SWOT Science Team Proposal Summary

Project Title	Inferring Ocean Transport from SWOT
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Objectives

SWOT is designed to measure sea-surface height (SSH) . However, its value to the oceanography community depends on our ability to infer SSH-adjacent quantities related to ocean transport. <u>Our team's overarching goal is to develop robust techniques for inferring ocean transport from SWOT measurements</u>. We concentrate on two main aspects of transport: lateral velocities near the surface and vertical fluxes of tracers in the upper ocean.

In previous generations of altimetry, the inference of near-surface lateral velocities was accomplished trivially via geostrophic balance. For SWOT data, the problem will be more difficult. The imprint of internal waves on the SWOT signal means that a large fraction of SSH variance is unrelated to geostrophic velocities. Furthermore, the higher spatial resolution of SWOT means that other ageostrophic submesoscale flows associated with high Rossby numbers may complicate the relationship between SSH and velocity. Our team will develop theoretical and data-driven models for the problems and wave filtering and velocity inference using high-resolution simulations and then apply them to the first SWOT observations.

Quantifying the vertical exchange between the ocean surface and interior is key to constraining global carbon, oxygen, and energy budgets. Evidence suggests that narrow fronts are vertical-flux-hotspots that contribute a significant fraction of these fluxes, but in situ observations are sparse, and most fronts are not resolvable by current satellite altimetry. Global remote sensing at SWOT scales offers the potential to quantify the statistics of fronts, and hence to constrain biogeochemical fluxes across the global ocean. Our second objective is to develop robust algorithms to estimate vertical fluxes from SWOT observations and apply these to SWOT data.

Achieving this goal requires a model connecting frontal sea surface height (SSH) to vertical transport, and for this, a number of intertwined challenges must be addressed first. (1) SWOT will observe lateral scales where ageostrophic motions project strongly onto SSH; filtering the wave component is a central part of our first objective. (2) The ageostrophic flow itself must be decomposed: internal waves do not contribute to vertical transport (Balwada et al. 2018), but frontal processes (which are highly ageostrophic) are likely key players in vertical exchange. Moreover, the low-temporal sampling rate of SWOT data means time-averaging cannot be used to remove the wave-component of the flow. (3) Even given an algorithm to extract the transport-active velocity from SSH, one still needs process models and theory to relate surface estimates of velocity fields to vertical flux rates.

The first phase of our participation in the SWOT Science Team was focused on quantifying vertical transport in submesoscale-permitting simulations, with the goal of finding the partition between mesoscale vs. submesoscale, and balanced vs. unbalanced transport of tracers (Uchida et al., 2017, 2019; Balwada et al. 2018). This work addressed parts of each of the challenges listed above. In this next phase of our participation, our aim is to develop a complete model for reconstructing fluxes from SWOT observations.

Approach

Our overall approach is to use high-resolution simulations to develop theoretical and data-driven models for inferring transport during the first phase of the project and then apply these models to real SWOT data as soon as it's available.

Our team has already begun to investigate the application of new machine-learning techniques to the transport inference problem. Sinha and Abernathey (2019) used simulated ocean data to train a deep neural net (DNN) to estimate velocities from a small neighborhood of SSH and other observables. This model was able to re-learn the physics of geostrophy and Ekman balance. Here we propose to extend this approach to submesoscale-resolving data, where frontogenesis, internal waves and other ageostrophic effects imply messier physics.

An intermediate step will be training such an algorithm on data with submesoscale features, but free of waves. A common approach is to smooth output over a few days, but this smears away some submesoscale features, while also incompletely removing waves. Shakespeare and Hogg (2017) showed that temporal smoothing in the particle-following Lagrangian frame is more effective, as it removes the Doppler shift of wave frequencies by strong flows. Using experience gained (Sinha et al., 2019) in the analysis of particle trajectories in the LLC4320 simulation (a high-resolution global submesoscale-permitting ocean simulation product produced by NASA — see figure below for example SSH and vorticity fields), we will apply Lagrangian filtering to the LLC4320 runs. The result will be a global dataset of filtered simulated data (to be shared with the community), which will be used to train our method to extract (wave-free) submesoscale velocities from SSH. This phase of the project will be conducted in close collaboration with the french team led by J. LeSommer, who will apply similar methods to the NEMO NATL60 simulations.

