Proposed PhD Research Project:

Hyperparameterization Framework for Mesoscale Oceanic Turbulence

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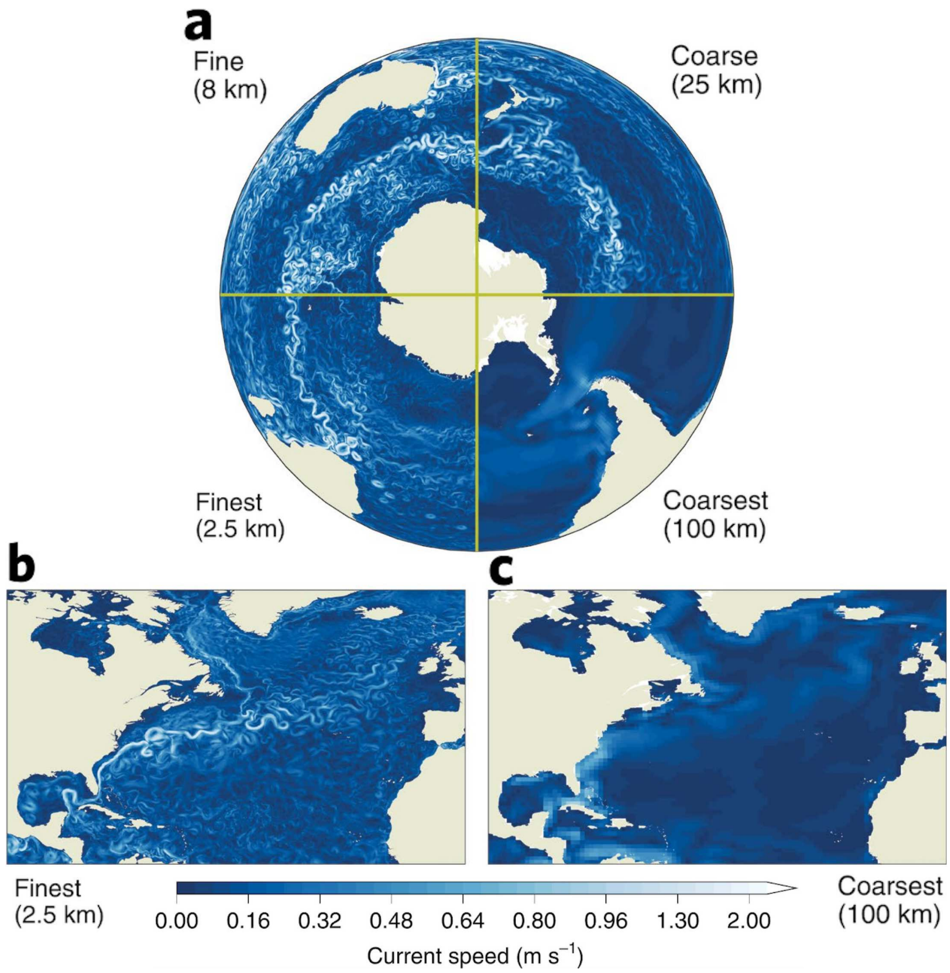

Figure 1: Illustration of the effect of spatial grid resolution on the quality of general circulation model solutions. Refining grids from coarse ($\sim$100 km interval) to relatively fine ($1-10$ km) results in dramatic improvement of the solutions, because the models begin to resolve the oceanic mesoscale (weather-type) turbulence, which in turn is crucially important for maintaining global climate variability. An aspiration of ocean modellers is to achieve fine-grid quality of solutions on coarse grids — this motivates theoretical search for *parameterizations*, that is, simple representations of missing turbulent effects.

Project Description

Big Picture. This Project is for a student who wants to develop skills in ocean modelling, dynamical systems, big-data analyses and scientific computing. The main goal is to meet the growing demand for the use of high-resolution simulations and their ensembles in ocean forecasting systems, in order to improve the near-term climate forecast and to extend its range. The stumbling block is so far inability to develop accurate and practical parameterizations of turbulence, that would allow use of computationally feasible coarse-grid numerical ocean models. The classical approach towards practical parameterizations focuses on reconstruction of the missing under-resolved physics, whereas this Project is based on a non-orthodox hyper-parameterisation (HP) approach based on the dynamical systems vision and theory.

