Sub-grid cloud parametrization issues in Met Office Unified Model

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Workshop on “Parametrization of clouds and precipitation across model resolutions”, ECMWF, Reading, November 2012

Met Office

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Operational Models

North Atlantic and Europe

12 km

Uses a convection scheme

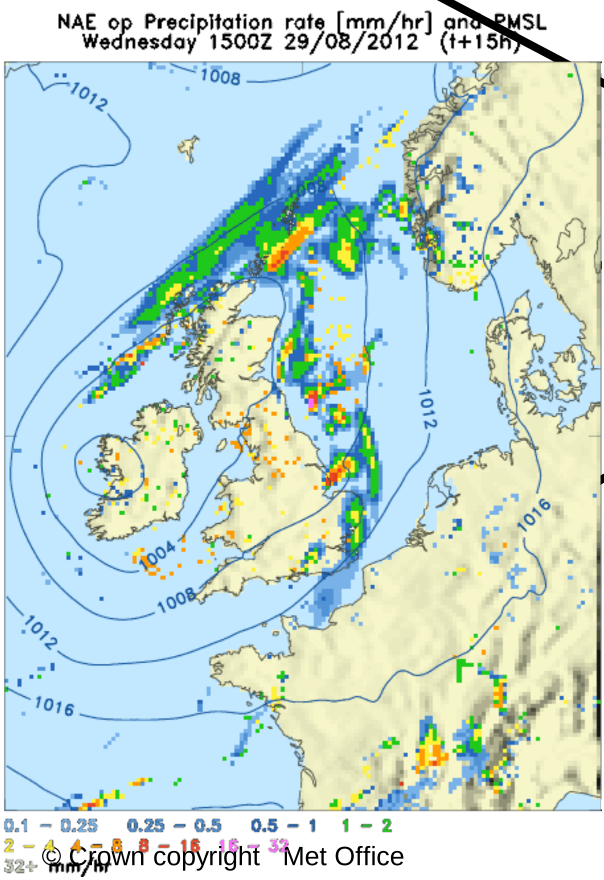
UK4 Model (4 km)

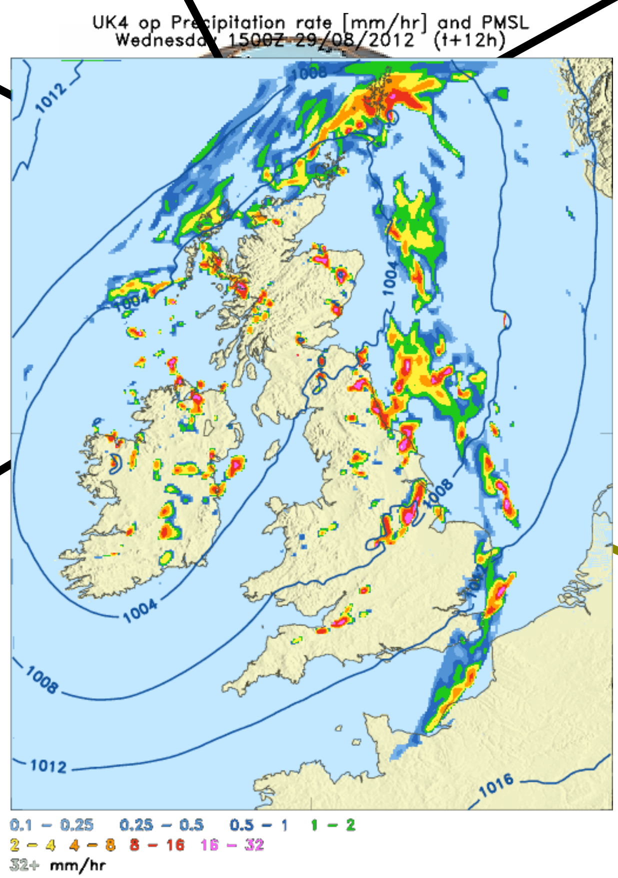
Convection scheme has CAPE-dependent CAPE-closure time-scale.

