The Met Office Unified Model
Seamless development for weather and climate prediction

Brown et al., BAMS, Dec 2012, 1865-1877.

David Walters: Global Atmospheric Model Development

Met Office, Exeter, UK
This presentation covers the following areas

- Met Office and the Unified Model
- GA: Seamless global atmospheric model development
Met Office and the Unified Model
We provide services for...
Seamless prediction

Essential support to decision making on all timescales

Analysis of past weather observations to manage climate risks

- Eg. Agriculture: informs crop choice, planting to yield optimisation and minimise crop failure risk.

Predicting routine and hazardous weather conditions.

- Public, emergency response, international Disaster Risk Reduction

Monthly to decadal predictions - probability of drought, cold, hurricanes....

- Contingency planners, national and international humanitarian response, government and private infrastructure investment

Global and regional climate predictions.

- Informs mitigation policy and adaptation choices. Impacts on water resources, heat stress, crops, infrastructure.

Forecast lead-time

Confidence boundary
Unified forecast/climate model

Cullen (1993)

- Technical consolidation of code
- **Benefit:** Improvements to regional NWP performance from improved (climate) parametrisations
- **Compromise:** Temporary step-back in some areas (e.g. regional model went from non-hydrostatic → hydrostatic)
Flexibility of the Unified Model

“Operational” applications of the Unified Model today

\[ \Delta x \approx 130 \rightarrow 60 \text{ km} \quad \Delta x \approx 33 \text{ km} \quad \Delta x \approx 17 \text{ km} \quad \Delta x \approx 12 \text{ km} \quad \Delta x \approx 1.5 \text{ km} \]
Flexibility of the Unified Model

Nigel Wood

A factor of ~100-1000 between these…

…the same dynamics has to continue to work

17 - 135 km

300 m
Current Unified Model
Using “ENDGame” dynamical core

Wood et al. (2014)

Dynamics:
• Regular lat/lon grid.
• Non-hydrostatic dynamics with a deep atmosphere.
• Semi-implicit time integration with 3D semi-Lagrangian advection.
• Atmospheric tracer advection

Physics:
• Spectral band radiation
• Diagnostic or prognostic cloud
• Mixed-phase ppn
• Mass flux convection
• Boundary layer
• Gravity wave schemes

Coupling possible to non-atmospheric components:
• Land surface model
• Ocean model
• Sea ice model
• Chemistry/aerosol model …
Unifying the Unified Model
Synergies between NWP models and GCMs

Senior et al. (2010)

Timescale
Resolution

• Many model characteristics present across all timescales

• Long runs to compare NWP models with climatologies

• Short runs with assimilation to study error growth in climate models

Met Office and UM community well placed to take advantage of these synergies

→ Develop single scientific configuration for use at all timescales
UM Global Atmosphere (GA)

Seamless global atmospheric model development
Global Atmosphere 6.0
UM Global Atmosphere Configuration

What is Global Atmosphere/GA6.0?

- Science config. of Unified Model
- Defined set of physics/dynamics settings
- Non-convection permitting resolutions
  - N96 → N1280/regional 12km
- Timescales from day 1 to 100s years
- Various system dependent options
  - e.g. energy/moisture conservation
  - Prognostic vs. clim. Aerosols
- Developed with community of UM partners and academic collaborators
The GA development process

Continuous research cycle

• All developments start here
• Includes multi-year projects and programmes
• Also includes Process Evaluation Groups (PEGs)
• Engagement with a wide range of partners
• **Benefit:** all systems can benefit from research work motivated/funded by a single application
The GA development process

Continuous research cycle

Roughly annual GA release cycle

Current std tests:
- 20 yr AMIP simulation
- 24 x 6 day NWP forecasts

Increase complexity of tests:
- Higher resolution/coupled climate
- NWP with cycling data assimilation
- Ensemble prediction system

Tuning:
- Individual phenomena e.g. dust, non-orog GWs
- Emergent properties e.g. TOA radiation
- Approach is to improve known problems and remain in obs. constraint
The GA development process

Continuous research cycle

Roughly annual GA release cycle

Annual model assessment

Top model problems → PEGs

- Std tests
- Review & science assurance
- “Chill” GAx+1
- “Freeze” GAx+1

Assessment runs/tests

Assessment workshop

Documentation

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The GA development process

Continuous research cycle

Roughly annual GA release cycle

Annual model assessment

System implementation projects

- Std tests
- Package testing
- Tuning

“Freeze” GAx
“Chill” GAx+1
“Freeze” GAx+1

Assessment runs/tests

Assessment workshop

Documentation

Top model problems → PEGs

- Parallel suite / implementation
- e.g. global NWP suite
- e.g. major climate release for CMIP

System implementation projects

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Benefits of seamlessness
Benefits and compromises from seamless approach

Horizontal resolution:

- UM (and parametrisations) developed to work across wide range of resolutions
- GA developed and tested from $\Delta x = 135 - 10$ km

Very few settings change with resolution:

