Bay of Somme: Magnetic Survey and Obstructions Detection

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The detection of wrecks and metallic obstructions at sea is a subject that has been developed by the Geodesy-Geophysics Division of the Service Hydrographique et Océanographique de la Marine (SHOM). A method for the reduction of the magnetic measurements has recently been defined and tested on deep-sea data (from Azores). This method is based on the simultaneous exploitation of marine and land magnetic data (with a fixed station near the zone of the marine survey), and allows the correction of the marine data for the magnetic field time variations, thus giving a better knowledge of the magnetic signature of wrecks and other metallic obstructions.

The shallow waters (10-15 m) of the Bay of Somme, rich in wrecks, have been used as a test zone for this new data treatment. The magnetic survey was performed between 23 March and 3 April 1995.
First the reader is reminded of the different magnetic field components. Then, the measuring equipment for land and marine applications is presented.
The developed treatments determining the field anomalies are presented and explained.
The completion of this work provides the magnetic anomaly map for the Bay of Somme. This map reveals several areas with strong gradients of magnetic field. For each of these areas the precision of the magnetic anomaly have been calculated. Finally, constraints brought up by this type of magnetic survey are reviewed.

Presentation of the Zone of Study

The surveyed marine zone is located in the Bay of Somme, north of Tréport and south-west of St-Valery-sur-Somme (Seine-Maritime, 76).
The geographic co-ordinates in the WGS 84 system are the following:

- North latitude: 50.1764°
- South latitude: 50.1001°
- North longitude: 1.29029°
- South longitude: 1.44591°

Nautical chart No. 783 from SHOM 'Abords de Dieppe et du Tréport' covers the zone, with a scale of 1:45,000.

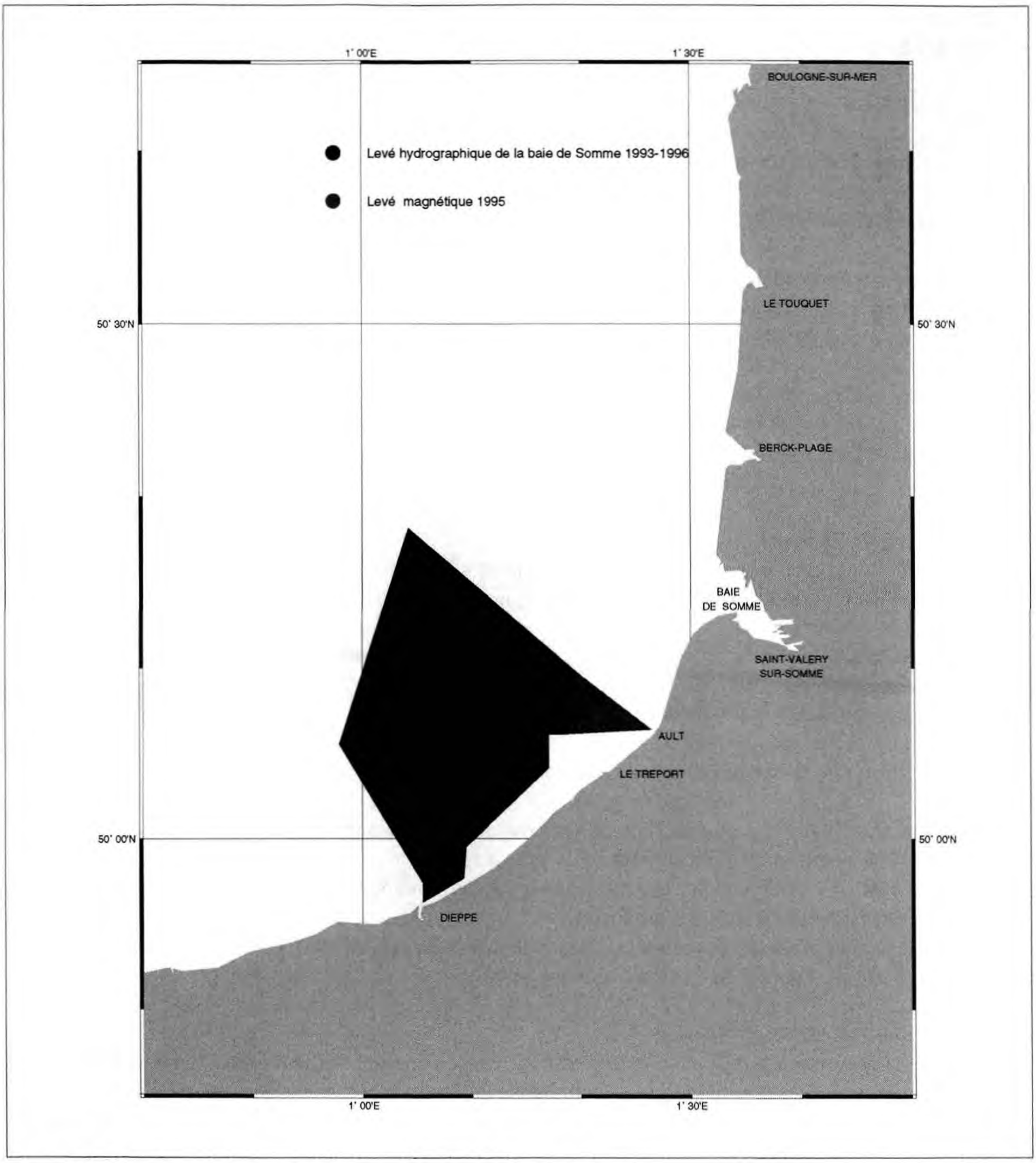


Figure 1: Schematic location of the prospected zone in Baie de Somme

The Earth's Magnetic Field and the Measure

Earth's Magnetic Field Components

The total value of the earth's magnetic field (global field) measured at sea or on land is composed of three components: the internal field generated by the core of the earth, the external field resulting mainly from solar activity, and the local magnetic field (field anomaly) created by metallic objects or masses near the point of measurement (lithosphere, oceanic crust, wrecks,...).

The Internal Field

The internal field and its variations are described by a model in spherical harmonics. The model used is the I.G.R.F. 95 (International Geomagnetic Reference Field) chosen by the Association Internationale de Geomagnetisme et d'Astronomie.

The External Field

The external magnetic field has periodic variations of diurnal frequencies and unexpected variations due to solar activity (spots, solar eruptions) called magnetic storms. This component is measured from a magnetic reference station on land. So, for the time of this study, a magnetometer was installed at the Ault's semaphore (land station).

The Magnetic Anomaly Field

The exploitation of the magnetic anomaly field map, based on the surface land and marine measurements, generally provides the characterises of the local magnetic structures, meaning defining the magnetic anomaly field.

Magnetometers of the SHOM measure the total magnetic field. In order to find out the local magnetic field, the measurement must be corrected from the internal and external field components.

The tools, techniques, and methods leading to the magnetic anomaly field are presented in the following pages.

The Measuring Equipment

The magnetic survey of the Bay of Somme has required simultaneous recording from a towed immersed marine magnetometer and from a fixed land magnetometer.

The Marine Magnetometer

The marine magnetometer is a Thomson-Geomag SMM92.

General Description

The magnetometer is composed of three main components:

- The processor, allows the operator to initialise the parameters and to visualise the measurements on a screen. The depth of the fish immersion is also indicated
- The tow cable is a coaxial cable that provides a strength member, the power supply for the fish, and the data communication with the processor
- The fish carrying the magnetometer at Overhauser Effect (see 2.2.1.1.) and associated electronics (analogic-numerical conversion, data communication with the processor)

Principle of the SMM92 Magnetometer

The principle relies on magnetic resonance. The body of a magnetometer is filled with a liquid rich in protons (water, kerosene,...) surrounded by a detecting coil. The protons, hydrogen nuclei, react in the surrounding magnetic field. The protons' spin take the bearing of the magnetic field. They emit electromagnetic radiation, which frequency, called Larmor, is proportional to the surrounding magnetic field. The measurement of the magnetic field is, in fact, the measure of the Larmor frequency.

The electromagnetic radiation is caused by the transition of the energy state of the protons. To enhance the radiation, and consequently the measured signal, the protons must be evenly distributed in the different energy levels, the so called polarisation.

In classical proton magnetometers, proton polarisation is achieved by the application of a strong magnetic field perpendicular to the earth's magnetic field, and during a very short time. After the release of this strong field, the magnetic spin orientates themselves along the earth magnetic field, and the measurement can be done.

For the Overhauser effect magnetometers, polarisation is continuous. In addition to the protons, an important part of free radicals, giving electrons are enclosed. The application of a very high frequency electromagnetic field transfers by coupling the energy of the electrons spins to the protons spins. This results in the continuous polarisation of the protons.

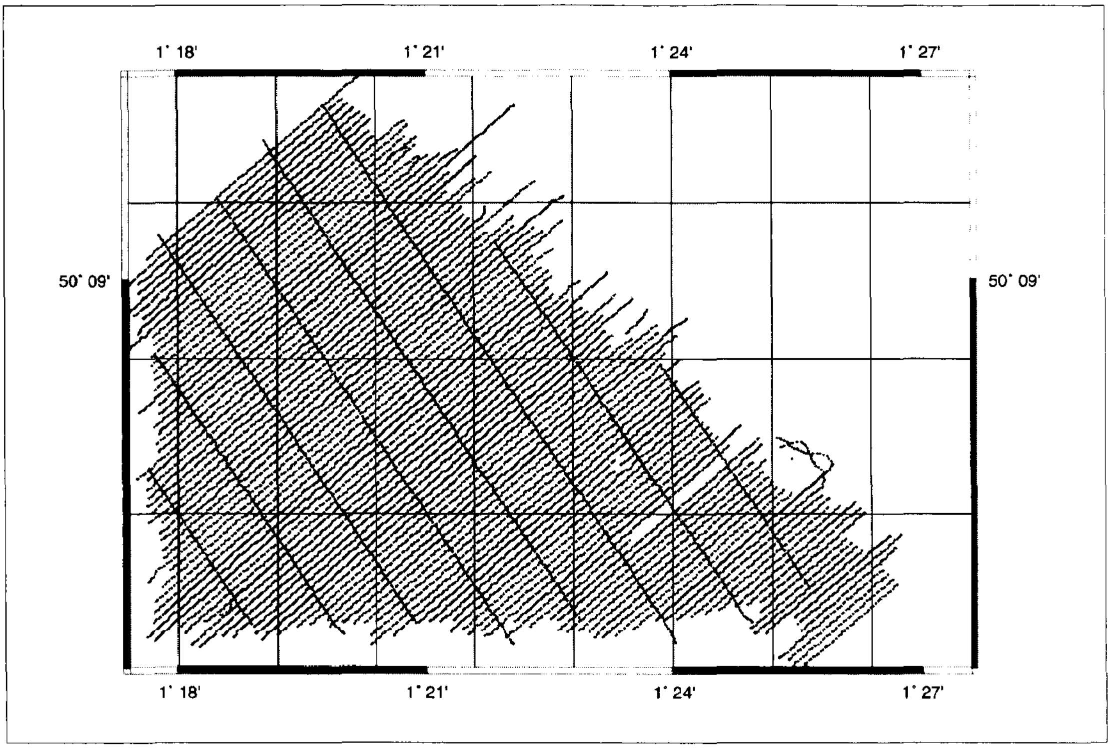


Figure 2: Points location

The advantage of the Overhauser effect magnetometer, compared to the classical proton magnetometer, is to provide a sustained signal of strong amplitude, instead of exploiting a fading and non redundant signal. In addition, the SMM92 treats a digital signal from the fish and the noise is then limited to the measurement at the magnetic sensor.