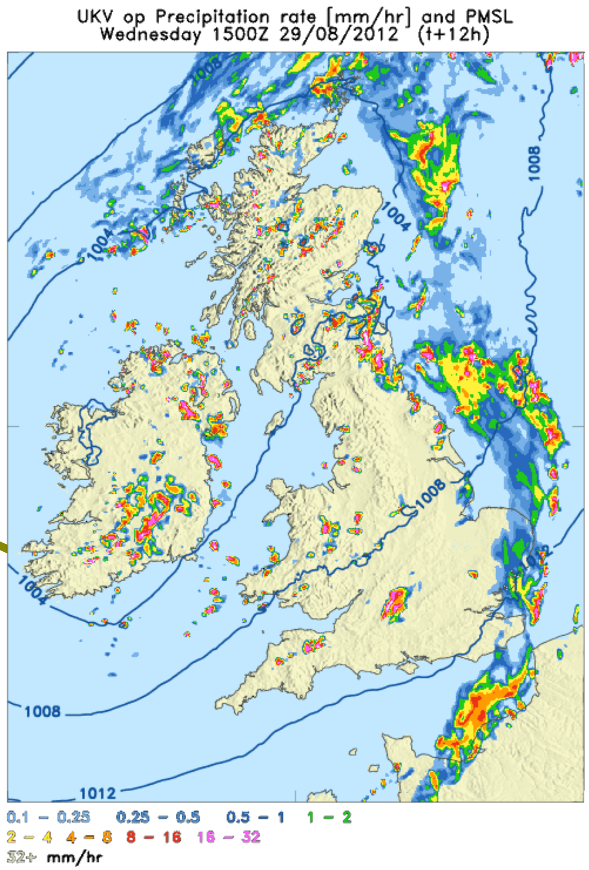
UK1.5 Model

1.5 km

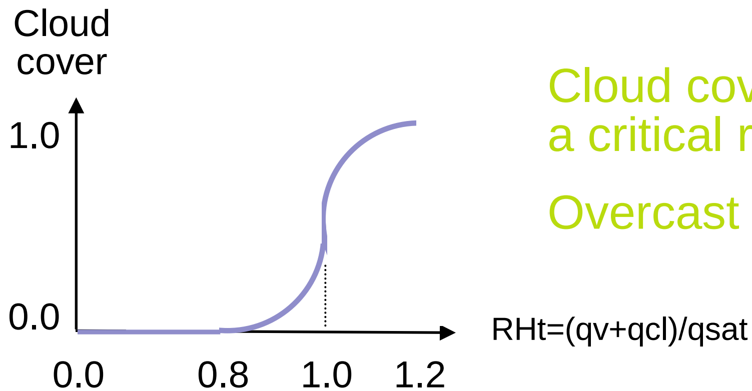
No convection scheme.







A simple cloud scheme

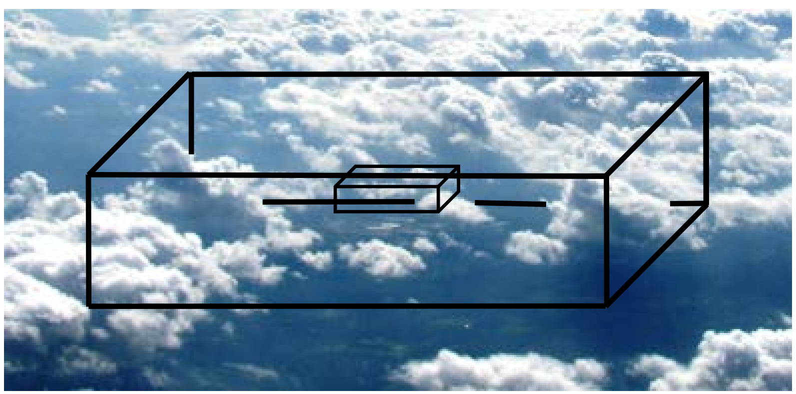


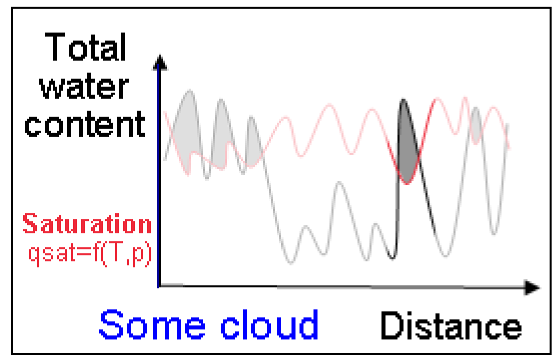
Cloud cover first rises above 0 when RH exceeds a critical relative humidity (RHcrit).

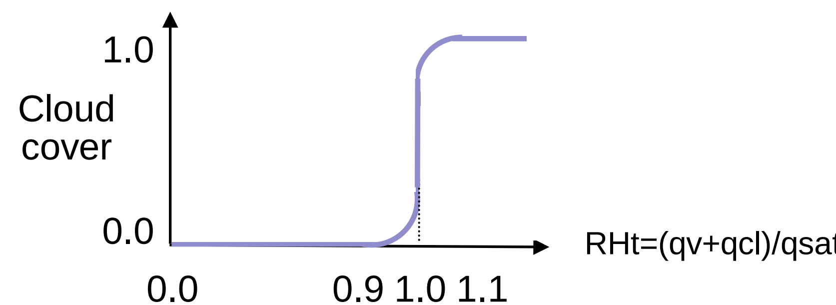
Overcast conditions reached when RH=2.0-RHcrit.

