Future directions for parametrization of cloud and precipitation microphysics…

Richard Forbes

(ECMWF)

ECMWF-JCSDA Workshop, 15-17 June 2010

Cloud and Precipitation Microphysics
A Complex System!

Time-height cross section of a front from the vertically pointing 94GHz radar at Chilbolton, UK

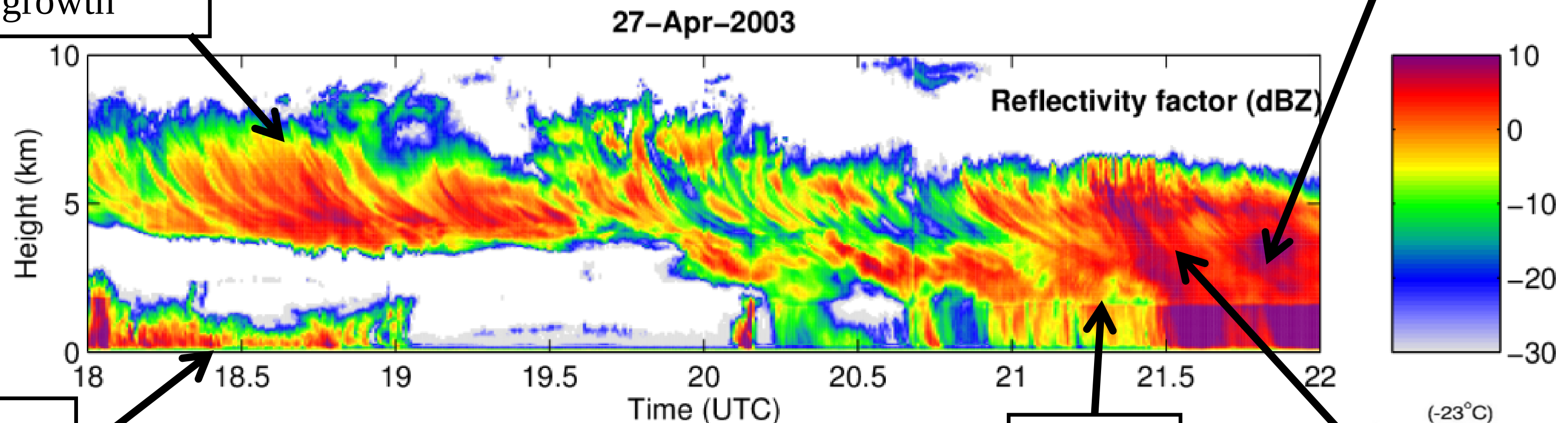


Image from Robin Hogan.
Data from RCRU RAL.

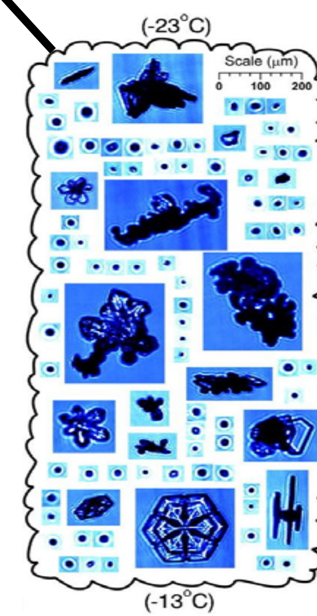
Ice Nucleation and diffusion growth

Aggregation

Warm phase

Melting

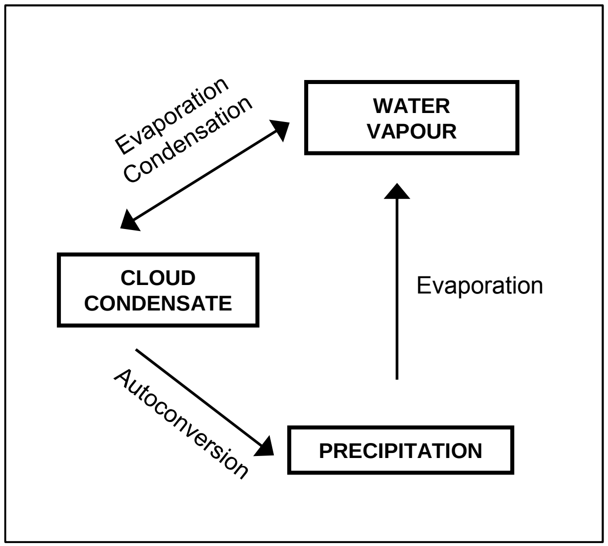
Cloud and precipitation microphysics
- Vapour, liquid, ice
- Different particle shapes and sizes
- Varying fall speeds
- Micro-scale physical processes
(condensation, evaporation, melting….)

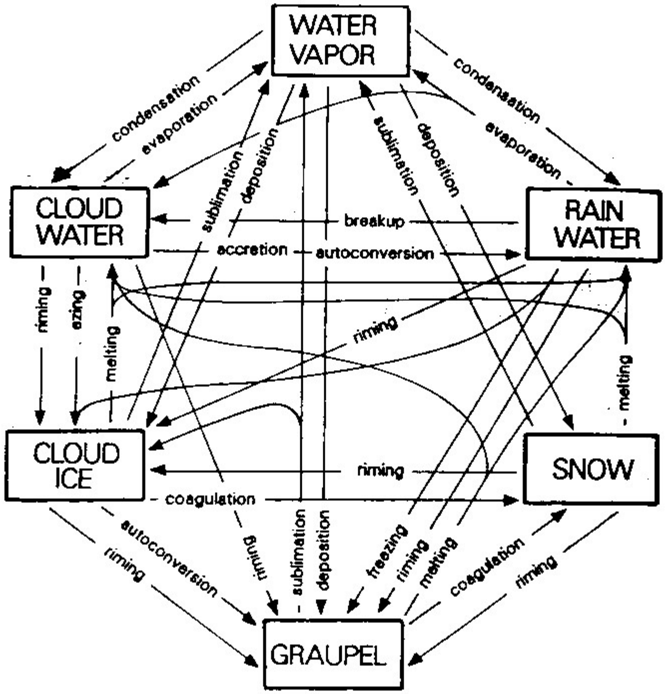


From Fleishauer et al (2002, JAS)

Cloud and Precipitation Microphysics
A Complex System!

We simplify…….





Cloud and Precipitation "Macrophysics" A Complex System!

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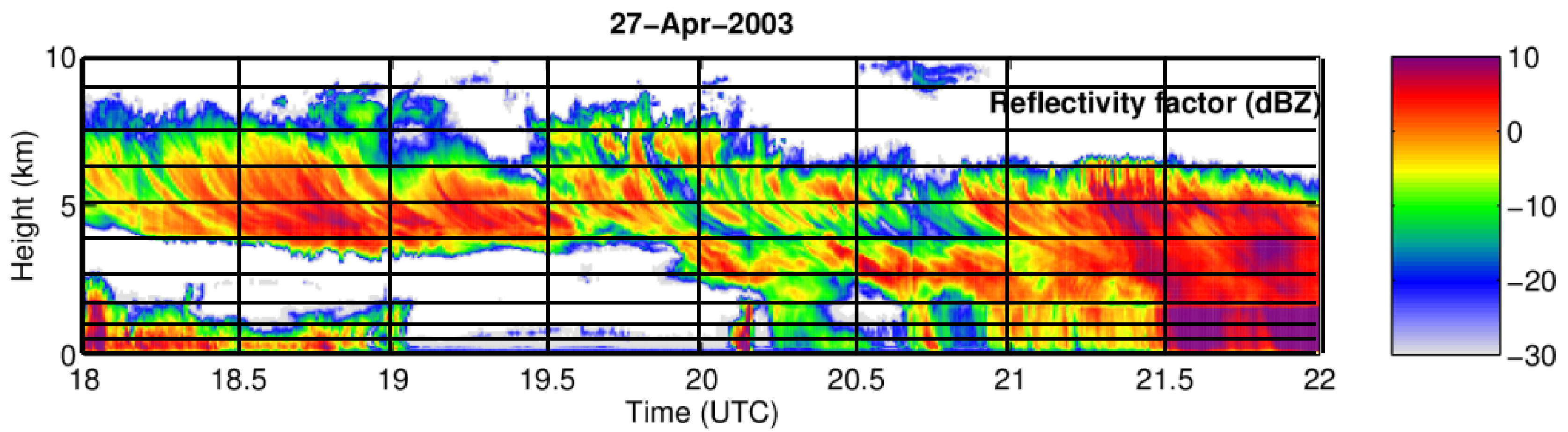


