

Modeling of turbulent wake of surface vessel and measuring its induced magnetic field

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In this paper, the magnetic field induced by the turbulent wake of a vessel was measured and were compared with the results of modeling and calculations. It contains two essential steps: the first stage of solving the Navier-Stokes equations using Open Foam model and the second step measures the magnetic field induced by the vessel and calculation. two types of waves were studied in this paper, firstwind-driven wave and other turbulent wakes of vessel. Depth varied area in spring and winter measurements were performed. Both the turbulent wake velocity vector and magnetic field are expressed as superposition of sinusoidal waves. Modeling and measurement results show that the magnetic fields produced by wind waves or a typical size body moving at moderate speed are on the order of Nano-Tesla near the sea level depends on vessel speedand physical properties of seawater.

[Keywords: magnetic field, turbulent wake, modeling, OpenFoam]

Introduction

In the turbulent case the wind induced surface wave amplitude are comparable by the turbulent wakes induced waves and it's graphs have been brought. Frequencies are produced by the both sources was extracted using MATLAB software & FFT.

Turbulent wake of a vessel is uniqueness in terms of the characteristics of acoustic, optical, resistance, magnetism, temperature and other physical parameters¹. And we can use it to attack a specific vessel or to identify and assess the situation of it.

The sea waves are combination of several sine waves, so to simplify the equations of wind are comparable by the turbulent wakes induced waves and it's graphs have been brought.

Weaver has modeled magnetic field induced by a sinusoidal surface wave and showed that the magnetic field is proportional to the amplitude and frequency of surface wave².

Sanford showed that the vertical average speed and electrical conductivity are important in shallow water³.

Podney proved that the electromagnetic field generated by an ocean wave in the stratified ocean can be described as a total of three fields of electrical, magnetic and electrostatic. That shows the importance of vertical component of current⁴.

Tuckt has conducted some investigations this case, especially for vessels moving in the water⁵.

Zou and Arye studied on detection method of turbulent-induced magnetic field using aerial magnetic transducers^{6,7}.

Yaakobi and Zilman⁸, Madurasinghe and tuckt⁹ have studied on detection the magnetic field caused by surface / under water moving vessels.

In this paper, we modeled the turbulent's wakes of surface vessel and also measured the magnetic field of wind driven waves and the wakes induced magnetic field.

We observed that turbulent wakes induced waves is inducing changes greater than the magnetic field of Wind-induced wave. Wind-induced wave is a wave that is shaped by the wind and grows. Usually the period of the waves is between 1 to 30 seconds¹⁰.

Materials and Methods

The study region has been situated in the Strait of Hormuz and the Gulf of Oman (figure1). The study area of field measurement has been limited between 56° 22' E - 56° 27' E and 26° 50' N -26°54'.

For field measurement of magnetic field of wake induced we used these facilities: the surface vessels with several different sizes and speeds;

