Collaborative Analysis of Large-Scale Simulation Data on Solid Earth Sciences

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Since FY2004, the Solid Earth Simulation Group of the Earth Simulator Center (SESG/ESC) has been in collaboration with the Department of Geology and Geophysics, University of Minnesota (DGG/UMN) on analysis and visualization of large-scale simulation data of mantle convection. Our analysis so far revealed (i) possible impacts of the post-perovskite phase transition on the dynamics in the Earth's lower mantle and (ii) an excellent performance of ACuTEMan, a simulation code developed by SESG/ESC, regardless of the computing architectures. We have also explored an "interactive visualization" of output data from three-dimensional mantle convection simulations for fast and efficient analysis of large-scale simulation results.

Keywords: solid earth simulation, mantle convection, data analysis, interactive visualization

1. Collaborative Research on Mantle Dynamics Simulations

Since FY2004, the Solid Earth Simulation Group of the Earth Simulator Center (SESG/ESC) has been conducting a collaborative research with the Department Geology and Geophysics of University of Minnesota (DGG/UMN) on the analysis of large-scale simulation data on solid earth sciences. Through this collaboration, we have conducted (i) an analysis and visualization of large-scale numerical results from three-dimensional simulations of mantle convection with the post-perovskite (PPv) phase transition in the lowermost mantle, and (ii) an installation and execution of the "ACuTEMan" [1, 2], a three-dimensional mantle convection simulation code developed by SESG/ESC, on the high-performance computers in DGG/UMN. Our collaboration on (i) had demonstrated the impact of the PPv transition on the formation of "superplumes" originating from the very base of the mantle [3], and on the thermal structure and convective planforms in the lower mantle [4, 5]. By the collaboration on (ii), the ACuTEMan code was proved to show an excellent performance on scalar architectures as well as on vector architectures like the Earth Simulator.

2. Interactive Visualization of Mantle Dynamics Simulations

In FY2007, we have explored fundamental developments for an "interactive" visualization of data from three-dimensional mantle convection simulations [6]. In this endeavor, the functions of interactive visualizations were implemented by the DGG/UMN into the mantle convection simulation code ACuTEMan developed by SESG/ESC. In Fig. 1 we show (a) a screen-shot of the software controlling the visualization parameters and (b)–(d) a series of snapshots of three-dimensional temperature fields at different elapsed times derived from numerical simulations by ACuTEMan for thermal convection of isoviscous fluids with the Rayleigh number $Ra = 10^6$. As shown in Fig. 1b–d, the evolving temperature fields output from the ACuTEMan are processed and visualized in a real-time manner on the ten panels of the PowerWall. In addition to the real-time data processing, the interface shown in Fig. 1a allows users to nominally "interact" with the rendered images by, for example, adjusting the color scale and opacity, moving the image, and changing the clipping planes. We thus believe that the working in an interactive visualization mode allows for fast and efficient analysis of mantle convection results.

References

[1] M. Kameyama, A. Kageyama, and T. Sato, "Multigrid iterative algorithm using pseudo-compressibility for three-dimensional mantle convection with strongly variable viscosity", J. Comput. Phys., vol.206, no.1, pp.162–181, 2005.

[2] M. Kameyama, "ACuTEMan: A multigrid-based mantle convection simulation code and its optimization to the Earth Simulator", J. Earth Simulator, vol.4, pp.2–10,

2005.

[3] D. A. Yuen, M. Monnereau, U. Hansen, M. Kameyama, and C. Matyska, "Dynamics of superplumes in the lower mantle", In D. A. Yuen, S. Maruyama, S. Karato, and B. F. Windley, eds., Superplumes: Beyond Plate Tectonics, pp.239–267, Springer, 2007.

[4] M. Kameyama and D. A. Yuen, "3-D convection studies on the thermal state in the lower mantle with post-perovskite phase transition", Geophys. Res. Lett., 33, L12S10, doi:10.1029/2006GL025744, 2006.

[5] D. A. Yuen, C. Matyska, O. Cadek, and M. Kameyama, "The dynamical influences from physical properties in the lower mantle and post-perovskite phase transition", In K. Hirose, J. Brodholt, T. Lay, and D. A. Yuen, eds., Post-Perovskite: The Last Mantle Phase Transition, Geophysical Monograph, pp.249–270, American Geophysical Union, 2007.

