Proposed PhD Research Project:

Clustering of Floating Tracers

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Big Picture. The ocean circulation is characterized by complicated types turbulence acting on length scales from hundred of meters to hundreds of kilometres, and on timescales from hours to months — the corresponding set of phenomena is an active research topic involving many fundamental and practical aspects. On the ocean surface there are many floating substances — plankton and marine life, floating ice, microplastic litter, oil spills, sargassum and wreckage debris — that are constantly moved around and redistributed by the ocean circulation in a complicated and poorly understood way. Many in-situ measurements of the ocean are also taken by surface drifters and internal floats attached to specific density isosurfaces — these devices are also influenced by the clustering.

There are many practical needs involving prediction of floating substances, but there is also big gap in the fundamental understanding of their transport and patterns. This Project aims to research the key phenomenon: strong tendency of the floating substances to form clusters, such as those seen in Fig. 1. Within some evolving turbulence, the clusters may be viewed as compact features (e.g., blobs or filaments) containing anomalously high concentration values of the tracer considered; the clusters are surrounded by voids of the tracer concentration. These flow features experience chaotic advection and stirring, but they are also governed by variety of other physical processes.

The PhD student leading the Project will benefit from the Project's interdisciplinary nature that combines Geophysical Fluid Dynamics, Mathematical Modelling, Statistics and Scientific Computing, as well as strongly links to Environmental Sciences.

Figure 1: Illustration of the clustering process driven by submesoscale flows: observed distribution of chlorophyll in the Baltic Sea. Any floating material, from fragments of ice to microplastic, tends to cluster into high-concentration features — this has profound effect on many physical and biogeochemical processes, including marine life. Mathematical models and physical understanding of the clustering are only beginning to emerge.

Main Objectives. The Project aims (i) to develop an hierarchy of mathematical models for different regimes of clustering driven by different physical processes, (ii) to understand the corresponding solutions and involved mechanisms, (iii) to develop analytical tools and methods for dealing with the clustering, and (iv) to provide guidance for the oceanic observational programs and biogeochemical modelling communities. Both the Eulerian and Lagrangian frameworks will be used for dealing with the clustering, and objective comparisons will be made for their ups and downs.

Work Plan. Clusters can emerge due to chaotic stirring and fragmentation of existing tracer gradients, but there is also even more important mechanism of exponential clustering, which is due to the tendency of positively buoyant tracers to float and, hence, experience 2D surface velocity divergence of the otherwise 3D non-divergent (i.e., incompressible) flow field. A good example of the diverging 2D surface velocity is ageostrophic advection accompanying geostrophically balanced mesoscale synoptic eddies. The other examples are Ekman drift, due to differential stress between air and water, and Stokes drift due to surface gravity waves. In these physical situations, spatio-temporal correlations, statistical moments and anisotropicity of the flow velocity field begin to matter decisively on the induced clustering process. Inertial effects, such as those described by the Maxey-Riley formalism (Maxey and Riley 1983) and dependent on floating-tracer/fluid density contrast and finite sizes of tracer particles, are also important and affect clustering. The least studied in the context of clustering are non-conservative effects due to reactions between various tracers, such as various species of marine life, nutrients and pollution — here clustering research connects to biogeochemical processes and modelling. Finally, effect of small-scale diffusion will be also taken into account, as it naturally limits intensity of growing clusters.

The Project will follow several parallel lines of research, simultaneously focusing on different but complimentary themes. For example, it may focus: on the role of anisotropicity and waviness in turbulence, on the Maxey-Riley equation and inertial effects, on the Ekman-drift effects, and on developing a family of increasing-complexity biogeochemical models. The ultimate research agenda will be adapted towards what the student likes most of all. For example, it can be significantly biased towards the search of optimal scenarios for oil spill clean-ups or for seeding out plastic-eating bacteria for micro-plastic clean-up. Another option is to consider clustering and its effects in models with actively propagating (in vertical) plankton species and with diurnal variability.

Depending on the specific research goals, the employed flow models will range from simple kinematic to intermediate-complexity kinematic, and further to fully dynamic, with different levels of complexity. One of the important outcomes will be developing methodologies and mathematical tools for clustering analysis, on the top those already existing.

Interactions of the student with ocean observationalists and biogeochemical modellers will be encouraged. This Project is a unique opportunity for applied mathematicians to lead the geophysical research communities.

References

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