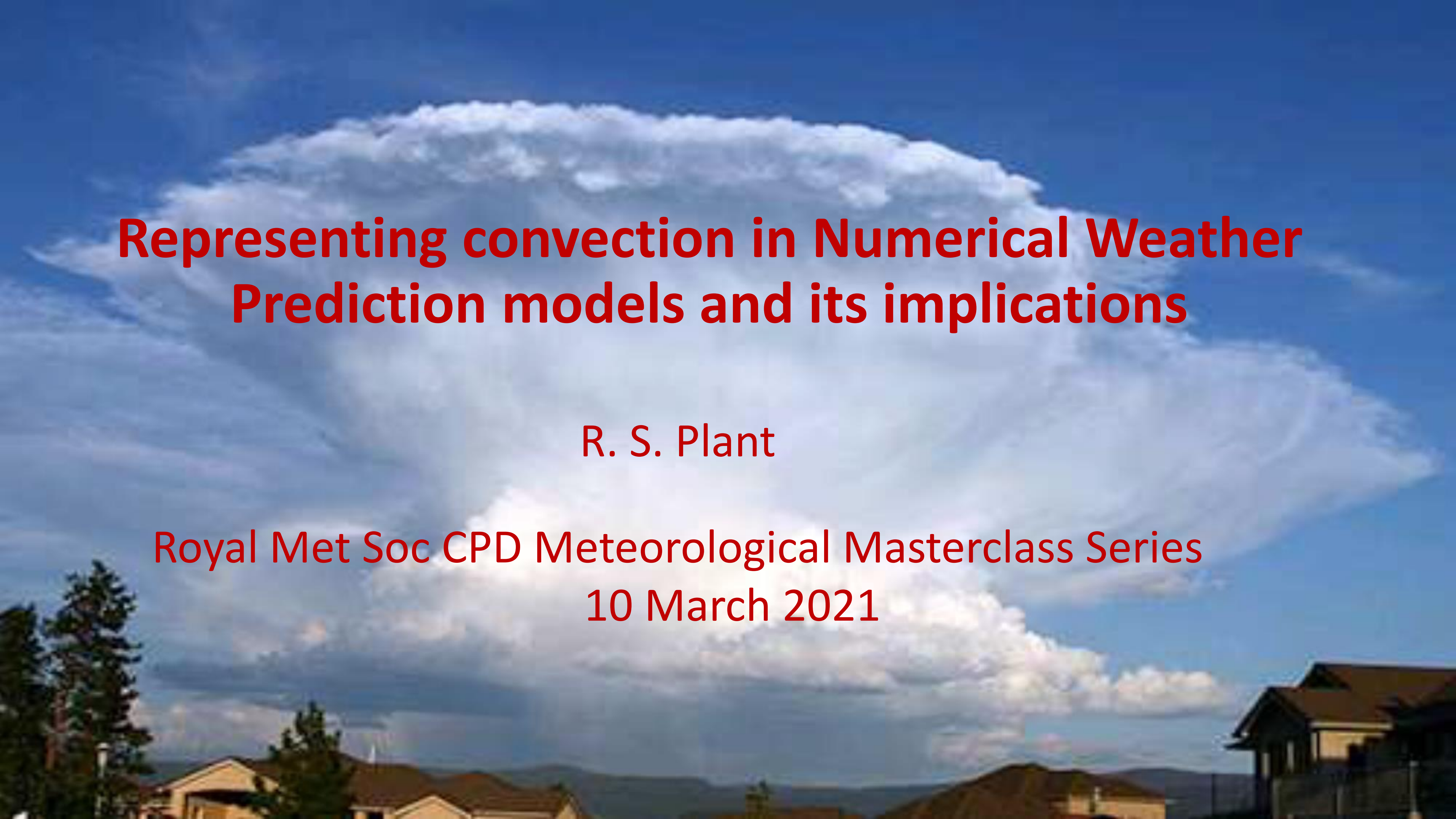


Representing convection in Numerical Weather Prediction models and its implications

R. S. Plant

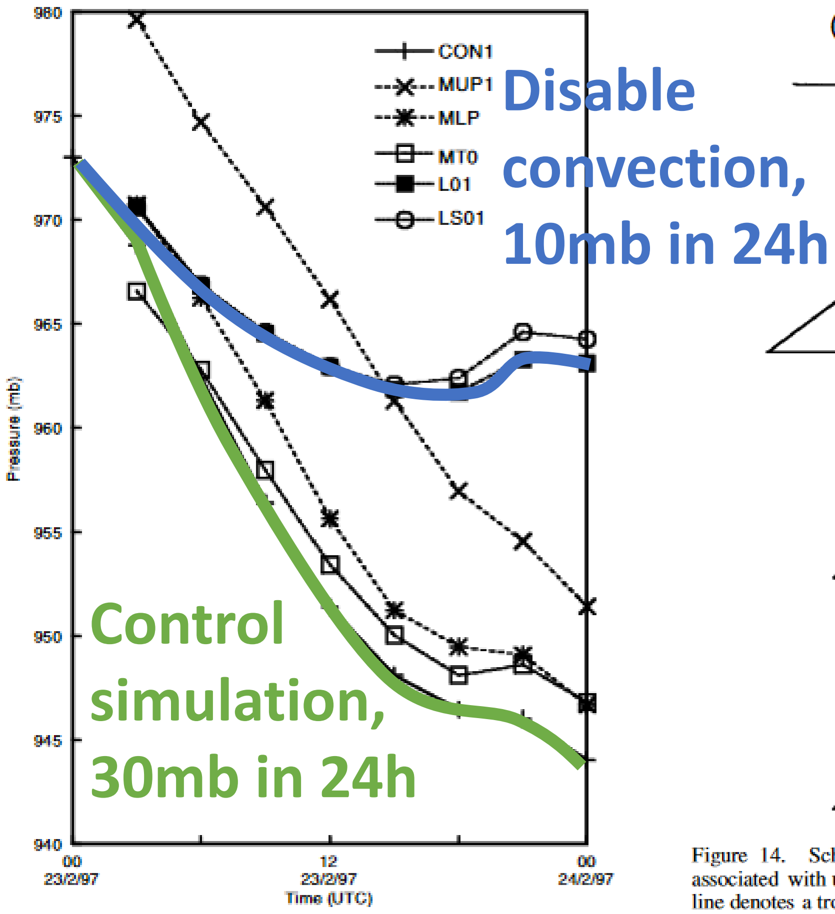
Royal Met Soc CPD Meteorological Masterclass Series
10 March 2021

Convection is important

- It plays a major role in planetary budgets of heat, moisture and momentum
- Development of organized, long lived systems such as squall lines and MCS
- Extreme events and flood forecasting
- Misrepresentation of US MCS can lead to “forecast busts” of mid-latitude cyclones over Europe (Rodwell et al 2013)

Boscastle flood 2004

An explosive extratropical cyclone



series at three-hour intervals of the minimum surface pressure of the] simulations. Each simulation is labelled by an identifer. The identifiers are listed in Table 1.

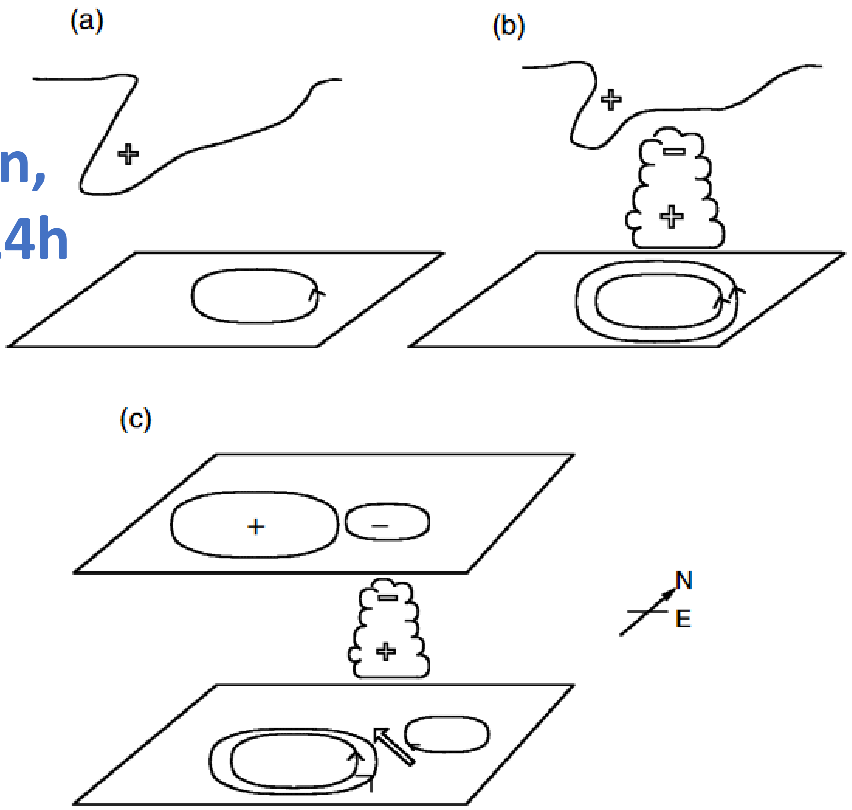


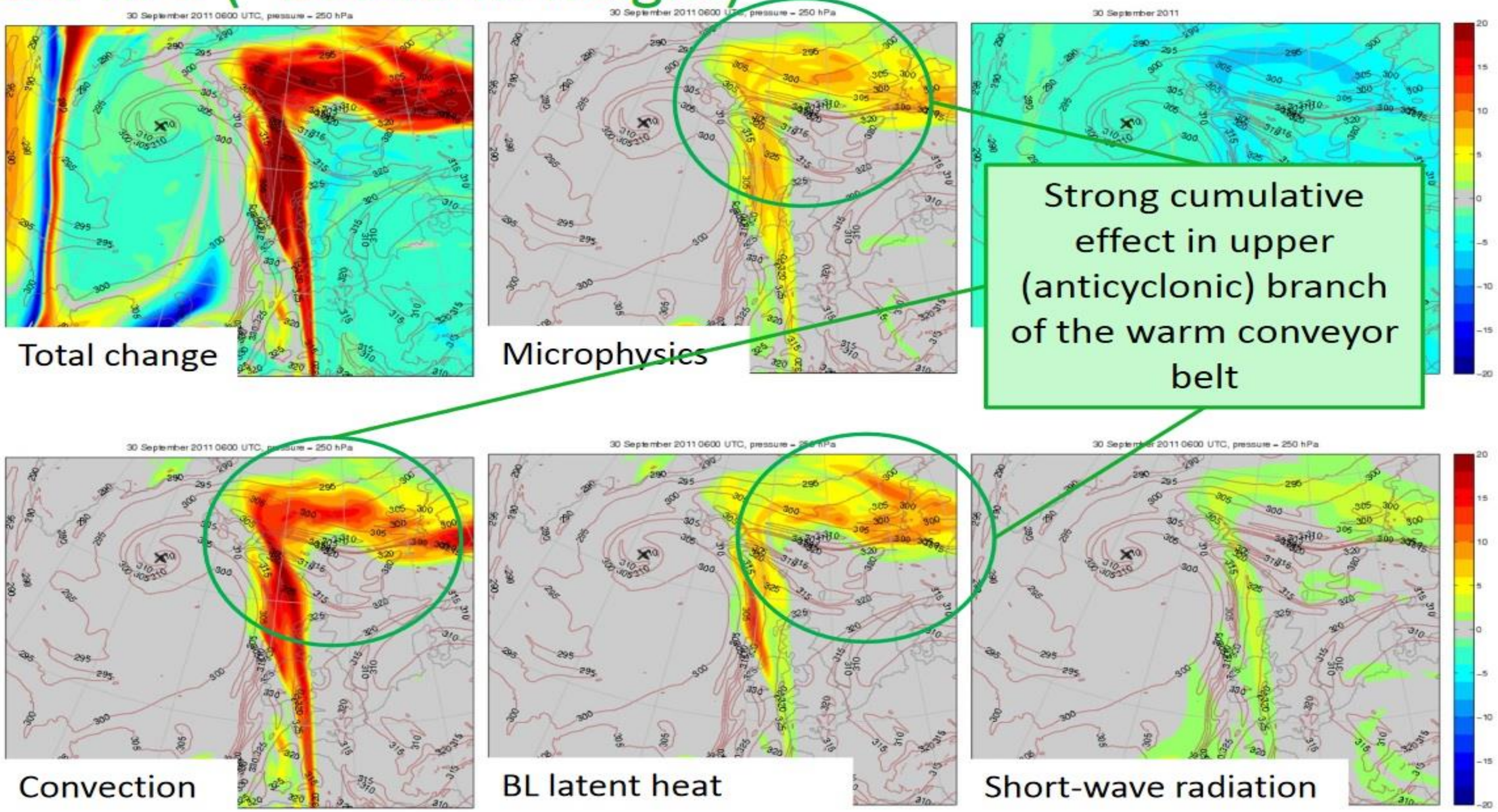
Figure 14. Schematic illustration of the various effects of latent-heat release on the low-level circulation associated with upper-level potential-vorticity anomalies. (a) The situation with no latent-heat release. The upper line denotes a tropopause fold, with associated positive PV anomaly. A low-level, cyclonic circulation is induced. (b) The dominant effects of latent heating. A positive low-level anomaly is formed which intensifies the low-level circulation. A local sink of PV is located above, and erodes the upper-level feature. (c) A subsidiary effect of latent-heat release. A downstream ridge is generated, and is associated with weak, downstream anti-cyclonic flow.