Measurement Precision

The magnetic sensor resolution is of 0.01 nT, the practical precision being of 0.03 nT.

The Magnetometer on Land Station (Ault)

The land magnetic measurements have been performed with a proton magnetometer E.G.&.G.Geometrics G-856X lent by IFREMER for the duration of the survey. Before the start of the survey, the reliability of the magnetometer has been calibrated on the site, Ault's semaphore. This calibration has shown a good coherence between the temporal variations recorded at Ault, and the temporal variations recorded at Chambon-la-Forêt (reference magnetic station).

General Description of the Magnetometer

The land magnetometer is also composed of three parts (see annexe):

- The sensor, of cylindrical form (9x13 cm) placed on top of a pole of 2.5 m high
- The small processor unit (18x27x9 cm) recording the total magnetic field value
- The cable transmitting the digital data from the sensor to the processor

Principle of the Proton Magnetometer EG&G GEOMETRICS G-856X

The EG&G GEOMETRICS G-586X is a classical proton magnetometer: the proton precession generates a signal recorded by the solenoid which has created the polarisation. The signal frequency is proportional to the intensity of the total magnetic field.

Precision on the Measurement
According to the manufacturer's specifications, resolution of this type of magnetometer is 0.1 nT in normal use conditions.

Magnetometers of the Chambon-la-Forêt Observatory
The measurements of the earth's magnetic field recorded at Chambon-la-Forêt have been used, along with the recordings from the Ault's station, to extract the external component of the magnetic field.
The determination of this external component, which has been performed with the same frequency cut-offs, leads to slightly different results depending on the reference station used. These results and implications are presented in paragraph 6.1.

Magnetometers Characteristics
Two proton magnetometers record the intensity of the earth's total magnetic field:

- A LETI magnetometer (CEA department of Grenoble) measures an instant value of the total field every second (this recording is kept for one month). A mean value per minute is then calculated, and it is this value which is retained, and which is used
- A GEM magnetometer is used as a control unit, and replaces the LETI in case of failure. The rate of the data acquisition is every 5 seconds

The recording of the X (North), Y (East), and Z (vertical) components is achieved through three fluxgate magnetometers working simultaneously: VFO-31, MAGNOLIA (TSA), and GEOMAG. The data acquisition is done every 5 seconds, and a mean value is then calculated each minute.
The recording of the absolute declination and inclination values is done at least twice a week by a DI-flux system.

Measurements Precision
Measurements precision is of 0.1 nT.

Data Acquisition

The following information come from the instruction report (ref 3), the report about the Baie de Somme survey (ref 4), and from information coming from the computer department of the SHOM (onboard systems).

Measurements at Sea
Measurements have been carried out during two periods from the hydrographic vessel LAPÉROUSE. The points are located on lines and perpendicular transverses. The crossing of the lines enables a control on the errors on the crossing points. Acquisition parameters of the marine magnetics measurements are also presented in this chapter.

Recording Periods
The recording periods at sea are also covered by recordings on land.

- First period: from Friday March 24, 1995 (03h50'00" U.T. to 22h17'59" U.T.) to Saturday March 25, 1995 (03h46'22" to 05h51'00" U.T.)
- Second period: from Saturday March 30, 1995 (09h13'39" UT) to Sunday March 31, 1995 (22h54'29" UT) and the Monday April 1, 1995 (00h09'41" UT to 22h21'49" UT)

The Profiles
The magnetic survey in the Bay of Somme has resulted In 17,449 points.
There are 107 lines regularly spaced every 100 m, with an orientation of N049°, which is roughly the

coastline direction. There are 8 transverse lines, with an orientation of 146°, crossing at regular intervals the main profiles, over the entire zone. There are 512 crossing points.

Acquisition Parameters

- Profile spacing: 100 m
- Leading cable: 150 m
- Vessel speed: 6 to 9 knots
- Acquisition rate: every 10 seconds
- Minimum distance between 2 points: 30.87 m
- Maximum distance between 2 points: 46.30 m
- Fish immersion: 1.5 to 2 m

Positioning Algorithm of the Sensor

The sensor placed in the towed fish takes a measurement every 10 seconds. While the value of the earth's magnetic field is recorded at the fish, the recorded position is the position of the GPS which is onboard. The positioning algorithm is necessary to calculate, from the GPS measurement, the actual position of the fish, taking into account the navigation parameters and the system geometry. This algorithm has been developed by the department onboard systems of the SHOM.
The algorithm is based on three main points:

- The reference point: which is the location point of the GPS onboard
- The hook point: which is the point at the vessel's stern, where the leading tow cable is connected
- The fish (or sensor): which is the point of measurement of the magnetic field

First of all, the position of the hook point is calculated from the reference point (1), then the position of the sensor is calculated from the hook point (2).

$$\begin{aligned} X_{croche} &= X_{réf} + L' \text{ sinus } (G' + Cap) \\ Y_{croche} &= Y_{réf} + L' \text{ cosinus } (G' + Cap) \end{aligned} \tag{1}$$

$$\begin{aligned} X_{poisson} &= X_{croche} + L \text{ sinus } (G + Cap) \\ Y_{poisson} &= Y_{croche} + L \text{ cosinus } (G + Cap) \end{aligned} \tag{2}$$

This algorithm gives an estimate of the sensor position with a precision of 20 m on the horizontal plane. All of the measurements done during the Bay of Somme survey have undergone the treatment of this algorithm by the department 'Systèmes embarqués', before being released to the geodesy-geophysics division.

Measurements from Land Station

On the contrary to the marine survey, the measurements at land come from a fixed point. The results are thus independent from the spatial variations of the total magnetic field, and thus give information on the temporal variations. The recordings are performed during recording periods at sea.

Ault's Station

Why had a magnetometer been installed at the Ault's semaphore, while the recording of the total magnetic field was available at the reference station of Chambon-la-Forêt?
The answer lies in the spatial variability of the external magnetic field (see 6.1). In fact, the transitory variations of the earth's magnetic field (due to solar activity) have different amplitudes at points located several hundreds of kilometres apart, because of meteorological reasons for example (different nebulosity...).

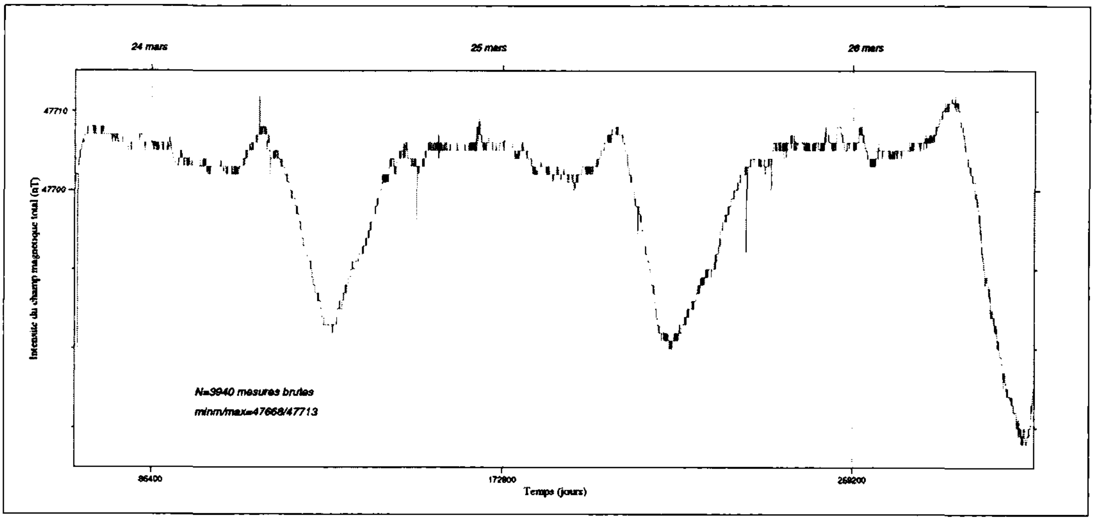


Figure 3: Magnetic measures from the Ault's station (from 23 to 26 March 1995), Raw data collected with a step of 60 seconds

The Ault's semaphore and the Chambon-la-Forêt observatory are more than 200 km apart.
Then, the magnetometer installed at the Ault's semaphore, nearest to the zone of study, should be more appropriate to correct the total magnetic field from the temporal variations affecting the results. This remark brings to note the 'local' character of the transitory variations.

Geographical Localisation
The geographical co-ordinates of the site are as follows:
Latitude: 50°06'19.68' North
Longitude: 001°27'16.782" West
Altitude: non determined

Recording Periods
The recordings are presented on Figures 3 & 4: the intensity of the total magnetic field measured (nanoTesla) is plotted against time.

- first period: from Thursday 23 March 1995 (18h47'00" UT) to Sunday 26 March 1995 (12h27'01" UT)
- second period: from Wednesday 29 March 1995 (15h48'00" UT) to Monday 03 April 1995 (07h55'00" UT)

Acquisition Parameters
The value of the total magnetic field has been recorded every 60 seconds.

Chambon-la-Forêt Observatory
Observatory Localisation
The observatory is located in the Parisian Basin, north of Orléans.
The geographic co-ordinates of the site are the following:
Latitude: 48.0126° N
Longitude: 02.1536° E
Altitude: 145 m

Recording Periods
The digital data of the 2 recording periods come from the observatory data base.

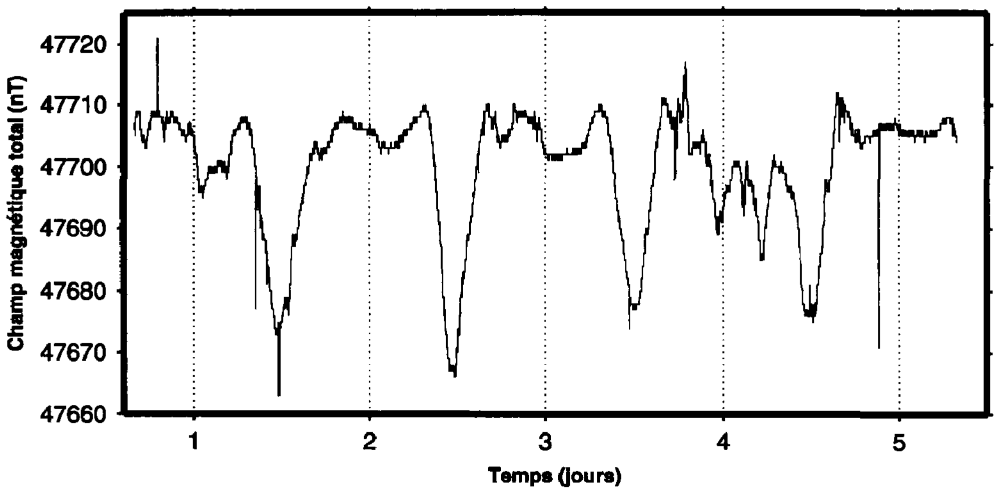


Figure 4: Ault's station: raw data collected at 60 s from 29 March to 3 April 1995

First period: from 23 March 1995 at 00 h to 26 March 1995 at 24 h, second period: from 28 March 1995 at 00 h to 04 April 1995 at 24 h.

