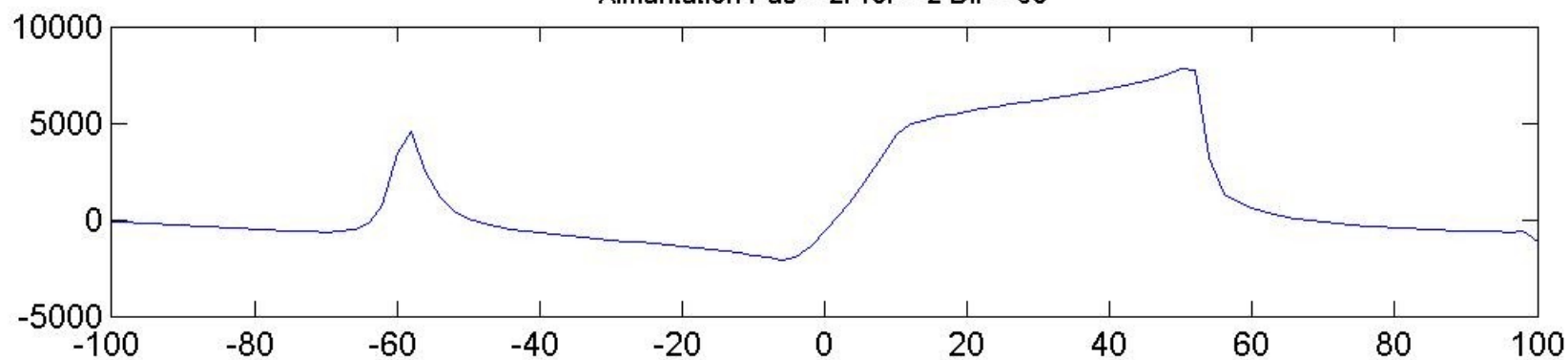
Nbre mesures 201, Nbre points 101



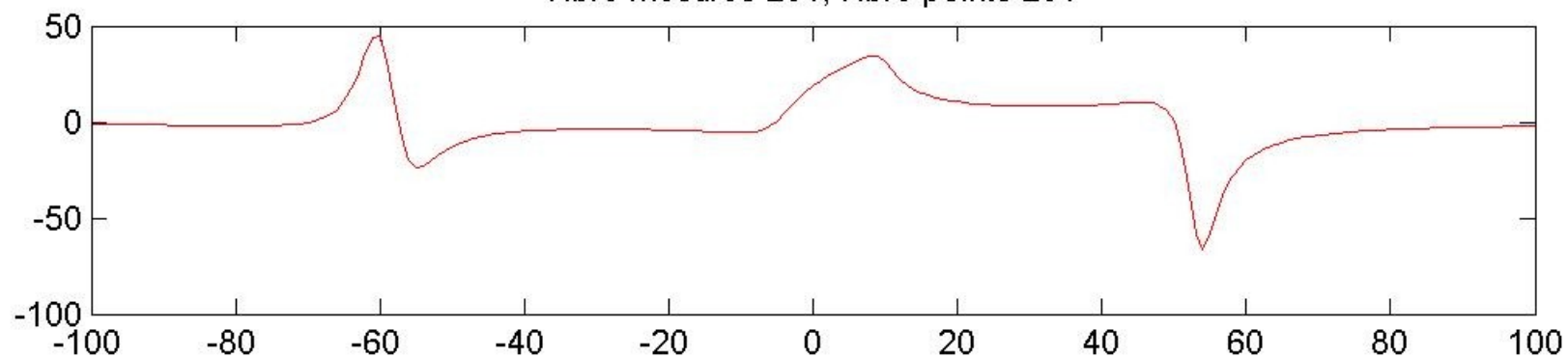
Moy. -0.0082426, Ecart-type 1.1561



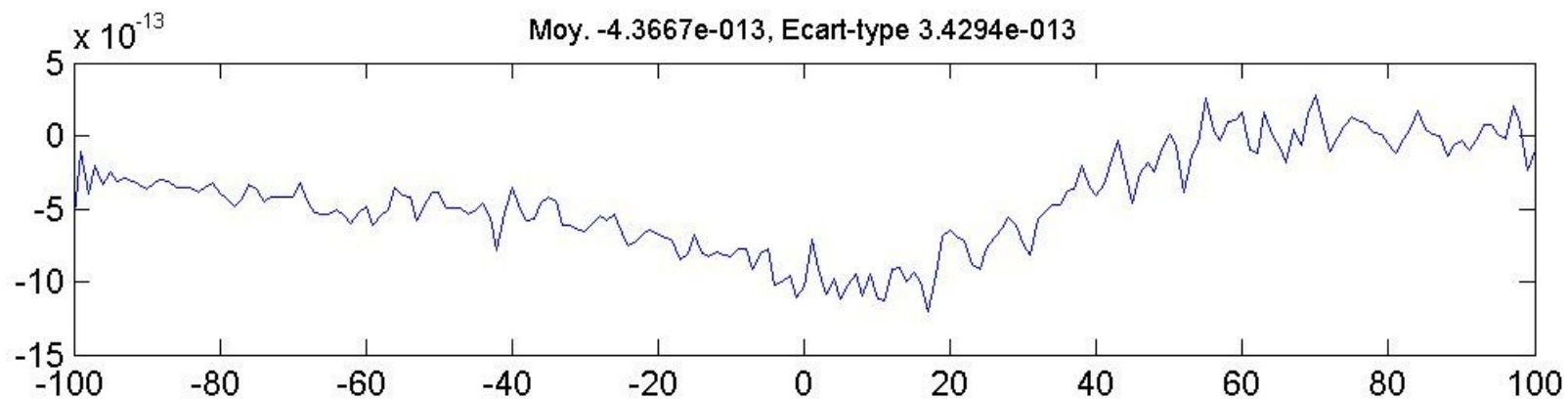
Aimantation Pas = 2 Prof = 2 Dir = 90



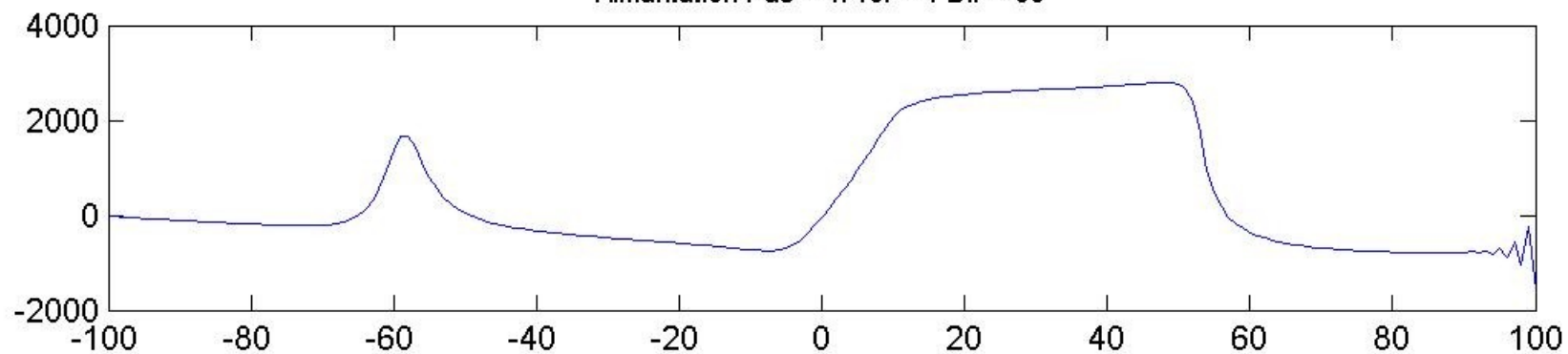
Nbre mesures 201, Nbre points 201



Moy. $-4.3667\text{e-}013$, Ecart-type $3.4294\text{e-}013$



Aimantation Pas = 1 Prof = 1 Dir = 90



❑ Mesure magnétique et traitement

❑ Outils d'interprétation et particularités de la méthode magnétique

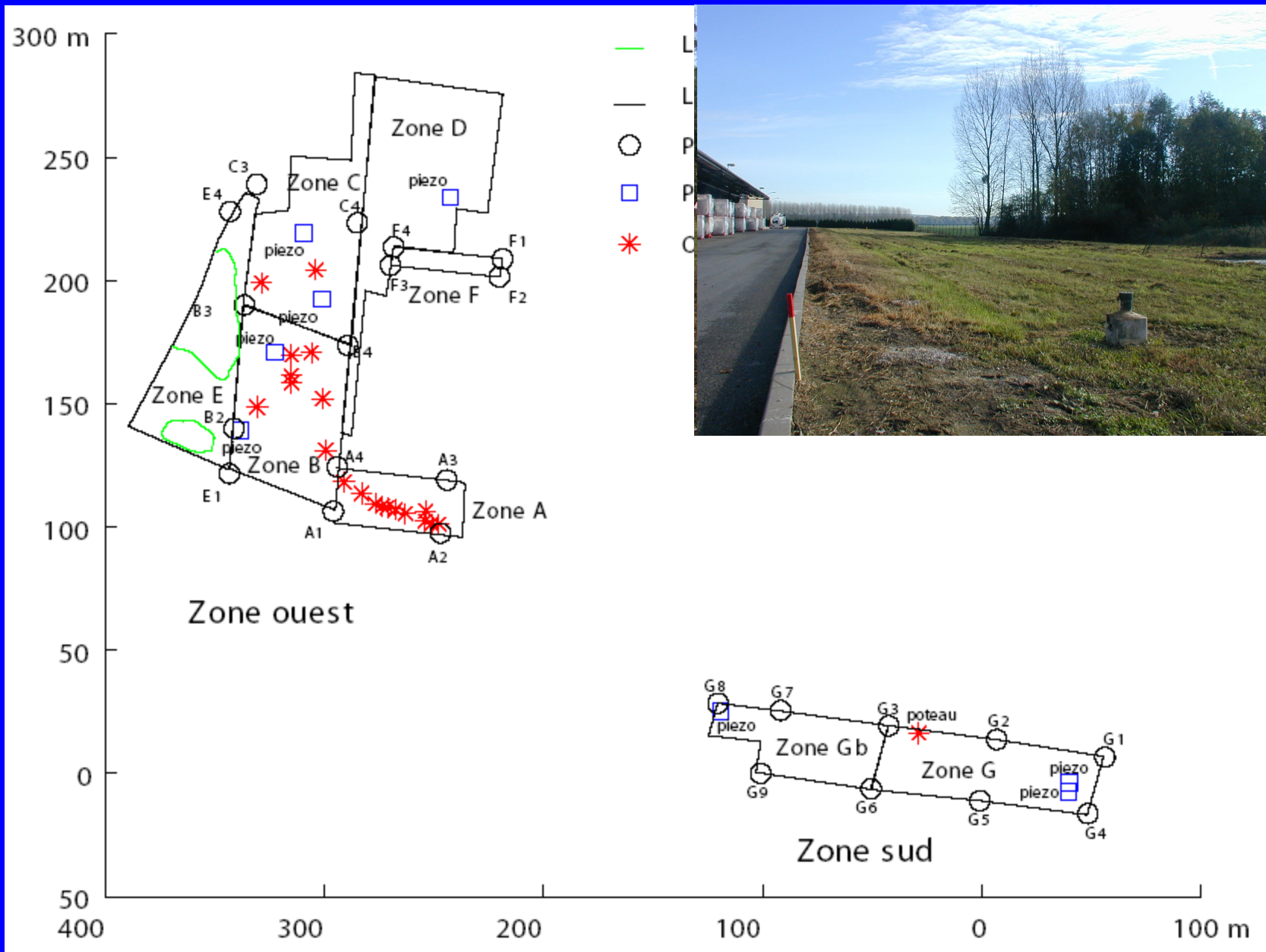
❑ Exemples anthropiques

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❑ Exemples naturels

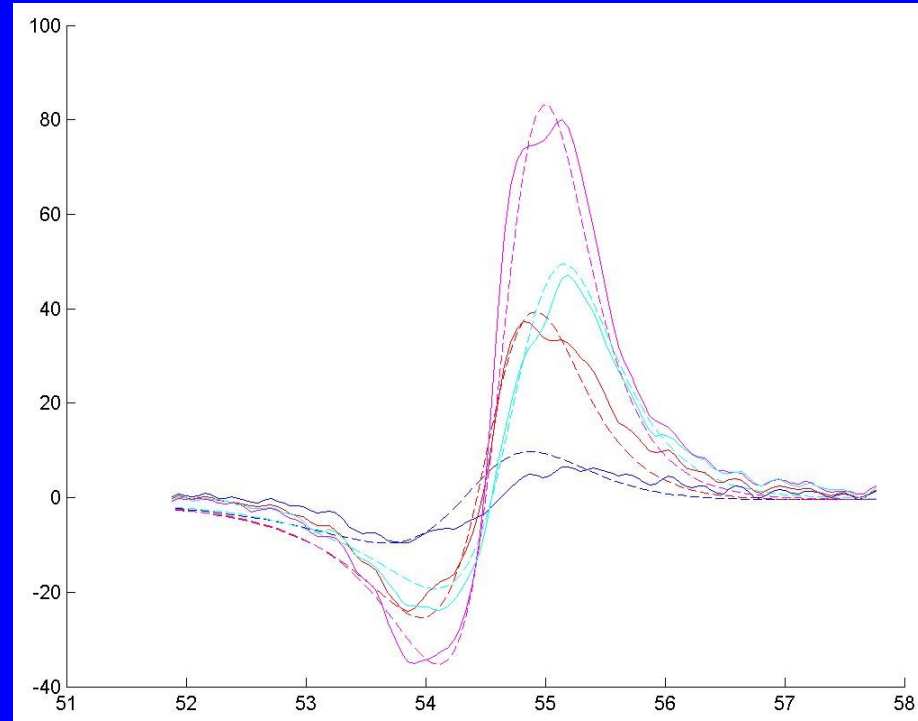
- ✓ Cartographie magnétique multi-échelles dans la région de Colmar
- ✓ Lithologie de la Bruche