An example where RHcrit=0.8

Now consider a smaller grid-box







An example where RHcrit=0.9

So expect RH crit to tend to 1.0 as grid-box gets smaller

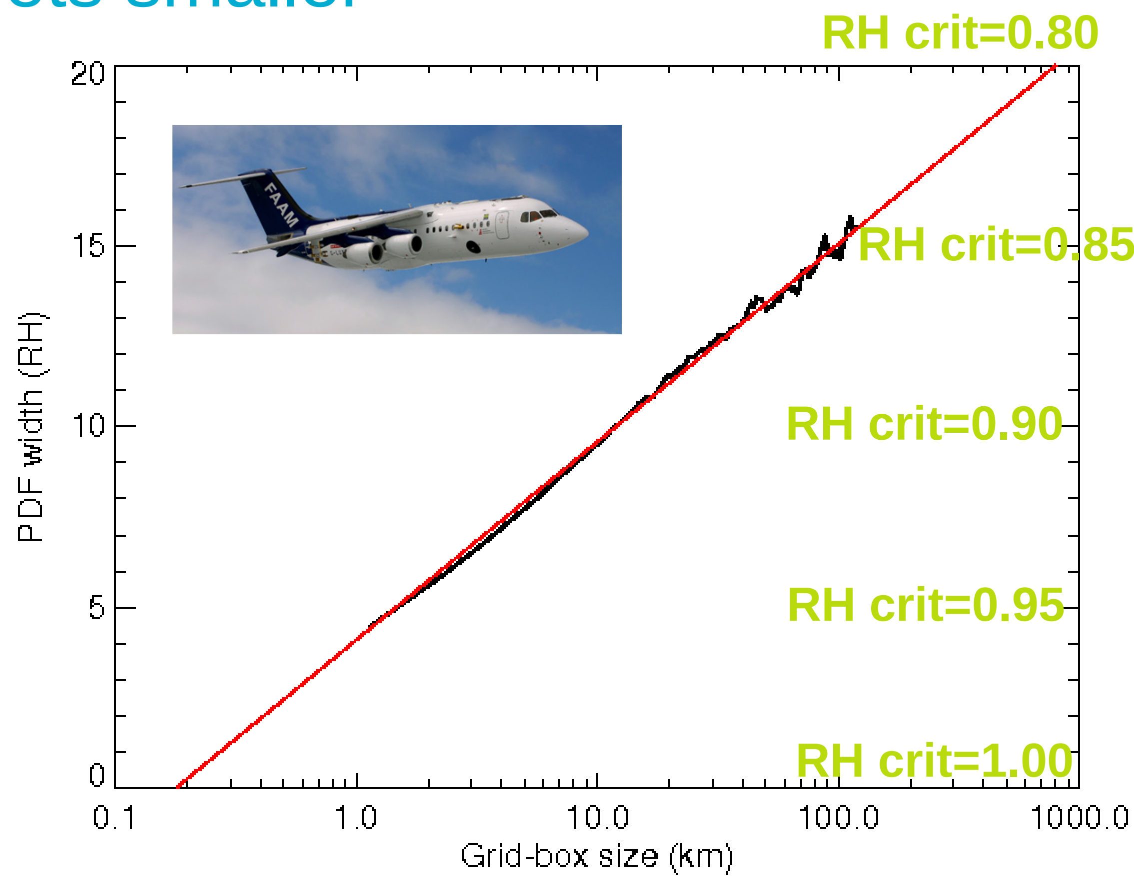
Use aircraft data from many flights in different synoptic conditions.

Consider flights legs of different lengths

Look at local variability and mean conditions and hence infer RH crit

Would be nice to look at sensitivity to changes in dz as well as dx.

Could we use data from tethered balloons?

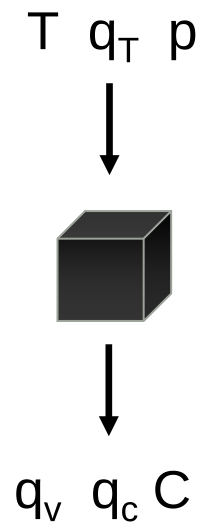


Extrapolation gives
RHcrit=0.95 at dx=1 km
RHcrit=1.00 at dx=180 m

Figure and analysis by Ian Boutle.

Smith (1990) cloud scheme

Currently, all operational limited area models still use the Smith (1990) cloud scheme.



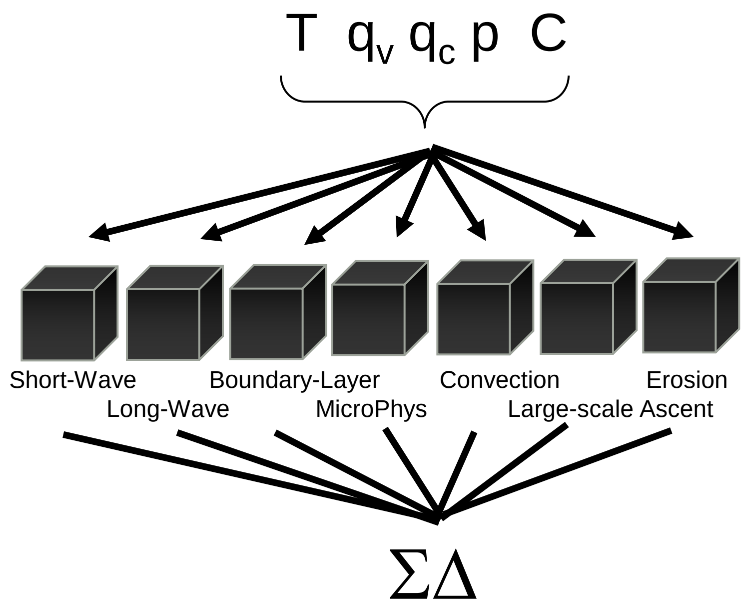
Then forget everything and start again next timestep

- However observations suggest that the same thermodynamic state (T,q,p) can be associated with different cloud cover and condensate amounts.
- So need to have a system where the clouds at a given point is the result of lots of different processes acting on the cloud and modifying it through-out its lifetime.
- Allows same thermodynamic state to have different cloud in it, depending on what has happened before.

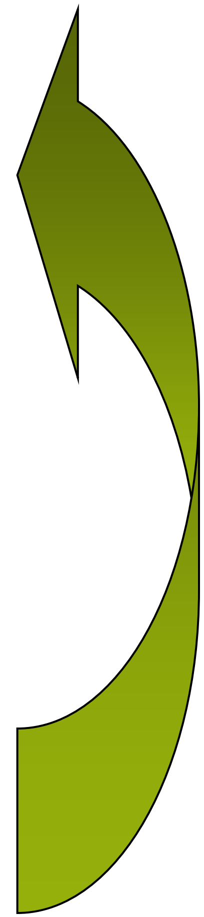
"PC2" cloud scheme

"**p**rognostic **c**loud, **p**rognostic **c**ondensate"

Wilson *et al.*(2008a)
doi:10.1002/qj.333
similar in concept to Tiedtke (1993) scheme.