Review on the Treatments of the Magnetic Measurements

The reduction method of the marine magnetic values as developed by the geodesy-geophysics division is composed of four main phases:

- Pre-treatment of the marine measurements
- Pre-treatment of the land measurements
- Adjustment of the land values to the marine values
- Calculation of the local field anomaly

Treatment Applied to the Marine Measurements

Two operations are applied on the marine magnetic values:

- Format definition for the software
- Determination of the internal field value: for each recording at sea (characterised by the geographic co-ordinates F and G, and the time of recording ti) is calculated the internal magnetic value. The model used is the International Geomagnetic Reference Field

Treatment Applied to the Land Measurements

- Cleaning: the recording of the total magnetic field includes noise induced by ambient phenomena, like any approach of a metallic mass (vehicle, plane,...). This noise is visible as spikes on the recordings, and these must be eliminated (figures 5 & 6)

Remark: for measurements at sea, it is not possible to distinguish the magnetic signal of a wreck from spikes of noise, (as points are taken every 30 or 50 m), so the values treated are the raw data.
This fact had been noticed on a first treatment of the marine data, which had been 'cleaned', and for which the magnetic field anomaly map had attenuated signals from wrecks and metallic obstructions.

- Interpolation and format definition: the elimination of spikes leaves out blank spaces in the recordings. The blank spaces are replaced by interpolated values. The interpolation method used is the cubic spline method. Moreover, the recordings on land are done every 60 sec., while the recordings at sea

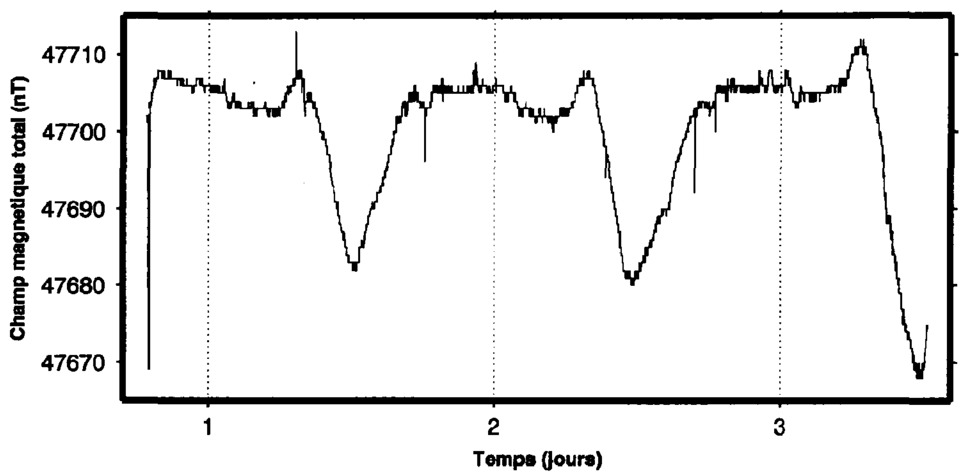
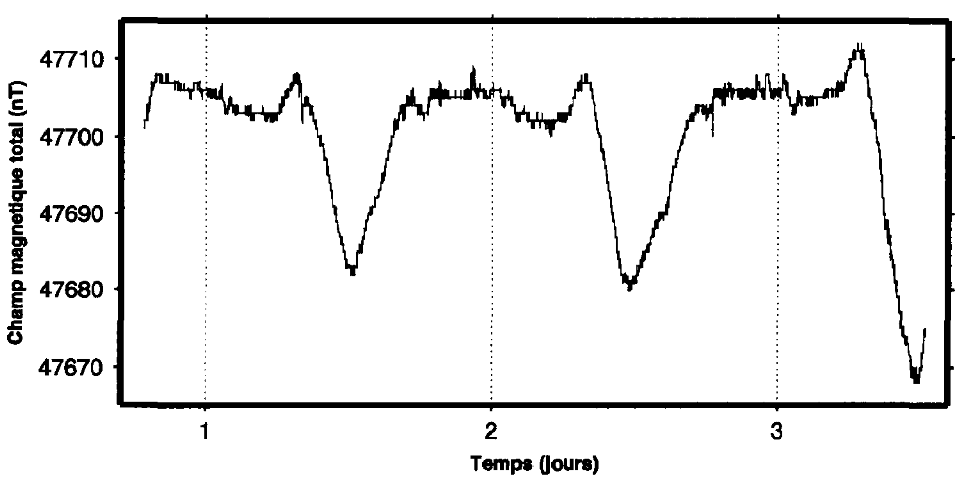


Figure 5: Ault's station:
a. Raw data collected at 60 s from 23 to 26 March 1995



b. Data after spikes removal and interpolation at 10 s from 23 to 26 March 1995

occur every 10 sec.. So, in order to homogenise the sampling rates with the sea recordings, the land measurements are interpolated every 10 sec.

- Filtering: separation of high and low frequency signals. For this operation, the following hypothesis has been retained: the diurnal variations of the marine affecting the marine measurements are the same as the ones affecting the land measure, at the same solar time. Once the diurnal variations recognised from the signal recorded at land, a low-cut filter is applied. This filter only lets out the part of the signal which has a period greater than 5 hours. The transitory variations of high frequency can then be isolated from the secular variations of low frequency (internal field).

Adjustment of the Land Measurements to the Measurements at Sea

This phase of treatment compares the time of acquisition at land and at sea (taking into account the time lag)

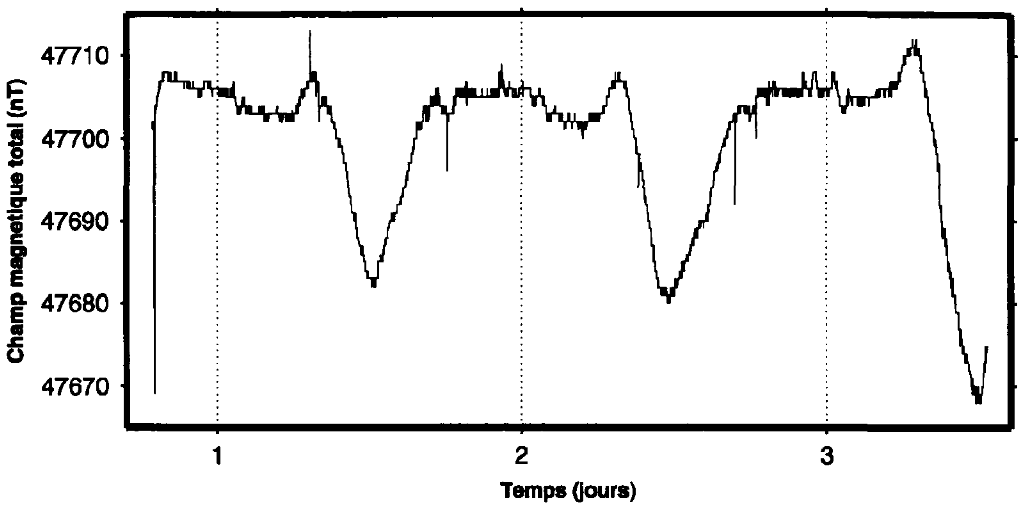
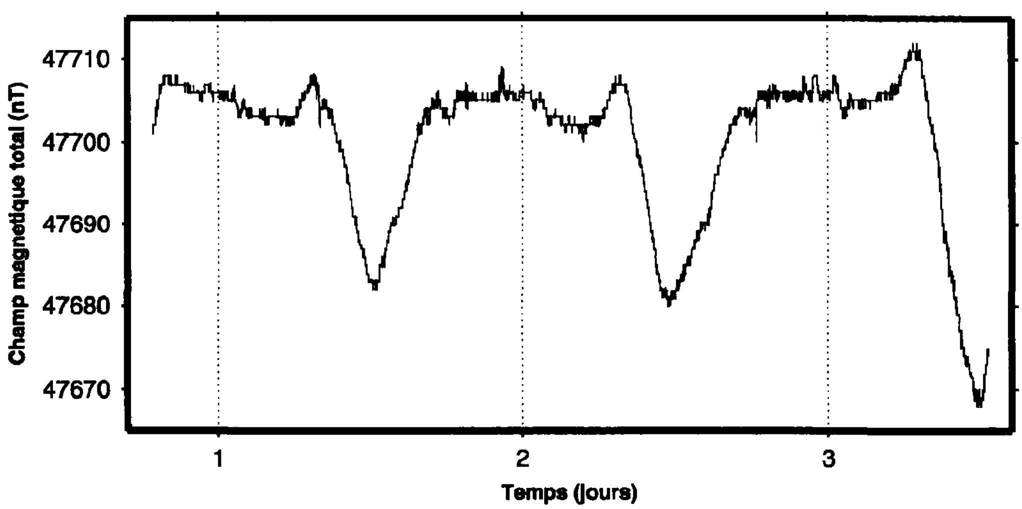


Figure 6: Ault's station:
a. Raw data collected at 60 s from 29 March to 3 April 1995



b. Data after spikes removal at 10 s from 29 March to 3 April 1995

Calculation of the Local Magnetic Anomaly

The magnetic field anomaly is then calculated as detailed in 1.3.

Comments

The magnetic survey in Bay of Somme has been conducted in two periods, which induced two successive steps of treatment.

