THE FUTURE OF WEATHER AND CLIMATE MODELLING

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A collective approach to weather and climate prediction

*The first-of-its-kind collaborative project **ESCAPE** is helping to facilitate high-resolution weather forecasting. By changing numerical algorithms and employing new programming models, significant improvements to both weather and climate predictions will be possible and affordable, leading to reliable and timely forecasted warnings*

While it is possible to reduce the human impact on the global climate, it is impossible to control the weather – irrespective of whether it is a result of global warming or naturally occurring. However, as technology develops and becomes more and more innovative, both weather and climate predictions are increasingly accurate, providing reliable forecasts and timely warnings.

Despite these advances, it is critically important that more precise forecasts are developed as soon as possible, not least because of the aforementioned long-term, human-induced climate change that is taking place all around us. For, while the weather has always generated natural disasters around the world, the frequency and severity of hazards related to the weather and climate is on the rise.

While the need for improvements to weather and climate predictions is evident, it is not a straightforward process. Weather forecasts are necessary throughout each day, where they are continuously updated to improve their reliability, and they therefore must be generated within strict time constraints. On the other hand, climate predictions are more focused on the long term, but both models need to produce somewhere between 100 and 1000 forecast days every real day. The problem is that the accuracy of weather and climate prediction is strongly affected by the computational affordability and, as models become increasingly complex, they become extremely expensive. Thus, a fundamentally different approach to computing and data management is required.

THE BENEFITS OF PARTNERING WITH WORLD-CLASS FACILITIES

With that in mind, the Energy-efficient SCalable Algorithms for weather Prediction at Exascale (ESCAPE) project has been established. It represents the first collaborative project between European weather prediction centres, academia, high-performance computing (HPC) centres and computer hardware vendors.

The project would not be possible without the excellent international collaboration that underpins this work. ESCAPE joins up operational meteorological services from Switzerland, France, Germany, Belgium and Denmark, a UK university, high-performance computing centres in Ireland and Poland and three industrial partners providing computing hardware. These organisations are all working hard to investigate new formulations of forecast model components to achieve better performances in the future. Importantly, the European Centre for Medium-Range Weather Forecasts (ECMWF) – an independent intergovernmental organisation supported by 34 states – is strongly involved in the joint research effort.

ESCAPE, coordinated by Dr Peter Bauer, benefits from evolutions in extreme-scale computing capabilities that have taken place over the last decade. Bauer notes that ECMWF has a long history of HPC facility management and optimising computer codes on a range of architectures for achieving the best possible efficiency given the available resources: 'Their foundation as a single European unit also helped centralise HPC capabilities to allow access to larger computing power than available in any individual Member State. This has enabled cutting-edge scientific research to be performed and translated into operational services.'

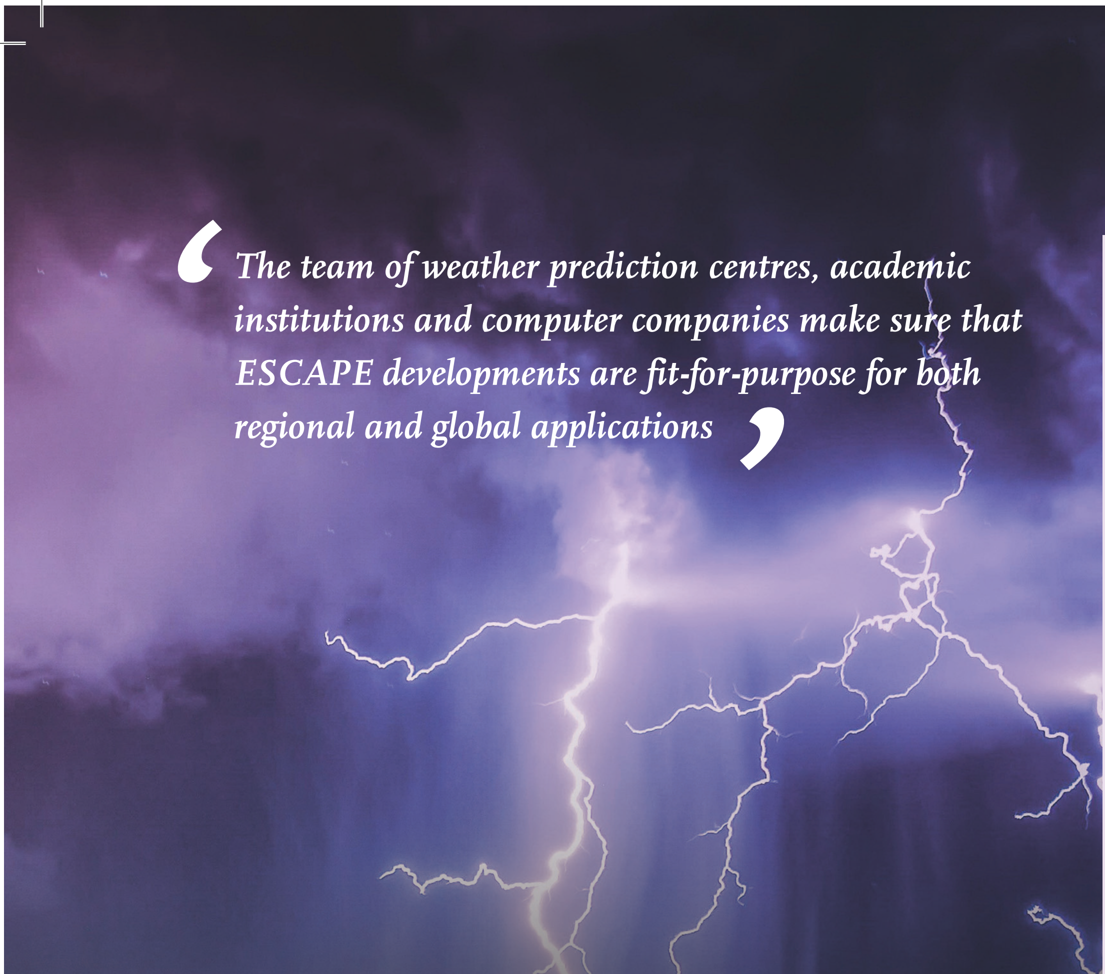
Ultimately, Europe's experience with advanced and explorative projects in numerical weather prediction, with HPC, code management and code sharing has helped define and initiate ESCAPE. 'The team of weather prediction centres, academic institutions and computer companies make sure that ESCAPE developments are fit-for-purpose for both regional and global applications, and that the latest developments in numerical techniques, programming environments and hardware capabilities are brought together,' says Bauer.