[6] M. Damon, M. C. Kameyama, M. Knox, D. H. Porter, D. A. Yuen, and E. O. D. Sevre, "Interactive visualization of 3D mantle convection", Visual Geosciences, doi:10.1007/s10069-007-0008-1, 2008.

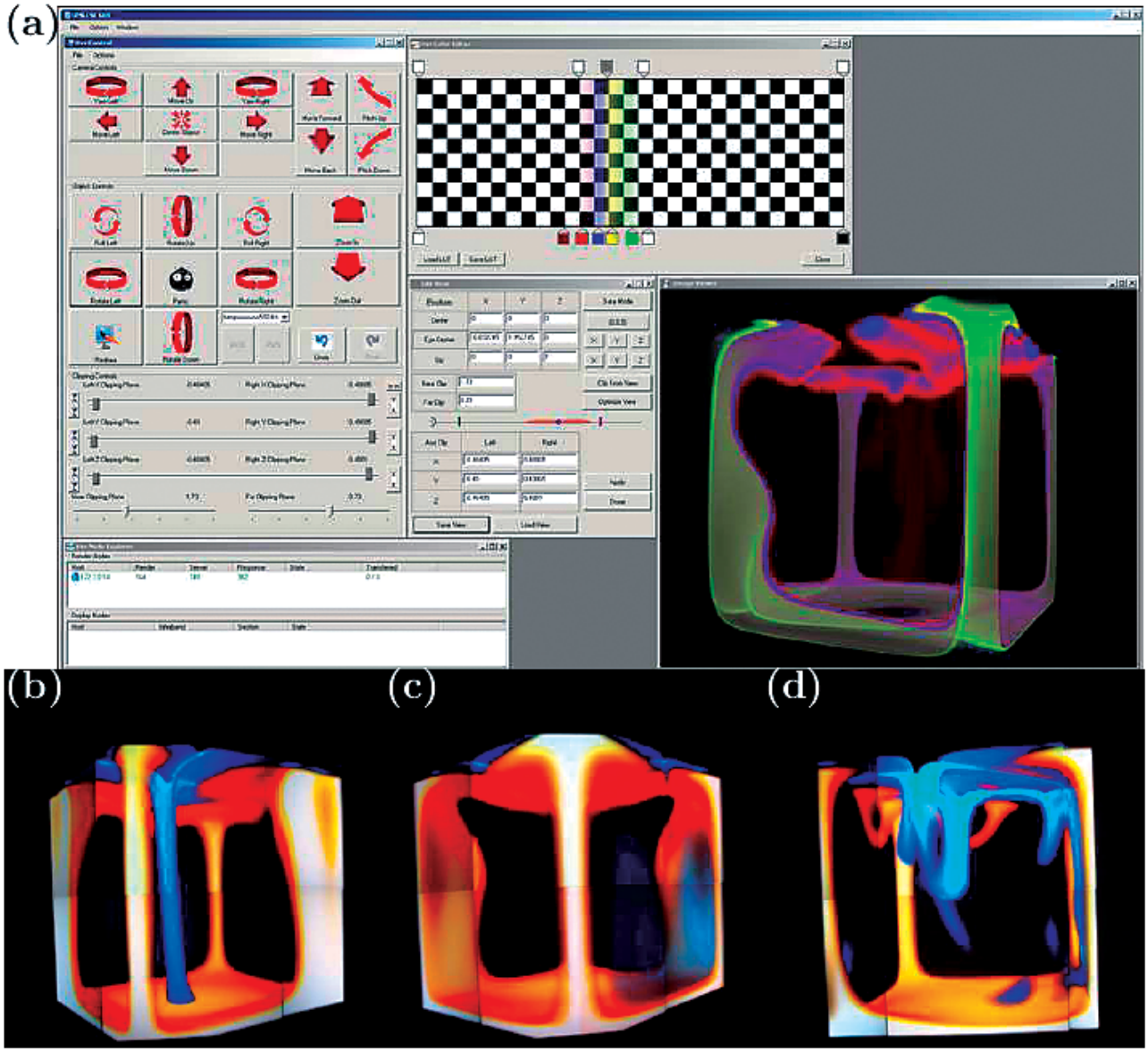

Fig. 1 Examples of an "interactive visualization" of data from mantle convection simulations in a three-dimensional rectangular domain. (a) A screen-shot of the control software. (b)-(d) Camera snapshots of three-dimensional temperature fields projected on the Power Wall installed on the University of Minnesota.