Then, the two anomaly files obtained have been regrouped to make a single file, which has been used for two applications:

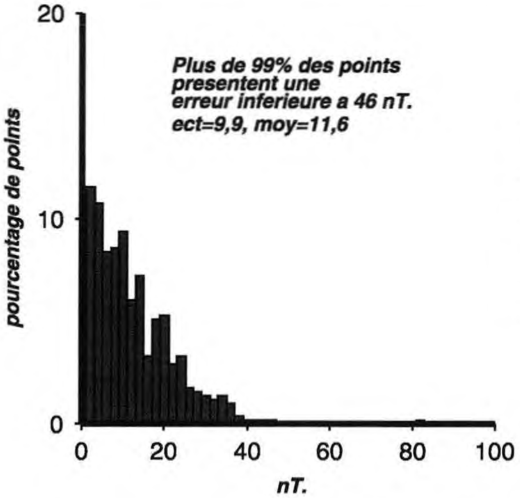


Figure 7: Corrected anomaly from IGRF (more than 99% of the points show an error inferior to 46 nT)

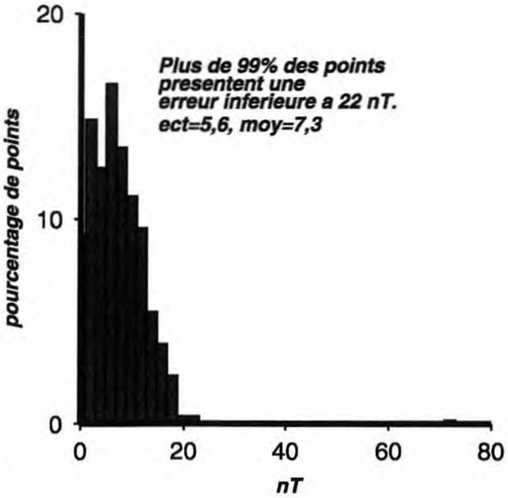


Figure 8: Corrected anomaly from Chambon-la-Forêt

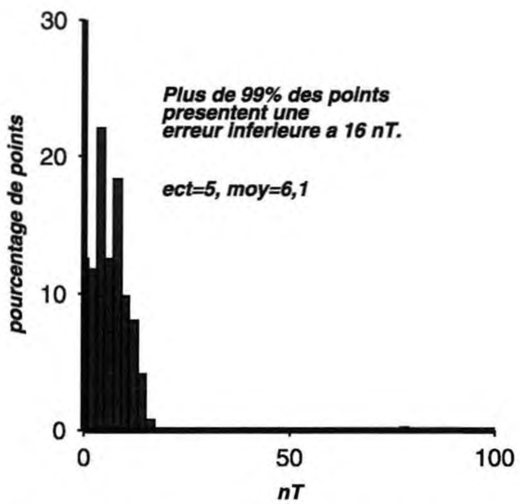


Figure 9: Corrected anomaly from ault's station

- The calculation of the errors on the crossing points, to estimate the precision of the measurements (see histograms)
- The drawing of the magnetic field anomaly map of the zone of study.

Results

This chapter presents the results obtained after application of the data reduction method described above. First, the 'cleaning' and interpolation phase is illustrated by Figures 3 & 4: these graphs provide information on the characteristics of the transitory variations. The diurnal component (daily variation) of

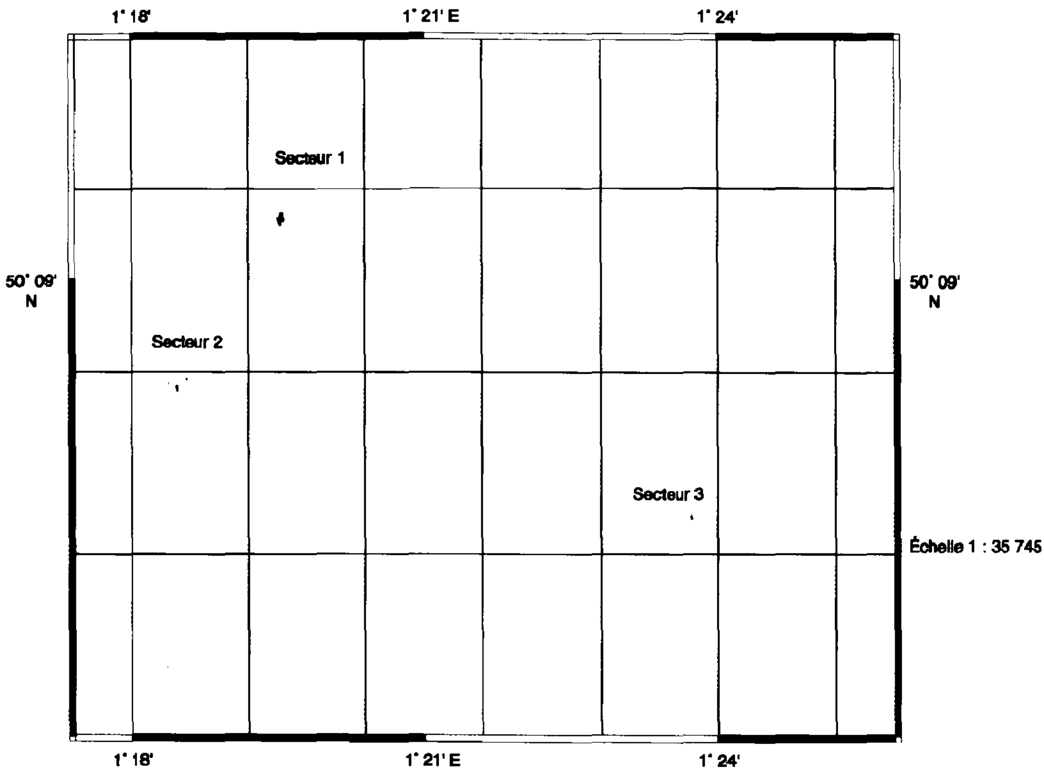


Figure 10: Magnetic anomaly in Bay of Somme: few variations (<3nT/km), except for 3 areas

the magnetic field is of the order of 25 to 45 nT during both recording periods.
Also, the agitation variations (ref 0) are weak (less than 5 nT) from 23 to 26 March, are more important (15 to 20 nT) from 29 March to 03 April 1995.

The Total Magnetic Field

The total magnetic field recorded over the zone of study has a mean value of 47,600 nT. The maximum values are essentially due to the strong anomaly (1,110 nT) detected.

The Magnetic Anomaly

The main objective of this reduction method of the magnetic measurements is to develop a precise map of the field anomaly characteristic of the zone.
The magnetic field anomaly has been determined following the three treatment variants, which are detailed above. For each of these variants, the error at the crossing points has been calculated.

The Error at the Crossing Points for the Field Anomaly

The error at the crossing points has been calculated for 3 cases:

- Case 1: anomaly calculation by removing the internal field value from the total field value measured at sea (Figure 7: histogram 1)

- Case 2: anomaly calculation after complete treatment using the Chambon-la-Forêt observatory as the reference (Figure 8: histogram 2)
- Case 3: anomaly calculation after complete treatment using the Ault's station to reduce the marine magnetic values (Figure 9: histogram 3)

Histograms Descriptions (table 1)
The three histograms present errors of the order of 72 to 82 nT on less than 0.5 per cent of the points. There are two possible reasons:
- First, the hypothesis that the land data represent the variations at sea (for the high frequencies) is not quite accurate, as the magnetic effect of the coasts and the filter effect of the water column should be taken into account
- Second, there can still be some errors on the magnetometer position at sea

	Histrogramme 1	Histrogramme 2	Histogramme 3
max	82.66 nT	73 nT	78 nT
mean	11.6 nT	7.3 nT	6.1 nT
σ	9.9 nT	5.6 nT	5 nT
skewness	0.18	0.1	0.19
kurtosis	-2.38	-2.8	-1.82

Table 1: Values of the errors at the crossing point

The three histograms are relatively symmetrical (small coefficient value). On the other hand, the flattening coefficient shows a significant variation between the two first histograms and the third one. This implies that the data treated from the Ault's station (histogram 3) have smaller errors (σ = 5 nT, at 99 per cent less than 16 nT) than the ones simply corrected pf IGRF, or reduced from the Chambon-la-Forêt values (at 99 per cent less than 22 nT, histogram 2, and 46 nT histogram 3), and dispersed around the 0 value.
Therefore, taking into account the temporal variations of the magnetic field for the corrections of the magnetic measurements decreases the error deviation of 9.9 nT to 5 nT, and concentrates the error distribution around the 0 value.
The difference between the reduced data from Chambon-la-Forêt and from Ault results mainly to a flattening coefficient and to a 99 per cent error value. For a deviation of 5 nT, the value of 99 per cent should be of 3 σ, meaning about 15 nT for the two histograms. This is not the case for histogram 2 (22nT>3σ). On the contrary, the reduced data from Ault are of greater quality (16 nT= 3σ). This difference is due to the fact that the temporal variations of the magnetic field in the chosen frequencies are better corrected for a station nearest of the study zone.
The residual error (histogram 3) seems to result from the greater distance between Ault and the zone, as well as from magneto-hydronamic effects.

Map of the Magnetic Anomaly in Bay of Somme
The general map of the magnetic anomaly in Bay of Somme (fig. 10) has been drawn with the data corrected as case 3. Four areas of strong magnetic gradients appear on this map (see 5.3). These gradients imply a strong spatial variation of the magnetic field induced by the presence of immersed metallic masses (also called sources), which lie on sandy bottoms.
The strongest mean gradient of the prospected zone is of 3.215 nT/km, along a N45 orientation.
The sandy bottoms on which, or in which, lie the sources are characterised by anomaly values of 50 to 80 nT. It is not possible, at this scale, to observe precisely and analyse the signal coming from each wreck, but only to position them. Thus, the following figures show a blow up of each of the four areas, and allow the analysis and interpretation of the anomalies facies.

Wrecks and Metallic Obstructions
In area 1 (Figure 11), a source creates a bi-polar anomaly, with a positive pole of 483 nT, and a negative