- Upper level feature → ascent → convection
- Convection → mid-level PV structure that interacts to drive explosive cyclognesis
- FASTEX IOP18, 22/02/97

(Ahmadi-Givi et al, 2004)

Convection downstream effects

Sources/sinks of potential temperature
250 hPa (~10000 m height)



Accumulate heating terms over 42h and advect these along with the flow

NAWDEX, 30/09/11

(Martinez-Alvarado and Plant, 2014)

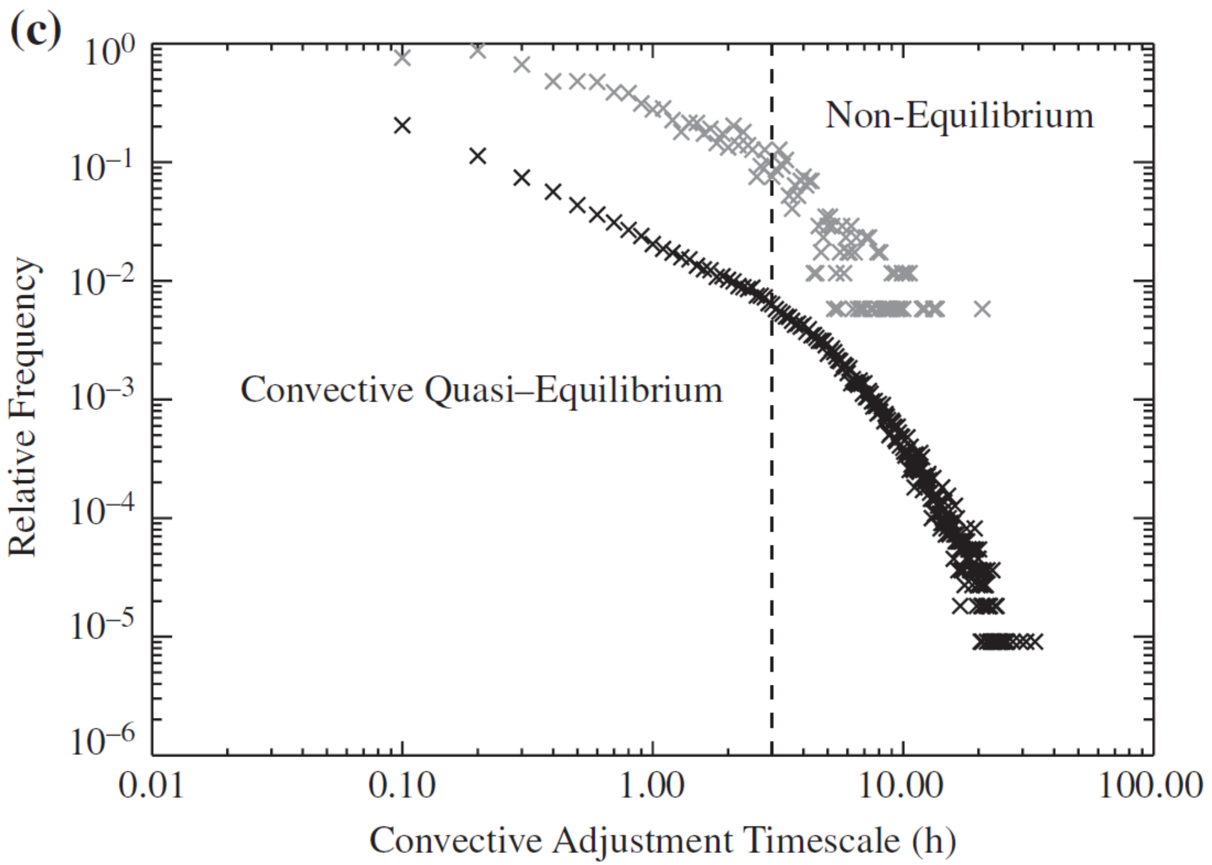
Equilibrium and non-equilibrium convection

- In equilibrium
  - Convection balances large-scale forcing
  - CAPE production by forcing determines rain rate
  - Convection often scattered or quasi-random within large-scale area (large uncertainty in location)
  - This is the usual assumption in a parameterization

- For non-equilibrium
  - CAPE build up made be hard to release
  - i.e. key factor is to overcome CIN (possibly large uncertainty in occurrence)
  - Harder to model – need to capture CIN-breaking mechanism
  - Convective location reliable if so but amounts uncertain

Measuring equilibrium

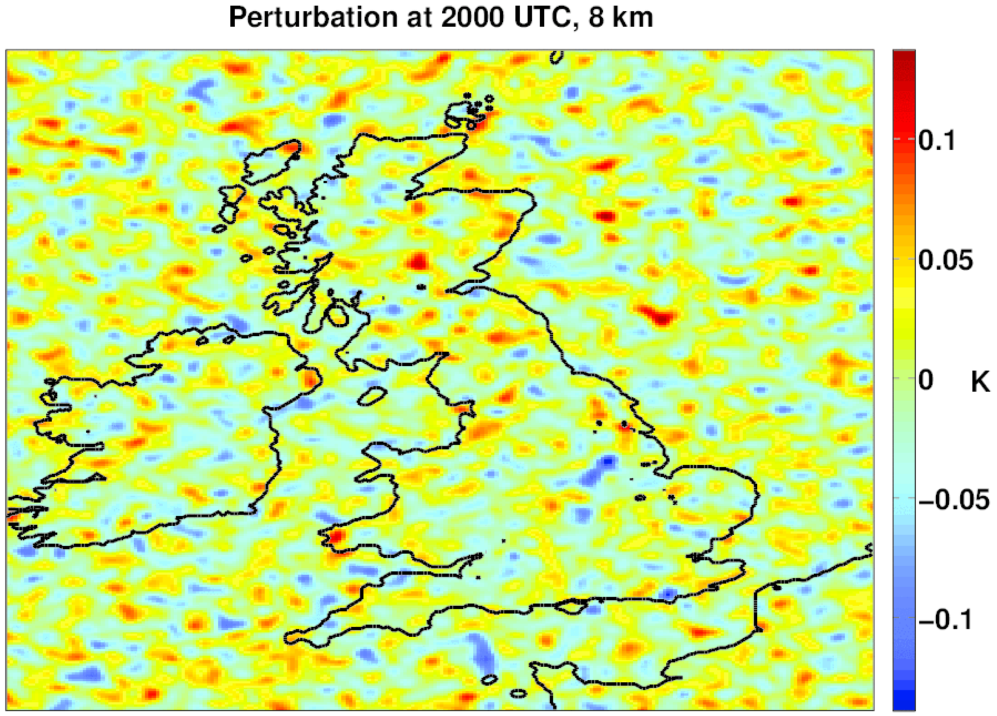
- Convective timescale, τ_c = CAPE / (dCAPE/dt due to convection)
- Estimate of time for convection to adjust the atmosphere towards a neutral profile
- Small in equilibrium conditions
- With a 3h threshold, convective rainfall in the UK is in equilibrium 80% of the time (70% in Germany)

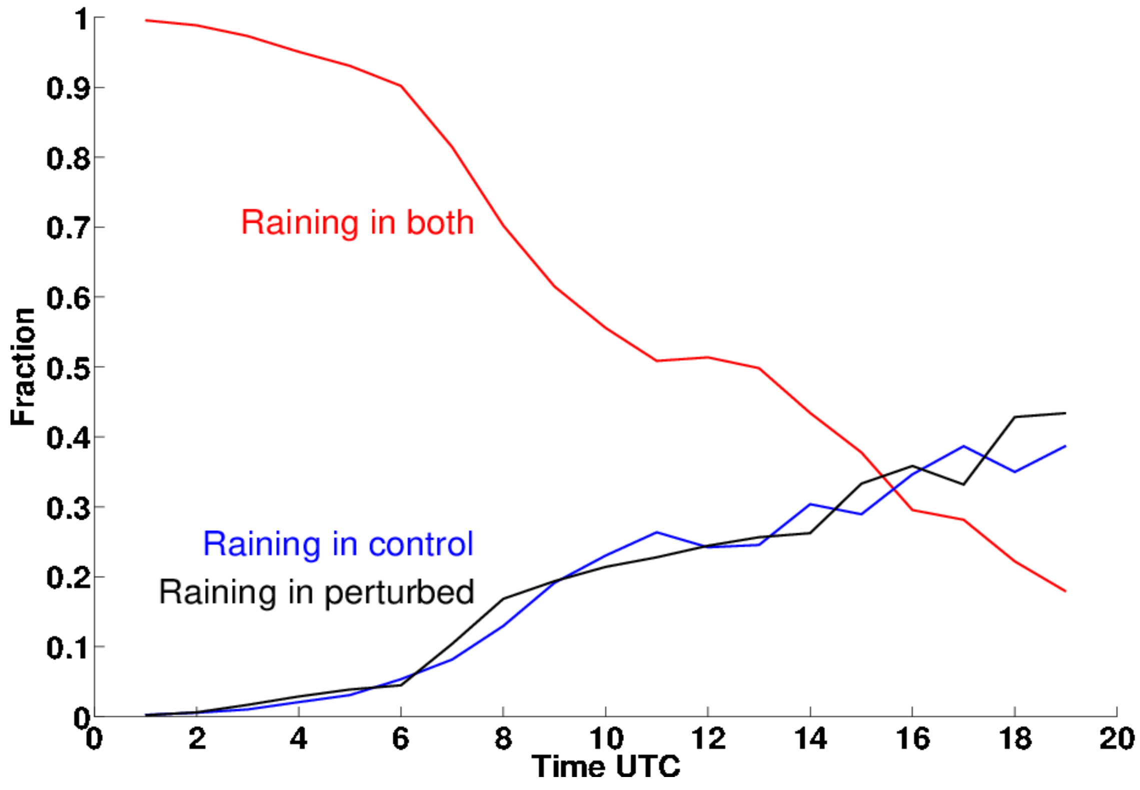


Done et al 2006; Flack et al 2016

Predictability in equilibrium convection

Small boundary layer fluctuations can easily shift the locations of precipitating cells





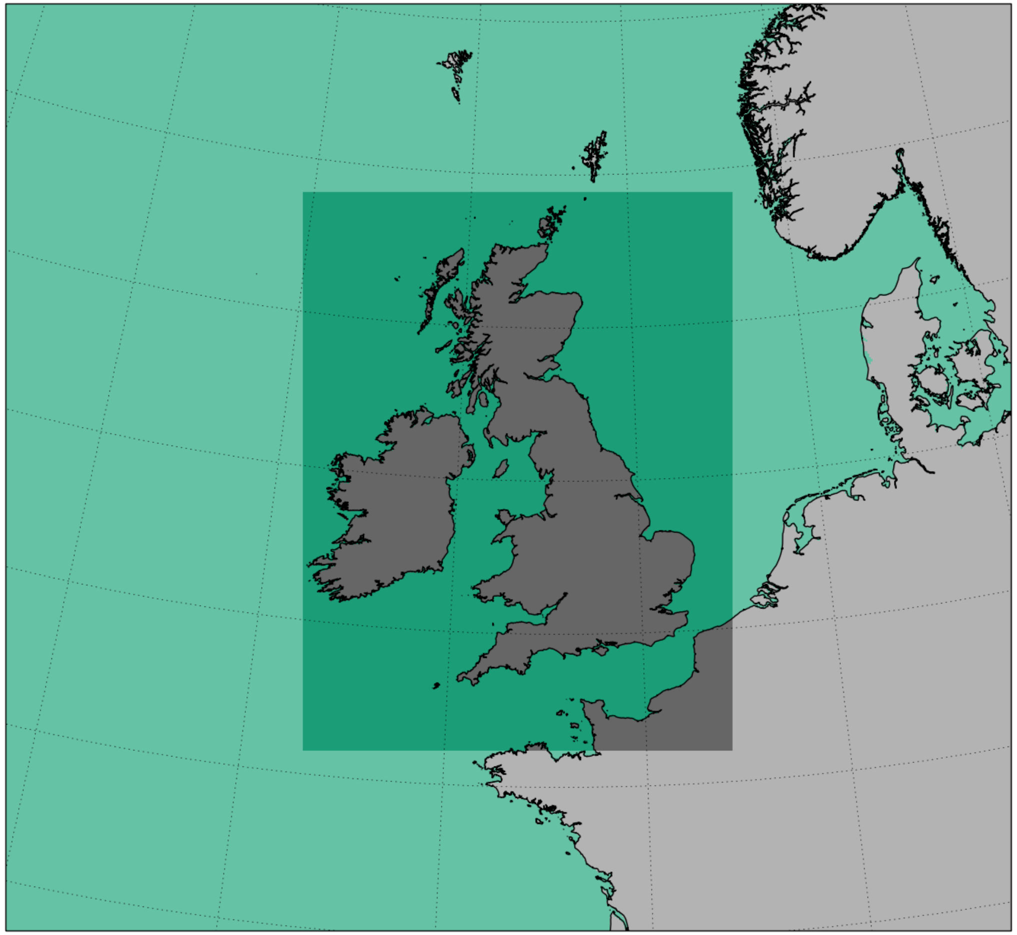
Fractions of rainy points in one or both simulations

