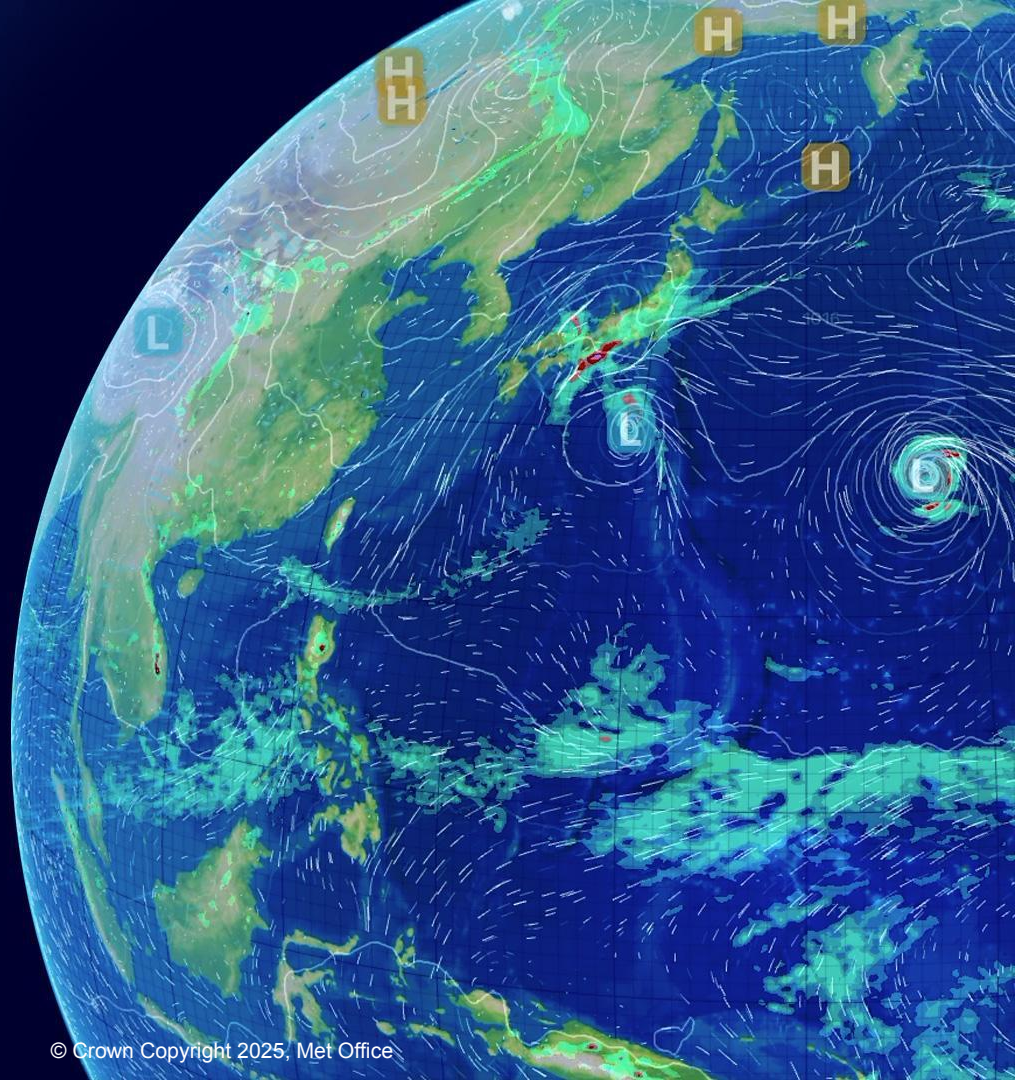


Unified Physics

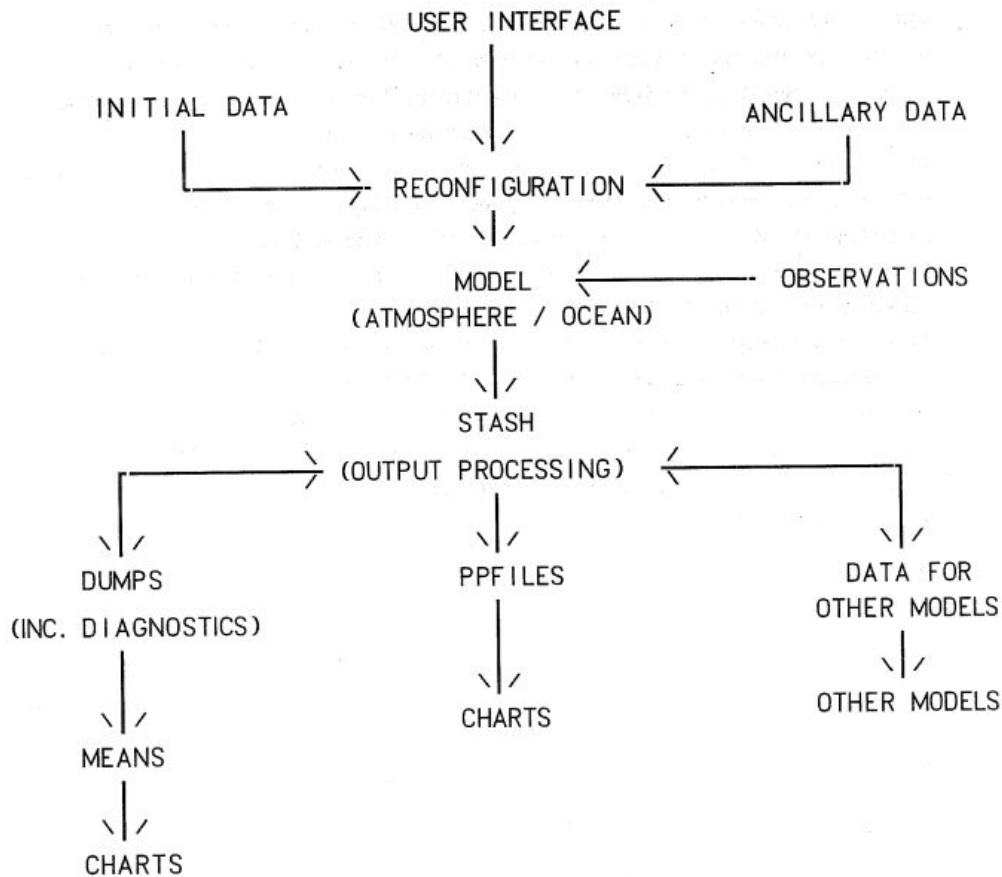
Keith Williams

Seamless Global Modelling workshop

June 2025



Unified model (*Cullen, 1993*)



