High resolution vector magnetic measurements onboard deep-sea vehicles: methodology and examples

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Purpose:

High resolution marine magnetic data are required to investigate the structure and age of the oceanic basement at a detailed scale. The basaltic crust not only retains the geomagnetic field polarity at the time of its cooling below the Curie temperature of (titano)magnetite, but is also a trustable recorder of geomagnetic intensity, allowing high resolution dating of the seafloor using intensity variation patterns recorded in the seafloor. Such studies can be achieved with a magnetometer attached to a deep-sea vehicle. Such vehicles usually navigate a few meters to tenths of meters above the seafloor and provide a higher resolution than deep-towed systems, navigated a few hundred meters above seafloor. However, these vehicles generate a magnetic field that have to be estimated and their effects corrected on magnetic data.

Estimation of the vehicle magnetic field

* The magnetic field measured by a magnetometer onboard a carrying vehicle is :

$$\vec{H}_{obs} = \vec{F} + \vec{H}_i + \vec{H}_p$$

with $\vec{H}_{obs}$: observed magnetic field

$\vec{F}$: ambient magnetic field

$\vec{H}_i$: induced magnetic field of the vehicle

$\vec{H}_p$: remanent magnetic field of the vehicle

$\}$ $\vec{H}_{vehicle}$: vehicle magnetic field, $\vec{H}_{vehicle} = \vec{H}_i + \vec{H}_p$

* $\vec{F}$ is assumed to be the IGRF (Fig. 1).

$\vec{H}_p$ is invariant in vehicle coordinate system.

$\vec{H}_i$ varies in amplitudes and in directions in vehicle coordinate system.

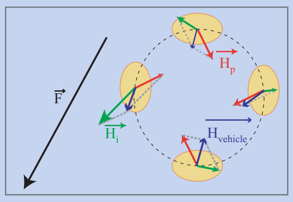

Fig. 1: Vehicle rotation in ambient magnetic field

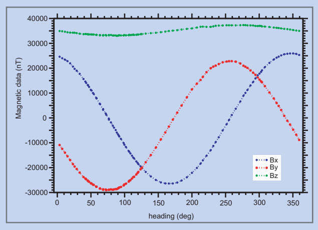

Fig. 2: Magnetic data during a calibration loop

$\Rightarrow$ $\vec{H}_p$ and $\vec{H}_i$ are estimated with a least-square method and using magnetic data acquired when the vehicle rotates.
(Further, such data are called calibration loop data.)

Application on data

The calibration method is tested on real data, acquired with a Remotely Operated Vehicle (ROV) or a manned submersible.

We estimated the vehicle magnetic fields (H_p and H_i) from the calibration loop data.

If the magnetic fields of the carrying vehicle is well-estimated, the corrected magnetic field from the calibration loop data should be close to the ambient magnetic field approximately.

Results obtained on data acquired on ROV

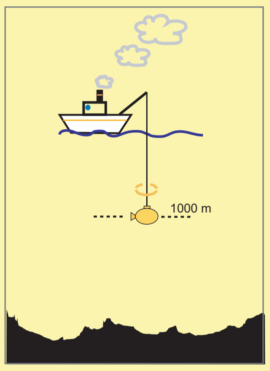

Fig. 3: Acquisition configuration with a ROV

The ROV is attached to the mother ship with a cable. Calibration loops are rotations carried out at a given constant depth. (Fig. 3)

We use calibration data acquired:
* at the RAINBOW site, Mid-Atlantic Ridge (36.20°N, 34°W)
* at 500 m, 1000 m and 1500m from the sea surface

The IGRF at the survey area was:

X_{igrf} = 25 290 nT

Y_{igrf} = - 6 271 nT

Z_{igrf} = 34 630 nT

The magnetic field obtained after the correction of the ROV magnetic field is almost constant and close to the IGRF (Fig. 4).

$\Rightarrow$ The calibration method estimates properly the remanent and induced magnetic field of the ROV.

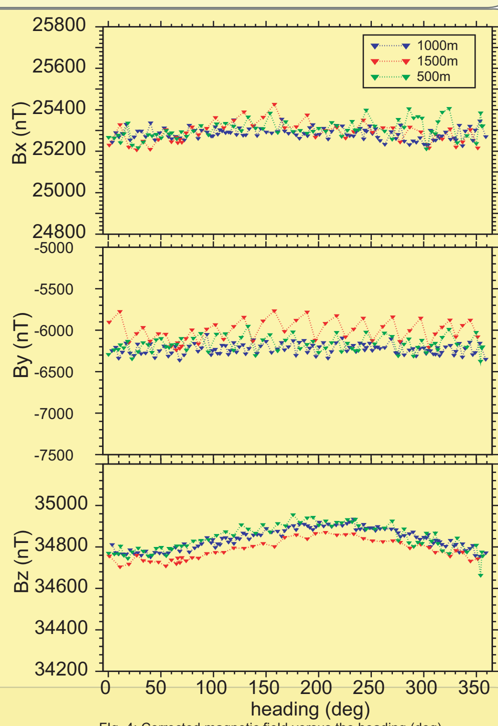

Fig. 4: Corrected magnetic field versus the heading (deg).

