European Science Foundation
Standing Committee for Life, Earth and Environmental Sciences (LESC)

ESF LESC EXPLORATORY WORKSHOP

Very High Resolution Environmental Modelling (VHREM)

Scientific Report

Stuttgart, Germany, 21 - 23 September 2006

Convened by:
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Convenors:
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Host Convenors:
Dr. Andreas Behrendt and Professor Voker Wulfmeyer, University of Hohenheim (De), Institute of Physics and Meteorology, Garbenstrasse 30, D-70599, Stuttgart, Germany

$ 1. Executive Summary

This summary provides the underlying description of the whole proposed programme of research, including the scientific background to the project, with the scientific content and future plans listed briefly in sections $2 and $3

Introduction and original workshop aim:

This overall aim of the workshop was develop fundamentally new ideas of atmospheric flow modelling. This would build on concepts of computational fluid mechanics, not previously applied to atmospheric flow.

The challenge of developing a terrain intersecting co-ordinates formulation, with cut cells, local grid refinement and parallelisation of algorithms was basic to the whole approach. Further it was anticipated that the development of new types of parameterisation of atmospheric physical processes would be needed. A specific objective was to initiate a European collaboration to enable a future research activity in this area.

The workshop involved scientists from seven countries (UK, Switzerland, Germany, Italy, Iceland, Croatia and Austria). The venue was chosen to be at the University of Hohenheim, Stuttgart, to maximise the number of participants. Other commitments prevented others interested in attending, but there is an expectation that more scientists will become involved in the next phase and in association with other projects such as THORPEX, and in our subsequent EU (EUROCORE?) application, as discussed in $3.

Current philosophy and scientific background.

The philosophy is to examine a design for a prototype of a new generation of meteorological research models, capable of exploiting emerging high performance computer hardware technology. Ultimately, these may lead to computer models with a local scale weather forecasting capability. Advances in computer hardware and parallelised software (including GRID technology) make high resolution (< 1 km) and short range (hours) weather forecasts technically feasible. There is a great demand for accurate forecasts of this type, particularly for hazardous weather warnings (e.g. flash floods or severe winds) and local air quality (particularly in urban areas). Virtually all existing operational forecasting models have a common structure, in which the (terrain following) computational mesh deformed vertically to fit around a smoothed representation of the surface topography. This has scaled down from meshes of 100s of km in the early days of numerical weather forecasting to 5--20 km in some of today's models. This approach has arguably reached the limits of its applicability, since on smaller scales, steep and abruptly changing surface features (e.g. narrow valleys, buildings) lead to unacceptably deformed meshes, computational errors and even numerical instability. Standard solutions to this problem, available from computational fluid dynamics (CFD), have not been successfully transferred to atmospheric models because they do not properly account for the main driving forces of atmospheric motion (e.g. Buoyancy, Earth's rotation) on global, regional or even local scales. There is a need to describe highly unsteady flows with thermodynamical and radiative forcings on a large variety of scales, and these have yet to be shown to be suitable for CFD type solutions.

A feature common to almost all models dating from the earliest days involves the way in which the complex Earth's surface is represented. The computational mesh is deformed so that the lowest mesh levels follow the surface. In this so-called ``terrain-following'' co-ordinate model, the deformation of the mesh persists through part or all of the depth of the computational domain. Essentially it is that the finer scale horizontal resolution combined with terrain-following co-ordinates means that increasingly distorted computational meshes are needed to represent the fine-scale topographic and land surface properties such as steep slopes and buildings. These mesh distortions have serious computational drawbacks, leading to poor accuracy and failure of numerical convergence. Unfortunately, because the terrain-following co-ordinate technique is embedded in virtually every aspect of operational models, the change to a new approach requires a step change of conceptual design.

An objective is to examine the novel computational methods to create new meteorological algorithms which do not suffer from the terrain-following co-ordinate accuracy and convergence problems described above. The approach is one in which the computational mesh is undistorted by surface features and instead passes directly through the topography.

Many scientific issues need to be addressed to achieve proper description of fine scale atmospheric processes. A crucial aspect of this work is the need to bring together of a multi-centre/multi-disciplinary team with the necessary range of expertise for this major effort. Without these developments, most of the important benefits of the new computational techniques could not be applied and tested in real high resolution applications.

Specific applications for improved understanding of and ultimately very high resolution forecasts are numerous. Physical understanding of convection processes is now sufficiently advanced that it is realistic to envisage, that with sufficient model resolution, accurate forecasts of localised severe thunderstorms leading to flash flooding could be predicted with a 3--6 hours warning, giving time for emergency services to react. Severe wind hazards, particularly in regions of complex topography, present dangers for transport and fixed infrastructure but the problems are often extremely localised. There are many other examples, but these and other research studies offer strong indications that these hazards are predictable with high resolution models.