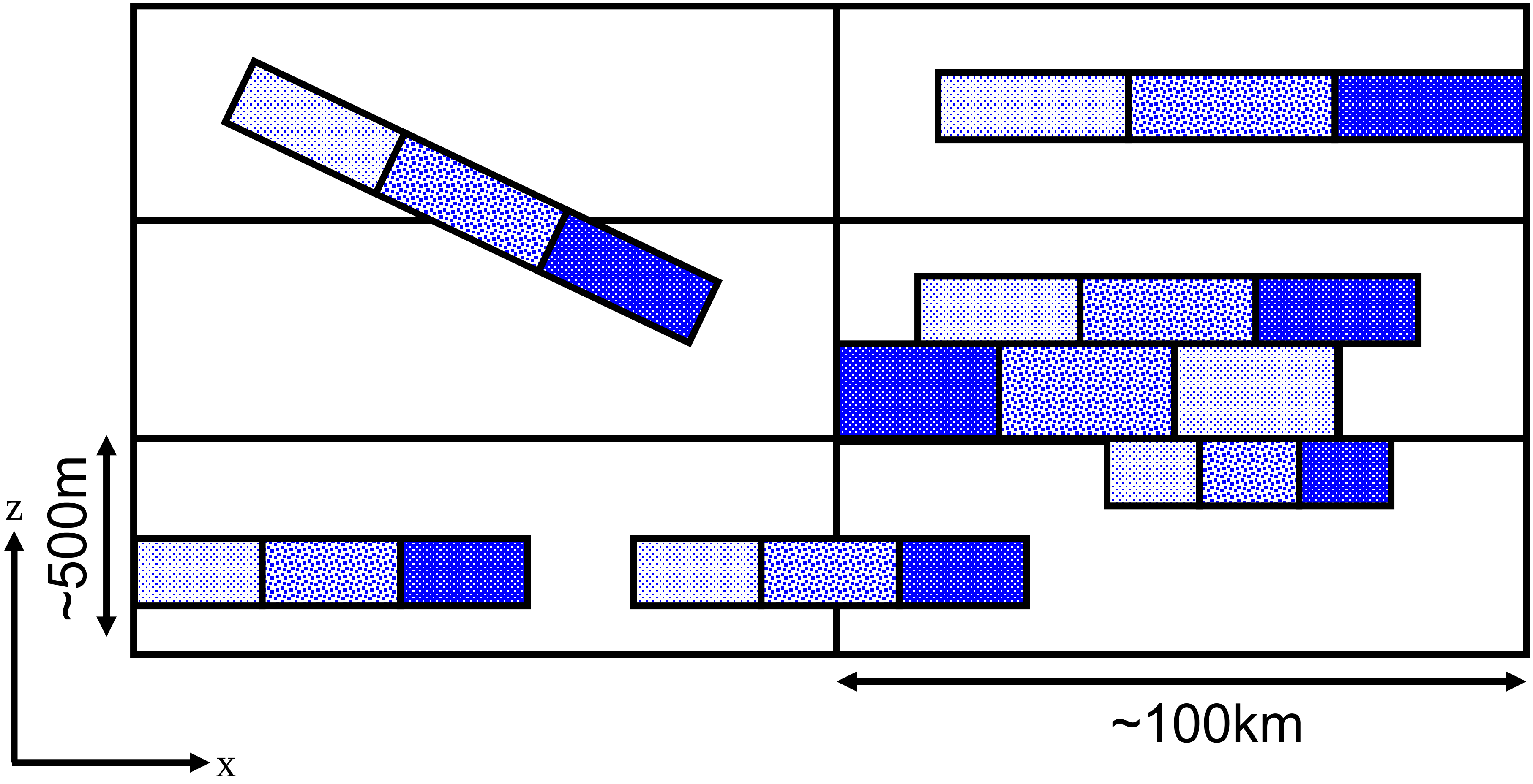
Image from Robin Hogan. Data from RCRU RAL.

Cloud and precipitation "macrophysics"

- Discretization on a grid
- Sub-gridscale heterogeneity
- Cloud fraction
- Variability of humidity/condensate

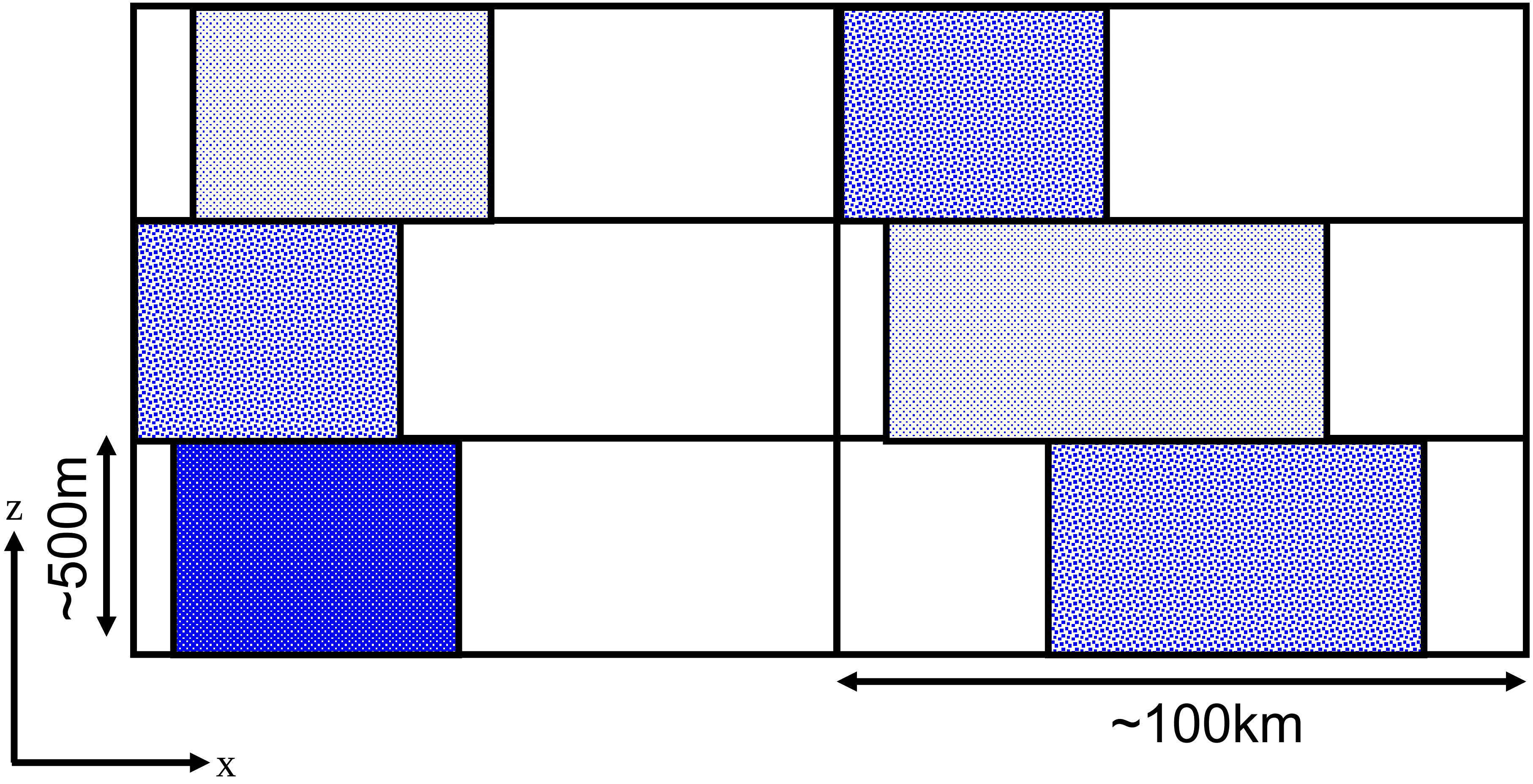
Cloud and Precipitation "Macrophysics" A Complex System!

- Sub-gridscale (horizontally and vertically)
- In-cloud heterogeneity
- Vertical overlap
- Just these issues can become very complex!!!



Cloud and Precipitation "Macrophysics" Simplified for the model…

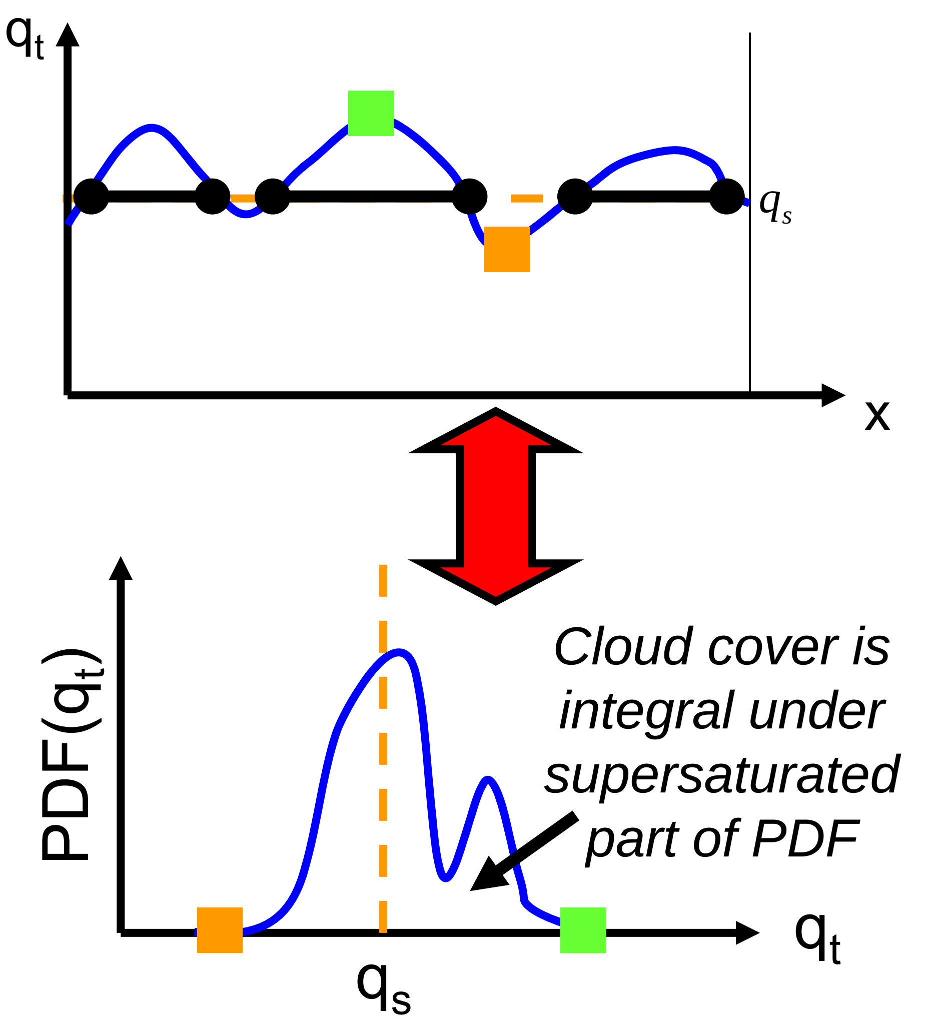
- Clouds often assumed to fill the layer in the vertical
- Horizontal cloud fraction (diagnostic or prognostic)
- Often homogeneous in-cloud condensate
- Vertical overlap assumptions (maximum/random/mixed)



