Interactions between submesoscale dynamics and sinking particles: a pre-EXPORTS study.

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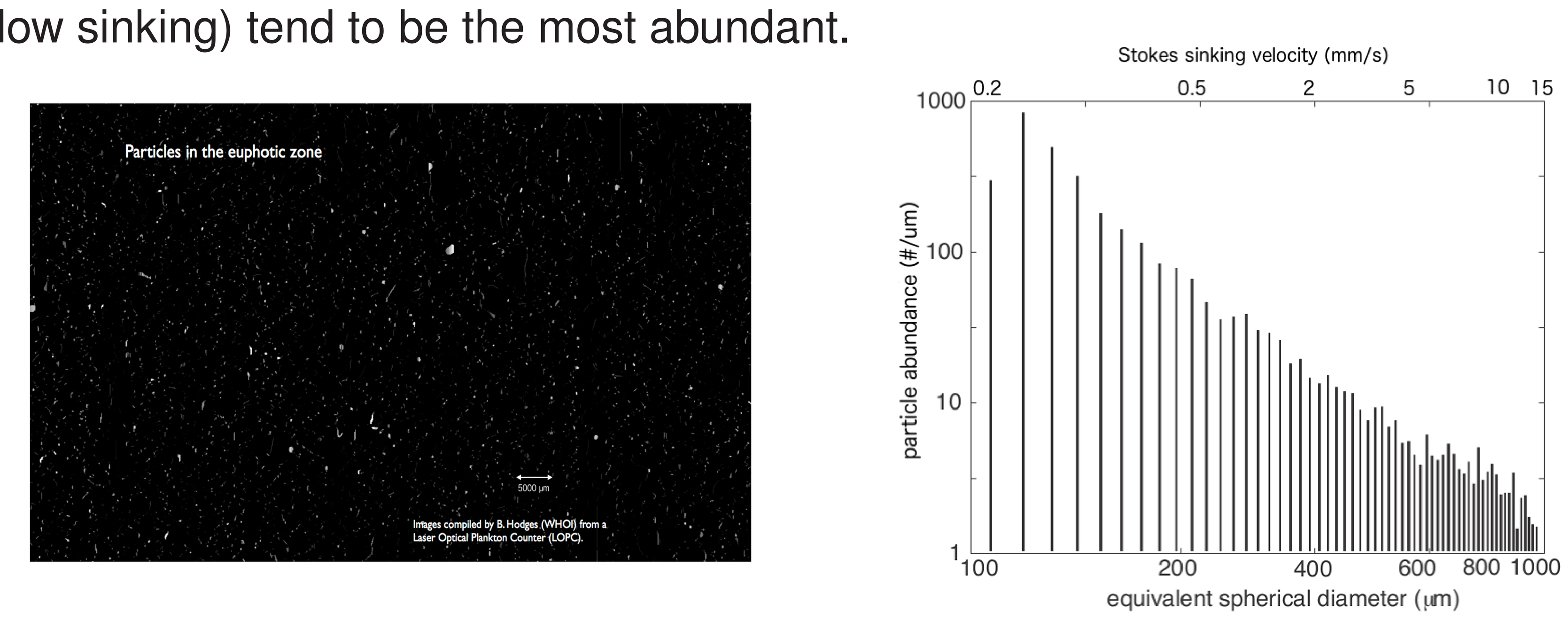
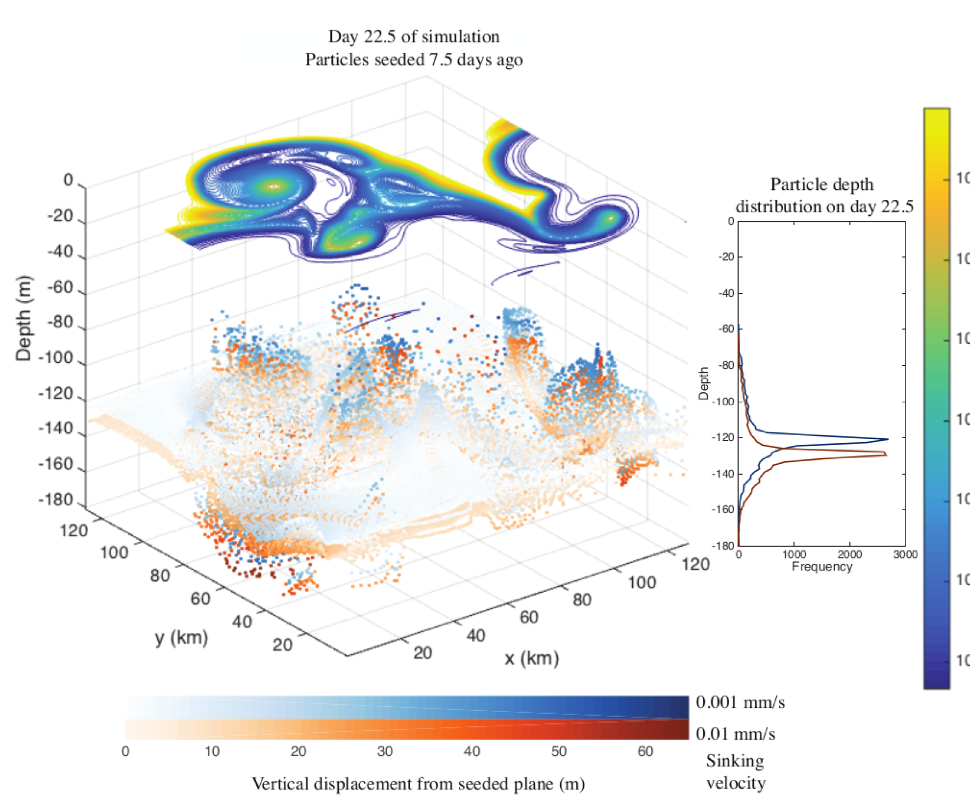
Scientific Background

