Magnetic signals generated by ocean swells

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SUMMARY

Ocean waves and swells generate magnetic signals which may be spurious for aircraft carrying out magnetic surveys over ocean areas, and particularly over continental shelves. To check the character of such signals at the sea surface, a magnetometer has been set free from a ship to float unrestricted on the ocean surface for periods of several days. The path of the magnetometer was tracked by satellite; this procedure enabled also the eventual recovery of the magnetometer by the ship.

Superimposed upon a background of slow change of magnetic field, as the magnetometer drifted across different patterns of crustal magnetisation, are high-frequency signals generated by the strong ocean swell present at the time. These wave-generated signals are typically 5 nT trough-to-peak, consistent with theory for their generation by ocean swells several metre trough-to-peak in size.

The magnetic signals reflect the oceanographic effects of wave dispersion, and changing sea-state. In particular, the power spectra for the observed magnetic field exhibit a strong (-7) power fall-off with increasing frequency above the peak of 13 s. This strong fall-off is consistent with oceanographic observations of the spectra of surface swell, and suggests higher-frequency disturbances in such situations will generally be negligibly weak in aeromagnetic data.

Key words: magnetic, surveys, signals, ocean, waves.

INTRODUCTION

Aeromagnetic imaging methods are used to determine the geological structure of continental shelf regions. Survey aircraft fly low over the ocean surface, and one limitation to their resolution is the magnetic signal which accompanies ocean waves and swell. This signal is generated by motional electromagnetic induction: seawater moves across the flux lines of Earth's main magnetic field, and in so doing generates electric currents which flow through the seawater. These electric currents have their own magnetic fields, which are magnetic fields generated by the wave motion.

To provide sea-surface information on such wave signals, and to provide guidance in filtering them from aeromagnetic data, measurements of the magnetic signals of wave motion were made in 1998 in the Southern Ocean off South Australia. The Southern Ocean was a suitable place for the observations, due to the presence there of consistent ocean swells which are several metres in height. The observations were part of the Southern Waters of Australia Geoelectric and Geomagnetic Induction Experiment (SWAGGIE).

METHOD

On two separate occasions a floating magnetometer was released from the vessel ORV Franklin and left to float free for several days, while the ship carried out other work. The complete floating package also carried a satellite transmitter, so that as it drifted under the influence of winds and ocean currents, the position of the magnetometer could be tracked, and eventually recovered. Care was taken in the package design to keep the magnetometer itself in a non-magnetic environment, and free of stray magnetic fields. A further description of the general experiment is given in Hitchman et al. (2000).

This paper presents an analysis of the floating-magnetometer data of the first deployment, termed Floater 1.

RESULTS

Time series

The magnetometer recorded the amplitude of the magnetic field every 3s. The time series for the Floater 1 deployment, when a plot is made of them, show large-scale changes in the total-field occurring slowly. These large and slow changes are the result of the magnetometer moving across the crustal magnetisation patterns of the seafloor, as it was carried by ocean currents and winds. Against this background of large slow changes the trace of the plot is quite thick, which indicates that there also are short-period signals in the time series.

When the plot of the time series is expanded, the short-period signal is easily seen, and the figure shows that the range of the signal typically is about 5 nT. The rapid small-scale fluctuations in the trace are caused by the magnetic variations associated with waves and swell (Weaver, 1965).

Power spectra

A power spectrum for the entire time series has been obtained using the spectral estimation feature (Welch's averaged periodogram method), as provided in the Signal Processing Toolbox of MATLAB.

The power spectrum of the wave signal shows a clear peak in power at approximately 13.3 s, which is caused by the ocean swell. The period of the swell found in this analysis corresponds closely to the findings of Hemer et al. (1999) for the swell period in the South Australian Sea in April 1998.

Evidence for dispersion

The speed of a wave across a deep ocean is primarily a function of wavelength and period, and dispersion occurs: the longer the period, the faster the wave. Close to a storm at sea, where the waves originate, the sea may consist of a myriad of wave forms with different lengths, heights and periods. As the waves move away from the source of the disturbance, the longest ones move at the fastest speeds. In this process of sorting themselves out by dispersion, the waves produce spectra at distant sites which are sharply peaked.

To investigate whether it is possible to see the pattern of such wave dispersion in the magnetometer data, the observed time series has been divided into groups of 10000 measurements, corresponding to the measurements of 8 hours and 20 minutes in each group. Individual power spectra for the groups in succession may then be inspected for a systematic shift of the peak in frequency at later times, and such a shift is seen: from 14.3 s to 12.5 s some 24 hours later.

Variation with sea-state

Looking at the six power spectra of the groups in succession it is obvious that the energy is largest in the beginning (group 1) and decreasing towards the end (group 5). This observation suggests that we can observe a decrease in sea-state occurring during the observation period of Floater 1.

An attempt has been made to find independent data about sea-state and swell during the period of interest, as well as meteorological information. The meteorological information confirms that a weather depression passed the southern part of Australia a few days before the deployment of the magnetometer, in agreement with the interpretation of a wave dispersion pattern from group 1 to 5, mentioned above. The ships' log about sea-state tells of increasing swell in the time when measurements in group 6 were collected, which confirms an interpretation from the magnetic data of the arrival of a new set of long-period (high speed) swells at that time.

Fall-off of signal at high frequencies

Under many circumstances the wave-energy spectrum of the ocean is approximately represented by the Phillips spectrum (Phillips, 1977). The Phillips spectrum has a characteristic fall-off with frequency of power -5, and when this characteristic is applied to the theory of Weaver (1997) for signals measured by total-field magnetometers, a fall-off with frequency with a theoretical slope of -7 is predicted. A double logarithmic plot of the power versus the frequency of the magnetic signal shows this phenomenon well.

CONCLUSIONS

Magnetic signals measured by a magnetometer floating freely on the surface of the Southern Ocean are of the correct magnitude to be created by motional induction due to an ocean swell close to 13 s in period. The constant of proportionality in the generation process is approximately 1.5 nT of magnetic signal for every 1 m of wave motion, as predicted by Weaver's theory. The wave signal shows dispersion over a matter of hours, consistent with the ocean swell signal having come from a distance source, and having travelled dispersively. Further, the sharp peak in the signal spectrum at 13 s period deceases very strongly with increasing frequency, consistent with a prediction from physical oceanography. Thus filters applied to aeromagnetic data to remove ocean-swell signal can have a similar sharp fall-off with increasing frequency.

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