Oceanographic effects on the geomagnetic field

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Three classes of ocean water movements are identified as significant sources of motionally induced electromagnetic (EM) fields in the frequency range 10^{-3}–10^{-1} c h^{-1}. These are: the barotropic steady-state and mesoscale eddies; tides; and internal waves, particularly at the inertial frequency. Other water motions may contribute significant EM fields such as tsunami and surface waves (Larsen 1971). The electric field components are more sensitive to the motional induction than the magnetic components since the magnetic field is a spatial average of electric currents. The vertical component of the electric field (VEF) is not contaminated by ionospherically induced signals and represents a purely oceanographic signal. When the ratio of ocean length scale (D) to ocean depth (h) is large (i.e. $D/h \gg 1$) the VEF can be approximated by

$$E_z = -V_e \times B_n$$

where E_z is the VEF, B_n is the horizontal north component of the earth's steady magnetic field, and V_e is the east-west velocity of the local fluid (Harvey 1972; Malkus & Stern 1952). The interpretation of the horizontal components of the electric field is more complex. The horizontal components of the electric current are in general non-zero and depend on the velocity field and, in the time varying case, on the conductivity structure of the mantle. The degree of mutual induction depends on the ratio of the skin depth (δm) of the mantle and the length scale (D) of the ocean current flow (Sanford 1971). Small $\delta m/D$ ratios indicate a strong coupling between mantle and ocean movements.

The conductivity structure and velocity structure are the geophysical targets of ocean-bottom EM experiments. Thus, for interpretation, some authors assume the depth-averaged horizontal electric current is negligible and obtain:

$$\boldsymbol{E} = -\boldsymbol{V} \times B_z \hat{\boldsymbol{z}}$$

where $\boldsymbol{E}$ is the horizontal electric field, and $\boldsymbol{V}$ is the conductivity-weighted horizontal mean ocean flow. B_z is the vertical component of the earth's magnetic field. The validity of this relation is critically dependent on the electrical linkage through the seafloor and is only strictly true for an insulating crust and time-independent streams.

Power spectral analysis of VEF data, collected as part of the Tasman Project of Seafloor Magnetotelluric Exploration,. shows the significance of internal waves, mesoscale currents and tides at the ocean bottom. The amplitudes of the spectrum of the internal waves (including the inertial waves) and tides are 1–3 orders of magnitude less than the amplitudes due mostly to ionospheric sources, measured by the horizontal electric fields for the frequency range 0.05–20.0 c h^{-1}. The large powers observed in the horizontal components of the electric field are inferred to be due to mesoscale currents for frequencies $\approx 10^{-3}$ c h^{-1}. Such large energies are negligible in the power spectrum for magnetic variations recorded by ocean bottom magnetometers for the same frequencies. This result indicates that curl $\boldsymbol{E}$ is small, and that these long period electric fields are due to ocean movements. The spectra for magnetic variations from this project show enhancement of spectral lines at tidal frequencies (M_2) when compared with land data.

References

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