ENDGame: The next Met Office atmospheric dynamical core

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ENDGame was formulated by the Dynamics Research team: Nigel Wood, Thomas Allen, Terry Davies, Markus Gross, Thomas Melvin, Chris Smith, Andrew Staniforth, John Thuburn* and Mohamed Zerroukat (*University of Exeter). Subsequently, many people in the Met Office have worked on its development and implementation, particularly the physics (APP), the global (GMED) and the regional (RMED) teams.

ENDGame is built on the foundation of New Dynamics (introduced operationally in 2002) and aims to be more robust and accurate whilst maintaining or improving conservation and efficiency. Since ENDGame is an evolution of New Dynamics, much has not changed:

1) Same equation set and variables (θ-π)
2) Same horizontal staggering (Arakawa C-grid)
3) Same vertical staggering (Charney Phillips)
4) Semi-implicit Semi-Lagrangian

The major changes are:

1) Improved (iterative) solution procedure (more implicit, approaching Crank-Nicolson) and reduced off-centring (alpha time-weights, all equal to 0.55).
2) Iterated approach allows much simpler Helmholtz problem (7 point stencil cf. 45 point)
3) Much simpler (red/black) preconditioner gives greatly reduced communications and leads to improved scalability
4) Same Semi-Lagrangian (SL) advection for all variables (cf Eulerian continuity equation + SL in New Dynamics) and removal of "non-interpolating in the vertical" for theta advection
5) Coriolis terms based on mass flux variables (removal of explicitly handled vertical Coriolis terms) improves Rossby mode propagation and leads to improved accuracy
6) No polar filtering or horizontal diffusion, control near lid and poles achieved by implicit damping of w giving improved scalability and accuracy
7) V-at-poles (cf. u, w and all scalars) means not solving Helmholtz problem at singular point of grid! Together with improved energy properties gives improved scalability and accuracy

High Resolution models:

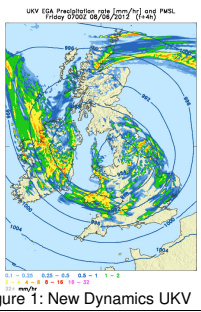

Figure 1: New Dynamics UKV

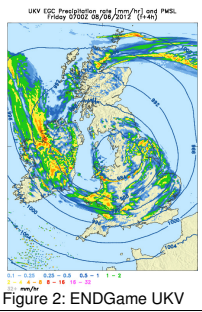

Figure 2: ENDGame UKV

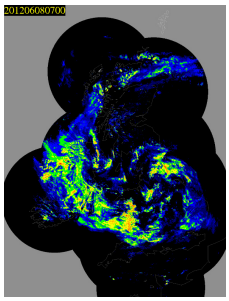

Figure 3: Radar image

Testing of Limited Area models such as the 1.5km variable resolution UKV model is still at an early stage, but initial results are encouraging. Precipitation forecasts for the "Ceredigion (Wales) floods" case of 8th June 2012 show New Dynamics (Figure 1) and ENDGame (Figure 2) runs together with the verifying radar image (Figure 3). The runs are very similar, although there are differences in the details, such as convective precipitation cells in the bottom left hand corner of the domain initiating earlier in the ENDGame run (they appear one hour later in the New Dynamics run, not shown).

Idealised experiments: Big-bubble Little-bubble test

Described in Robert 1993 (JAS, 50, 1865-1873). A small, negatively buoyant bubble slumps down around a large rising bubble. The plots show snapshots of potential temperature at various times. New Dynamics (Figure 4) has a few problems with noise, which is absent in ENDGame (Figure 5).

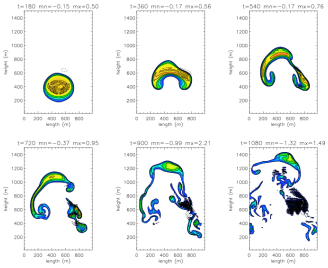
Figure 4: New Dynamics

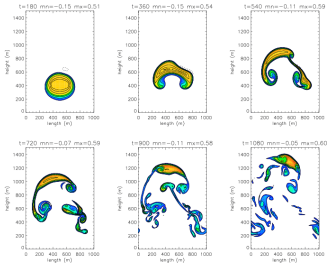
Figure 5: ENDGame

Global model:

The current Operational Global NWP model has a horizontal resolution of N512 (~25km in mid-latitudes) and has a configuration of model settings known as GA3.1. GA5.0#99.2 refers to a version of the model with the ENDGame dynamical core and revised physics settings. The operational implementation of ENDGame will see the resolution of the model being increased to N768 (~17km in mid-latitudes) at the same time as the dynamical core and physics changes.

ENDGame is less diffusive than New Dynamics and this leads to improved levels of Eddy Kinetic Energy at all resolutions (Figure 6). Wind speed biases (Figure 7) are reduced and tropical cyclones (TCs) have reduced track errors (Figure 8) and are systematically deeper (Figure 9), giving stronger winds (Figure 10). Resolution has relatively little impact on track errors compared with the model configuration change (ENDGame plus physics changes) but has more impact on the intensity.

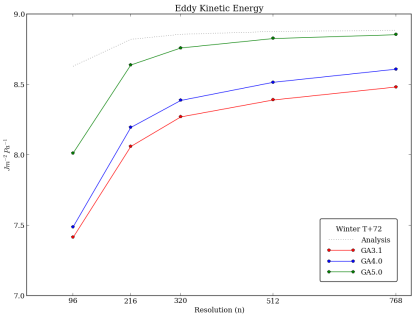

Figure 6: Eddy Kinetic Energy

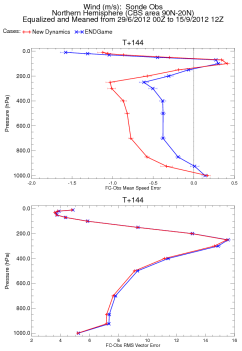

Figure 7: Wind speed bias (top) and RMS Vector Error (bottom)

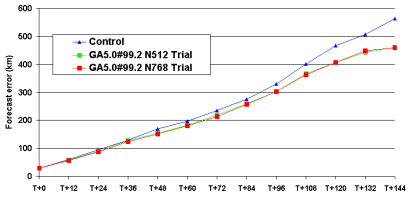

Figure 8: TC mean track error

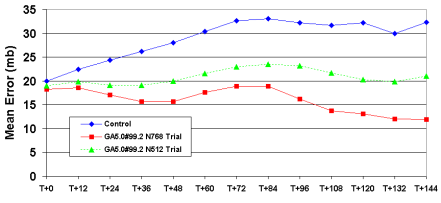

Figure 9: TC Central Pressure Mean Error

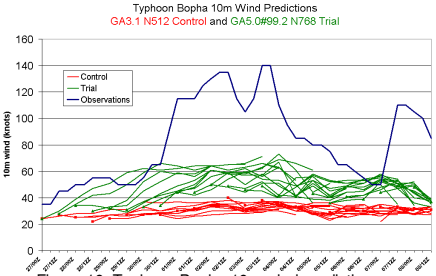

Figure 10: Typhoon Bopha 10m wind predictions

The ENDGame dynamical core is due to become operational at the Met Office in 2014, first in the Global model and then in the limited area model configurations. The Global model change will be accompanied by a change in model resolution from N512 to N768 and an update to the model physics. ENDGame is an evolution of the New Dynamics and aims to be more robust and accurate whilst maintaining or improving conservation and efficiency. ENDGame is less diffusive than New Dynamics resulting in increased Eddy Kinetic Energy. This leads to more intense development of storms and improved wind biases.

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