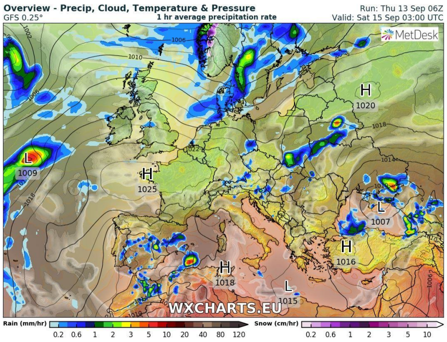
PROJECT TITLE: Changing the scale of Numerical Weather Prediction

DTP Research Theme(s): Changing Planet

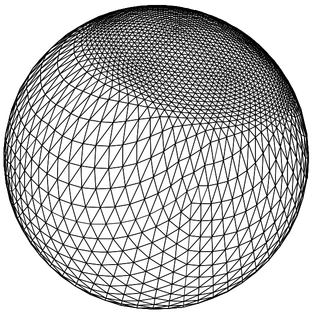
Lead Institution: University of Bath

Lead Supervisor: Prof Chris Budd OBE, University of Bath, Mathematics
Co-Supervisors: Prof John Thuburn (University of Exeter), Dr Melvin (Met Office)

Project Enquiries: mascjb@bath.ac.uk



Numerical weather forecast



Adaptive mesh for a global weather forecast

Project Background

Accurate forecasting of the weather is essential for the functioning of modern society, from agriculture and transport, to sport and tourism. All of us pay close attention to the weather forecast. The same methods used for weather forecasting are also a vital component of climate and environmental modelling. A key aspect of do this well is numerical weather prediction (NWP). This uses carefully designed numerical algorithms to simulate the motion of the (moist and heated) atmosphere. The Met Office currently uses the Unified Model (UM) to do this in which the time evolution of the weather is determined by the ENDGAME routine. This in turn uses the Semi-Implicit, Semi-Lagrangian method (SISL), which permits the use of large time steps. (John Thuburn (co-investigator) was one of the designers of ENDGAME and his advice and expertise is essential to this project.) However a problem of the UM is that it uses a uniform computational mesh which does not allow it to resolve global meteorological phenomena on a scale smaller than 25km. Many meteorological phenomena are thus on a sub-grid scale and cannot be resolved. This can be a devastating problem if these small scale phenomena are storms which may cause catastrophic damage and loss of life. An effective way to overcome this is to cluster mesh points close to evolving phenomena such as tropical storms (see figure above). However such *adaptive methods* are either unstable or require very small time steps and are thus very inefficient to use. A potentially very promising solution to this issue is to couple an adaptive method with a SISL method. Preliminary work by a PhD student [1,2,3] on the (relatively simple) Bergers' equation model of fluid motion has shown that this approach can work very well on simple problems. This new project aims to make it work on problems of real meteorological significance. The possible impact to numerical weather prediction will be enormous as it will allow the development of methods which can not only resolve small scale features, but which are stable and efficient to use over long time scales.

Project Aims and Methods

The primary **aim** of the project is to develop, analyse **adaptive SISL** methods and to apply them to realistic meteorological problems including the local UK forecast and tropical weather forecasts.

This will be achieved through a series of **objectives**

1. Extend the preliminary work in [1,2,3] to develop adaptive SISL methods which can solve the *shallow water* system of partial differential in one spatial dimension, which model the shallow atmosphere. Test these methods on some challenging problems in which small scale features evolve on what would be a sub grid scale level for a uniform mesh. Examine the accuracy and stability of these methods.
2. Extend these methods further to a vertical column model of the atmosphere in which realistic thermodynamic and moisture effects are included. Test these on the challenging and important problem of resolving inversion layers. (These features evolve on small scales and play a vital role in our understanding of fog and of near Earth pollution)
3. Develop a more realistic two/three dimensional adaptive mesh method based on the *optimal transport moving mesh strategy* described in [4]
4. Apply, and test this on the full Euler equations for the atmosphere, extending the model in 2 above to realistic geometries, in particular the local UK forecast and tropical forecasts, looking at meteorological phenomena such as storms which have significant developing structure on small scales.