Dépollution d'un site Seveso 2 (seuil haut), ANTEA



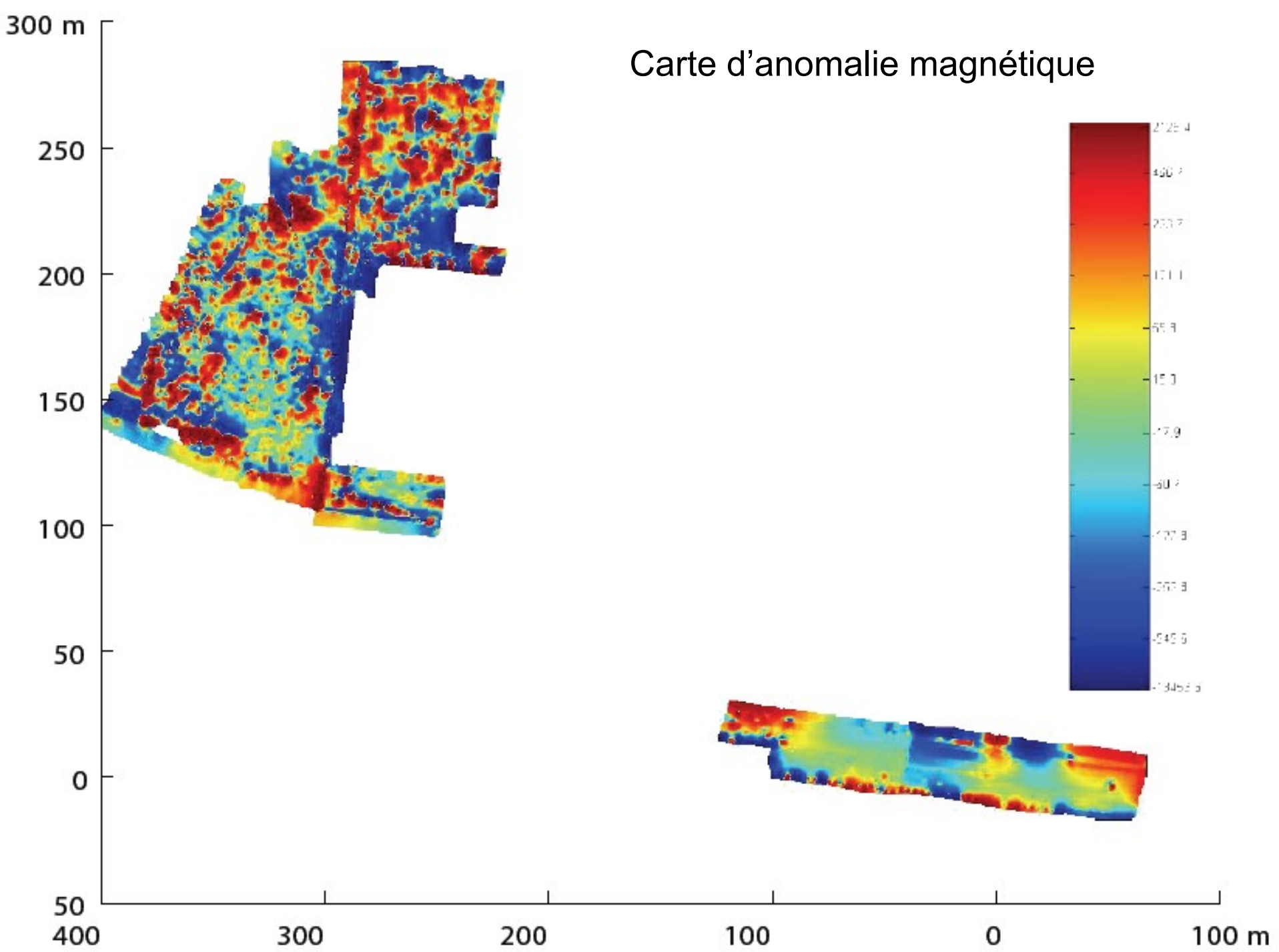
Inversion des données multi-capteur

Objet ponctuel : localisation (x, y, z) - vecteur aimantation

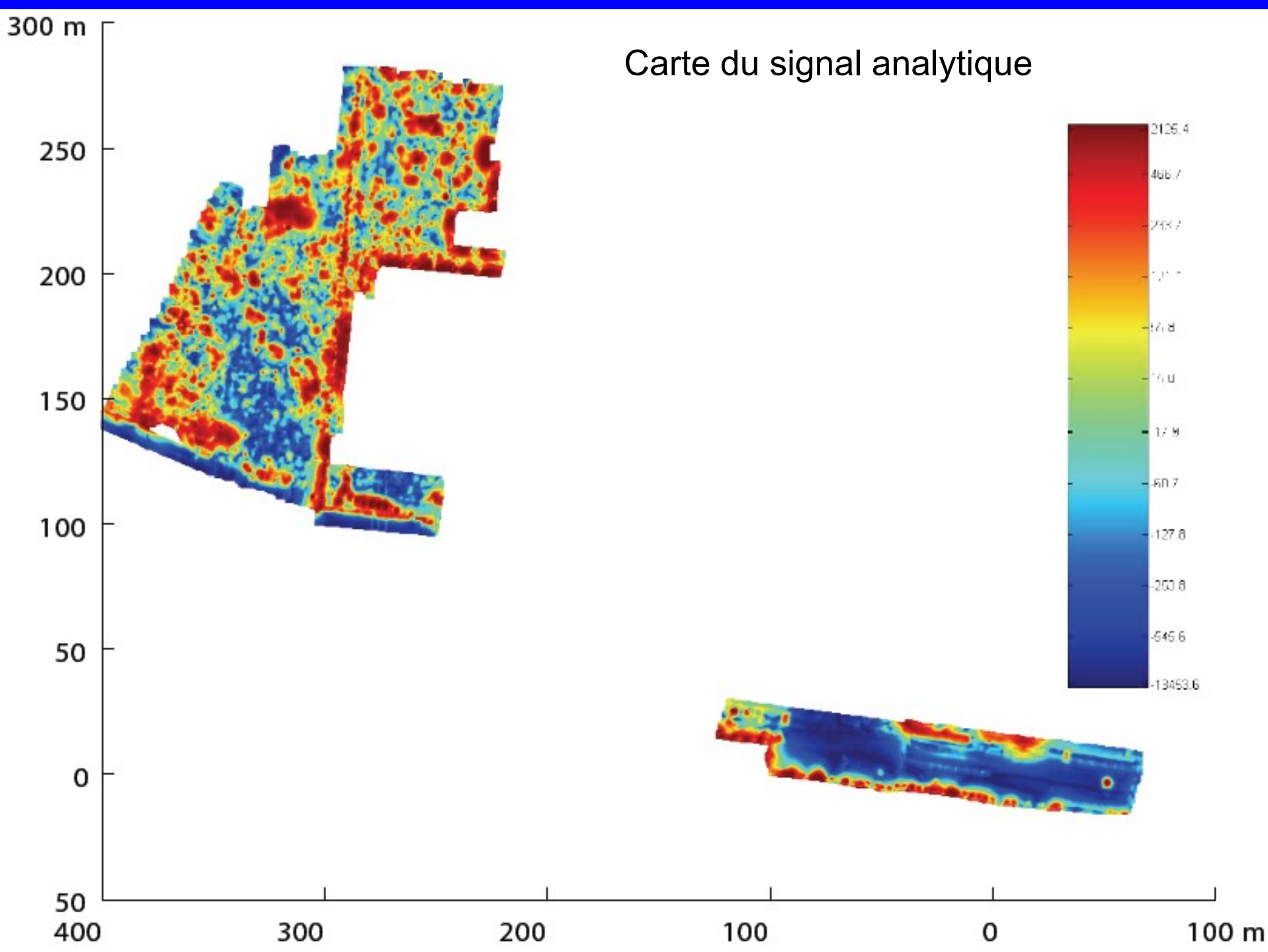


Point	Latitude	Longitude	Xref	YRef	Xma	Yma	Zma	Amplitude	Inclinaison	Déclinaison	Fit
1	49.4997563	2.9260107	9.5	5.6	3.1	-1.7	-0.2	43.8	14.3	146.1	69.6
2	49.4997609	2.9260099	9.2	6.0	3.0	-1.2	-0.2	37.8	11.4	142.6	69.0
3	49.4997582	2.9260155	9.7	6.0	3.4	-1.5	-0.3	26.7	27.8	144.9	66.9
4	49.4997572	2.9260089	9.4	5.6	3.0	-1.6	-0.2	46.7	8.8	147.8	75.1

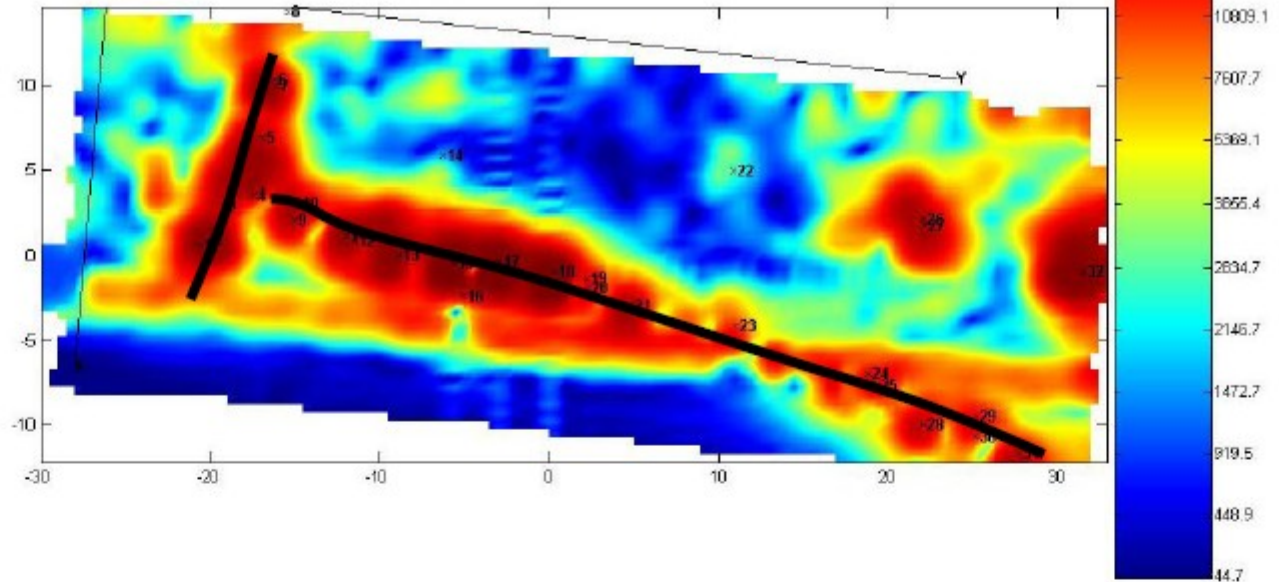
Carte d'anomalie magnétique



Carte du signal analytique



Au total, environ 571 objets identifiés
dans la zone ouest essentiellement



Identification d'une ancienne clôture sur la carte du signal analytique

Point	Latitude	Longitude	Xref	YRef	Xma	Yma	Zma	Amplitude	Inclinaison	Déclinaison	Fit
1	49.5001436	2.9261455	11.9	4.6	-22.6	3.5	0.1	860.6	-46.1	301.2	69.5
2	49.5001178	2.9261736	14.5	6.8	-20.6	0.6	1.3	14527.1	-60.4	238.1	71.9
3	49.5001217	2.9261823	14.0	7.4	-20.0	1.1	0.4	7260.0	52.1	147.8	82.5
4	49.5001384	2.9261927	12.1	8.0	-19.2	2.9	0.4	3634.3	-9.8	69.8	41.2
5	49.5001441	2.9262171	11.3	9.7	-17.5	3.6	0.5	44286.3	48.3	109.0	44.8
6	49.5001742	2.9262236	7.9	9.9	-17.0	6.9	0.7	11694.6	-3.2	280.7	72.6
7	49.5002055	2.9262334	4.4	10.3	-16.3	10.4	0.2	4005.6	43.3	80.2	68.8
8	49.5002021	2.9262353	4.7	10.5	-16.1	10.0	0.2	3313.5	34.1	68.3	61.4
9	49.5002417	2.9262451	0.3	10.8	-15.4	14.4	0.8	10944.2	-27.2	204.7	67.9
10	49.5001310	2.9262502	12.5	12.2	-15.1	2.1	0.7	4668.1	-60.2	227.2	71.0
11	49.5001396	2.9262536	11.5	12.4	-14.8	3.1	0.4	4725.2	41.6	107.4	76.6
12	49.5001227	2.9262927	13.1	15.4	-12.0	1.2	0.3	4068.3	-42.4	194.0	73.5
13	49.5001203	2.9262996	13.3	15.9	-11.5	0.9	1.1	18536.6	74.3	1.2	56.7



Inversion des données multi-capteur

Recherche de bombes, obus
explosés, non-explosés
22 sites

OBUS ORDINAIRE DE 15 CM MLE 1880

Corps en fonte
Poids total 27.5 kg
Poids explosif 1.9 kg

Les dimensions sont en mm

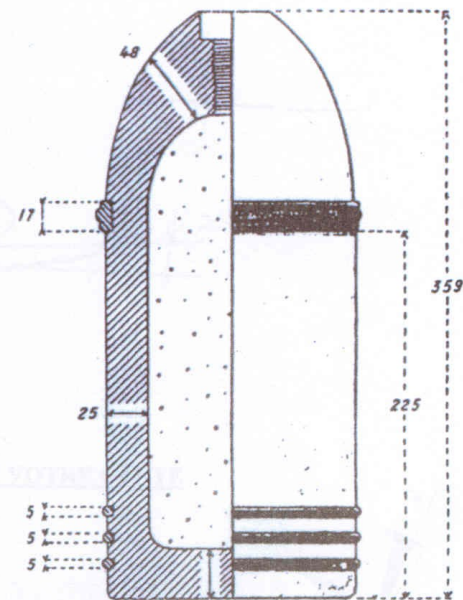
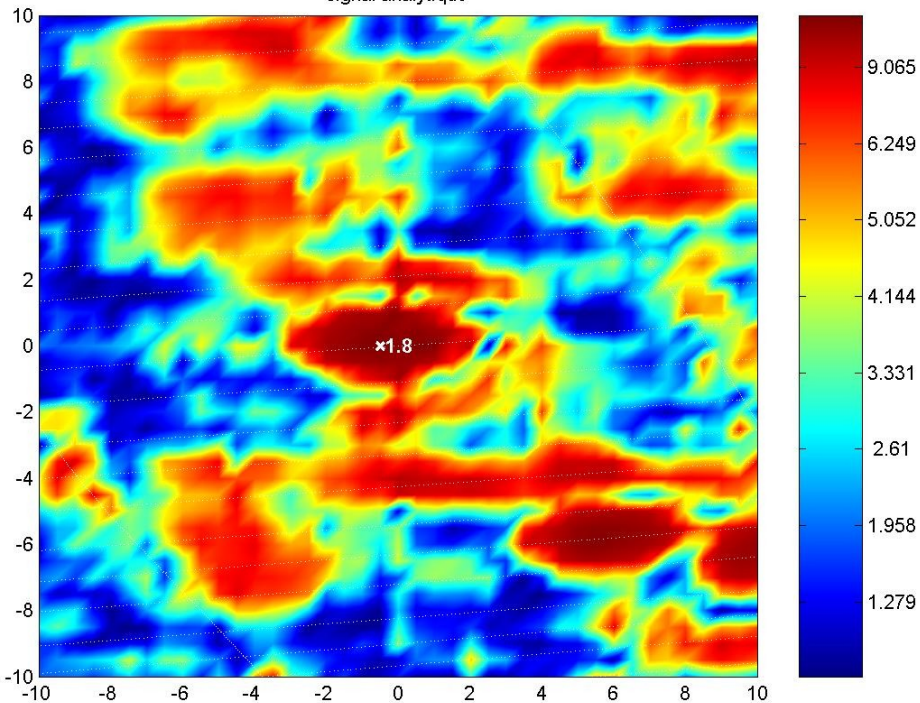