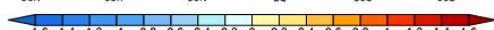
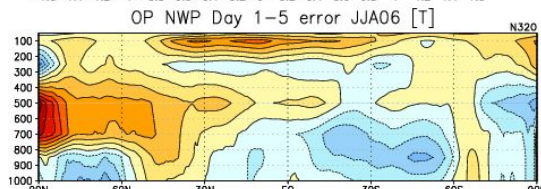
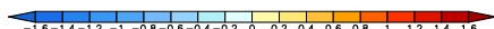
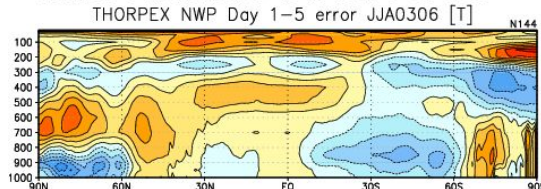
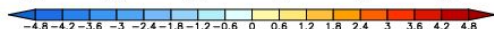
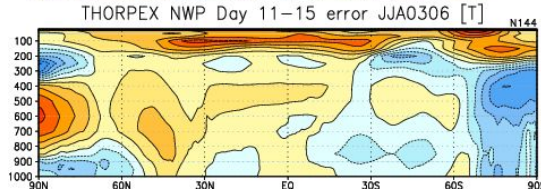
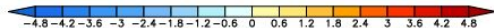
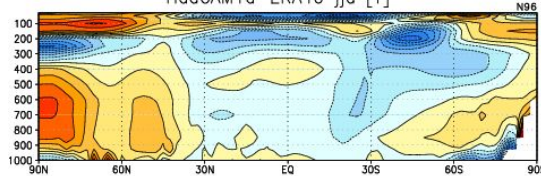


Systematic errors – NWP & climate



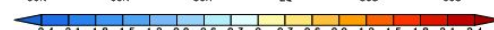
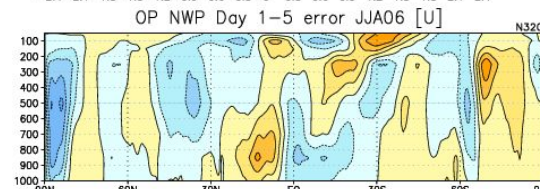
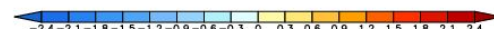
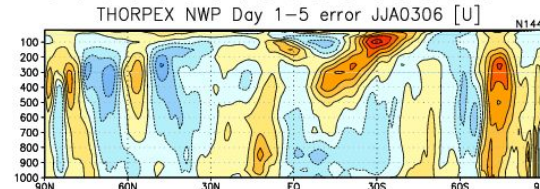
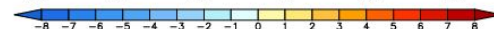
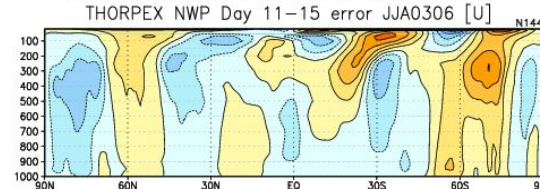
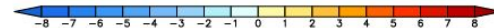
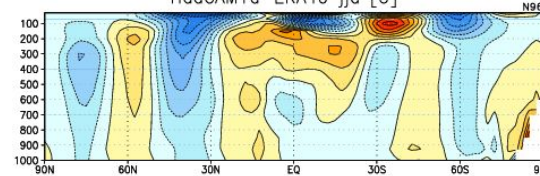
Zonal mean T error

HadGAM1a-ERA40 jja [T]

