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Japan Agency for marine-Earth Science and Technology
Kobe University

Earth Simulator Portrays New Zonal Flow Formation in Earth's Outer Core

Outline

A team of researchers led by Takehiro Miyagoshi, Institute for Research on Earth Evolution(IFREE)at the Japan Agency for Marine-Earth Science and Technology (JAMSTEC), and Akira Kageyama, Professor of Graduate School of Engineering at Kobe University, have successfully reconstructed a new convection regime possibly existing in the Earth's outer core. The simulations were performed on the Earth Simulator, the nation's most powerful supercomputer operated by JAMSTEC.

Their previous computer simulations for the outer core dynamics revealed a convection regime that takes the form of sheet-like radial plumes (August 28, 2008 Press Release). The simulations this time showed the additional formation of a strong westward zonal flow in the outer core near the core-mantle boundary(Fig. 1).

The findings represent a great stride for simulation studies in understanding the mechanism of geomagnetic field generation, which is believed to be closely intertwined with the Earth's environment.

Their work will be published in the February 11 issue of the English science journal Nature.
Title:Zonal flow formation in the Earth's core
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Background

The Earth has several distinct geophysical layers. A layer about 3000 to 5000 km deep beneath the surface is called the "outer core" and believed to be mainly composed of liquid iron melted at several thousand degrees. Since the Earth's temperature is cooled down toward its outer edge, the gradient in temperature causes a motion of liquid iron, called "convection

(*1)."

When electrical conductors move in a magnetic field, they create electromotive force that produces electric current flow. As the Earth has its own magnetic field, a motion of the liquid iron through the field generates electric currents. If these currents reinforce the original magnetic field, the continuation of this process can maintain the magnetic field energy without dissipation. As in the principle of "dynamo," a generator that converts mechanical energy into electric power, a process to maintain the Earth's magnetic field by the electromotive force induced in the outer core is referred to as "geodynamo."

Details of the geodynamo mechanism, however, are not yet fully understood. In particular, due to the low-viscosity of the outer core, the numerical modeling of its fluid dynamics requires greater resolution, making the computation increasingly challenging.

To solve this problem, the team developed a new spherical grid system called the Yin-Yang grid (*2), and used for geodynamo simulations at the highest resolution ever performed before. The results showed a convection structure composed of sheet-like plumes that aligned like curtains along the rotation axis of the planet, instead of the previously thought structure comprising of many columnar vortexes.

Summary of results

In this study, geodynamo simulations were performed at even higher resolutions. The results revealed a dual convection structure in the outer core; in the inner part near the inner core, the radial component of the velocity flow was dominant, with narrow streamlines alternating in up and down directions (sheet-plume flows in three dimensions). The outer flows, in constant, were dominated by the azimuthal component, which formed westward zonal flows (Fig. 2). The three dimensional imaging of the zonal flow convection indicated its cylindrical structure, elongating from north to south (Fig. 3). Furthermore, the inner convection has a higher flow velocity, resulting in strong dynamo action.

The dual-convection structure accompanying such zonal flows was also found to be more distinct in low-viscosity simulations.

Future perspectives and Challenges

When a compass tells directions, we feel that the Earth has its magnetic field, but the integral role of the Earth's magnetic field is seldom appreciated in our daily lives.

The Earth's magnetic field shields the Earth's surface from the solar wind (high-speed charged particles from the Sun) and high-energy particles called cosmic rays. If it disappeared at this moment, a sizable impact would be felt in the Earth's environment. It would certainly "confuse" some birds and bacteria which can sense the magnetic field with their internal "compass" to navigate.

Thus the magnetic field generated by the convection of molten iron deep inside the Earth has a close relationship with the Earth’s environment and animals’ behavior, and consequently clarifying its characteristics and mechanisms is essential.

It is believed that the Earth’s surface system and mantle activity influence each other through their boundary, as are the mantle activity and the fluid outer core. Understanding the behavior of the outer core has therefore a significant importance in comprehensively understanding the dynamics of the Earth’s interior.

Yet at present, no method is available to directly observe the flow characteristics or the magnetic field structure within the outer core. In other words, there is no way to confirm whether the dual convection structure discovered in this study actually exists in the outer core of the real Earth. Given that the simulations were performed using a model carefully tuned to imitate the real Earth to a much greater extent than any of its predecessors and that they successfully revealed the previously unknown dual convection structure, their work will make a giant step in the basic study of geodynamo action.

The team will pursue their study not only on the convections in the Earth&rs core but also on the dynamics of the Earth’s interior, including how the convections are related with mantle activity.

*1: convection
The motion of a fluid in gravity when the bottom is warmed and the upper part is cooled. The heated portion of the fluid expands and thus becomes lighter than the ambient fluid. Thus, the fluid spontaneously makes a flow called thermal convection.

*2: ‘Yin-Yang’ grid
A numerical grid system in spherical geometry. By combining two identical parts (“Yin” and “Yang”) with partial overlap on their borders, one can solve numerical problems with mutual interpolations. It is similar to the seam curve of a baseball.

