Scenario
DOCTORAL TRAINING PARTNERSHIP
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SCIENCE OF THE ENVIRONMENT

Improving convective storm simulations through scale-adaptive and flow-adaptive sub-grid methods

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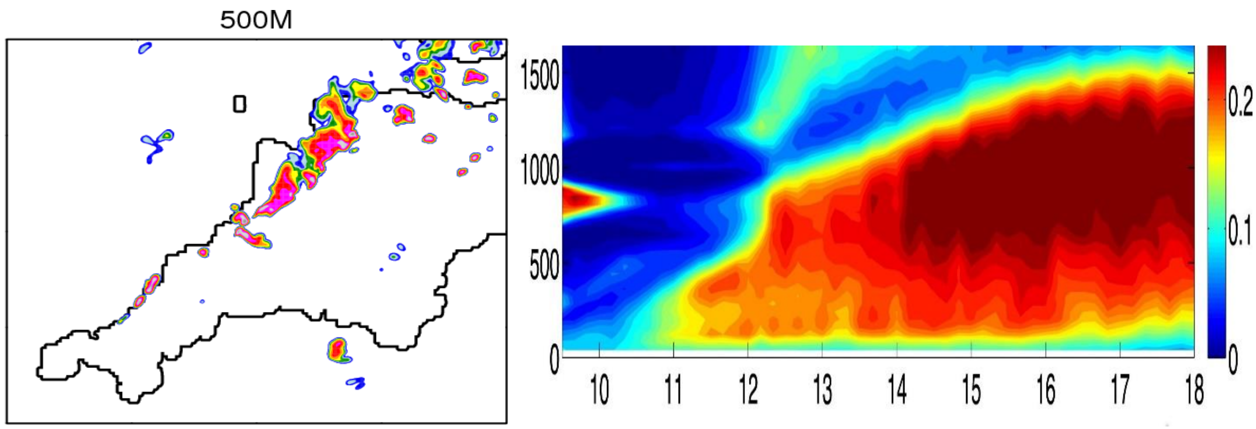
The project is concerned with improving the numerical simulations required for short-range numerical weather prediction and small-scale regional climate prediction. Over the past decade, such simulations have become practical at "convection-permitting" resolutions. Convection-permitting simulations have enabled a step change in our forecasting capabilities because individual convective storms can now be simulated directly with the numerical model (e.g. figure on the left). Many high-impact weather events are associated with such storms, particularly in cases of flash flooding and damaging wind gusts.



Left: an example of output from a convection-permitting model showing hourly rainfall totals for a storm over Cornwall. **Right:** an example showing the time of day (horizontal axis) and height (vertical axis) dependence of the "Smagorinsky parameter" as calculated using the dynamic technique. The Smagorinsky parameter is a key quantity controlling the turbulent mixing in models and is commonly assigned a fixed value of 0.23. However, the example simulation was much improved by applying these dynamic variations.

There continues to be a steady increase in the use and reliance on such models, and their benefits are well recognized. However, that experience has also revealed some important issues and limitations.

a. The simulations are strongly sensitive to the model resolution. Increases in model resolution do not translate into improvements in simulation in any straightforward way. Indeed, we have recently found evidence that key metrics do not converge in current models even at very high resolutions.
b. The simulations are strongly sensitive to choices made in the treatment of turbulent mixing.
c. The simulations are strongly sensitive to assumptions about cloud formation and microphysics.

These issues are strongly related. In reality processes that happen on smaller scales than the model grid interact with and influence the processes that take place on larger scales. In "model world" the smaller scales simply do not exist, but we try to mimic their effects by introducing extra assumptions about turbulent mixing and cloud schemes. It is those assumptions that create problems.

In the engineering fluid dynamics community, improved model behaviour as a function of resolution has been achieved using "dynamic" techniques in which key turbulent mixing parameters are no longer prescribed. Rather, they can be computed "on the fly" during the simulation as a function of the evolving flow (e.g. figure on the right). The key principle invoked in making the computation is to ensure respect for the proper scale-dependence of the turbulent characteristics of the flow.

Compared to the current applications of the technique, simulations of convective storms have additional thermodynamic and microphysical complications (or, as we like to think of it, additional physics that makes the atmosphere produce such rich and interesting forms of flow). This PhD project will extend and enhance the dynamic technique to develop a scale-adaptive and flow-adaptive sub-grid turbulence model that is suitable for simulations of convective storms at convection-permitting scales.

Training opportunities:
The student will be trained in the dynamics and thermodynamics of the atmosphere, numerical modelling and data analysis. Training and support will be given for running and developing the new Met Office NERC community cloud model (MONC).

Student profile:
The project would be suitable for students with a 1st or upper 2nd class degree (or equivalent) in meteorology, mathematics, physics or a closely related quantitative environmental or physical science. The disposition to follow a theoretical approach and/or existing skills in programming and/or data analysis would all be assets in getting off to the strongest start, but full training will be provided.

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