ミネソタ大学とのMOU共同研究：固体地球シミュレーションに関する大規模データの解析

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ミネソタ大学側のコンタクトパーソンであるYuen教授の地球シミュレータセンター訪問(平成16年1月)を契機に、固体地球シミュレーションデータの可視化を中心とした研究協力を行うこととなった。この目的は、固体地球シミュレーショングループで実施している大規模なシミュレーションデータの可視化・解析作業を効率化すること、及びこの作業を通してミネソタ大学側の若手研究者の啓蒙やトレーニングに資することである。これまでの共同研究において、(i)マントル最深部での鉱物相転移(ポストペロブスカイト相転移)を考慮したマントル対流シミュレーションのデータ解析、及び(ii)ESCで開発した3次元箱型マントル対流プログラム ACuTEMan[1, 2]のミネソタ大学計算機への移植、を実施した。(i)では、この相転移とマントル深部からの巨大上昇流(「スーパープリューム」)の起源との関連 [3]、及びこの相転移に代表されるマントル深部での物性変化がマントル対流の構造に与える影響 [4, 5] を解明した。また(ii)の結果、ACuTEManは地球シミュレータだけでなく、IBM BlueGene/L、SGI Altixなどのスカラー型並列計算機でも高い計算性能を示すことが確認された。

さらに今年度は、3次元マントル対流シミュレーションデータの"interactive visualization"を実現するための研究開発を実施した [6]。これは、ACuTEManによる3次元マントル対流シミュレーションを実行させながら、時々刻々出力される計算データにリアルタイムでボリュームレンダリング処理を施し、生成される画像をミネソタ大学設置のPowerWall型大型スクリーンに表示できるようにしたものである。また単なる「リアルタイム」な可視化処理に留まらず、可視化パラメータをその都度「対話的」(interactive)に変更することも可能になっている。この機能は、ESCが提供した3次元マントル対流プログラムACuTEManを基に、interactive visualization 機能及びPowerWallへの表示機能をミネソタ大学が追加することで実現した。

参考文献

[1] M. Kameyama, A. Kageyama, and T. Sato, "Multigrid iterative algorithm using pseudo-compressibility for three-dimensional mantle convection with strongly variable viscosity", J. Comput. Phys., vol.206, no.1, pp.162–181, 2005.

[2] M. Kameyama, "ACuTEMan: A multigrid-based mantle convection simulation code and its optimization to the Earth Simulator", J. Earth Simulator, vol.4, pp.2–10, 2005.

[3] D. A. Yuen, M. Monnereau, U. Hansen, M. Kameyama, and C. Matyska, "Dynamics of superplumes in the lower mantle", In D. A. Yuen, S. Maruyama, S. Karato, and B. F. Windley, eds., Superplumes: Beyond Plate Tectonics, pp.239–267, Springer, 2007.

[4] M. Kameyama and D. A. Yuen, "3-D convection studies on the thermal state in the lower mantle with post-perovskite phase transition", Geophys. Res. Lett., 33, L12S10, doi:10.1029/2006GL025744, 2006.

[5] D. A. Yuen, C. Matyska, O. Cadek, and M. Kameyama, "The dynamical influences from physical properties in the lower mantle and post-perovskite phase transition", In K. Hirose, J. Brodholt, T. Lay, and D. A. Yuen, eds., Post-Perovskite: The Last Mantle Phase Transition, Geophysical Monograph, pp.249–270, American Geophysical Union, 2007.

[6] M. Damon, M. Kameyama, M. Knox, D. H. Porter, D. A. Yuen, and E. O. D. Sevre, "Interactive visualization of 3D mantle convection", Visual Geosciences, doi:10.1007/s10069-007-0008-1, 2008.