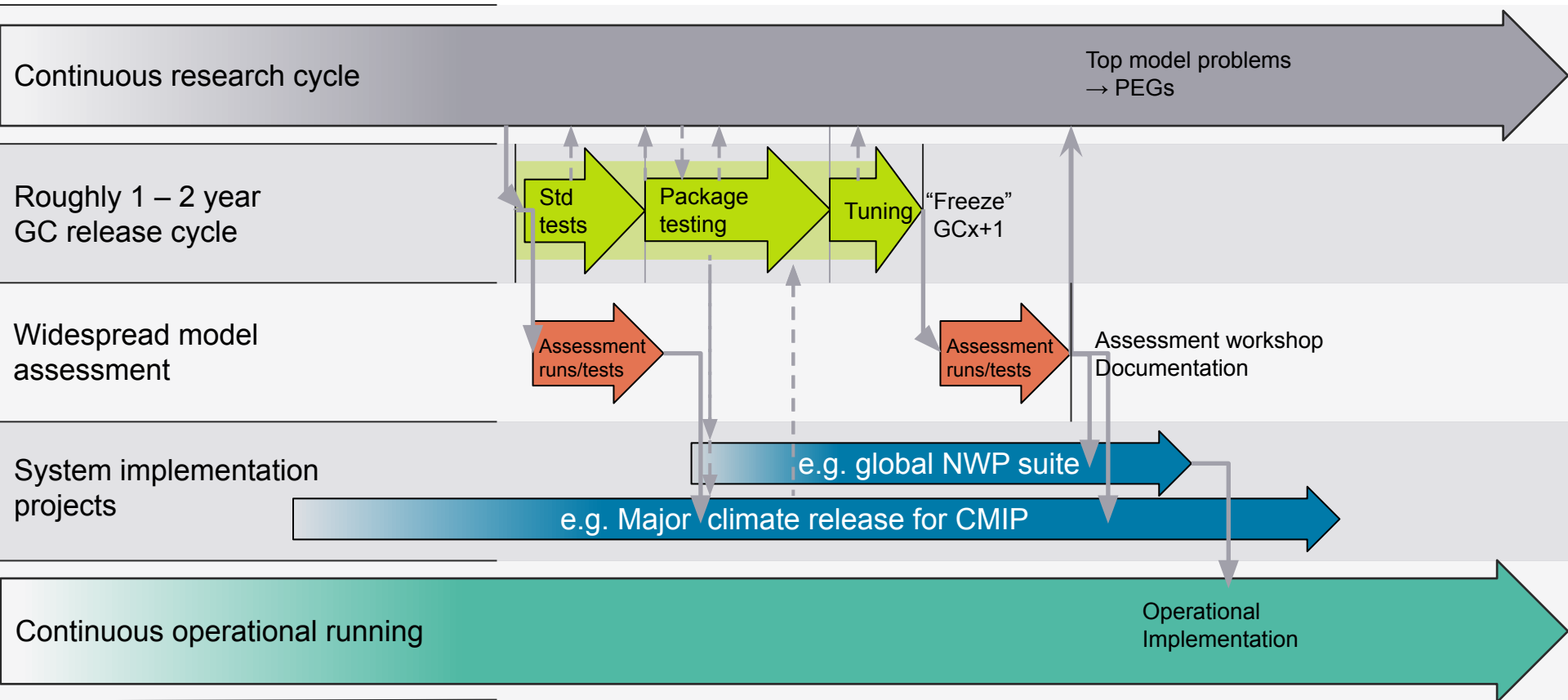


Zonal mean U error

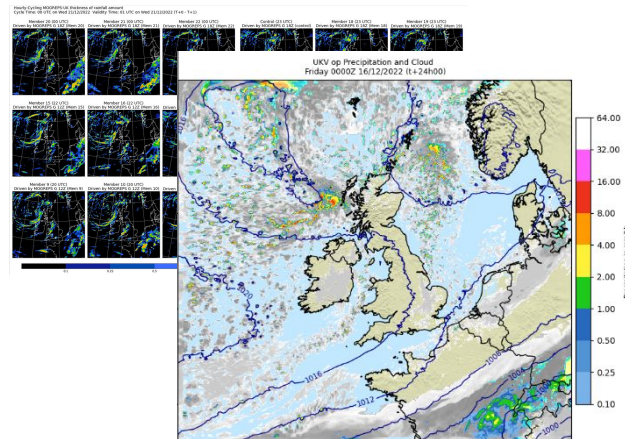
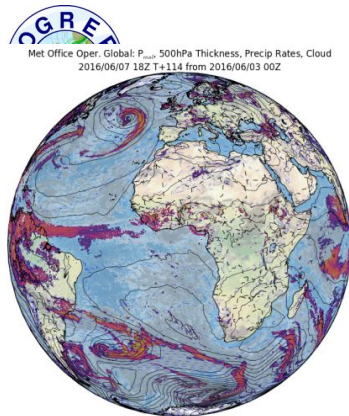
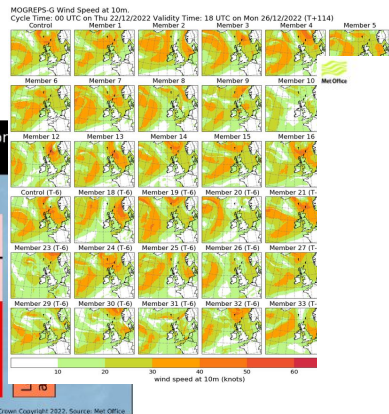
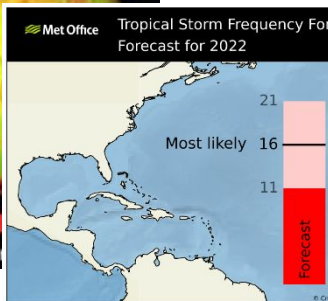
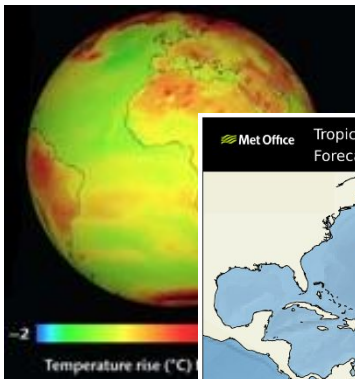
HadGAM1a-ERA40 jja [U]



The GC development process



The Met Office Unified Model



$\Delta x \approx 130 \rightarrow 60$ km

$\Delta x \approx 20$ km

$\Delta x \approx 10$ km

$\Delta x \approx 2.2$ km

$\Delta x \approx 1.5$ km



Met Office seamless modelling: Current situation

- Global & convective-scale model science is unified across timescales in Met Office models.
- However there are a number of differences between global (GAL) and regional (RAL) configurations, most notably:

Scheme	GAL	RAL
Convection parametrization	On	Off
Cloud fraction	PC2 (Wilson et al., 2008)	Bi-modal (Van Weverberg et al., 2021)
Cloud microphysics	Wilson and Ballard (1999)	CASIM (Field et al., 2023)
Radiation cloud inhomogeneity	MclCA	Simple representation
Orographic GWD	On	Off
Turbulence	Various historical differences	Various historical differences

Removing outstanding seams to create a seamless system

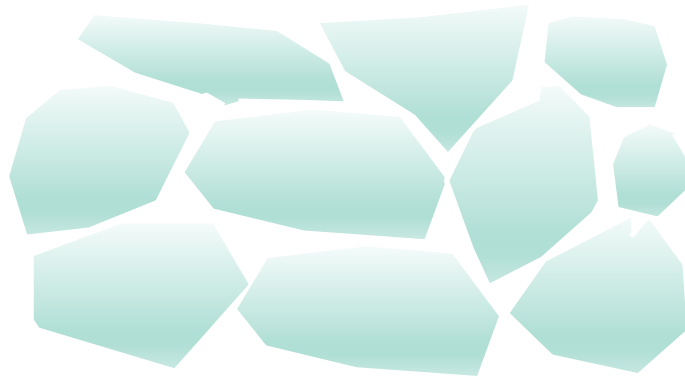
- This is desirable because:
 - Plans to run the global model in the convective ‘grey zone’ mean a configuration distinction between parametrized and explicit convection is no longer appropriate.
 - It is increasingly problematic to develop new science (e.g. CoMorph & CASIM) within two significantly different model configurations (end up with different versions of new schemes).
 - The overheads associated with maintaining and testing new science in different configurations in terms of staff and computer time are significant.
 - There are potentially significant benefits for parametrization development (traditional and ML approaches) from having a more unified configuration
 - **The requirements for training datasets for AI mean that there is likely to be a desire to run higher resolution benchmark simulations.**