CSIP IOP18, 25/08/15

Leoncini et al 2010

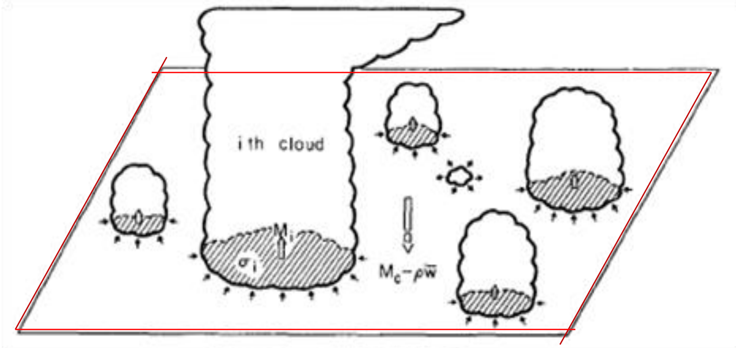
The Unified Model

- Unified Model (UM) is the main NWP and climate tool in the UK
- With a convection parameterization:
  - Climate models at typically 40 to 200km grid spacing
  - Global model runs at 10km grid spacing (ensemble at 20km)
- With explicit convection:
  - UKV model runs at 1.5km spacing (ensemble at 2.2km)



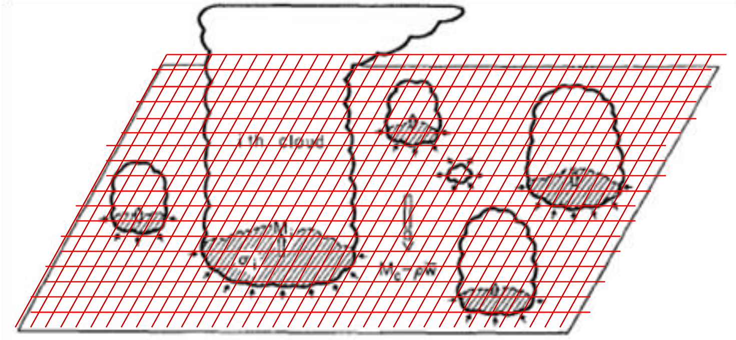
Parameterization and its recent development

Representation of Convection in Numerical Models



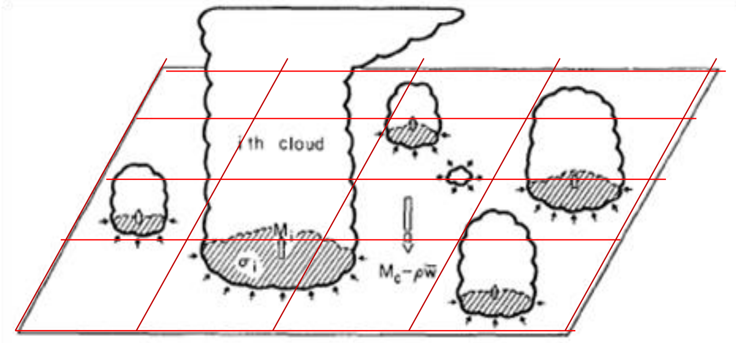
Parameterized

- Δx ~ 100km or larger
- Many clouds in a grid cell
- Represent the effect of all clouds on mean properties of the grid



Explicit (large-eddy modelling)

- Δx ~ 100m or smaller
- Many cells for each cloud
- Each cloud full resolved



Grey zone

- Δx ~ 1-10 km
- Not enough clouds in a cell for parameterization
- Not enough grid cells to resolve individual clouds
- Representation should be scale-aware and stochastic

Convection Parameterization

- Purpose is to feedback effects of unresolved processes on the model-resolved flow

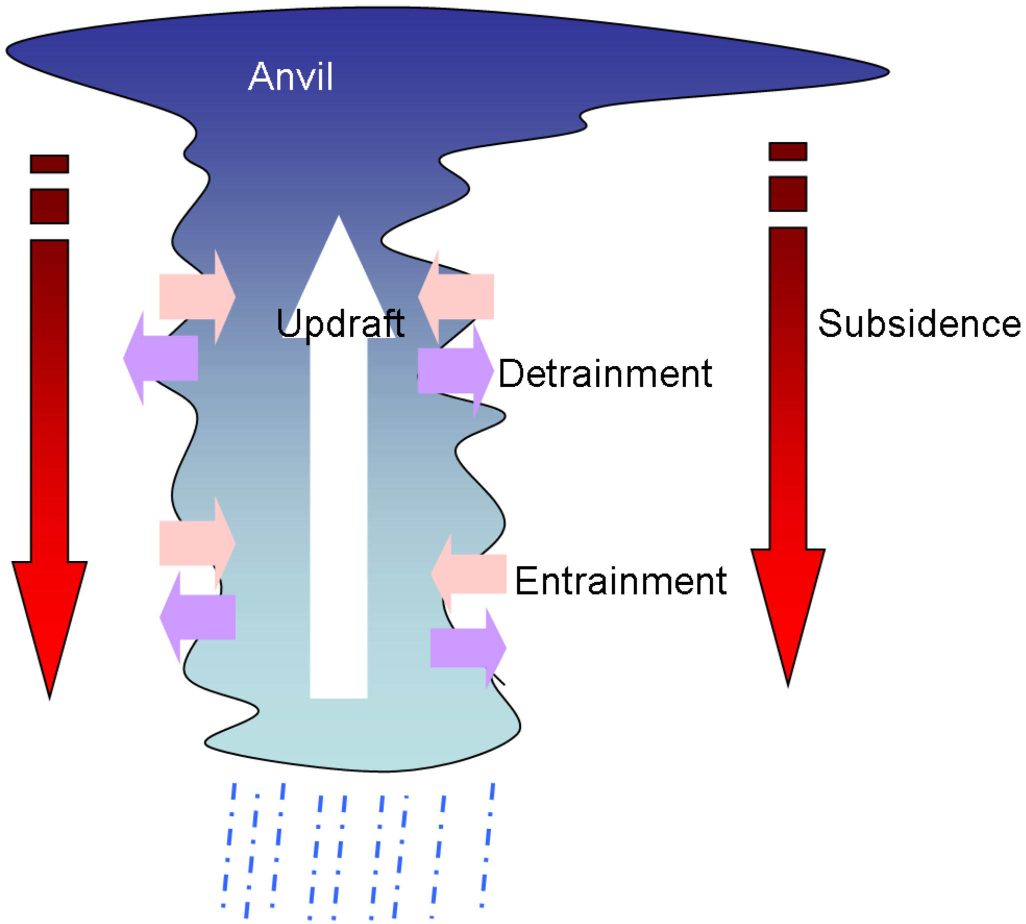
- Simplified physical picture of a set of convective clouds within the grid box

- A key variable is the mass flux

$$M = \rho\sigma w$$

- Because we need to model the fluxes

$$\rho\overline{w'q'} = M(q_{cloud} - q_{env})$$



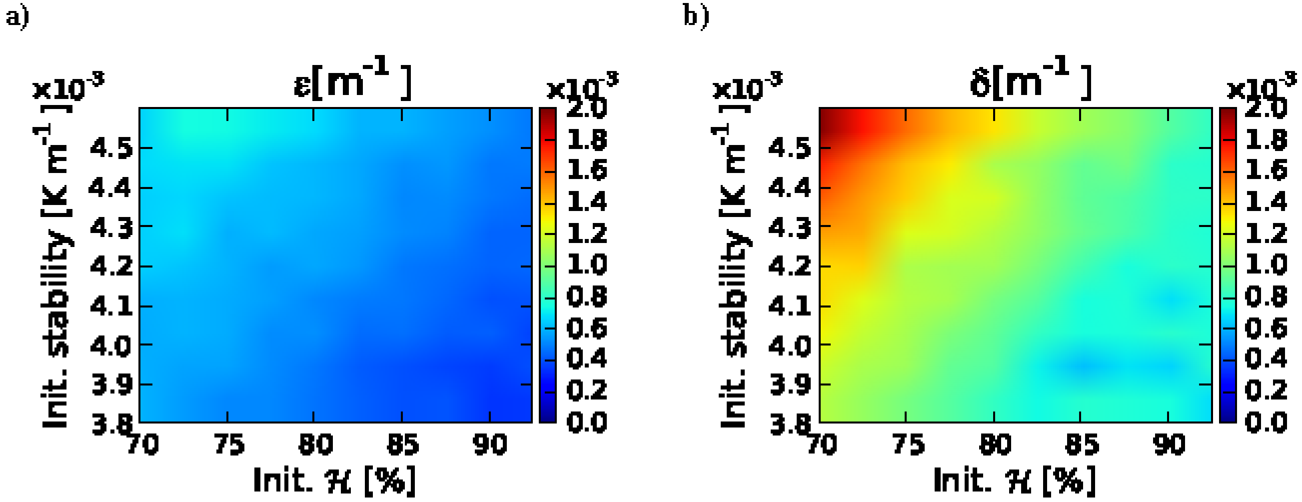
Convection Parameterizations

- Most schemes based on mass flux
  - Increasing interest in σ and *w* (Peters et al 2021)
  - And in very new perspectives e.g. multi-fluid, assumed pdf (Thuburn et al 2018)
- Need to estimate entrainment and detrainment
  - Increasing use of large-eddy simulations to extract exchange rates (de Rooy et al 2013)
- Most schemes are “bulk”
  - Increasing interest in spectra of different cloud types (Plant 2010)
- Most schemes use “equilibrium closure”
  - Increasing interest in non-equilibrium and alternative forms of closure (Bechtold et al 2014)

Entrainment / detrainment estimates from LES

- Link entrainment to cloud sizes
- Link detrainment to cloud heights
- Not enough sensitivity to environmental RH
    - Derbyshire et al 2004, Bechtold et al 2008
- More variation in detrainment than entrainment rates
    - e.g. adaptive detrainment scheme of Derbyshire et al 2011
- Increased interest in cloud spectra

Estimate from large-eddy simulations with grid lengths around 100m



Boing et al 2012

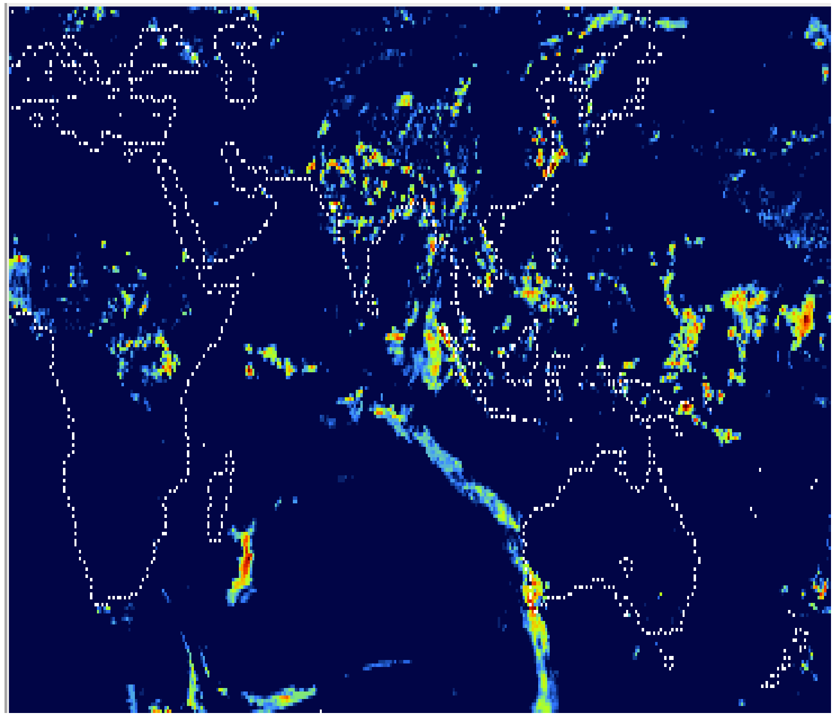
CoMorph

- New mass flux scheme for the UM, currently in trials
- Developed through large MO / university partnership, ParaCon, but especially by Mike Whitall
- Improved functionality includes:
  - Single-moment in-plume microphysics scheme, that allows for the mixed phase and graupel
  - Representation of in-cloud w, allowing convective overshoots
  - Separate consideration of cloud-mean and cloud-core properties in detrainment calculations
  - Simple representation of cold-pool effects, providing memory
  - Initiation of mass at any level, proportional to buoyant instability

