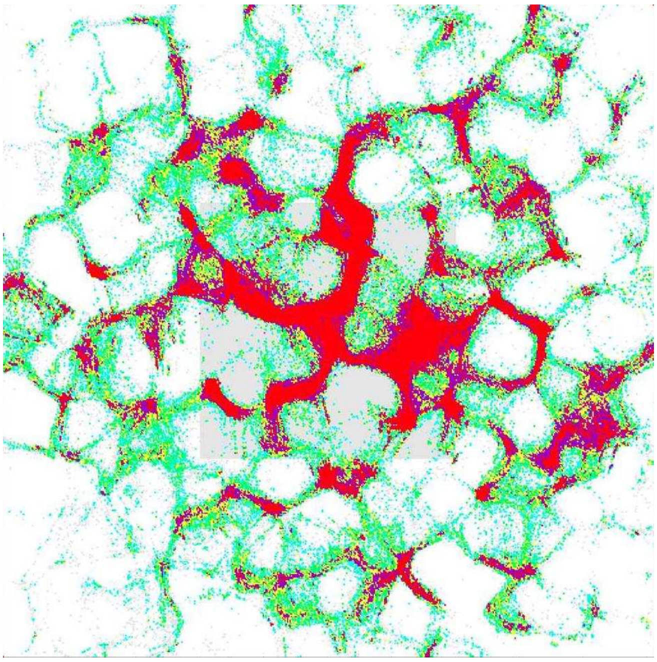
Proposed PhD Research Project:

Transport and Clusterization of Floating Particles in the Ocean

1. Summary



Ocean circulation is characterized by complicated mesoscale and submesoscale turbulence acting on length scales from a few to hundreds of kilometres, and on timescales from days to months — this set of phenomena is an active research topic involving many fundamental and practical aspects. On the ocean surface there are floating substances — plastic litter, oil spills, plankton, floating ice, and wreckage debris — that are constantly moved around and redistributed by the ocean circulation in a complicated and poorly understood way. There are many practical needs involving prediction of floating substances, and most of the uncertainties and deficit of fundamental understanding come from the transport effects by the oceanic turbulence. The progress is hindered by the lack of (expensive) in situ observations and by the enormous computational burden required to brute-force resolve the mesoscale and submesoscale turbulence in operating-forecast general circulation models. Thus, the situation is favourable for theoretical investigation of underlying physical processes, building up foundations of predictive understanding, and development of relevant and computationally inexpensive mathematical transport models for practical applications.

This Project aims to explore one of the key phenomena — transport and clusterization of floating tracers — from the theoretical, process-study and modelling perspectives by focusing on the key physical processes and employing wide range of applied mathematical methods. The student will benefit from the interdisciplinary nature of the Project that combines Geophysical Fluid Dynamics and Mathematical Modelling.

2. Research Aims

The **motivation** is to gain predictive understanding of the concentrations and spatio-temporal evolutions of practically important substances floating on the ocean surface. The **approach** will be systematic theoretical analysis of a set of physical processes represented by fluid-dynamical and kinematic models. The **objectives** are: (1) to produce and analyze phenomenology of *clusterization*, which is emergence of specific patterns and structures of tracers; (2) to gain fundamental understanding of the underlying physical mechanisms and their relative importances; and (3) to develop simple mathematical models (e.g., stochastic Lagrangian, diffusive Eulerian) for representing the clusterization either separately or as parameterization in general circulation models. Focus will be on how mesoscale and submesoscale oceanic turbulence contributes to *concentration clustering* via (1) transient and inhomogeneous horizontal velocity divergence due to ageostrophic motions, (2) Ekman velocities due to the accompanying ocean-atmosphere coupling, and (3) inertial effects, and to *structural clustering* via persistent local correlations that result in stirring effects, such as long-range transports (e.g., inside vortex cores), partial transport barriers (e.g., across fronts) and emergence of coherent Lagrangian patterns (e.g., templates of robust tracer patches). Clusterization statistics, both transient and equilibrated, will be systematically extracted, sorted out, and interpreted. Investigation of specific physical factors (and their combinations) will include: (i) roles of different flow features (e.g., ageostrophic surface divergences associated with coherent vortices, wave turbulences, various spatio-temporal eddy correlations, fronts); (ii) effects of tracer properties (e.g., density, lifetime, particle sizes); (iii) external influences of small-scale diffusion or stochastic fluctuations and of large-scale shear.

3. Project Specifics

Practically important substances (here, tracers) distributed on the ocean surface — plastic litter, oil spills, plankton, floating ice, and wreckage debris — have tendency to form both concentration clusters (i.e., compact regions of aggregation) and structural clusters (i.e., persisting patches).

So far, the emerging theory of stochastic clusterization focuses on Lagrangian particles and explores their geographical and statistical distributions in highly idealized, random velocity fields. This Project aims at major breakthrough on the subject by considering physically and dynamically constrained flows dominated by quasi-2D mesoscale and submesoscale eddies, as well as several most relevant physical processes. We'll consider 3 main physical processes resulting in converging surface velocity fields and, therefore, responsible for the concentration clusterization in different eddy fields: ageostrophic advection (on the top of geostrophically balanced eddies); mesoscale Ekman advection (due to differential stress between air and water); and inertial drift (due to floating-tracer/fluid density contrast and finite sizes of tracer particles). Other relevant processes, such as downwelling, overturning, convection and gravity waves will be left aside, because they are either geographically localized or operate beyond the targeted range of eddy scales.

Mesoscale eddy fields will be represented by either dynamically generated geostrophic turbulence (from beta-plane quasigeostrophic model forced by different imposed vertical shears and controlled by other parameters) or their simplified kinematic approximations (e.g., as superposition of deterministic or stochastic flow patterns). Ageostrophic flow field will be reconstructed and added (e.g., on the basis of omega equation solutions), Ekman flow correction will be calculated interactively, inertial effects will come from the Maxey-Riley dynamics (or its simplified form); and extra effects will come from tracer lifetime and small-scale diffusion. All combinations of these physical factors, wide ranges of parameters, and various flow morphologies (e.g., different eddying flow regimes and ensembles, controlled by parameters of the dynamical model and by kinematic approximations, will be systematically explored. Here is specific situation for the sake of illustration: a cyclonic vortex core in the southern hemisphere (negative Coriolis parameter) will be associated with the ageostrophic divergence, Ekman divergence, and inertial convergence of floating tracers; on the other hand, submesoscale filaments in the mixing zone around the core will produce completely different clusterization phenomenology.

Structural clusterization is largely controlled by coherent flow structures, that result in complex stirring patterns of tracer patchiness, homogenization, and both long-range and inhibited types of transport. We'll systematically explore nonlinear and poorly understood interplays between both types of clusterization. Statistical laws of clusterization will be extracted from Lagrangian and Eulerian analyses of tracer particle trajectories and concentrations (e.g., by considering concentration PDFs, spatio-temporal spectra, trajectory-following velocity divergence and deformation tensor, cluster strength and distance functions, relative particle dispersion, cluster measures and indices, etc.). These laws will be related to flow patterns and features, and physically interpreted.

Guided by the above process studies, and facilitated by the accumulated expertise of the group, we'll start developing simple mathematical models of clusterization by incorporating randomness in drift terms of stochastic particle models and in eddy diffusivity (tensor) coefficient of advection-diffusion tracer models.