Update the cloud fields then advect with the wind, ready for use next timestep.



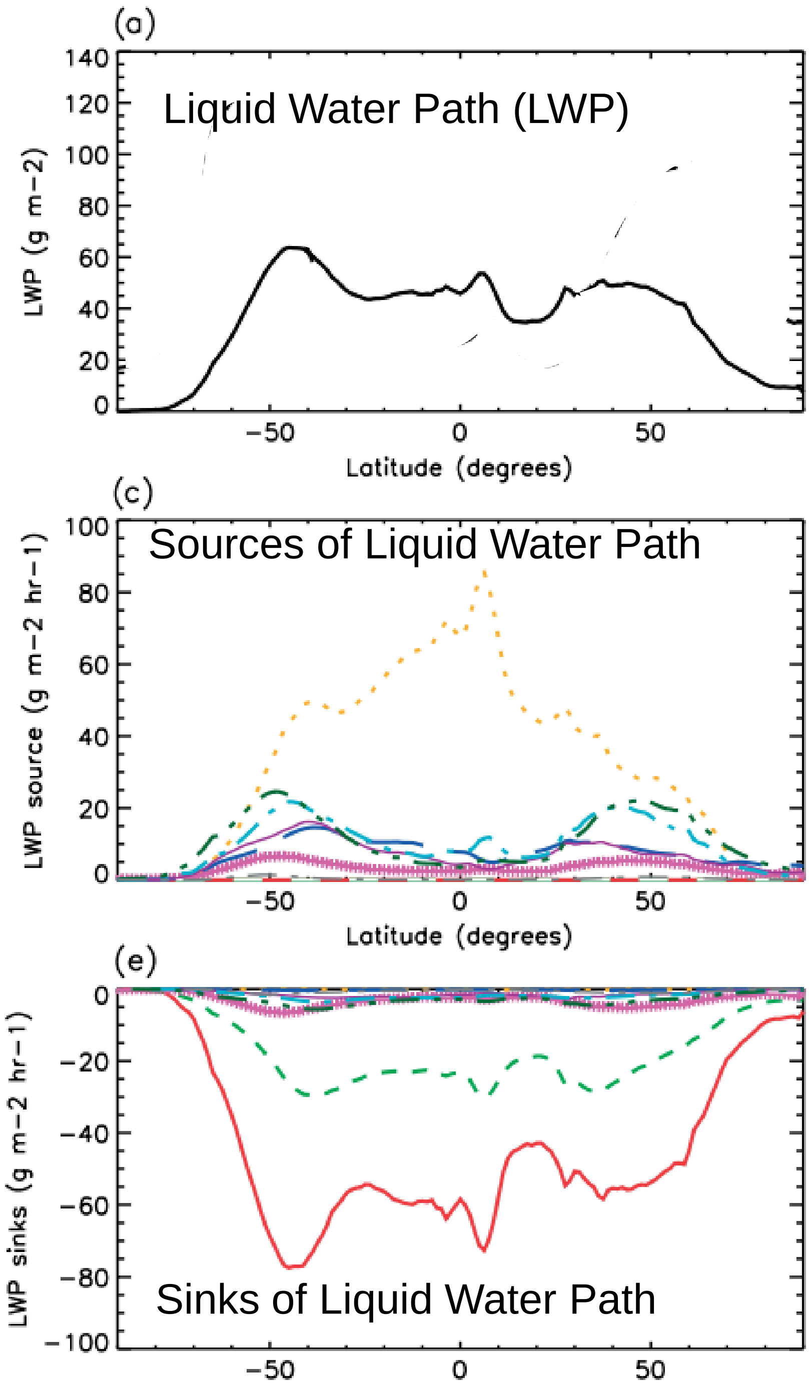
System has memory

PC2 cloud scheme is now used for:
- global deterministic NWP
- global EPS
- global climate-simulations (e.g. next IPCC).

What physical processes affect liquid water path in PC2?

Zonal-mean, annual-mean from 10-year simulation of present-day climate.

Microphysics
Convection
Erosion
Large-scale ascent
Initialization
Long-wave
Boundary-layer
Advection
Short-wave
Numerical checks



Morcrette (2012) DOI: 10.1002/asl.380

The "Convection scheme" is the dominant source of LWP in PC2.

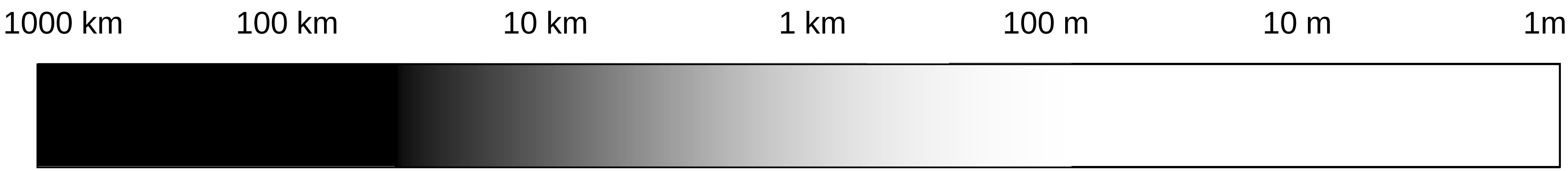
"Numerical checks" i.e. checking that
CF>0 if LWC>0
CF>0 of IWC>0
LWC+IWC>0 if CF>0

If this term is large then there is probably a bug!