Cloud and Precipitation "Macrophysics" Representing sub-grid heterogeneity

- Most sub-grid cloud schemes can be formulated in terms of a probability density function (PDF) for the total water q_t (and sometimes also temperature)

- More later…



Cloud and Precipitation Parametrization

- Wide range of cloud microphysics and precipitation parametrization schemes in use of different complexities.
- CRMs, convective-scale/regional/global NWP, climate
- “Micro-physical” and “Macro-physical” aspects
- Are there general trends for parametrization development in the future ?
- What are the drivers for change……?

Microphysics Parametrization Development Drivers for Change….

1. Improving the large-scale dynamics
   - latent/radiative heating
2. Improving forecasts of weather parameters
   - cloud, rain, snow
3. A desire to improve the physical basis of the parametrization
   - new observations, trust in model, right answer for the right reasons, internal consistency
4. Increasing model resolution
   - towards convective resolving - graupel, hail
5. Representing aerosol-cloud-radiative interactions
   - improving feedbacks, climate
6. Assimilation of cloud/precipitation affected data.
   - to extract the maximum info from observations

Future Directions for Cloud and Precipitation Parametrization Development

1. Improved physical basis
2. Improved use of observations
3. Increasingly unified underlying assumptions

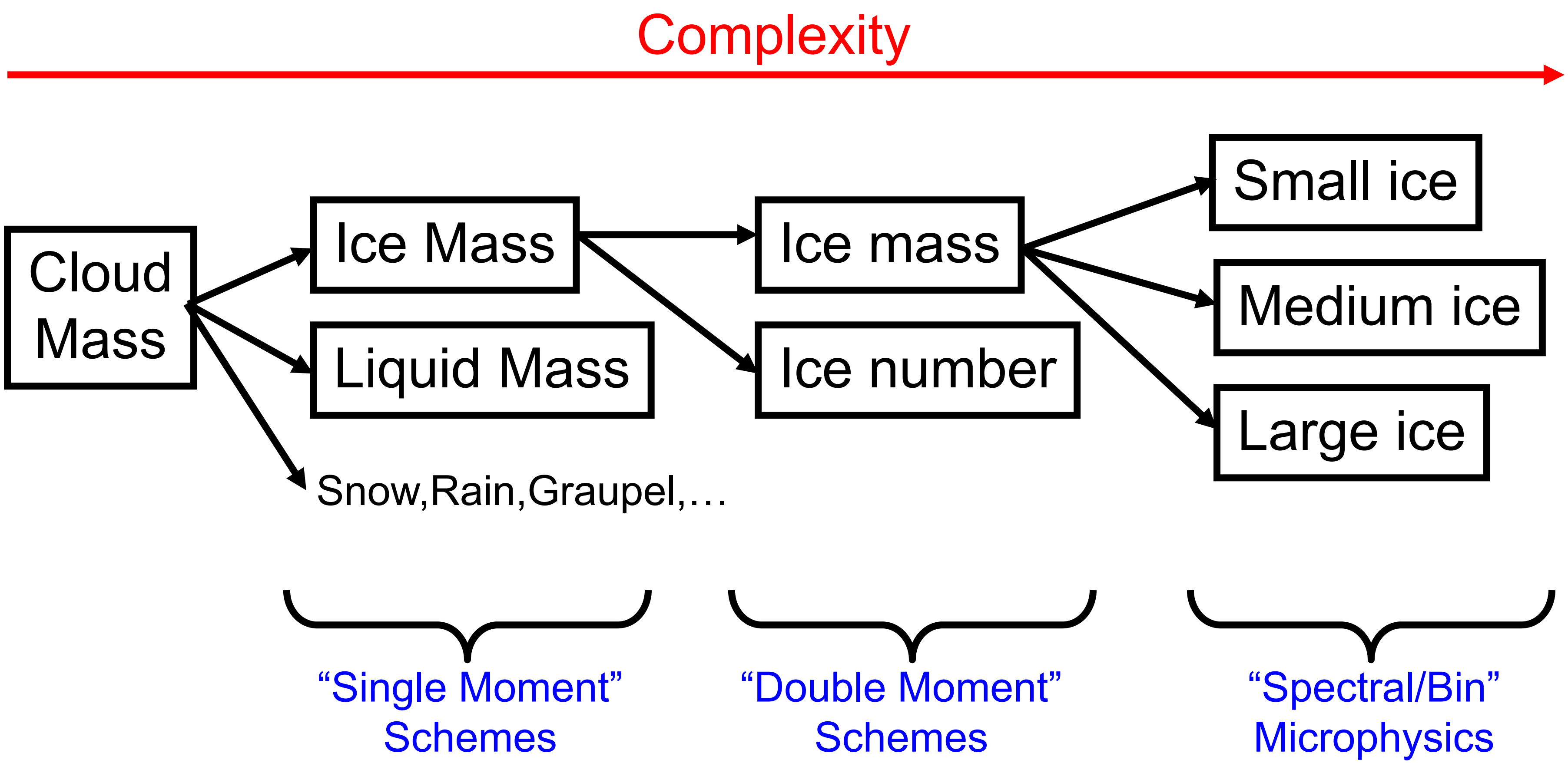
Future directions for cloud and precipitation parametrization development:

1. Improved physical basis
2. Improved use of observations
3. Unifying underlying assumptions

Future Directions of Cloud/Precip Param
Micro-scale physical processes

- Complexity of microphysical schemes will increase
  - Number of hydrometeor categories (diagnostic or prognostic?)
  - Representation of particle size spectrum (single moment, double moment, assumed shape of pdf, spectral bin)
  - Microphysical processes (particularly ice phase)
  - Representation of ice supersaturation
  - Representation of aerosol and cloud-aerosol interactions
  - Compromise between complexity, efficiency and knowledge

Cloud/Precip Parametrization
Complexity, categories, PSD moments

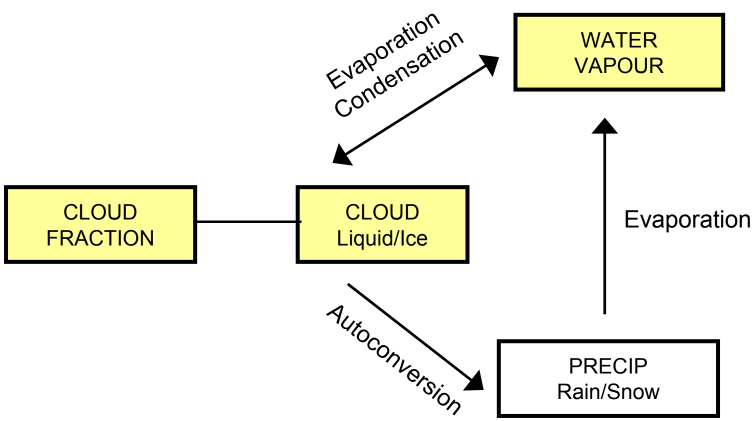


Most GCMs only have simple single-moment schemes

Cloud/Precip Parametrization
Recent ECMWF Developments

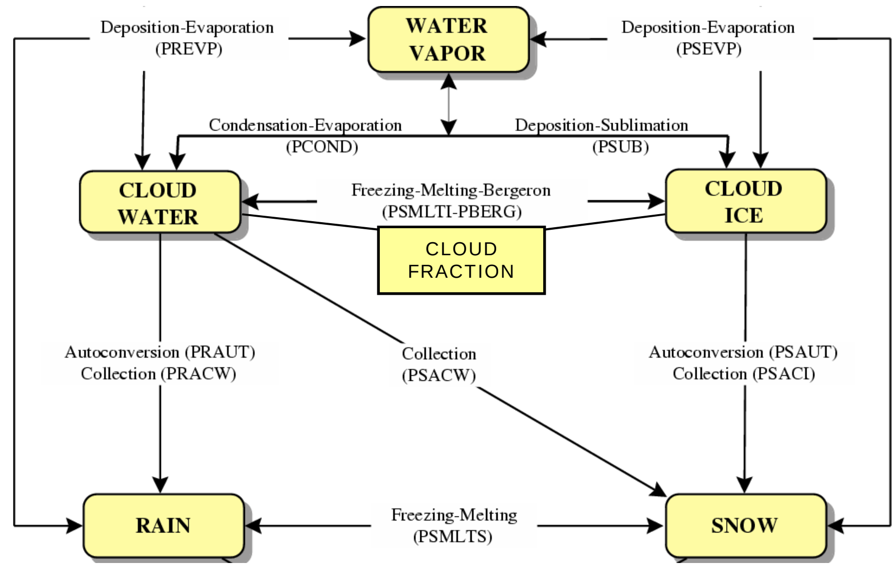
ECMWF-JCSDA Workshop Jun 2010

Current Cloud Scheme



- Prognostic condensate & cloud fraction
- Diagnostic liquid/ice split as a function of temperature between 0°C and -23°C
- Diagnostic representation of precipitation