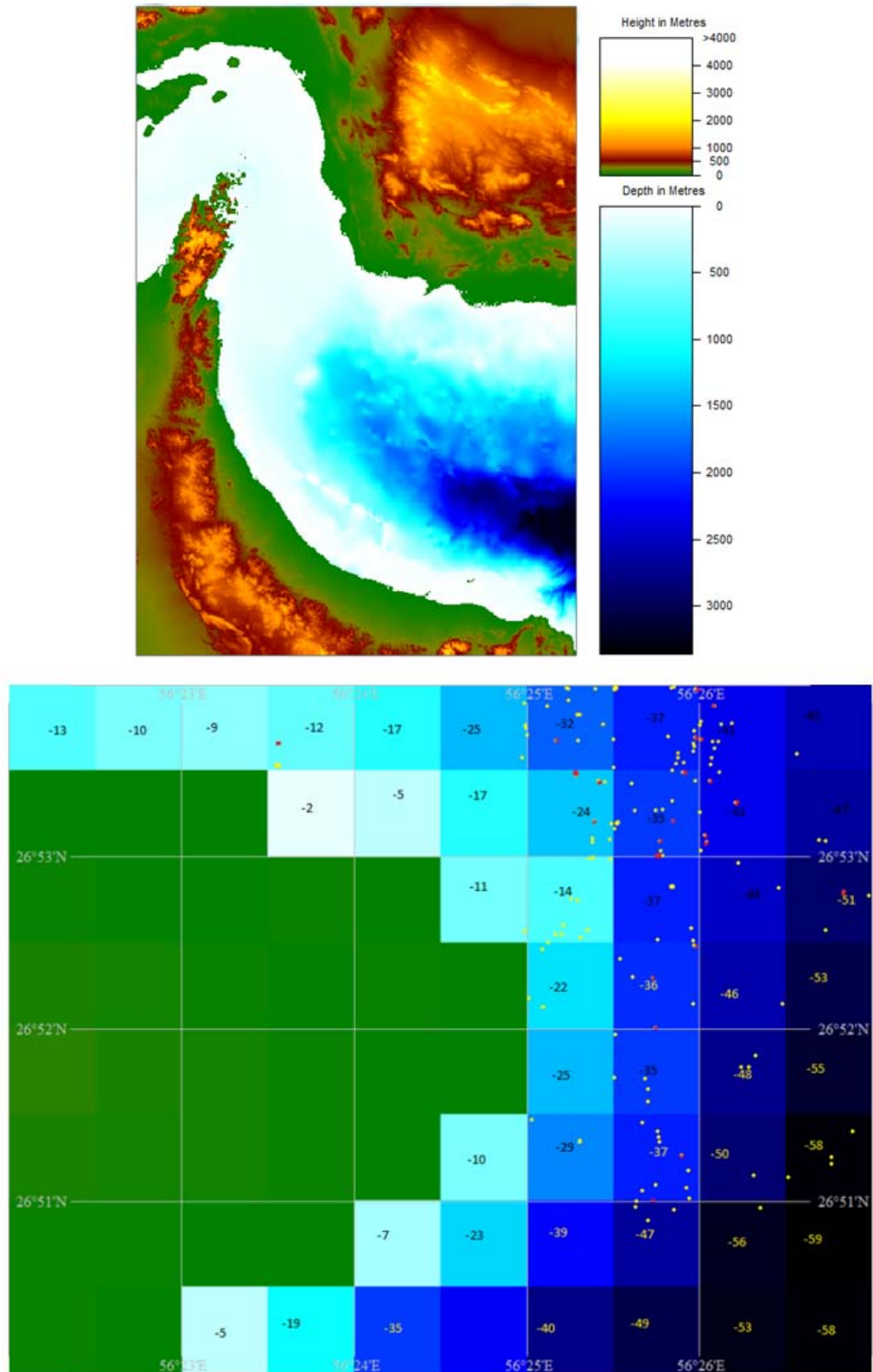


Fig. 1 —The study region (up) and measurement cells(down)

Tow fish magnetometer. (With 100 pico-Tesla at a distance of 30 meters).

A GPS with sampling rate frequency 4 Hz: recording the location and time data and speed.

Sealink Software ; which provides an interface for data recording and displaying the diagram;

Since the purpose of measurement is turbulent wake induced magnetic field, the magnetometer was situated in the middle of wake in depth about one meter from the water surface (figures 2 and 3).

The measurement has been done in various times and using various vessels with different size and speed. The vessel speed varies between to 20 knots (figure 4).

The measurements were carried out during two periods: May and June 2013 and date february 2015.

At first the inappropriate data was filtered.

In figure 5 shown an example measured data related to the turbulent wake induced magnetic field and wind-induced waves (which is a few Nano Tesla) and geographic magnetic field (about 44800 nt).

Two steps should be taken to evaluate the magnetic field of the sea current or turbulent wake of vessels. First, find finding the velocity of the fluid by using the Navier-Stokes equations and finding the speed of sea currents or waves¹². The second stage is the solution of Maxwell's equations under the ocean condition.