The student will be expected to gain a good understanding of numerical methods for weather prediction in general and semi-Lagrangian methods in particular and also atmospheric dynamics by reading widely both in the open literature and also from Met Office technical reports. See for example [5-9]. They will also become skilled in programming in Python, and advanced High Performance Computing, making full use of the new GW4+ super computer cluster *Isambard.*

In this project expertise in adaptive numerical methods will come from Budd, in SISL methods and their implementation from Thuburn and in NWP and its applications from Melvin (and the Met Office). All three will be closely involved in all aspects of the project supervision. The project will start with the plan as described above, but as with all research this plan will develop as the project continues. We will have weekly meetings with the student in which they will be expected to lead creatively on the evolution of the project. Indeed a vital part of the project will be the placements at the Met Office and at NOAAH. Student will be encouraged to interact closely with many Met Office staff. This will certainly lead to evolution of the project as they gain a better understanding of the state of the art of NWP. The student will also be expected to play an active role in the PhD group meetings at Bath and also in Exeter and to describe their work on a regular basis. Experience has shown that this process excellent way to develop new creative ideas.

Candidate Requirements

On a scientific level, the candidate will need to have a background in numerical analysis/scientific computing. This could come from a good degree in mathematics, physics or engineering. They should also have an interest in the application of this to practical problems arising in meteorology/climate science.
On a personal level, the candidate must be able to work in an interdisciplinary team and think outside of the box. They should be able to communicate their work to a non technical audience.

Collaborative Partner

It is expected that the student will spend about one month per year at the Met Office during the course of the project. The Met office will provide the student with direct experience of operational weather forecasting and allow them to work with, and learn from, experienced practitioners in numerical weather prediction. They will also provide direct experience in the application of semi-Lagrangian time-stepping methods in an operational context. As well as playing a direct role in the theoretical aspects of the project (Tom Melvin is an expert in this) they will also be able to provide realistic meteorological examples for the development and application of the methods examined in the project.

Training

The student will be able to take full advantage of the NERC training, including the NERC Autumn school.
The student will receive training in mathematics at the University of Bath. In particular they will be aligned to the SAMBa (statistical applied mathematics at Bath) centre for doctoral training. This will give them direct access to graduate level training in applied mathematics, numerical analysis and scientific computing as well as the week long ITT (integrative think tanks) which provide hands on training in technical problem solving. They will form part of a group of PhD students at the University of Bath managed by Prof Budd. This group meets weekly to discuss their work and have targeted training talks from internal and external speakers. They will attend week long focused courses in numerical weather prediction at ECMWF and at others provided by the Met Office. The student will also have the opportunity to have extended visits to NCAR and NOAAH in the USA. Both supervisors have excellent links with these two leading organisations in numerical weather prediction. They will have extensive training in public engagement and will take part in the Bath Taps Into Science Festival.

References / Background reading list

[1] S. Cook, C. Budd, A Hill, T Melvin, (2018) *Error estimates for SISL methods applied to Bergers' equation,* submitted
[2] S. Cook, C. Budd, A. Hill (2018) *The one-dimensional moving mesh SISL method*, submitted
[3] S. Cook, (2017), *Adaptive methods for problems in meteorology*, PhD Thesis, University of Bath
[4] P. Browne, C. Budd, M Cullen and C. Piccolo, (2014), *Fast three dimensional r-adaptive mesh redistribution*, J. Comp Phys, 275, 174—196.
[5] A. Robert, (1982) *A semi-Lagrangian and semi-implicit numerical integration scheme for the primitive meteorological equations,* Japan Meteor. Soc., 60, 319—325.
[6] W. Huang and R. Russell (2010), *Adaptive moving mesh methods*, Springer
[7] C. Kuhnlein, P. Smolarkiewicz and A. Dombrack, (2012), *Modelling atmospheric flows with adaptive moving meshes,* Journal of Computational Physics, 7, 2741—2763.
[8] C. Smith, (2000), *The semi-Lagrangian method in atmospheric modelling*, PhD Thesis, University of Reading.
[9] A. Staniforth, A. and J. Cote, (1991), *Semi-Lagrangian integration schemes for atmospheric models - a review,* Monthly Weather Review, 9, 2206—2223.

Useful links

Enquiries relating to the project should be directed to the lead supervisor (see email address above for Project Enquiries). Enquiries relating to the application process should be directed to doctoraladmissions@bath.ac.uk

In order to apply, you should select the relevant University of Bath PhD online application form found here: https://www.bath.ac.uk/study/pg/applications.pl. When completing the form, please state in the 'Finance' section that you wish to be considered for GW4+ DTP funding and quote the project title and lead supervisor's name in the 'Your research interests' section. Further information about the application process may be found here: http://www.bath.ac.uk/topics/postgraduate-research/

The application deadline is 1600 hours GMT Monday 7 January 2019 and interviews will take place between 4 and 15 February 2019. For more information about the NERC GW4+ DTP, please visit https://nercgw4plus.ac.uk.