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Working Group 3 Report

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What have we learnt about the Grey Zone over the past decade?

In recent years, National Met Services (NMSs) have increasingly been running their operational models at grid-spacings of 1-5 km, placing them firmly in the grey zone for deep convection. The NMSs agree that forecasts from these grey zone models have offered considerable advantages over their lower resolution counterparts – both arising from the finer detail of the topography and surface heterogeneity; and through convection (partially) becoming a dynamically-resolved entity.

As models have transitioned to simulate deep convection explicitly, it has been found that turning down or modifying the existing convection parametrisation can be preferable to simply switching it off. This appears to imply that representing under-resolved convection as a heat source that drives the dynamics may still be a good enough approach to the problem, even at these small grid spacings. From a pragmatic perspective, a re-tuning of existing schemes is far simpler than attempting to introduce dynamical source terms directly.

However, both simple re-tunings and abandoning convection schemes altogether evidently fail to capture all the required physical sensitivities, and this is illustrated by experience at the UKMO where the nature of errors in convective behaviour depends on the region, requiring different tunings for each regional model. This regional sensitivity would, of course, be problematic in a global model.

In addition, the use of a semi-Lagrangian transport scheme is proving troublesome at UKMO due to its lack of conservation. They observe an “infinite fountain” problem, where low-level convergence can develop into an excessive moisture source to the plume above because of the tendency to select a departure point directly below the plume where moisture is more abundant (e.g. Ben Shipway presentation).

This problem can also be reproduced in idealised small planet simulations with the IFS, and although applying a global mass fixer can bring some improvement, it does not address the systematic errors to the dynamics of individual plumes. The alternative cell-averaged interpolation method COMAD has been investigated which improves the underlying dynamics and reduces mass conservation error, however, it does not eliminate it (Malardel and Ricard, 2015)

More generally, even at 1km grid-spacing, the dynamics and initiation of convection are under-resolved. When operating without a convective parametrisation, this leads to delayed triggering times, and once initiated, incorrect rates of environmental mixing into the plume, resulting in errors to the heating response generated. In cases where parametrisations are used, the parametrised convection needs to be coupled very carefully with the explicit convective motions occurring on the model grid. One reason this can be difficult is that explicit motions will develop in the vertical over multiple timesteps whereas parametrisations are generally based on heating rates averaged over cell lifetimes, often using vertically-integrated closures which assume the full range of heights has already been reached.

As deep convection develops, the departure from spatial and temporal equilibrium within these smaller grid boxes means that some knowledge of the inherent physical length and time scales is required. These can then be used to enable feedback from other processes over more than one timestep via `memory’ terms; application of stochastic behaviour where cloud spacings are smaller than the mesh length; and then as clouds grow to become resolvable by the mesh, to turn down the contribution of the scheme (see e.g. presentations from Michael Whitall and Mirjana Sakradzija).

In the absence of carefully designed convection schemes, both UKMO (working with the UM) and DWD (with ICON) have found that operating on a 1km grid is preferable to ~5km (for both mid-latitude and tropical regions). These findings are perhaps not surprising in view of the fact that deep convective updraughts are typically around 1-2km wide, and so dynamically explicit convection at this scale better mimics individual cloud structures.

Thus 1 km seems to provide an awkward but nonetheless useful grid spacing. However, it is not possible to “jump over” grey zone issues by going to still finer grids because important circulations within the convective boundary layer then enter a grey zone regime. There are analogies in the approaches taken for the “boundary layer grey zone” to those explored for the deep convection grey zone. These include modifying existing NWP parametrisations (see e.g. Kay Suselj presentation) or extending high-resolution LES methods into the grey zone (see e.g. George Efstathiou presentation) or else attempting to develop a judicious blend between parametrised and dynamic contributions to the turbulence (see e.g Rachel Honnert presentation).

What do we need to understand better?

While there is clearly significant scope for progress by redesigning convection schemes to couple better with the dynamics, and to operate with awareness of the grid in which they are embedded, fundamental questions remain that are of immediate consequence to global modelling at 5 km.

1. Controls on upscale error growth

How do small-scale (unresolved) processes impact on larger-scale circulations? Do resolved and parametrised processes impact the larger scales in the same way? Can experience with regional models help our understanding?

Recent studies have explored how energy cascades between scales are represented in the IFS (Augier and Lindborg, 2013; Malardel and Wedi, 2016). At convection-permitting scales, Selz and Craig (2015a) demonstrate that where convection is active, initial error growth is fastest and that such errors project upscale via deep gravity wave adjustment onto balanced scales. There is potential for such mechanisms to be appropriately captured when convection is parametrised by using stochastic methods (Selz and Craig, 2015b). However, can we use/extend existing work to identify where we should focus efforts to minimise the impact of errors associated with representing deep convection in the grey zone (i.e. partially resolved and partially parametrised situations)?