- Particulate Organic Matter (POM) produced in the mixed layer is composed of a wide range of particle sizes and sinking velocities (10 - 1000 m/day). Small particles (i.e. slow sinking) tend to be the most abundant.



POM observed in the euphotic layer (left) and the associated particle size distribution (right; courtesy of M.M. Omand).

- The flow field in the mixed layer is expected to have a greater impact on smaller particle size classes, which spend more time in the mixed layer due to slower sinking speeds, resulting into a sorting effect on the particle size spectrum.
- Submesoscale features ($\mathcal{O}$(0.1-10 km)) play an important role in driving the flow field in the mixed layer:



- In the horizontal, submesoscale features are associated with strong vorticity and strain rates that enhance mixing and stirring, generating "hot spots" of POM.
- In the vertical, submesoscale features are associated with large vertical velocities ($\mathcal{O}(10^{-3}$ m/s)) capable of subducting patches of POM below the mixed layer

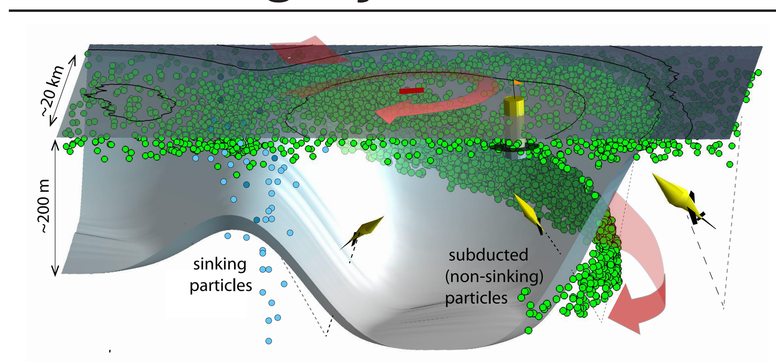
Modeled surface density field picturing an unstable front. Particles with two different sinking velocities were seeded in the model at a depth of 120 m; 0.001 mm/s (approximately 0.1 m/day; in blue) and 0.01 mm/s (approximately 1 m/day; in red). Some particles are transported upward by the fluid velocity, and others downward, but the particles are seen to separate on account of their different sinking speeds. A depth distribution of particles (inset) shows how the different sizes become sorted with time.