Grey Zones

Black: process should be parametrized

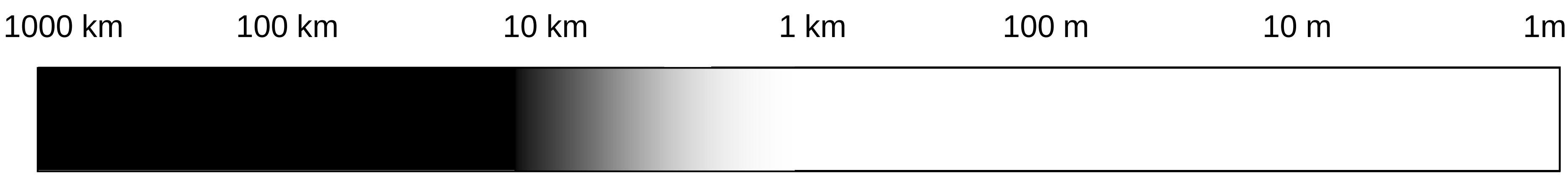
White: process should be done explicitly



Need cloud scheme to determine fractional cloud cover.

Cloud scheme grey zone

All-or-nothing. Each grid-box is either cloudy or clear.



Need convection scheme to represent stabilization of profile by sub-grid convective motions.

Convection scheme grey zone

Convective motions are resolved by the grid.

In order to get through the cloud grey zone, one must also get through the convection grey zone.

Given that “convection scheme” is main source of cloud in PC2: Can we use PC2 in a model without a convection scheme?

Yes we can, model will run.

But need to consider:

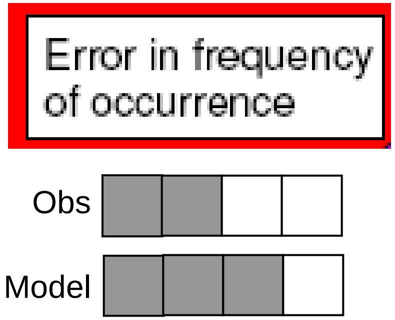
- Re-tuning cloud erosion rate
- RH crit (can we use value derived from aircraft obs?)
- Missing process:
    - UK1.5 model also uses sub-grid turbulence scheme (in horizontal) which is not used in coarser-resolution models
    - This diffuses T and q,
    - But does not currently consider the direct impact on LWC and CF.