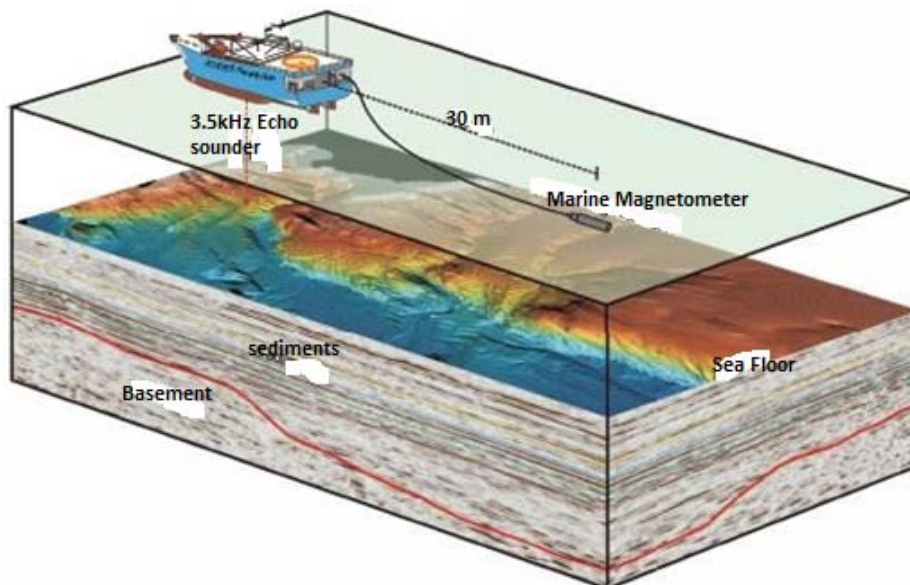


Fig. 2 — Measurement equipment and facility configuration

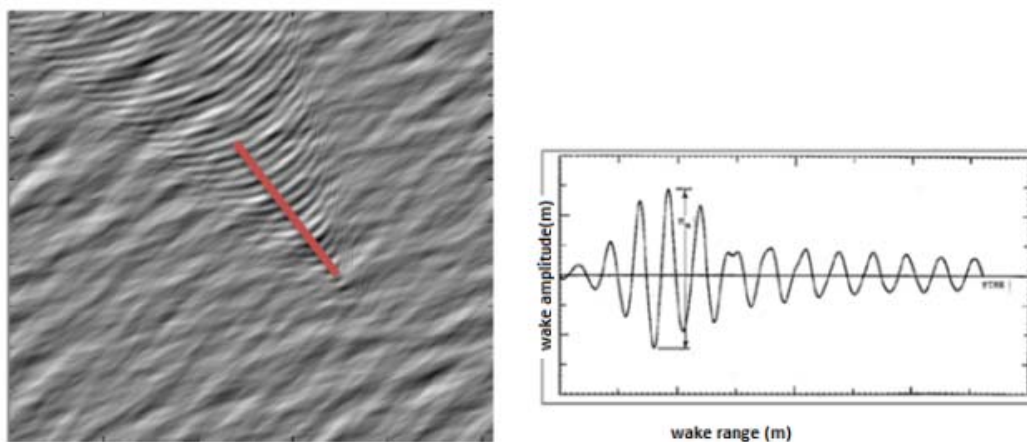


Fig. 3 — The location of magnetometer (the red line .left), amplitude of turbulent wake (right)¹¹

