Recent development of physical parametrizations in the Met Office models

ARM radiative processes & cloud modelling meeting

Wed Nov 19th

Jon Petch

John Edwards, Peter Hill, James Manners, Cyril Morcrette & Jonathan Wilkinson, Ben Shipway, Paul Field and several others…

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Contents

- What we do with our model
  - operational models and collaborators
  - research models
  - research frameworks
- Recent & ongoing parametrization development
  - radiation and clouds
  - radiation – clear sky
  - microphysics
  - clouds
  - convection & boundary layer & aerosols (if time which I doubt)

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What we do (with our Unified model)?

What do our parametrizations need to do?

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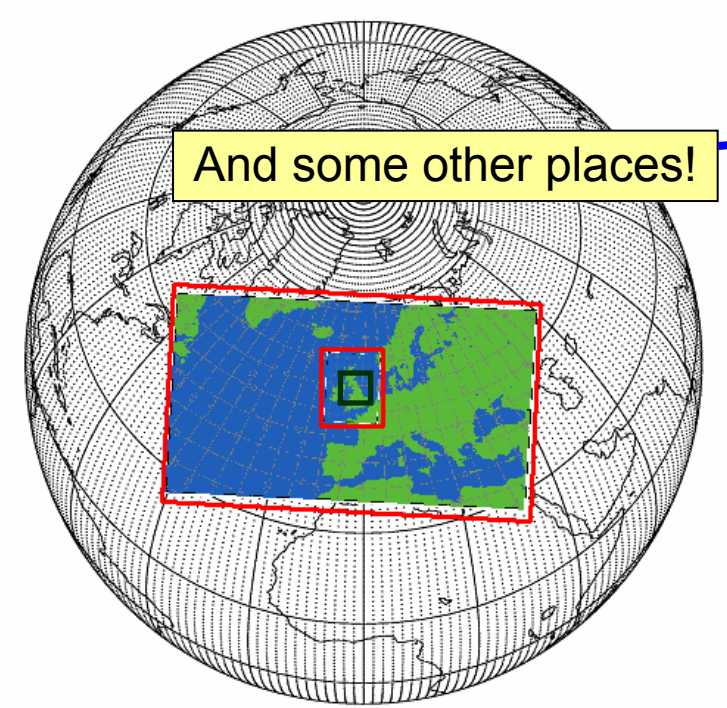
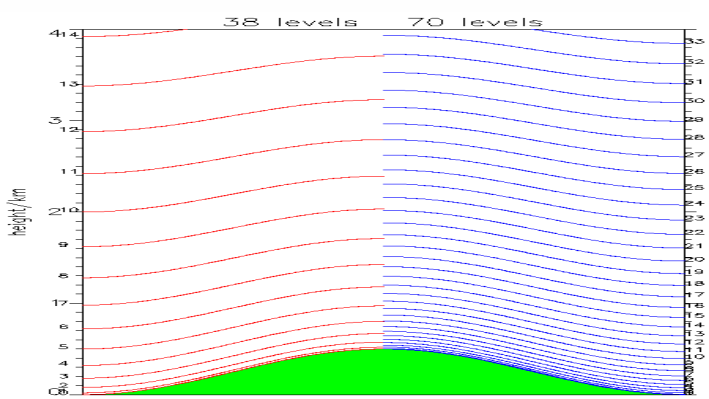
The operational forecast models





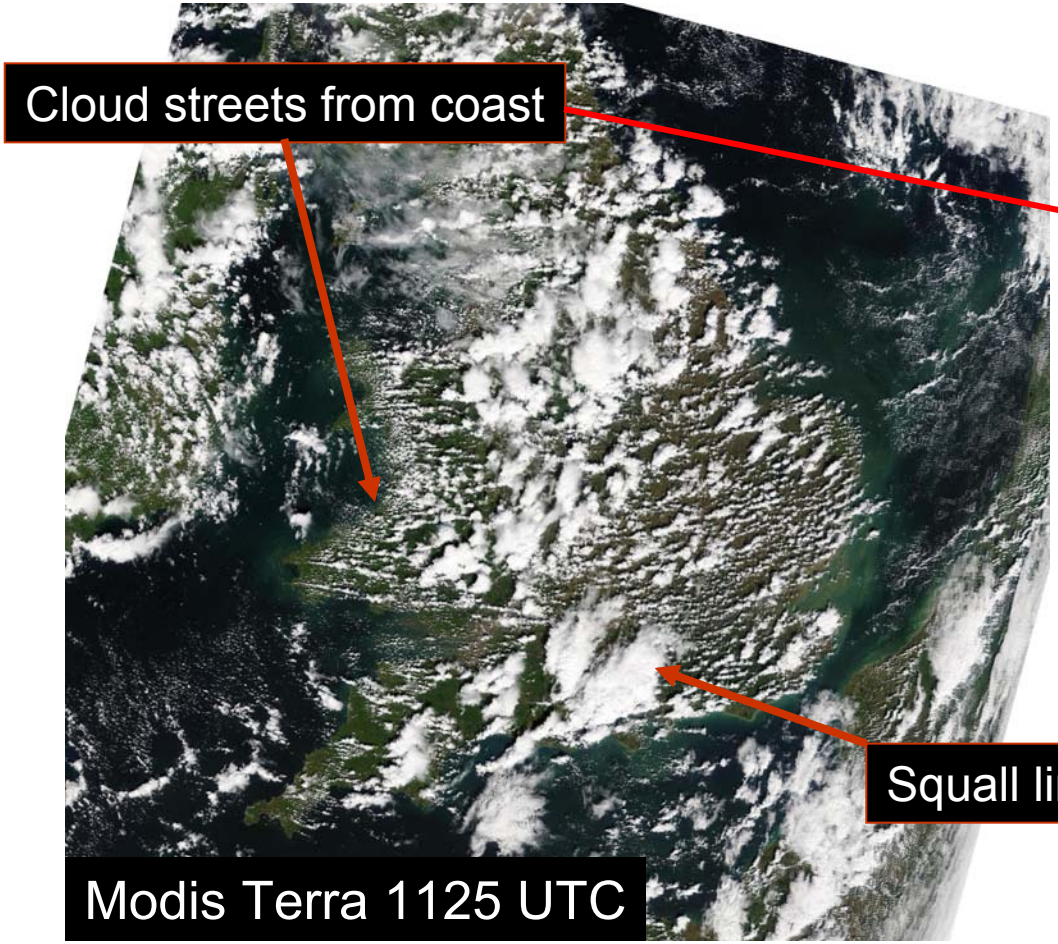
- NWP (horiz) now soon
  - Global: 40^ km 25 km
  - Atlantic/Europe: 12* km 12 km
  - UK: 4 km 1.5 km
  - UK (on demand): 1.5 km

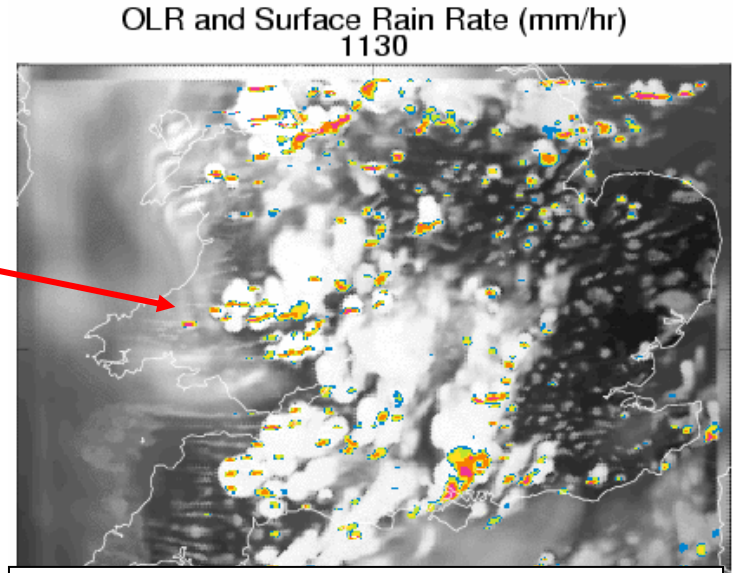
^24 ensembles at 90 km grid length

*24 ensembles at 24 km grid length

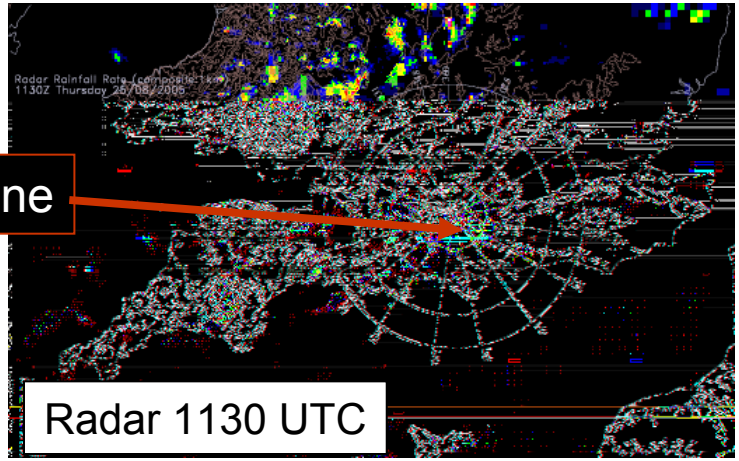
- NWP (levels) now soon
  - Global: 38 70
  - Atlantic/Europe: 38 70
  - UK: 70 70
  - UK (on demand): 70

The benefits of the kilometre-scale model





Model OLR and rain rate 1130 UTC



Radar 1130 UTC

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The ever changing model – a parametrization nightmare?

- **April 2009**
  - UK model to 1.5 km
- **September 2009**
  - Global and NAE to 70 levels
  - Global EPS to 60km / 70levels
- **December 2009**
  - Global Model to 25km
  - NAE EPS to 16km / 70 levels
- **2011/12**
  - Global Model to 16km
  - NAE EPS to 12km
  - UK 1.5km EPS

NEC SX-6/8

6x

2009 Phase I: IBM

3x

2011:Phase II: IBM

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The climate models

- Climate (global) 250-120 km
- Seasonal (global) 90 km
- Regional climate 12 - 30 km

Ultra high resolution

- 'Global' Atmosphere (N320, CASCADE, …)
- Reduced domain (RCM, NAE, CAM, UK4, 1km)

Seasonal/Decadal

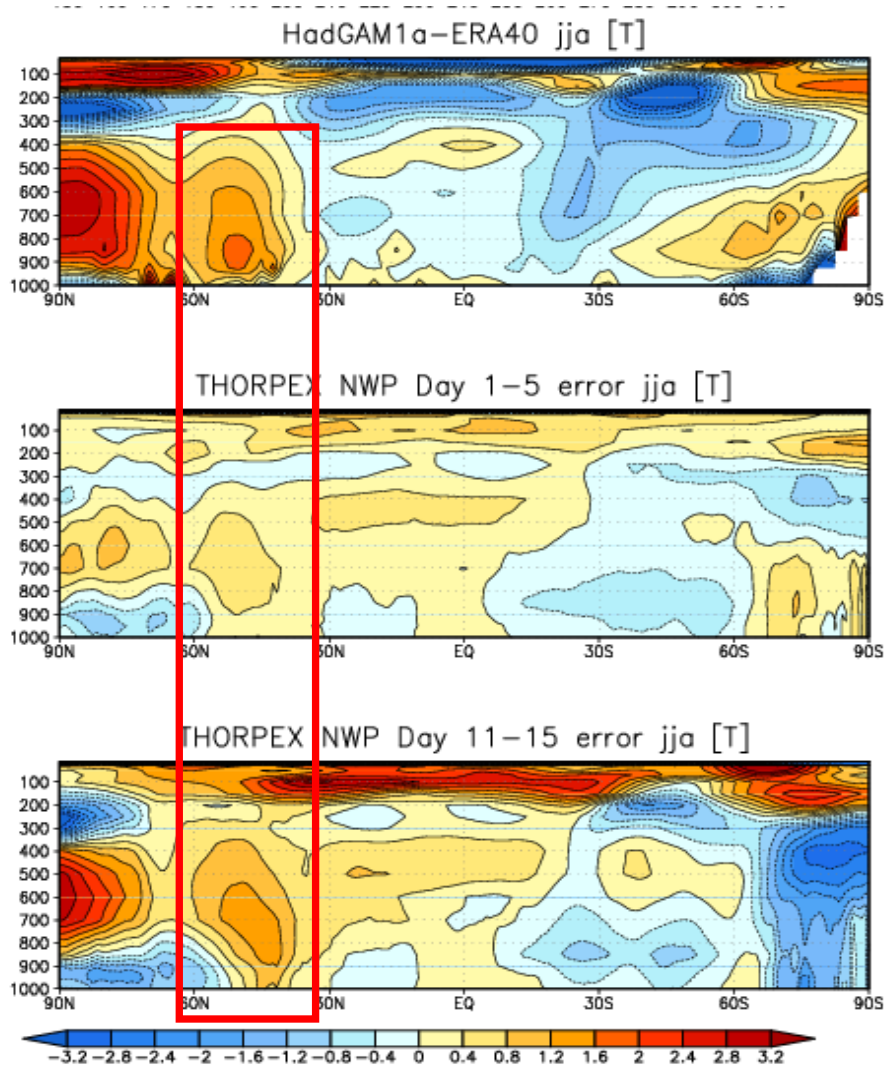
- Global OAGCM (N216,0.25° L85)
- Run for multidecades on joint supercomputer
- Balanced/tuned climate NOT required

Centennial/Ensembles

- Global AOGCM (N144/N96,0.5°/1° ?)
- Multiple multicentury runs or S2D ensembles
- Needs balanced/tuned climate simulation

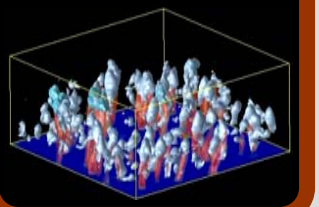
Earth System

- Global AOGCM (N48, 2°)
- Large multicentury ensembles, rapid response
- Needs balanced/tuned climate simulation

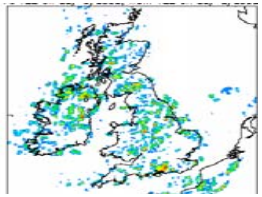


Research models

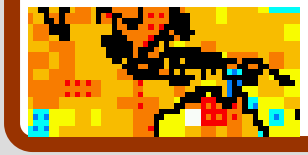
Ideal UM



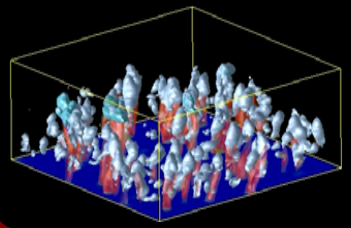
UM as LAM



Cascade



CRM (bin)