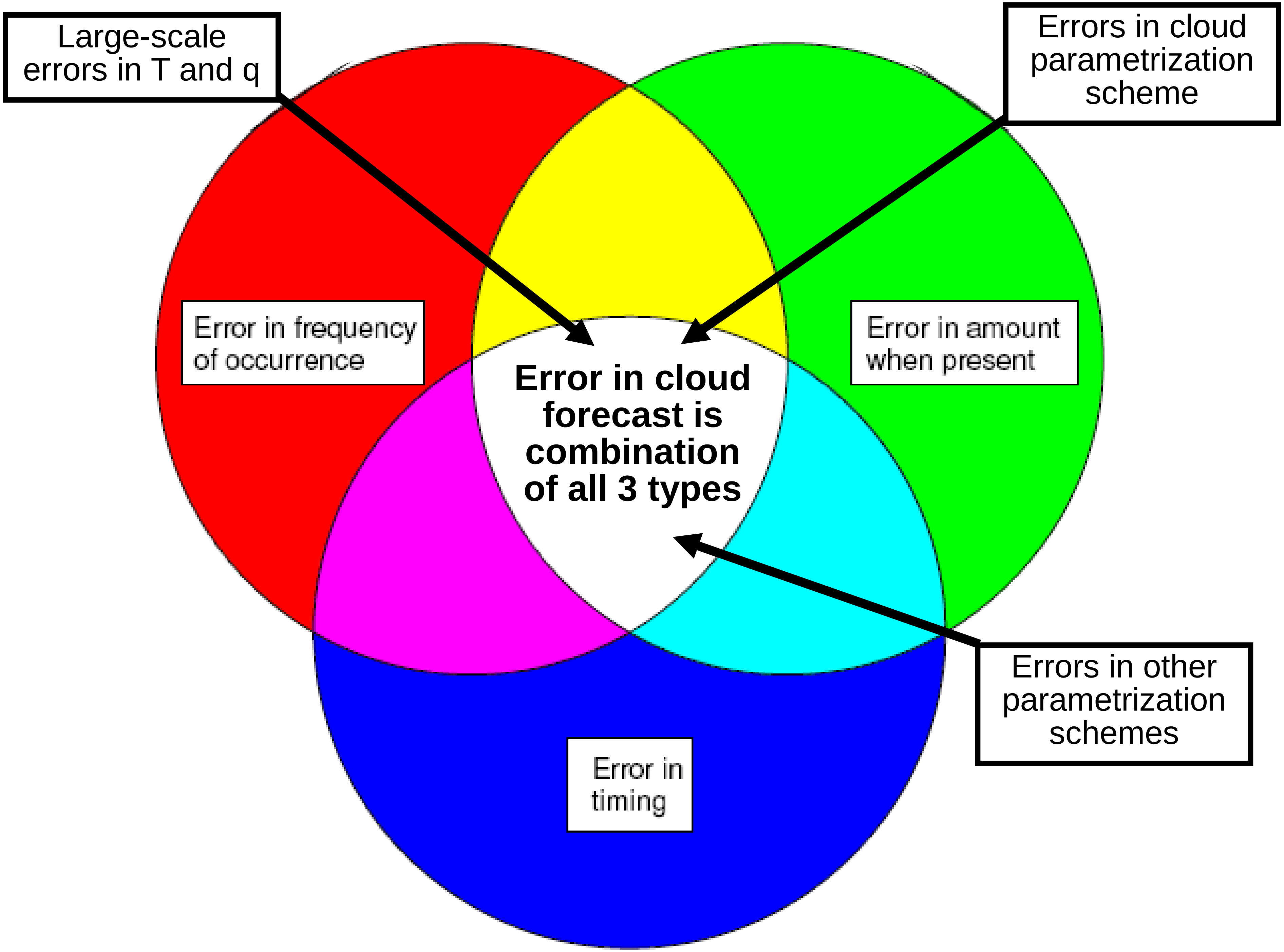
This is all work in progress…

Evaluation of cloud forecasts

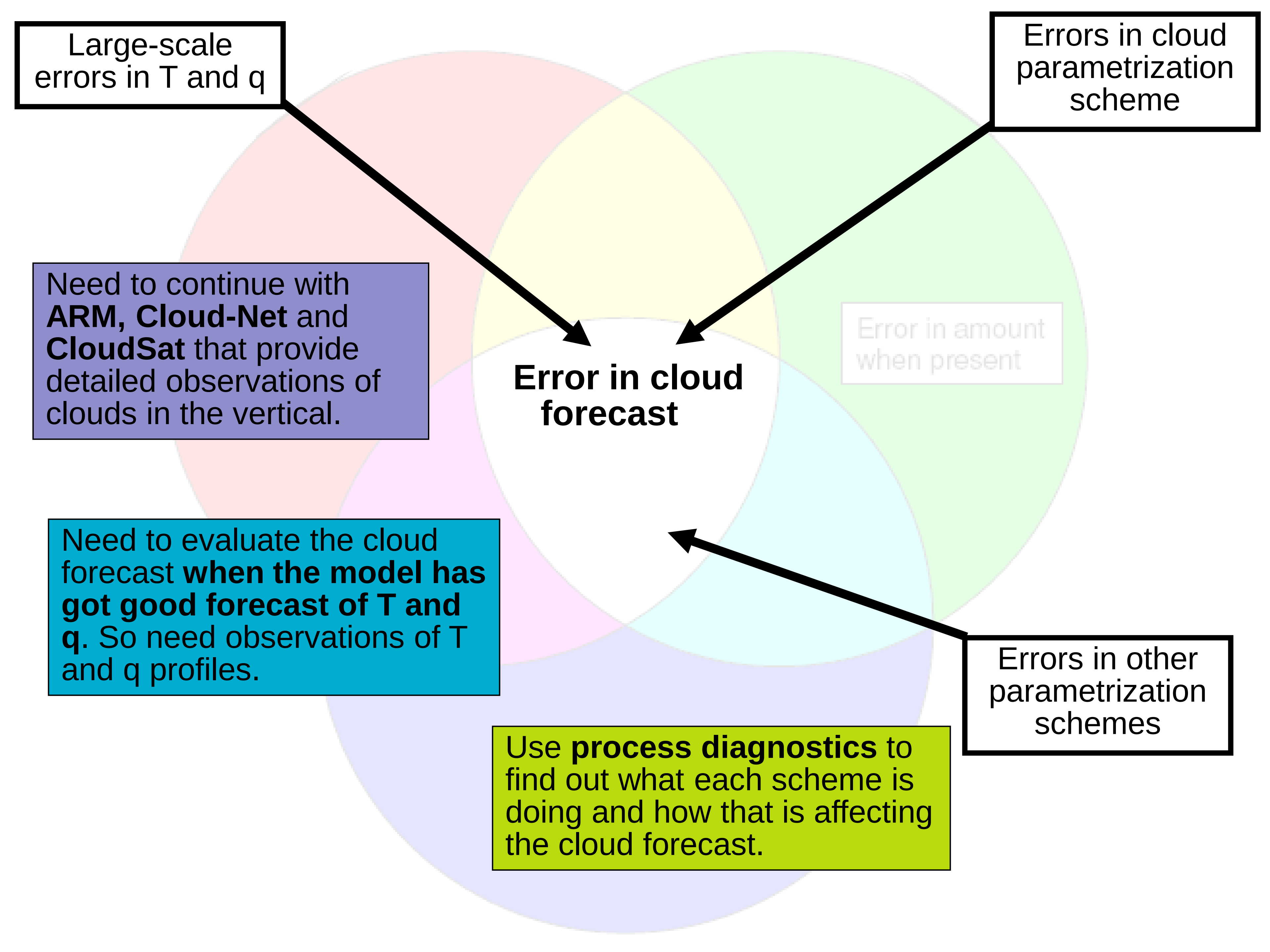
- Imagine you have 2 sets of cloud forecasts
- **Which one is "better" ?**
- "Better" one has smaller errors.
- But there are different types of cloud errors…

Cloud errors can be:





Large-scale errors in T and q
Errors in cloud parametrization scheme
Error in frequency of occurrence
Error in amount when present
Error in cloud forecast is combination of all 3 types
Errors in other parametrization schemes
Error in timing


Large-scale errors in T and q
Errors in cloud parametrization scheme
Error in amount when present
Need to continue with **ARM, Cloud-Net** and **CloudSat** that provide detailed observations of clouds in the vertical.
Error in cloud forecast
Need to evaluate the cloud forecast **when the model has got good forecast of T and q**. So need observations of T and q profiles.
Errors in other parametrization schemes
Use **process diagnostics** to find out what each scheme is doing and how that is affecting the cloud forecast.