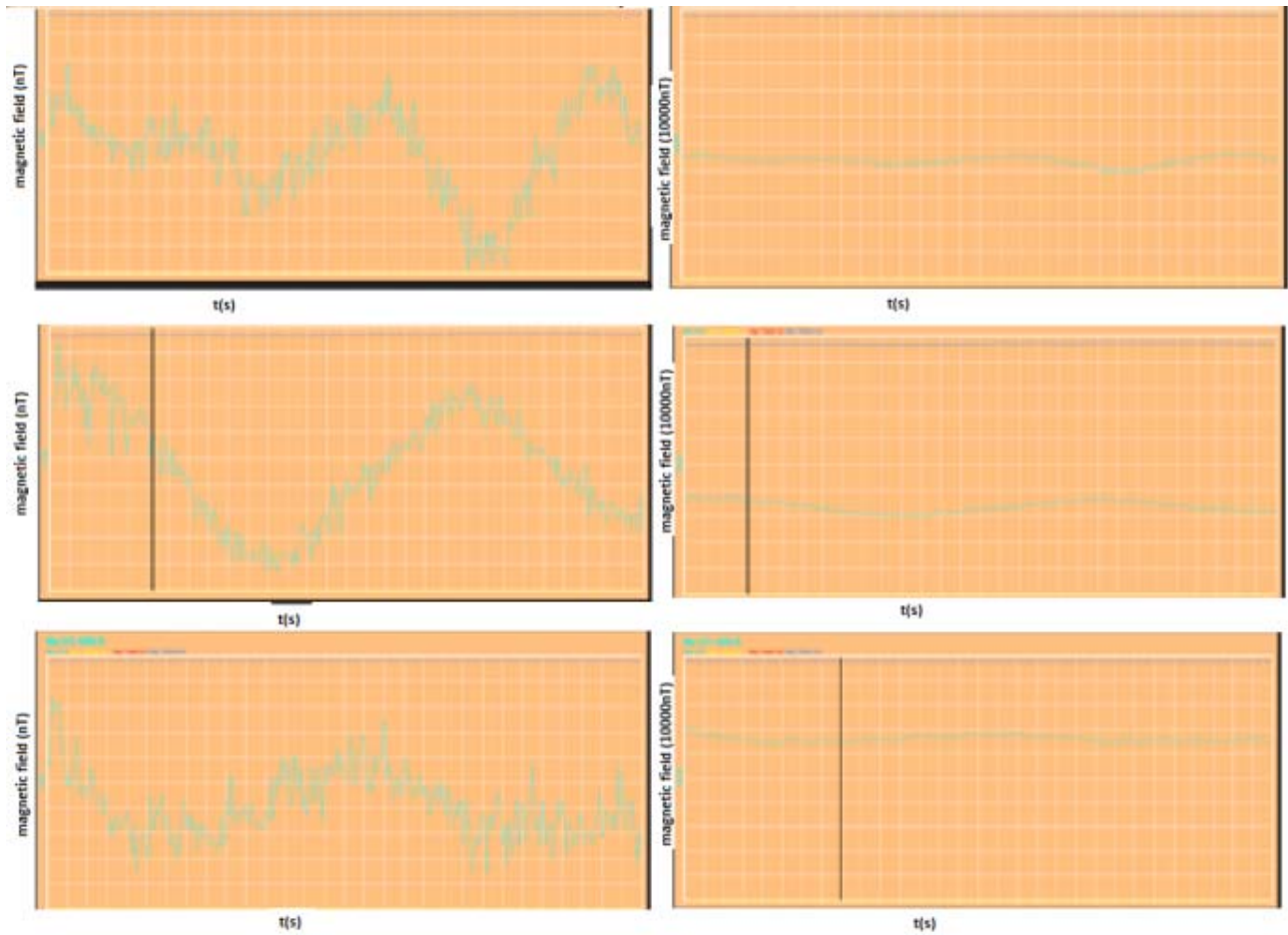


Fig. 4 — The results of measurement of magnetic fields in the study region (right) and wind-induced and turbulent wake-induced magnetic field (Figure left) in different vessel speed

The results of the measurements were compared with the results of calculations and the were compared the wave frequency caused by the turbulent wake with wave frequency is measured using by the magnetic field

Continuity equation is as follows¹³:

$$\nabla \cdot (\rho V) + \frac{\partial \rho}{\partial t} = 0 \quad \dots (1)$$

Conservation of momentum equation is as follows¹⁴.

$$\left(\frac{\partial}{\partial t} + (V \cdot \nabla) \right) V = -\nabla P + J \times B + \nu \Delta V \quad \dots (2)$$