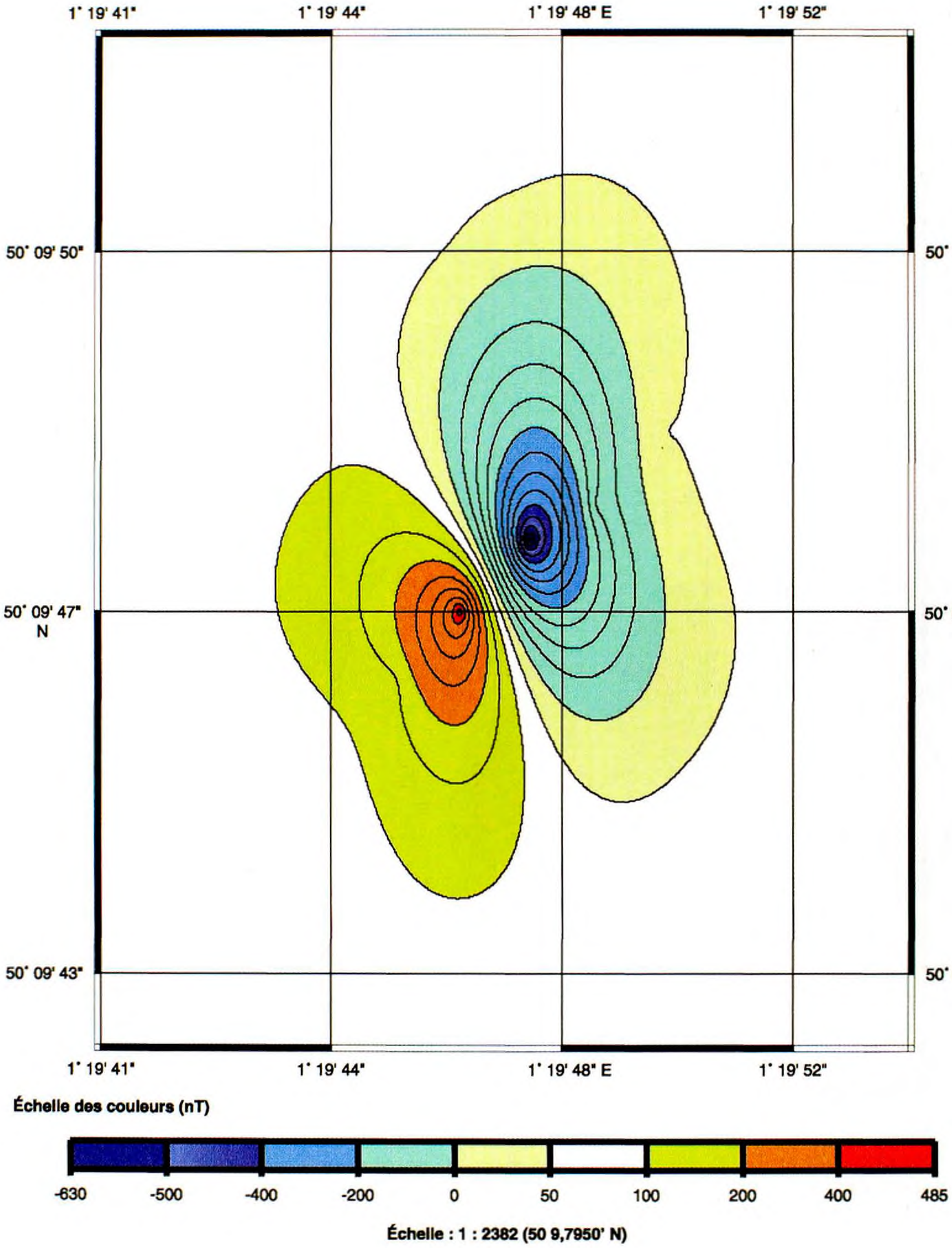


Figure 11: Magnetic anomaly of area 1

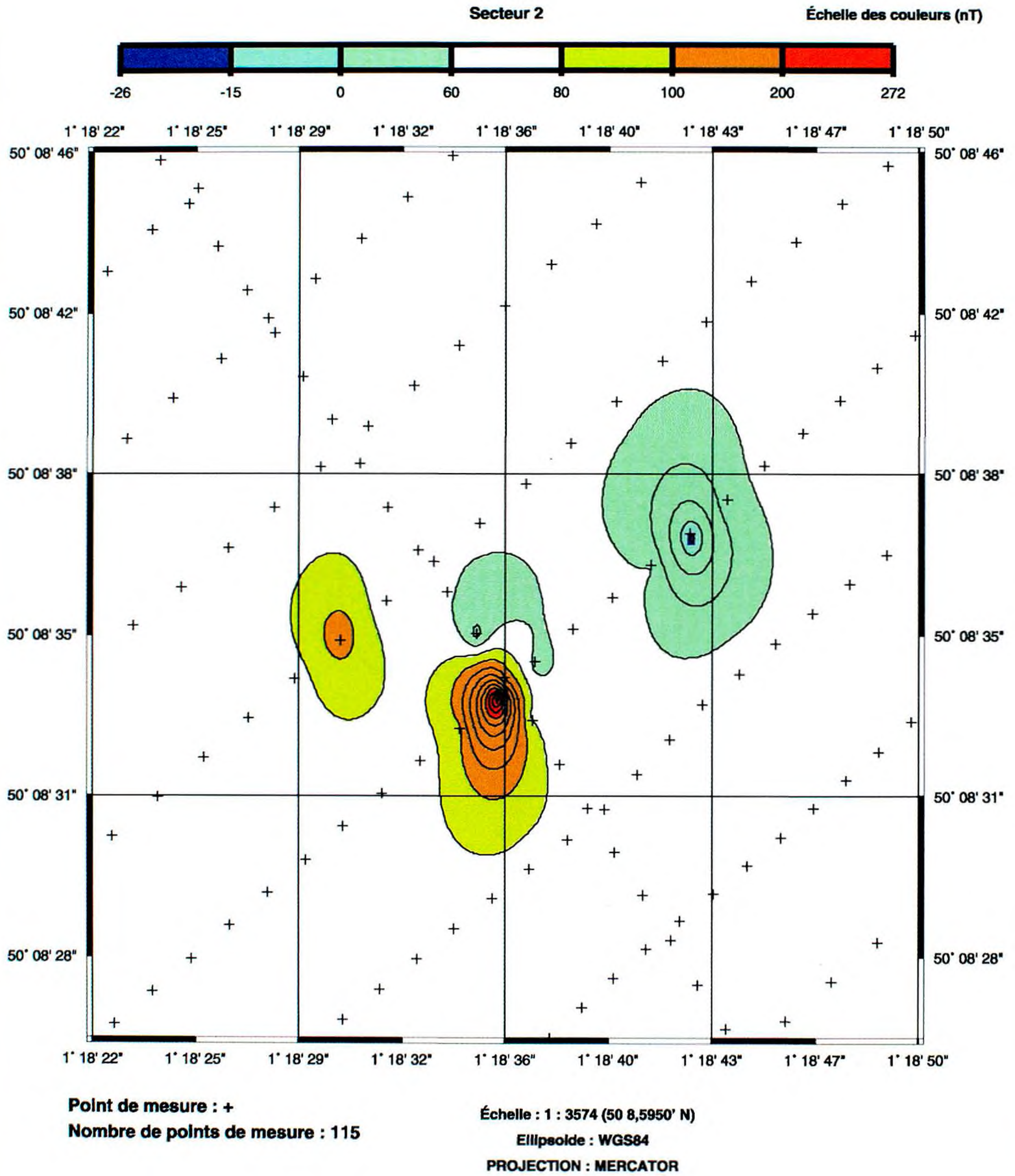


Figure 12: Magnetic anomaly of area 2

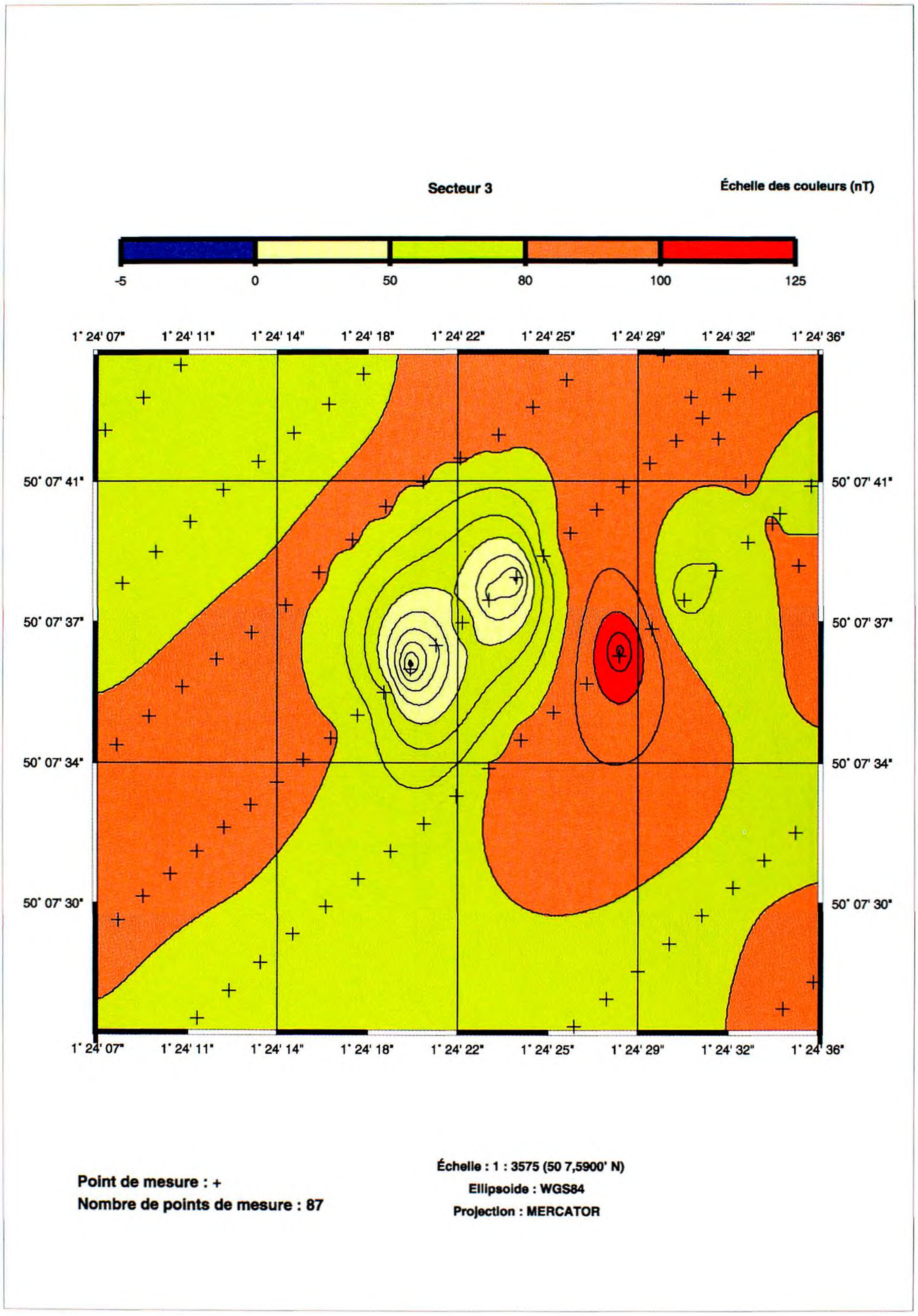


Figure 13: Magnetic anomaly of area 3

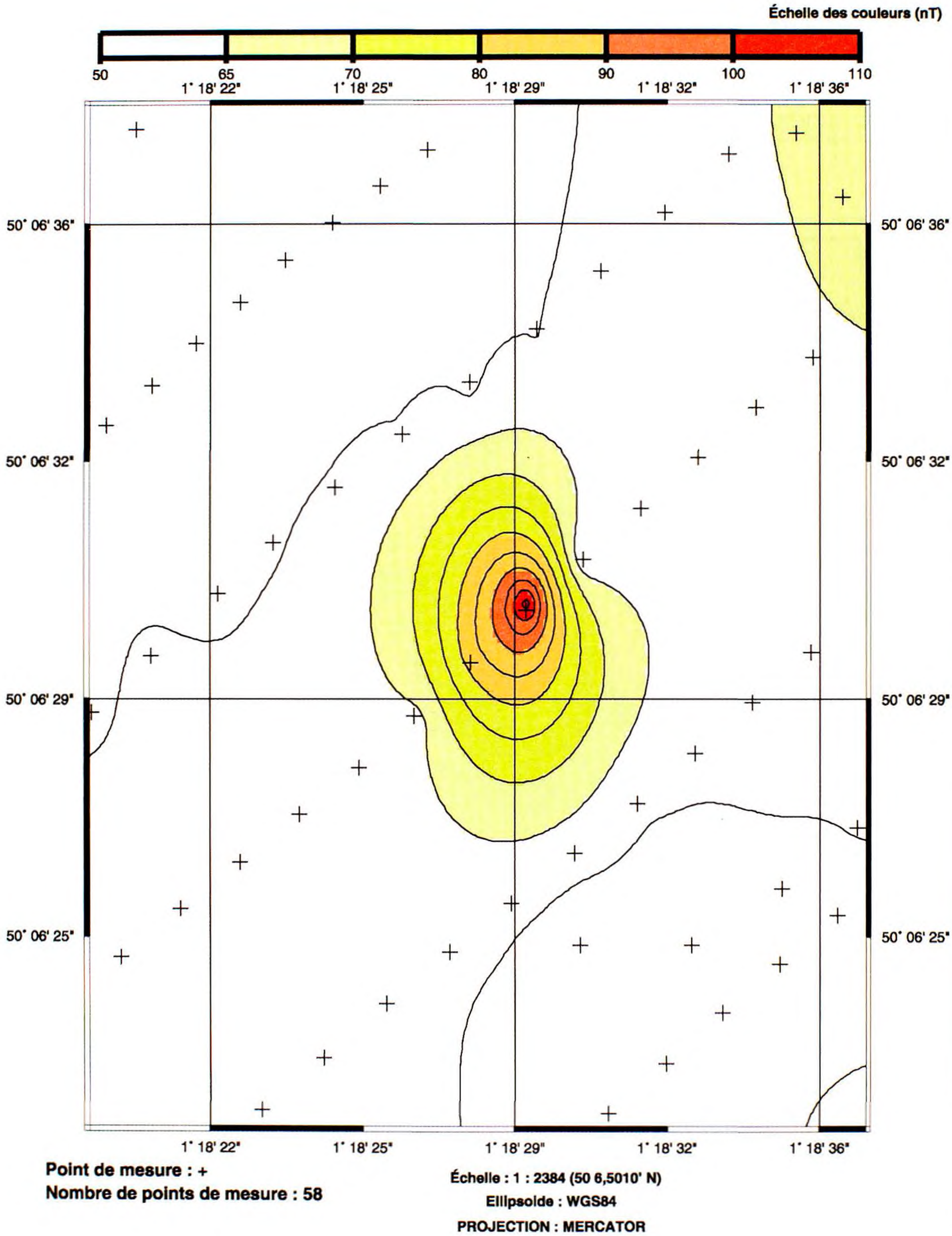


Figure 14: Magnetic anomaly of area 4

pole of –627 nT. The anomaly amplitude is then of 1110 nT. The mean gradient: 0.4 nT/m, is a thousand times stronger than the local magnetic gradient (see 5.2.2.).
In area 2 (Figure 12), the anomaly looks more complicated. The presence of two positive poles associated to two negative poles suggests the possibility of two close sources. Here the maximum amplitude is of 296 nT. Mean gradient: 0.3 nT/m.

The bi-polar anomaly of the area 3 (Figure 13) has an amplitude of 128 nT. The negative pole has a value of –4 nT, and the positive pole a value of 124 nT. Mean gradient:? nT.

Area 4 shows (Figure 14) a magnetic anomaly with only one positive pole (maximum value 108 nT). Mean gradient: 0.08 nT/m. This first approach of the anomalies will later be completed by studies which should determine the depth of burial of the source, the orientation, and the metallic mass.

Discussions

This reduction correction of the shallow marine magnetic measurements, using a land-based reference station, was new for the SHOM. So, the elements to compare, quantify, and qualify the expected results are lacking, meaning the field anomaly map and the precision.
However, the SHOM's experience in deep-sea magnetic surveys, and the bibliographic research, help to answer some of the questions brought up by the operators, the interpretators, and users of the field anomaly maps.

Chambon-la-Forêt Observatory or Magnetic Station?