What do we really want from a cloud scheme?

Climate

• Average impact of cloud

• Radiative impact of clouds depends on FOO, AWP, LWC & IWC (can be non-linear).

• Willing to accept some error in average cloud properties if it makes climatological radiative balance better.

• Do not really care about timing.

Weather Forecasting

• Correct FOO

• Correct AWP

• Timing is crucial

• Not too worried if radiative balance is out on long timescale.

But how do we score ourselves?

NWP index (global)

The global index is compiled from the following parameters:

- mean sea-level pressure
- 500 hPa height
- 850 hPa wind
- 250 hPa wind

Verified over the following areas:

- Northern Hemisphere
- Tropics
- Southern Hemisphere

At the following forecast ranges:

T+24 T+48 T+72 T+96 T+120

… nothing about cloud!

NWP index (UK)

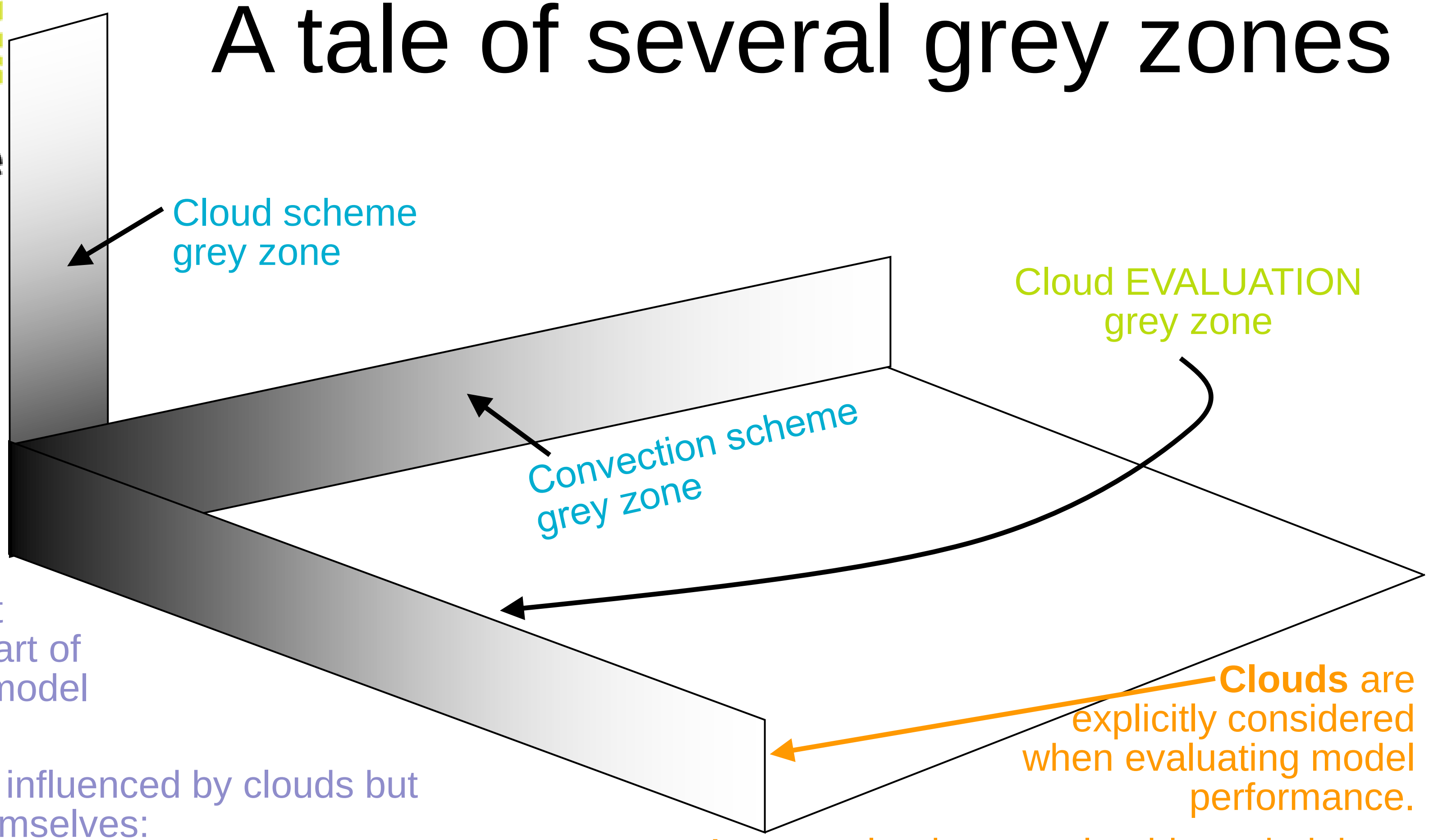
The UK index is compiled from the following parameters:

- Temperature (surface)
- Wind (surface)
- Rainfall (6 hour accumulation)
- Visibility
- Total Cloud Amount (TCA)
- Cloud base height (CBH)

Verified over the UK area

6-hourly out to T+48

A tale of several grey zones



Clouds do not form explicit part of evaluation of model performance.