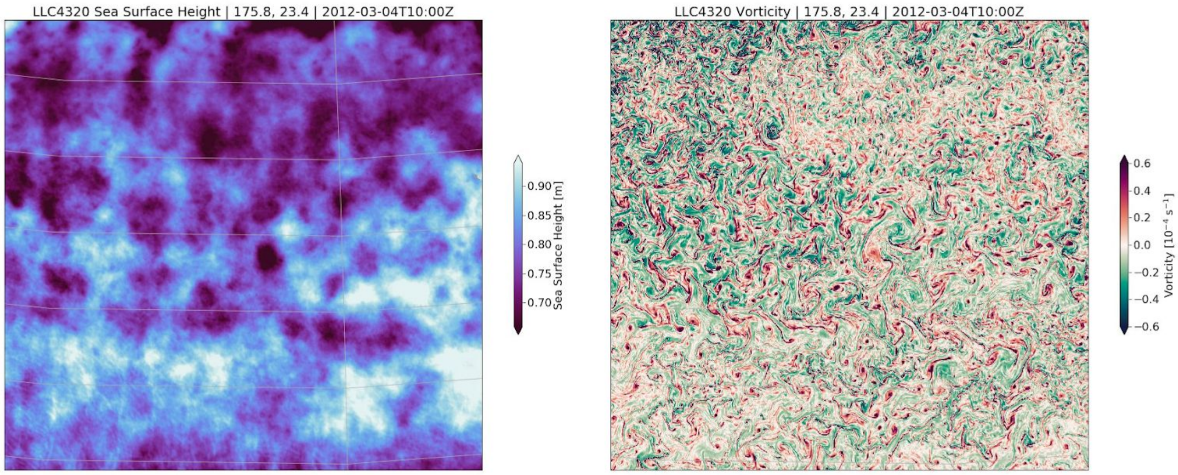

Figure: Snapshots of SSH and vorticity from MITgcm LLC4320 simulation, approximately 5 x 5 degrees in extent.

Then, we will attempt to use a deep neural net to extract the waves from unfiltered simulated SSH from SWOT-simulator-sampled LLC4320 runs. The methods, trained on simulations, will be validated against surface drifter data, which provide a ground truth velocity measurement.

Given a successful method for extracting submesoscale flows, we can return to the problem of connecting surface flow statistics with vertical fluxes. Here we will continue using the controlled submesoscale simulations from phase 1 to explore, using physics-informed machine learning techniques to attempt to learn the averaged vertical fluxes below the mixed layer, driven by filtered surface SSH statistics, and climatologies of subsurface tracer and buoyancy.

Expected results and milestones

1. Production of Lagrangian filtered surface velocity dataset from the LLC4320 simulation.

   Milestones: Release dataset of filtered velocities to SWOT community, along with publication describing computational methodology and statistical analysis.

2. Fast-Repeat Velocity Estimation from Simulated and Real SWOT Data

   Use the simulated Lagrangian-filtered surface velocity field, together with the LLC4320-simulated SWOT observations, to train ML-based velocity estimators for the fast-repeat phase. Upon the SWOT launch (estimated Sept., 2021), methods will be applied first to SWOT data and then validated with Global Drifter Program drifters.

Milestones: Publication of velocity estimation results from simulated SWOT fast-repeat data. Publication of preliminary estimates of velocity from real SWOT fast-repeat data.

3. Slow-Repeat Velocity Estimation from Simulated and Real SWOT Data

   Next, we will tackle the more difficult problem of velocity estimation during the slow-repeat phase.

   Milestones: Publication of velocity estimation results from simulated SWOT slow-repeat data. Publication of preliminary estimates of velocity from real SWOT slow-repeat data.

4. Vertical Flux Estimation from an Idealized Channel Model

   We will use existing and new idealized MITgcm simulations to train ML models to estimate vertical flux from virtual SWOT fast- and slow-repeat data.

   Milestones: Publication of results from idealized model analysis.

5. Vertical Flux Estimation from Realistic Global Model and SWOT Data

   We will finally pursue an ML-based estimation of vertical fluxes from synthetic SWOT observations in the global high-resolution LLC simulations, and apply the algorithm to real SWOT data.

   Milestones: Publication of results from simulation analysis. Publication of results from real SWOT data analysis. Providing community access to the algorithms developed by our team.

References

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