Installation, maintenance, and supervision of a land-based reference station in the proximity of the zone of marine survey has obviously a cost. This cost is greater than the recovering of the file of the total magnetic field recording coming from a magnetic observatory, like the one of Chambon-la-Forêt. So, the economic question of a magnetic survey installation or not a land-based station should be approached! Three methods have been tempted to approach this question, drawing histograms for the errors at the crossing points, drawing the absolute value of the difference between the 2 high frequency signals (agitation variations), the spectral analysis of the two recordings (coherence and spectral density).

Histograms of the Errors at the Crossing Points over the Anomaly:
As described earlier, the histograms of the errors at crossing points over the anomaly show that the error induced by the reduction of the marine data from the land-based recordings is 6 nT smaller than the one induced by the data reduction from the observatory recordings.
These errors and percentages are calculated on the amplitude of the detected anomalies, and presented on table 2.
It may be recalled here that the values of 22 nT and 16 nT, respectively for Chambon-la-Forêt and Ault, are the maximum error values in 99 per cent of the cases.
So, the error on the anomaly is as big as the amplitude itself is small and as big as the land-based station is far from the zone of study.

Error on magnetic anomaly	Chambon-la-Forêt (22 nT)	Ault (16 nT)
Secteur 4: amplitude de 108 nT	20.37%	14.81%
Secteur 3: amplitude de 128 nT	17.19%	12.50%
Secteur 2: amplitude de 296 nT	7.43%	5.40%
Secteur 1: amplitude de 1 110 nT	1.98%	1.44%

