Oceananigans: A Programmable, Multi-Architecture Design for High-Performance Simulation of Ocean Dynamics

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Abstract

Scientific progress in Earth system modeling is increasingly limited by software rather than theory or hardware. We present *Oceananigans*, a high-performance ocean modeling framework designed to address this bottleneck through a combination of modern language design, programmable interfaces, and GPU-first execution. Oceananigans is written in Julia and supports simulations across an exceptional range of scales, from meter-scale turbulence to global ocean circulation, while achieving state-of-the-art performance on modern accelerators.

The key architectural idea is to expose a simple, structured finite-volume dynamical core through a fully programmable, library-style interface. This design allows users to configure models, implement custom forcing and boundary conditions, run simulations, and perform analysis within a single scripting environment, without sacrificing performance. Performance portability across CPUs and GPUs is achieved through kernel-based abstractions, enabling efficient execution while avoiding domain-specific languages or code generation pipelines.

We show how this approach collapses the traditional separation between "prototype" and "production" codes, allowing numerical methods, parameterizations, and performance optimizations to be developed, tested, and deployed within a single framework. Oceananigans demonstrates how modern scientific software can reconcile accessibility with extreme performance, offering a case study in sustainable, accelerator-aware scientific computing for complex PDE-based models.