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UNDERSTANDING THE 4-D EVOLUTION OF THE SOLID EARTH USING GEODYNAMIC MODELS WITH DATA ASSIMILATION

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EXECUTIVE SUMMARY

We use numerical models with data assimilation to reproduce the complex processes of Earth dynamic evolution, which requires consideration of large amounts of data distributed over many computer nodes. With Blue Waters, our research projects during the past year include: 1) investigating mantle dynamics behind the widespread intra-plate volcanism associated with the Yellowstone hotspot, 2) simulating subduction and mantle flow beneath South America since the Mesozoic, and 3) measuring the strength of the continental lithosphere by approximating its electrical conductivity as effective viscosity based on geodynamic modeling. By now, our Yellowstone work has been published in *Geophysical Journal Research*, which received extensive media attention, including from *Scientific American, Science Daily, Science News*, etc. Work on South American subduction has led to three papers in *Earth & Planetary Science Letters*, which was also reported in *Science Daily, Science News*, etc. Last but not least, our project on quantifying lithosphere viscosity was published in *Science* magazine, which also generated many news pieces.

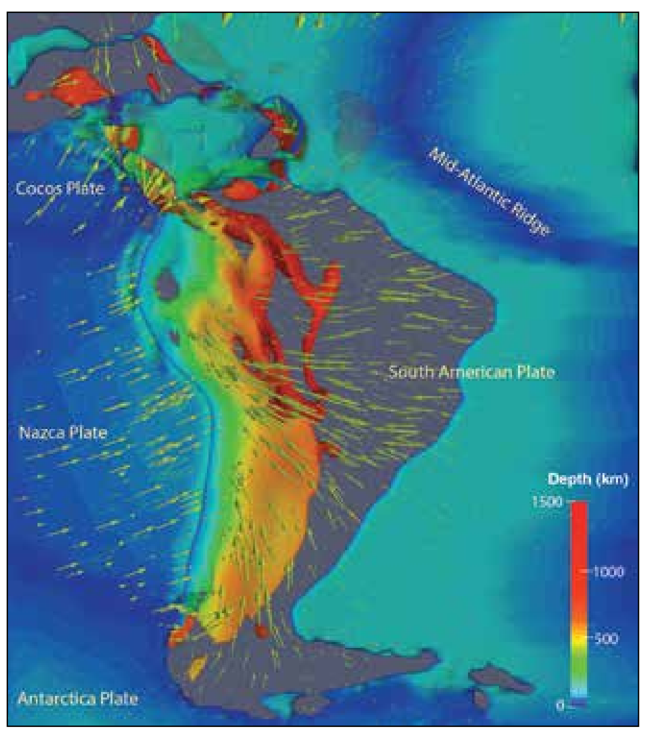

Figure 1: Geometry of the subducting Nazca slab (3D colored surface) and mantle flow (3D arrows) beneath the southern Atlantic. The regional mantle deformation represented by flow vectors is dominantly controlled by the subduction of the slab.

RESEARCH CHALLENGE

Dynamic processes of the deep Earth such as heat source fueling of volcanoes far away from a subduction zone, the influence of subduction on the mantle and the surface, and earthquake- and volcano-generating deformation of continents, are complex in nature. A quantitative understanding of these processes, especially their history, is vital for explaining the various geological, geophysical, and geohazard observations. The challenge in progress is the overall inaccessible nature of the present deep mantle, and more so during the geological past.

METHODS & CODES

To quantitatively understand the current and past dynamic processes within the deep Earth, we adopt various data assimilation techniques in large-scale geodynamic modeling. For example, we employ seismic and magnetotelluric tomography images to represent the present-day mantle temperature and viscosity profiles. We assimilate the motion of tectonic plates that are geologically reconstructed as velocity boundary conditions of a geodynamic model. We combine these data into a single physics-based numerical model using either sequential (forward) or adjoint (inverse) data assimilation techniques. The software package we use is a well-benchmarked finite element code, CitcomS [1]. We have further expanded the scalability and I/O performance of this code on Blue Waters.

RESULTS & IMPACT

In our first project, we evaluated the traditional hypothesis that Yellowstone volcanism is caused by a deep-rooted mantle plume [2]. We found that this hypothesis is flawed, because a hot upwelling plume is always blocked from above by the sinking oceanic plate. Therefore, Yellowstone has to have been formed by a different mechanism. This work challenges the traditional view on this important topic of intra-plate volcanism.

Our second project is to reproduce the subduction and mantle flow history below South America since 100 mega anum (100 million years). We found that the seismically observed flat slabs beneath the continent are mostly due to the subduction of thick and buoyant seafloor anomalies (oceanic plateaus) [3]. We also found that the formation of these flat slabs tears the slab itself, leading to the absence of earthquakes within the flat portion and formation of special volcanisms above [4]. The slab-induced mantle flow dominates the deformation of the surrounding mantle (Fig. 1), as confirmed by the model predicting the observed seismic anisotropy in the region [5].

Our third project concerns the mechanical strength and its lateral variation of continental lithosphere [6]. We demonstrate that the electrical conductivity of rocks is an excellent proxy for the effective viscosity of the lithosphere (Fig. 2). Consequently, this finding provides a practical way to "measure" the strength of the Earth's rigid outer shell that is otherwise difficult to estimate. This also opens a new direction of geodynamic research.

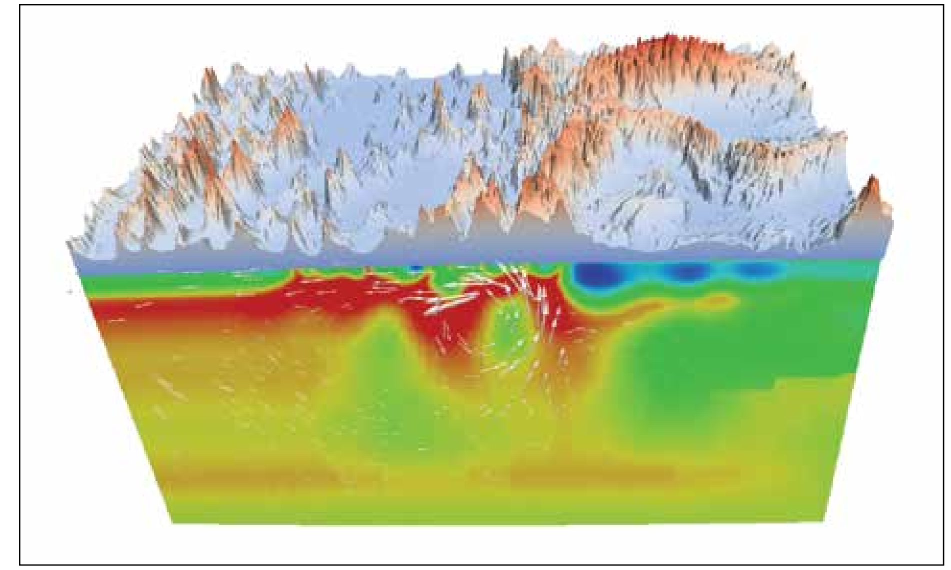

Figure 2: Lithosphere viscosity (color) and mantle flow (arrow) beneath the western United States. The viscosity is converted from electrical resistivity, and the flow is calculated from a geodynamic model.

WHY BLUE WATERS

The enormous amount of data processing and computation makes Blue Waters the best platform. The code CitcomS is community-based software, and this code has been designed and tested mostly on traditional supercomputers.

PUBLICATIONS AND DATA SETS

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