New Cloud Scheme



- Prognostic liquid & ice & cloud fraction
- Additional degrees of freedom for mixed-phase
- Prognostic snow and rain (sediments/advects)
- Additional sources and sinks for new processes

Future Directions of Cloud/Precip Param
Micro-scale physical processes

- Complexity of microphysical schemes will increase
  - Number of hydrometeor categories
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  - Microphysical processes (particularly ice phase)
  - Representation of ice supersaturation
  - Representation of aerosol and cloud-aerosol interactions
  - Compromise between complexity, efficiency and knowledge

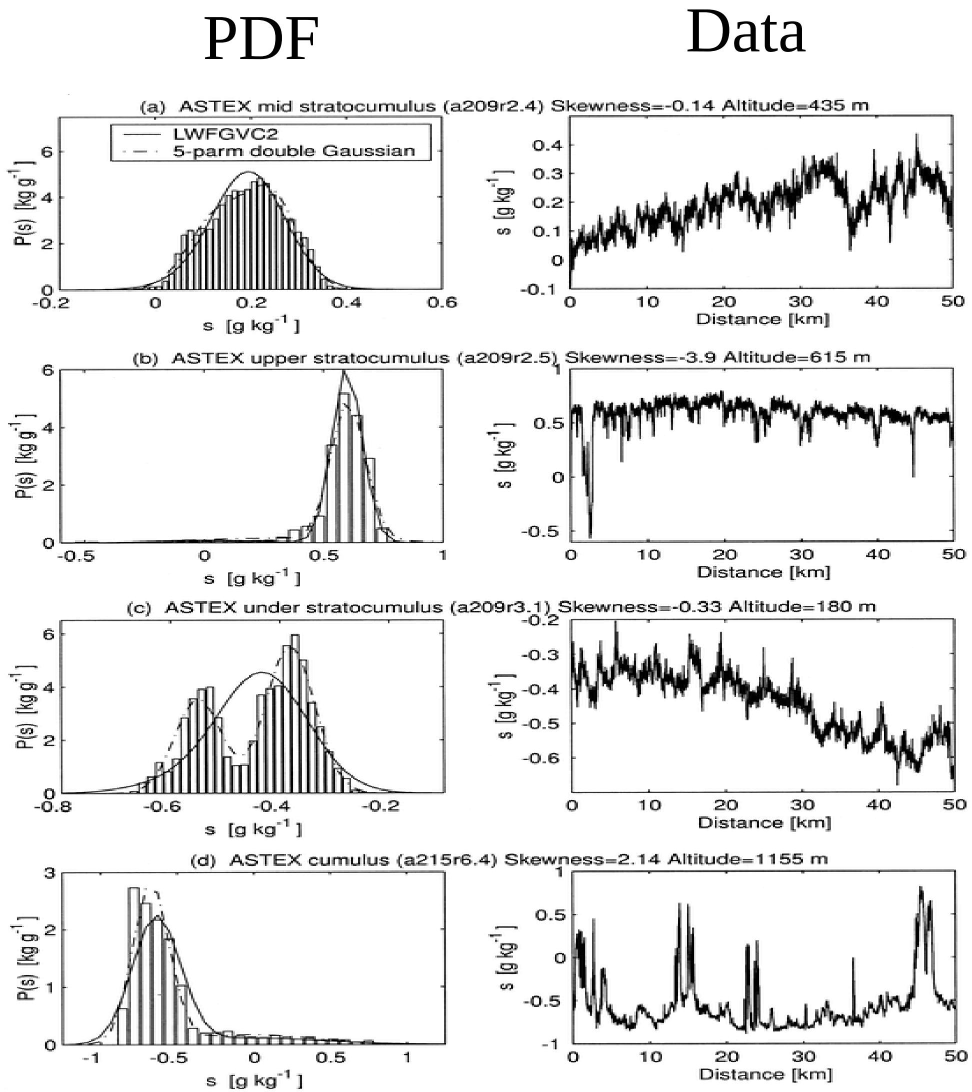
- Challenges for DA:
  - Making the most of new hydrometeor categories
  - Making use of particle size distribution information?
  - Non-linearities may increase!
  - Uncertainties (particularly ice phase)
  - Errors will still be there!

Future Directions of Cloud/Precip Param “Macro-scale”

- Complexity of sub-grid cloud schemes will increase
  - Improved physical representation of total water PDFs (humidity and condensate), sources and sinks.
  - Additional degrees of freedom for evolution of PDF? Diagnostic PDF versus prognostic
  - Mixed phase and ice phase cloud cover/overlap
  - Vertical overlap (generalised overlap)

Cloud and Precipitation "Macrophysics" Representing sub-grid heterogeneity

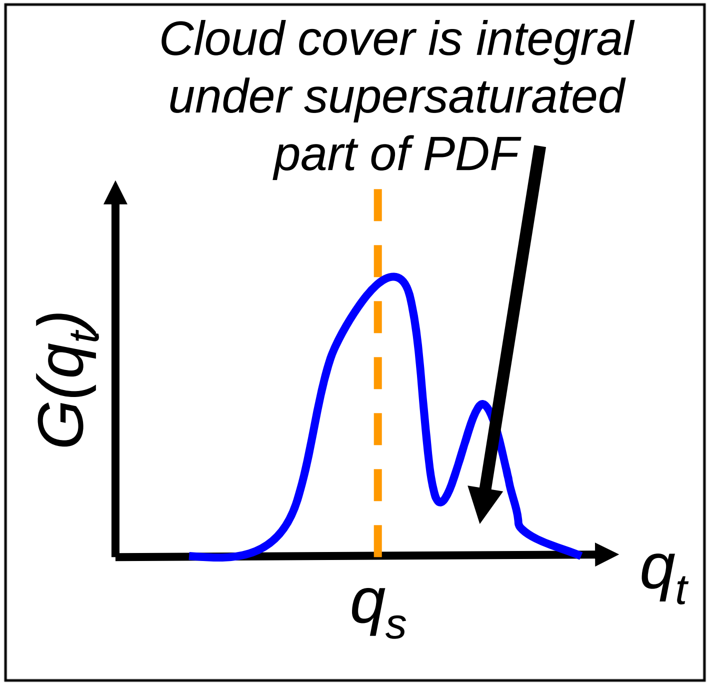
Observations show that the PDF of humidity and cloud condensate variability can be mostly approximated by uni- or bi-modal distributions, describable by a few parameters.



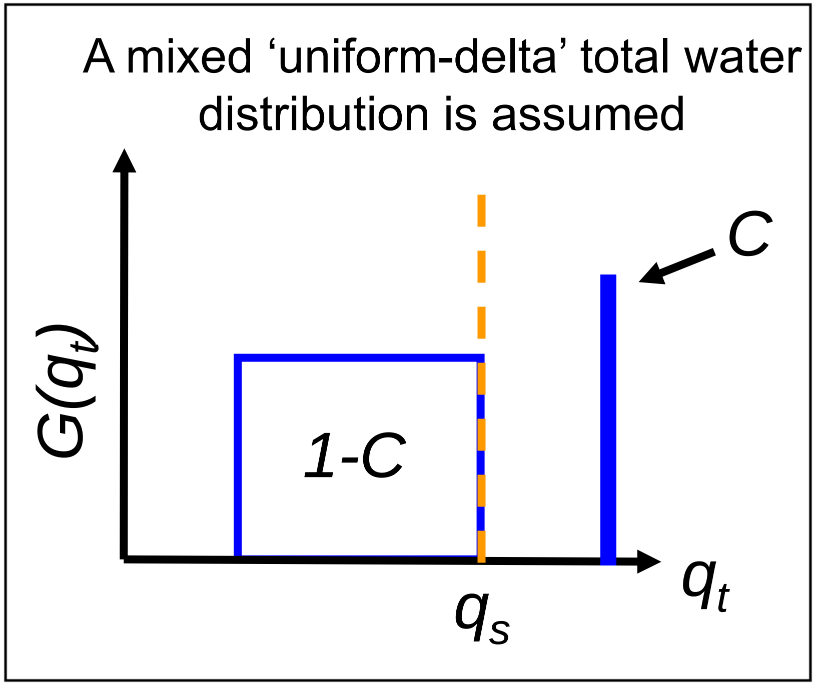
Larson et al. JAS 01/02

Cloud and Precipitation "Macrophysics" Representing sub-grid heterogeneity

In the real world



ECMWF cloud parametrization (Tiedtke 1993)

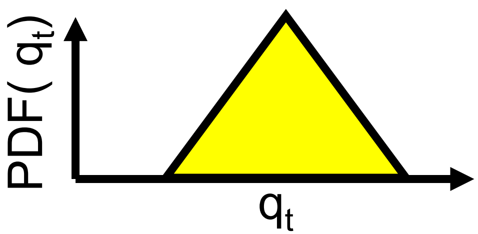


Other models use different underlying assumptions about sub-grid variability and differing degrees of freedom, e.g. the Smith (1990) diagnostic scheme, the Tompkins (2002) scheme with prognosed variance and skewness.