Table 2: Errors at Chambon-la-Forêt and Ault

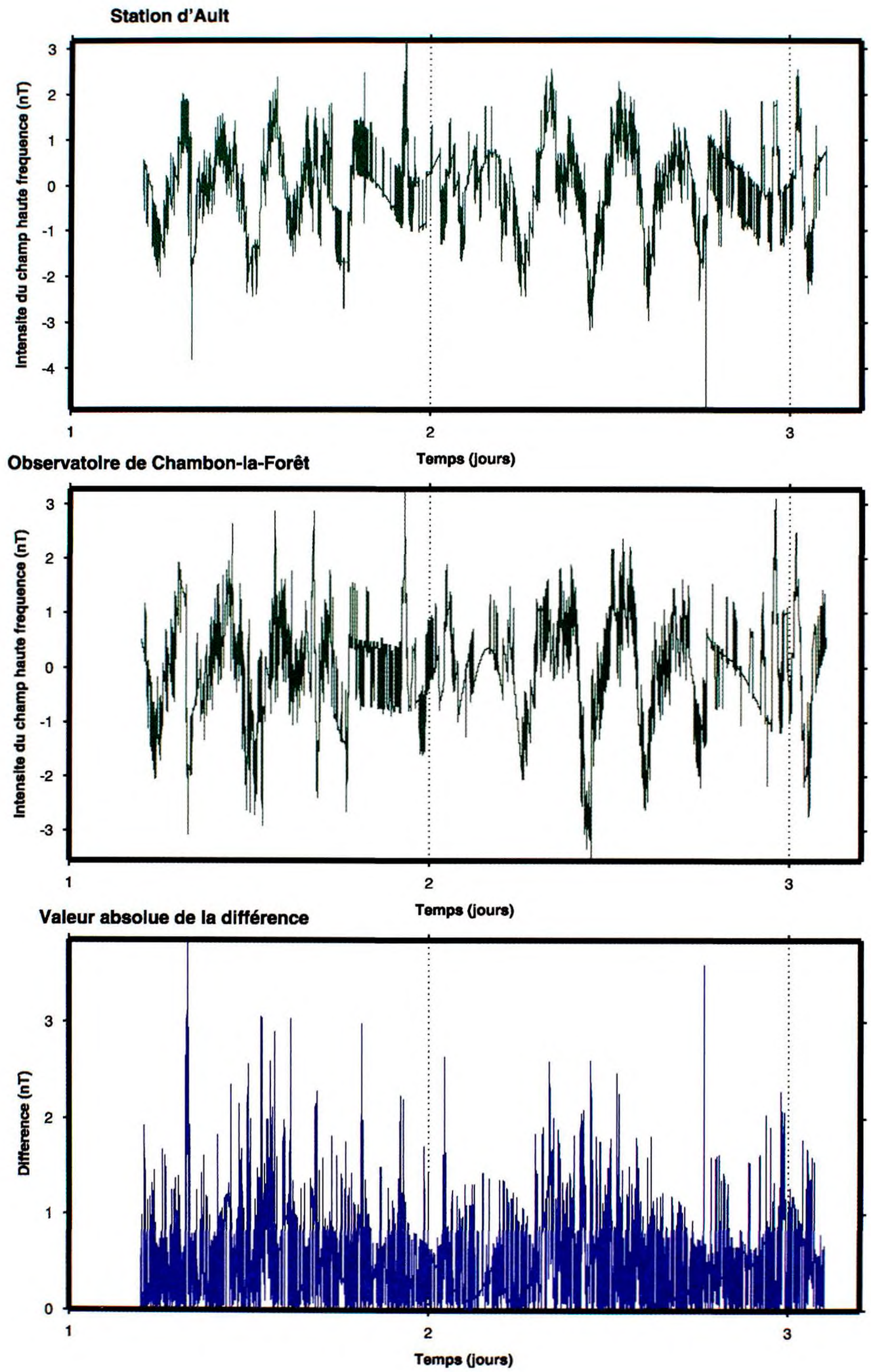


Figure 15: Comparison of the high frequency signals from 24 to 26 March 1995

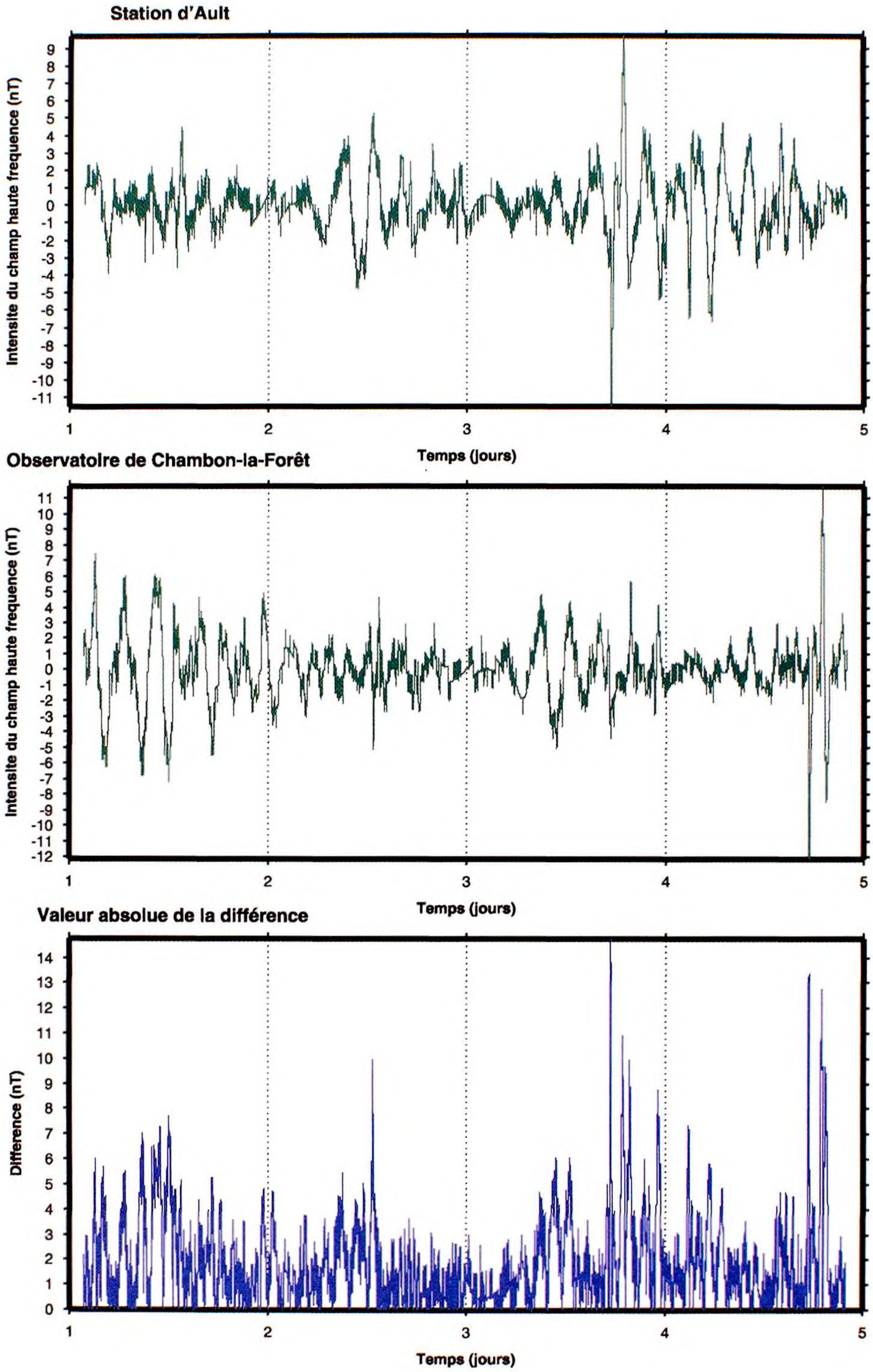


Figure 16: Comparison of the high frequency signals from 30 March to 2 April 1995

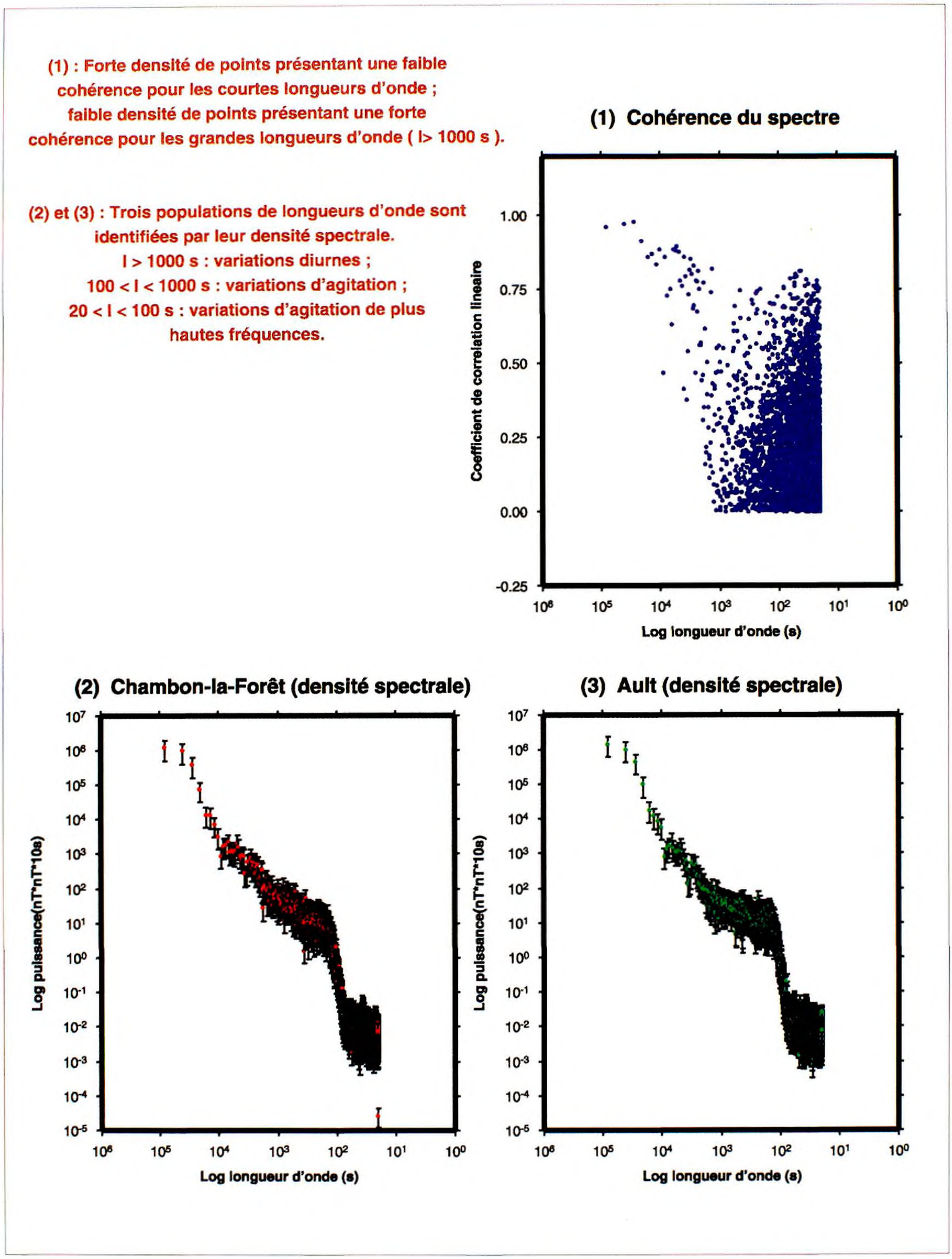


Figure 17: Spectral analysis of the total magnetic field : comparison between Ault and Chambon-la-Forêt

a. *Period 1: from 24 to 26 March 1995. High point density with a weak coherence for the short wave-lengths; low point density with a strong coherence for the long wave-lengths (l>1000s)*

b. *Three populations of wave-lengths are identified by their spectral density : diurnal variations, agitation variations, agitation variations of higher frequencies*

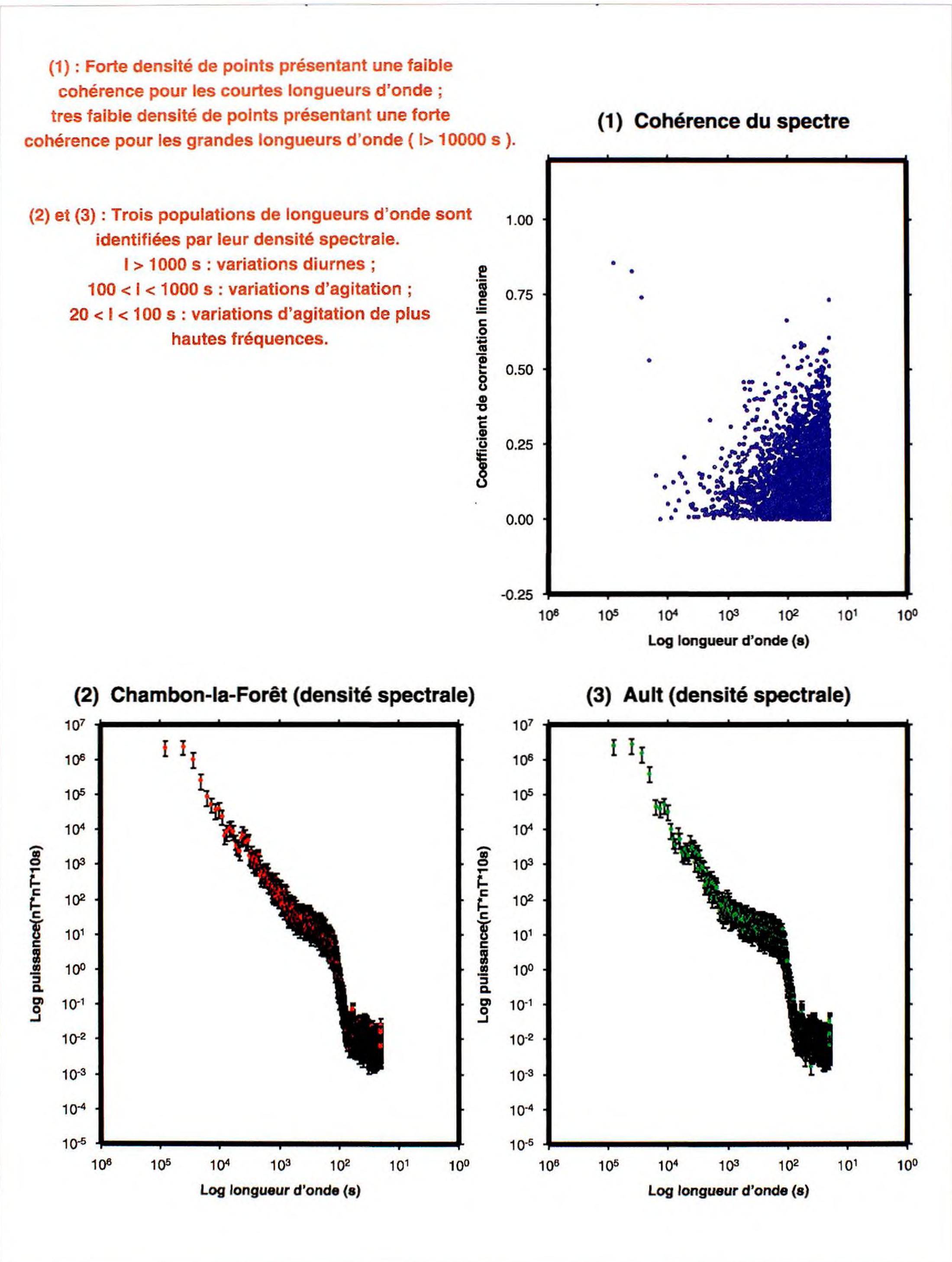


Figure 18: Spectral analysis of the total magnetic field : comparison between Ault and Chambon-la-Forêt

a. *Period 2: from 30 March to 2 April 1995. High point density with a weak coherence for the short wave-lengths; low point density with a strong coherence for the long wave-lengths (l>1000s)*

b. *Three populations of wave-lengths are identified by their spectral density : diurnal variations, agitation variations, agitation variations of higher frequencies*