2. Convective physical processes

For convection, there are aspects of the process itself and its representation that still need better understanding as we move to higher resolutions:

- What are the limitations of representing convection simply as a heating term, without mass sources and sinks - e.g. the implications for momentum transport, and the representation of cold pools and anvils?
- Do we have enough understanding of the dynamics and microphysics within convective systems to predict individual up/downdraughts behaviour? And is this the case even in the organising presence of shear? And what components of this are stochastic?
- How can we predict the horizontal scale of the cloud, its separation from its neighbours, and its lifetime?

- Can we predict the spatial statistics, both of transport within the boundary layer, and of the triggered convective entities above?
- Do we need to be able to represent anvils and cold pools separately?

3. Dynamical formulation

As we start to resolve the dynamics of convection, can we find suitable conservation fixes for semi-Lagrangian schemes? Or do we need to turn to alternative transport schemes?

What scales are truly resolvable for a given mesh size?

Can convection-resolving simulations teach us how to represent convection in the grey zone and at convection-permitting resolutions? And if so, at what resolution can we trust the dynamics to simulate convective processes explicitly? These questions are complicated by the fact that many existing “convection-resolving” studies have actually been performed within the boundary-layer grey zone.

4. Model construction

More generally, does sensitivity to the details of a model’s construction increase at higher resolutions, e.g. the representation of interactions between processes via separate schemes; the physical (in)consistency of representations; the sequence of schemes within the integration?

To prioritise our future efforts, we need to be able to quantify their relative importance and dependence on resolution:

- At what resolution does the representation of 3D-effects in parametrisations become necessary? How does it differ for different processes?
- What level of complexity do we require from each parametrisation (most obviously for microphysics, but relevant to all schemes)?
- Does the representation of physics-dynamics coupling need to change at higher-resolution?
- How do we deal with partially-resolved processes? For deep convection, the consensus has been to continue parametrising (to dx > 1km). What about for partially-resolved turbulent eddies?
- Can we ensure that overlap between physical schemes does not lead to double counting?

5. Data Assimilation

Higher-resolution also poses new challenges for data assimilation. Increased resolution must enable a finer-scale description of the initial state – it is not enough to input fields that are (unphysically) smooth relative to the grid-resolution. Does this require new observations, e.g. radar irradiances? Revised sampling of the observations? How do we tackle the increasing difficulty of predictability at finer scales? Do we require larger ensembles? Can lessons be learnt from regional models?

How might these questions be addressed?

Projects that link experts around a common question, like ECMWF’s USURF (Understanding uncertainties in surface-atmosphere exchange), are acknowledged as an important way forward. Key to progress, of course, will be the development of discerning testing and verification strategies centred on the questions posed in the previous section.

Among approaches already undertaken at ECMWF:

1. Conditional model verification will be important for identifying biases and systematic errors. It was noted that this is an approach that ECMWF already undertakes with great success. It must be continued.
2. Recent work to explore process interactions via model tendency budgets is proving a useful way forward and should be further exploited, e.g. Mark Rodwell's EDA reliability budgets, Richard Forbes' analyses of HRES tendencies, and ENS analyses of ensemble spread in tendencies (Sarah-Jane Lock's presentation).
3. Use observations and independent analyses for verification to explore biases and better understand compensating errors.

Approaches that should be explored by ECMWF and in collaboration with others:

1. Developing a suite of test cases that include full physics, e.g. the DCMIP academic tropical cyclone case; aquaplanet experiments to reduce the surface complexity; small planet experiments to enable efficient high-resolution experiments. Such tests would facilitate model intercomparisons to explore differences and similarities in behaviour from different models; and provide a platform for reducing the complexity of the full system.
2. Using very high-resolution/LES studies and coarse-graining the results to compare with equivalent parametrised cases. This offers a very useful resource for understanding behaviours and testing parametrisation ideas (e.g. Moeng et al, 2010; Sakradzija et al 2016).
3. Explore global simulations at increasingly high resolutions with super-parametrisation active in every grid-box to infer the limits to column-based parametrisations. We may find there are greater potential gains by investing resources differently than in refining existing column physics.
4. Encourage ECMWF to work closely with centres that operate high-resolution regional models to gain the full benefit of their experience, for example in convection-permitting studies [*e.g. Impala's CP4Africa project*], progress in model development, and data assimilation.
5. Explore (the results of) process studies based on observational campaigns to better understand what the models are doing well/poorly. Engage with the research communities – in particular, there is lots of understanding of microphysical processes (and their interaction with convection) in the wider community. It was noted that this knowledge should be better represented at future grey zone discussions but also recognized that such communities may need to be encouraged to engage more actively with grey zone issues.
6. Finally, an exploratory question for the future: can we exploit machine learning to efficiently establish a hierarchy of processes in terms of their relative importance as model-resolutions increase?

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