Cloud and Precipitation "Macrophysics" Representing sub-grid heterogeneity

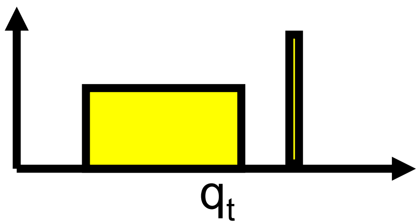
- Many functional forms for total water pdfs have been used.
- Diagnostic and prognostic formulations. More degrees of freedom require more information on sources and sinks.......

Comparing three schemes…



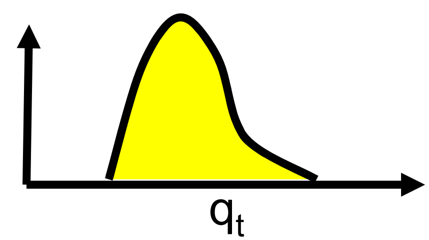
Triangular:

Smith QJRMS (90)



Uniform/Delta:

Tiedtke (91)



Beta:

Tompkins JAS (02)

- Symmetric
- Prognostic mean qt
- Diagnosed PDF width (variance)

- Prognostic mean humidity
- Prognostic condensate
- Prognostic cloud fraction
- Sources and sinks physical variables

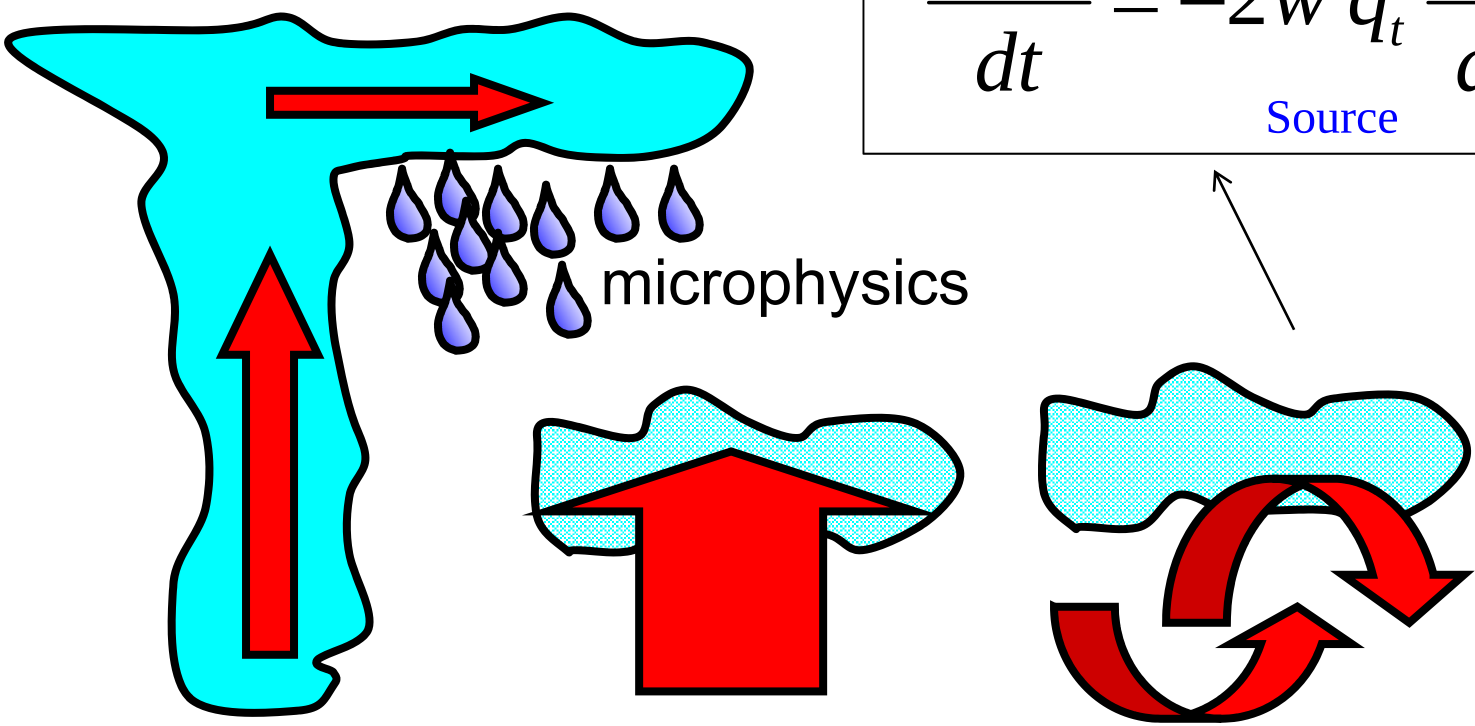
- Prognostic PDF mean
- Prognostic PDF variance
- Prognostic PDF skewness
- Sources and sinks of variance and skewness need to be parametrized

Cloud and Precipitation "Macrophysics"
Sub-grid heterogeneity sources/sinks

Example: vertical and horizontal mixing due to b.l. turbulence

$$\frac{d\overline{q_t'^2}}{dt} = -2\overline{w'q_t'}\frac{d\overline{q_t}}{dz} - \frac{q_t'^2}{\tau}$$

Source Dissipation



Future Directions of Cloud/Precip Param "Macro-scale"

- Complexity of sub-grid cloud schemes will increase
  - Improved physical representation of total water PDFs (humidity and condensate), sources and sinks.
  - Additional degrees of freedom for evolution of PDF? Diagnostic PDF versus prognostic
  - Mixed phase and ice phase cloud cover/overlap
  - Vertical overlap (generalised overlap)

- Challenges for DA:
  - Mismatch of spatial scales – using sub-grid information
  - Making the most of improved info on humidity and condensate variability (PDFs)?
  - Using info on vertical overlap (cloud and precipitation)

Future directions for cloud and precipitation parametrization development:

1. Improved physical basis
2. Improved use of observations
3. Unifying underlying assumptions

Improved use of observations

- New ways of using observations will improve validation/verification
  - Wealth of remote-sensing observations (satellite (CloudSat/CALIPSO, ground based – ARM, European sites)
  - Much more to extract to inform model development
  - But need to compare like-with-like
  - Both model validation and DA potentially benefit

→ Take account of sub-grid info from the model and use a forward operator for the parameters.

and/or

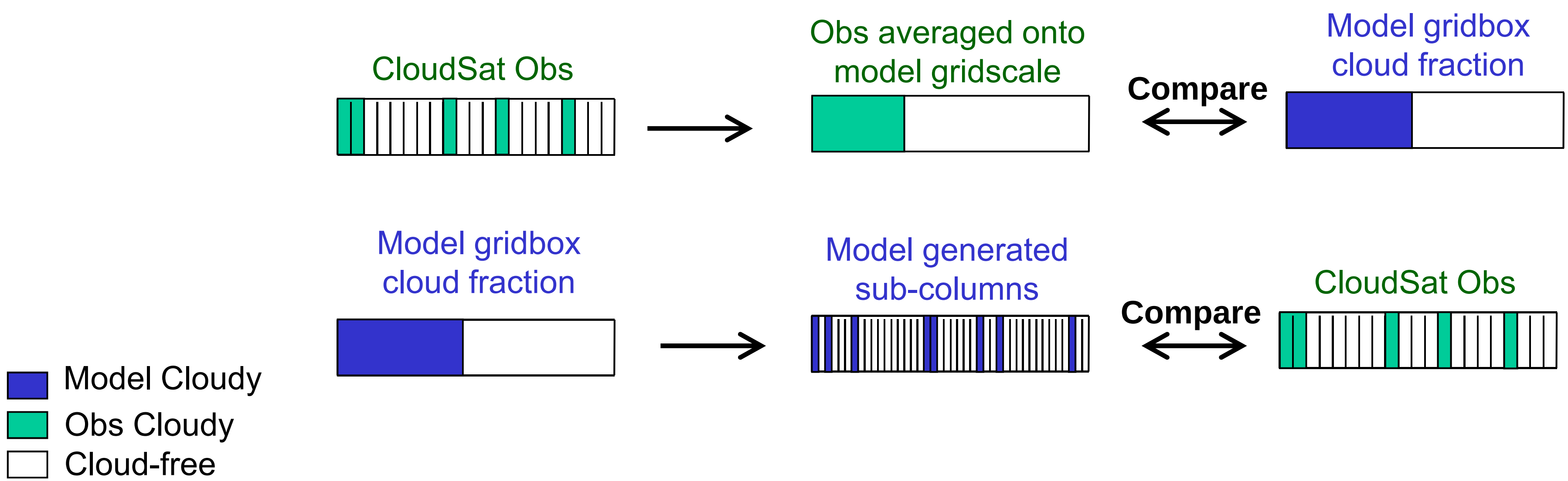
→ Use synergistic retrieval of model variables using multiple obs sources (e.g. ice from CloudSat/CALIPSO, Delanoe and Hogan 2010)