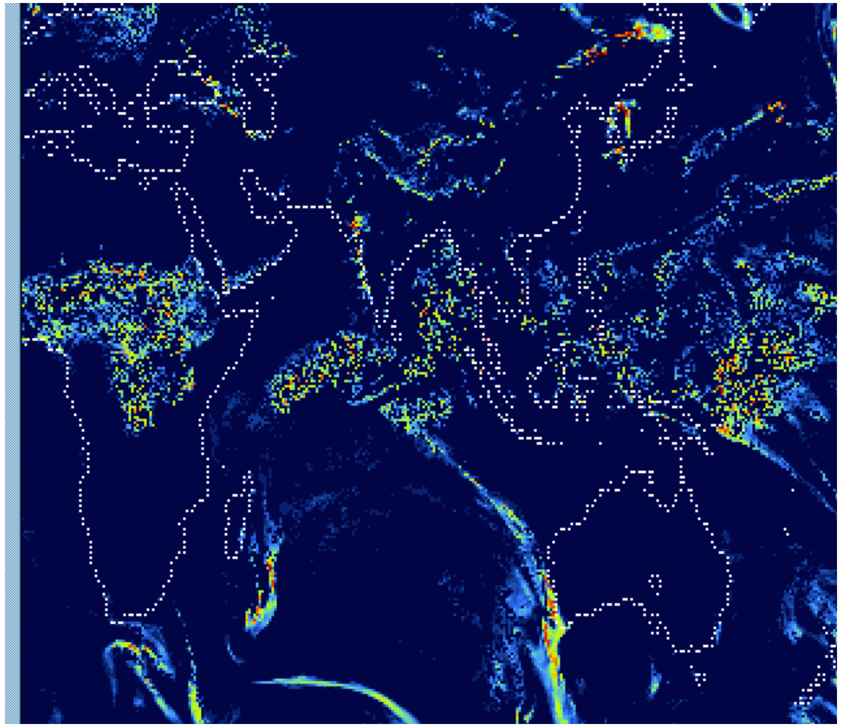
- And much better numerics to prevent artificial on/off behaviours

Snapshot of rain rates

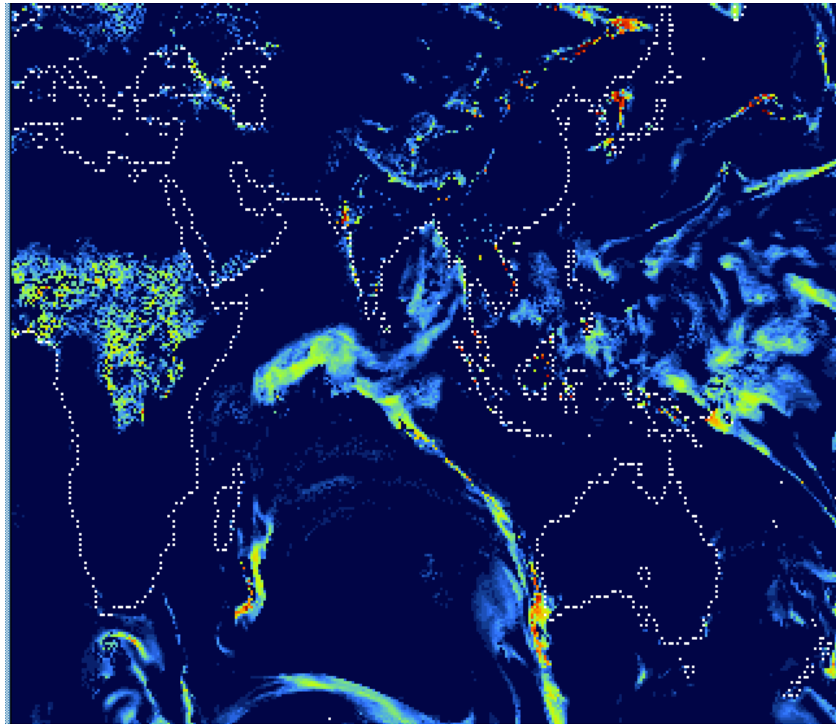
Many common closures (e.g. based on CAPE) have problems with intermittency



TRMM data



Old scheme, CAPE closure

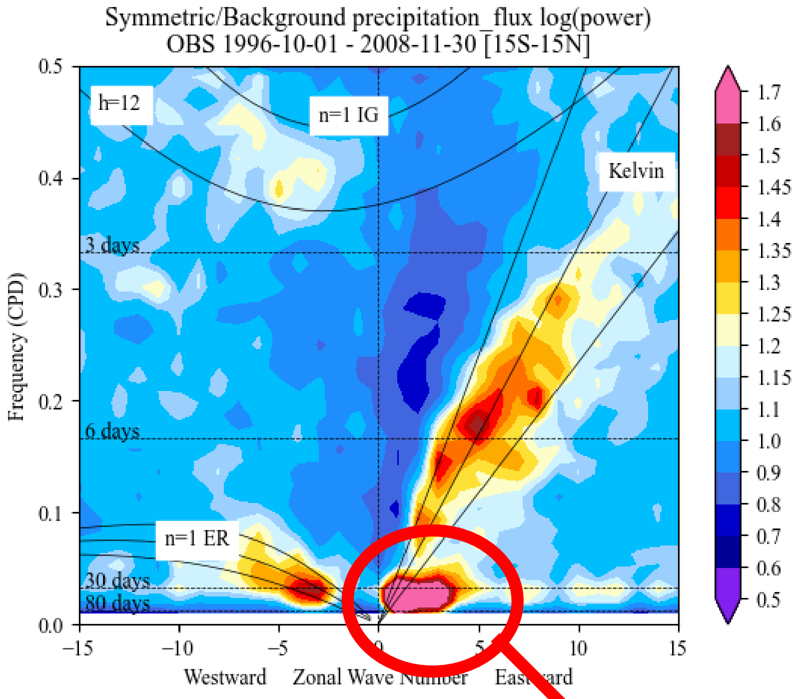


A Comorph test

Mike Whitall

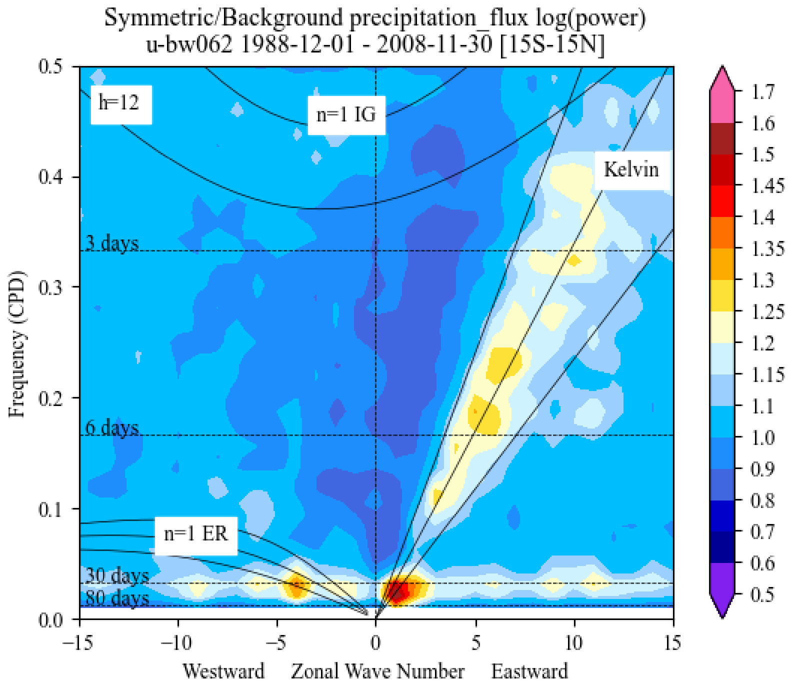
Tropical Waves and the MJO

Good improvements, especially in capturing the MJO

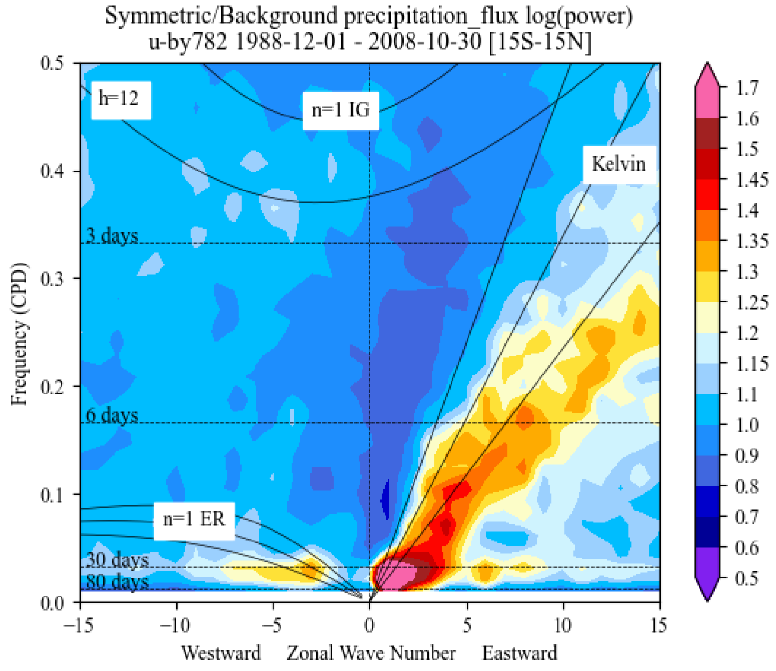


Observational wave spectrum

MJO



Old scheme



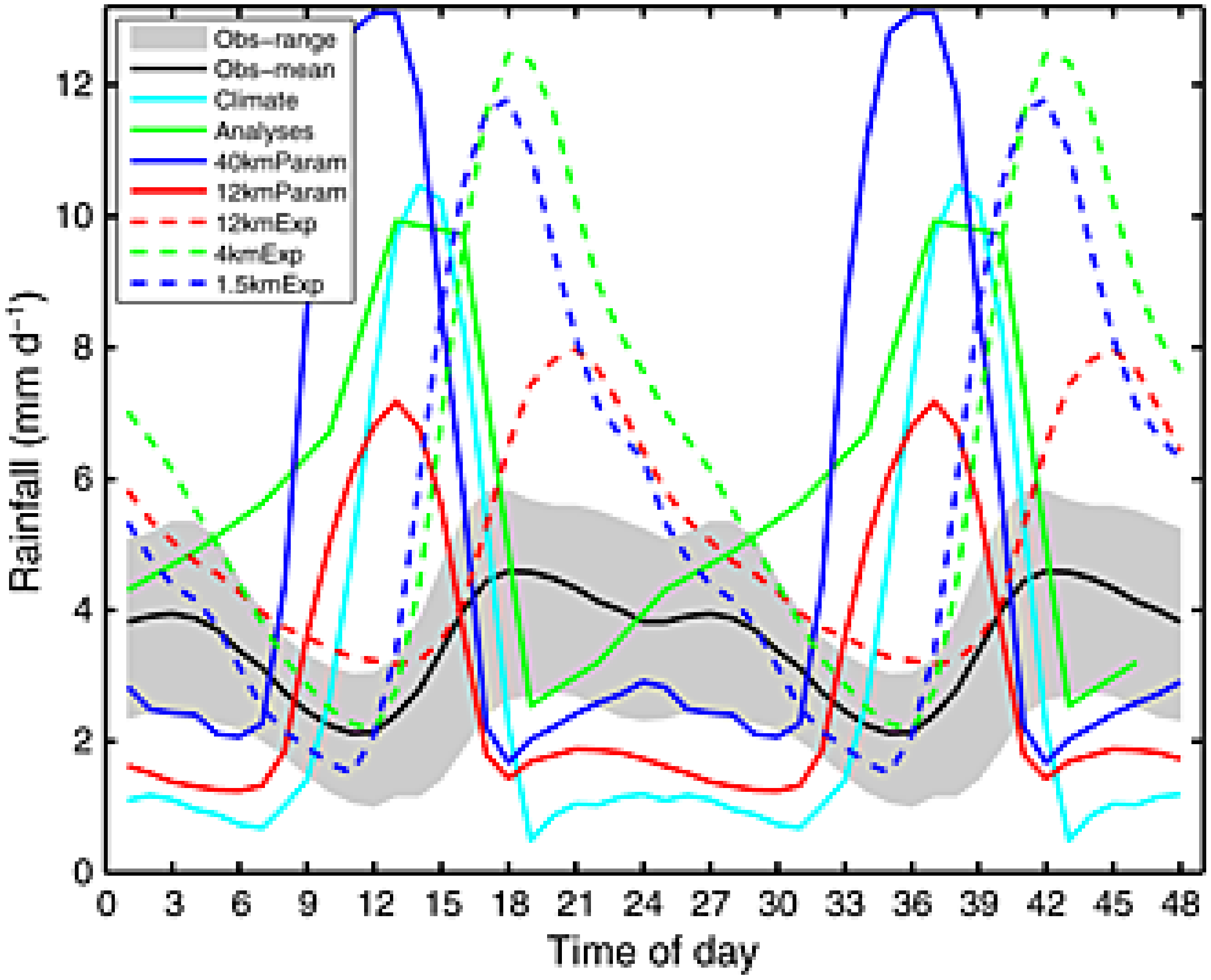
A Comorph, better sensitivity to environmental moisture

Prince Xavier, Sally Lavender

Diurnal cycle

- Parameterized convection often peaks too early, around midday

- Birch 2014, West African Monsoon system, cycle timing also feeds back onto mesoscale circulations.