PHOTO DE TROIS OBUS IDENTIQUE



signal analytique

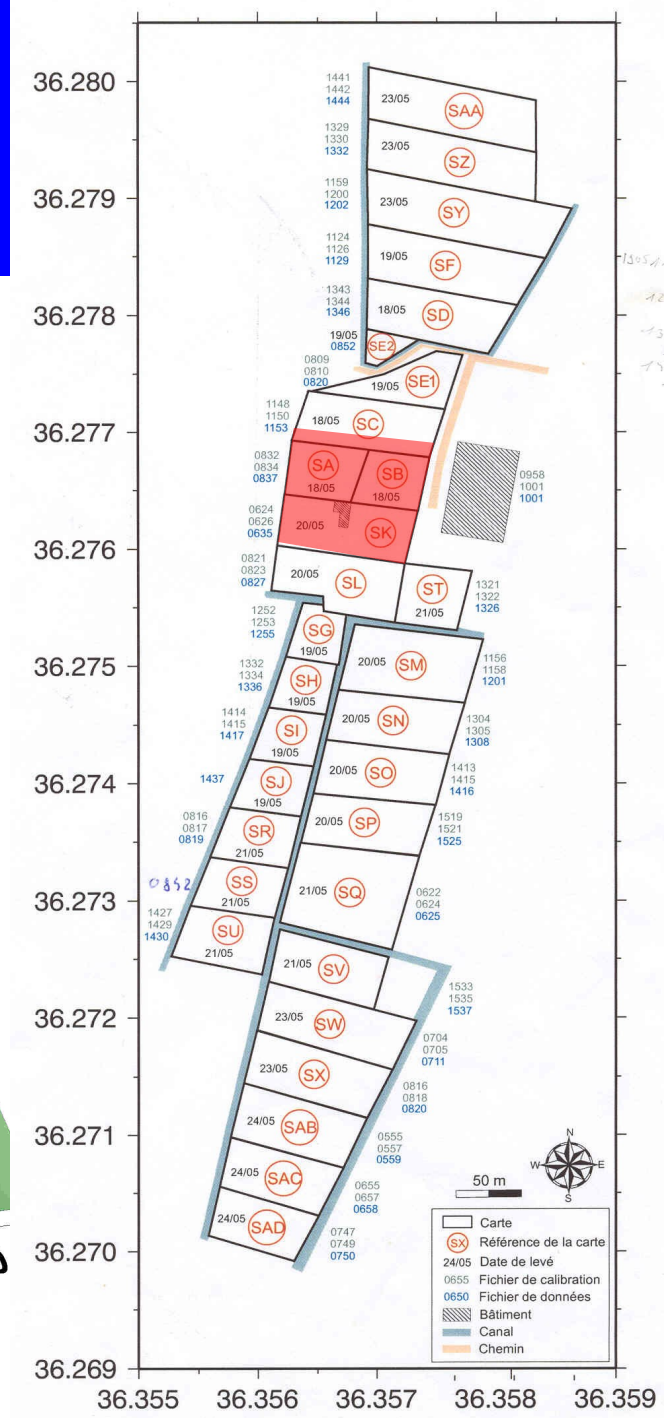
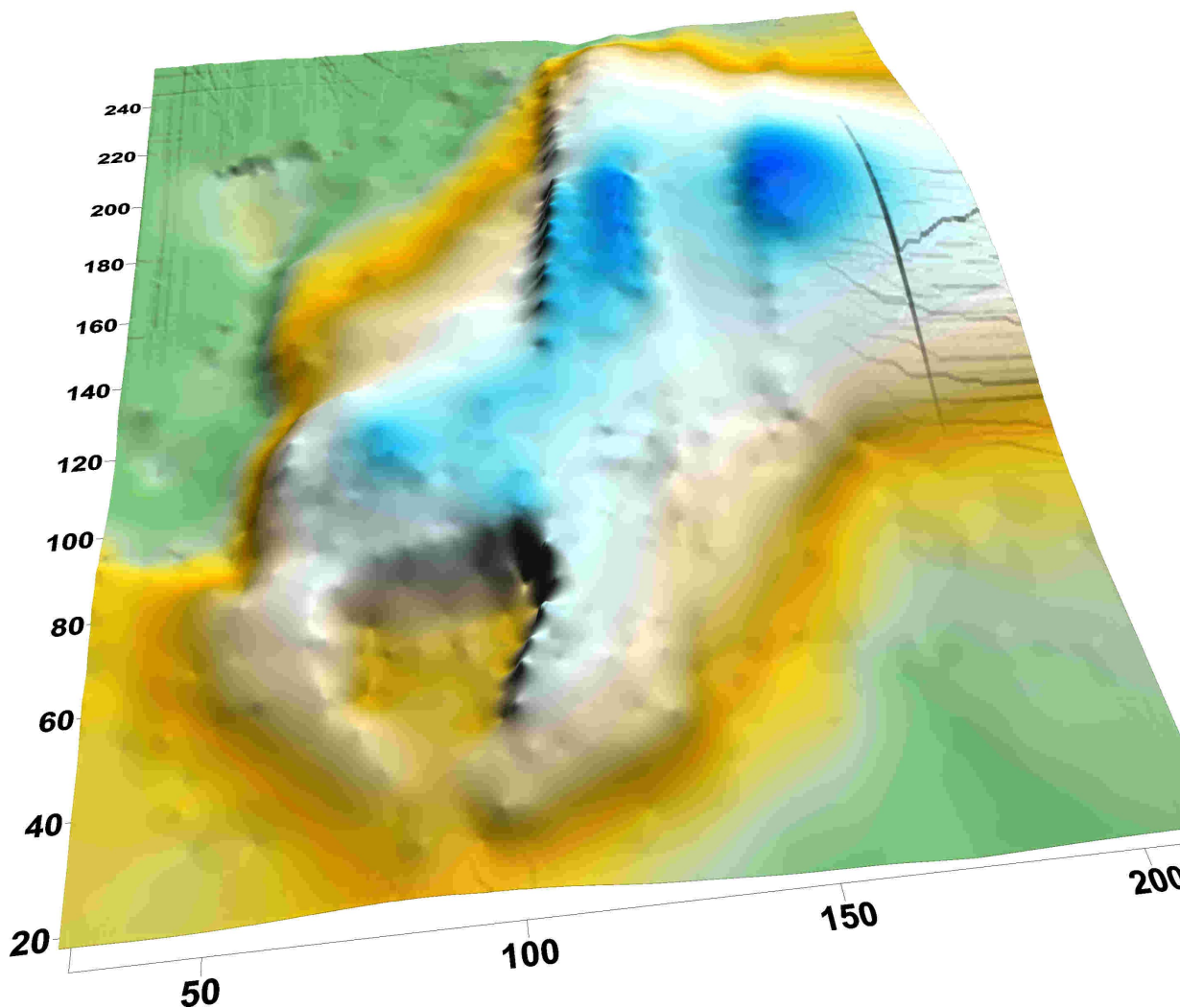


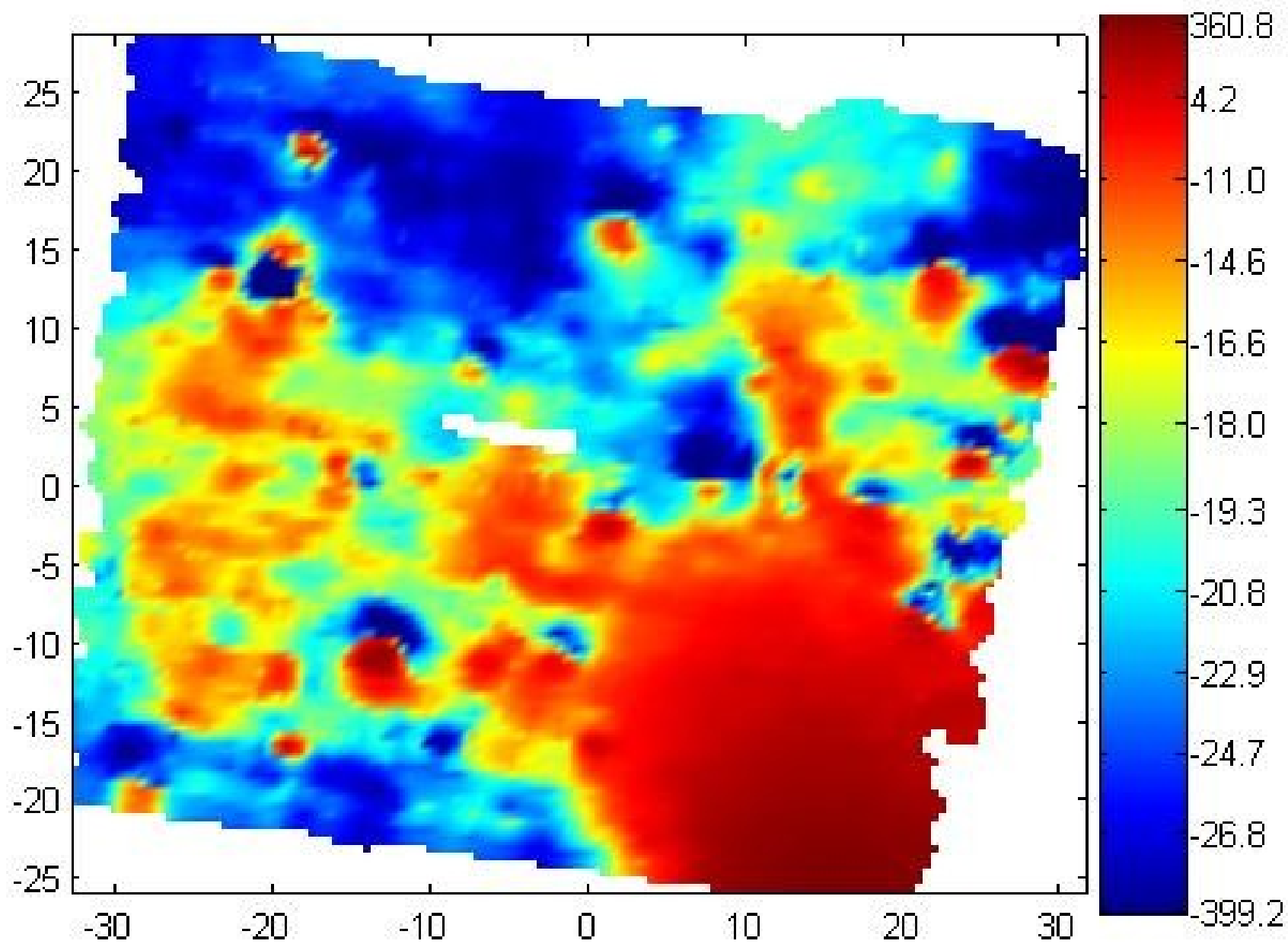
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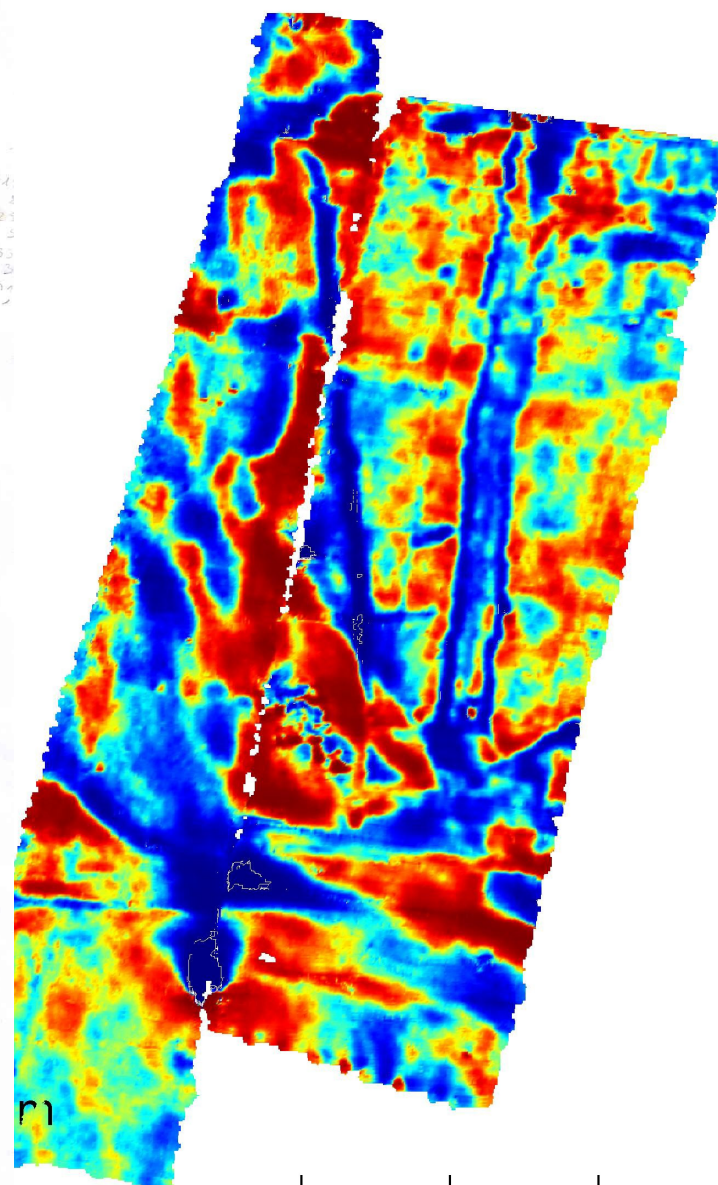
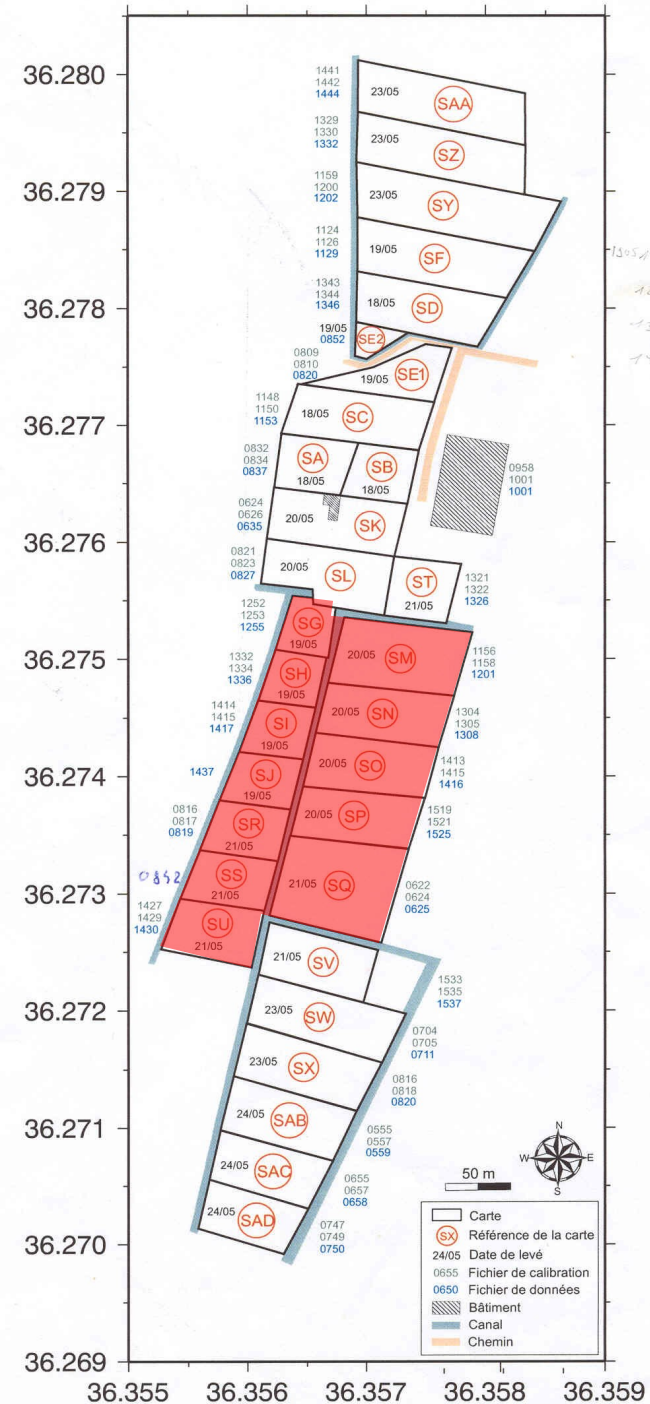
Bassin de Karasu, Tell de Sicantarla

