ANALYZING OCEAN MIXING AT EXASCALE: LAGRANGIAN, IN SITU, GLOBAL, HIGH-PERFORMANCE PARTICLE TRACKING (LIGHT)

The LIGHT software provides a new capability to analyze ocean mixing within the Energy Exascale Earth System Model (E3SM, e3sm.org), which simulates the interactions of atmosphere, ocean, land, and ice components of the global earth system. The particle tracking is performed within the ocean component, making it more computationally efficient than other approaches (like data post processing), and the "virtual" particle floats follow the natural motion of ocean currents, making it more accurate than other approaches.

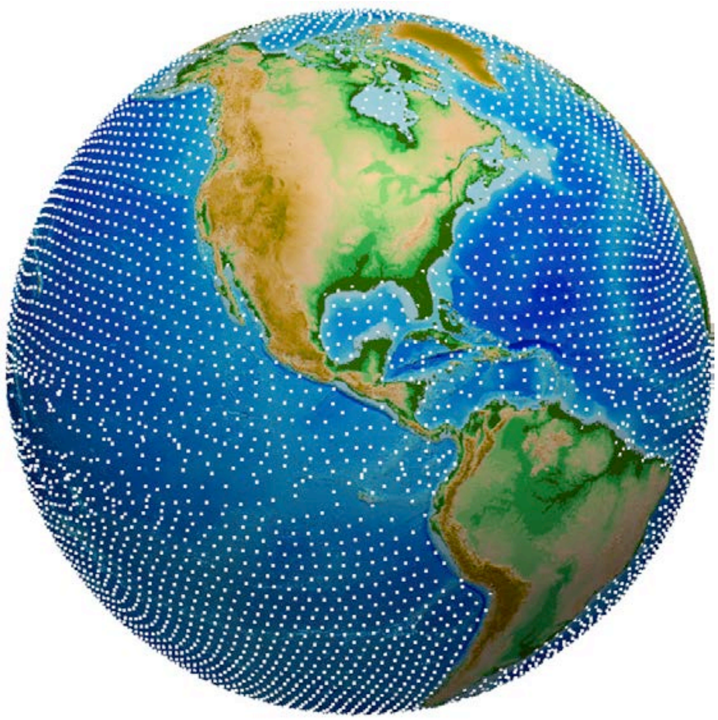

Figure 1. Global Lagrangian floats in E3SM using LIGHT, with 1 out of 5000 floats plotted for clarity.

LAGRANGIAN MIXING STUDIES

To understand the ocean and its interactions within the entire Earth system, it is necessary to analyze marine transport and mixing of heat and carbon. Such studies usually are performed in a Lagrangian (flow-following) frame of reference. The motion of Lagrangian floats (Fig. 1) is typically derived from model-output datasets generated in Eulerian (Earth-centric) coordinates. Calculation accuracy of float motion is limited in the standard approach of saving velocities to disk at low-frequency time intervals instead of using each time-step within the model to compute the float motion.

EXASCALE COMPUTING

As the models shift toward higher resolution (finer than 25 km per grid), simulations will be performed on exascale computers (processing speeds of 10^{18} operations per second), and Lagrangian particle tracking of floats will need to be calculated *in situ* (within the simulation code) to ensure spatio-temporal fidelity and to avoid prohibitive computing costs. The Lagrangian, in Situ, Global, High-Performance Particle Tracking (LIGHT)[2] analysis software was developed with this goal in mind. LIGHT operates as a module of the ocean component (MPAS-Ocean) of the E3SM — one of the first earth system models to support this capability.

MATHEMATICAL METHODS

LIGHT computes individual float trajectories by first interpolating velocity fields vertically, for example along isopycnal (constant-density) surfaces. Lateral motions are computed from interpolation[3] of the horizontal velocity field and

Get LIGHT

LIGHT is part of MPAS-Ocean v6.0. Download MPAS-Ocean for LIGHT.

- **Code – https://github.com/MPAS-Dev/MPAS-Model**
- **Docs – https://github.com/MPAS-Dev/MPAS-Documents**

temporal integration is performed by a generalized Runge-Kutta method. Operations are implemented for highly parallel computers, allowing LIGHT to be applied in the highest-resolution ocean simulations.