SCMs

NWP

Climate

High res

SCMs with same settings as full models (i.e. same timestep, vertical grid, physics etc…)

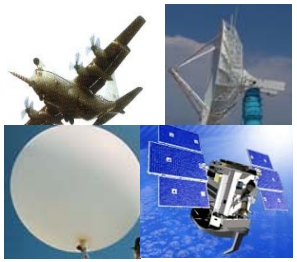
Intercomparison

ARM

GCSS

TWP-ICE

Observations



Forward modelling (or simulators) often used for comparison with observations e.g. cloudnet; cloudsat

© Cr

Current UM partners

1. Norwegian Meteorological Institute. met.no (Feb 2007)

2. South African Weather Service (Mar 2007)

3. Australian Bureau of Meteorology & CSIRO (Mar 2007)

4. New Zealand NIWA Ltd (Dec 2007)

5. Indian Ministry of Earth Sciences (Aug 2008)

6. (South) Korea Meteorological Administration

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Radiation and clouds

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Radiation and clouds

- Recent
  - Implemented a more accurate temporal sampling of clouds for better diurnal cycle (climate) and better forecast
- Ongoing/future
  - Inhomogeneity representation
    - Cloud generation and McICA
    - Coupling McICA with temporal cloud sampler
  - Ice size distributions consistent with microphysics and direct use of size distribution (Baran)

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Teporal sampling of clouds

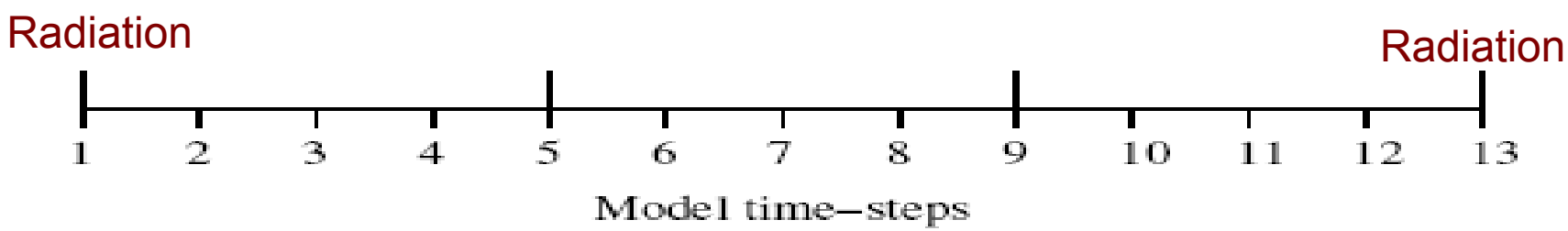
QUARTERLY JOURNAL OF THE ROYAL METEOROLOGICAL SOCIETY
Q. J. R. Meteorol. Soc. **00**: 1–11 (2008)
Published online in Wiley InterScience
(www.interscience.wiley.com) DOI: 10.1002/qj.000

Two fast radiative transfer methods to improve the temporal sampling of clouds in NWP and climate models

J. Manners*, J.-C. Thelen, J. Petch, P. Hill & J.M. Edwards
Met Office, FitzRoy Road, Exeter, EX1 3PB, UK

Submitted Oct 2008

Current situation



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Solar zenith angle correction

- Original update to fluxes and heating was simply:

$$\alpha = \cos\theta' / \cos\theta$$

- Some simple assumptions to take the change in optical path length into account to give a better correction for surface fluxes:
  - Ignore the extra absorption due to the change in path length by assuming that scattering will dominate
  - Assume half the extra scattered radiation escapes to space and the other half reaches the surface.
  - Assume the extra surface reflected radiation is transmitted directly to space with no further scattering

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Solar zenith angle correction

Direct surface flux

$$\Delta Z'_{Surf} = \left(\frac{Z_{Surf}}{Z_{TOA}}\right)^{\frac{1}{\alpha}} \alpha Z_{TOA} - \alpha Z_{Surf}$$

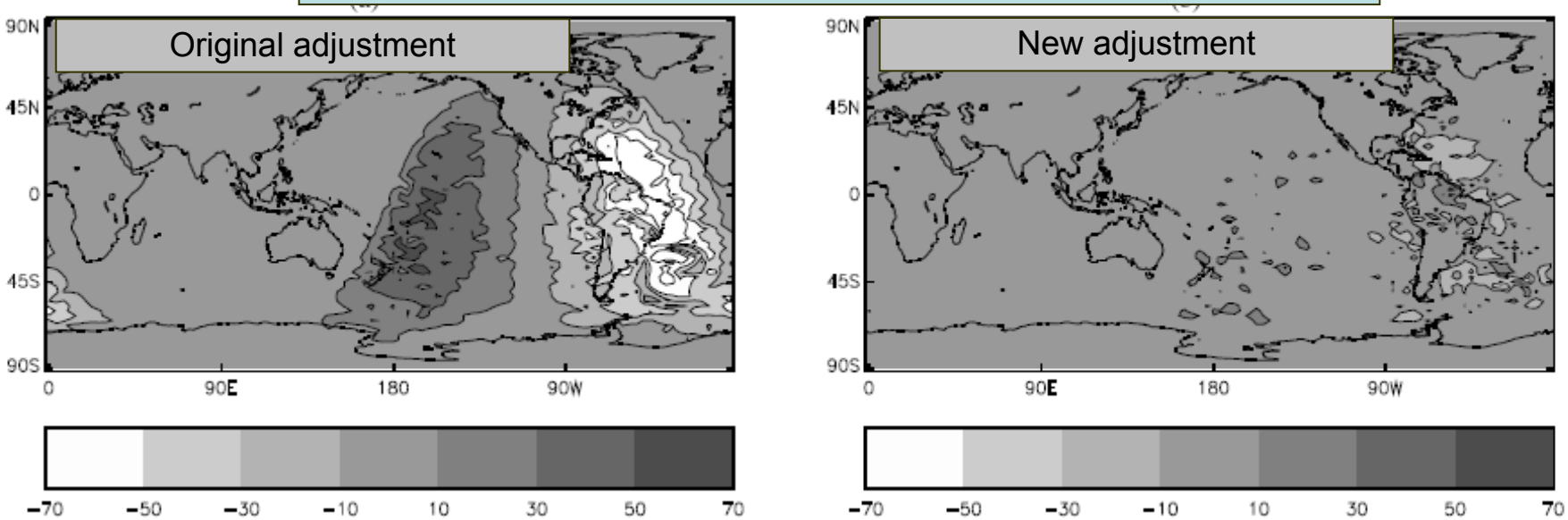
Total surface flux

$$\begin{aligned} \Delta V'_{Surf} &= \frac{1}{2}\Delta Z'_{Surf} \\ &= \frac{\alpha}{2}\left[\left(\frac{Z_{Surf}}{Z_{TOA}}\right)^{\frac{1}{\alpha}} Z_{TOA} - Z_{Surf}\right] \end{aligned}$$

Net surface flux

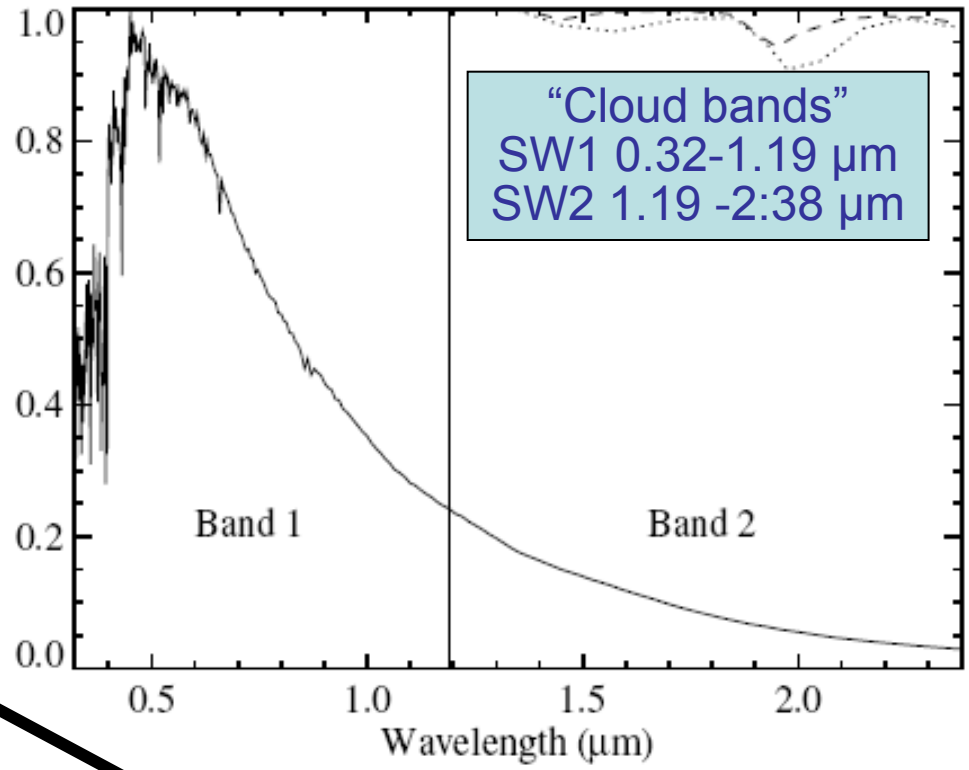
$$\Delta N'_{Surf} = \frac{\Delta V'_{Surf}}{V_{Surf}} N_{Surf}$$

Error in the net surface flux at the start of a 3 hour time step

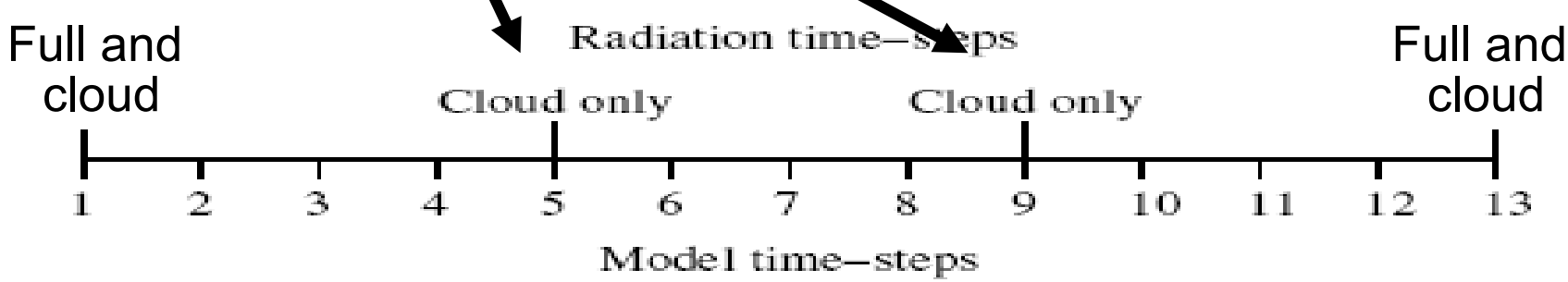


The incremental time-stepping scheme

"Cloud band"
LW 7.52 -13.3 μm



Heating and Fluxes from **Full+Δcloud**



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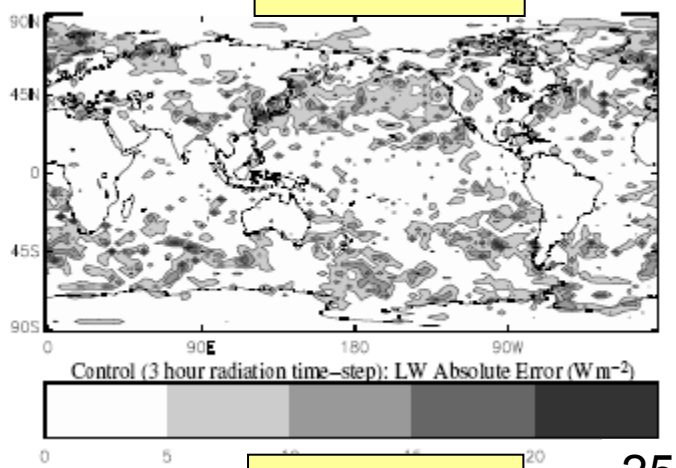
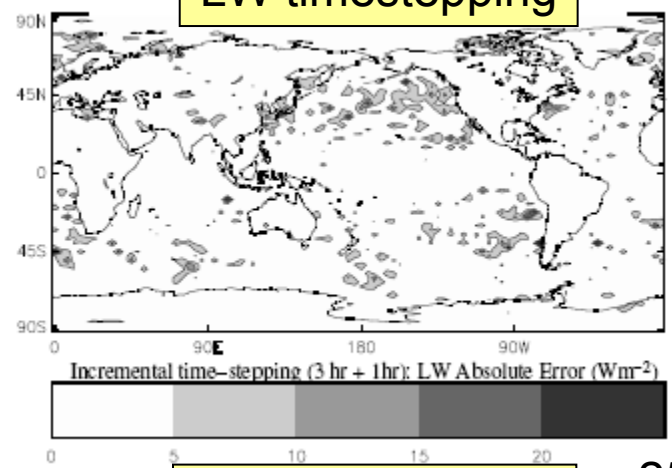
The incremental time-stepping scheme - surface improvement

