Numerical Simulation of Magnetic Field Induced by Electrical Conductivity Anomaly Associated with a Hot Plume in the Mantle

Fumiko Tajima[1], Ryoji Matsumoto[2], Wenchien Chou[3]

[1] U C Berkeley Seismo. Lab., [2] Dept. Physics, Fac. Sci., Chiba Univ., [3] RIST

http://www.seismo.berkeley.edu

We carried out computer simulations of electromagnetic (EM) responses given an external electric field oscillating in x-direction and electrical conductivity (EC) anomaly in a vertical column (i.e., a plume like feature) in the mantle using a time-domain 3-D finite difference code. The skin depths of a frequency band of 0.00001 to 0.0001 Hz which is prominent in magnetic substorms, fall in the upper mantle and the transition zone. Results show observable difference of EM responses in the amplitude of the induced By above the anomalous EC distribution, and Bz is also induced due to the anomalous 3D EC distribution. The phase shift of the induced magnetic field is observable between locations relative to the center of the EC anomaly.

Recent 3-D seismic tomography studies captured stunning features of low velocity anomaly, which are almost continuous from the core mantle boundary to upper mantle beneath Africa and South Pacific [Ritsema et al, 1998; Megnin and Romanowicz, 2000]. The blurred images of low velocity anomaly with a lateral extent of over 2000 km may indicate hot plumes which are, however, assumed to be upwelling in a much narrower column. If they exist, the contrast of electrical conductivity (EC) anomaly between a hot plume and the surrounding mantle is substatntially larger (by a factor of several or greater) than that of observable seismic properties (within a few percent). This contrast could be effectively used to characterize features associated with hot plumes.

We carried out large-scale computer simulations of an induced magnetic field by the coupling of an external electromagnetic field with the EC anomaly in a vertical column (i.e., a plume like feature) in the mantle. We use our newly developed time-domain 3-D finite difference (FD) codes [Chou et al., 2000a, b]. This time domain approach is efficient to simulate transient responses such as those due to magnetic substorms driven by solar winds. A plain electric field (or a vector potential A differenciated by time) which oscillates with a period of 10000 to 100000 sec in one direction (i.e., along x-axis), is given to represent the external field. This setting is equivalent to an external magnetic field that is axi-symmetric and poloidal. We first tested the sensitivity of the codes for skin depths in a layered Earth of various EC values provided by magnetotelluric modelings and recent experimental measurements under high temperature and pressure. The skin depths of this frequency band of 0.00001 to 0.0001 Hz, which is prominent in magnetic substorms, fall in the upper mantle and the transition zone. We then simulated electromagnetic responses given EC anomalies in a narrow column of various size (with a diameter of 100 to 400 km) embedded in the depth range from 660 km to 1000 km. After the 3D FD computation for a sufficient time length (~several times as long as the given period of oscillation of the external field), the induced magnetic field is evaluated at the surface. The initially induced magnetic field is also compared with that computed for the entire time length.

Results show observable difference of electromagnetic responses for different EC distribution, and that a high conductivity region in a narrow column can be detected. The amplitude of the y-component induced magnetic field (By) above the anomalous EC distribution is as large as ~120 % of that induced without the anomaly. Magnetic field in z-direction (Bz) is also induced due to the anomalous 3-D EC distribution. The phase shift of the induced magnetic field is observable between locations relative to the center of the conductivity anomaly. A critical issue is whether the induced amplitude and phase variation can be distinguished from the external magnetic field in the observed data.

Chou, W., M. Matsumoto, and F. Tajima, Simulational modeling of time-domain electromagnetic induction using parallel computational schemes: (I) in the cartesian coordinates, Computer Physics Communications, 131, 24-40, 2000a.

Chou, W., M. Matsumoto, and F. Tajima, Simulational modeling of time-domain electromagnetic induction using parallel computational schemes: (II) in the spherical coordinates, in review, Computer Physics Communications, 2000b.

