EFFECT OF THE CHANGE IN THE GEOMAGNETIC DIPOLE MOMENT ON THE RATE OF THE EARTH'S ROTATION

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Abstract. The electromagnetic coupling between the Earth's core and the mantle is studied when the geomagnetic dipole field varies periodically. The oscillation of the geomagnetic dipole moment with a period of 8000 years, its amplitude being 50% of the present moment, is capable of causing a fluctuation of 10^{-11} rad/s in the angular velocity of the mantle. The angular velocity increases with a decrease in the dipole moment.

The electromagnetic coupling between the Earth's core and the mantle is regarded as one of the most likely causes for the irregular fluctuations with a time scale of decades in the Earth's rate of rotation. A small amount of leakage of toroidal fields from the core into the mantle is considered to be sufficient for producing the observed variations per decade in the length of the day.

The recent development of archaeomagnetism has revealed that the geomagnetic dipole has been changing its moment with a period of about 8000 years, its amplitude amounting to 50% of the present dipole moment. It is also likely that small fluctuations in the dipole moment are superposed on this large amplitude variation. These variations may possibly produce a considerable amount of change in the toroidal field. Then non-tidal variations in the Earth's rate of rotation are expected in association with the changes in the geomagnetic dipole moment.

The electromagnetic coupling between the core and the mantle has been calculated for a simplified model of the Earth. The core is approximated by a rigid sphere and a concentric spherical shell, both rotating around the same axis with different angular velocities. The electrical conductivity is assumed to be 3×10^{-6} emu throughout the core. The conducting mantle of 10^{-9} emu is considered to be covered with an insulating spherical shell of about 400 km thickness.

The result is that the oscillation of the dipole moment with an amplitude of half of the present value, having the period of 8000 years is capable of causing a fluctuation of 10^{-11} rad/s in the angular velocity of the mantle. (In terms of angular acceleration, 2.5×10^{-22} rad/s^2.) The angular velocity increases as the dipole moment decreases. Since the dipole moment has been decreasing during the past 1500 years, the mantle is expected to have been accelerating its rotational speed.

Though the dipole moment has been decreasing during the past centuries, small fluctuations are superposed on it. There was a maximum in the change at a time around 1800 AD. If we assume that this is due to a sinusoidal oscillation superposed on the general trend, the period is approximately 400 years and the amplitude amounts to about a tenth of the present dipole moment. Then a change in the angular velocity of 10^{-12} rad/s is easily excited. This is approximately of the same order of magnitude as that expected from Newcomb's Great Empirical Term in the Moon's longitude.

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From these considerations, it may be said that the electromagnetic coupling plays an important role not only for the variations over a decade but also for phenomena having periods as long as hundreds and thousands of years.

However, when averaged over a sufficiently long period, the electromagnetic coupling due to the change in the dipole moment has little effect on the acceleration of the mantle, because, from palaeomagnetic investigations, the average intensities of the dipole field on a geological time scale are approximately the same as the present one. Another feature to be noted is that angular momentum is transferred only between the mantle and the core or within the core, so that the coupling may exert no effect on the orbital motion of the Moon.

DISCUSSION

J. A. Jacobs: Most people believe that the toroidal field in the core $\simeq 100$ times greater than the surface poloidal field. If the dipole field decreases by about 50%, I personally do not believe that there was a corresponding change in the toroidal field in the core.

T. Yukutake: A kinematic dynamo as proposed by Bullard and others is a system of such high efficiency that any small change in the dipole field may produce a corresponding change in the toroidal field. The present model is not complete for the whole process of the geomagnetic dynamo, but still a large amount of change in the toroidal field has been caused. Another case was also considered when the change in the dipole field tòok place only near and above the core mantle boundary and had no effect on generating the toroidal field within the core. This modification, however, has not altered the conclusion for the long period variations. At present we have no sufficient data to find out whether every small fluctuation in the dipole field is directly connected to generation of the toroidal field.

H. Jeffreys: There has been some difficulty in explaining how the tidal friction couple is transmitted to the core. Does your model explain this?

T. Yukutake: Yes, I think there is no great difficulty in transmitting the tidal friction couple. When the rotation of the mantle (ω_m) is subjected to a time variation $e^{\lambda t}$ under the steady dipole field, the angular velocity of the core (ω_1) becomes approximately $\omega_1 = \nu/(\lambda + \nu)\omega_m$, where ν is the free decay constant of the mantle, which depends on the electrical conductivity of the mantle, the intensity of the dipole field and the moment of inertia of the core. Since $\nu \approx 10^{-9}$ s^{-1} and if we take the rate of the tidal retardation as $\lambda \approx 10^{-17}$ s^{-1}, then $\omega_1 \approx \omega_m$. The core follows the motion of the mantle.