Absolute errors over a 6 hour period

LW control

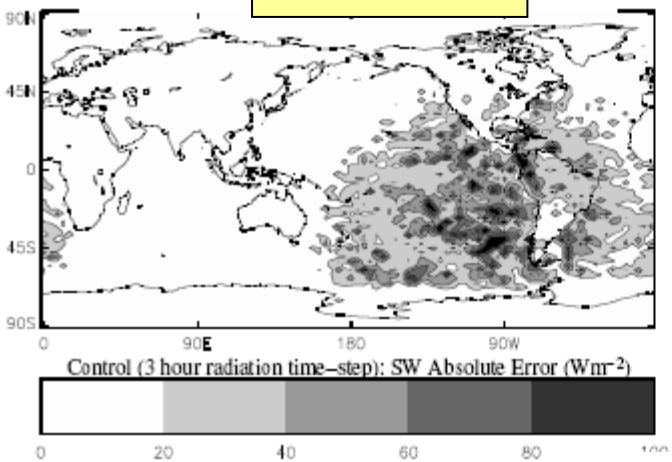


LW timestepping

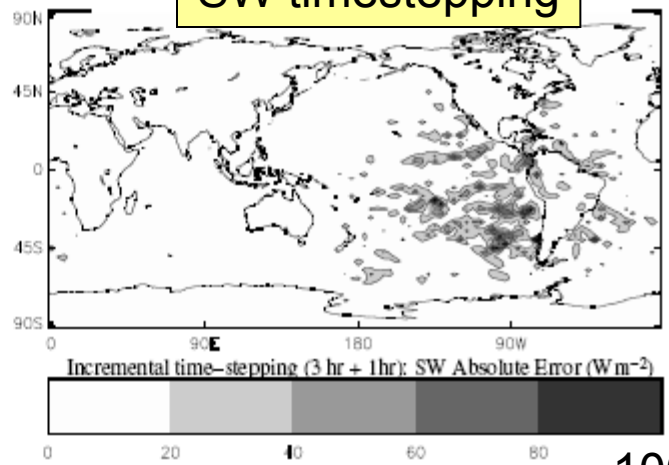


25

SW control



SW timestepping



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100

100

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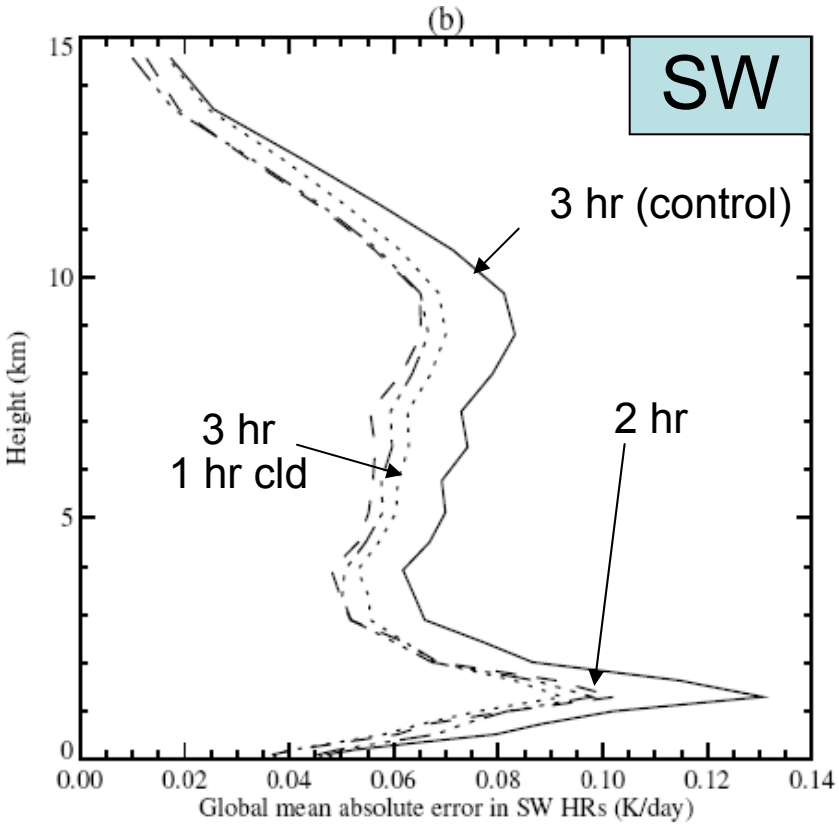
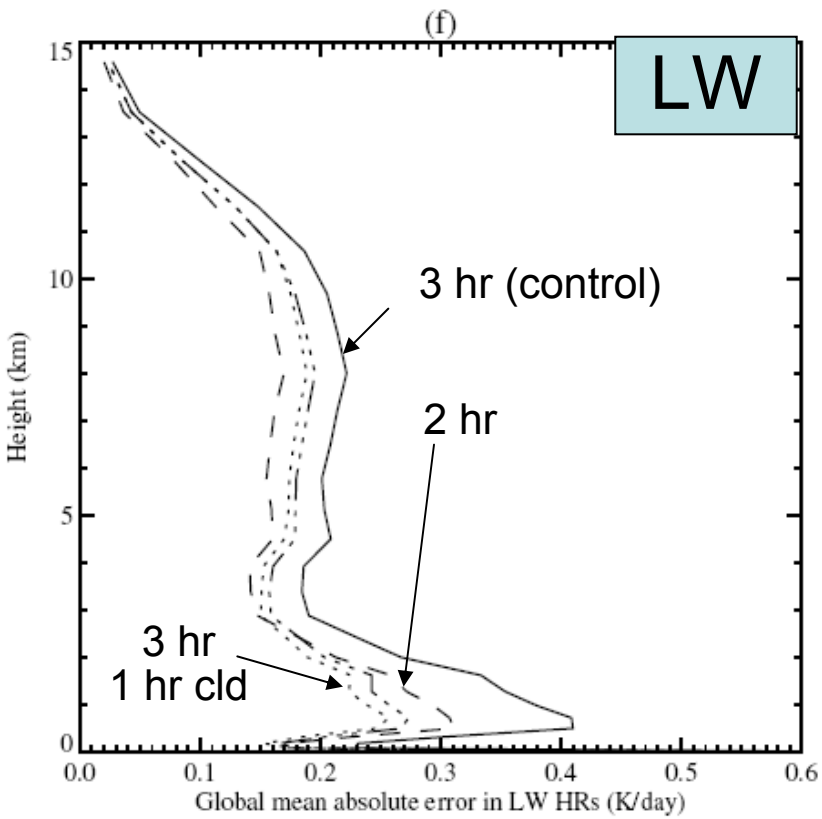
The incremental time-stepping scheme – heating rate improvement





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The costs and surface flux improvement

Radiation configuration	CPU time
15 minute radiation timestep	143.8%
3 hour radiation timestep	13.8%
2 hour radiation timestep	20.6%
split timestep: 3 hr slow + 1 hr fast	22.0%
incremental timestep: 3 hr full + 1hr incs	16.8%

	Mean magnitude of bias		Mean absolute error	
	SW	LW	SW	LW
3 hour radiation timestep	7.97	2.93	14.71	3.95
3 hr rad tstep + zenith angle correction	7.43	2.93	10.66	3.95
2 hour radiation timestep	5.63	1.97	11.45	2.96
2 hr rad tstep + zenith angle correction	5.35	1.97	8.51	2.96
split timestep: 3 hr slow + 1 hr fast	3.26	1.65	6.82	2.45
incremental timestep: 3 hr full + 1hr incs	2.86	1.09	6.01	2.21

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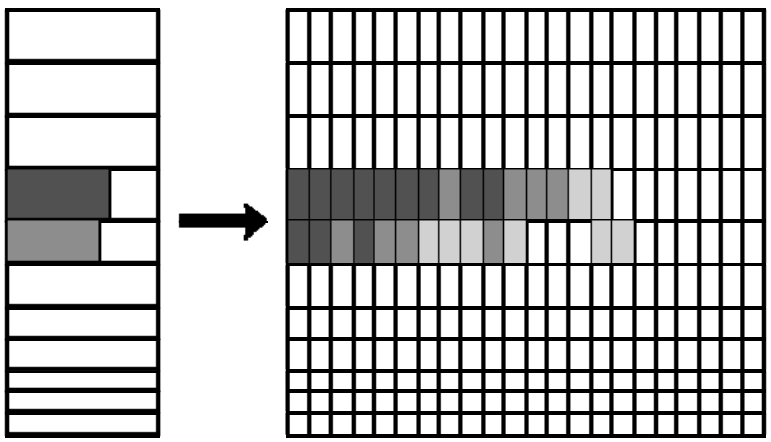
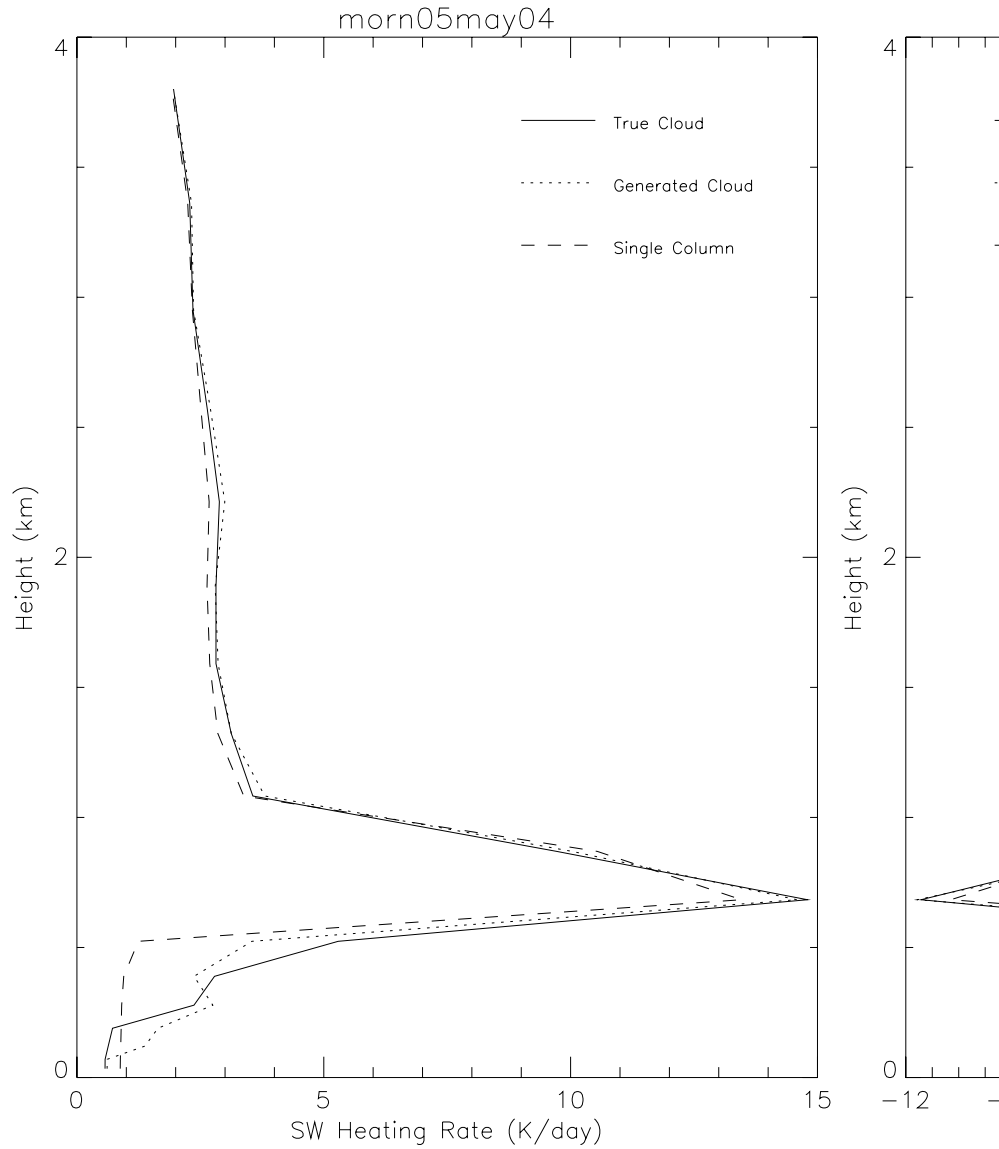
Ongoing – representing inhomogeneities

•A cloud field generated (Raisanen et al 2004) has been tested against radar and CRM.



•Chilbolton radar (for all of May 04) can be sufficiently described using a single set of variance and overlap parameters (e.g 5th May).

•However, deep convection from CRM is better described with greater variance and more vertical overlap.



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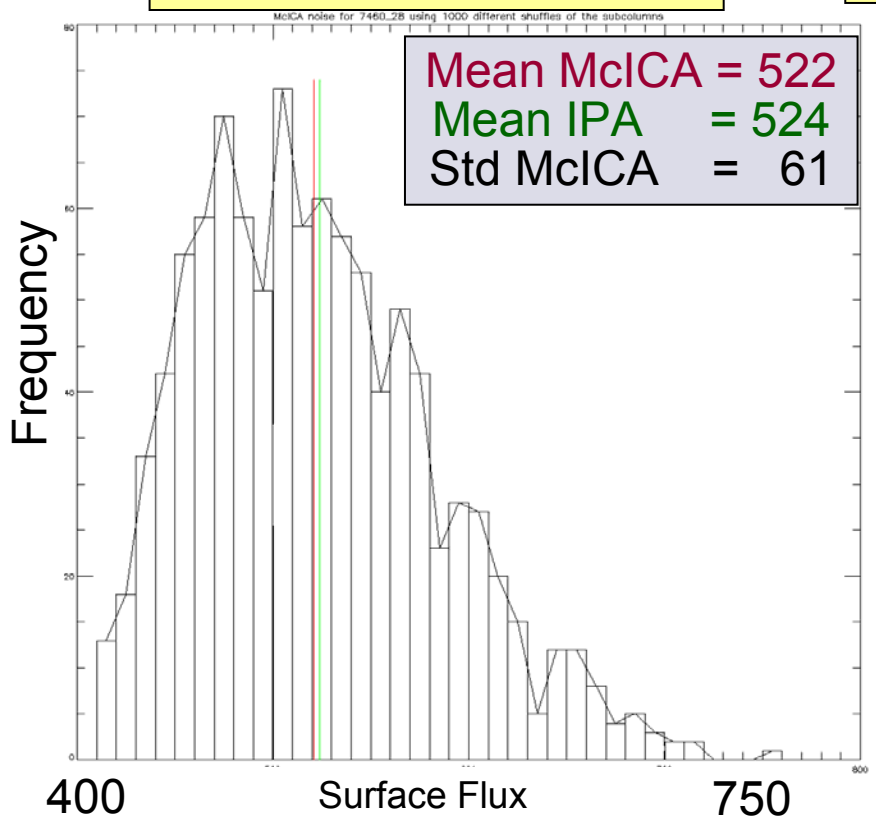
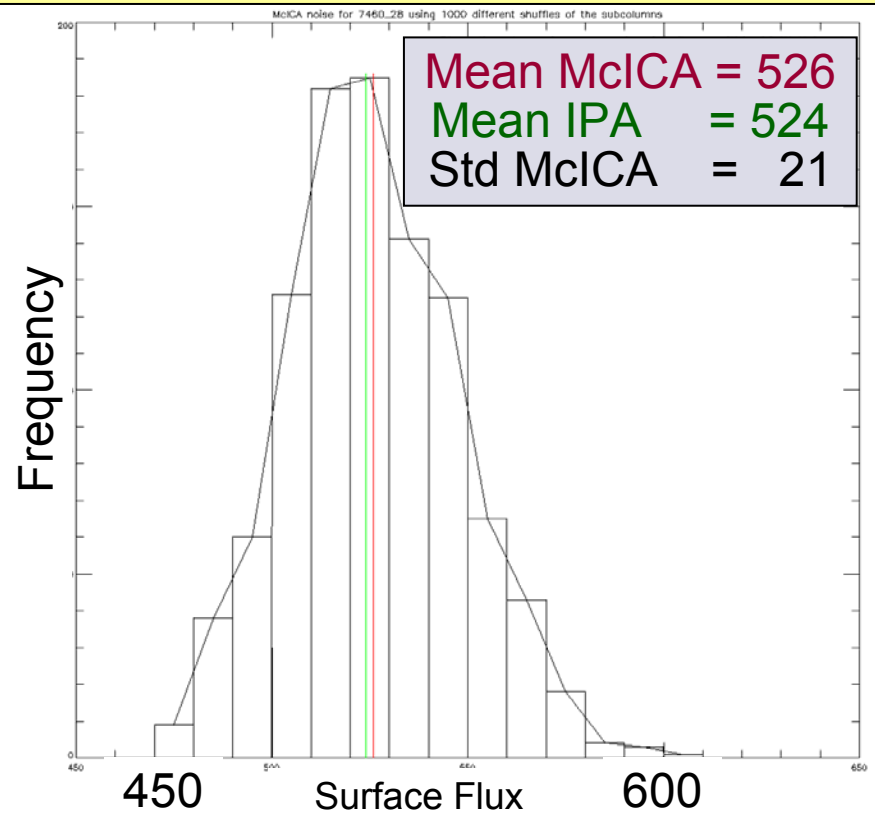
Ongoing - sampling generated cloud using McICA