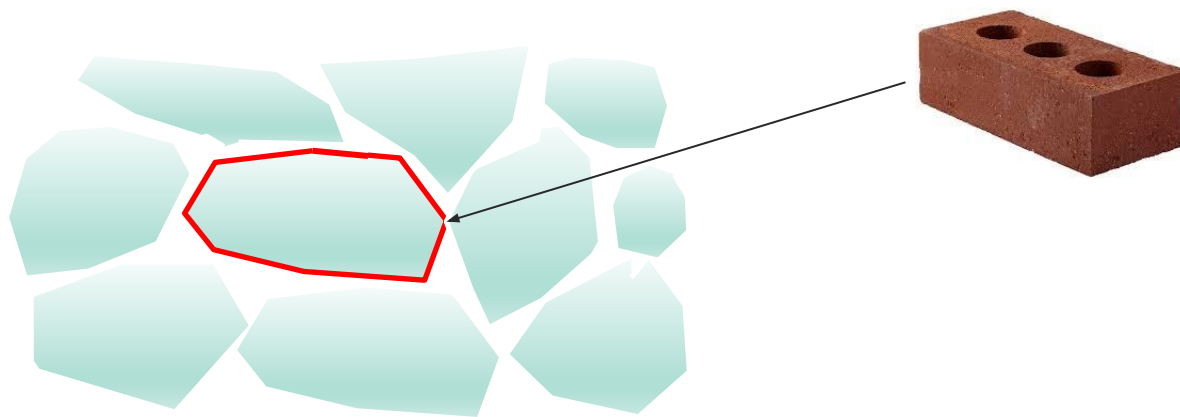
Unified Physics

Working to develop a Unified Physics configuration for GAL and RAL which includes CoMorph, CASIM and a single cloud scheme. This will be a physical improvement on what's used currently and aims to reduce systematic errors.

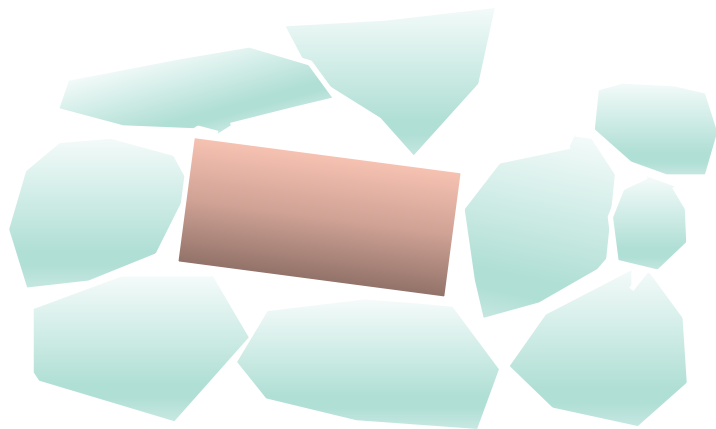
Parametrization development: The challenge of implementing a new scheme



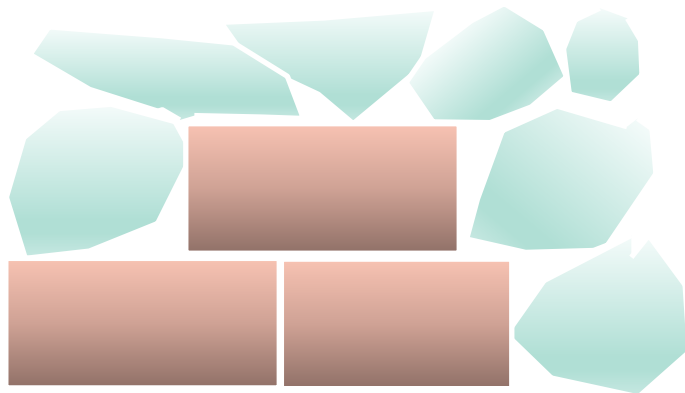
Parametrization development: The challenge of implementing a new scheme



Parametrization development: The challenge of implementing a new scheme



Parametrization development: The challenge of implementing a new scheme



Chosen schemes

Convection

6A
Separate schemes for deep, shallow and mid-level convection

CoMorph
Single parcel ascent / descent code for all plumes

Microphysics

Wilson & Ballard
Single moment

```

    graph TD
      V[VAPOUR] -- "Autoconversion/Accretion" --> L[LIQUID]
      L -- "Condensation" --> V
      V -- "Evaporation" --> R[RAIN]
      R -- "Evaporation" --> V
      R -- "Fall in" --> V
      R -- "Fall out" --> V
      R -- "Melling" --> I[ICE]
      I -- "Capture" --> R
      I -- "Fall in" --> R
      I -- "Fall out" --> R
      L -- "Riming" --> I
      I -- "Nucleation" --> V
      V -- "Deposition/Sublimation" --> I
      I -- "Bergeron Process" --> L
  
```

CASIM*
Can have multiple moments

```

    graph TD
      WV[Water vapour, qv] -- "Heterogeneous nucleation" --> CW[Cloud water, qc, nc]
      CW -- "Heterogeneous nucleation" --> CI[Cloud ice, qi, ni]
      CW -- "Homogeneous freezing" --> CI
      CW -- "Melting" --> R[Rain, qr, nr]
      CI -- "Melting" --> R
      CI -- "Rime-ripening" --> S[Snow qs, ns]
      S -- "Rime-ripening" --> CI
      R -- "Accretion" --> G[Graupel, qg, ng]
      S -- "Accretion" --> G
      G -- "Accretion" --> CW
      G -- "Accretion" --> CI
      G -- "Accretion" --> R
      G -- "Accretion" --> S
      G -- "Sedimentation" --> S
  