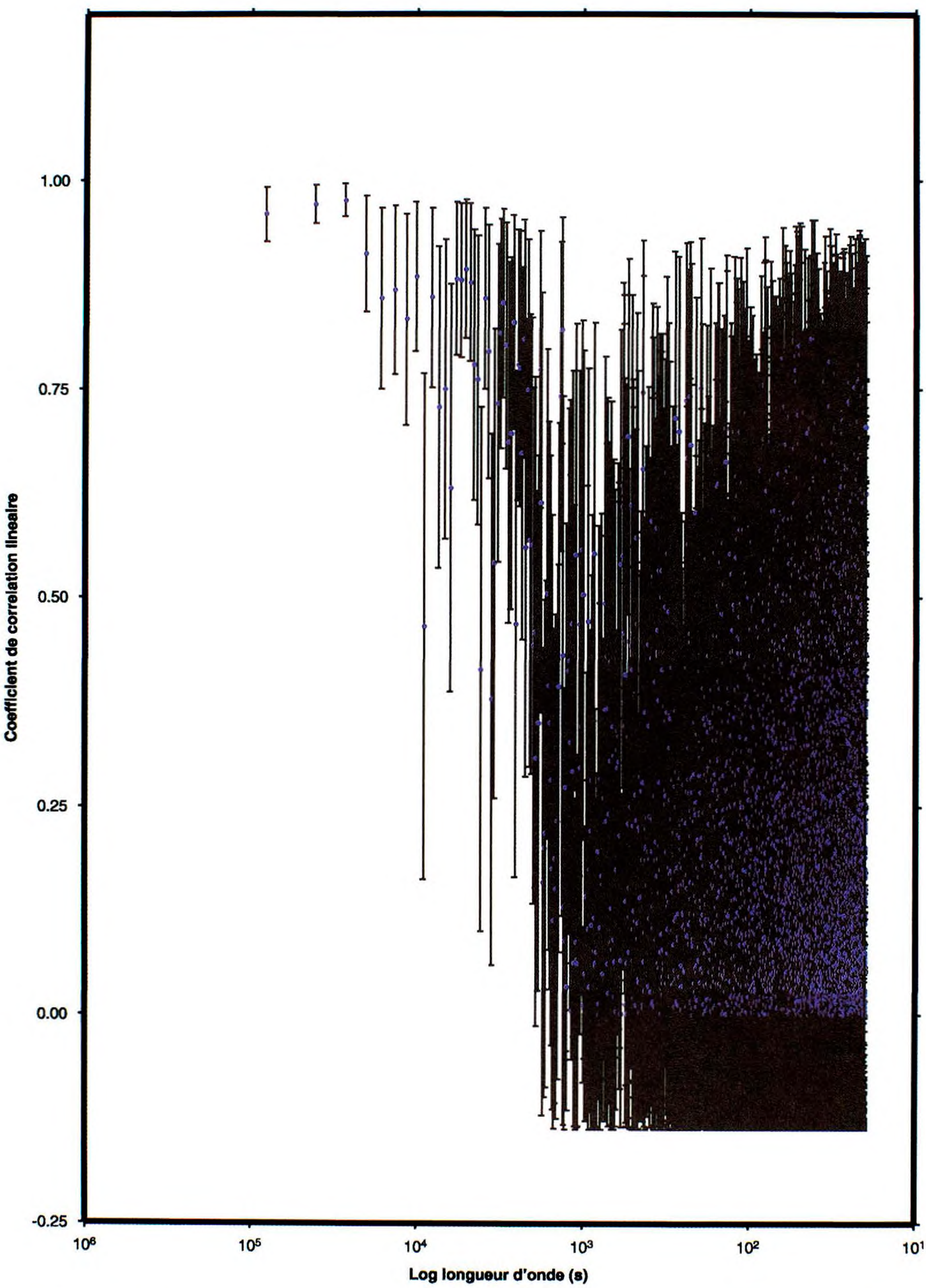


Figure 19: Spectral analysis of the total magnetic field: comparison between the Ault's station and the Chambon-la-Forêt observatory

Absolute Value of the Difference Between the Agitation Variations Recorded Simultaneously at Ault and at Chambon-la-Forêt:

To verify and illustrate the importance of the spatial variability of the external magnetic field, the high frequency signals recorded simultaneously at Chambon-la-Forêt and at Ault during the two periods of recordings are then compared (figures 15 & 16): if the two plots look roughly alike, the plot of the absolute value of the difference shows a lot of divergences. Then, the value of the difference between the two recordings can be equal to the value of the agitation variations.

Spectral Analysis of the Total Magnetic Field Recorded Simultaneously at Ault and Chambon-la-Forêt:

The spectral density of both recordings of the total magnetic field at Chambon-la-Forêt and at Ault, calculated separately, reveal three populations of wave-lengths composing the external magnetic field. There are wave-lengths greater than 1000 s (30 minutes), corresponding to the diurnal variations, wave-lengths between 100 and 1000 s (agitation variations) and wave-lengths between 20 and 100 s (higher frequencies agitation variations).

The spectral coherence is represented by the value of the linear correlation coefficient (number between 0 and 1) as a function of the logarithm of the wave-length. This coherence allows the comparison between two series of measures and the estimate of the differences. The correlation coefficient is equal to 1 when the two series are identical, and equal to 0 when the two series do not have any similarities. Figures 17 & 18 indicate that, for each of the two series of measures done simultaneously at Chambon-la-Forêt and at Ault, the recordings are very poorly correlated (correlation coefficient < 0.3 in most of the cases).

Figure 19 is an enlargement of the spectral coherence representation of Figure 17, on which have been superimposed the error bars: it appears then that the uncertainty on the linear correlation coefficient decreases when the wave-length increases.

The spectral analysis of the total magnetic field shows that the recordings at Ault and at Chambon-la-Forêt have a lot of divergences, mostly for the short wave-lengths. Now, the purpose of the land station is to subtract the external magnetic field to the total field measured. The wave-length limit to separate these two components is of 5 hours, or 1.8 10^4 s. And the spectral coherence indicate that the correlations between the recordings at Ault and the recordings at Chambon-la-Forêt are mediocre above this wave-length limit!

This study confirms the importance of the spatial variability of the external magnetic field and illustrates the necessity of a station in the nearest proximity of the marine survey zone, to get the best approach of the field anomaly.

Positioning of the Sensor

As explained earlier the position of the sensor towed behind the vessel is calculated by an algorithm. This algorithm takes up the navigation parameters, the length of the leading tow cable, the point of hook, and the reference point.

Integration of these different parameters introduces a final error of the sensor position of the order of 20 m in a horizontal plane.

Error Associated to the Position of the Fish

The strongest magnetic gradient calculated over the zone, along a direction of N45, is of 3.215 nT/km. Thus, with an error on the position of 20 m, the maximum error associated is of 0.064 nT (20x3.215 x 10^{-3}).

On the covered zone, outside the areas of anomalies, the field anomaly varies between 55 and 85 nT. The maximum error associated to the error in the fish position (0.064 nT) is then around 0.075 per cent to 0.0116 per cent of the anomaly value. This error can be considered as negligible.

However, in order to improve the precision on the positioning of the sensor, it would be interesting for example to place a positioning system (radar reflector, for example) at the vertical from the immersed sensor. This type of lay-out is already used by geophysical services companies (Compagnie Generale de Geophysique) during seismic reflection surveys (to position the streamer).

Compatibility between the Magnetic Measurements and the Hydrographic Survey

The magnetic survey in Bay of Somme has yielded the acquisition of 17449 points. The magnetic anomaly map,

resulting from this study, has revealed four areas of strong magnetic anomalies (from 108 nT to 1110 nT). Moreover, the error calculations on the crossing points give an estimate of the precision of 5 nT (deducted from the standard deviation: σ) on the determination of the anomaly. Which is relatively small compared to the amplitude of the anomalies.
Thus, the acquisition of magnetic data during hydrographic surveys can yield to satisfying results.

Improvement on the Resolution and on the Precision
The resolution is defined in the spatiality. It could be improved by adapting the spatial coverage to the marine measurements, as a function of depth.
The precision is illustrated by the standard deviations on the differences found at the crossing points. The smaller the standard deviation, the better the precision. Thus, the example of the Bay of Somme shows the standard deviation on the divergences is reduced by 50 per cent if the land-based station used for the temporal variations is near to the zone of study. Moreover, the residual magneto-hydrodynamic effects (σ = 5 nT) could be reduced by using a reference station located in the centre of the zone of study.

Conclusion and Perspectives

The shallow-water magnetic survey in the Bay of Somme has demonstrated that the simultaneous acquisition of sedimentological and magnetic data during hydrographic surveys gives results of good quality. However, if the reduction method of the magnetic measures is effective, it is still possible to improve the techniques for the detection of metallic masses on sea-bottom (small-size objects, cables, ...). This improvement could notably be by modifying the conditions of marine data acquisition:

- It would be advisable to find a compromise between the speed of the hydrographic vessel and the frequency of the data acquisition, in order to reduce the sampling steps to at least less than 30-45 m. Of course, it should be adapted to the size of the searched objects
- The position of the fish should be improved
- Recent studies of the LETI (ref 5) indicate that the system sea-water/marine sediments would act as a filter, which according to the various conditions (sediments conductivity, thickness of the sedimentary strata, morphology of the platform, ...), attenuates or enhances the recorded signal ('coast effect'). But, the coastal stations used (Ault, les Azores) do not allow the quantification this filter effect of the marine environment. So, it would be interesting for future surveys to immerse a magnetometer in the centre of the zone of study, in order to subtract this filter effect

Otherwise, studies leading to the determination of the burial depth of the magnetic sources, and to the contour definition of the metallic masses are in process. The results of these new developments should enable to complete the phase of detection of wrecks and metallic obstructions in shallow waters.

Biography

In 1988 Dr Marie-Françoise LeQuentrec-Lalancette worked with the Phd Thesis of the University of Brest (France) in geophysics in the IF REMER geosciences department on magnetic studies. Her research was specially on the 3-D inversion of deep tow magnetic data on the Atlantis II deep (Red Sea). These modelisation contribute to hydrothermal and geodynamic interpretation in the Red Sea.
In 1989 She was research assistant at the University of Quebec In Montreal (UQAM – Canada) in the GEOTOP labo where she worked on geophysical modellisation (thermal modelisation of the continental crust – Canadian LITHOPROBE Project – gravity and magnetic modelisation). She began academic teaching to bachelor program at the UQAM in geophysical prospecting.
From 1990 Dr LeQuentrec-Lalancette worked in charge of geophysical studies in the Service Hydrographique and Oceanographique de la Marine (SHOM) in Brest (France). She is supervising a small

team on gravity and magnetic potential field. They work on geophysical data mining, geophysical marine data acquisition, processing and modelisation. Dr LeQuentrec-Lalancette is teaching geophysic in various educational program: school engineer, school of the Navy, school of hydrography.