KEEPING COSTS DOWN WHILST MAINTAINING PERFORMANCE

The chief aim of the ESCAPE collaboration is to reformulate the key model components that drive the significant increases in cost. The proposed reformulation considers scientific elements, such as different equations, mathematical solvers and algorithms, and computational elements, such as programming models, software libraries and more efficient processors. One crucial consideration is the need to ensure that by reformulating these elements the scientific performance is not deteriorated.

However, taking such a significant step in defining the fundamental algorithmic building blocks of weather predictions is no mean feat. Indeed, one of the first deliverables of the project is the definition of those building blocks. These follow from the hierarchy and sequence of logical tasks in the forecast model that reflects how groups of physical processes are represented in the simulation model and which mathematical algorithms are needed by the chosen numerical methods. As the latter are also part of the redefinition step, several options for numerical methods and thus mathematical methods are investigated at the same time.

As the project evolves over time, the multi-disciplinary team will be able to determine which building blocks are important in



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terms of their relevance to future models, with consideration given to the fact that the level of importance might change. Indeed, ESCAPE includes steps down the line to re-select and re-evaluate the components as the understanding of them develops. Importantly, the computational cost of the building blocks can be ascertained using code profiling tools, so the team can focus on those that help keep costs down. In addition to the computational performances, ESCAPE gives special attention to power usage, as large HPC facilities require substantial electric power sources that could become impossible to sustain for future systems. Because the project is focused on solving anticipated problems in the future, it makes sense to give consideration to the feasibility of the solutions they proffer.

THE FAR-REACHING ASSOCIATED BENEFITS

As part of the proposed structure for the project, ESCAPE includes a goal that focuses on dissemination and training that provides future recruitment opportunities in the field. Traditionally, the combination of physical, mathematical and computer science skills is exploited in computational fluid dynamics and engineering, but ESCAPE wants to draw scientists skilled in those areas into weather and climate prediction.

The project is designed to present young researchers with career and training opportunities in an area with high societal relevance. ESCAPE offers employment opportunities and provides computer training with access to the latest hardware architectures, as well as practical experience with very large science codes in some of the largest HPC facilities in the world. These opportunities are very attractive for young researchers and present them with career paths that have not been accessible to this extent before.

The fact that ECMWF is an international organisation with mostly European members and cooperating states means that ESCAPE will benefit the European public by providing the highest forecasting quality with affordable computational cost. However, ultimately, the benefits of ESCAPE are further reaching than that, not least because improvements to weather forecasting will not only save lives – ESCAPE will help save vast amounts of money currently associated with natural disasters around the world. More reliable and earlier weather and climate forecasting leads to better preparation by those potentially affected and, given the expected effects of climate change in the future, the weather will become an increasingly societal concern.

ESCAPE represents a huge step forward in weather and climate modelling, but it also helps develop interdisciplinary research on energy-efficient HPC which has obvious uses in other fields. The future of computational modelling looks increasingly bright, whatever the weather.