- Reducing the noise in McICA - choosing our k-terms carefully… Surface shortwave fluxes

1 sub-column per k-term



5 sub-columns for 4 most important k-terms



Radiation – clear sky (hardcore)

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Updated parametrization of gaseous absorption

In collaboration with Zhian Sun at the BMRC in Australia and Wenyi Zhong at Imperial College:

- The dependence of gaseous absorption on temperature and pressure will use a lookup table of **59 reference pressures**, each with **5 reference temperatures**.
- Overlapping gaseous absorption is treated using a mixture of the two major absorbing gases in each band.
- **CH4 and N2O** are included in the **SW** (as recommended by IPCC AR4 report).
- New optimal selection of k-terms leading to a total of 58 (SW+LW) giving possible 20% speed-up.
- Coefficients based on Hitran2004/06, including updated ozone coefficients in the SW and LW.
- Use of a new observational solar spectrum from Lean 2000 (updated 2004).

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Microphysics

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Microphysics

- Recent
  - Droplet settling
  - Coupling of rain generation to aerosol in NWP model
  - SCM type analysis from the forecast models
  - A new 1D framework for testing microphysics in isolation
- Ongoing/future
  - New size-fall speed relationship for rain based on Abel-Shipway 2007 into operational models
  - Changes to ice size distributions and densities consistent with observations (Field 2005), radiation and data assimilation
  - Further comparisons between high resolution forecast model and CRM microphysics

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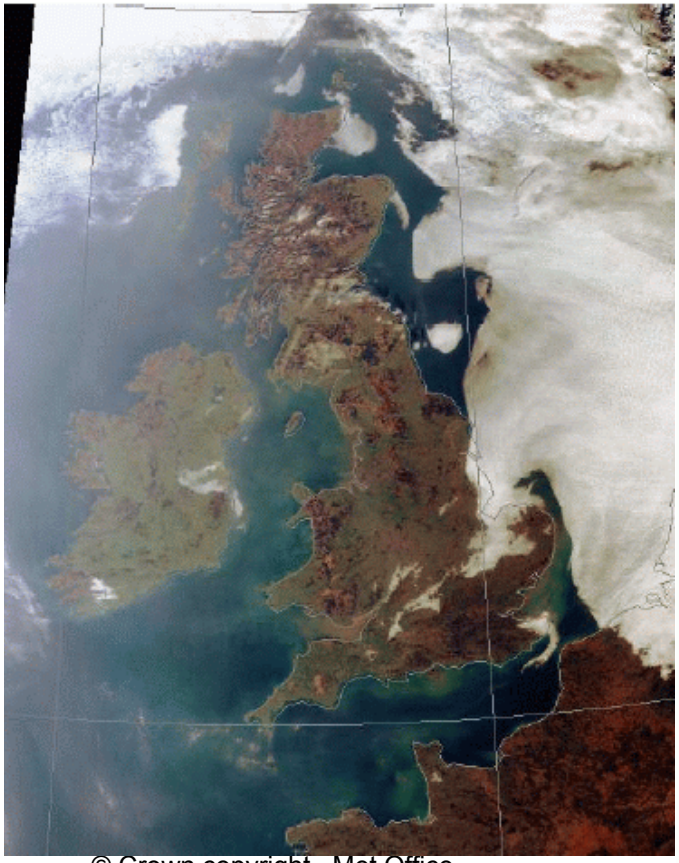
Droplet settling

- Uses Stokes Law (good for sub 30 microns)
- Assumes a second order gamma function for DSD (Khrgian and Mazin)



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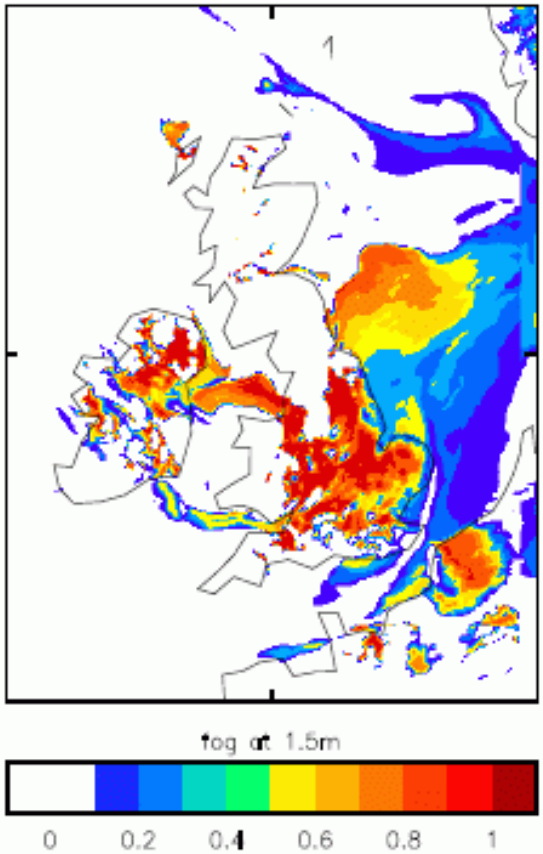
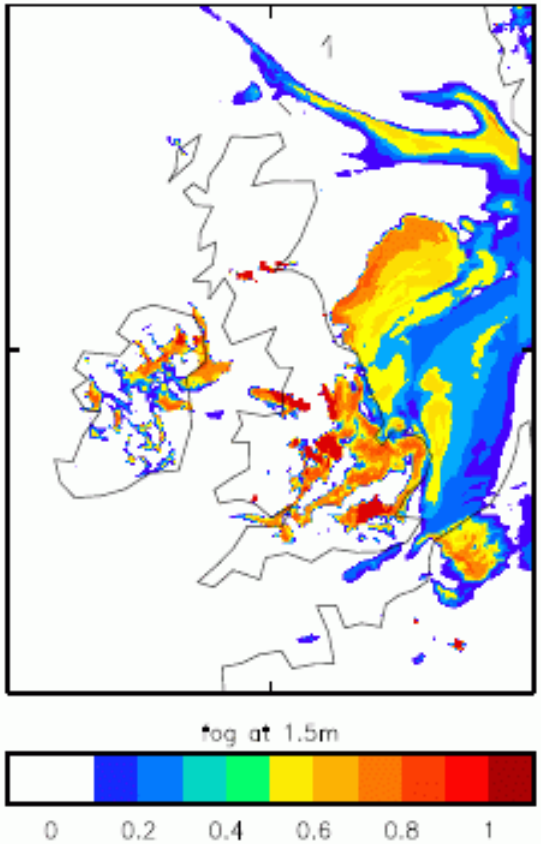
Control

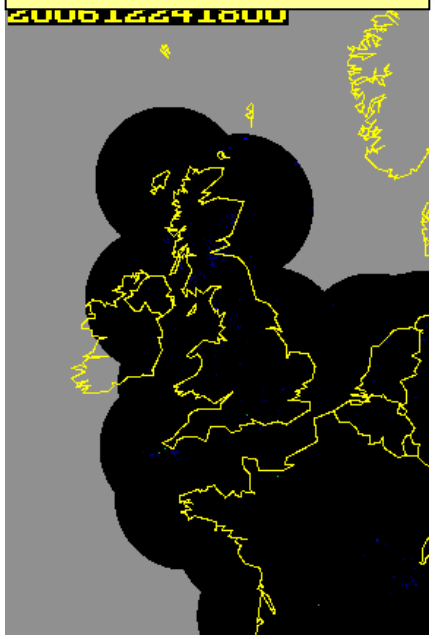


With droplet settling



Linking rain generation to aerosol

Radar



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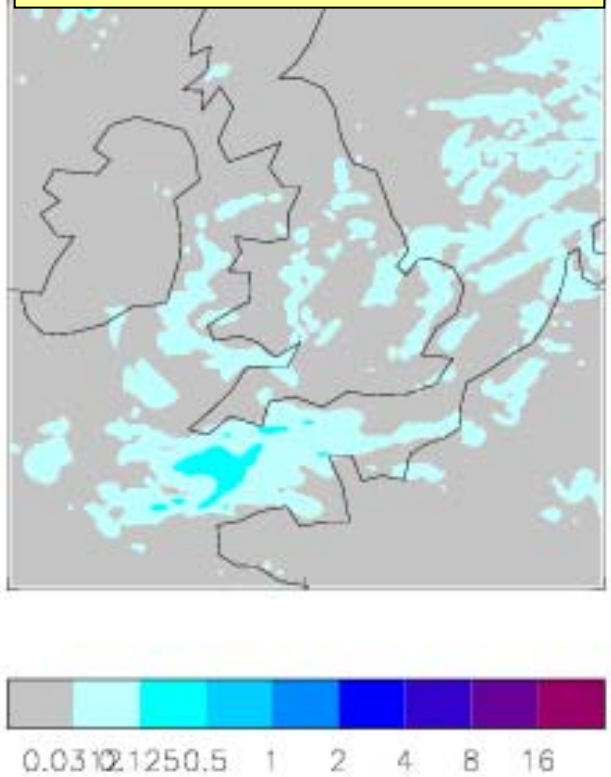
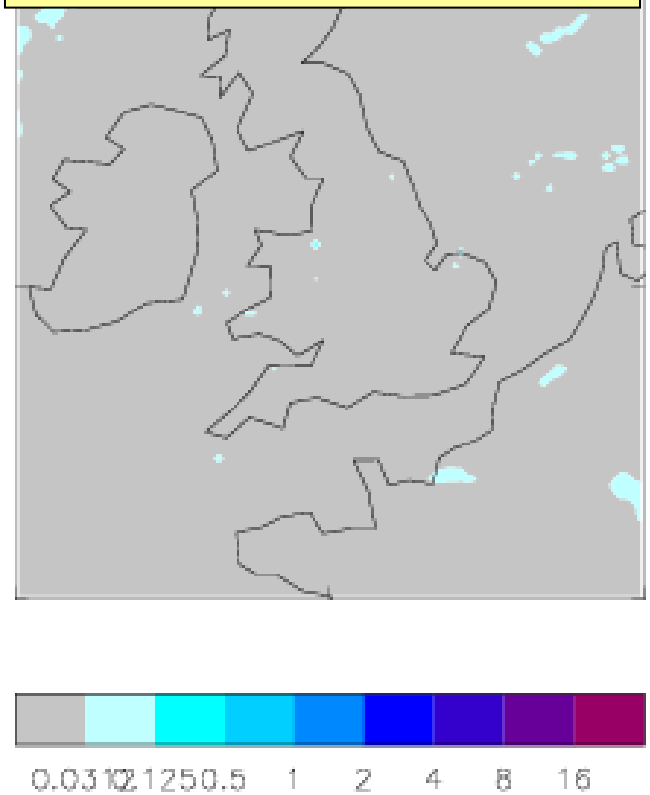


Aerosol autoconversion



Removal of spurious drizzle which upset forecasters no end!
One of many examples (this e.g. 24/12/06)