Mustapha Meghraoui, Sophie Bertrand

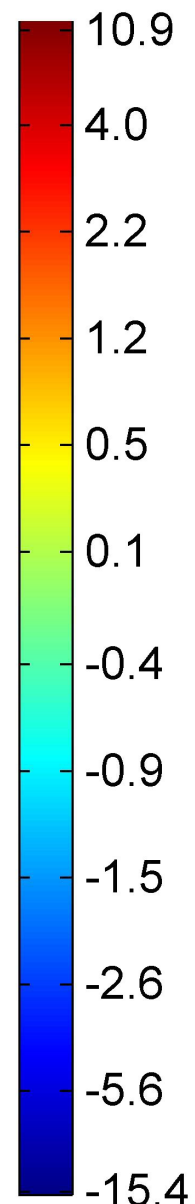
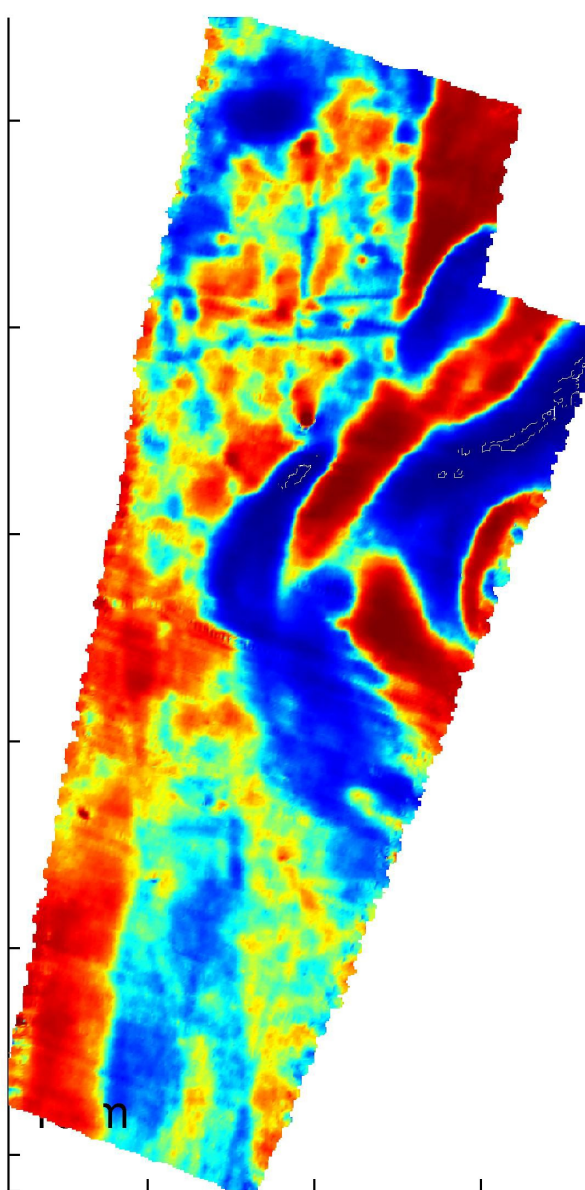
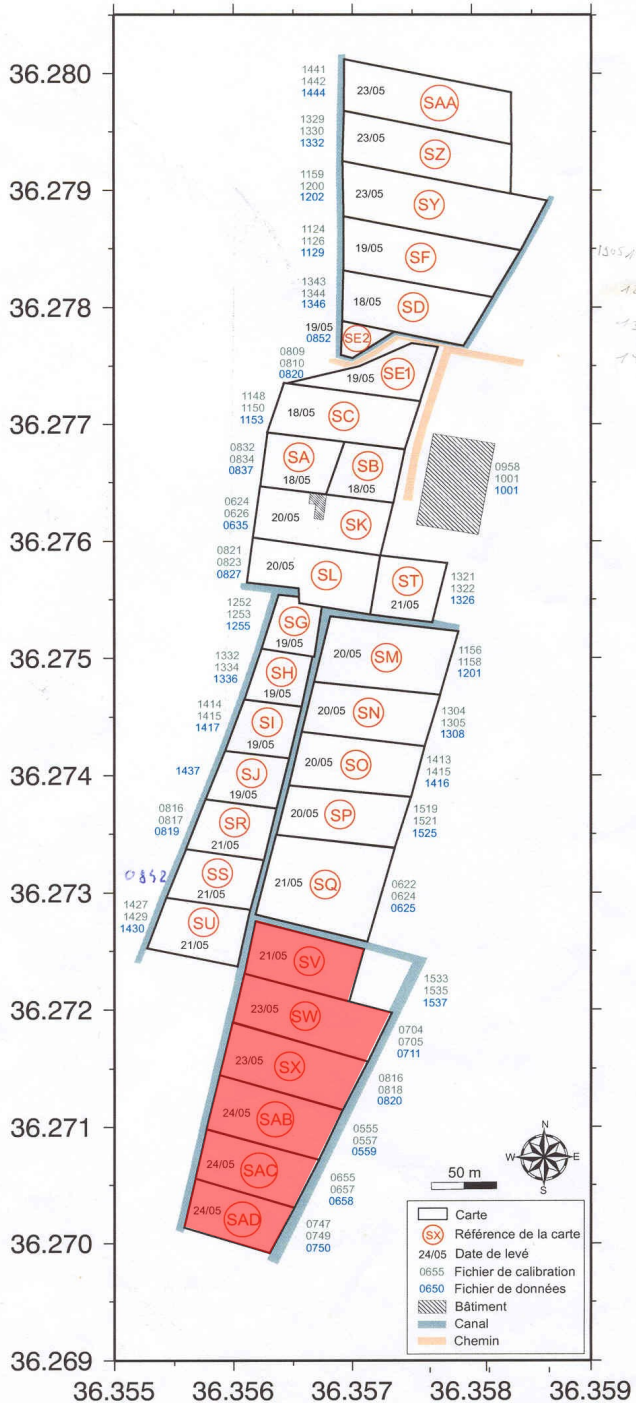


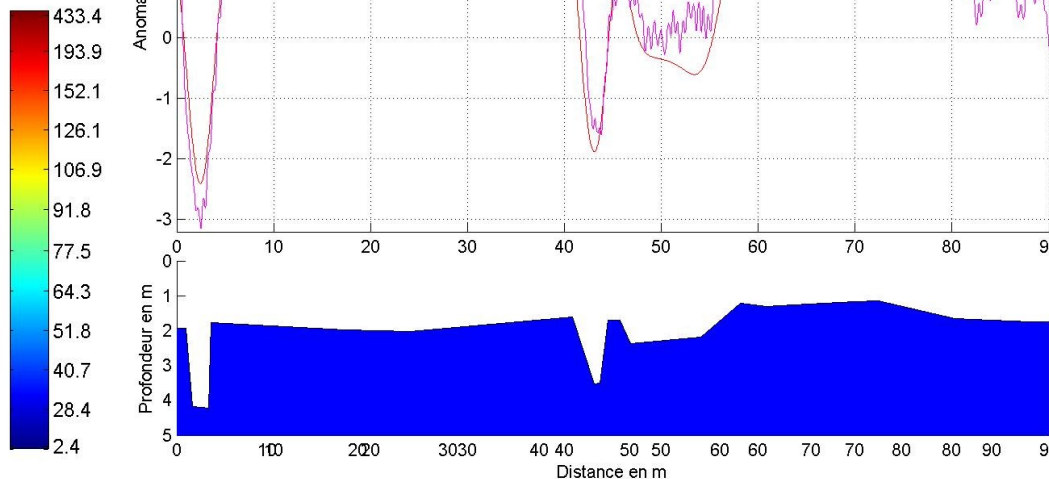
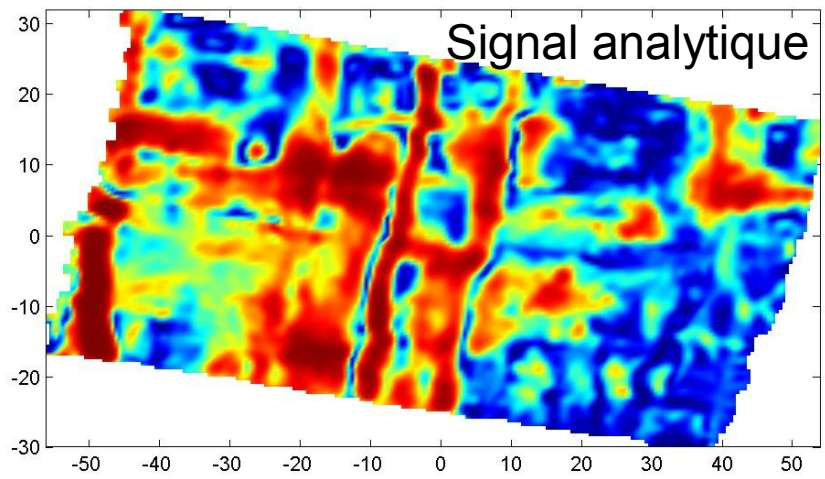
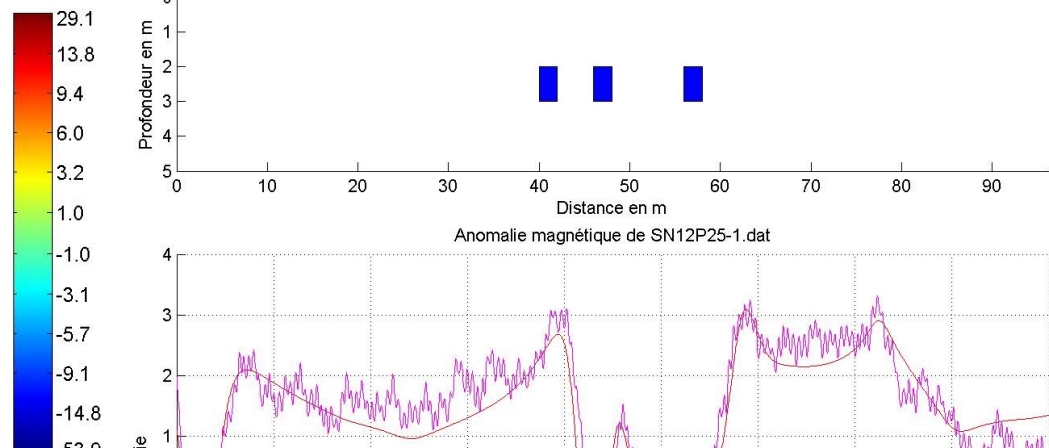
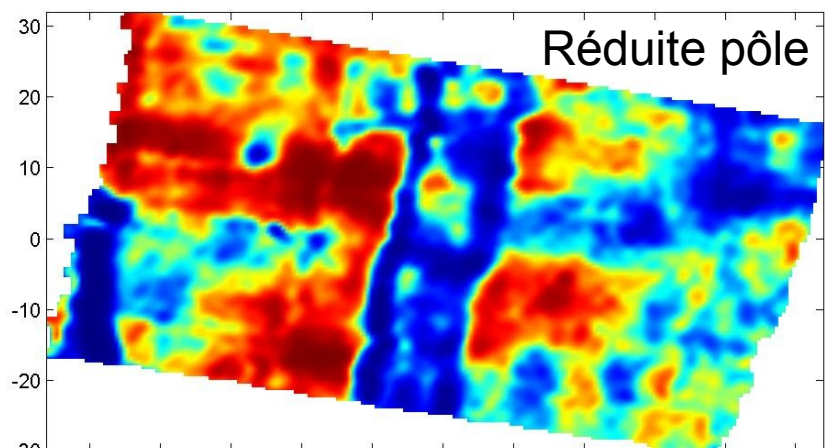
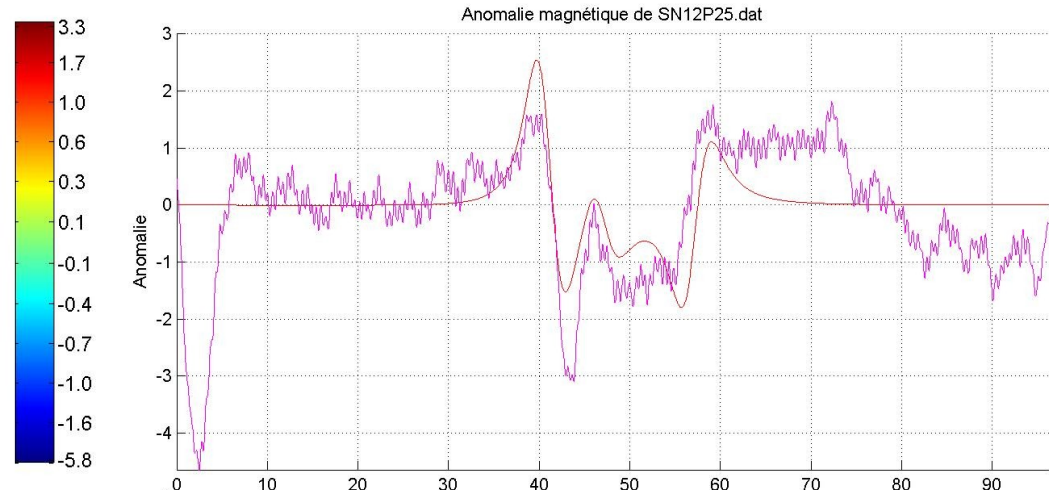
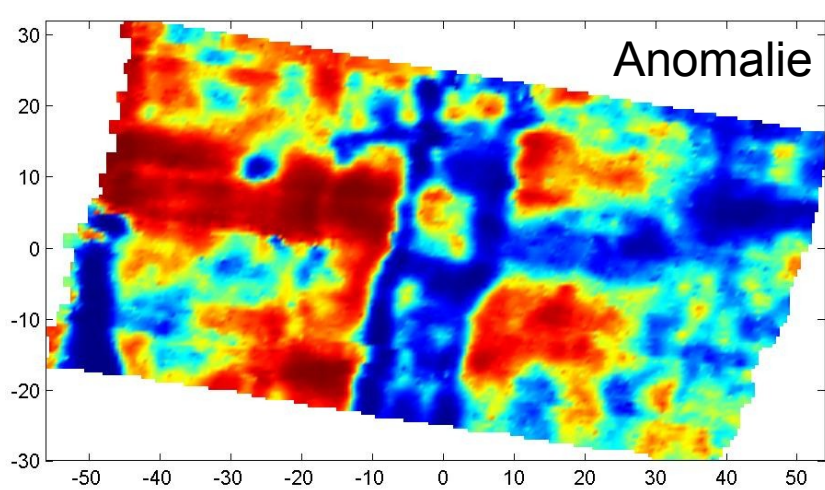