Diurnal cycle

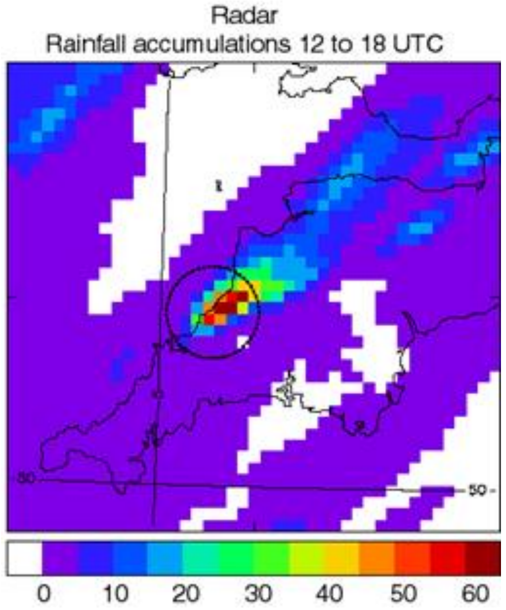
- Improved by:
  - Revised trigger so convection needs a dynamical forcing as well as the thermodynamics (Xie et al 2019)
  - Revised closure so not overly sensitive to boundary-layer changes to CAPE (Bechtold et al 2014)
  - Revising entrainment rate to capture increasing cloud sizes over the day (Stirling and Stratton 2012)
  - Introducing cold-pool mechanisms (memory) (Colin et al 2019)

- They are all right!

Use of convection-permitting models

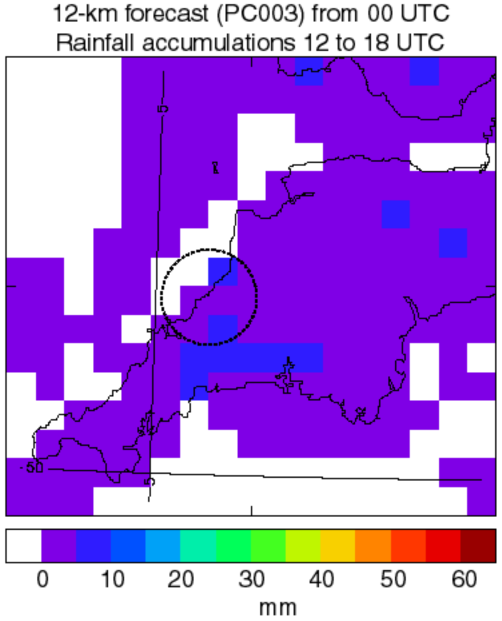
Boscastle Flood, 16/08/04

Location very good but errors and uncertainties at cloud scale – too little rain.