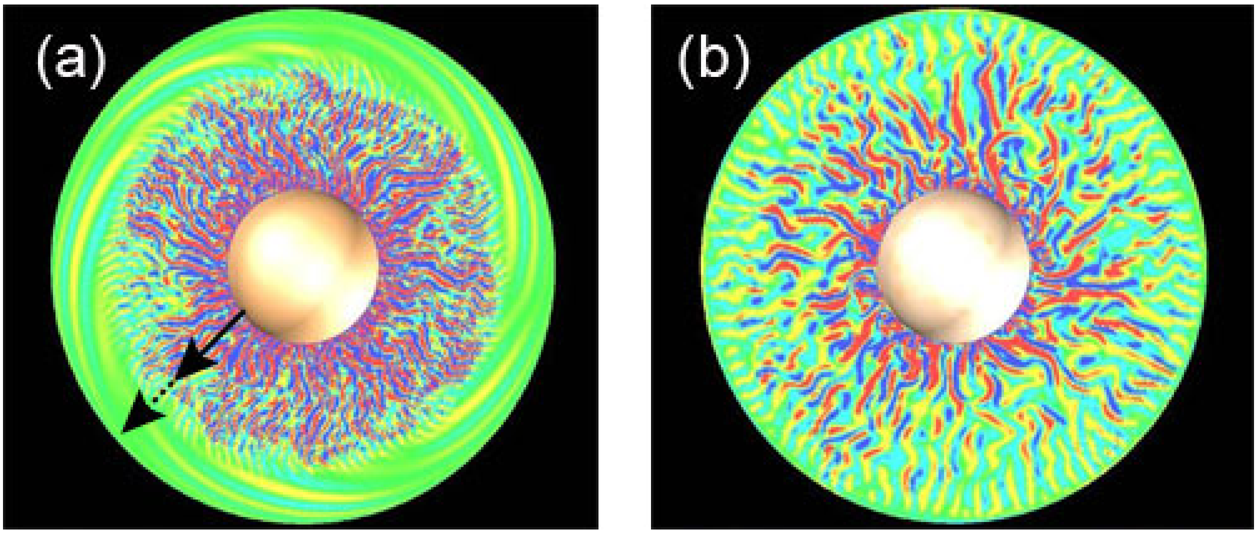

Figure 1. Convection structure in the outer core for different viscosities
Axial component of vorticity(red, positive values; blue, negative values), over the equatorial cross-section viewed from the north. (a) Low viscosity simulation. The solid arrow in (a) indicates the radial range of sheet-plume convection, and the dotted arrow indicates the range of zonal flow in which sheet flow is absent.
(b)Simulation for higher viscosity. The dual convection structure shown in (a) is not observed.