Project Insights

FUNDING

European Union Horizon 2020

PARTNERS

Danish Meteorological Institute (DMI) • German Meteorological Service (DWD) • Royal Meteorological Institute of Belgium (IRM) • Météo-France • Meteo Swiss • Institute of Bioorganic Chemistry, Polish Academy of Sciences • Loughborough University, Leicestershire • National University of Ireland, Galway • Bull SAS • NVIDIA Corporation • Optalysys Ltd

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PROJECT COORDINATOR BIO

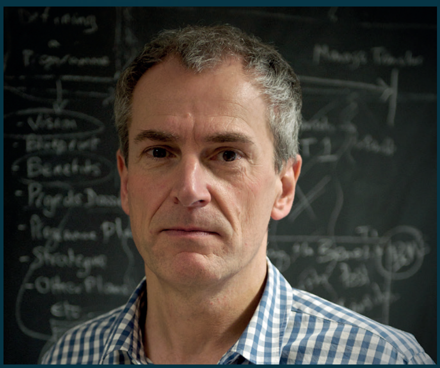
Dr Peter Bauer joined ECMWF in January 2000 and is the Deputy Director of the Research Department.

Impact Objective

- Develop world-class, extreme-scale computing capabilities for European operational numerical weather prediction and future climate models

The future of weather and climate modelling

***Dr Peter Bauer** is Coordinator of a project established to develop world-class, extreme-scale computing capabilities for numerical weather prediction and future climate models. Below, he discusses the challenges the project seeks to address, the coordination of complex research initiatives, and upcoming dissemination events*



Could you begin by describing some of the current challenges associated with weather and climate predictions?

Both weather and climate predictions need to produce forecasts and products within strict time constraints. Weather forecasts are issued regularly several times per day and therefore the models need to run in specified time slots every day. Since climate models produce predictions for long time periods – often over decades and longer – they need to complete these predictions within reasonable periods and with continuous processing. Either through burst (weather) or continuous (climate) mode, the required production rates are about 100–1000 forecast days per real day. This requirement will not change and becomes extremely challenging for high-resolution and complex models, even more so if models are run in ensemble mode.

In what ways will the Energy-efficient SCalable Algorithms for weather Prediction at Exascale (ESCAPE) project overcome these challenges?

The enhancement of spatial resolution and complexity of forecast models makes the models physically more realistic and thus will improve forecast skill. We assume that the dimension of the models will increase by a factor of 100–1000 in the next 10 years because of that. Obviously, the acquisition and power supply for 100–1000 times larger high-performance computer (HPC) facilities will be extremely expensive. ESCAPE aims at identifying and reformulating the key model components (called 'weather and climate dwarfs' inspired by the Berkeley computational dwarfs) that drive this cost.

Coordinating such a complex and multifaceted technological research initiative must present some major obstacles. How you have dealt with these?

The coordination of ESCAPE is clearly challenging, just like all projects with many partners with multidisciplinary backgrounds. We have set up an effective project managing structure, including a science coordinator and project manager, which helps separate the scientific and formal aspects of ESCAPE. Up to now, no major obstacles and problems have surfaced. The partners are very competent and responsive, and we have not experienced delays in any work area. Also the European Commission (EC) project officer has been very helpful and one can see that the EC is really interested in the subject.

The EC recognises that weather and climate prediction offers a very challenging case for future HPC development, and that weather and climate forecast requirements need to be fulfilled, given their significant importance for European society.

Have you achieved any results that you are particularly pleased with?

It is too early to report on actual results from the software developments, but we are certainly very satisfied with the feedback we receive on the importance and design of the project, and its high relevance for the weather and climate community. Also, through ESCAPE, the HPC community have realised how challenging our particular application is and how important therefore our participation in their co-design efforts is.

What plans do you have for ESCAPE in 2017?

Next year will see the first full cycle through the iteration loop – from the definition and extraction of the dwarfs via the software adaptation that employs new programming models – towards the testing of components on novel hardware, including an estimation of compute performance. This will be a proof of concept of the main ESCAPE development path.

Finally, do you have any dissemination planned where you will be sharing the results from ESCAPE?

We have a News and Events column that your readers can visit at www.hpc-escape.eu for more information. Important events are the first Dissemination Workshop in October 2016 and a range of training events. ECMWF's Scalability Programme (http://www.ecmwf.int/en/about/what-we-do/scalability) and ESCAPE will also be prominently represented at the biannual European Centre for Medium-Range Weather Forecasts (ECMWF) HPC in Meteorology Workshop. To find out more about this, your readers can head to www.ecmwf.int/en/learning/workshops-and-seminars/17th-workshop-high-performance-computing-meteorology.