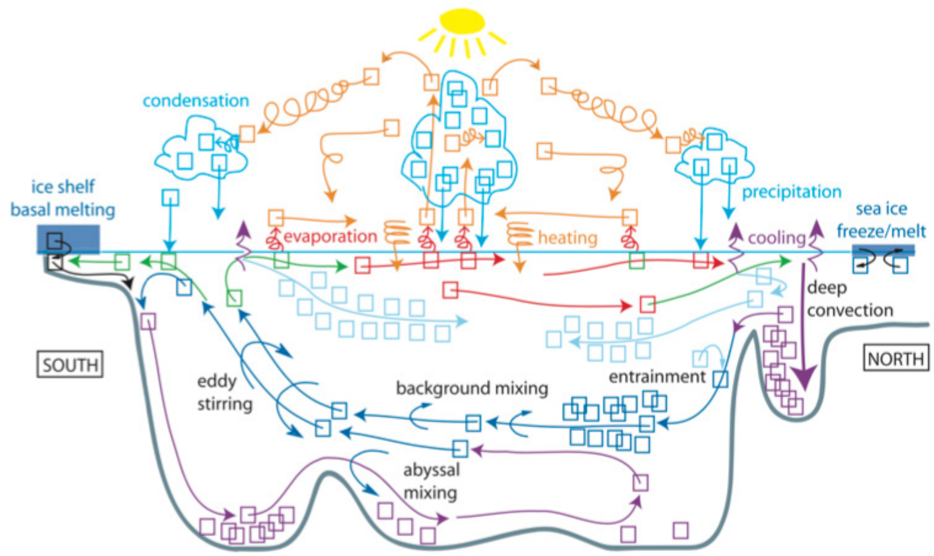

Figure 3. Schematic of water parcel interconnectivity within the global water cycle[1].

DIFFUSIVITY CALCULATIONS

LIGHT computes high-accuracy float trajectories that can be used to evaluate mixing via a diffusivity calculation[2] (Fig. 2). An idealized, mid-latitude ocean basin simulation, analogous to the Gulf Stream, used LIGHT to understand how diffusivity is affected by model grid resolution. Resolution affects simulation cost and eddy size, which in turn affect the strength of mixing[2]. The results indicate that the largest eddies contribute most strongly to mixing, but representing these requires a grid scale of at least half the Rossby radius of deformation, which is the characteristic scale of eddy size that varies by latitude and is on the order of 1 to 10 km in the Southern Ocean. Analysis of average ocean currents and eddies in a simplified model that represents the ocean in the South around Antarctica indicates that the current and eddies work together to produce an enhanced diffusivity larger than their individual contributions. This demonstrates that eddy contributions to mixing must be resolved using high-resolution (e.g., in the 1 to 10 km range for the Southern Ocean) to obtain the correct transport and mixing of oceanic heat and carbon.

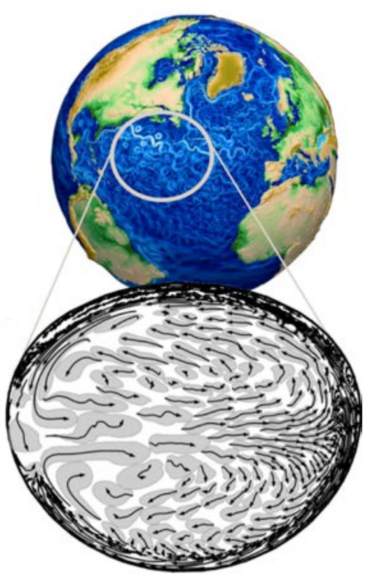

Figure 2. Idealized Gulf Stream float statistics; black arrows denote the average ocean current path and the gray area its mixing along the path. Local diffusivity is the rate at which the gray area grows perpendicular to the black line[2].

ADDITIONAL CAPABILITIES

Ocean water constituents, like salinity and temperature, affect the movement of oceanic water masses. The mixing of these constituents can be quantified by an effective diffusivity. A novel application of LIGHT is to compute mixing using outputted float trajectories, which can be used to derive an effective diffusivity[4]. This method extends the traditional concept of Eulerian-based effective diffusivity to apply it to the information-rich Lagrangian datasets generated by LIGHT. Also floats can be used as a proxy for the movement of ocean water, heat, and carbon in MPAS-Ocean.

LIGHT brings a best-in-class ocean diagnostic capability to E3SM. When applied to other E3SM components, LIGHT will foster a better understanding of the global water cycle (Fig. 3).

SUPPORT

DOE Office of Science, Biological and Environmental Research

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[2]Wolfram, PJ, et al. (2015). “Diagnosing isopycnal diffusivity in an eddying, idealized midlatitude ocean basin via Lagrangian, in Situ, Global, High-Performance Particle Tracking (LIGHT).” *J. Phys. Oceanography*, 45(8): 2114.

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[4]Wolfram, PJ, & Ringler, TD. (2017). “Computing eddy-driven effective diffusivity using Lagrangian particles.” *Ocean Modell.* 118: 94.