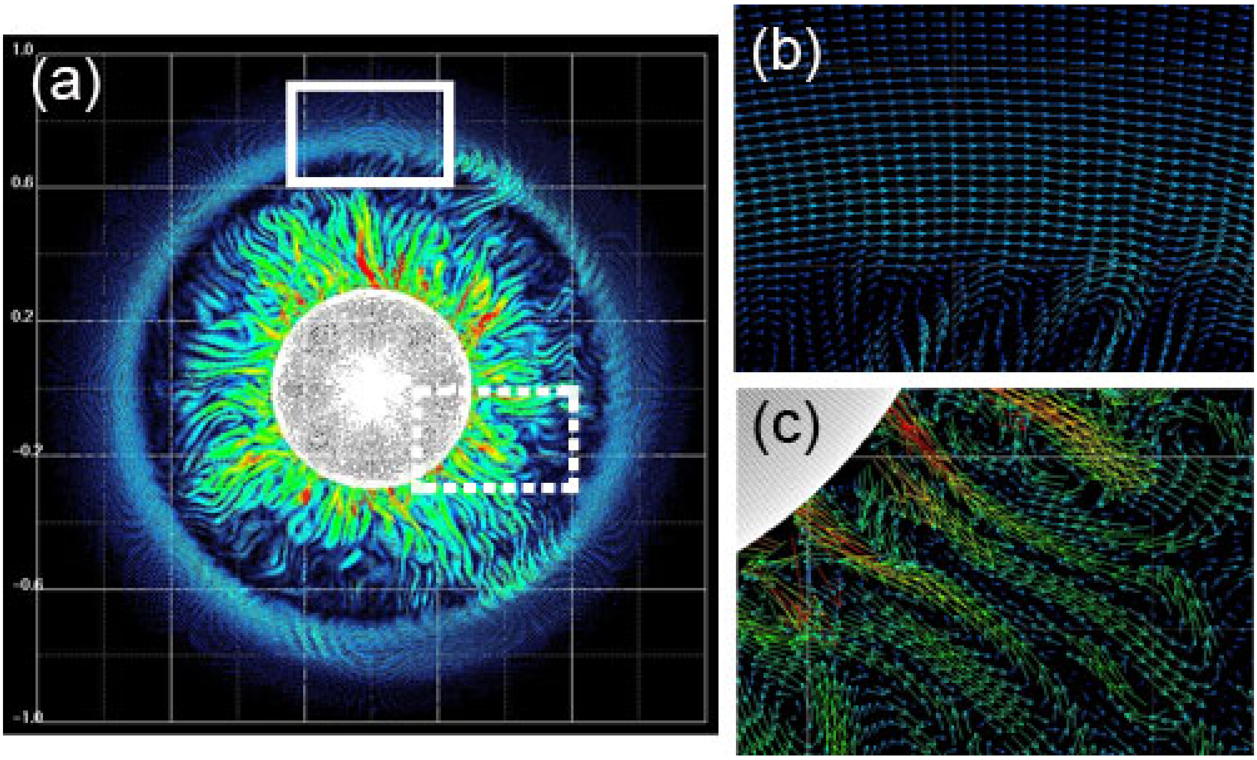

Figure 2. Flow regime in low-viscosity simulations
(a) Velocity arrows in the equatorial plane (red, fast flow; green, intermediate flow velocity; blue, slow flow) viewed from the north. Plume structure is visible around the inner core as a spoke-like (radial) pattern. The shell in the center is the inner core. (b) Magnified view of the region within the solid line in (a). Westward flows are dominant. (c) Magnified view of the region within

the dotted line in (a). The radial component is dominant in the plumes. Vigorous sheet-plume flows are indicated by red arrows.

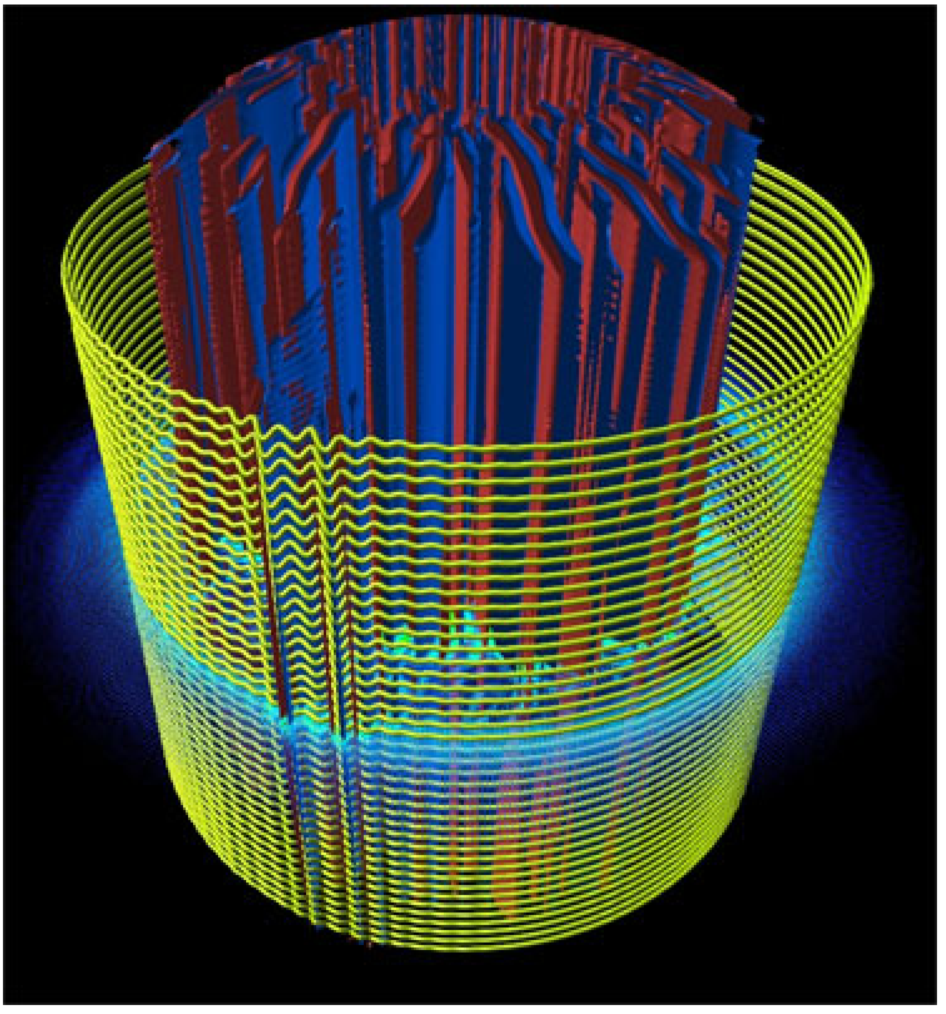

Figure 3. 3-D view of the convection regime from a different angle
The upper area of the diagram is north and the lower area is south. Red and blue sheets represent axial component of vorticity(red, positive values; blue, negative values), which correspond to those in Figure 1(a). Unlike the spoke-like equatorial cross-sectional profiles in Figure 1, the inner convection is composed of thin sheet-like plumes, with their axial structures almost unchanged. Yellow lines denote streamlines. Outside the sheet flows, strong azimuthal zonal flows are formed, surrounding the inner flow structure. The axial structure of this flow field also remains vertically unchanged, thus forming a cylindrical zonal flow structure.

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