Research Objectives

Export of POM

- Develop a mechanistic and predictive understanding of the export of POM to depth as a function of
  1. the spatio-temporal variability in the production of particles,
  2. a range of particles with a spectrum of sizes, masses, and sinking velocities,
  3. the physical setting comprising mixed layer depth, stratification, presence of fronts and eddies, air-sea fluxes, and the flow field.
- This will be achieved by:
  1. Developing a model for meso- and submeso-scale ocean dynamics statistically representative of ocean conditions.
  2. Seeding Lagrangian particles with a range of properties in the model to simulate POM.

Observing System Simulation Experiments (OSSEs)



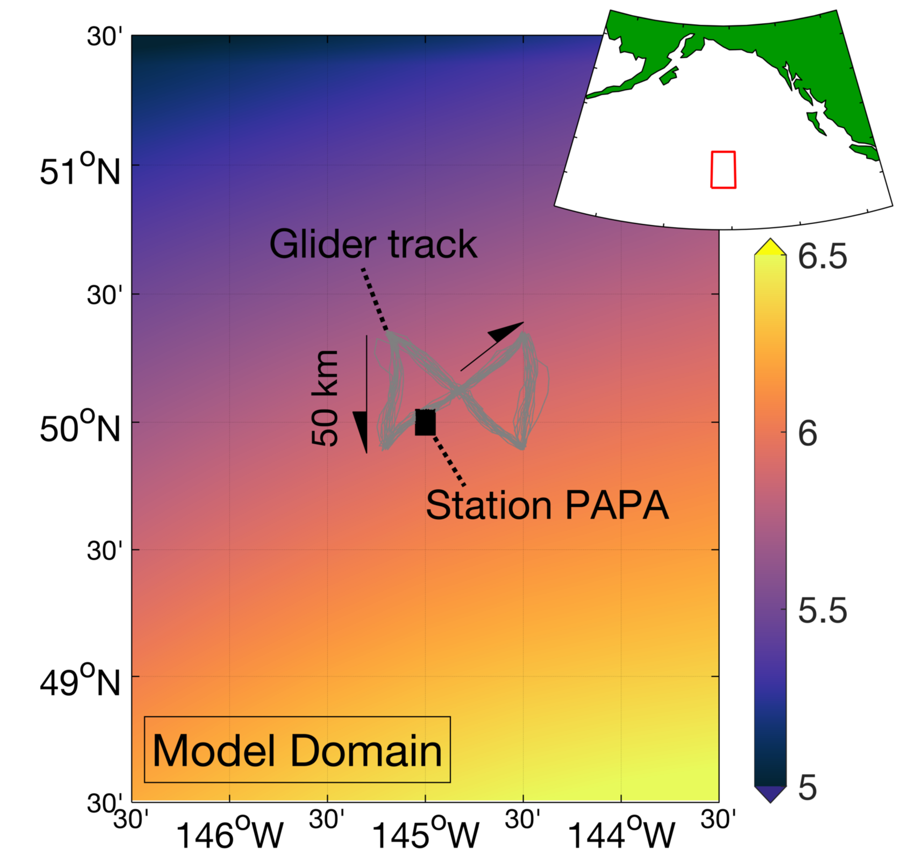
Schematic showing the sorting of a plume of POM due to advection and sinking. Blue and green particles have different sinking speeds.

1. Assess feasibility of statistically estimating the export flux with point measurements.
2. Test Eulerian and Lagrangian sampling strategies using virtual autonomous platforms.
3. Examine scale-up of virtual observations to represent the integrated export flux.