```

Large-Scale Cloud

Smith
Diagnostic

Assumes triangular subgrid saturation-departure probability density function with a fixed width, linked to profile of critical relative humidity

PC2
Prognostic

Calculates increments to liquid and ice cloud fraction and condensate amounts that get advected by the resolved wind

Bi-Modal
Diagnostic

Like Smith scheme but accounts for coexistence of two modes of variability within a grid box near entrainment zones

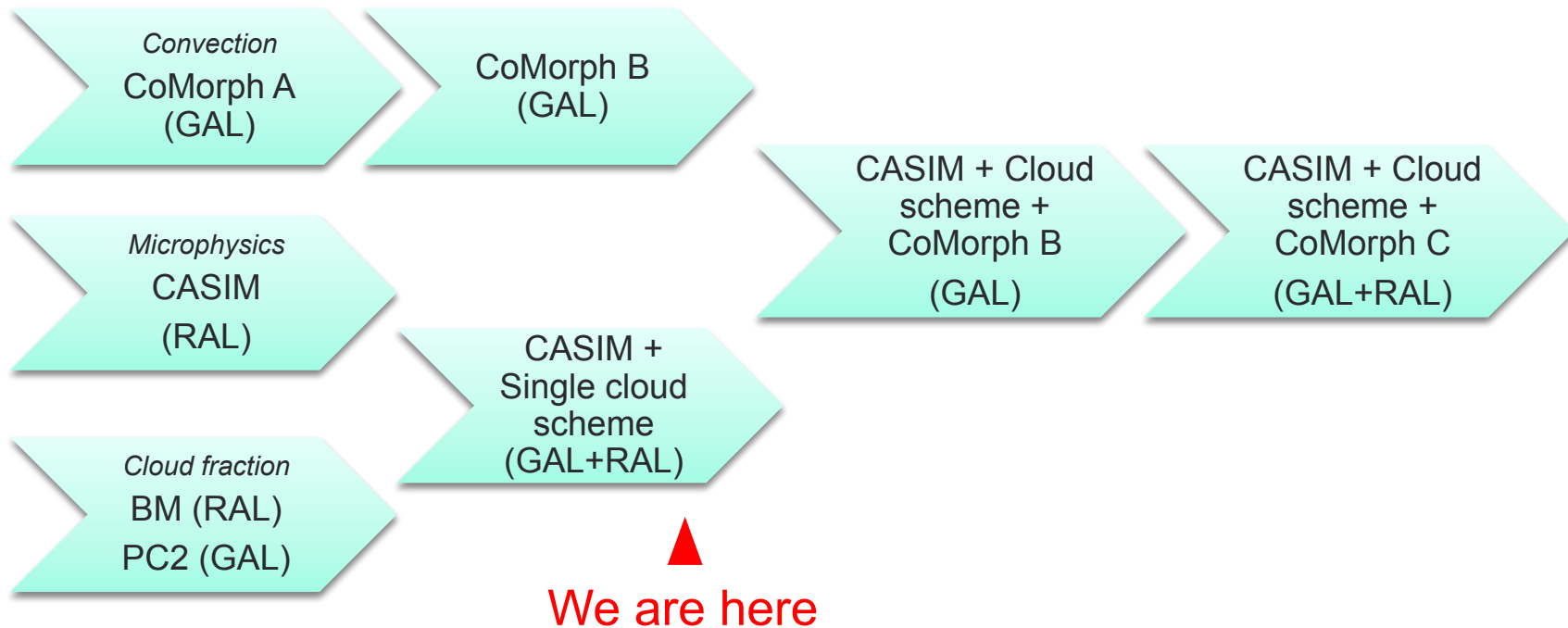
A hybrid scheme e.g. PC2+
Prognostic/diagnostic

PC2 for ice, Bi-modal for liquid

?

*CASIM = Cloud-Aerosol Interacting Microphysics

Order of work





5km 'trailblazer' (lower level of data readiness; opportunity for early use of CoMorph)

- CoMorph-A on top of GAL9.

CoMorph B (improving diurnal cycle) & CoMorph C (scale-aware)

- Significant further developments to CoMorph.

CASIM microphysics

- Performs well at high resolution (RAL3 and KID-A), so as much as possible, looking to take 'as is'.
- Needs more work around coupling to CoMorph & Cloud fraction scheme.

Cloud fraction

- Undertaking Single Column Model and 300m regional simulations of cloud scheme options.

Aerosol

- Developing a traceable hierarchy of schemes based on full UKCA used in climate

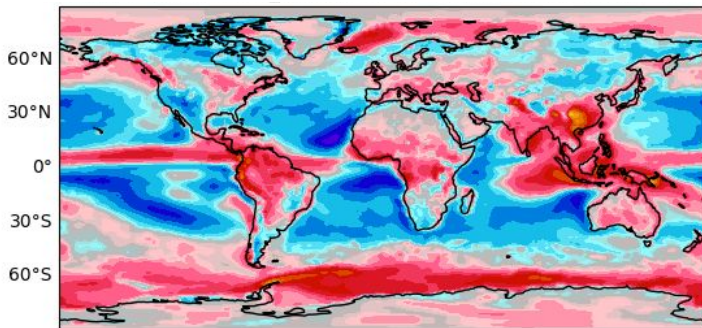
CoMorph A – Cloud Radiative Effect bias

vs EBAF4.1

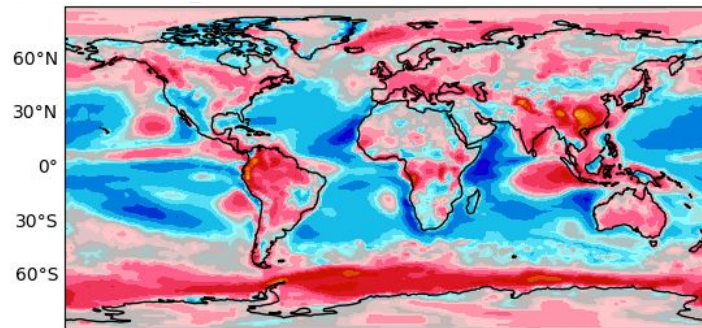
Ctrl (GC5)