This workshop was aimed at developing an overall plan. The scientific summary in $2 below, provides a summary of the scientific content of the workshop. An assessment of the future plan is provided in $3

$2. Scientific Content

The following brief discussion of scientific content relies on the initial comprehension of the background of the approach, as described in the executive summary ($1), above. This includes some of the original underlying scientific discussions and objectives which provided the philosophical approach for the workshop.

The workshop's science was directed towards the development of novel methods for the generation of research model for very high resolution modelling of environmental flows. The underlying science objectives are highlighted by the content of the presentations and in the assessment of the scientific proposals for study, which are provide in the presentations.
(http://www.env.leeds.ac.uk/~alan/vhrem/VHREM_output.dir)
These presentations provide the detailed science each participant was proposing should be included in the development of the new facility. There was much discussion the elements during the talks and towards the end of the workshop.

The approach of the workshop was to progress from the more theoretical and mathematical structure of the terrain intersecting approach, with comparisons of current techniques, to the very much more applied nature of the physical parameterisations which are needed as boundary conditions and thermodynamic forcings within the new modelling framework.

<u>The scientific issues raised covered the following topics:-</u>

<u>Terrain intersecting grids and their current developments</u>
- The motivation for terrain interesting grids.
- Preliminary results of a SISL dynamical core.
- An outline for the development issues ahead for a VHREM project.
- Discussion of various model Implementation Scenarios.
- Realistic NWP forecasts using a cut cell terrain intersecting approach.
- Prospects for application on an icosahedron.

<u>Other technical approaches and considerations</u>
- Adjoint atmospheric models and a proposal for adaptive refinement.
- Direct implicit solvers for cut cell terrain intersecting coordinate models.
- Application of lower boundary conditions in high resolution model and the development of a new terrain intersecting approach in relation to other systems
- A well-balanced scheme for a 2D finite difference, non-hydrostatic atmospheric model
- What can cfd approaches give us?
- 4DVAR Assimilation of State of the Art and New Observations into Mesoscale Numerical Weather Prediction Models.

Important physical processes to be included in the new model
- High-resolution simulations for forecasting and climate studies in complex terrain
- Entrainment in cumulus clouds.
- The role of future field campaigns for studying very high resolution models
- Modelling of boundary layer processes in steep orography.
- Modelling and observation of bora, valley and slope winds.
- Snow/ice-atmospere interactions (measured, modelled and proposed)
- Surface energy and mass exchange in small scale models
- Standard testcases for numerical modelling with RAMS
- Modelling aoelian snow transport in mountainous terrain with Alpine 4D

Finally, it should be noted that the scientific conclusions, with the resulting decisions and plans for future developments in terms of scientific content and a concrete proposal are discussed below in ($3).

$3. Assessment of scientific proposals and future plans

Throughout the workshop there was extensive discussion of the most effective way forward to produce a successful plan to develop a terrain intersecting model which could be applicable for a very high resolution model of atmospheric flow. The scientific approach was agreed in broad outline, but it was felt that the ideas have to be developed into a most coherent and effective manner.

Thus the final discussion focused on the most effective way to progress with a proposal for funding. The main consensus was to apply for a EUROCORE proposal. At this stage it was felt that the Framework 7 structure was uncertain, and therefore applicability was unknown.

The scope of the proposal is to support and coordinate research aiming at the development of a common European tool for the study of micro scale atmospheric flows and very high resolution atmospheric simulation. It was decided that the objective was not to produce a NWP (Numerical Weather Prediction) tool, but importantly to include the wider issues of environmental prediction.

The approach is to develop a new, modular model infrastructure, based on a new dynamical core, and using where possible, techniques and components from existing models

The dynamical core would be almost certainly terrain intersecting, or at the very least an alternative which has been demonstrated to work at high resolution with steep topography.

Validation with observations is regarded as important, but new measurements would not be required, or not without a convincing case that existing data are so inadequate that the model produced could not be validated.

The specific research areas, and critical elements of the programme to be considered (i.e. potential projects within the proposed EUROCORE programme):

1) Model design,software engineering, documentation, interfacing to existing models, GRID includes model infrastructure, software engineering, use of existing technology.
2) Dynamical core
3) Predictability/ensemble modelling
4) Turbulence modelling (the necessity of 3d turbulence)
5) Radiation
6) Physical parameterizations
7) Data assimilation
8) Urban scale meteorology (buildings)
9) Surface exchange processes (vegetation, soil,snow, sea)
10) Validation+ applications: hydrology, air quality, avalanches, local extreme weather, downscaling climate
11) Communications / Project management.

The way forward and specific plans
There was discussion on how progress forwards in the coming months, and to define the next steps. The following stages were agreed.