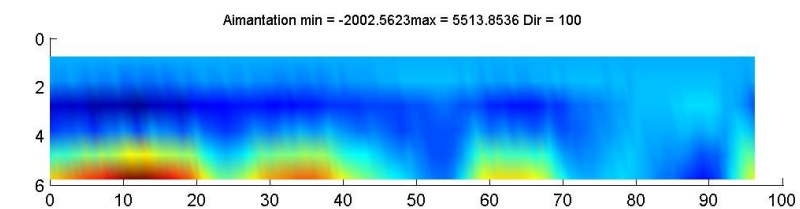
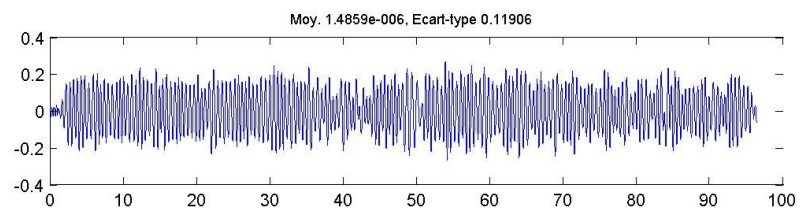
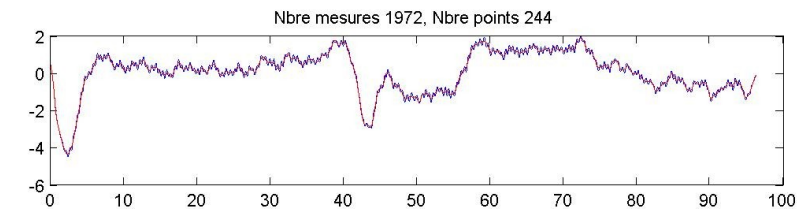
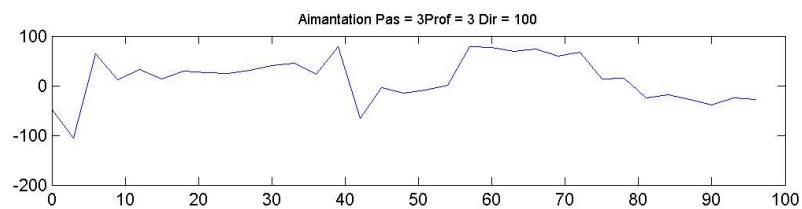
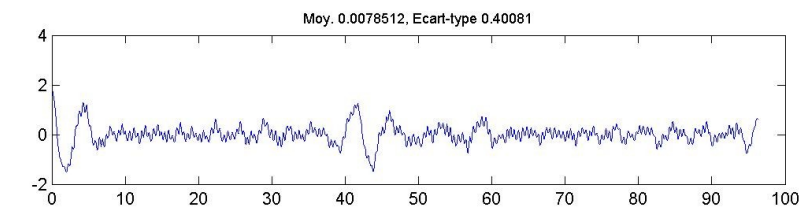
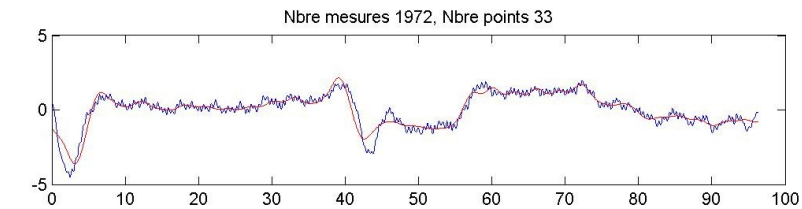
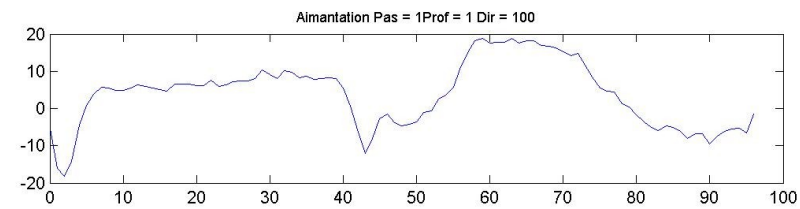
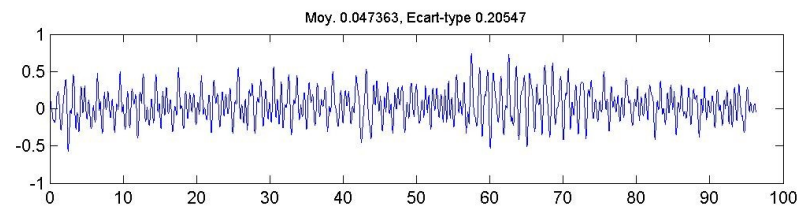
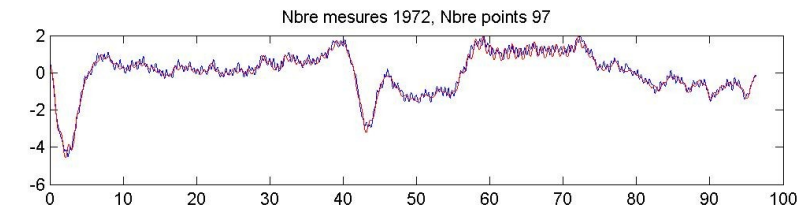
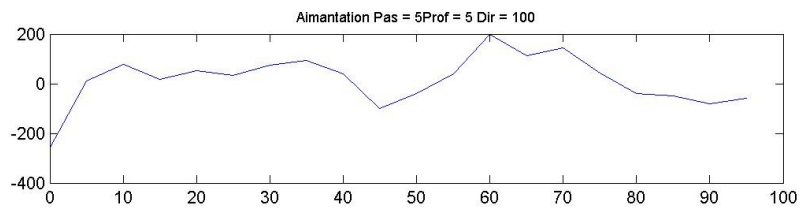
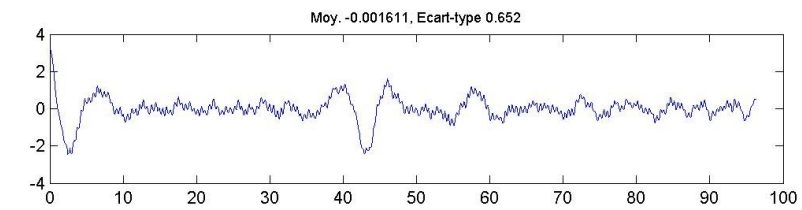
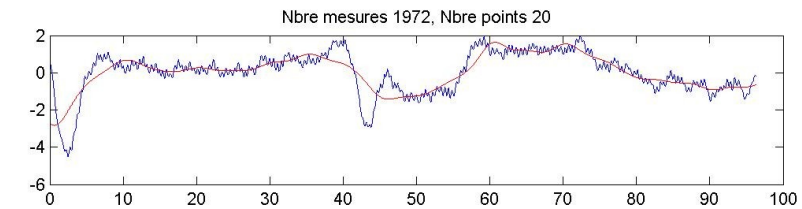




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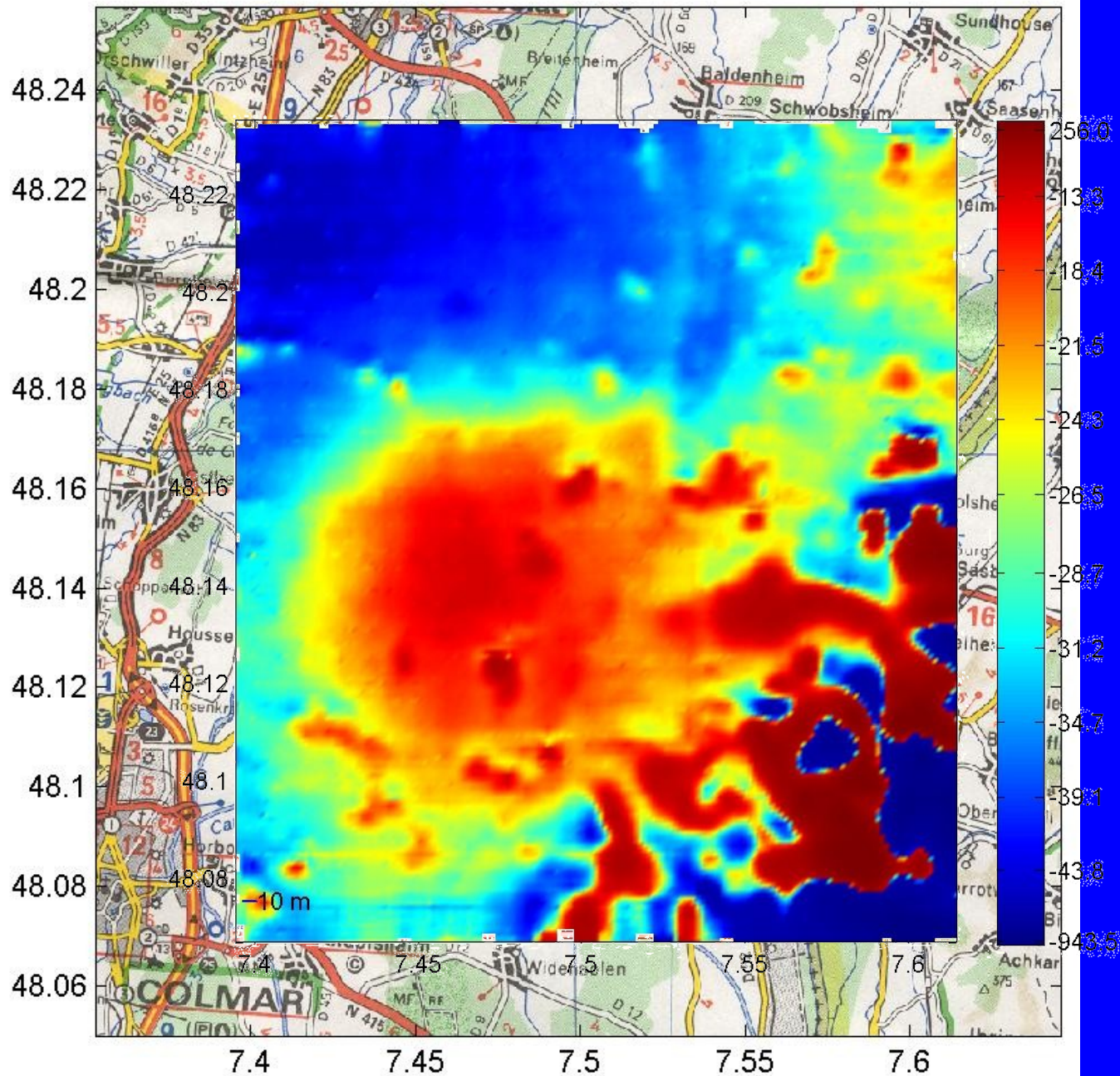


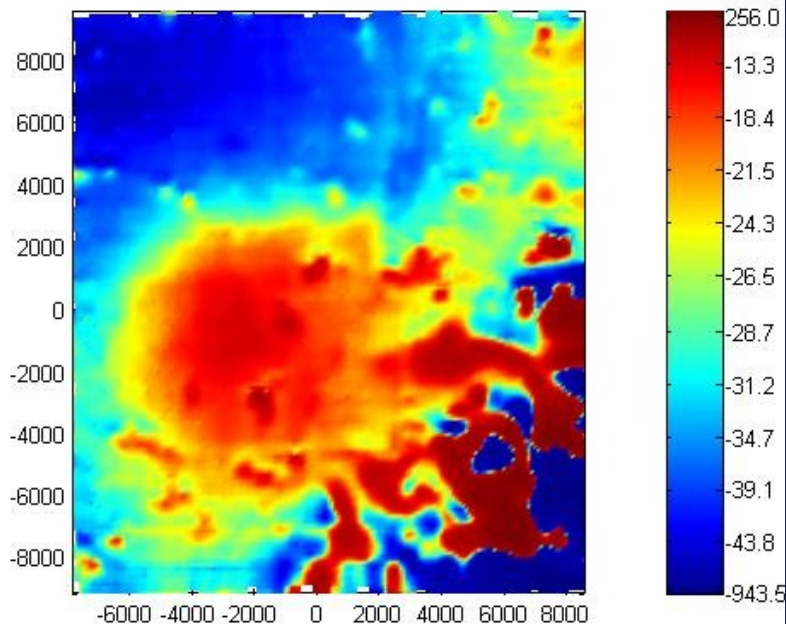




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Cartographie multi-échelle, région de Colmar