Data Mining and Numerical Simulations

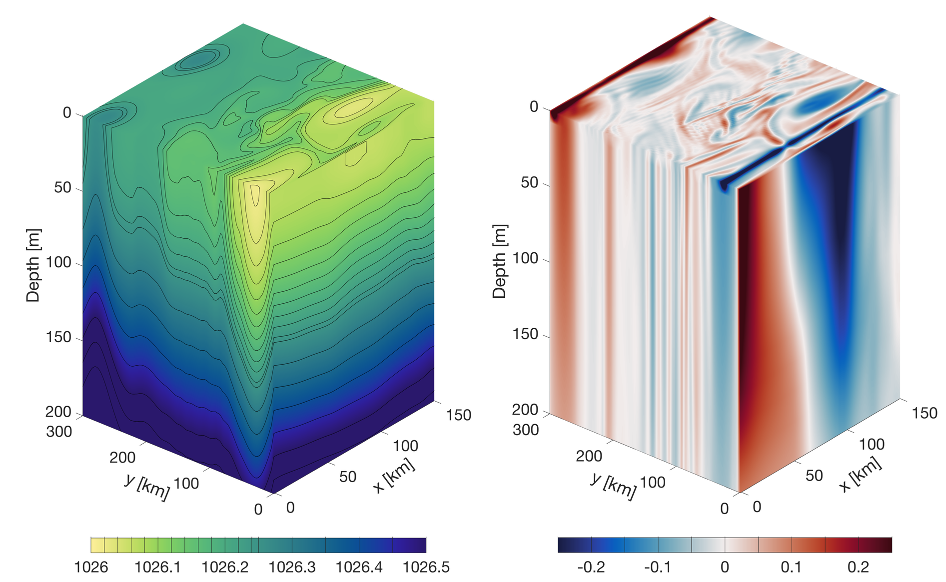
Observations

- **ARGO floats:** used to prescribe temperature and salinity gradients for model initialization.
- **Station PAPA:** Time series of wind stress and heat fluxes used for model forcing.
- **Underwater Gliders:**
  - Measured T, S, O_2, Chl F and backscatter for 18 months (2008-2010).
  - Used for tracking both seasonal cycle and spatial gradients in the region.
  - Used to validate both model physics and particle dynamics.



Map of the region modeled in PSOM. Color scheme shows the surface temperature from ARGO float used to initialize the model.