CoMorph A

SW

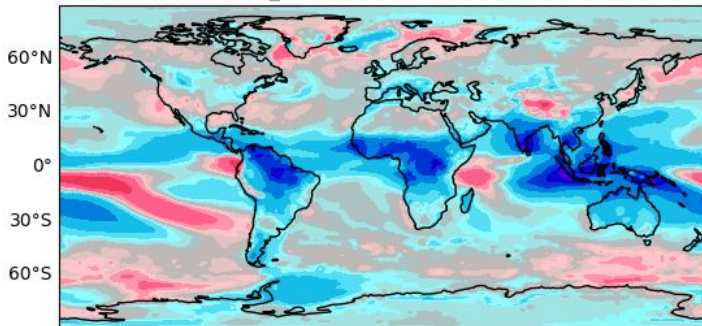


Area-weighted rms diff = 8.82

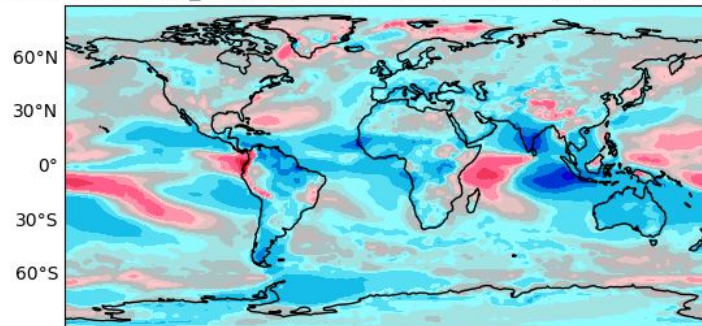


Area-weighted rms diff = 7.76

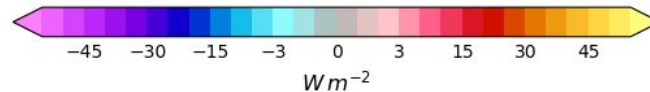
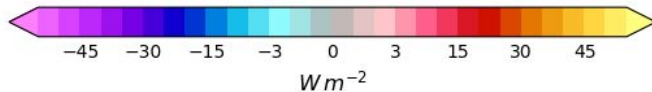
LW



Area-weighted rms diff = 6.44



Area-weighted rms diff = 4.56

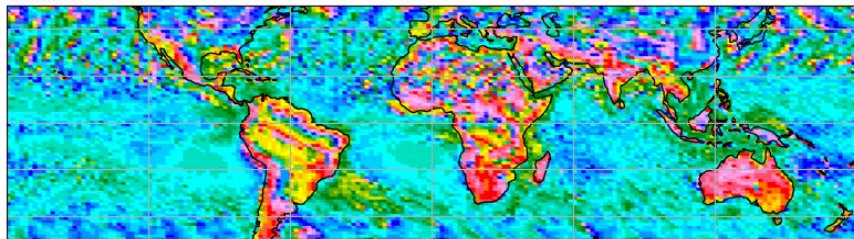


Notable cloud improvements illustrated by reduced spatial RMSE's.

CoMorph-B: Diurnal cycle

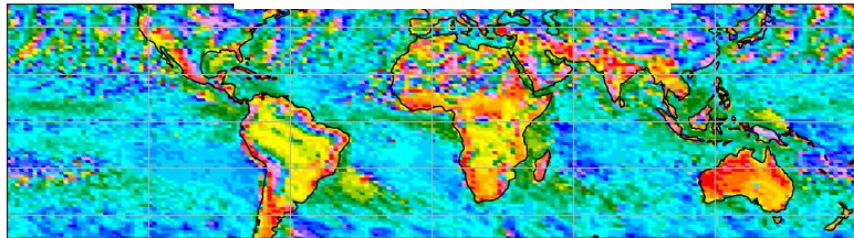
GAL9

Control : u-dh497



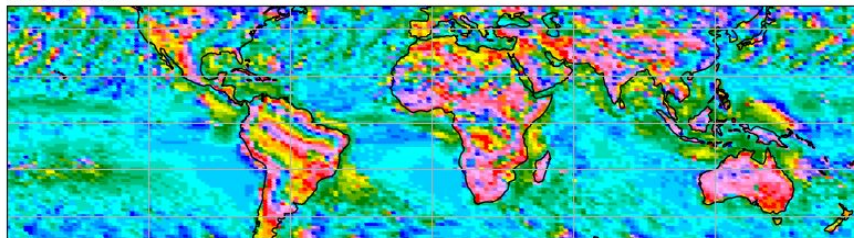
CoMorph-A (CoMA9)

Control : u-cq369



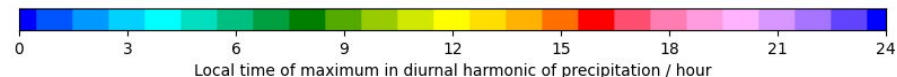
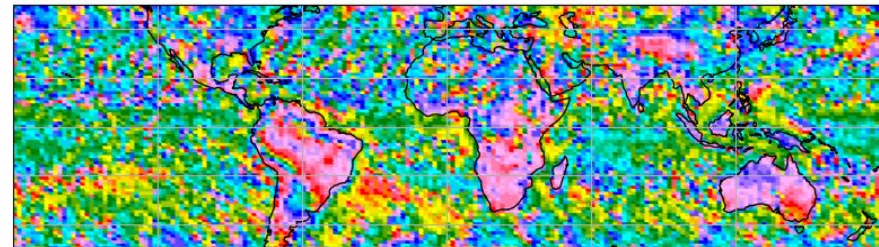
Test version of CoMorph-B