Results obtained on data acquired on manned submersible

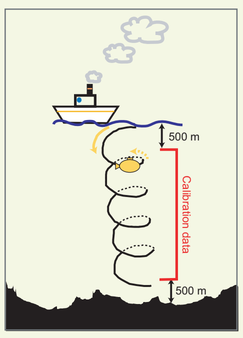

Fig. 5: Acquisition configuration with a submersible

During the descent, the submersible motion is not strictly vertical but describes about 12 helical loops. (Fig. 5)

The IGRF at the survey area was:

X_{igrf} = 23 500 nT

Y_{igrf} = -7 500 nT

Z_{igrf} = -32 070 nT

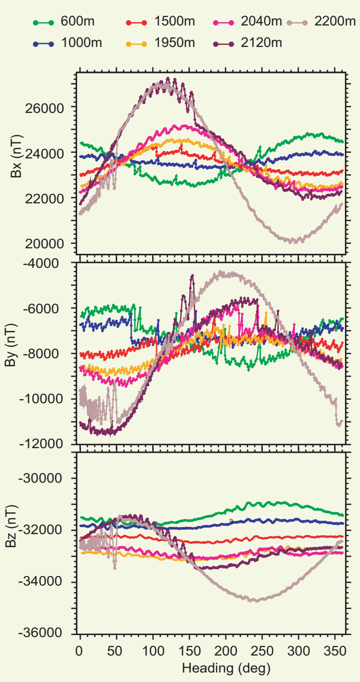

Fig. 6: Magnetic data corrected with submersible magnetic fields estimated with all calibration loops data together.

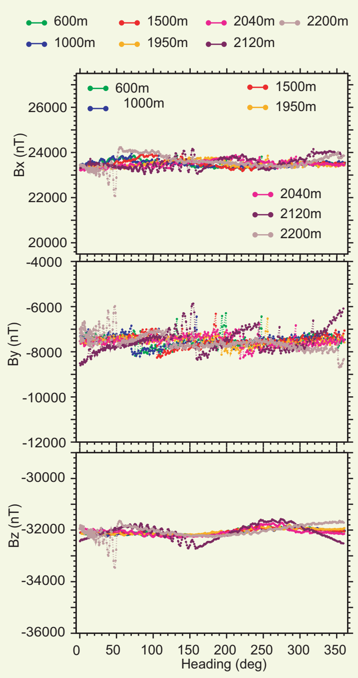

Fig. 7: Magnetic data corrected with submersible magnetic fields estimated with one calibration loop data at once.

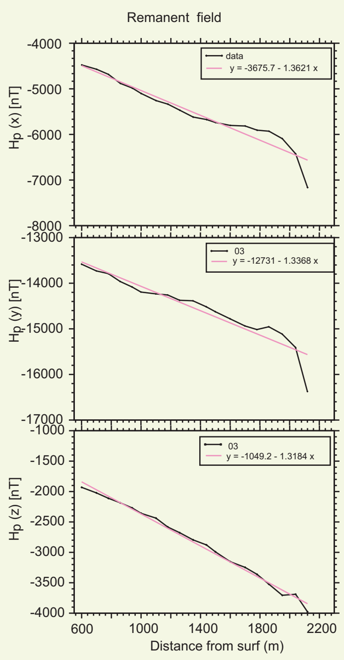

Fig. 8: Remanent magnetic field H_p of the submersible against depth

First, the magnetic effect of the submersible is estimated with all calibration loops data together.
The resulting corrected magnetic field still depends on the heading and depth. The magnetic data are not well-corrected (Fig. 6)

Then, the magnetic effect of the submersible is estimated for each calibration loop separately. The corrected magnetic field is close to the ambient magnetic field (IGRF): the submersible magnetic effect is well-estimated. (Fig. 7)

In order to explain the difference between both results, we check the variation in depth of the submersible magnetization.
The remanent magnetization of the submersible varies linearly with depth, whereas the induced magnetization does not significantly vary (Fig. 8).

Conclusion:

For the ROV, the calibration method well-estimates the ROV magnetic field.
For the submersible, the remanent magnetic field of the submersible varies linearly with depth.
The linear dependence of the submersible remanent magnetization is not clearly understood but its effect has to be taken into account to properly correct the magnetic data collected with a submersible.