Lorentz force $J \times B$ using the following equation and amperes rule can be expanded:

$$\frac{1}{2} \nabla (B \cdot B) = (B \cdot \nabla) B + B \times (\nabla \times B) \quad \dots (6)$$

$$J \times B = \frac{(B \cdot \nabla) B}{\mu_0} - \nabla \left(\frac{B^2}{2\mu_0} \right) \quad \dots (7)$$

Maxwell is the first law as follows:

$$\nabla \times B = \mu J \quad \nabla \cdot B = 0 \quad \dots (8)$$

Ohm's Law is as follows:

$$0 = E + V \times B \quad \text{Faraday's law as follows:}$$

$$\frac{\partial B}{\partial t} = -\nabla \times E \quad \dots (3)$$

The following equations of electromagnetism are clear:

$$B = \mu H \quad \dots (4)$$

$$J = \sigma E \quad \dots (5)$$

Where ϵ is the permittivity, μ is the magnetic permittivity in free space and σ is the electrical conductivity.

These equations show that the fluid velocity change induces a magnetic field that can be measured.

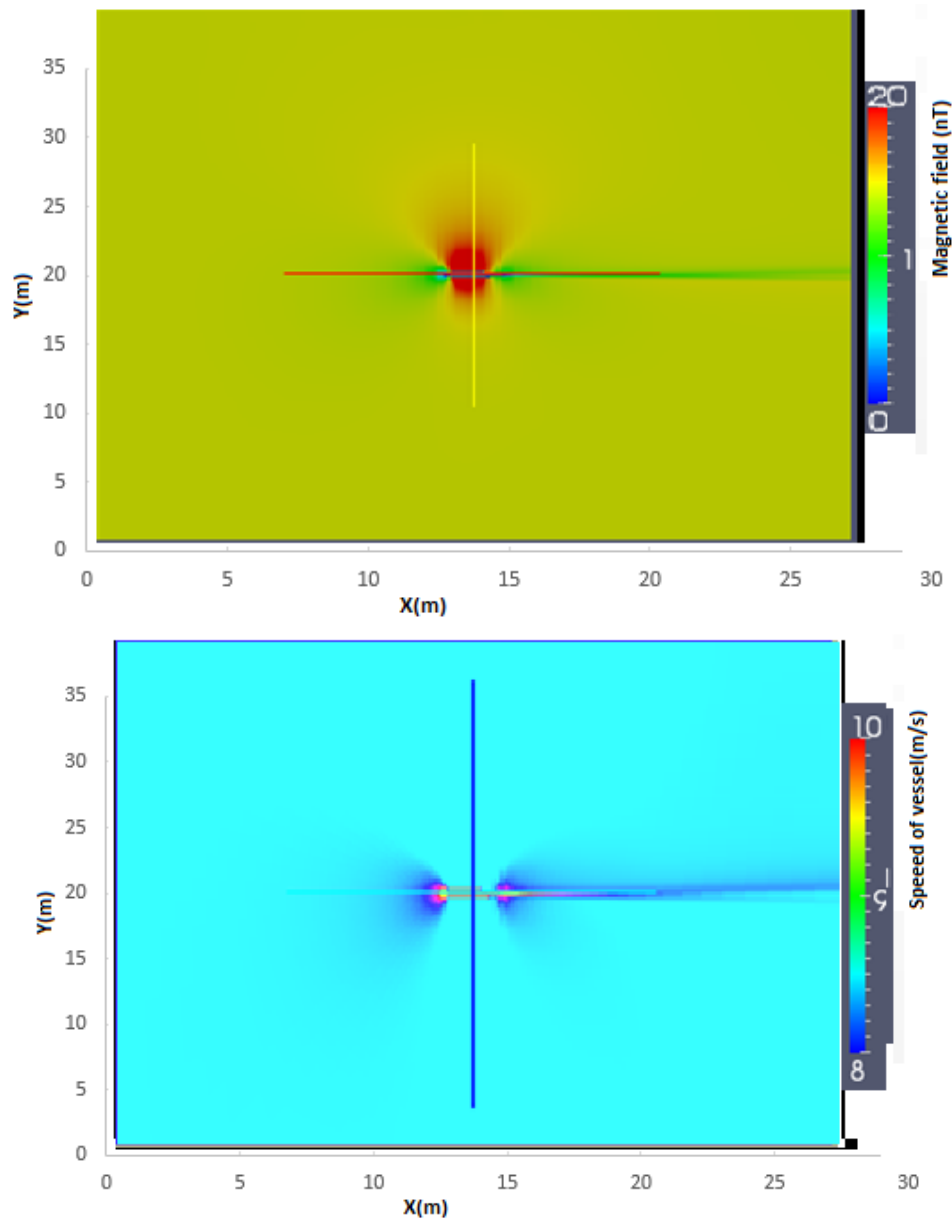


Fig. 5 — The turbulent wake by modeling at speeds of around 20 knots

With discrete equations and their numerical modeling can be modeled turbulent wake induced magnetic field.

Eirik showed that the magnetic field in the x and y directions due to flow of a wave in the ocean with speed v_0 and wave number k in an environment characterized by σ and μ and the Earth's magnetic field in the middle of it is B_0 in depth h meters of water surface can calculate as follows¹⁵:

$$A_y = \frac{\mu\sigma v_0 B_0}{4k^2} e^{-kh} \cos kx_0 \quad \dots (10)$$

Or:

$$B_x = -\frac{\mu\sigma v_0 B_0}{4k^2} e^{-kh} \cos kx_0 \quad \dots (11)$$

Where μ is the magnetic permittivity in free space and σ is the electrical conductivity.

By measuring the magnetic field at a depth of one meter and hydrophysic characteristics of the study region, calculated and measured magnetic field induced by turbulent wake were compared.