Signal monogénique

$$f(x, y) \rightarrow F(u, v)$$

$$\frac{iuF(u, v)}{\sqrt{u^2 + v^2}}$$



$$f_1(x, y)$$

$$\frac{ivF(u, v)}{\sqrt{u^2 + v^2}}$$



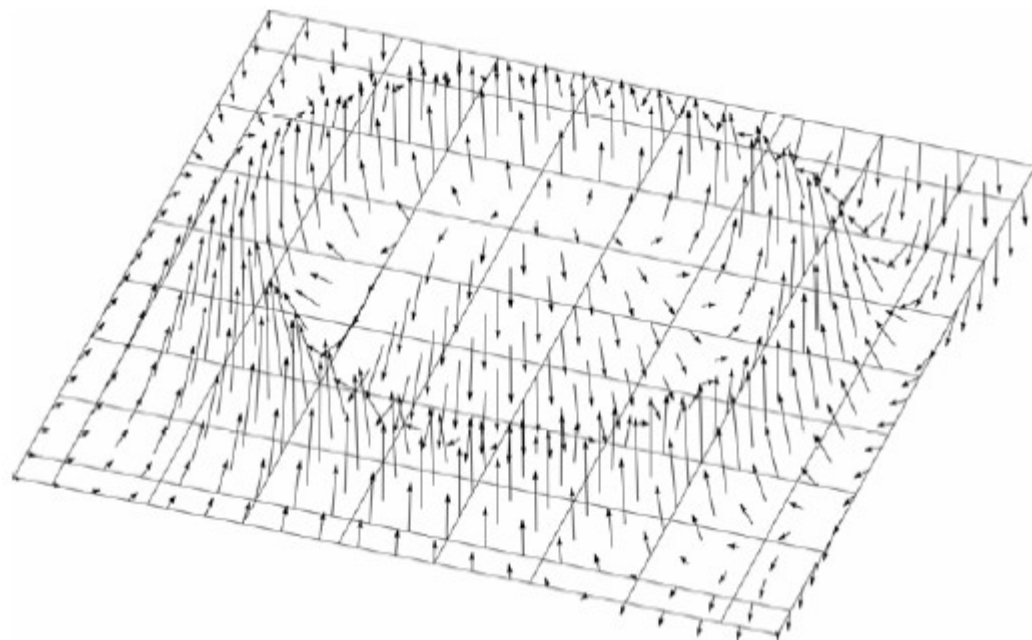
$$f_2(x, y)$$

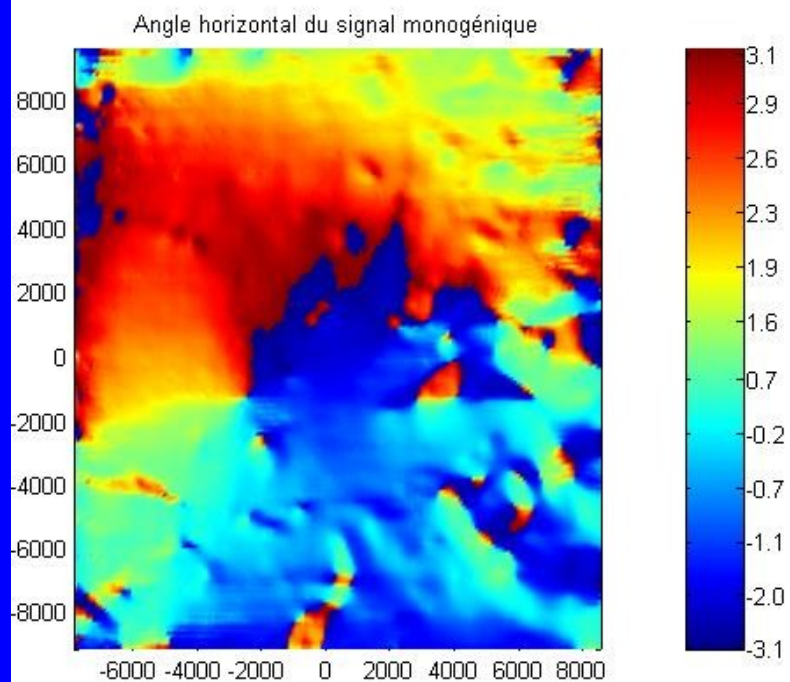
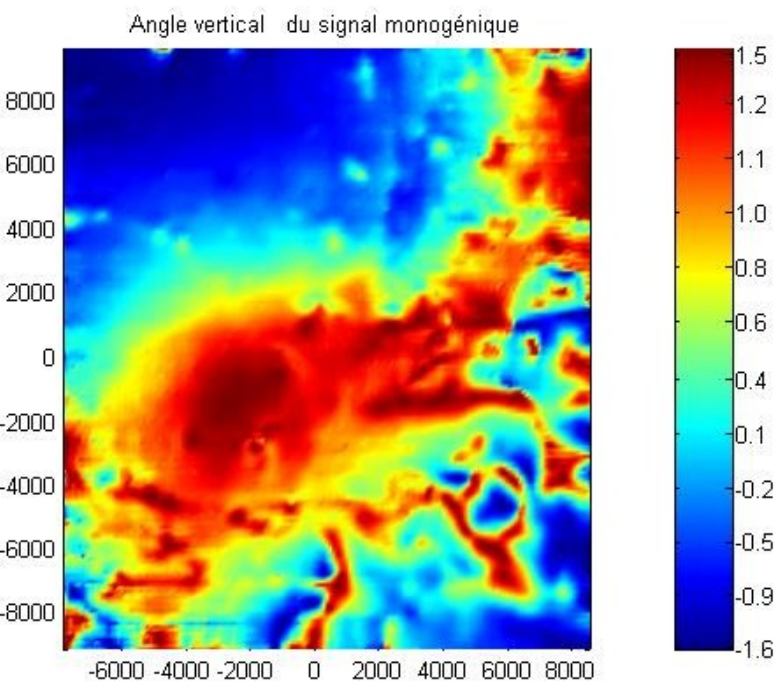
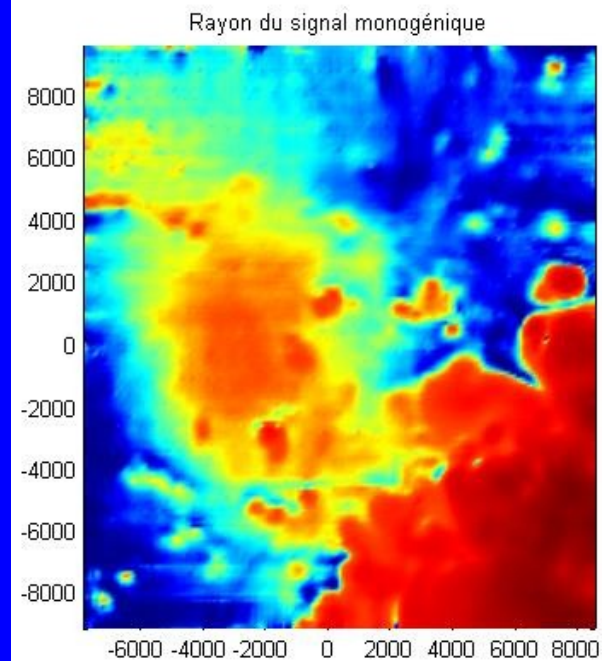
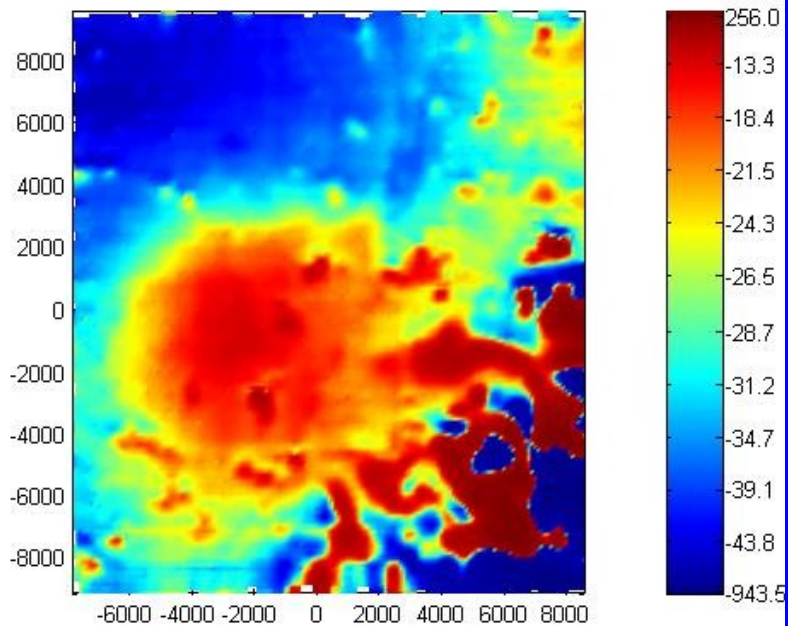
$$F(u, v)$$

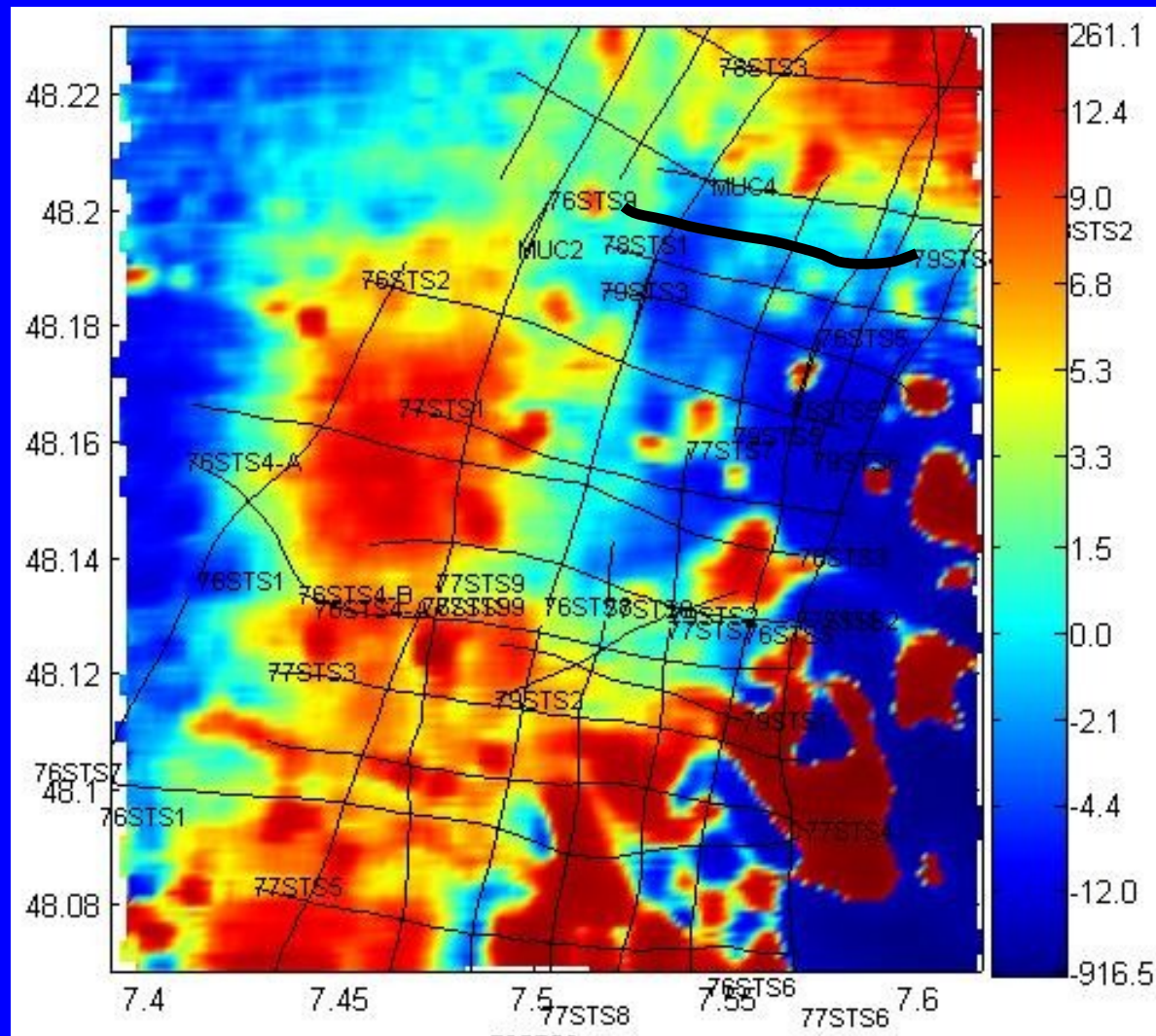


$$f_3(x, y)$$

Amplitude, angle vertical, angle horizontal

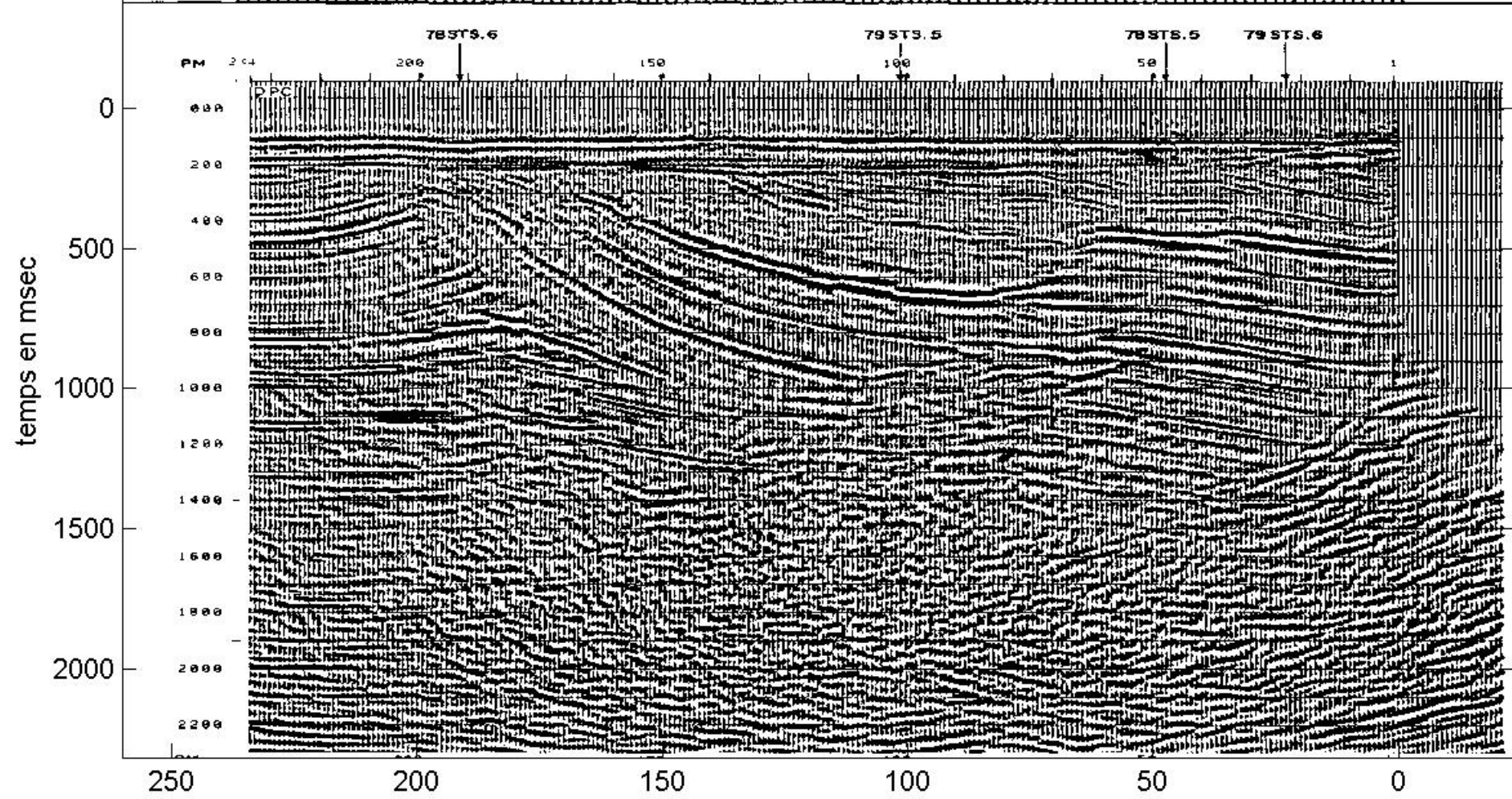
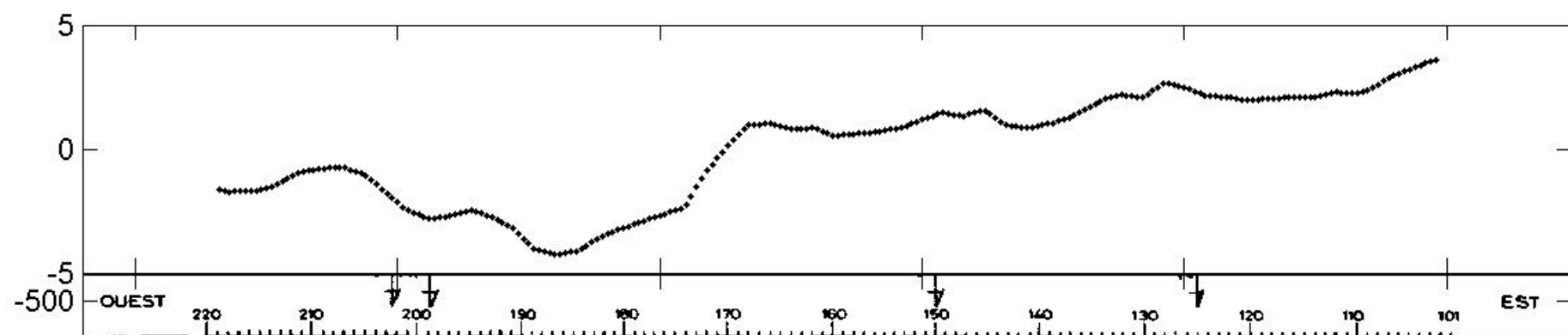