Phase 1.
The production of a short report to satisfy the deadlines of:-
- Thorpex 9-11 October
- ESF MOs 18 October

This summary incorporating the above scientific ideas will be collated by Alan, Luca, Stephen, Michi, Mathias.
The meeting of the ESF MOs was seen as an opportunity to raise the viability of the EUROCORES proposal. Critically, how do the MOs handle EUROCORES, and can it be useful for individuals to approach their representatives.
Germany:- Volker and George
Switzerland:- Michi
Italy:- Luca
UK:– Stephen
Austria:- Martin
Norway and Iceland:- Haraldur.
Overall, how do the MO's handle Eurocores? Further consultation with ESF (Inge), to assess the most effective manner to progress.

Phase 2 (post 18 October)
The results of initial contacts, the Thorpex meeting and other discussions will be fed back into the development of an overview. A list of all collaborators with the current workshop members, should be included. More specific details of the 10 projects (see above) and the project management should be produced by the initial group bey the end of December.

Phase 3.
Optimally, it is envisaged that a larger sub group (say 10 ???) plus Inge should meet at ESF, with any MO's in February March

Phase 4.
Final submission

$ 4. Final programme

Day 1
9:00 - 9:05 Welcome to Workshop
9:05 - 9:15 ESF representative presentation

Sessions:

Day 1
9:15 - 10:30 Session 1 Introduction and project motivations
Coffee
11:00 - 12:45 Session 2
Lunch
14:00 - 15:30 Session 3
Break
16:00 - 17:30 Session 4
17:30 - 18:00 Discussion and recap of the days topics.
Noting of recommendations

Day 2
09:00 - 10:30 Session 5
Coffee
11:00 - 11:45 Session 6
Noting of recommendations
11:45 - 14:30 Overall Discussion of the main issues for implementation
Lunch break at approximately 12:45 – 13:30
14:30 - Break
15:00 - Construction of the plan for follow up research activities, collaborative actions report and a forward plan for implementation.
16:00 - Close

$1
1. *Inge Jonckheere*
   European Science Foundation
2. *Luca Bonaventura, Marco Restelli, Davide Cesari*
   Terrain interesting grids: motovations, preliminary results of a SISL dynamical core and outline of major development issues ahead for a VHREM project.

2a. Davide Cesari & Luca Bonaventura (presentation added)
Model Implementation Scenarios

3. *Juergen Steppeler, H. Bitzer & P.Ripodas*
   Realistic NWP forecasts using a cut cell terrain intersecting approach and prospects for application on an icosahedron

$2 & S3

4. *Martin Ehrendorfer*
   Adjoint atmospheric models and a proposal for adaptive refinement.
5. *Juergen Steppeler*
   Direct implicit solvers for cut cell terrain intersecting coordinate models.
6. *Alan Gadian, Stephen Mobbs, D. Woodhead, S-J Lock, X. Wen*
   Application of lower boundary conditions in high resolution model and the development of a

new terrain intersecting approach in relation to other systems
7. *Andreas Dobler*
A well-balanced scheme for a 2D finite difference, non-hydrostatic atmospheric model
8. *Zhengtong Zie and Ian Castro*
What can cfd approaches give us?
9. *Hans-Stefan Bauer, M. Grzeschik, F. Zus, A.Behrendt, and V. Wulfmeyer*
4DVAR Assimilation of State of the Art and New Observations into Mesoscale Numerical Weather Prediction Models.
10. *Haraldur Olafsson, H. Agustsson, O. Rognvaldsson, E M. Einarsson & M. Brotzmann*
High-resolution simulations for forecasting and climate studies in complex terrain

$4 & S5

11. *George Craig, Andreas Dornbrack & Romain Coharde*
Entrainment in cumulus clouds.
12. *Volker Wulfmeyer*
The role of future field campaigns for studying very high resolution models
13. *Mathias Rotach*
Modelling of boundary layer processes in steep orography.
14. *Alexander Gohm*
Modelling and observation of bora, valley and slope winds.
15. *Friederich Obleitner*
Snow/ice-atmospere interactions (measured, modelled and proposed)
16. *Michael Lehning*
Surface energy and mass exchange in small scale models
17. *Felix Schueller*
Standard testcases for numerical modelling with RAMS
18. *Francoise Faure, Nora Helbig & Henning Loewe*
Modelling aoelian snow transport in mountainous terrain with Alpine 4D

$ 5. Statistical Information:

- 22 participants from 7 countries (see list below)
- 2 female participants
- 7 participants: 20 – 30yrs. 6 participants: 30-40yrs. 5 participants: 40-50yrs. 3 participants 50-60yrs. 1 particpant 60+ yrs

$ 6. Final list of participants:

N.B. There are ~ 7 others on the mailing list and who were not able to attend

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