Studies conducted by various researchers show that the turbulent wake created in the back of a surface

vessel has a wavelength equal $\lambda = \frac{2\pi}{g} V^2$.¹⁶ In the other hand because of vessel speed and speed of the created wave is equal so we can calculate the wave period by following equation:

$$\lambda = \frac{2\pi V^2}{g}, V = \frac{\lambda}{T} = \lambda f \Rightarrow f = \frac{g}{2\pi V} \quad (12) \quad \dots (12)$$

Modeling the turbulent wake was performed on using OpenFOAM numerical model. It is a C++ objective programming language. Using this property allows the development and customization of code to solve any particular problem is possible. This model has some solvers to calculate PDE and to model multi-physics problems, including CFD¹⁷.

Another advantage of it is the close link with other programs for pre-processing and post-processing.

Along with the standard edition, graphical environment is not provided. Modeling a physical process of entering information to generate a grid,

select the solution and ultimately determine the physical parameters and time through the edit text files occurs.

Results

Figure 4 shows the results of measurement of magnetic fields in the study region.

Turbulent wake of the model at speeds of around 20 knots shown in figure 5.

An example of measured data after removing inappropriate data, using MATLAB software is shown in Figure 6. The results of FFT measurement of the magnetic field is shown in Figure 7.

Figure 6 shows a correlation between increasing and decreasing magnetic field and speeds of vessel.

In Figure 8, Earth's magnetic field (about 44897 nT) has been reduced from the original measured signal. The magnetic field of the turbulent wake and wind-driven waves are shown. As is clear in figure 8 changes in the magnetic field caused by the turbulent wake of vessel and wind-driven waves is about 1 to 10 nT.

