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Relation between energy spectra in the fluid core and time spectrum of the dipole moment inferred from geodynamo simulations

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The Earth's magnetic field is generated by fluid motion in the liquid outer core, where highly turbulent flow is expected because of its extremely low viscosity. However, direct observation of the small scale features of the fluid motions is inherently impossible. In order to infer the turbulent state in the fluid core, we examined the relation between the energy spectra in the fluid core and the time spectrum of the dipole moment based on geodynamo simulation models. We carried out numerical simulations of geodynamo employing a spectral transform method for solving the dynamo equations. The simulation code was ported to the Earth Simulator for attaining the high resolution models. As for the non-dimensional parameters, the Ekman number is 10ˆ(-5) and the Rayleigh number is 4 x 10ˆ7. The magnetic Prandtl number and the Prandtl number are both set to unity. The ratio of inner and outer shell radii is 0.35. The model exhibits a self-exciting dynamo dominated by an axial dipole field. The numerical integration was continued to about 100 kyrs provided that the magnetic diffusivity of the fluid is 2 m2s-1, after a quasi-stable state is achieved.

The time-averaged kinetic and magnetic energies contained in the fluid shell as functions of the angular order m were calculated. The kinetic energy spectrum shows the nature of MHD turbulence. The linear portion of the spectrum from m=6 to 40 with a slope close to mˆ(-3/2) suggests the inertial range, where the kinetic energy which is injected through a typical scale of around m=6 is transferred to smaller scale flows . At the higher wave numbers, the kinetic energy rapidly decreases nearly coinciding with the magnetic one, showing equipartition of the energies probably due to the Alfven effect in which a large-scale strong magnetic field causes equal excitation of small-scale kinetic and magnetic energies. At the lower wave numbers, the magnetic fields are effectively generated by dynamo action. We conducted another run with smaller Ekman number and larger Rayleigh number. It is found that the magnetic and kinetic energies become significantly higher and the inertial range shifts to the higher wave number due to the faster rotation and the higher Rayleigh number.

Time series of the Gauss coefficients at the core surface were calculated. The time average of the magnetic energy calculated from the Gauss coefficients shows a wavenumber spectrum similar to the magnetic energy spectrum in the fluid shell, and the spectrum of its standard deviation bears a remarkable resemblance to the kinetic energy spectrum in the core and also has an inertial range corresponding to the wavenumber range between m=6 and m=40. The power spectral densities of the time series of the zonal and sectorial components up to degree 159 were calculated. The harmonic degree l and the angular order m are considered as wave numbers for the zonal and the sectorial components, respectively. The characteristic frequency (corner frequency), f, increases with the increase of the wavenumber, k, and the apparent linear k-f relation indicates that the fluctuation of the Gauss coefficients is mainly due to the advection current caused by large scale flows. The power spectrum of the time derivative of the axial dipole moment is calculated. Due to the resemblance of the wavenumber spectrum of the standard deviation of the temporal fluctuation of the Gauss coefficients and the linear k-f relation, the time spectrum seems to have the inertial range between the periods of 2000 years and 300 years. These two periods may correspond to the energy cascade region from m=6 to 40 in the kinetic energy spectrum. The good correspondence between the time spectrum of the dipole moment and the kinetic energy spectrum in the fluid shell indicates a possibility that the kinetic energy spectrum in the core can be inferred from the time variation of the dipole moment.