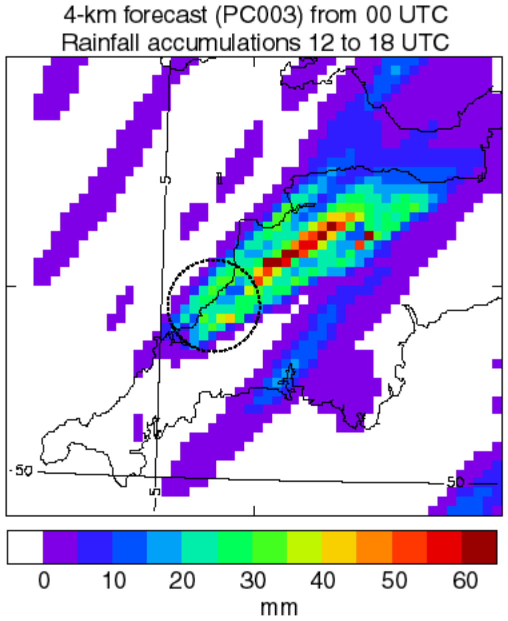


Radar accumulations on 4 km grid

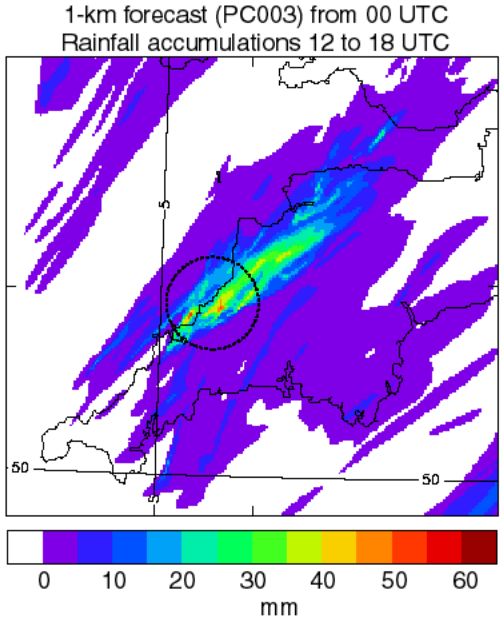
12 km parameterized



4 km explicit

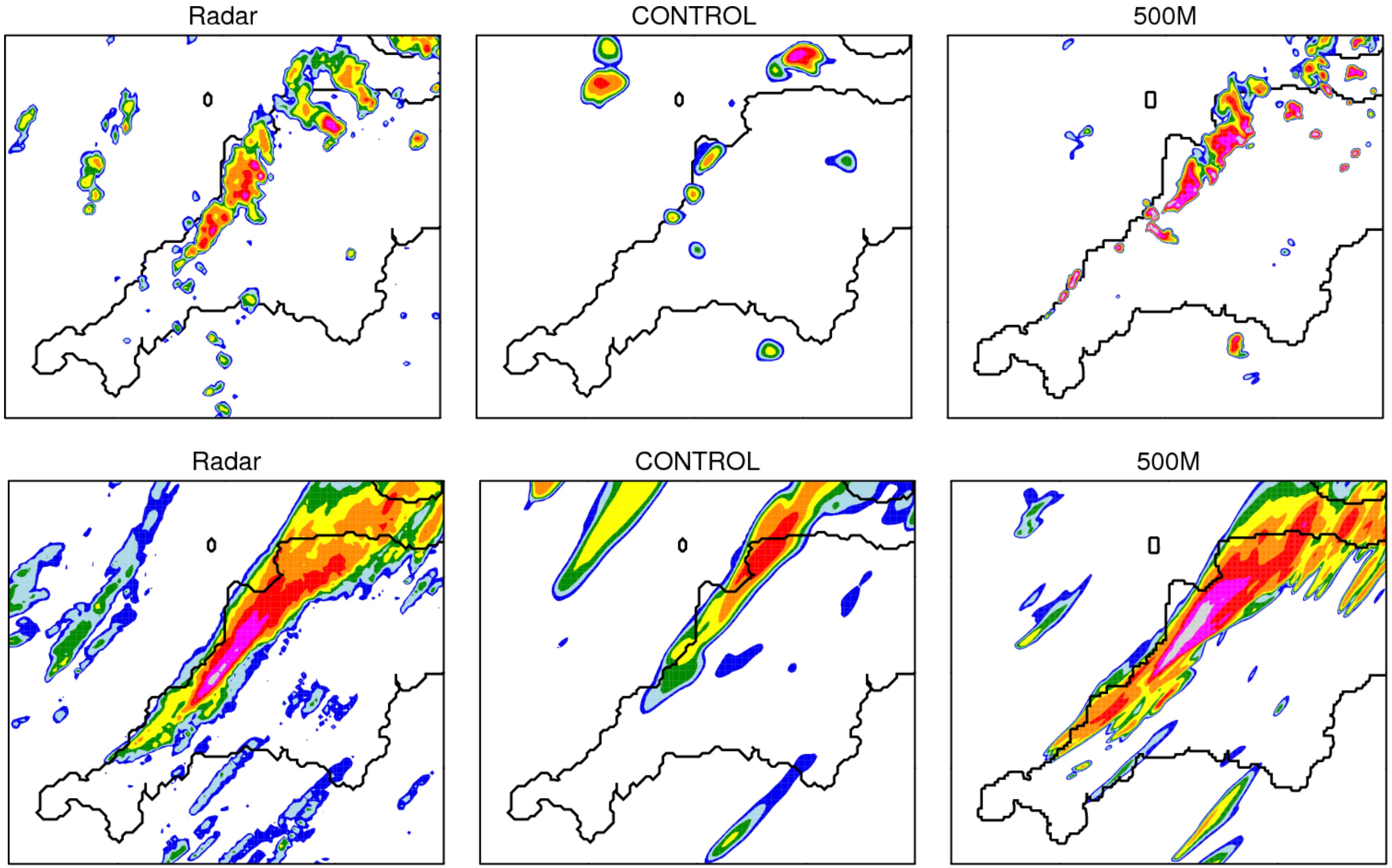


1 km explicit



Peter Clark

A similar case from 21/07/10

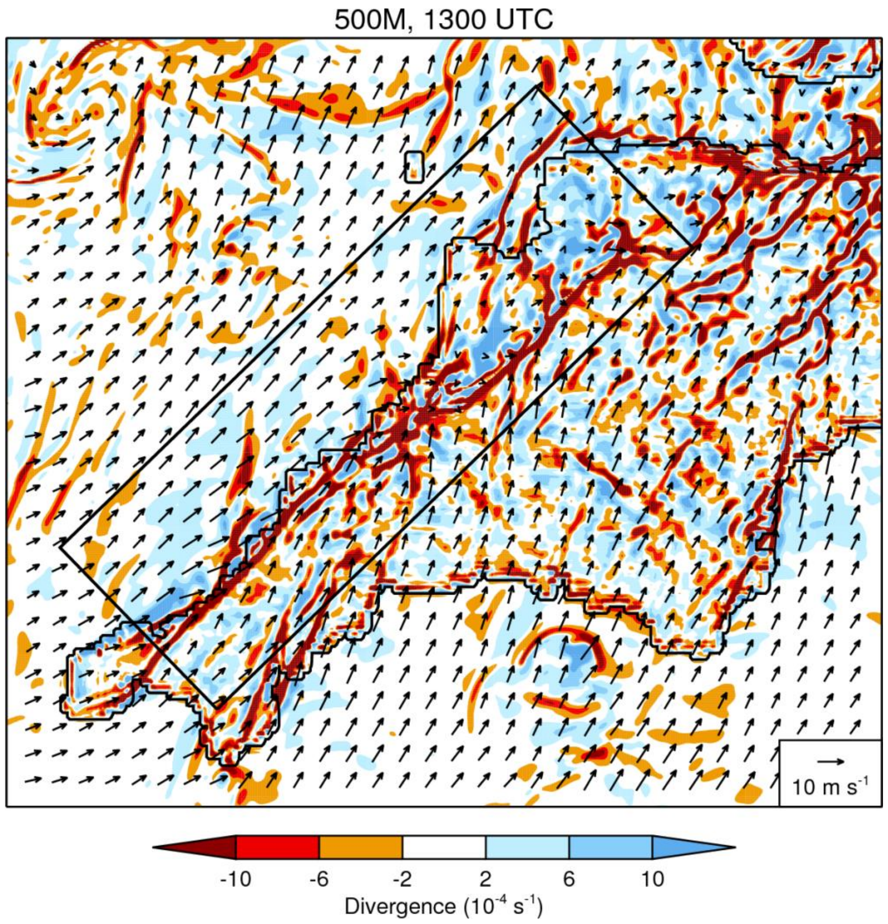


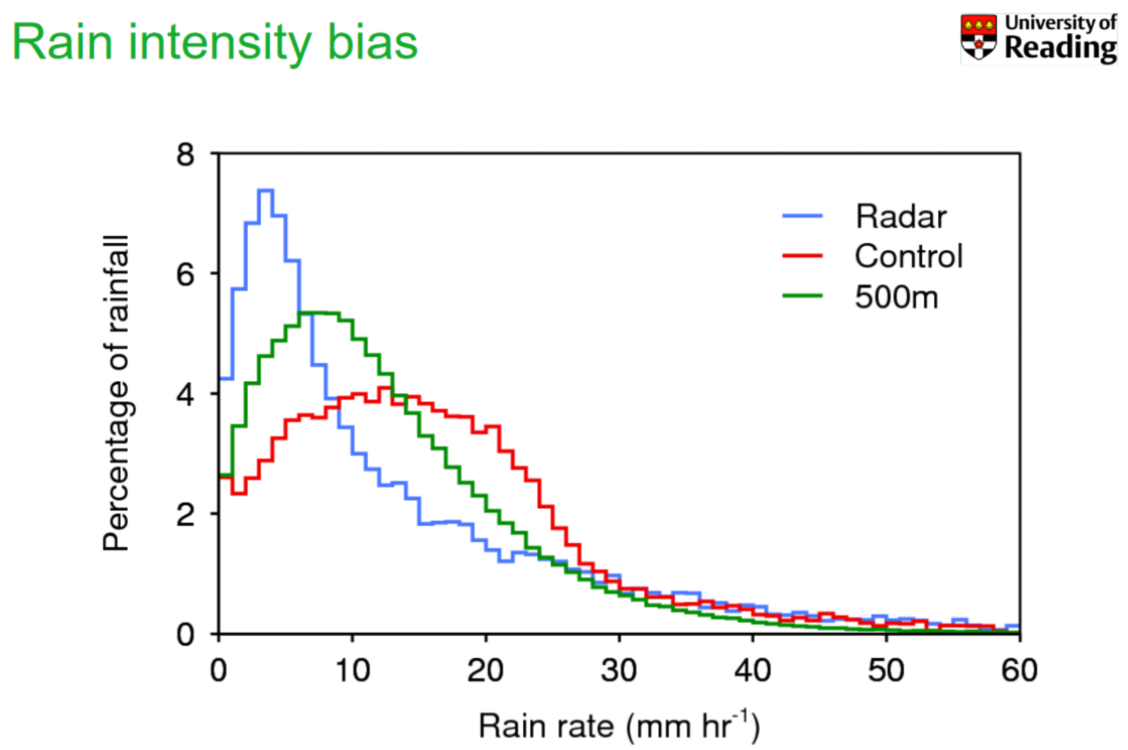
Snapshot of rain rates

Accumulations

(Warren et al 2014)

A similar case from 21/07/10



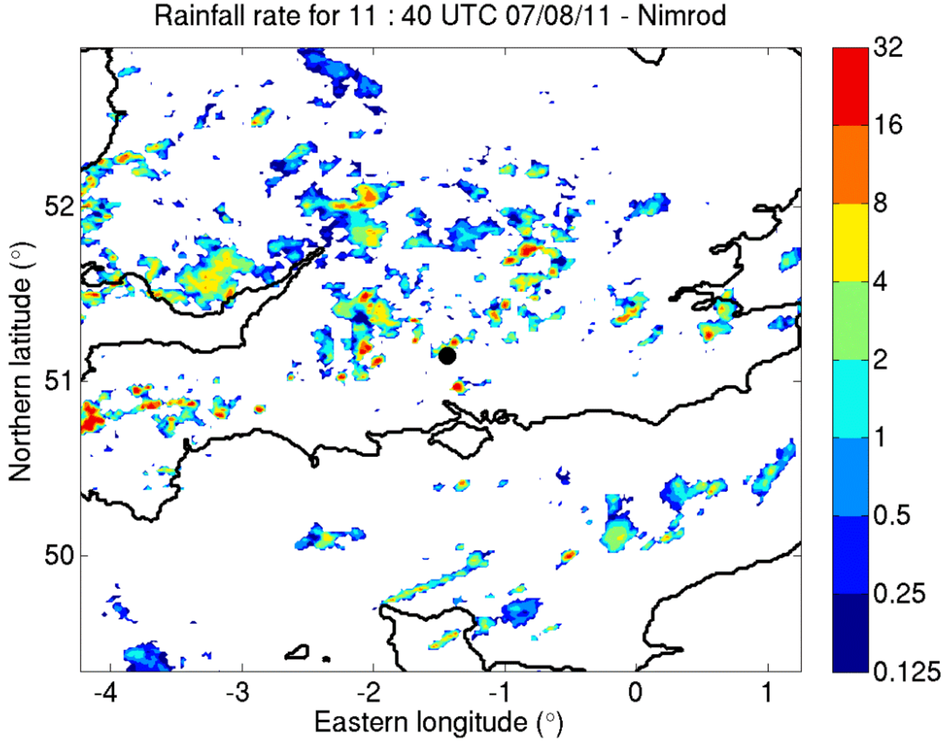


500m gives better location and strength of a sea-breeze convergence line

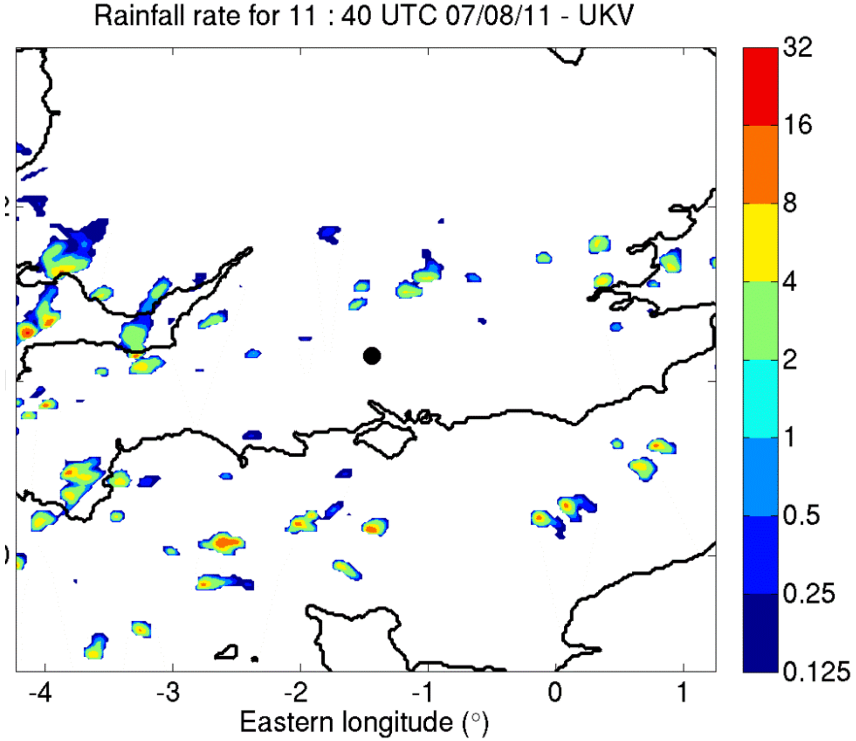
Improved rain rates – lighter but more coverage

Are the details right? Example, 07/08/11

Rainfall radar (Nimrod)



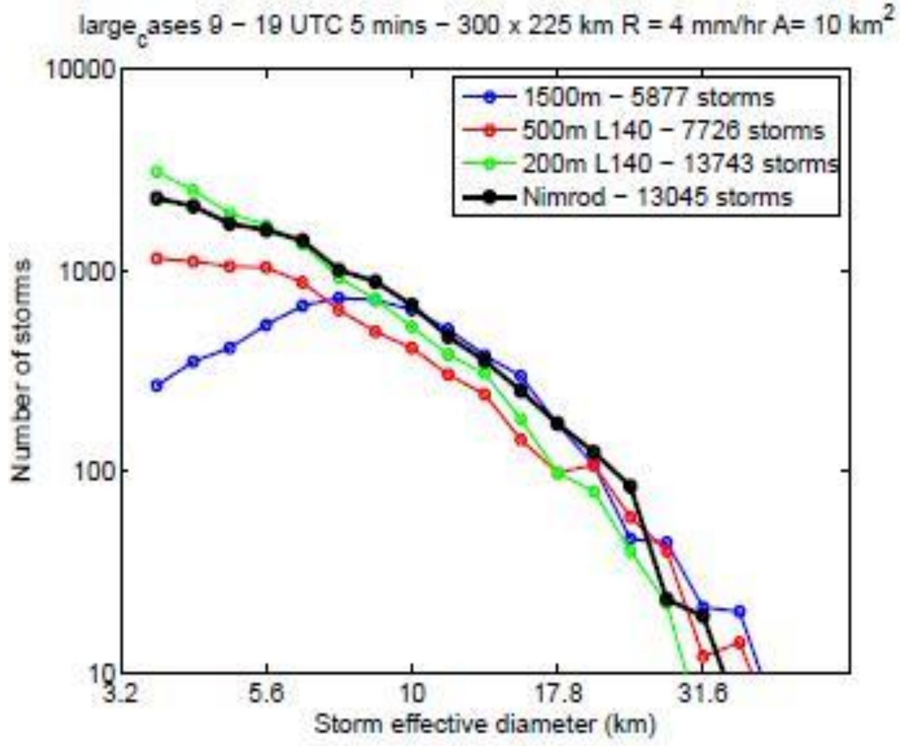
1.5 km forecast model (UKV)



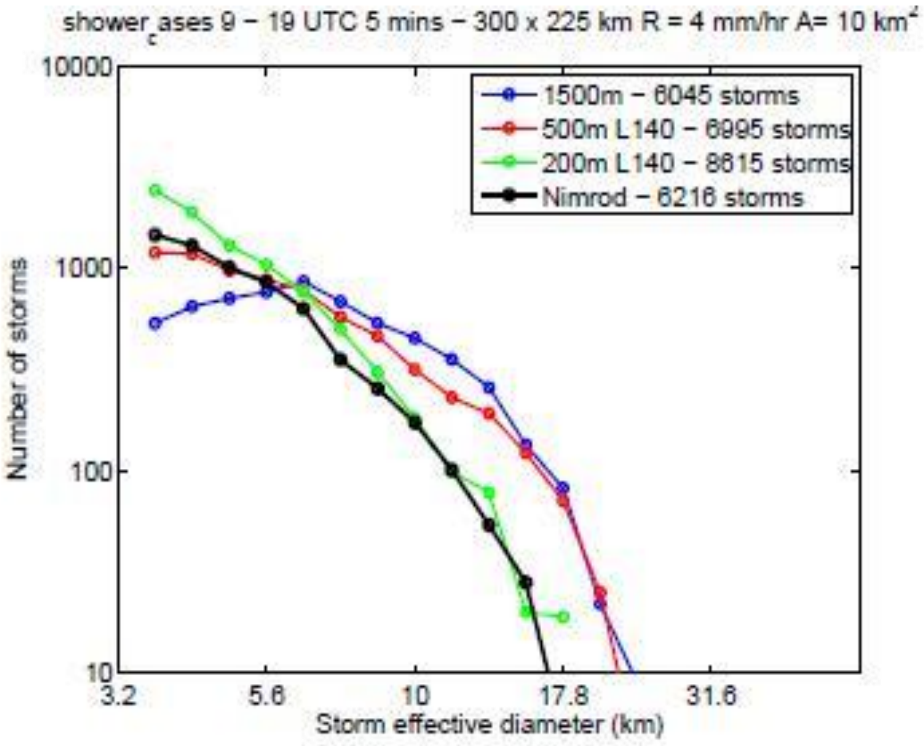
- By eye, UKV does not have enough small storms in this case