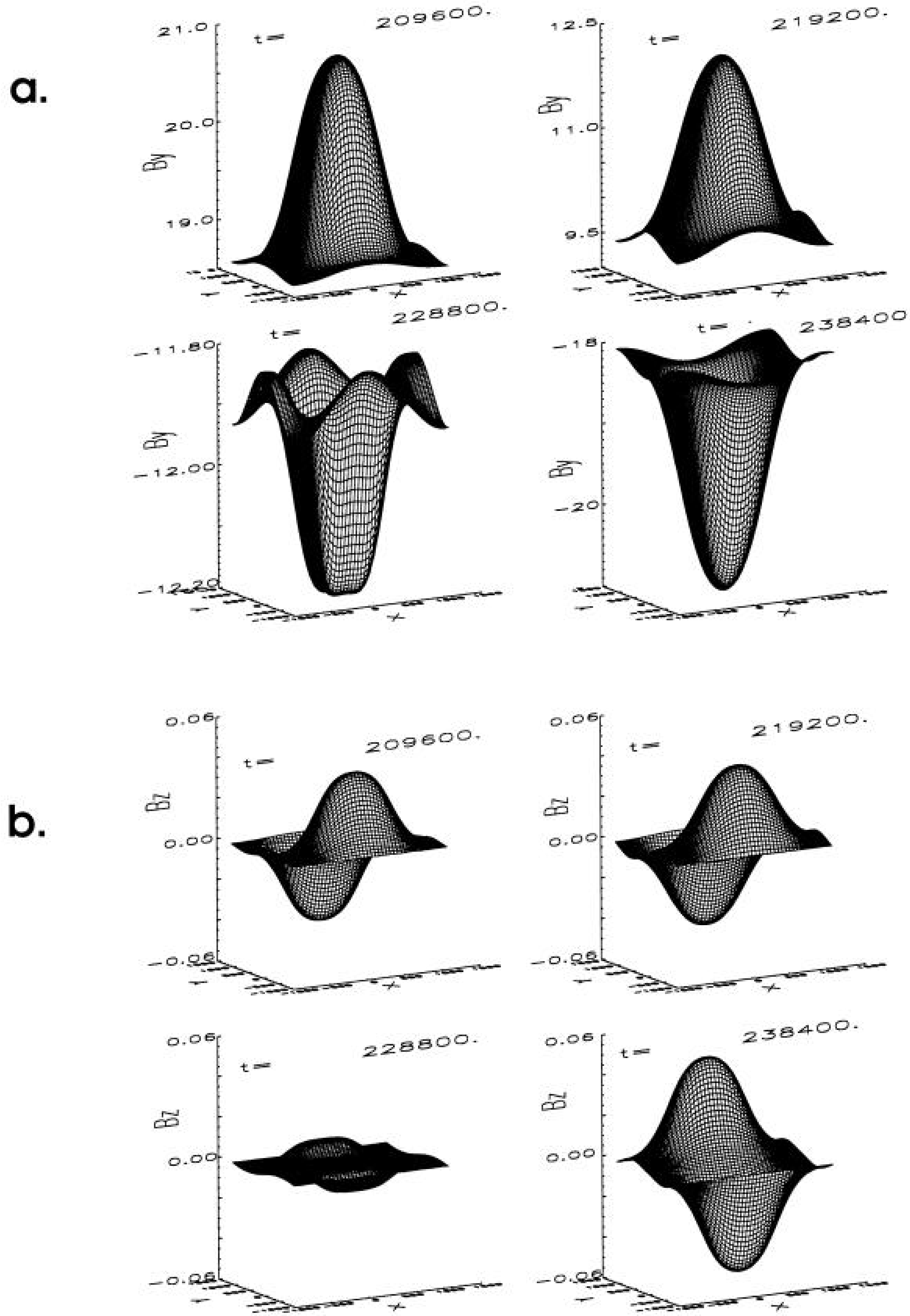

Fig. 1. Induced magnetic field by the coupling of an external field with the mantle, given electrical conductivity anomalies in a vertical column with a diameter of 400 km embedded in a depth range from 660 to 1000 km and in a overlaid broader layer (~1000 x 1000 km**2) right beneath 660 km (i.e., a plume like feature). A plain electric field that oscillates with a period of 50,000sec in x-direction is given to represent the external field. a. **By**'s at t=209600, 219200, 228800, and 238400 sec after the onset of the simulation, respectively. Note the amplified magnetic field above the anomaly. b. **Bz**'s computed for the same durations as in a. The induced magnetic field that oscilates only above the EC anomaly is observed.