Research Program. This project offers a unique opportunity to work at the interface of idealized ocean models mainly used for development of new methods and process studies, and comprehensive ocean models used in the leading weather forecast institutions (MetOffice, ECMWF, etc.), for providing operational weather forecasts and future climate predictions. The Project assumes going all the

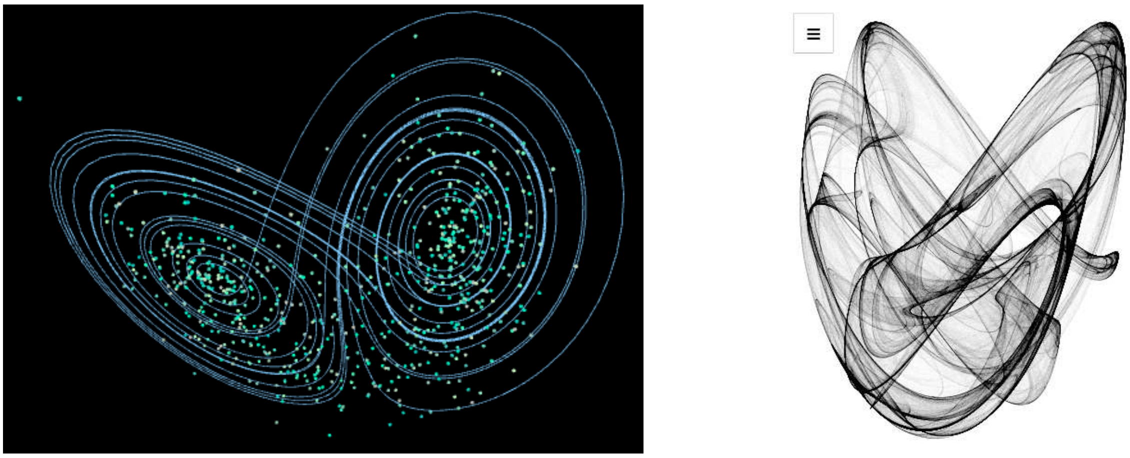

Figure 2: Dynamical systems approach translates evolution of a model solution, such as any of those in Fig. 1, into trajectory of an image point travelling in a hugely multi-dimensional phase space of the corresponding multi-dimensional dynamical system. Novel hyperparameterization methods correct trajectories in phase spaces, and this is translated into the corresponding corrections of the general circulation models. *Left panel* shows a data-driven trajectory on the Lorenz attractor, that is governed and steered by information stored in the indicated reference points. Now, imagine much more complicated phase-space attractor, as the one shown on the *right panel*, but in a million-dimensional phase space: Can you steer a trajectory (i.e., an evolving coarse-grid global ocean circulation) to follow this attractor, hence, to reproduce a realistic ocean?

way from original ideas, to their conceptual verification and tests in conceptual and low-dimensional dynamical systems, to the ultimate implementation in realistic ocean models.

The Research Program will be gradually unfolding from relatively simple low-resolution models allowing for fast testing and calibration of new HP methods, going through high-resolution realistic models for perfecting the methods, to its final destination – applying the methods within the context of ultra-high-resolution configurations intended for the use on exascale-class computers of the future. The whole Program is tailored with one goal in mind: advancing high-resolution ocean forecast and the use of large ensembles with elevated prediction skills and extended forecast horizons.

The ocean general circulation is the most computationally intensive part of any comprehensive ocean-atmosphere forecasting system and, therefore, its most limiting factor. This is because the model needs to resolve mesoscale eddies, which induce crucial effects on the large-scale circulation. The situation is aggravated by the need to produce ensembles of solutions for the probabilistic ensemble forecast, but the capabilities are severely limited by computational resources. Ocean ensemble forecasts in eddy-resolving regimes are far beyond what supercomputers will be able to compute over the next decades, and here comes in the HP approach which allows to achieve this goal within only a few years. The Project is of high-impact nature for the following reasons: (i) striking novelty in contrast with the mainstream parameterisation approaches that focus on small-scale physics, (ii) ambitious scale of research program that goes from development of the methodology applied in conceptual models to working with the most comprehensive oceanic data sets and models.

Finally, this Project will allow the student to gain experience not only from combining ocean modelling with dynamical systems theory, but also to get the best out of the multi-institutional arrangement between the National Oceanographic Centre (NOC) and Imperial College London.

References

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