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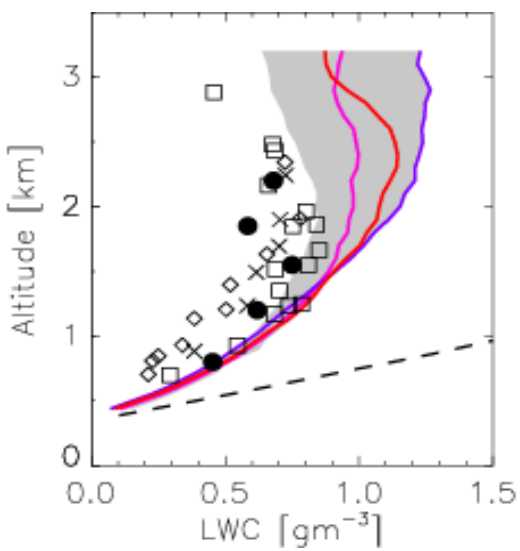
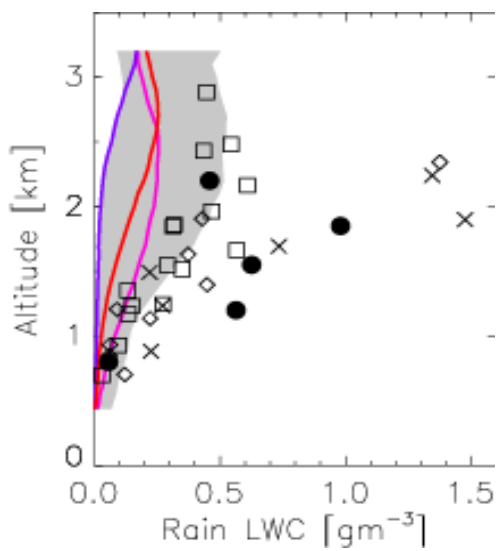
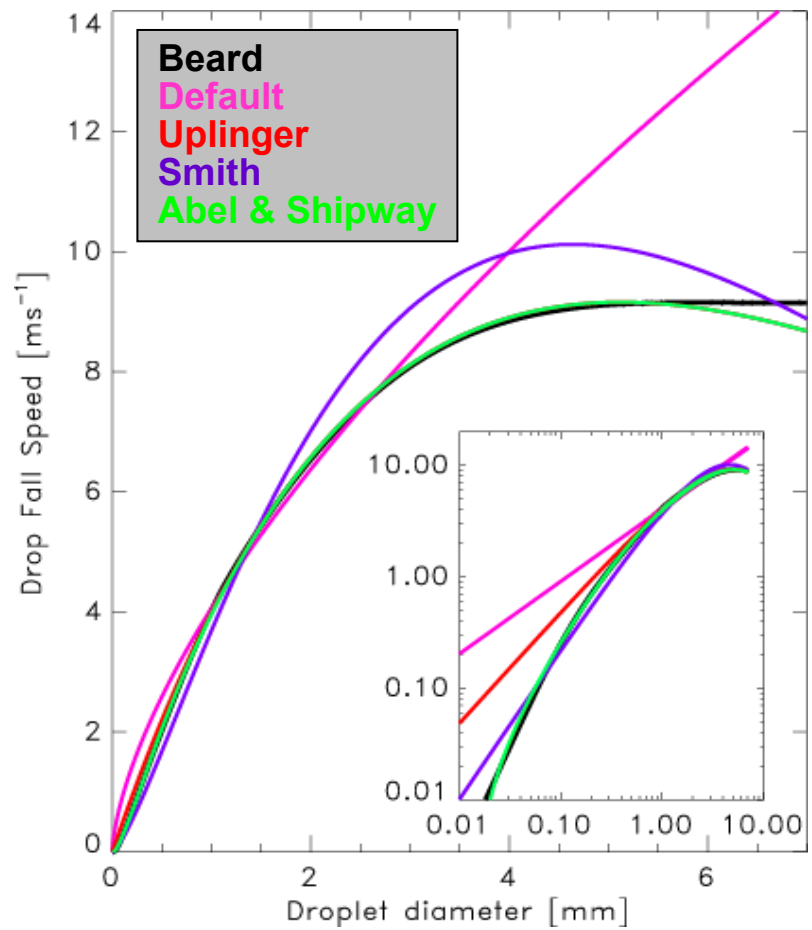
Abel-Shipway fall speed relationship

- Improved size-fall speed relationship at the drizzle end (based on RICO)
- Ongoing testing in UM; results from RICO in CRM show matching drizzle part important







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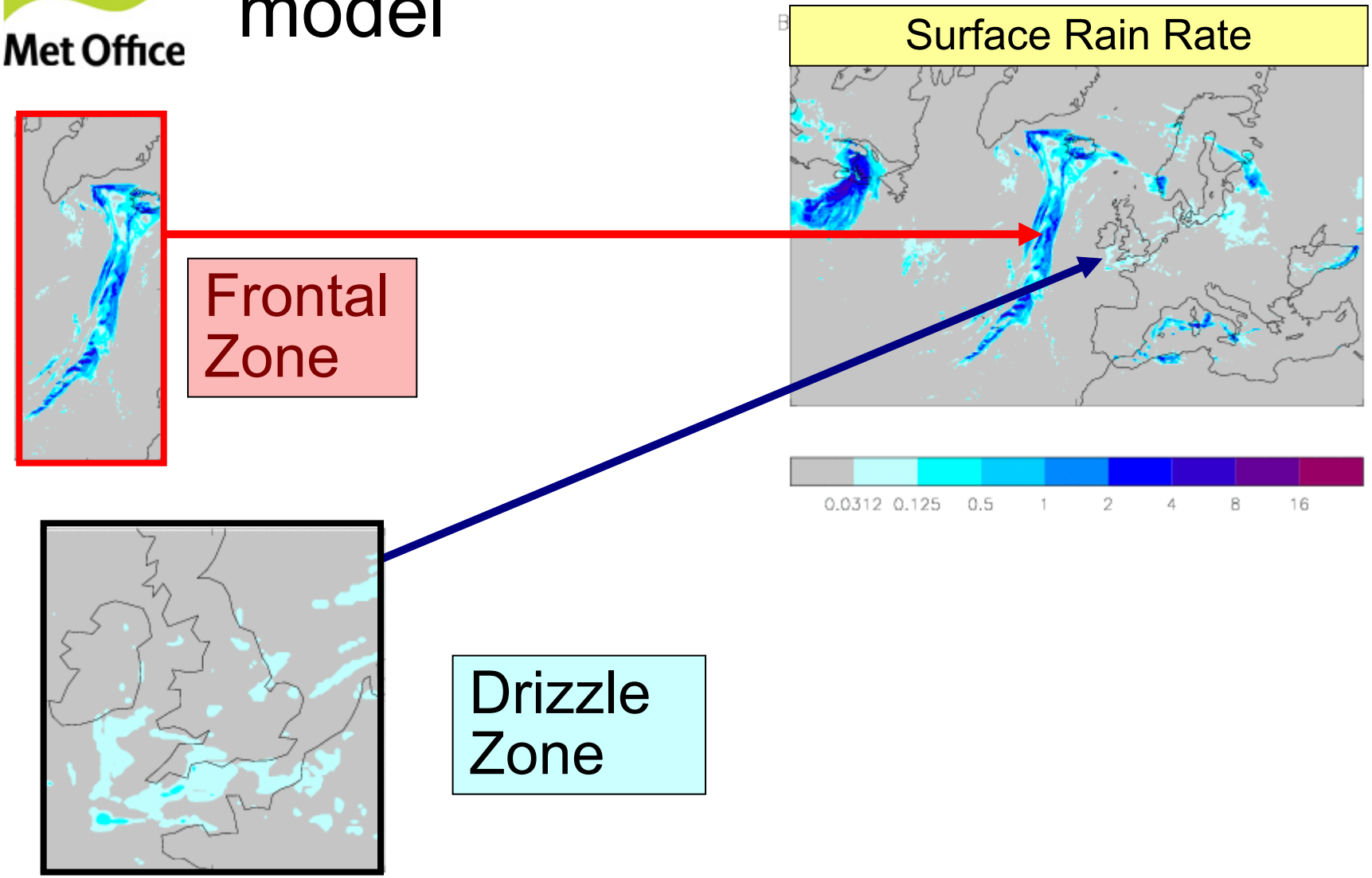
SCM type analysis from forecast model



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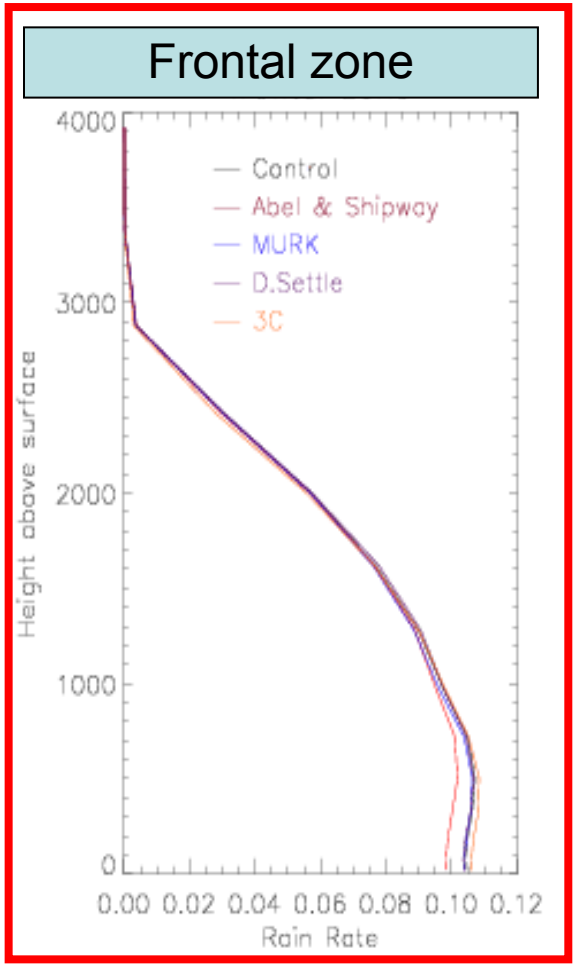
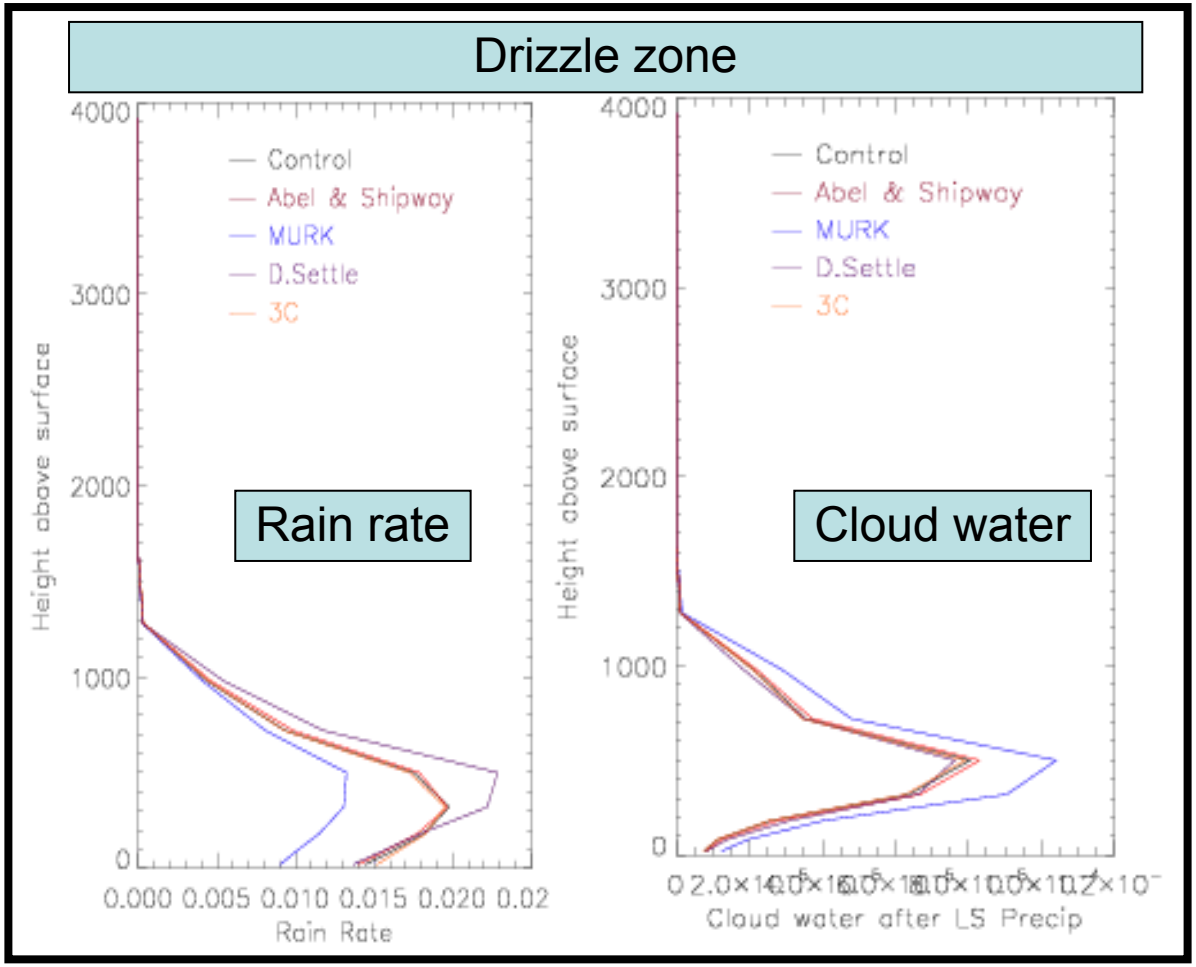
SCM type analysis from forecast model





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Ongoing – 1D offline testing of microphysics

- Part of a **GCSS** model comparison project Ben Shipway is setting up
- Dynamics and initial profiles are chosen to stimulate particular processes of interest in the microphysics code. e.g. ice nucleation, drizzle formation…
- A constrained environment will simplify identifying differences between microphysics schemes and also allow a much larger parameter space of “tuneable” constants to be investigated.
- We have a common driver model (**KiD** – Kinematic Driver), to make interfacing of microphysics modules simple (to get a copy of the KiD model, please email ben.shipway@metoffice.gov.uk)

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Ongoing – 1D offline testing of microphysics

- Current case
  - GCSS SHEBA (Arctic stratocumulus)
    - CRMs don't well represent the partitioning between liquid cloud and ice cloud (c.f. also recent M-PACE intercomparison
    - Can we see this same problem in a simple 1D (oscillating column) model?
    - Can we test this hypothesis (and many others), without the need for expensive 3D simulations?
- Other planned cases
  - Shallow precipitating convection (c.f. RICO)
  - Deep convection (c.f. TWP-ICE)
  - Mixed phase cases (c.f. MPACE, SHEBA)