Cell sizes

Average over strong cases



Average over shower cases

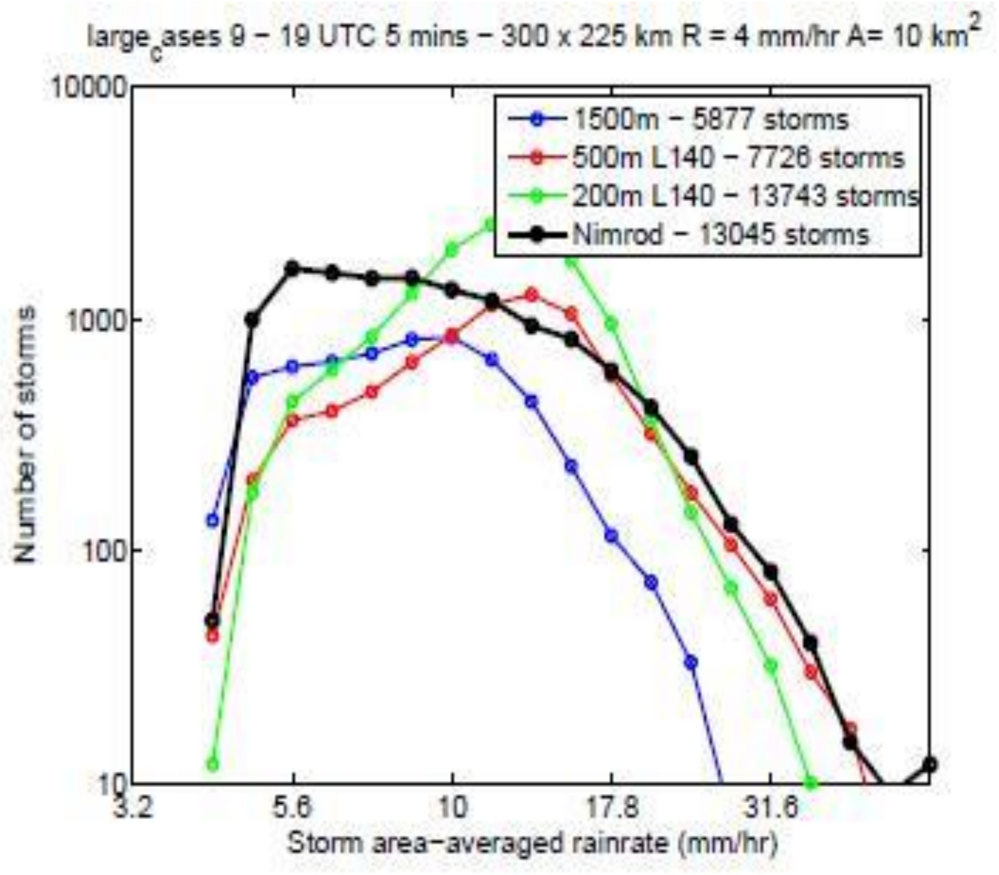


- Storms are identified using an area threshold of 10 km^2 and a rain rate threshold of 4 mm/hr.
- 1.5km model is expected to be poorly resolved for the small storms
- Mixing length is a key parameter controlling these distributions

Hanley et al 2015

Rain rate distributions

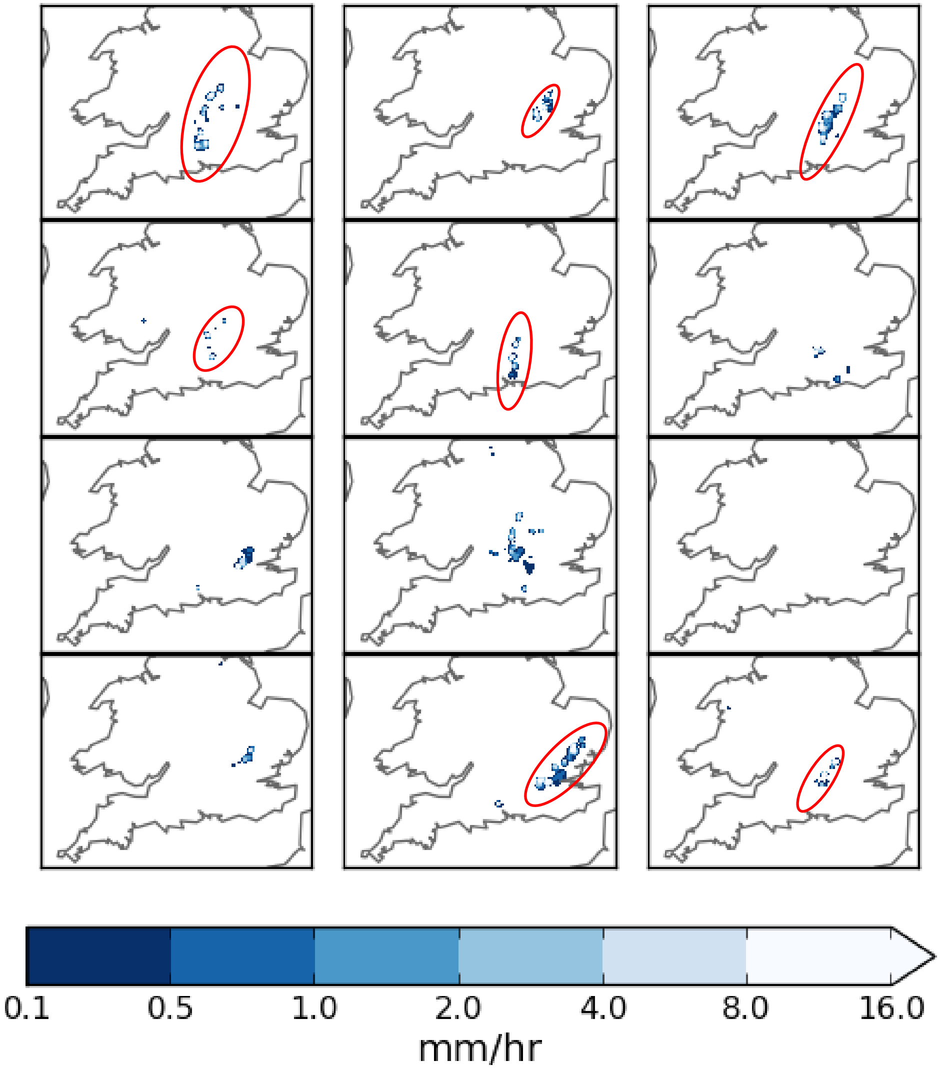
Average over strong cases



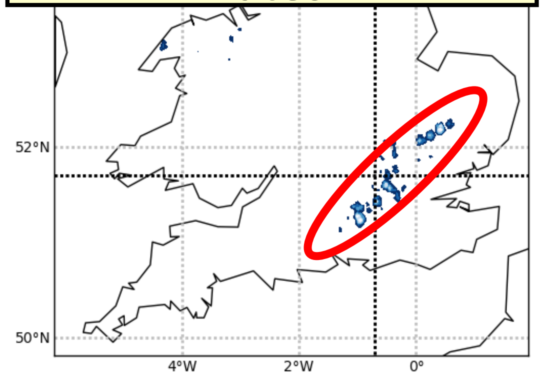
- UKV struggles to get the largest rain rates
- Improves for stronger cases at higher resolutions
- In general, model cells are not variable enough

