Scenario DOCTORAL TRAINING PARTNERSHIP

NERC SCIENCE OF THE ENVIRONMENT

A novel approach to modelling small-scale cloud variability in the atmosphere.

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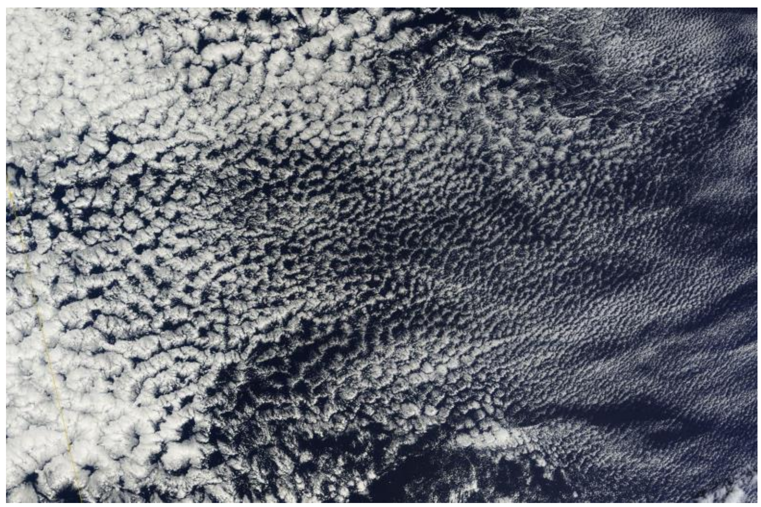
Why do large-scale patterns of clouds form, and what impact do they have on the mean atmospheric flow? How can we represent this in large-scale models?

When we design weather-forecasting and climate models we have to spatially and temporally average over ('parametrize') smaller scales of the atmospheric flow. Our parametrizations are generally based on our understanding of idealizations, typically the assumption that the smaller-scales are horizontally homogeneous and in steady-state (equilibrium). The resulting parametrization thus produces horizontally homogeneous steady-state solutions. In reality, even where this is a good approximation, the real flow has variability at scales that are larger than the dominant energy containing scales of the process being parametrized but are important for other aspects of the system.

For example, convective clouds may be close to equilibrium, but one needs to average over thousands of km to achieve a uniform average – averages over the scales represented in climate models, ~100 km, have variability which may be important in driving the large-scale circulation. One consequence of this is that weather forecast models can over-estimate the certainty of a forecast because the model is inherently less variable than reality.



MODIS Satellite image showing cloud developing over the northern Pacific west of California on 8th December 2015. The area shown is about 1000 km wide. (Courtesy NASA Worldview)

Over the last decade or so, a great deal of activity has focussed on representing this additional source of variability through stochastic versions of the parametrizations. This has met with some success, and operational forecast systems now routinely include stochastic parametrizations as part of an ensemble of forecasts designed to estimate the uncertainty in the forecast. However, the amplitude, and the space and time correlation of the stochastic process are generally tuning parameters, utilising very simple models of space/time correlation. These are not capable of representing the organized features (such as cells or rolls) that emerge from the flows being parametrized.

In parallel, there has been a revolution in our understanding of the structure of turbulence. This has been based on identifying the coherent structures in the flow and then studying their dynamics. By focusing on these structures, the enormously complex flow can be reduced to a relatively simpler or 'lower order' dynamical system. The objective has then been to understand the properties of such low-order dynamical systems.

In this project we propose bringing together these two fields to investigate whether the extremely low-order approximations of a flow, combined with conventional averaged parametrization of the overall flow can be used to represent the larger-scale variability within the flow as well is its mean properties.

The longer-term aim is to understand a cloudy system (shallow, non-precipitating cumulus, progressing eventually to deep, precipitating, cumulo-nimbus). However, the starting point will be dry systems that have already been studied from a coherent-structure viewpoint in the literature. The simplest is the neutral surface-layer (the failure of large-eddy simulations to reproduce correct mean profiles without an appropriate 'stochastic-backscatter' term is the first justification for stochastic parametrizations). However, buoyant convection is of more relevance and some preliminary work has been undertaken by a previous student using 2D Rayleigh-Bénard Convection. We plan to start by adapting this approach to the convective atmospheric boundary layer (CBL).

The project will use two and, eventually three-dimensional simulations of the CBL, and develop a truncated analytic model of the CBL. Specific hypotheses to test are:

1) It is possible to represent the variability of the CBL using a low-order representation of the system with additional modelled terms to represent the impact of the truncated terms and the larger-scale decorrelation of the larger-scale structures?

2) Can a combined parametrization be constructed with the correct mean behaviour and correct larger-scale variability?

Student profile:
This project would be suitable for students with a degree in (ideally) mathematics, physics or a closely related environmental or physical science with the aptitude to learn to use and apply advanced methods such as Galerkin projections, to understand both stochastic processes and dynamical systems. However, while a level of mathematical rigour is expected, this needs to be combined with physical insight. Experience with using and writing numerical models and processing substantial amounts of data will be an advantage. Good oral and written communication skills are desirable but in particular this project would suit a student with a strong interest and enthusiasm for mathematical problem solving.