Test : u-dk079



Observations

Obs : TRMM

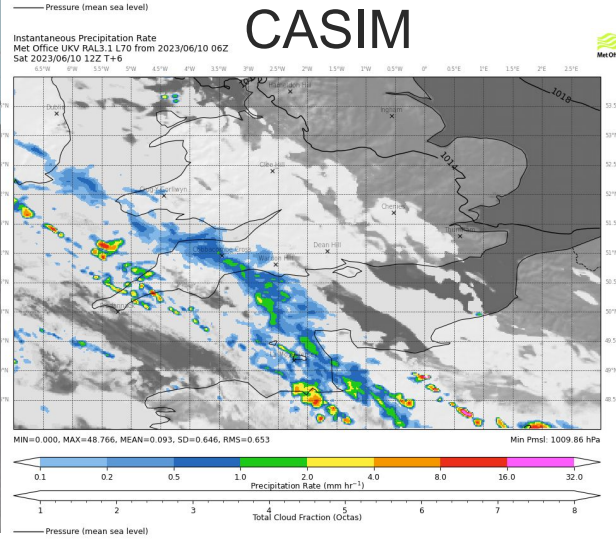
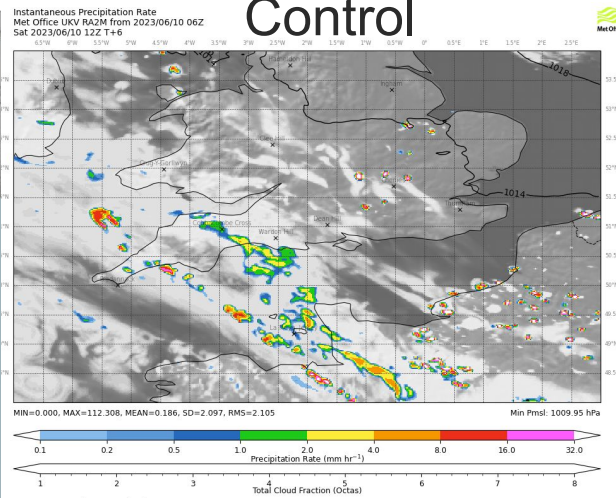
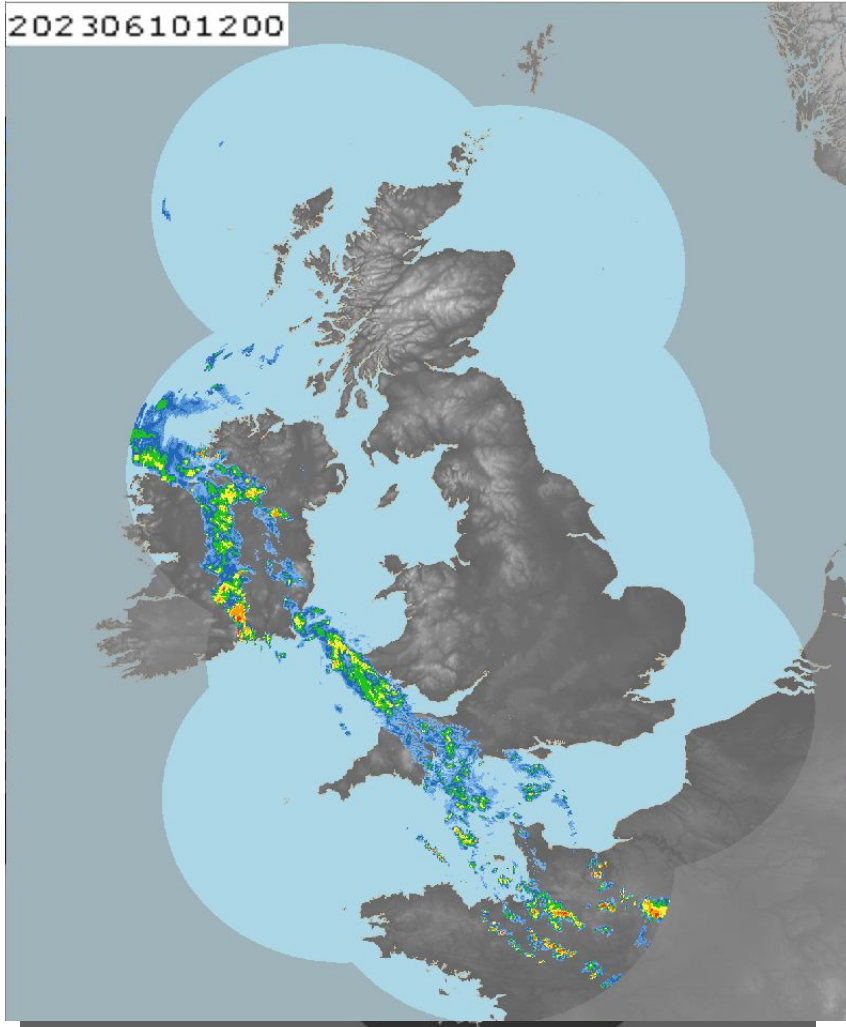