Use of Ensembles

Ensemble members

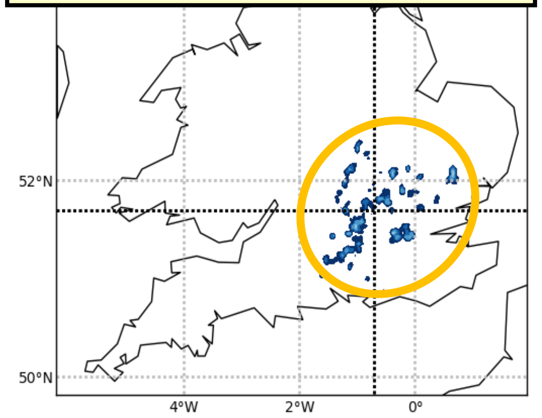


Radar derived rain rates



Spatially aligned cells

Ensemble mean



Scattered showers

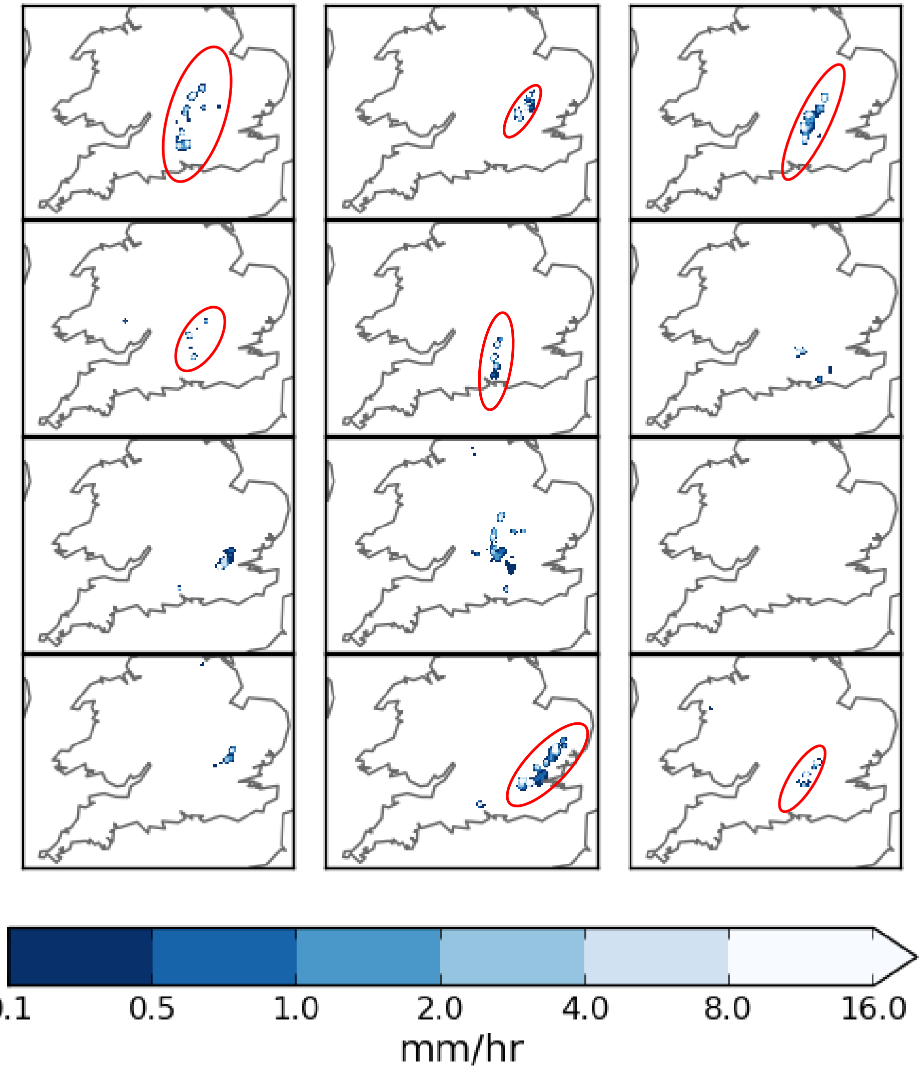
Ensmeble mean not representative

Spatial uncertainty also an issue in forecast verification

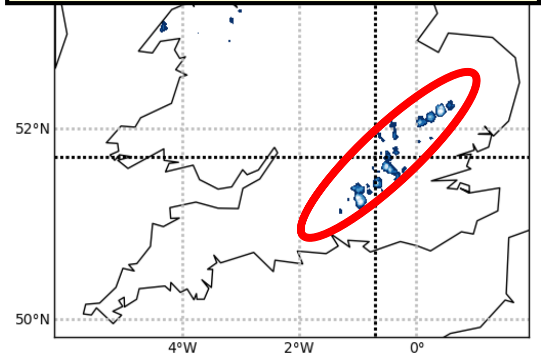
Dey et al 2016

Use of Ensembles

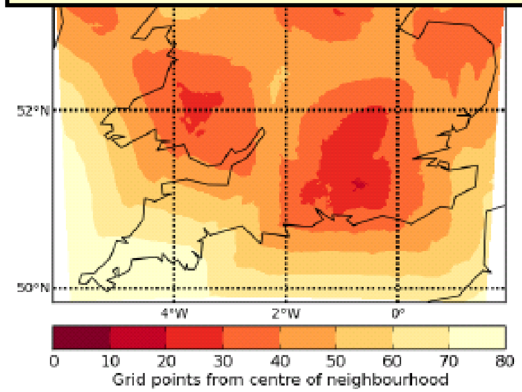
Ensemble members



Radar derived rain rates



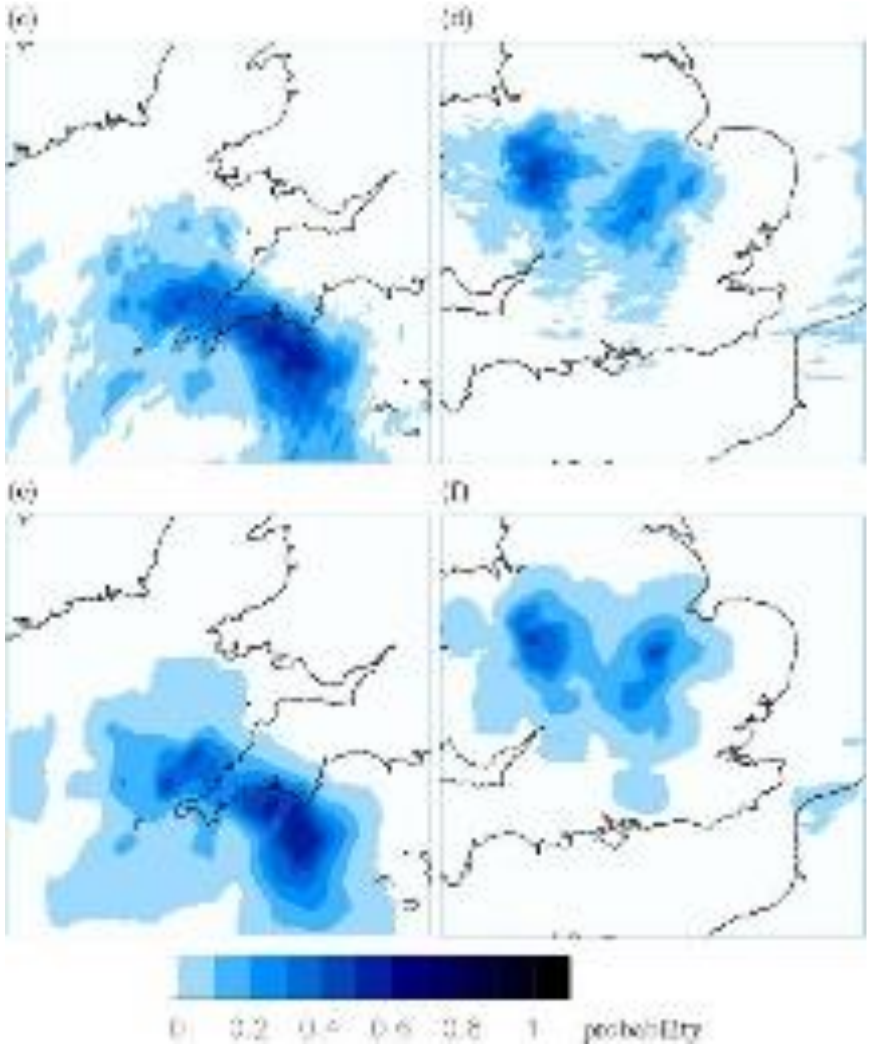
Ensemble Agreement Scales



- Agreement scale asks what is the least amount of averaging needed for 2 members (or a forecast and radar data) to agree
- Mean then measures the spatial uncertainty
- MOGREPS-UK has good spread-skill by this measure though where it is confident about the location of precipitation, it can be over-confident

Presentation of Outputs

Probability of hourly accumulation > 4 mm



Coverack floods, MCS, 18/07/17

Kent floods, 05/08/17

Large ensembles of 144 members

Small ensembles of 12 members with smoothing based on the agreement scale

Flack et al 2021

Conclusions

- Parameterized convection focuses on feedbacks to large-scale flow
  - Typically too much light rainfall, and not enough heavy
  - Diurnal cycle not reliably well captured
  - Difficulties with large-scale, low-frequency organized structures like MJO

- It is blamed for many model issues but it has and continues to be improved

- Convection permitting models are very valuable, especially in non-equilibrium conditions if the small-scale initiation processes can be resolved
- But they are not convection resolving – be cautious about the details of storms
- Important to think about predictability, but ensembles at these scales produce vast data that needs to be summarised and communicated

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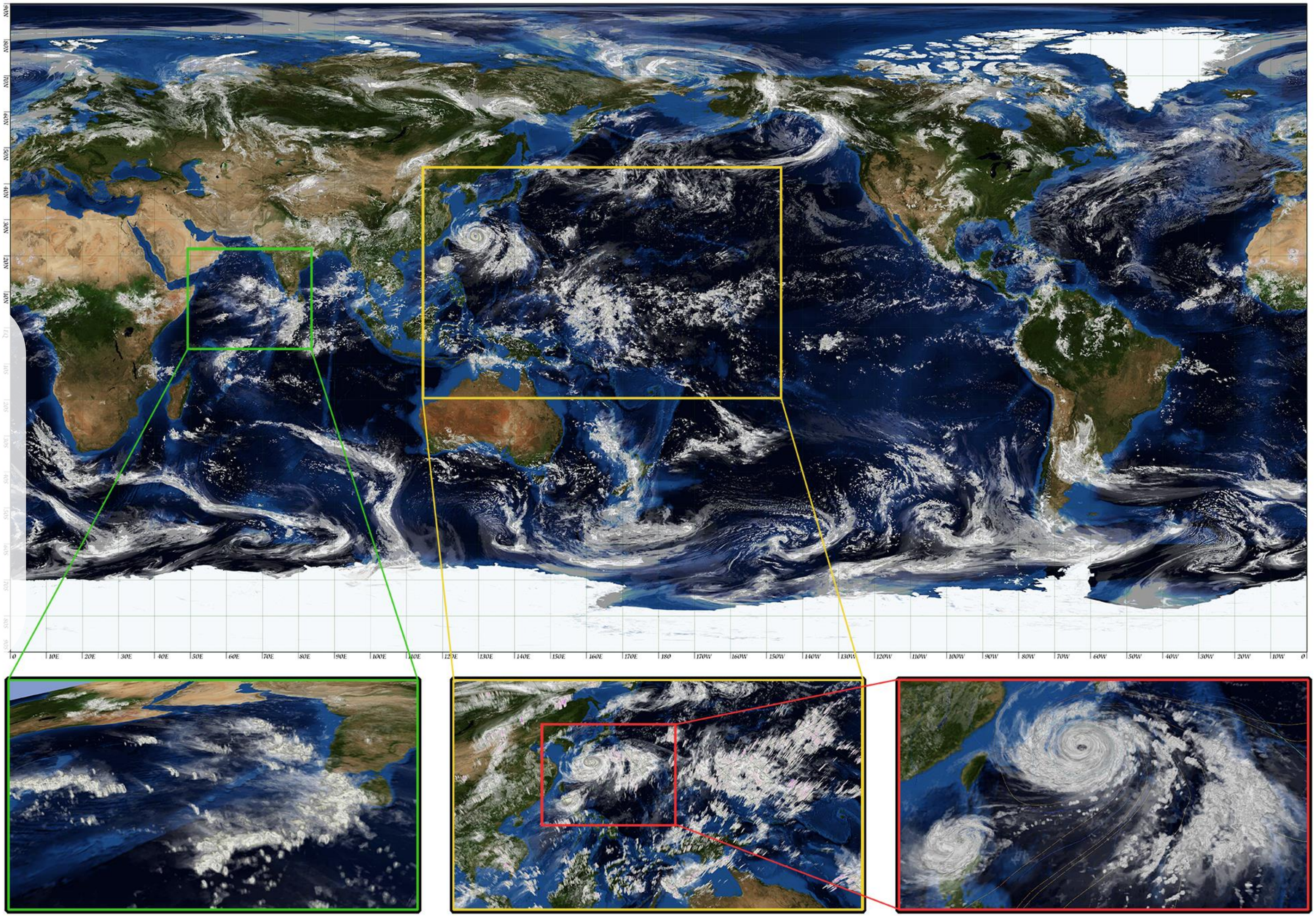
Possible extras, if useful for questions

- 48h global simulation
- 870m grid spacing
- 4.5h real time for 1h simulation
- 320TB data needing days to process



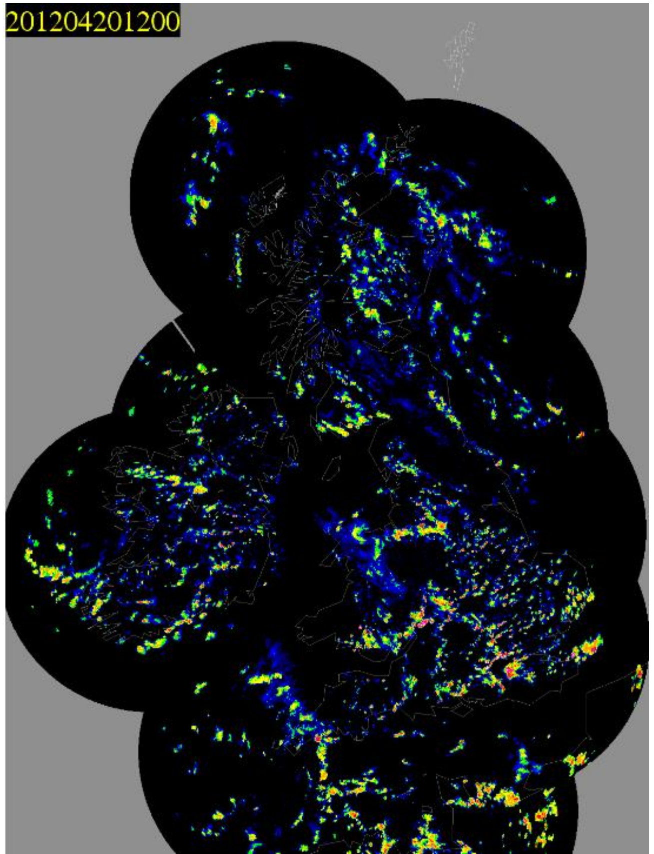
Miyamoto et al, 2013

Troubles in the Grey Zone

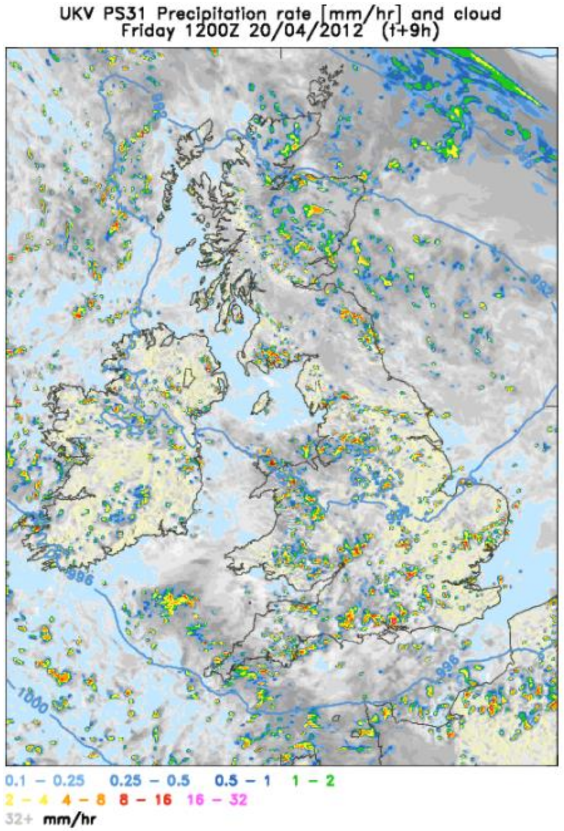
Standard mass-flux convection scheme designed to represent full spectrum of updrafts under an equilibrium

i.e. tries to parameterise the updrafts that should be resolvable, assuming many updrafts per grid-box!

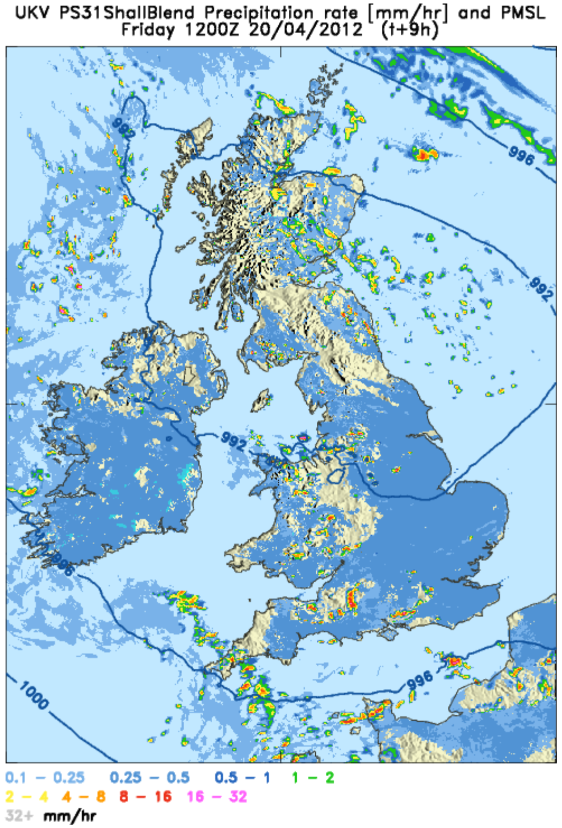
Radar



1.5 km explicit



1.5 km parameterised



Example from
Adrian Lock