Seamless model development at the Met Office

Keith Williams
Unified forecast/climate model

1950s-1980s: Regional/global NWP and climate GCM
Late 1980s: Met Office codes need rewriting to port computers
Decision: Put effort behind a single “Unified Model”

Cullen (1993), Brown et al. (2010)
Unified forecast/climate model

- Common control/infrastructure
- Common grid structure/dynamical core
- Access to common set of parametrisation schemes selected by user
- Common diagnostic/processing code
- Later drive to make model portable across architectures

Cullen (1993), Brown et al. (2010)
The Met Office Unified Model

Primary applications of the UM today

\[ \Delta x \approx 130 \rightarrow 60 \text{ km} \]
\[ \Delta x \approx 20 \text{ km} \]
\[ \Delta x \approx 10 \text{ km} \]
\[ \Delta x \approx 1.5 \text{ km} \]
\[ \Delta x \approx 330 \text{ m} \]

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Cullen (1993), Brown et al. (2010)
Global Seamless Physical Model

- Global Atmosphere
- Global Land
- Global Ocean
- Global Sea Ice
- Global Waves

Component Models
- GA6, GL6, GO5, GSI6

Coupled AOIL Model
- GC2.0

Deterministic Atmos & Marine
- Atmos Ensemble
- GloSea

Decadal Climate Change & UKESM1

- NWP - AL, OI, W

- Multi-model A1B JJA
“...these models are our laboratories where we can explore the processes, feedbacks and interactions in and between the holistic atmosphere-ocean-land-ice system...”

Julia Slingo, Met Office Science Strategy 2016-2021
Towards a UK coupled model

Huw Lewis – UKEP project

WAVES

Wind, Wave height, Period, Surface stress

Waves, Pressure, Temperature, Radiation, Surface fluxes

SST

Wind height, Surface stress, Bottom stress, Dissipation

Currents, height, Roughness

Bottom stress

ATMOSPHERE

Radiation, Temp, Precip, Evap

Surface fluxes

OCEAN

Inundation

Freshwater discharge

Currents

Bottom stress

LAND SURFACE

Freshwater, Nutrients, Temperature

SEDIMENTS/BIOGEOCHEM
Seamless model assessment

Seamless Model Assessment is the exploitation of the seamless nature of the Unified Model across space and timescales to assess and improve the simulation of processes within the model.
Systematic Errors – NWP to Climate

Resolution

Timescale

N96

Decadal

N320

5 Days
Systematic Errors in Precipitation

(a) TRMM Annual Precipitation 1998-2007

(b) GPCP (V2.0) Annual Precipitation 1998-2007

(c) MetUM Day 1 Forecasts - GPCP Annual Precipitation 1998-2007


NWP error

Climate error

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Bias in cloud cover
(against CALIPSO)
SST Bias Evolution Coupled NWP vs. Climate

NH. Winter

Climate: 50-yr mean

NH. Summer

Coupled NWP: 10 cases

Day 14

Johns et al. 2012
Aerosol indirect effects
An example of seamless model development

Jane Mulcahy

- Direct & indirect aerosol effects:

Pre-2007: NWP models assume fixed values for land/sea
2007-2014: Direct effect only uses 3D climatologies

Adapted from Haywood & Boucher (2000)
Aerosol indirect effects
An example of seamless model development

Mulcahy et al (2014)

Impact of full “climate” aerosol scheme on surface SW (W/m²) at day 5 in 1 month of rerun global NWP forecasts (June 2012):
Aerosol indirect effects
An example of seamless model development

Reverse experiment: impact on JJA surface SW from running 20 year climate model with NWP treatment of aerosol scheme
Impact of adding climatological indirect aerosol effects on 20 year mean JJA T$_{1.5m}$ error:
Aerosol indirect effects
An example of seamless model development

Tom Riddick

- Impact on operational implementation (alongside other model changes)

- High lat improvements from aerosol climatologies
- Lower lat improvements from other changes
Aerosol indirect effects
An example of seamless model development

Seamless framework helped progress by:

• Exposing sources of errors in one system by studying in the context of another

• Providing appropriate tools/systems with which to develop the improved schemes

Other good examples include ENDFGame, stochastic physics, multi-layer snow scheme …

… but most GA developments benefit from this sort of seamlessness, albeit often more subtly
Example of lack of cloud over Southern Ocean