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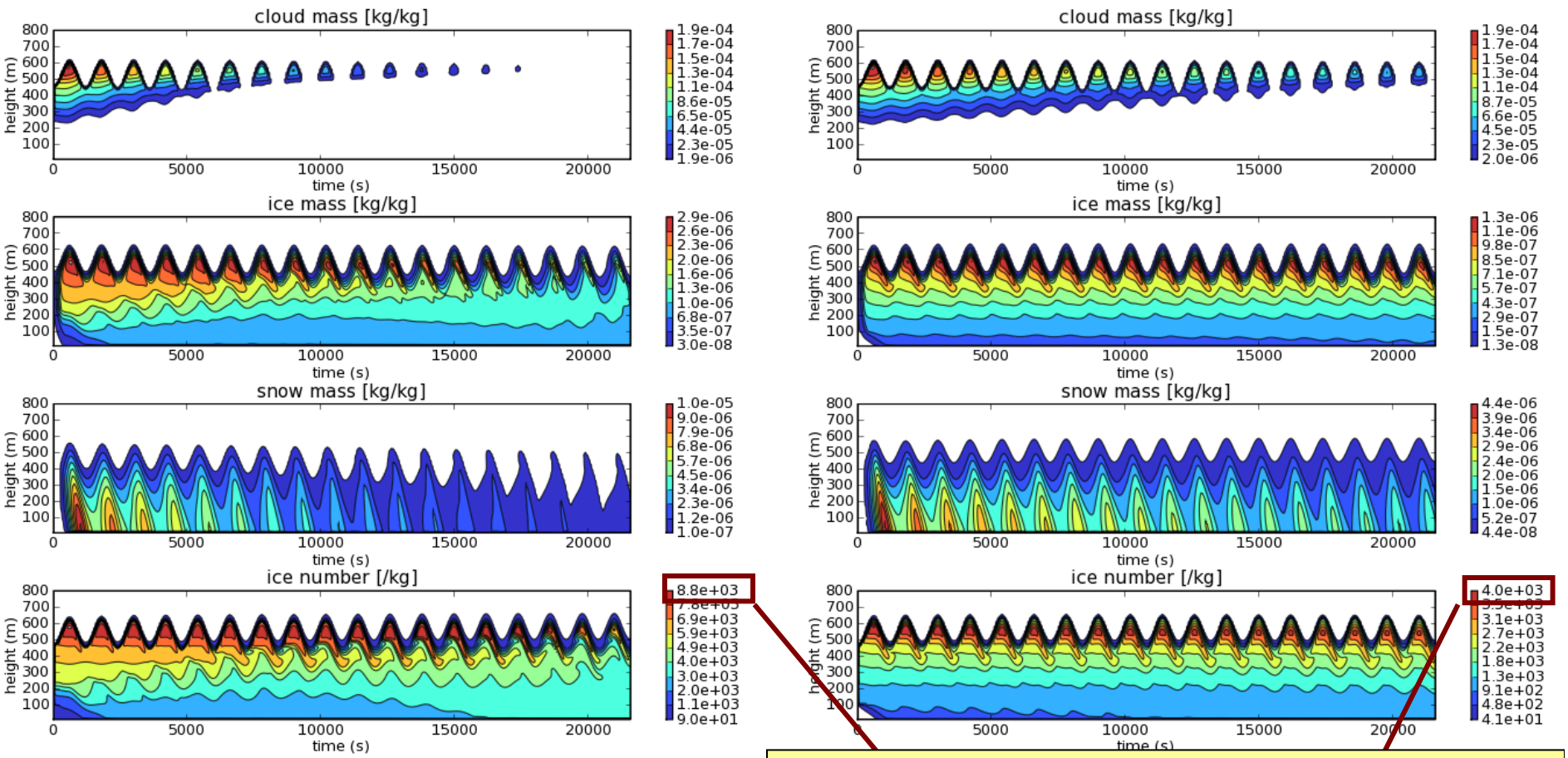
Example: Mixed-phase
(c.f. SHEBA)

Results from coupling UKMO LEM bulk microphysics to KiD model



Decreasing nucleation rate (SS threshold for primary nucleation using Cooper rather than Meyers)

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Cloud scheme

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Clouds

- Recent/current
  - Prognostics cloud fraction & condensate scheme (PC2) included in climate model
  - Evaluation of PC2 in a CRM framework
  - SCM testing of PC2 using TWP-ICE ensembles
- Ongoing/future
  - Inclusion of PC2 in forecast models
  - Evaluation and development of PC2 based on forecast performance (cloudNET radar; cloudSAT; and forecast skills)

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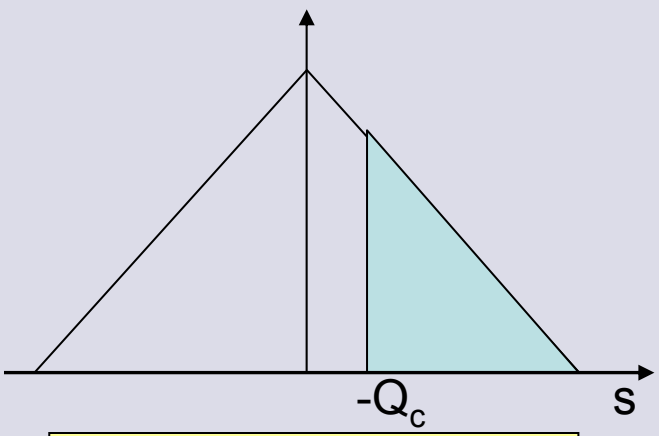
Moving to a prognostic cloud scheme

- Smith (1990) *large-scale* cloud scheme was in past versions of climate model and still is in NWP model



$$-Q_c = -a_L(q_T - q_{sat}(T_L))$$

$$s = a_L(q_T' - \alpha T_L')$$

- PC2 (Wilson et al 2008) is in the climate model and being trialled in the NWP model.

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RMetS
Royal Meteorological Society

PC2: A prognostic cloud fraction and condensation scheme. II: Climate model simulations

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$$\Delta C = \sum_{i=1}^{N \text{ processes}} \Delta C_i \qquad \Delta q = \sum_{i=1}^{N \text{ processes}} \Delta q_i$$

$$\Delta q_{cl} = \sum_{i=1}^{N \text{ processes}} \Delta q_{cli}$$

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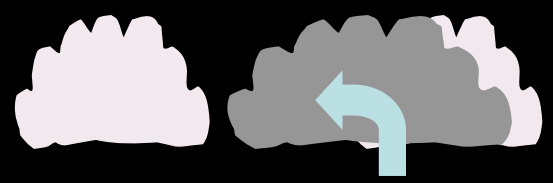
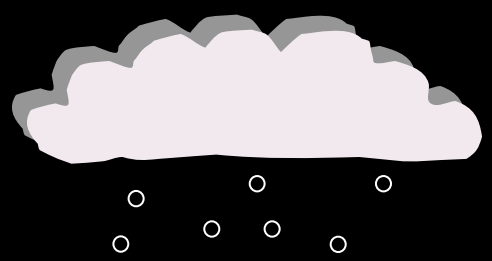
PC2 processes

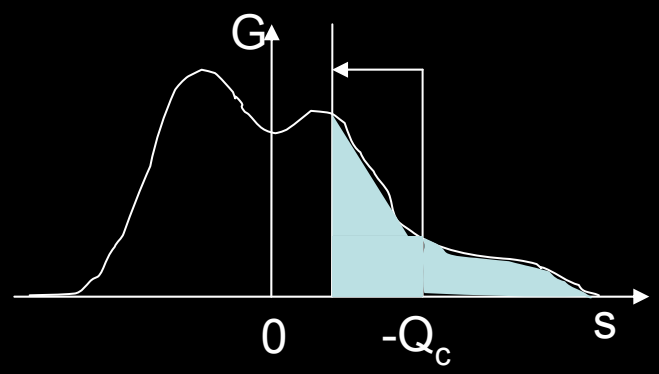
- Convective cloud is modelled as a detraining plume.



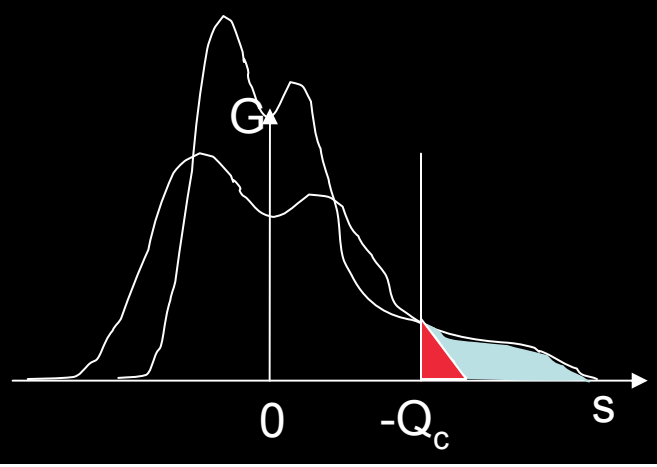
- No cloud fraction change from drizzle/rain production process



- Condensation due to radiative increments assumes a homogeneous forcing of temperature



- Cloud erosion mixes dry and moist air within a gridbox



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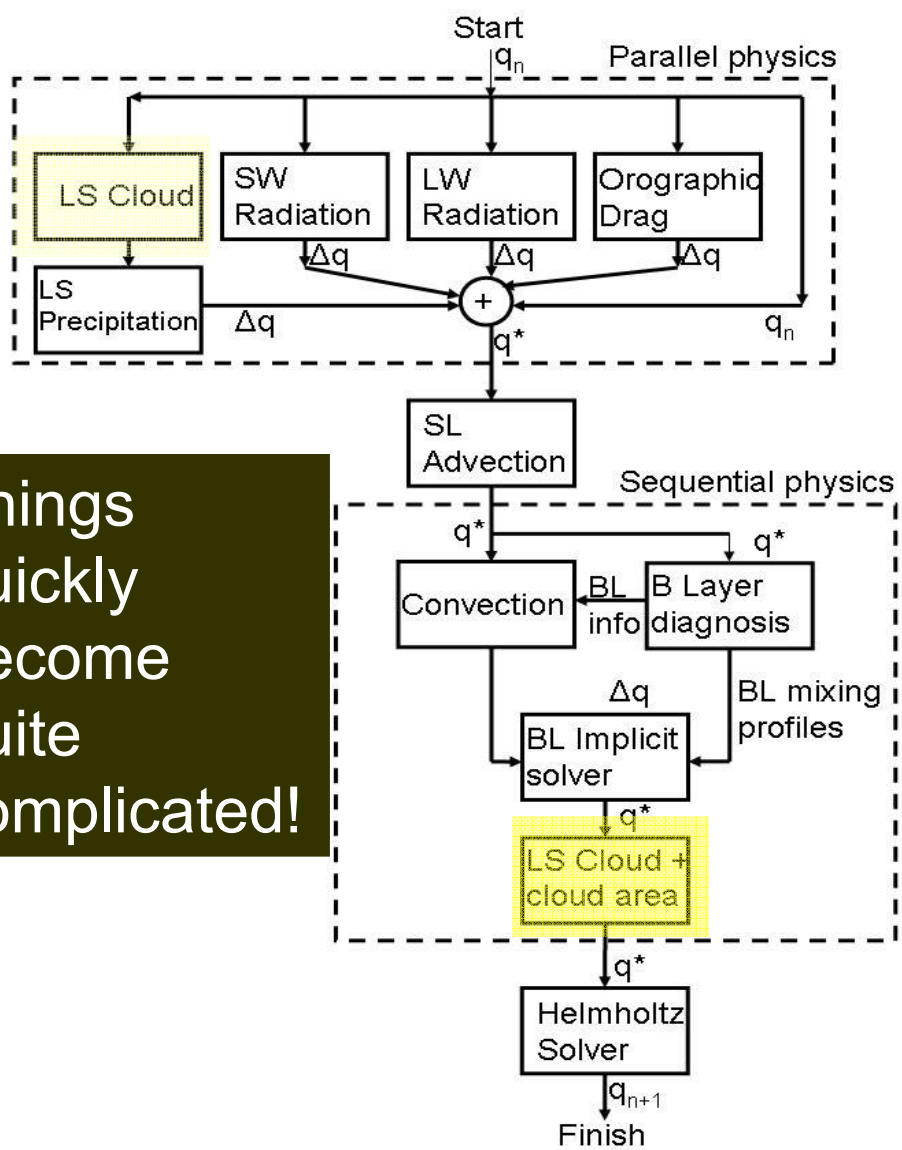
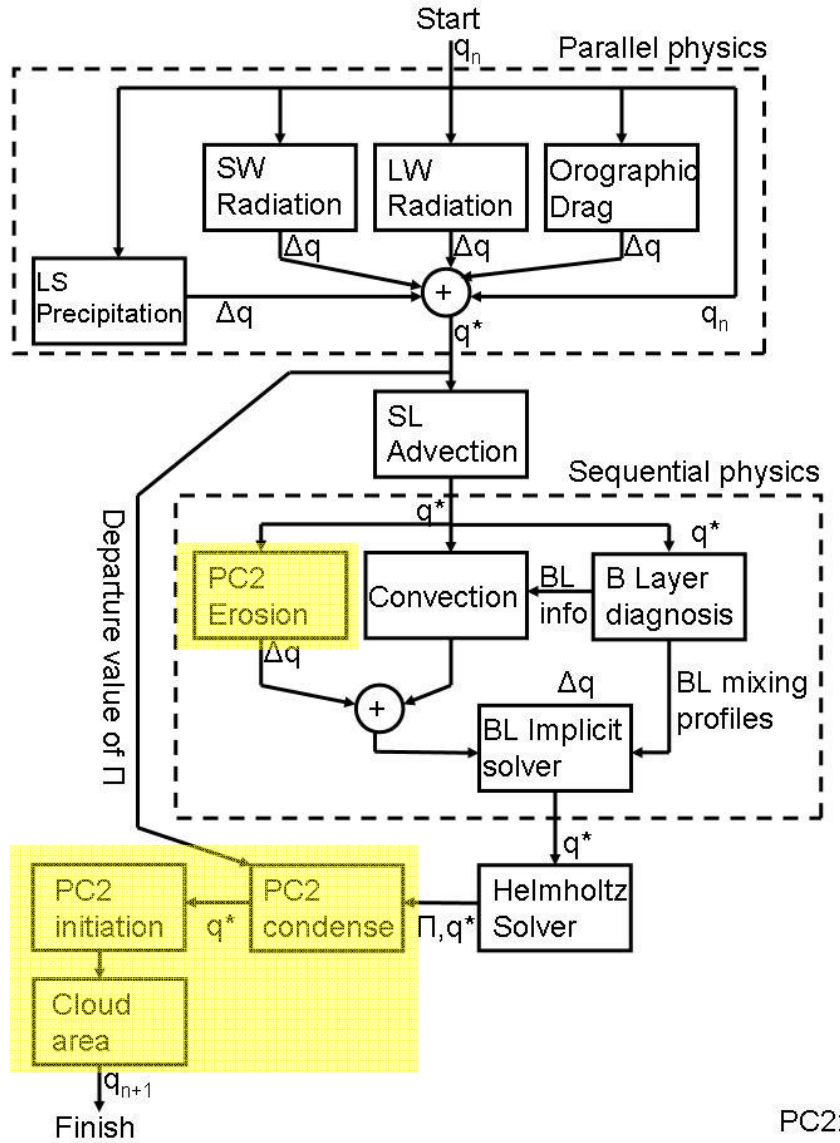
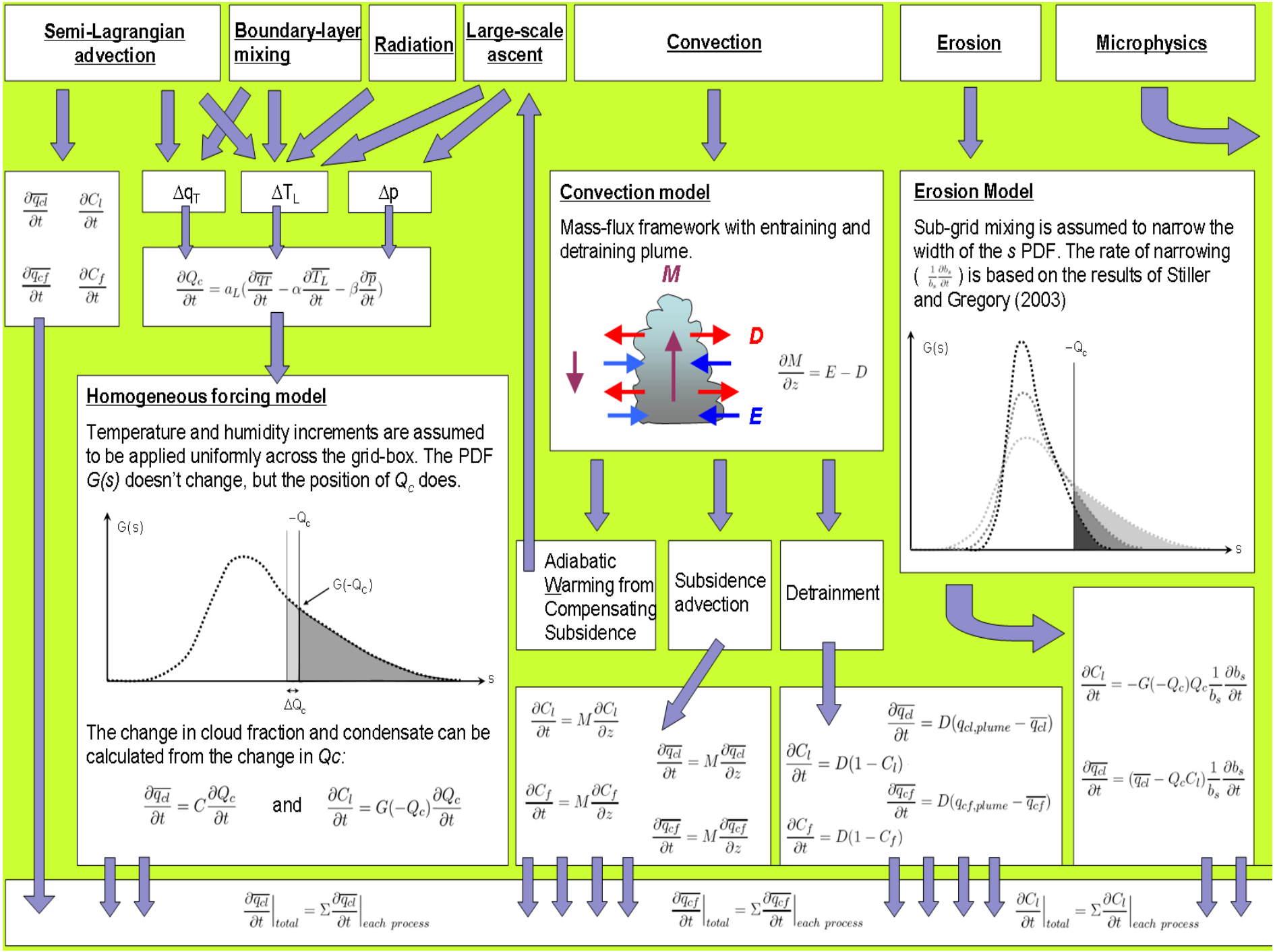
PC2 processes: Basic timestepping