Timing of maximum in diurnal harmonic of precip DJF

Mike Whittall
Alison Stirling

10/6/23
Precip rates
T+6 from 6z

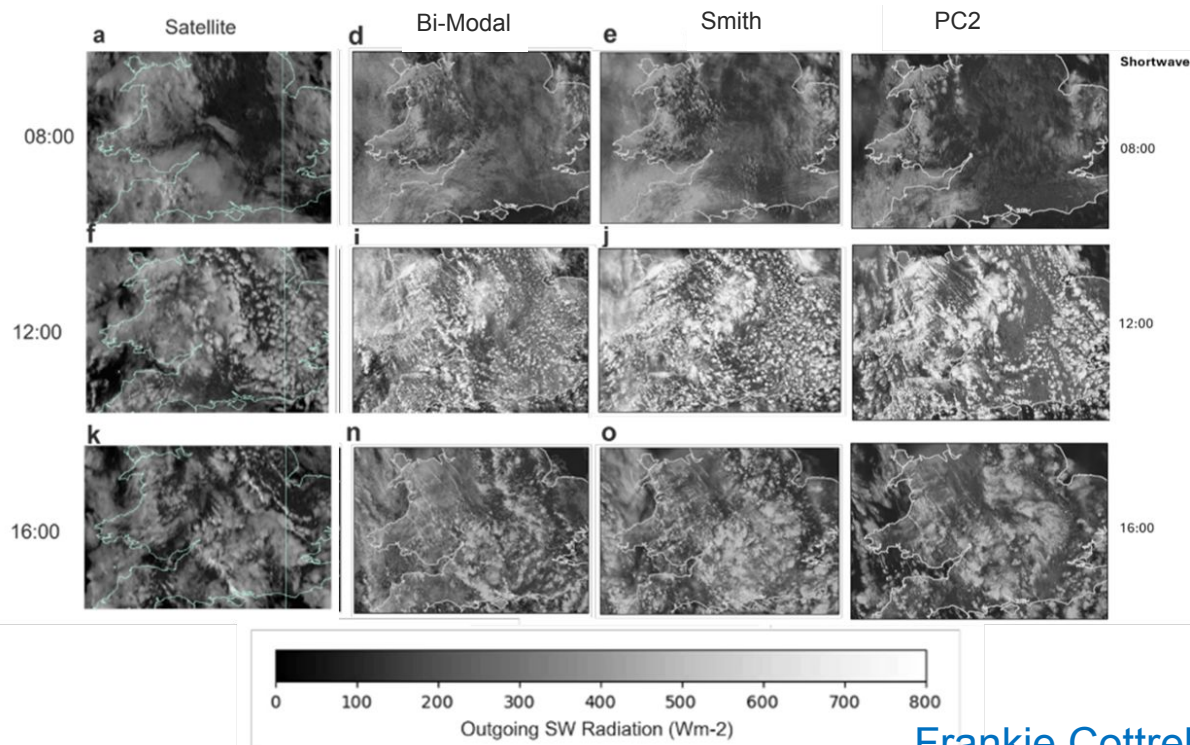
Better frontal
structure
(contiguous)
with CASIM



WesCon shallow convection day

3rd August 2023

- 300 m grid-spacing, no convection
- Configs to test PC2 (RA2T), BiModal (RAL3p2) and Smith (RA2M)
- Outgoing SW shows subtle differences in
 - Convective cell sizes, organisation,
 - Stratiform coverage
- ...which show up in precipitation statistics



Frankie Cottrell
Paul Barrett

SOL/INSOL: aerosol scheme for NWP

SOL/INSOL coupled to CASIM. Case study test for 14/01/23+T36H, with 12hr spin up

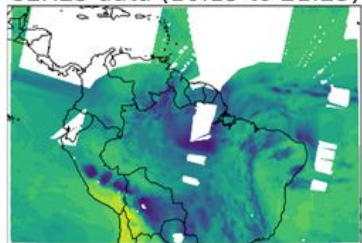
- **CONTROL:** No aerosol scheme. Fixed CDNC (150/cm³) and Cooper INC vs T relation
- **ARB-AER:** 2 moment aerosol (SOL/INSOL) with arbitrary initialisation
- **CAM-AER:** 2 moment aerosol with CAMS initialisation

Joseph Carton-Kelly
Anthony Jones

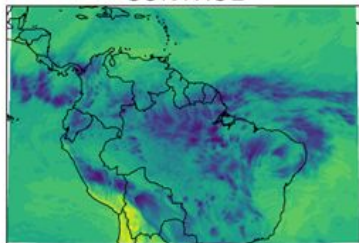
Outgoing longwave radiation

Outgoing shortwave radiation

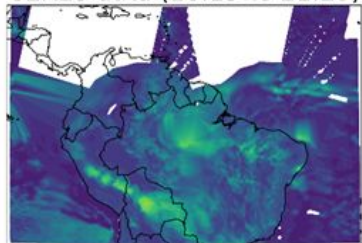
CERES data (16:15 to 21:23)



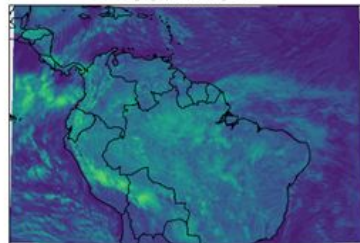
CONTROL



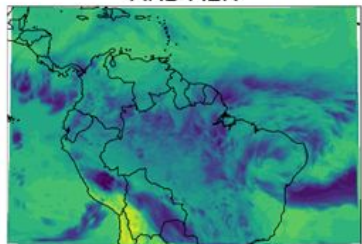
CERES data (16:15 to 21:23)



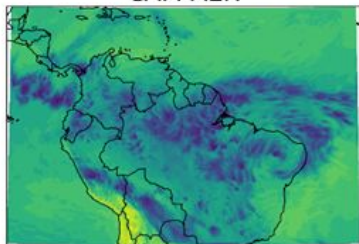
CONTROL



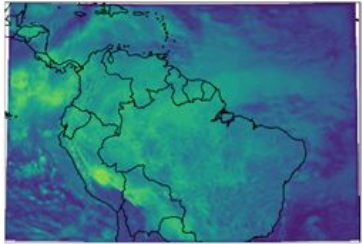
ARB-AER



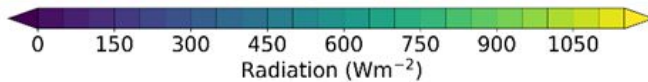
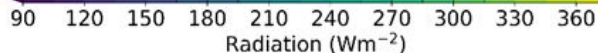
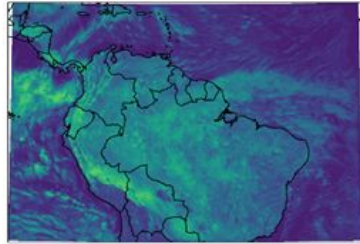
CAM-AER



ARB-AER



CAM-AER



A realistic aerosol initialization (CAMS) is needed for a decent simulation of aerosol-cloud interactions

Summary

- CoMorph and CASIM are major new developments to the convection and microphysics parametrizations in the Met Office model (arguably the two parametrizations there is most sensitivity to).
- Development of single, seamless, cloud fraction and aerosol schemes are also very significant pieces of work which are essential for unifying our physics.
- All are showing significant improvements and reduce some long-standing systematic errors.
- The Unified Physics (UP) project aims to produce a seamless moist physics package across resolutions (<1km to >100km).
- The ultimate vision is for self-consistent physics using the new LFRic infrastructure, from very high resolution (LES) to global climate modelling resolutions. Having a traceable, high-resolution benchmark also help with parametrization development and new machine learning approaches.