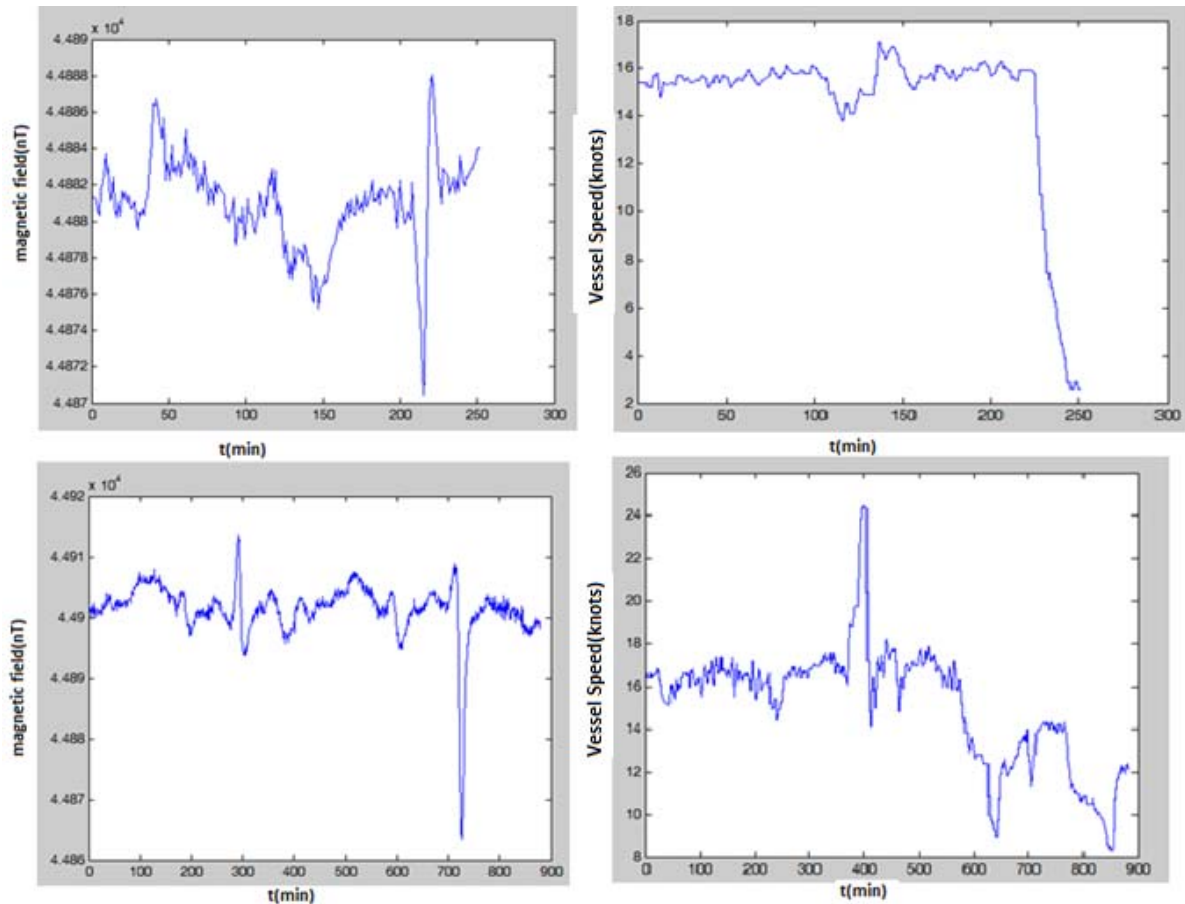


Fig. 6 — The magnetic field measured data (left) and vessel speed (right)