Spatial resolution mis-match
Example of ECMWF model and CloudSat

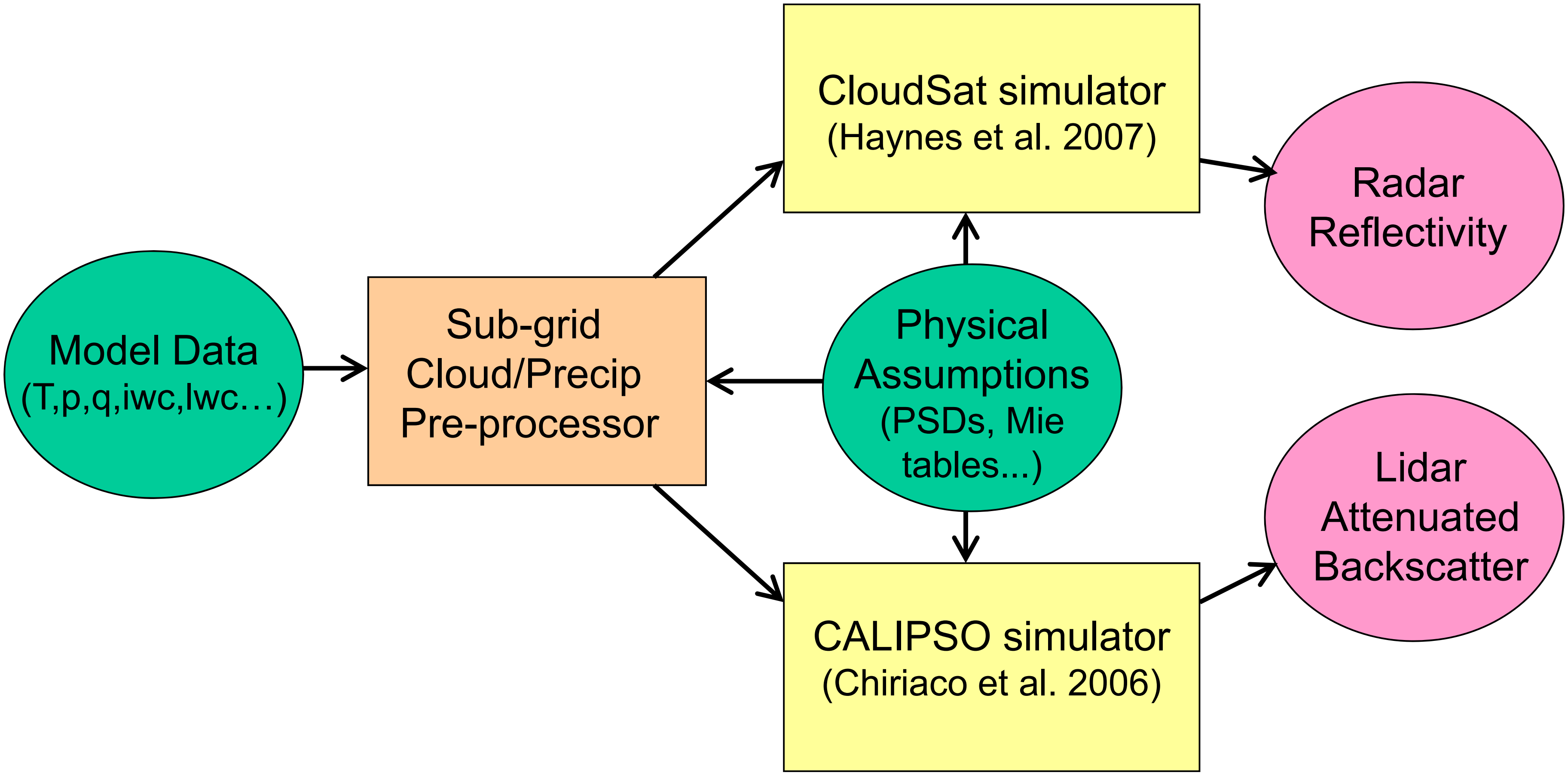
- Addressing the mismatch in spatial scales in model (50 km) and obs (1 km)
- Sub-grid variability is predicted by the IFS model in terms of a cloud fraction and assumes a vertical overlap.
- Either:

  (1) Average obs to model representative spatial scale

  (2) Statistically represent model sub-gridscale variability using a Monte-Carlo multi-independent column approach.

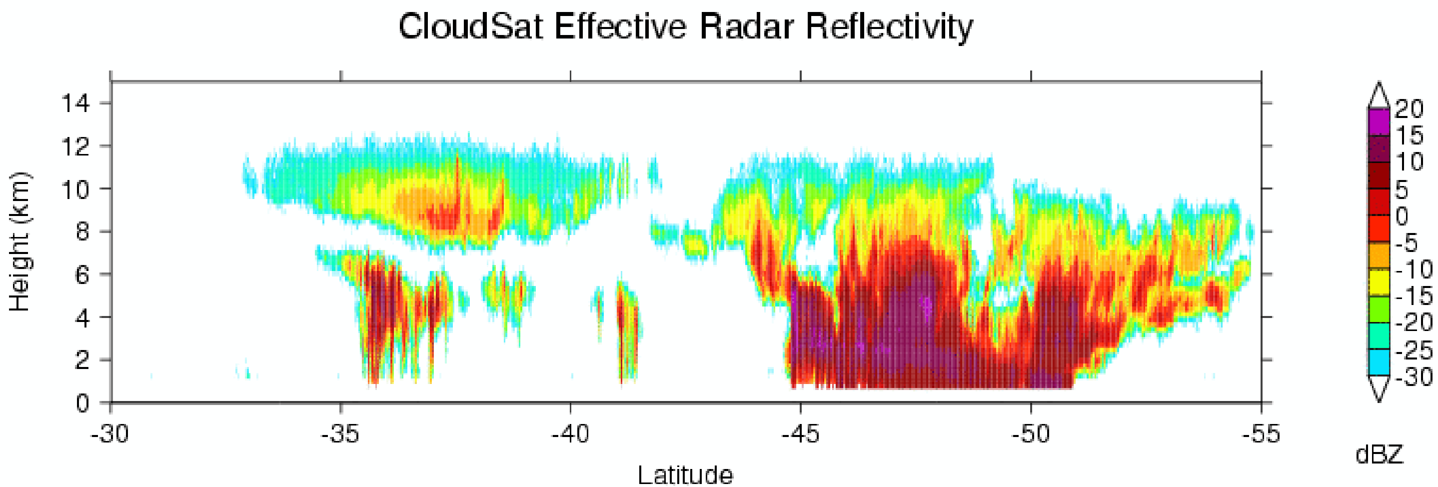


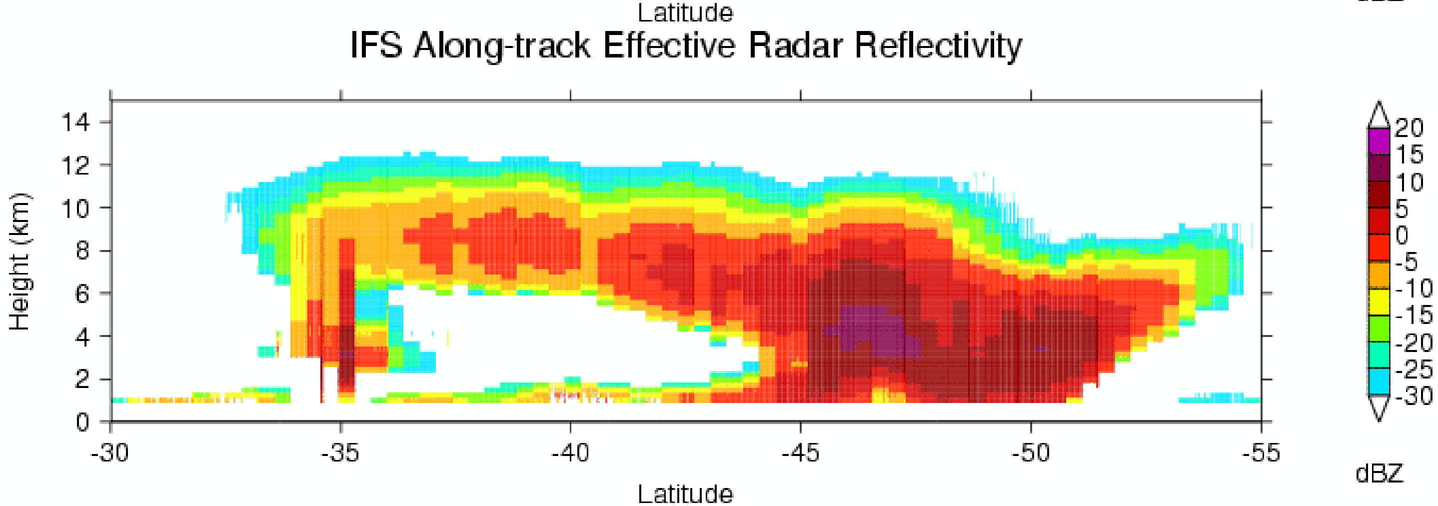
Simulating Observations
CFMIP COSP radar/lidar simulator



http://cfmip.metoffice.com

Comparing like-with-like:
Radar reflectivity





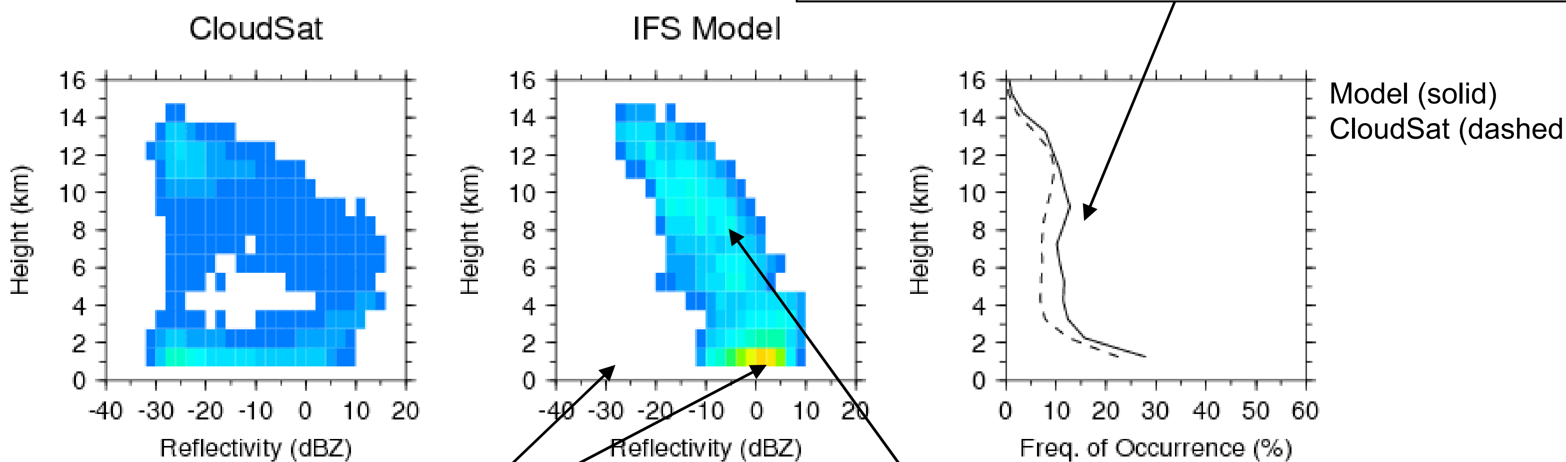
Examples: ESA-funded QuARL project at ECMWF
or Bodas-Salcedo et al. (2009)