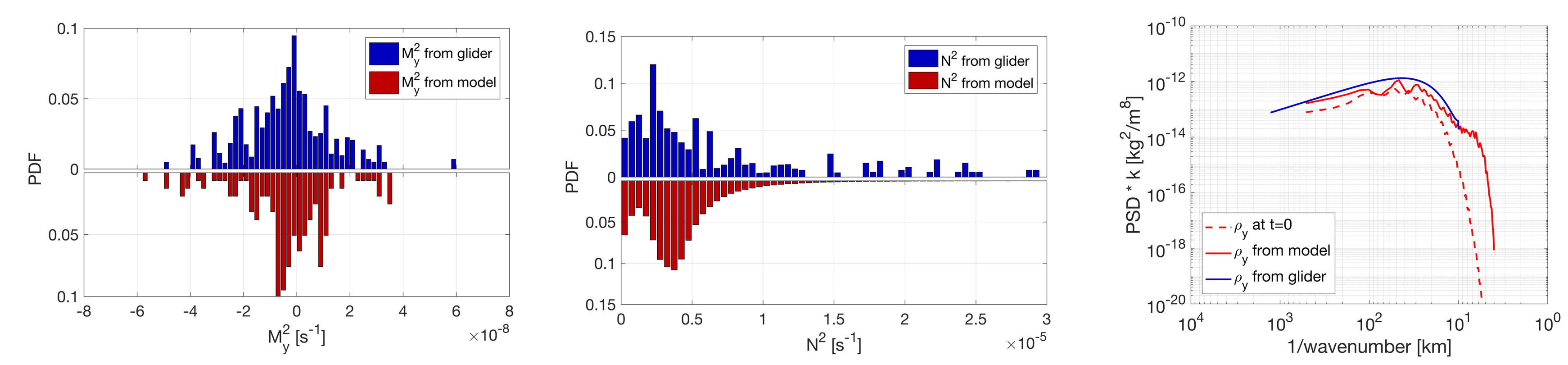
Submesoscale features in PSOM



Spun-up surface density (in kg/m^3; left) and vertical component of vorticity ($\zeta = v_x - u_y$) normalized by the planetary vorticity f (right).

- Model is run for 90 days after initialization to spin-up an eddy field.
- Filament-like features can be observed at submesoscales of the order of $\mathcal{O}$(10 km).
- Submesoscale features are associated with high vorticity, suggesting large vertical velocities.

Model vs. Observations

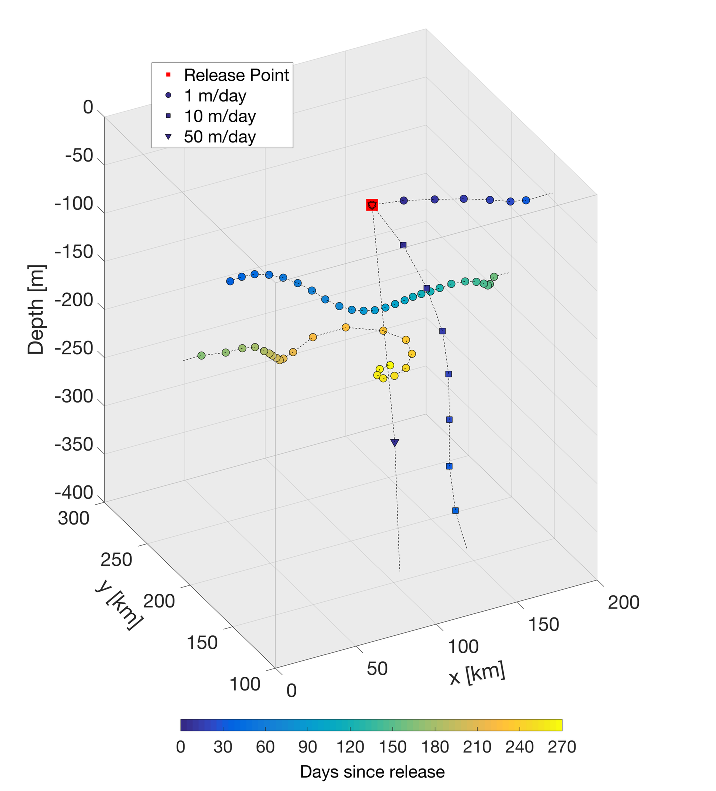


Normalized PDFs of M_y^2 ($M_y^2 = -g\rho_y/\rho_0$; left), and the buoyancy frequency N^2 (right) computed from the glider data (blue) and the model results (red) near the surface.

Variance-preserving wavenumber spectra of the meridional density gradient ρ_y.

- After spin-up, the power spectral density (PSD) shows an increase at submesoscales compared to the PSD at initialization, demonstrating the development of submesoscale features.
- Good statistical agreement between numerical simulation and glider observations.
- Model results to be representative of ocean conditions of the Station PAPA site.

Particle Tracking



- Particles are seeded in PSOM and advected with the model flow field.
- Particles are prescribed a range of sinking velocities to simulate size spectrum.
- Slow-sinking particles are more affected by the horizontal flow.
- Physical and dynamical conditions affect the horizontal and vertical transport of particles as they are sinking.

Particle trajectories of three selected particles seeded in the same location (red square) and sinking at three different rates: 1 m/day (circles), 10 m/day (squares), and 50 m/day (triangles). The color scale represent the number of days since release. Note the periodicity in the x-direction.