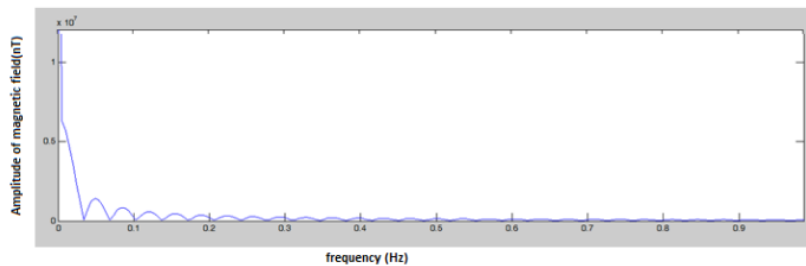


Fig. 7 — The results of FFT belong to measured magnetic field

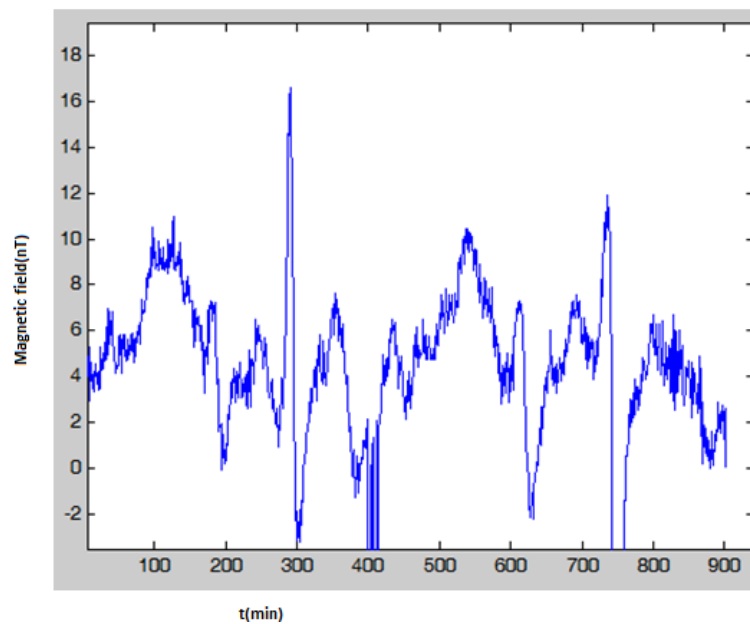


Fig. 8 — Measured magnetic field of ocean waves and turbulent wake

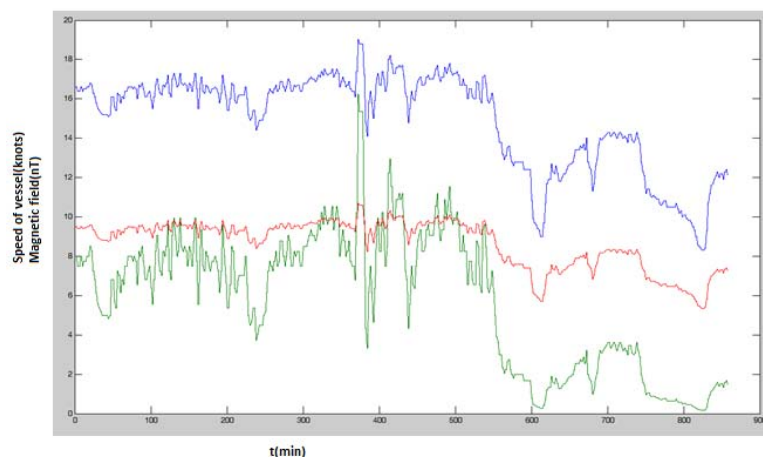


Fig. 9 — Speeds and magnetic field measurements and calculation (water vessel speed in knots(blue), magnetic field of the measurement in nT(red), magnetic field of calculation(green))

The results of measured and calculated magnetic field caused by turbulent wake, at different vessel speeds are shown in Figure 9.

Conclusion

In this case the static magnetic field of region was 44897 nT. The vessel began to move and wake

induced magnetic field was measured. The frequencies of waves induced by turbulent wake was achieved using Excel software and modeling and showed that the frequency of turbulent wake of vessel is about 0.1 to 0.15 Hz and is similar to the results of FFT of measured magnetic signal. Frequencies showed that the magnetic field induced by turbulent wake is the main cause of these waves. Of course, other frequencies that are under one Hz are involved in the creating a magnetic field. The amplitude of the waves is small compare to the turbulent wake. According to the calm weather at the time of measurement and frequencies obtained under one hertz, it can be concluded that the changes in the magnetic field is related to wind waves. All measurements show the same result.

Results of other researchers indicate that change in the magnetic field of wind-driven waves is one to a few nT that is similar the measurement results.

The results of the measurements was with a good agreement with the results of calculations. The reason for this difference is that the above calculations have been considered constant electrical conductivity but the electrical conductivity can change according to temperature and salinity.

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