<table>
<thead>
<tr>
<th>Variable</th>
<th>N96</th>
<th>N144</th>
<th>N216</th>
<th>N320</th>
<th>N400</th>
<th>N512</th>
<th>N768</th>
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</thead>
<tbody>
<tr>
<td>Atmos $\rightarrow$ Model resolution and domain</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Number of columns</td>
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<td>432</td>
<td>640</td>
<td>800</td>
<td>1024</td>
<td>1536</td>
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<td>Number of rows</td>
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<td>216</td>
<td>324</td>
<td>480</td>
<td>600</td>
<td>768</td>
<td>1152</td>
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<tr>
<td>Extended EW halo size</td>
<td>4 points</td>
<td>4 points</td>
<td>4 points</td>
<td>4 points</td>
<td>5 points</td>
<td>5 points</td>
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<tr>
<td>Extended NS halo size</td>
<td>5 points</td>
<td>5 points</td>
<td>5 points</td>
<td>6 points</td>
<td>7 points</td>
<td>8 points</td>
<td>8 points</td>
</tr>
<tr>
<td>Number of land points</td>
<td>Use values in mask</td>
<td>Use values in mask</td>
<td>Use values in mask</td>
<td>Use values in mask</td>
<td>Use values in mask</td>
<td>Use values in mask</td>
<td>Use values in mask</td>
</tr>
</tbody>
</table>

| Atmos $\rightarrow$ Sd params $\rightarrow$ Timestepping |     |      |      |      |      |      |      |
| Number of timesteps per period (timestep) | 72 (20 mins) | 72 (20 mins) | 96 (15 mins) | 120 (12 mins) | 120 (12 mins) | 144 (10 minutes) | 192 (7.5 minutes) |
| Atmos $\rightarrow$ Sd params $\rightarrow$ Sec-by-sec $\rightarrow$ Sec4: LSP $\rightarrow$ Number of substeps over full column* | 10 | 10 | 7 | 6 | 6 | 5 | 4 |
| Atmos $\rightarrow$ Sd params $\rightarrow$ Sec-by-sec $\rightarrow$ Sec5: Convection $\rightarrow$ Threshold vertical velocity | 0.3 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 |
Benefits of seamlessness
Benefits and compromises from seamless approach

Resolution:

• UM (and parametrisations) developed to work across wide range of resolutions
• GA developed and tested from $\Delta x=135 - 10\text{km}$
• **Benefit:** increasing res. in lower-res systems (e.g. seasonal forecasting) is almost trivial
• **Benefit:** can trust lower-res tests to teach you about higher-res systems $\rightarrow$ cheaper testing
• **Cost:** more thought and care must be taken when initially developing and testing science
Benefits of seamlessness
Benefits and compromises from seamless approach

Complexity/system dependence:

• UM (and parametrisations) developed and tested across all timescales

A number of system dependent options:

<table>
<thead>
<tr>
<th>Variable</th>
<th>NWP forecasts</th>
<th>Seasonal forecast</th>
<th>Climate projections</th>
</tr>
</thead>
<tbody>
<tr>
<td>Input/Output Control -&gt; General Configuration -&gt; Use 360 day calendar</td>
<td>Off</td>
<td>Off</td>
<td>On*</td>
</tr>
<tr>
<td>Ind sec ots -&gt; Misc sec 94-98 -&gt; Summation type</td>
<td>Fast, non-reproducible</td>
<td>Double-double precision reproducible</td>
<td>Double-double precision reproducible</td>
</tr>
<tr>
<td>Atmos -&gt; Sci params -&gt; Sec-by-sec -&gt; Sec3: BL -&gt; Land -&gt; Use coastal tiling</td>
<td>Off</td>
<td>On</td>
<td>On</td>
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<tr>
<td>Atmos -&gt; Sci params -&gt; Sec-by-sec -&gt; Sec12: Advection -&gt; Moisture conservation</td>
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<td>More accurate</td>
<td>More accurate</td>
</tr>
<tr>
<td>Atmos -&gt; Sci params -&gt; Sec-by-sec -&gt; Sec14: Energy corr.</td>
<td>Energy adjustment not included</td>
<td>&lt;1B&gt; Standard energy adjustment included</td>
<td>&lt;1B&gt; Standard energy adjustment included</td>
</tr>
<tr>
<td>Atmos -&gt; Sci params -&gt; Sec-by-sec -&gt; Sec17: Aerosol</td>
<td>Including dry mass correction</td>
<td>Off</td>
<td></td>
</tr>
</tbody>
</table>

% can use prognostic aerosol or *traceable* climatological aerosol

**also** can obviously run atmospheric model in coupled or uncoupled mode
Benefits of seamlessness
Benefits and compromises from seamless approach

Complexity/system/time scale dependence:

• UM (and parametrisations) developed and tested across all timescales

• Benefit (& cost?): seamless configuration provides additional constraint (and confidence)

• Benefit: wider assessment improves understanding

• Cost: harder to “tune” performance for a particular application (beneficial in the long run?)
Benefits of seamlessness
Benefits and compromises from seamless approach

Complexity/system/time scale dependence:

• UM (and parametrisations) developed and tested across all timescales

• **Benefit:** increased testing/stress improves the robustness of the model

• **Benefit:** traceable hierarchies makes extending complexity simpler (e.g. aerosols for NWP)

• **Cost:** code can become complex because of the number of different “use cases”. Requires higher level of governance and top-level control
Practicalities/compromise
Evolution of the GA “trunk” and “branches”

GA3.1/GL3.1
Minor diffs in NWP configuration

GA3.0/GL3.0
Dyn, Land, Conv

GA4.0/GL4.0

GA5.0/GL5.0

GA6.0/GL6.0

GA6.1/GL6.1
Aggregated surface tile
Shorter CAPE ts
Reduced ice conductivity

GA7.0/GL7.0

GA7.1/GL7.1
Reduced aerosol forcing

PS26/PS27: Global NWP suite → GA3.1

PS34: Global NWP suite → GA6.1/GL6.1

PS28
GloSea → GA3.0/GL3.0

PS34+?
GloSea → GC2.0

UKESM1 / CMIP6
Summary

- Unified Model allows seamless approach to model dev.
- GA applied over wide range of spatial/temporal scales
- MO extending this approach to coupled and regional model
- Significant technical and scientific benefit
- Up front cost in development and testing
- Possible to make pragmatic implementation choices and maintain the integrity of the seamless “trunk”
- Once adopted, the benefits outweigh the costs
Questions?