Surface net downward SW bias

Coupled SST bias
CONSTRRAIN field campaign (off NW Scotland)
Example of warm rain microphysics

Excess hydro-meteor at low levels

Comparison of mean radar reflectivity over the tropics against CloudSat

Excess “drizzle” (<0.005mm/hr)
Addressing excess drizzle in the model using field experiments

Develop new cloud microphysics parametrizations from observations

Evaluate in high resolution NWP case-studies

Implement in UK/global NWP and climate models

Steve Abel (OBR) & Ian Boutle (APP)

10 JJA NWP case-studies (model - land based observations in extratropical Northern hemisphere)
Example of warm rain microphysics

Comparison of mean radar reflectivity over the tropics against CloudSat
The GA (and RA) development process
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
The GA development process

Continuous research cycle

Roughly annual GA release cycle

“Freeze” GAx

Review & science assurance

“Freeze” GAx+1

Plan next release:
• Aims/scope
• Resources
• Constraints
• Timescales

Identify changes:
• Maturity
• Priority

Current std tests:
• 20 yr AMIP simulation
• 24 x 6 day NWP forecasts
Ticket Details #64

Main developer: Martin Willett

Scientific description
The fix convective scheme is primarily a major rewrite of the convective scheme's parcel calculations that provides a more accurate estimate of parcel properties during the ascent. It does this by iteratively solving the implicit equations for the mass ascent and the forced draught. Additionally it also addresses numerous issues that were identified during the review of the convective schemes' authors and the development of the IC scheme. These improvements include: the full integration of IC into the convective scheme including some of the latest Martin's own calculation; a simpler and more robust indentation condition for evaporation; improved triggering of multi-level mechanisms including changes to prevent overshooting evaporation; allowing parcels that become subsaturated parcels to re-saturate any condensate; more robust handling of forced convection including the rejection of dry convection; connection to the inclusion of downwash; the option to include heating due to convective momentum transport and an energy correction; and a general cleaning up of the code.

Physical basis for the change
The original convective scheme was originally developed at a time when model resolution (especially vertical resolution) and the demand for accuracy in the parcel ascent were lower than they currently are. Although the current scheme performs very well there is considerable anecdotal evidence that deep convection terminates too low down. The change promises a more accurate estimate of the parcel properties and hence allows convection to go deeper (if it should do).

Resolution and timescale dependence
In the change dependent on model resolution, timescale or applications (yes/no)? If yes (This should be exceptional as interrelated points resolution-dependence should be built into the code)
If yes, please details here>

Technical implementation
Please describe in detail how the change should be applied to UM jobs. These changes should be UPLUG based for UM version 8.1, and KASS app based for version 9.1. This should include any UM branches, hand-edits, SIGMAmaster files, changes to inputs/outputs etc. Also, please continue to duplicate this table for each UM version until the code is fully validated.

UM v8.1 (UPLUG based)

- Request
date
- Reconfiguration
- Model run
- Remedies
- Hand-edits
- User
- Provisions
- Any other changes

- Reconfiguration
- Model run
- Remedies
- Hand-edits
- User
- Provisions
- Any other changes

Please note any complications that either arise in any particular system.

<Add details here>

UM v9.1 (KASS based)

- Request
date
- Reconfiguration
- Model run
- Remedies
- Hand-edits
- User
- Provisions
- Any other changes

- Reconfiguration
- Model run
- Remedies
- Hand-edits
- User
- Provisions
- Any other changes

Please note any complications that either arise in any particular system.

<Add details here>
Continuous research cycle

Roughly annual GA release cycle

“Freeze” GAx
Review & science assurance
“Chill” GAx+1
“Freeze” GAx+1

Plan next release:
• Aims/scope
• Resources
• Constraints
• Timescales
Identify changes:
• Maturity
• Priority

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

Assessment runs include:

- ~100yr Higher resolution/coupled climate simulations
- High resolution NWP with cycling data assimilation
- High resolution Ensemble prediction system
- Seasonal forecast/hindcast runs
The GA development process

Continuous research cycle

Roughly annual GA release cycle

Annual model assessment

System implementation projects

Top model problems → PEGs

Std tests — Package testing — Tuning — “Freeze” GAx+1

Assessment runs/tests → Assessment runs/tests → Assessment workshop Documentation

e.g. global NWP suite → e.g. Major climate release for CMIP

The GA development process
The GA development process

- Continuous research cycle
- Roughly annual GA release cycle
- Annual model assessment
- System implementation projects
- Continuous operational running