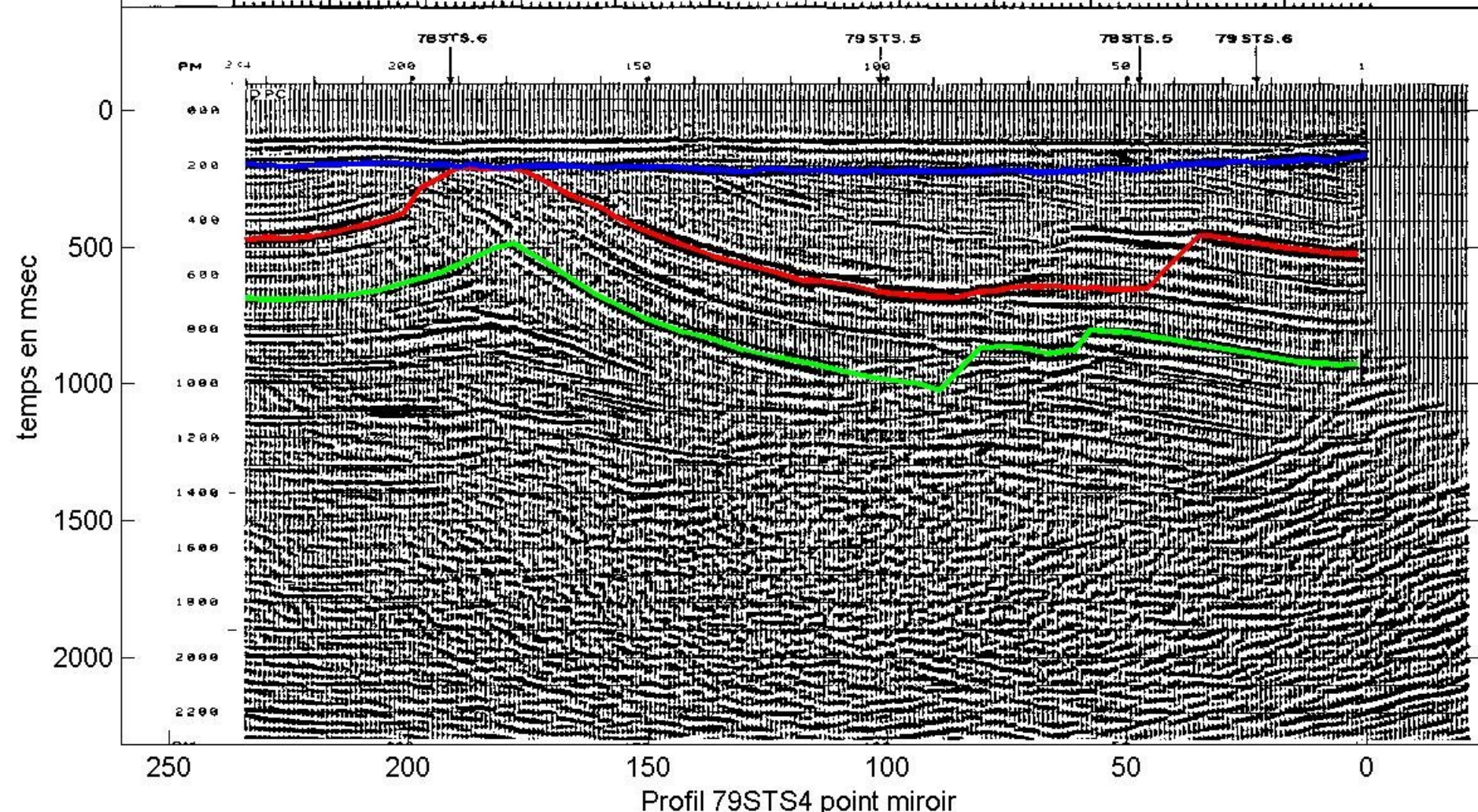
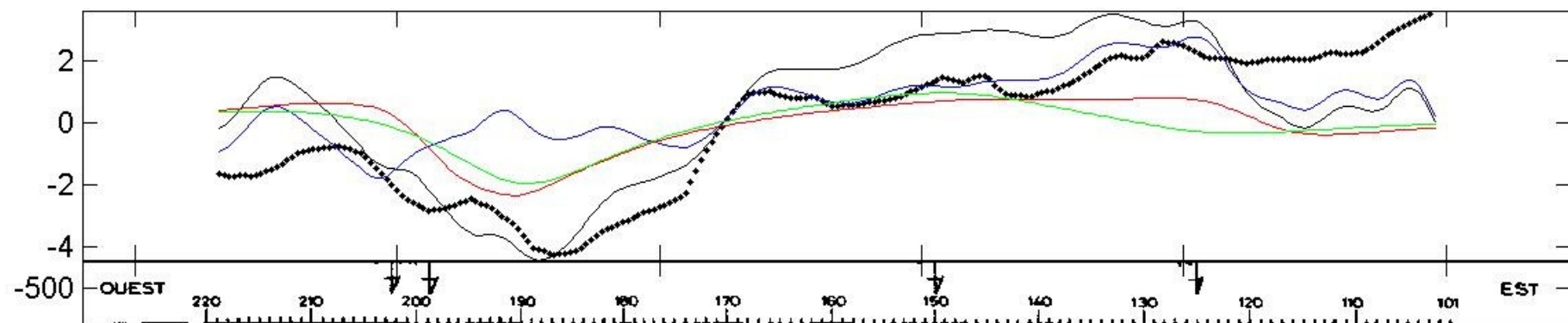


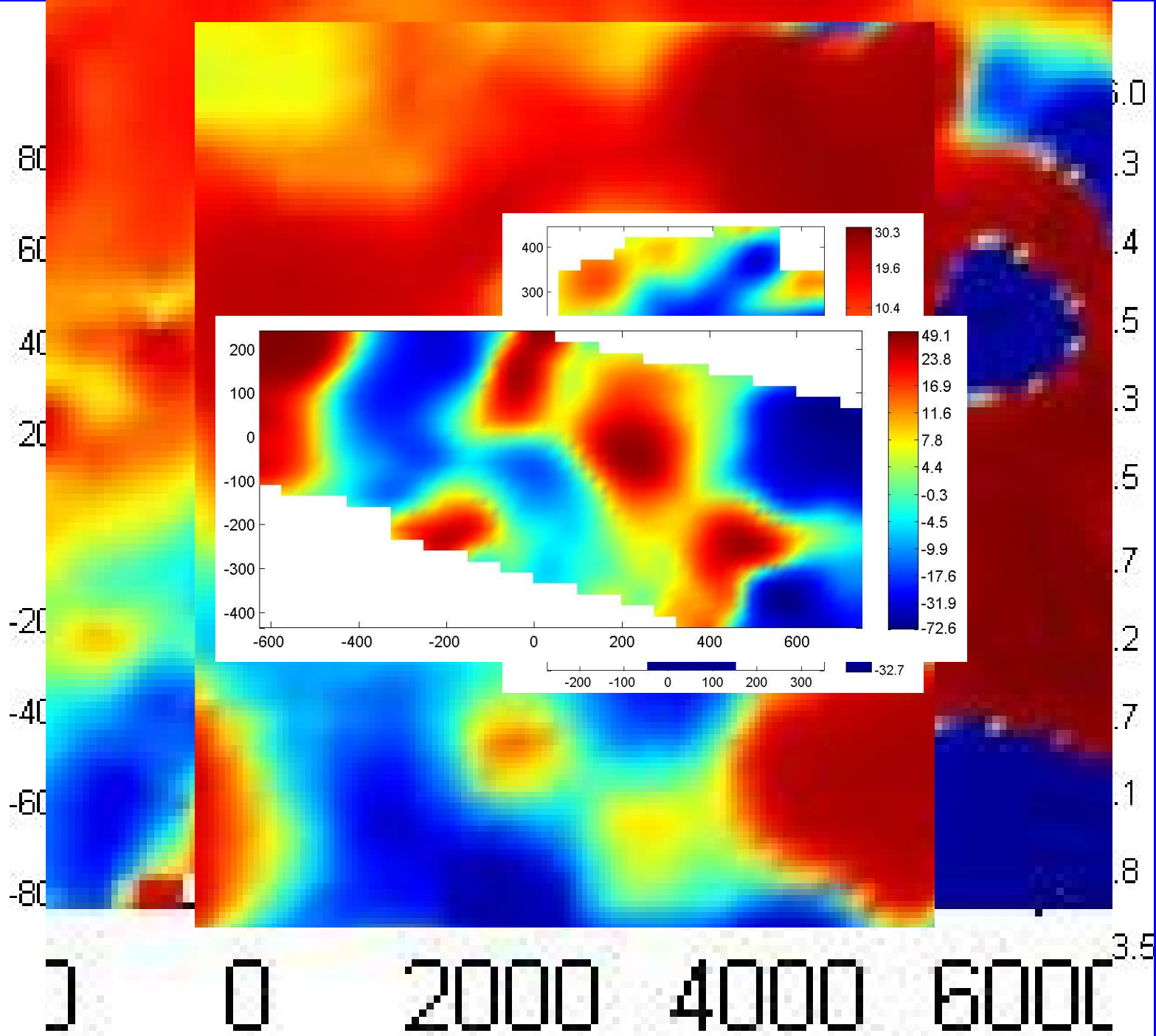


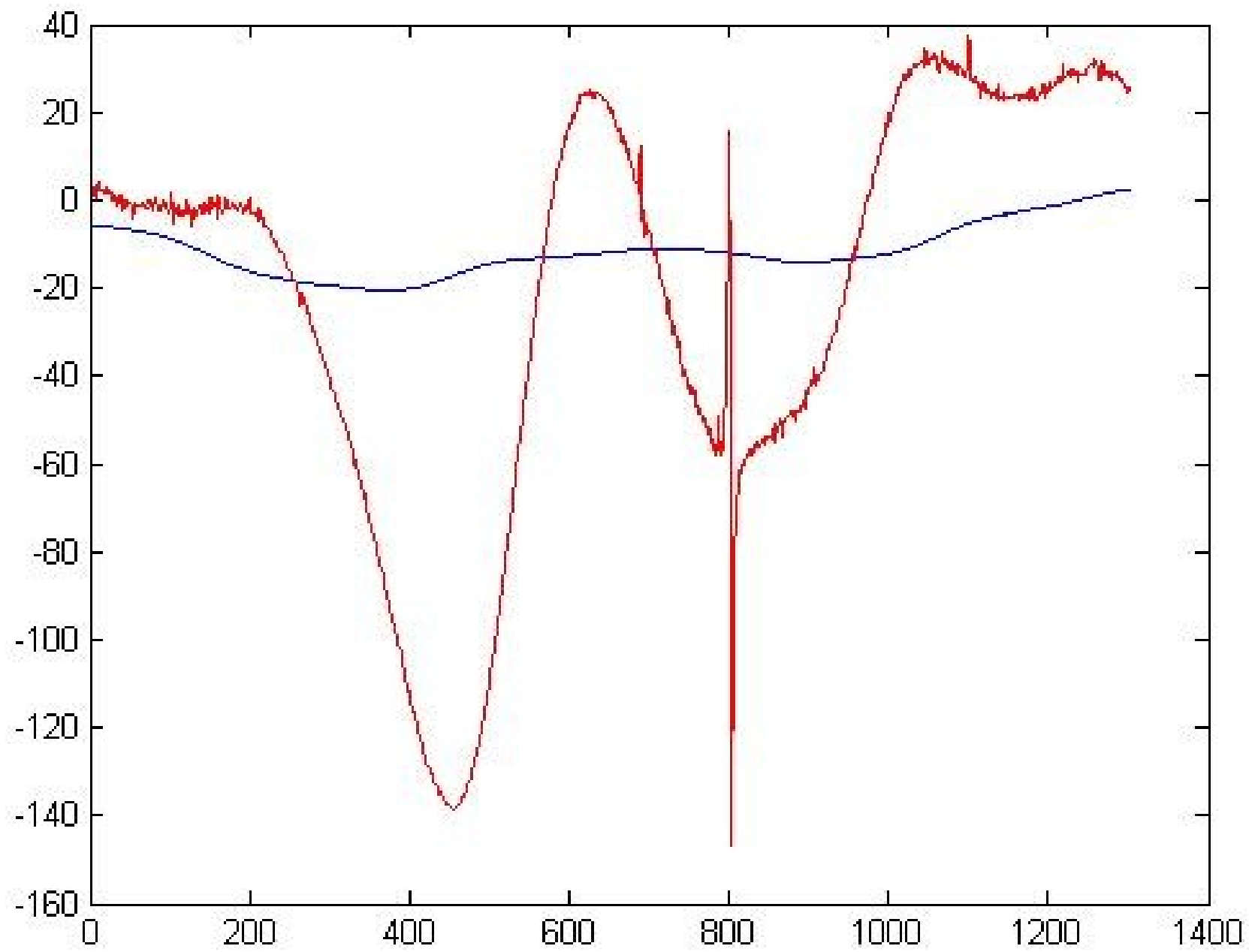
Localisation des profils sismiques

Synthèse interprétation sismique, Lutz et Cleintuar (2000)