(2) Radar Reflectivity
Statistical comparison example

ECMWF-JCSDA Workshop Jun 2010

Tropics (30S-30N) over ocean for July 2007

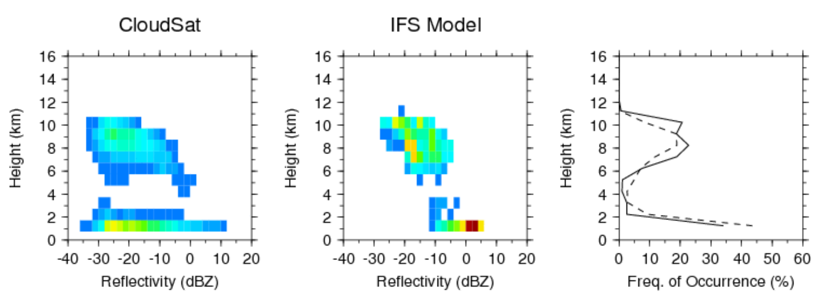
Higher occurrence of cloud/precip in model
(but sensitive to precipitation fraction assumptions)



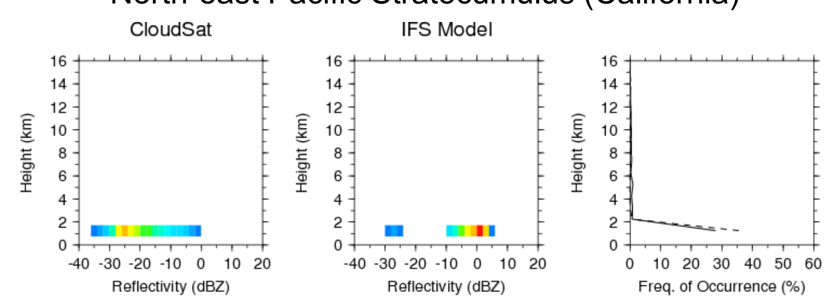
Model dominated by low level rain mode (obscurs cloud mode)

Distribution of reflectivity too narrow. Lack of low and high values.

South-east Pacific Stratocumulus (Chile)



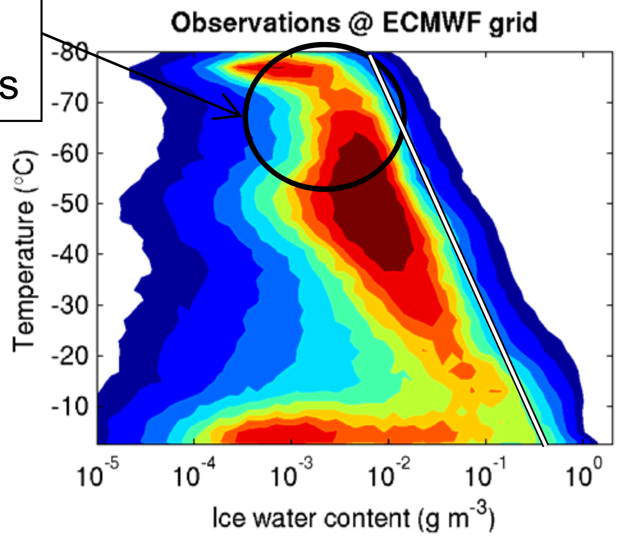
North-east Pacific Stratocumulus (California)

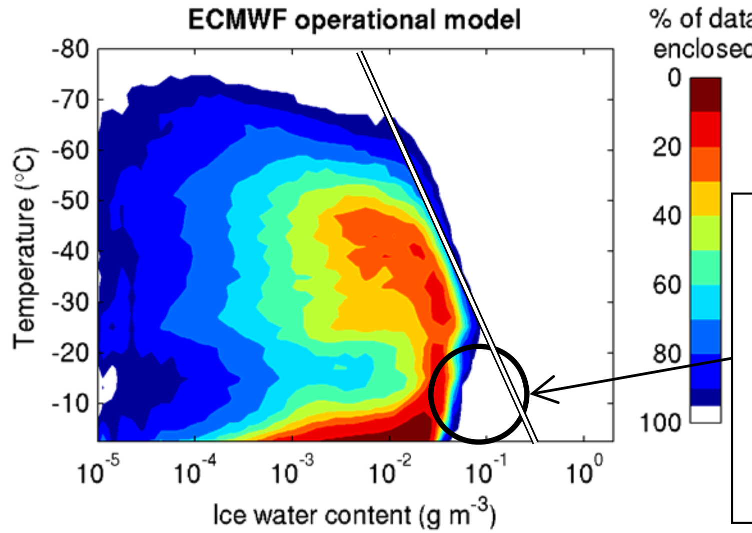


CloudSat/CALIPSO Model Verification

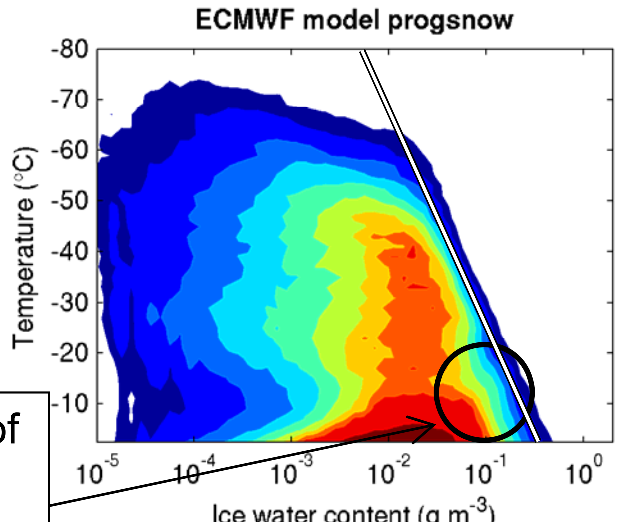
GLOBAL Ice Water Content vs. T distributions

Lack of ice at very cold temperatures





Current scheme misses larger IWC (snow)



Distribution of IWC in new scheme is improved

- New prognostic microphysics scheme is closer to obs in 0 to -23°C range due to:
  - Improved mixed-phase
  - Prognostic snow

(In collaboration with Delanoë and Hogan, Reading Univ.)

Improved use of observations

- New ways of using observations will improve validation/verification
  - Wealth of remote-sensing observations (satellite (CloudSat/CALIPSO, ground based – ARM, European sites)
  - Much more to extract to inform model development
  - But need to compare like-with-like
  - Both model validation and DA potentially benefit

- Challenges
  - Different spatial scales
    - E.g. Resolution (Model O[50 km] versus CloudSat O[1 km])
    - 1D vs 2D (narrow track versus grid-box)
  - Different parameters
    - For example: Reflectivity/Backscatter vs. Ice/Liq/Rain/Snow Content
    - Need accurate forward model or enough obs constraints for retrieval
    - Microphysical assumptions needed both ways
  - Uncertainties and limitations of the observations and the model
  - Model validation benefit from DA

