ENERGETIC DYNAMICS OF A ROTATING HORIZONTAL CONVECTION MODEL OF THE SOUTHERN OCEAN WITH SURFACE BUOYANCY AND WIND FORCING

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RESEARCH SUMMARY

The global ocean is on average stably stratified, which makes vertical mixing play an important role in distributing heat and nutrients. Vertical mixing is essential because it supplies dissolved oxygen from the surface to the deep waters and brings nutrients that result from bacterial decomposition back to the surface, where they can be used by organisms. If the ocean-atmosphere interactions change, from both directly from heat exchange and indirectly from of winds at the ocean surface, the amount of vertical mixing in the ocean will be affected. Quantifying the changes in vertical mixing is one of the important questions in oceanography today.

The Southern Ocean, part of the global ocean between the Antarctic continent and 60°S latitude, is an ideal place to study the relative contributions of differential surface heating and surface wind stress to ocean mixing. The Antarctic Circumpolar Current, which is driven by eastward winds, goes around Antarctica unobstructed by continents, unlike the currents in other ocean basins. Because of such predominantly unidirectional flow, it can be modeled in a periodic domain that decreases computational demand without sacrificing completeness of the problem. This region also experiences significant differential heating and cooling at the surface; dense water formation occurs near the Antarctic continent where the surface waters are cooled, while surface waters in the mid-latitudes receive more heat and become less dense. This problem can be studied in the form of horizontal convection, a model of a fluid flow forced by differential surface buoyancy forcing. The simulations are run on Blue Waters using SOMAR [1], which is a finite element method adaptive mesh refinement code that solves incompressible Navier-Stokes equations with Boussinesq approximation and added rotation rate consistent with the Southern Hemisphere.

For this study, several combinations of surface and wind boundary conditions and rough bottom topography conditions are considered. All cases are forced to the top surface with a prescribed density distribution matching the average meridional surface density distribution in the Southern Ocean. The simulation with only buoyancy forcing is taken as a base state, and simulations with different magnitude of wind stresses and rough or smooth bottom topography are compared to the base state. All simulations are run to a steady state before terms in the energy cycles, such as the generation of kinetic and potential energies and transfers between energy reservoirs, and vertical mixing can be quantified. From the preliminary results, even a small magnitude of wind forcing shifts the energy paradigm of the simulation into an energetic regime observed in the ocean, in which the amount of vertical mixing can be estimated from the amount of surface generation of available potential energy due to differential buoyancy forcing [2]. The rough topography enhances the amount of vertical mixing compared with the base state; however, the competing effect of wind forcing and bottom topography is still to be investigated.

WHY BLUE WATERS

The computational resources of Blue Waters were essential for this research because I was able to run simulations that have sufficiently large resolution and aspect ratio of the domain to capture forward and inverse energy cascades. Such simulations are very computationally costly, and the allocation on Blue Waters allows me to compare results from multiple simulations with varying boundary conditions. In addition to having many mesh points to allow for sufficient resolution, the simulations must also be run for months before converging to a statistical steady state. It is particularly important for the simulations with rough bottom topography where grid cells become irregularly shaped and additional resolution is required. While for the calculations of the energy budget I only need to keep the files for the last few time steps, intermediate time steps are also necessary for determining whether the simulation has converged and for making videos of the evolution of the simulation. The large storage space allocated by the Blue Waters is essential for making this part of the project feasible for running multiple simulations at the same time. With my continuing allocation I plan to extend this project to analyze the sensitivity of mixing and energetics in the Southern Ocean to changing boundary conditions that either correspond with estimated past climate conditions or future climate predictions.

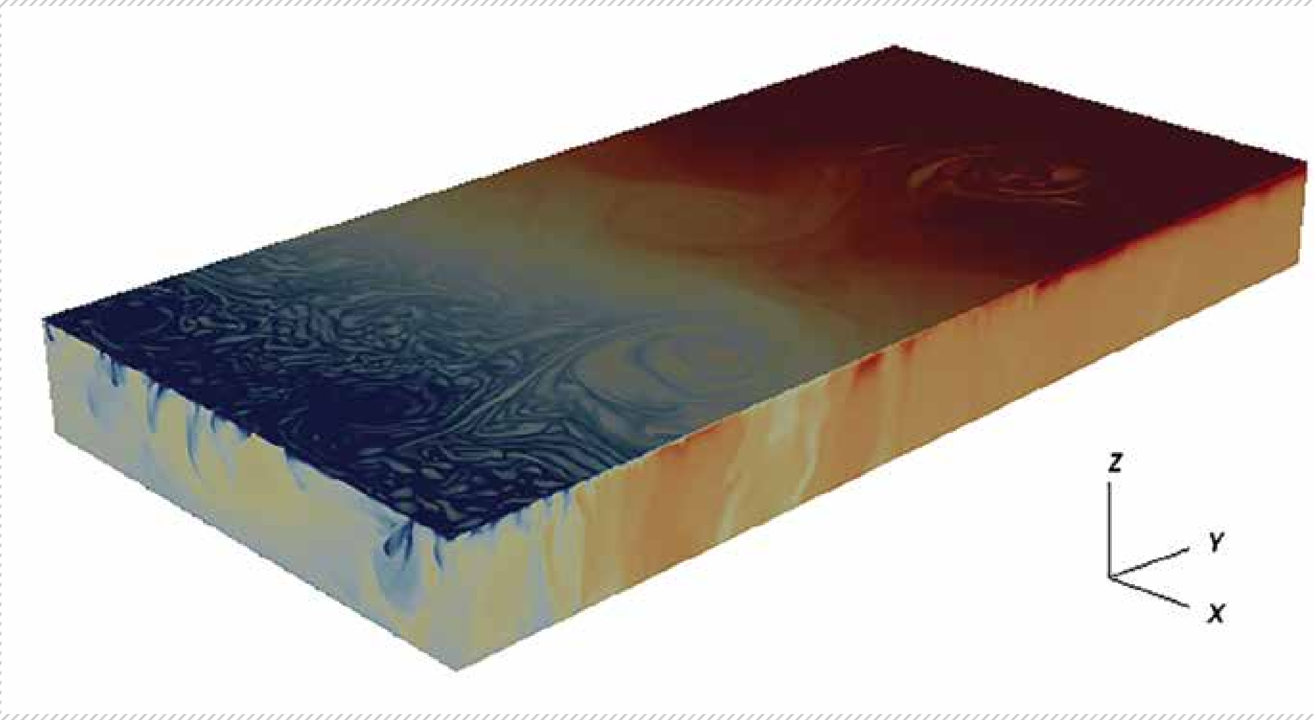

FIGURE 1: The density distribution for the simulation with realistic wind and buoyancy forcing in the Southern Ocean (north pointed into the page). Blue colors indicate cooler, denser fluids, which are sinking near the pole and red colors are warmer, less dense waters. Many eddies and complex vertical structures can be observed.

Vervara Zemskova works with advisors Brian White and Alberto Scotti and expects to complete her Ph.D. in geoscience from the University of North Carolina at Chapel Hill in May 2018. Upon graduation, she would like to continue research in an academic setting and combine her background in oceanography with the experience in supercomputing.

"My primary interest lies in small-scale physical oceanography and how such small scale mechanics affect the biological aspects in the ocean. Because continuous ship measurements of small scale dynamics are both difficult and expensive, my main focus is understanding these dynamics through numerical modeling."