Top model problems → PEGs

- Std tests
- Package testing
- Tuning
- “Freeze” GAx+1

Assessment runs/tests

- e.g. global NWP suite
- e.g. Major climate release for CMIP

Assessment workshop

Documentation

Parallel suite Implementation

System implementation projects
Global Model Development Process

Multi-year timescales

Model Development Research Cycle

- Research projects
- Diagnostic studies
- Process Evaluation Groups (PEG)
- Observations & Field Experiments

Model "trunk"
Annual or bi-annual

Model Development Release Cycle

- Assessment metrics

Model Evaluation/Verification

Prediction Systems

Operational Implementation/Use

- Routine verification
- Monitoring/feedback
- Forecaster feedback

Key Decision Point
Practicalities/pragmatism

Evolution of the GA “trunk” and “branches”

PS26/PS27: Global NWP suite → GA3.1

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

Dyn, land, conv

GA4.0/GL4.0

PS28

GloSea → GA3.0/GL3.0

PS26/PS27: Global NWP suite → GA3.1

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

ENDGame core, physics upgrades

GA4.0/GL4.0

GA5.0/GL5.0

Improved ENDGame

GA6.0/GL6.0

Major physics upgrades

GA7.0/GL7.0

PS34: Global NWP suite → GA6.1/GL6.1

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

PS35

GloSea → GC2.0

PS34: Global NWP suite → GA6.1/GL6.1

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

GA7.1/GL7.1 Reduced aerosol forcing

UKESM1 / CMIP6
Seamless aerosol modelling
Seamless aerosol modelling

- Interactive aerosols are expensive!
- On shorter timescales, does the improved forecast capability justify the expense?
- How do we initialise them?
Seamless aerosol modelling

• Interactive aerosols are expensive!
• On shorter timescales, does the improved forecast capability justify the expense?
• How do we initialise them?
• Our intended way of working is to:
  • Use dust interactively on all timescales.
Justification for interactive dust
Interactive aerosols are expensive!

On shorter timescales, does the improved forecast capability justify the expense?

How do we initialise them?

Our intended way of working is to:
- Use dust interactively on all timescales.
- Apply aerosol concentrations calculated interactively in AMIP simulations for shorter timescale forecasts.
- Aerosol direct and indirect effects are calculated in the same way on all timescales.
Impact of using aerosol climatologies from previous configuration

Mean bias in reflected SW
GA7 with interactive aerosols using Glomap-MODE

Mean bias in reflected SW
GA7 with GA6 CLASSIC climatologies

Area-weighted rms diff = 8.55
Area-weighted rms diff = 8.51
Things to consider when writing schemes for a seamless system

- The scheme needs to work for all applications of the model (not just the timescale the developer interested in).
- Cost is an important issue for many users.
- Can the level of complexity of the scheme be adjusted such that there is a traceable solution which appropriately balances cost and benefit for each application?
Developments in computing
Challenge of exploiting modern HPC
General considerations for inclusion of new processes or more complexity

- Complexity we might want to include to be able to forecast new things
  - Air quality forecasts
  - Seasonal Arctic sea-ice
  - Algal blooms

- Complexity we might want to include to be able to forecast traditional things better
  - Better ‘traditional’ physics, dynamics etc
  - Aerosols, ice etc in as much as they matter for ‘weather’
Future challenges
Resolution and scalability
The consequence of unification

A factor of ~100-1000 between these...

...the same dynamics has to continue to work

17 - 135 km

300 m
Resolution and scalability

Running global models on ~ 100,000 cores

Tommaso Benacchio, Chris Maynard, Ben Shipway, Nigel Wood

- At 10km mid-latitude resolution, grid spacing near poles = 12m!

We need to remove the poles
“LFRic:” Next generation Unified Model using the GungHo dynamical core

Tomasso Benacchio, Chris Maynard, Ben Shipway, Nigel Wood

- Uses mixed finite element approach on a cubed sphere
- Many aspects of formulation (dynamics, physics etc.) based on current Unified Model ...
- ... but using completely rewritten code designed to separate scientific aspects (physics eqns) and computational aspects (grid layout, communication, etc.)
Summary

We have seen significant benefit from developing a seamless system including:
- Greater scientific robustness of the model
- Improved ability to investigate model systematic errors
- More efficient use of resources

It does, however, pose challenges with our developers being required to consider all users of the model when developing schemes.