Things quickly become quite complicated!



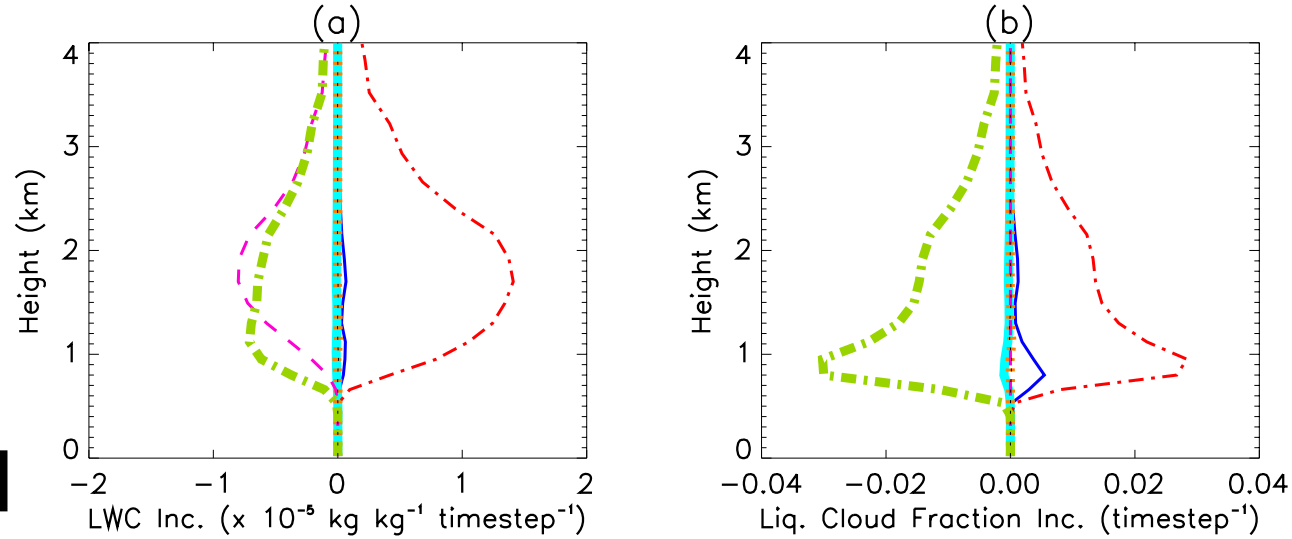



Semi-Lagrangian advection
Boundary-layer mixing
Radiation
Large-scale ascent
Convection
Erosion
Microphysics
$\frac{\partial \overline{q_{cl}}}{\partial t}$ $\frac{\partial C_l}{\partial t}$
$\frac{\partial \overline{q_{cf}}}{\partial t}$ $\frac{\partial C_f}{\partial t}$
Δq_T
ΔT_L
Δp
$\frac{\partial Q_c}{\partial t} = a_L(\frac{\partial \overline{q_T}}{\partial t} - \alpha\frac{\partial \overline{T_L}}{\partial t} - \beta\frac{\partial \overline{p}}{\partial t})$
Homogeneous forcing model
Temperature and humidity increments are assumed to be applied uniformly across the grid-box. The PDF G(s) doesn't change, but the position of Q_c does.
G(s)
$-Q_c$
$G(-Q_c)$
s
ΔQ_c
The change in cloud fraction and condensate can be calculated from the change in Qc:
$\frac{\partial \overline{q_{cl}}}{\partial t} = C\frac{\partial Q_c}{\partial t}$ and $\frac{\partial C_l}{\partial t} = G(-Q_c)\frac{\partial Q_c}{\partial t}$
Convection model
Mass-flux framework with entraining and detraining plume.
M
D
E
$\frac{\partial M}{\partial z} = E - D$
Adiabatic Warming from Compensating Subsidence
Subsidence advection
Detrainment
$\frac{\partial C_l}{\partial t} = M\frac{\partial C_l}{\partial z}$
$\frac{\partial \overline{q_{cl}}}{\partial t} = M\frac{\partial \overline{q_{cl}}}{\partial z}$
$\frac{\partial C_f}{\partial t} = M\frac{\partial C_f}{\partial z}$
$\frac{\partial \overline{q_{cf}}}{\partial t} = M\frac{\partial \overline{q_{cf}}}{\partial z}$
$\frac{\partial \overline{q_{cl}}}{\partial t} = D(q_{cl,plume} - \overline{q_{cl}})$
$\frac{\partial C_l}{\partial t} = D(1 - C_l)$
$\frac{\partial \overline{q_{cf}}}{\partial t} = D(q_{cf,plume} - \overline{q_{cf}})$
$\frac{\partial C_f}{\partial t} = D(1 - C_f)$
Erosion Model
Sub-grid mixing is assumed to narrow the width of the s PDF. The rate of narrowing ($\frac{1}{b_s}\frac{\partial b_s}{\partial t}$) is based on the results of Stiller and Gregory (2003)
G(s)
$-Q_c$
s
$\frac{\partial C_l}{\partial t} = -G(-Q_c)Q_c\frac{1}{b_s}\frac{\partial b_s}{\partial t}$
$\frac{\partial \overline{q_{cl}}}{\partial t} = (\overline{q_{cl}} - Q_c C_l)\frac{1}{b_s}\frac{\partial b_s}{\partial t}$
$\frac{\partial \overline{q_{cl}}}{\partial t}\Big|_{total} = \Sigma\frac{\partial \overline{q_{cl}}}{\partial t}\Big|_{each\ process}$
$\frac{\partial \overline{q_{cf}}}{\partial t}\Big|_{total} = \Sigma\frac{\partial \overline{q_{cf}}}{\partial t}\Big|_{each\ process}$
$\frac{\partial C_l}{\partial t}\Big|_{total} = \Sigma\frac{\partial C_l}{\partial t}\Big|_{each\ process}$

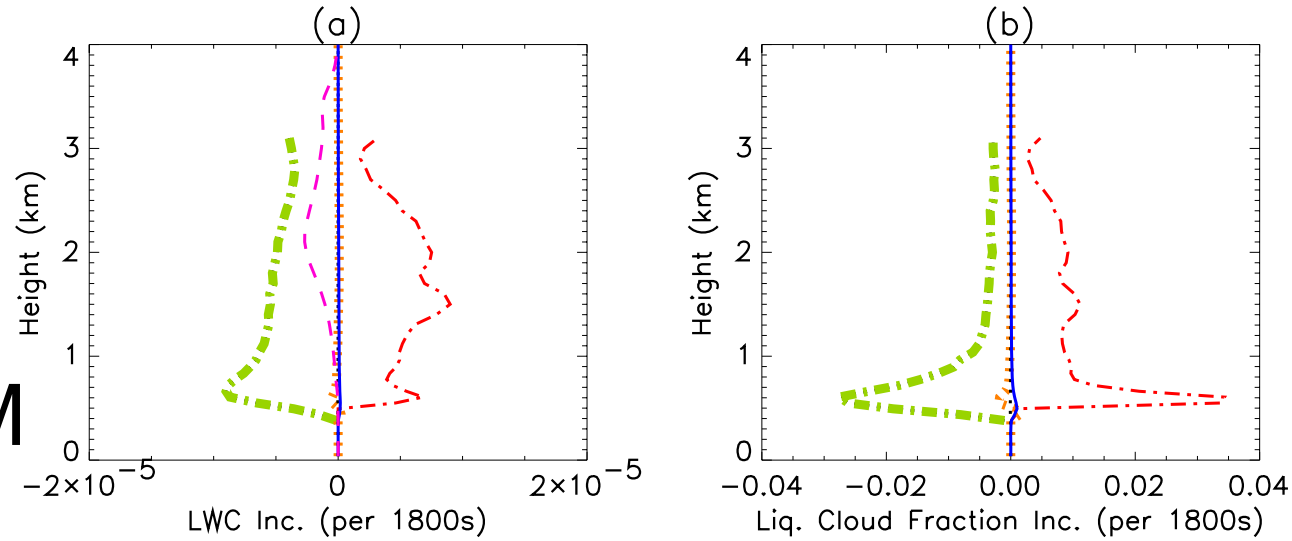
PC2 increment analysis for RICO

Convective detrainment
Erosion
Microphysics
LW rad
SW rad
BL turbulence
Dynamics

UM



LEM



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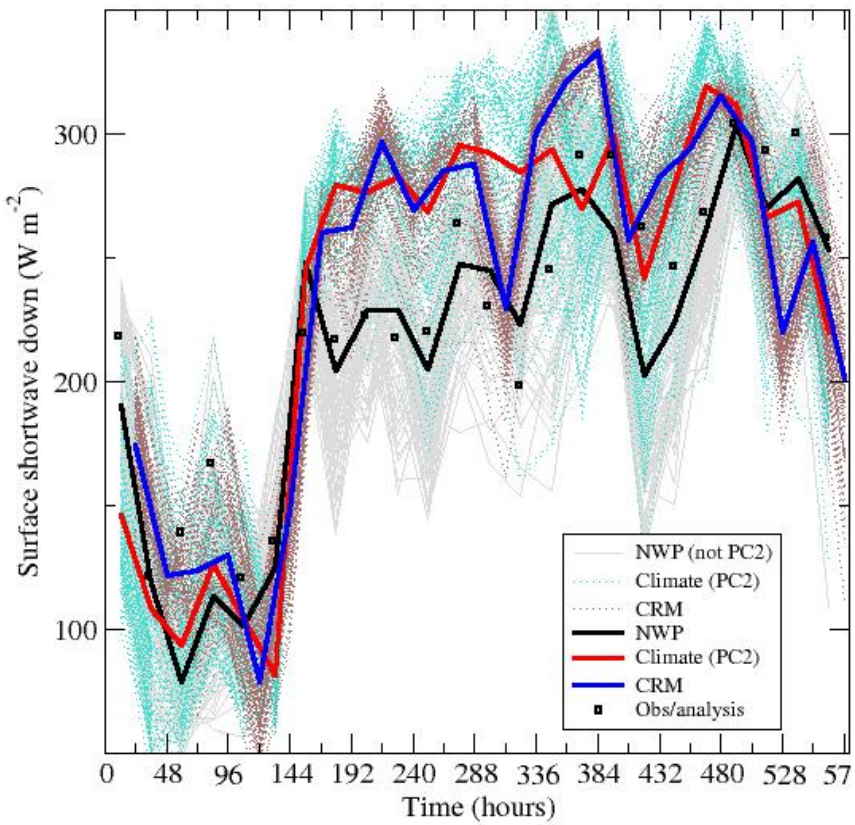
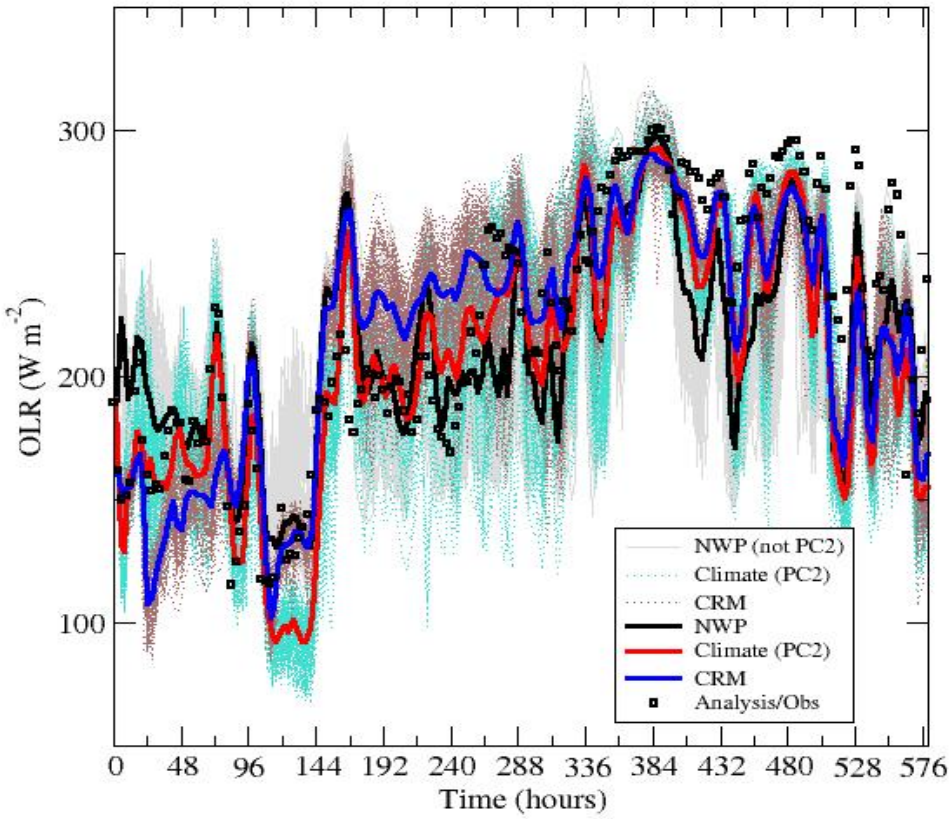
PC2 testing in TWP-ICE