Assess things influenced by clouds but not clouds themselves: [e.g. LS flow, LS T,q, T(surf), surf(precip)]

Assess: cloud cover, cloud-base-height.

- How does relative model performance differ simply by changing how 2 models are assessed.
- How does this depend on current compensating errors in: cloud cover, condensate amount, radiative properties, microphysics scheme and diurnal cycle of convection…

Sub-grid variability of condensate and impact on microphysical process rates

Met Office

Because of:

- sub-grid variability
- non-linearity

the TRUE grid-box mean value of the process rate IS NOT the value calculated from the grid-box mean properties.

Consider a microphysics process rate:

$$M = aq^b,$$

Following Morrison and Gettelman (2008) and Larson and Griffin (2012), the sub-grid variability in q can be written as a PDF (e.g. Gamma or log-normal) defined using the grid-box mean q and f, the fractional standard deviation of q.

e.g. gamma distribution:

$$P(q) = \frac{q^{\nu-1}\xi^{\nu}}{\Gamma(\nu)} \exp(-\xi q),$$

where $\nu = f^{-2}$, $\xi = \nu/\bar{q}$ and Γ is the Gamma function.

The **unbiased** process rate can then be calculated from the grid-box mean q and a correction factor, E:

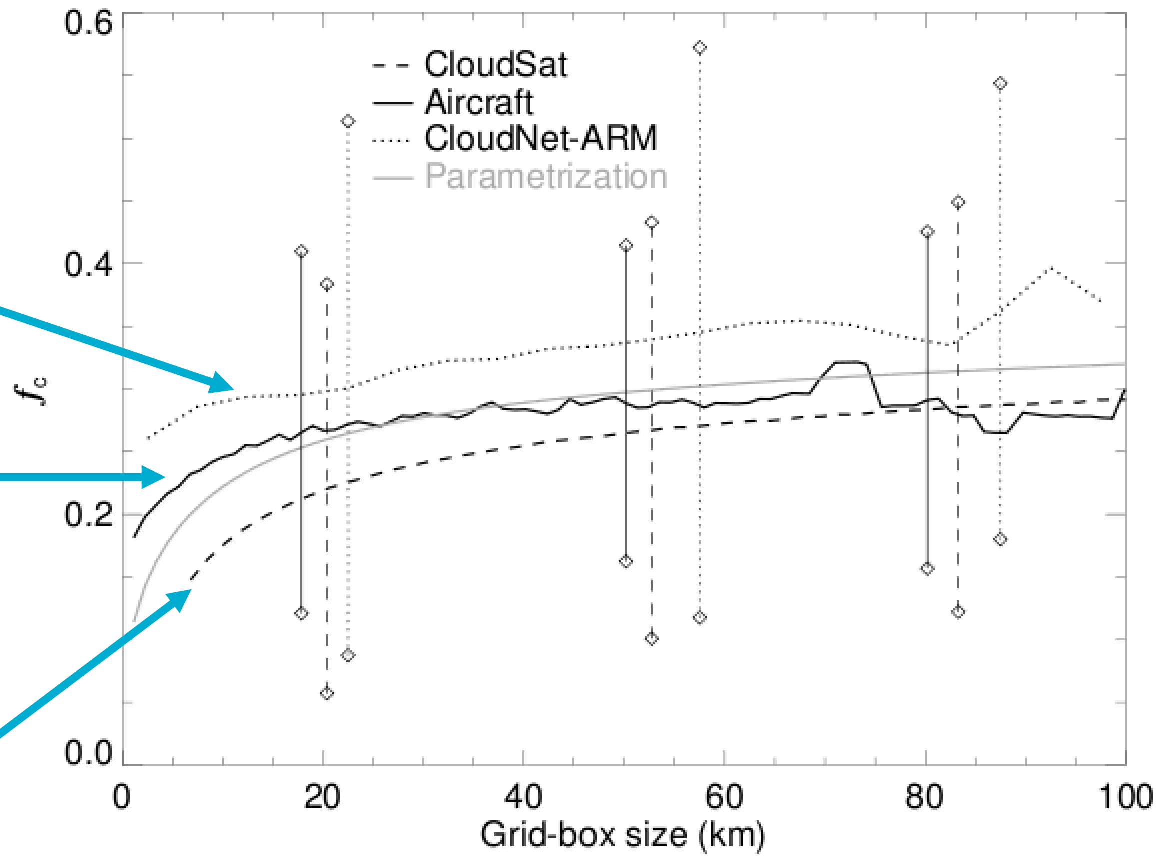
$$M = E(f, b) a\bar{q}^b,$$

where

$$E(f, b) = \frac{\Gamma(f^{-2} + b)}{\Gamma(f^{-2}) f^{-2b}},$$

All we now need is f, the fractional standard deviation of the liquid water content.

Fractional standard deviation of liquid water content



This f can also be used in the cloud-generator used by McICA for doing radiation. [Hill et al (2012) DOI: 10.1002/qj.1893]

Further details in: Boutle *et al.* (submitted to QJRMS) or from Ian Boutle.

Questions and discussion