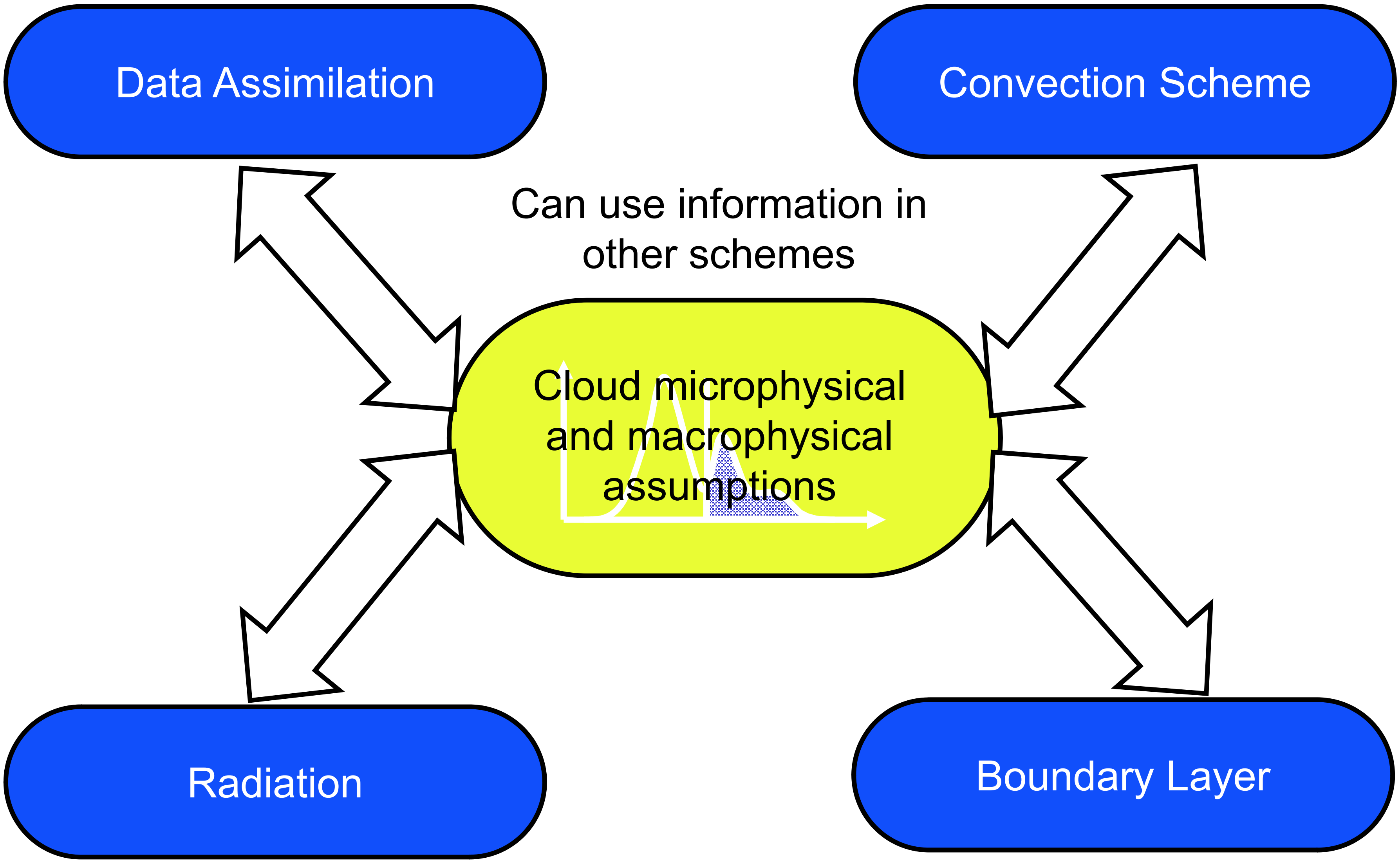
Future directions for cloud and precipitation parametrization development:

1. Improved physical basis
2. Improved use of observations
3. Unifying underlying assumptions

Unifying cloud/microphysical assumptions across the model system

- Assumptions will become more consistent
  - Microphysical assumptions (e.g. particle size distributions, effective radius, ice particle characteristics)
  - Macrophysical assumptions (PDFs of humidity/condensate, vertical overlap assumptions)
  - Cloud/microphysical assumptions appear in the cloud/convection/boundary layer/radiation/forward models/data assimilation

Unifying cloud/microphysical assumptions across the model system

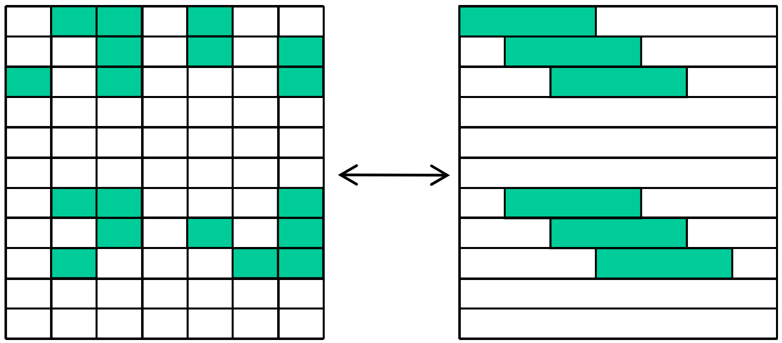


Unifying cloud/microphysical assumptions across the model system

- Example: McICA radiation scheme (e.g. McRad in ECMWF model - Morcrette et al, 2007) can use sub-grid information in a flexible way
- Can feed in PDF of condensate etc., cloud fractions, vertical overlap…

<u>Monte Carlo Independent Column Approximation</u>

In each sub-column, each pixel is fully cloudy or clear but overall reproduces the grid-scale cloud characteristics



Unifying cloud/microphysical assumptions across the model system

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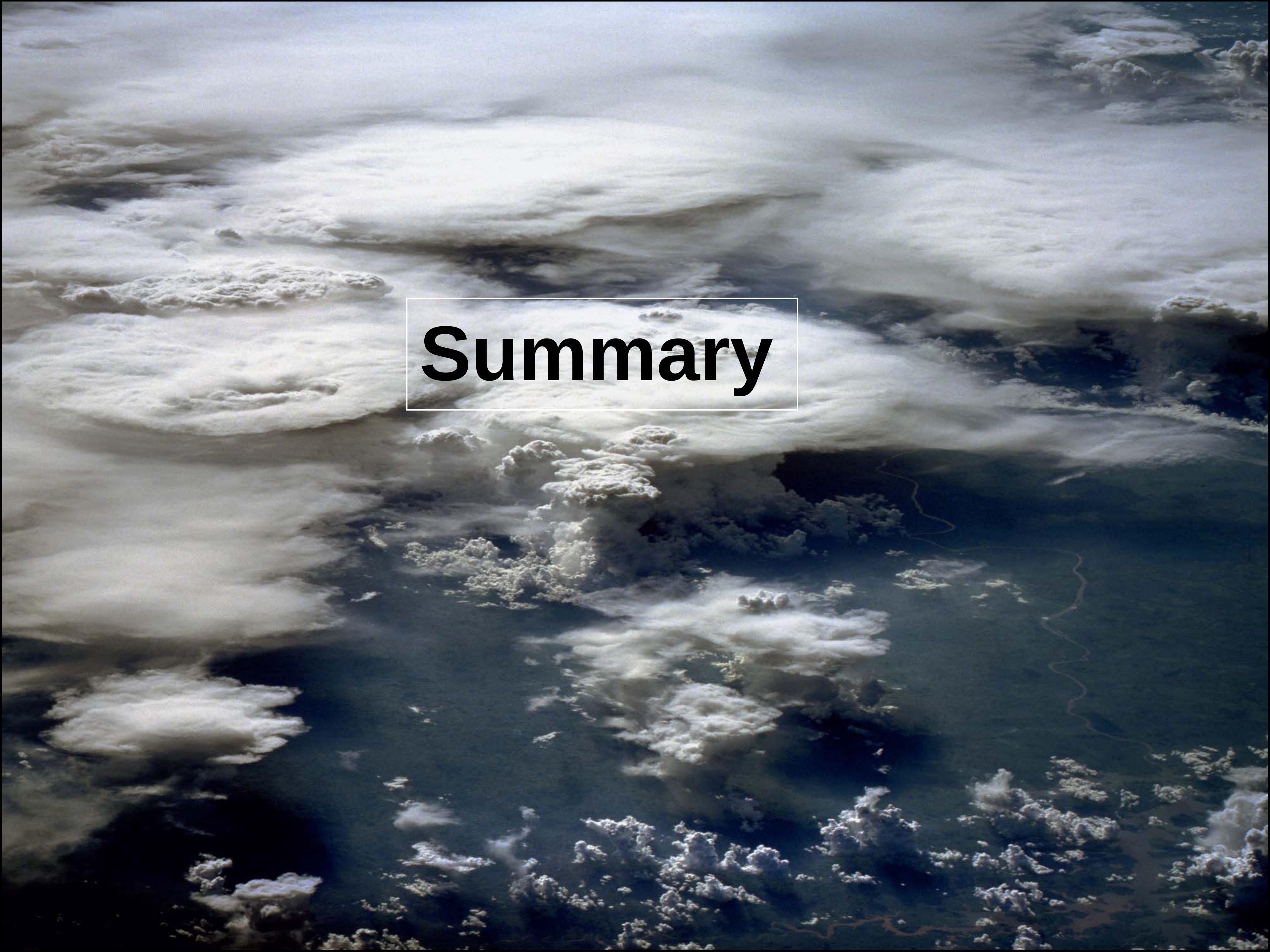
- Challenges
  - Different parts of the particle size spectra important for different processes/wavelengths (Mass=D^3,Z=D^6,Lidar=D^2)
  - Including parametrized convection as sub-grid info to other parts of the model?
  - Simplified scheme in TL needs different assumptions.
  - Potentially computationally expensive to treat PDF as in McICA

Summary



Summary of future directions for parametrization of cloud/precip

1. Improved physical basis
   - Improved 3D distributions of cloud and precipitation
   - Improved info for DA
2. Improved use of observations
   - More comprehensive validation/verification
   - Improved forward models/retrievals
   - Benefit for cloud parametrization development
3. Increasingly unified assumptions across the model
   - Consistency
   - Using the best information we have for all parts of the model

BUT many **challenges** and must recognise the **limitations of our knowledge** and not extend the degrees of freedom beyond what can be constrained by observations.

A few recommendations for accelerating progress……..

1. Get parametrization, data assimilation and observation researchers talking more to each other!

2. Work on improving forward models and retrievals.

3. Ensure we use the wealth of info from DA to benefit the continued development of cloud parametrization.