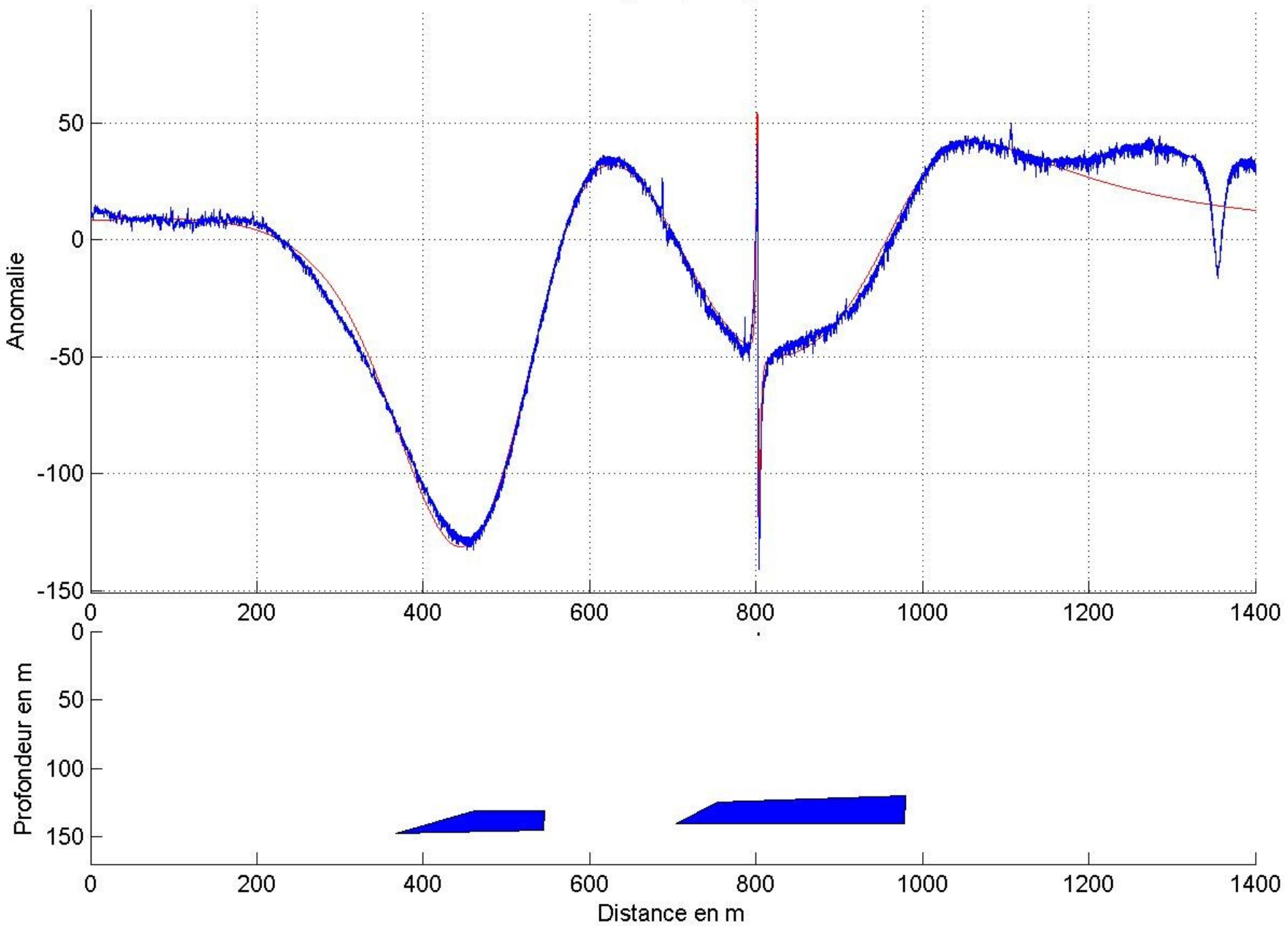






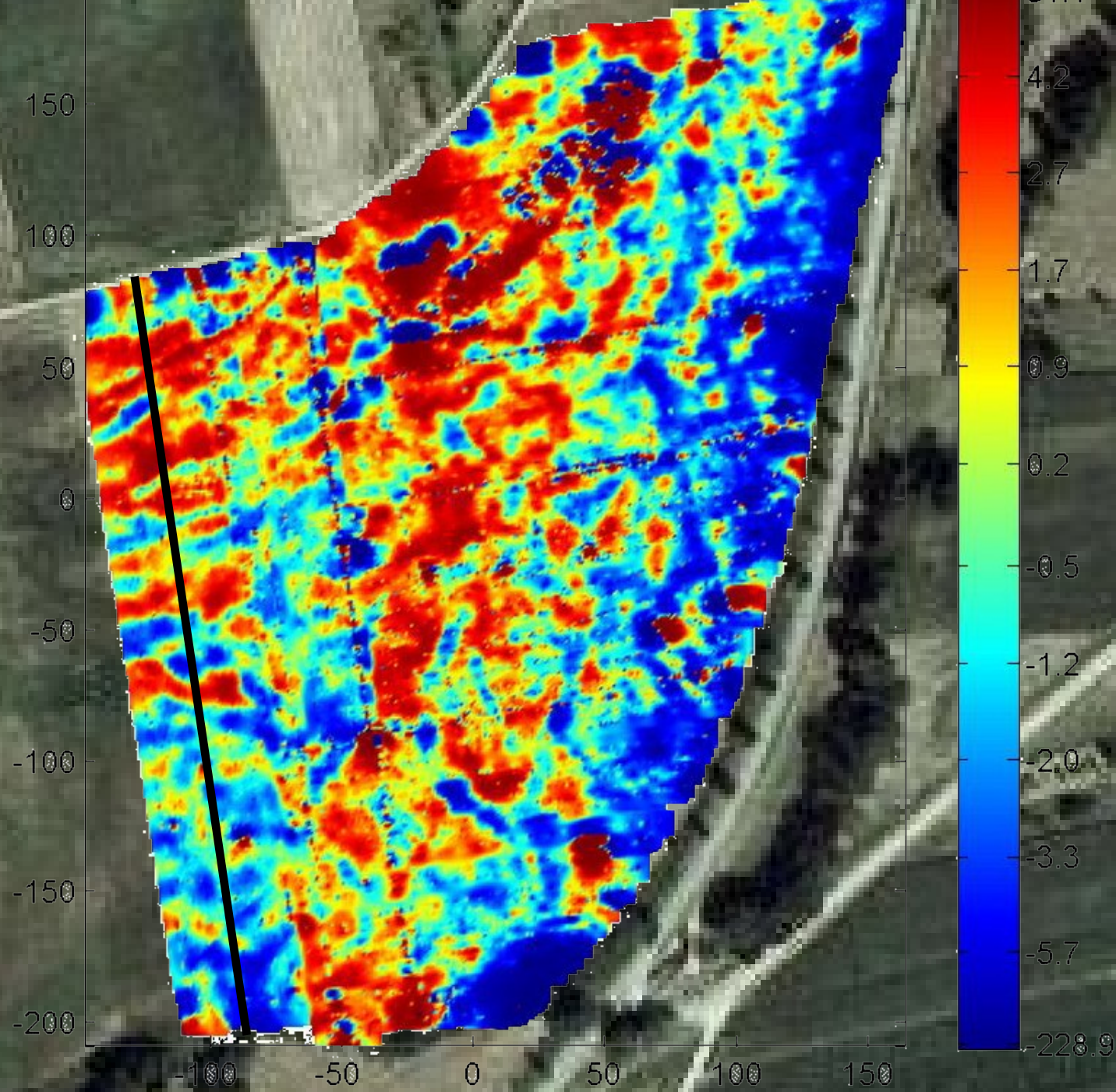


Anomalie magnétique de profsol.dat

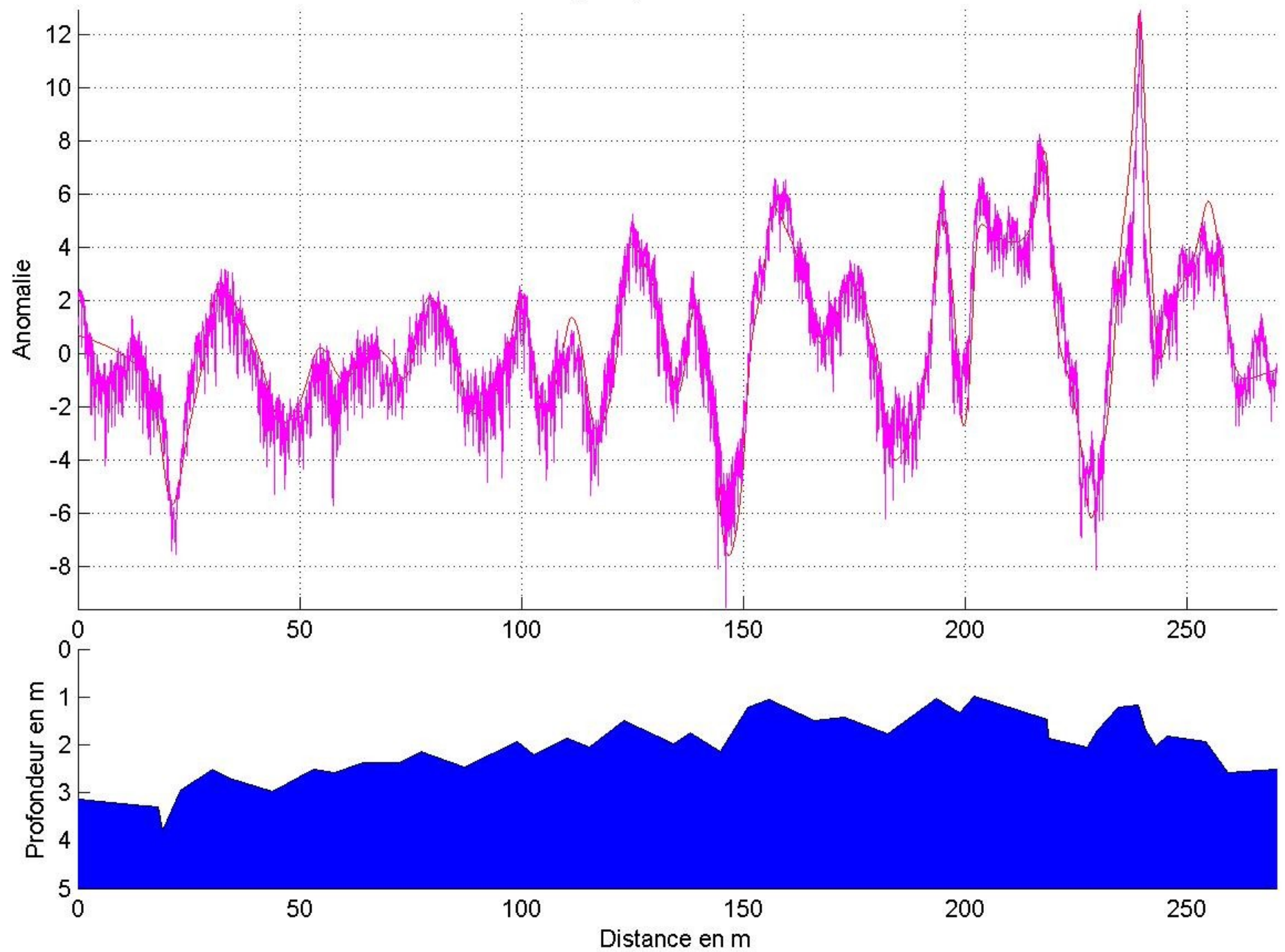


Lithologie de la Bruche, Dachstein (Auzet, Liebault)

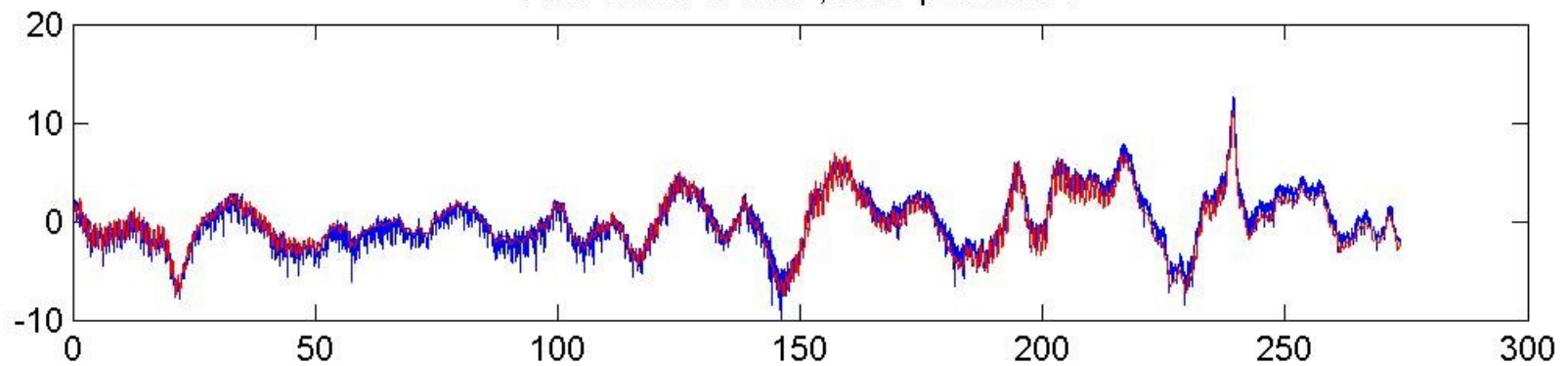




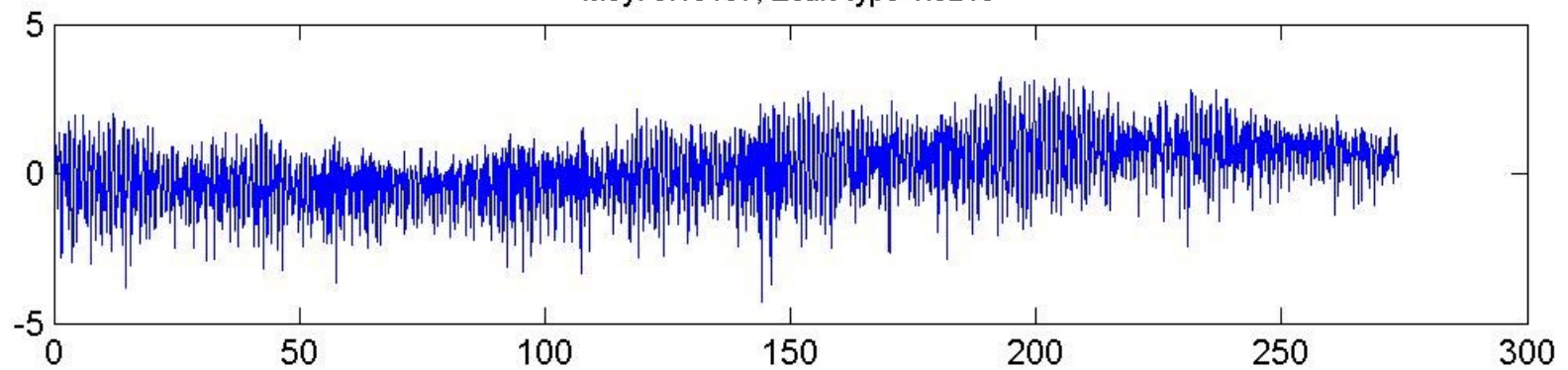
Anomalie magnétique de carto2P6couche.dat



Nbre mesures 5552, Nbre points 274



Moy. 0.16437, Ecart-type 1.0249



Aimantation Pas = 1 Prof = 1 Dir = 180

