From Satellite Observations to Submesoscale Ocean Dynamics: Geostrophic Field Smoothing and Diffusion-Based Reconstruction

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Modeling and predicting ocean currents at small scales of less than 50 km help better understand ocean phenomena such as biogeochemical fluxes and nutrient flows. However, this small scale, known as the submesoscale, remains difficult to observe with traditional satellite altimetry. The Surface Water and Ocean Topography (SWOT) mission overcomes this limitation by providing high-resolution sea surface height (SSH) measurements using radar interferometry. However, instrumental noise and noise amplification make it challenging to compute velocities and vorticities from the available data. This paper models SWOT SSH fields in the Gulf of Mexico using bell curve-shaped smoothing to suppress high-frequency noise while preserving submesoscale ocean features. Vorticity fields computed from the smoothed SSH are validated against high-resolution simulations from the MIT MSEAS GRASE experiment. To reconstruct vorticity from the incomplete observations given by the satellite, a deterministic U-Net and a guided diffusion model based on neural stochastic differential equations were trained. The diffusion model achieved a low reconstruction error of 3.2×10-2, while also providing uncertainty estimates. These results highlight the potential of combining SWOT observations with generative modeling to resolve submesoscale dynamics for forecasting and climate applications. This represents one of the first demonstrations of data-driven submesoscale prediction at SWOT's unprecedented resolution, paving the way for a new era of high-fidelity ocean forecasting.

Awards Won:

Zydus Pharmaceuticals USA Inc.: Third Place Earth and Environmental Sciences