Ensemble TWP-ICE forcing thanks to Laura Davies and Christian Jacob





Convection & boundary layer (if time)

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Convection – S. Derbyshire

- Recent:
  - Adaptive entrainment & detrainment
  - Changes to boundary layer mixing of downdraughts
- Ongoing
  - New “turbulence” based convection scheme
  - Diurnal cycle improvements through entrainment rates related to BL depth (based on CRM analyisis)

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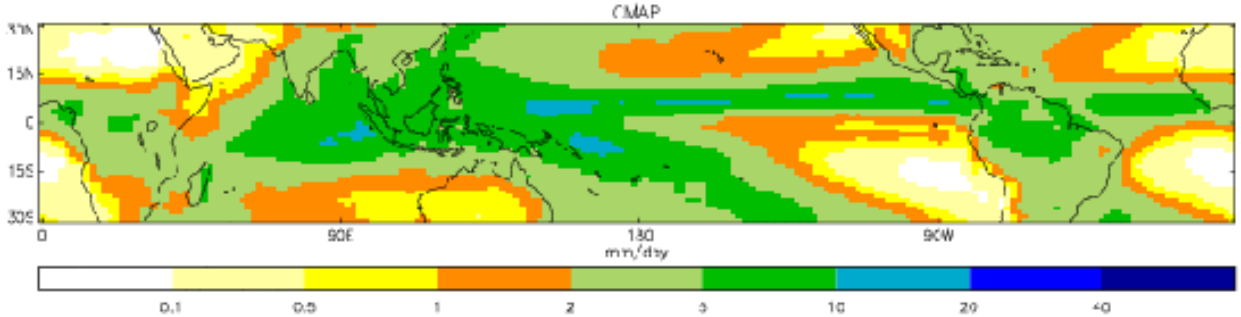
Illustration of adaptive detrainment impact on tropical climate [1-year annual mean precipitation]

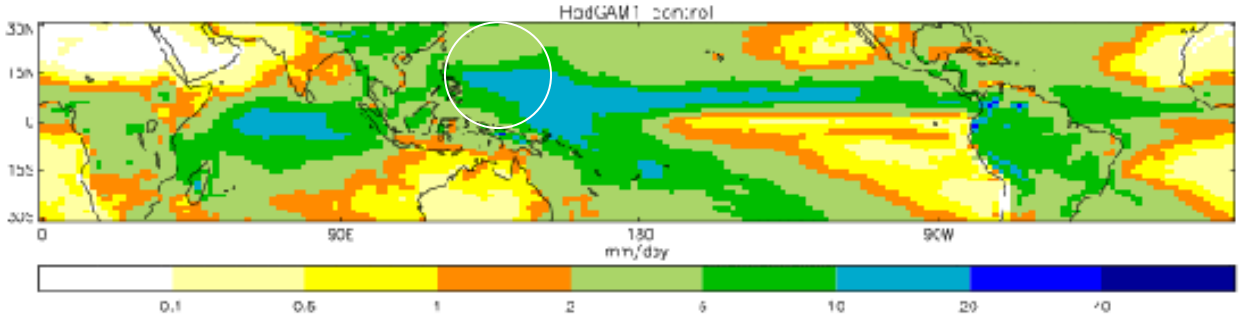
Adaptive mod seems to improve Tropical W. Pacific with benefits to Pacific wind-stress

Further validation confirms main impacts as systematic

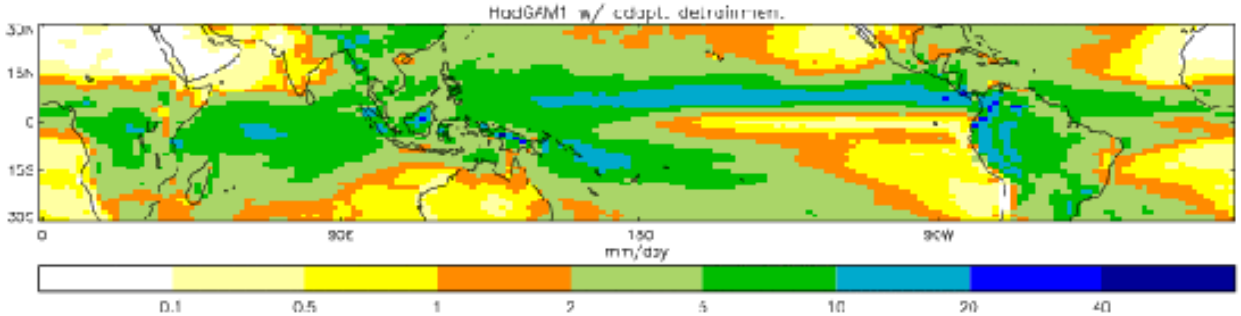
Observations



HadGAM1 control



HadGAM1 with adaptive detrainment



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Boundary layer – A. Lock

- **Recent**
  - Changes to unstable and stable turbulent mixing contributed significantly to NWP skill by reducing wind errors:
    - Stable mixing: sharper stability function over the sea
    - Unstable mixing: non-local component to momentum mixing
- **On-going**
  - near-surface temperature profiles
    - Improvements focusing on interaction between turbulent and radiative fluxes using very high resolution modelling
  - Boundary layer clouds
    - Evaluation of the effects of drizzle on turbulence (and thence entrainment) in stratocumulus, using LES
    - Improved representation of the coupling between the boundary layer and cumulus cloud layers (impact of cold pools, spreading of cumulus into stratocumulus, etc.)

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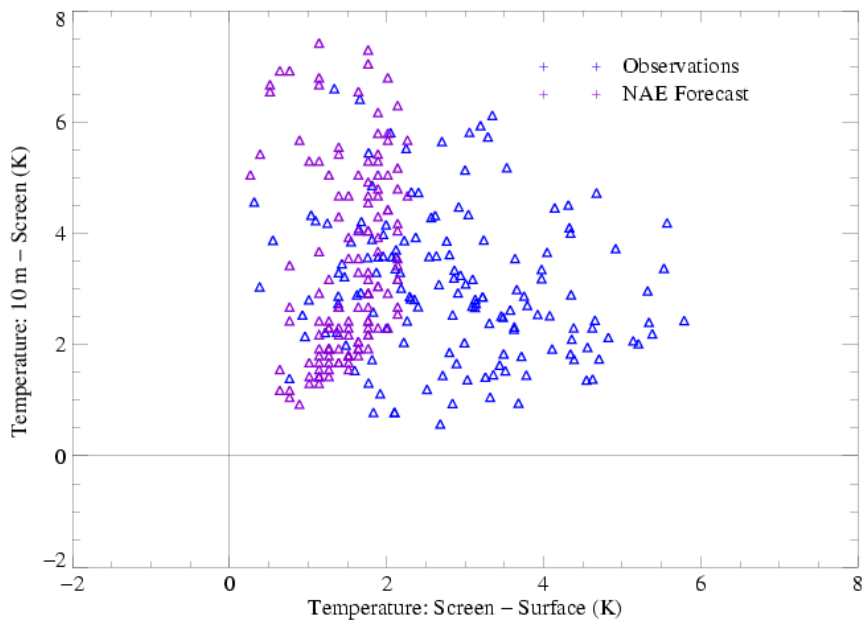
Improvements to screen temperatures

- Cold bias in screen temperatures found to occur predominantly at night under clear-skies with light winds, i.e., very stable conditions
  - Screen diagnostic is too closely coupled to the surface

April 2007 nocturnal temperatures at Cardington



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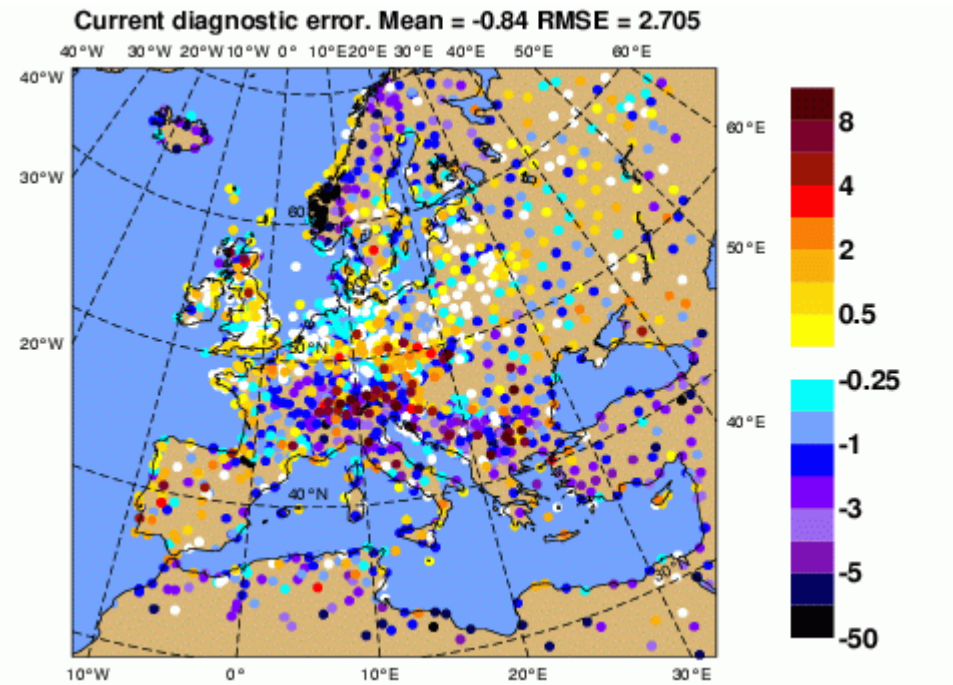
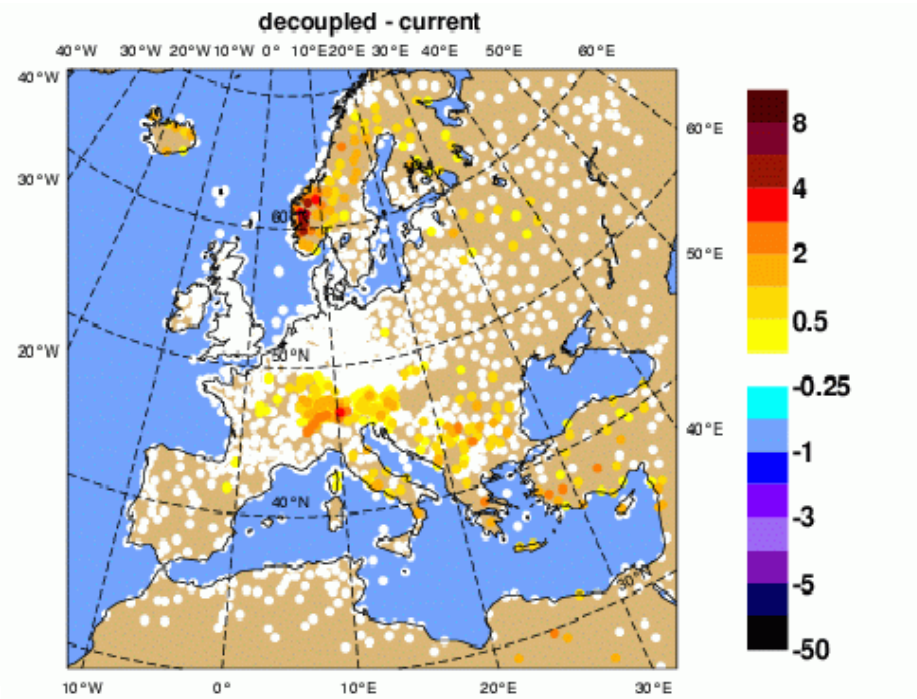
Improvements to screen temperatures

- Revised screen temperature diagnostic shows significant reduction of cold bias

Example NAE screen T errors



Impact of new diagnostic



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Aerosols (almost certainly not time)

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Aerosols – Jim Haywood

- Aerosol research at the Met Office involves:
  - Modelling for climate GCM (forcings, future scenarios)
  - Modelling for regional and dispersion models (mineral dust, air quality)
  - Modelling for Numerical Weather Prediction GCM (aerosol climatologies, visibility forecast)
  - Observations (satellite applications, NERC/MetO FAAM)

- Activities interact with and complement each other.

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What can ARM do to help?

Actually ARM help a lot…

- Intercomparisons
  - Coordination; observations; forcing e.g. TWP-ICE; MPACE etc…
- ARM radar
  - The cloudNET type approach is very valuable to us and this can hopefully be expanded to include ARM radar sites

Can ARM help more…

- Direct collaboration
  - When possible, work with us – don't just take a model result submitted to some comparison or result from a paper etc..
    - current version of our models
    - our current key problems/focus

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The end (finally)

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Questions and answers

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