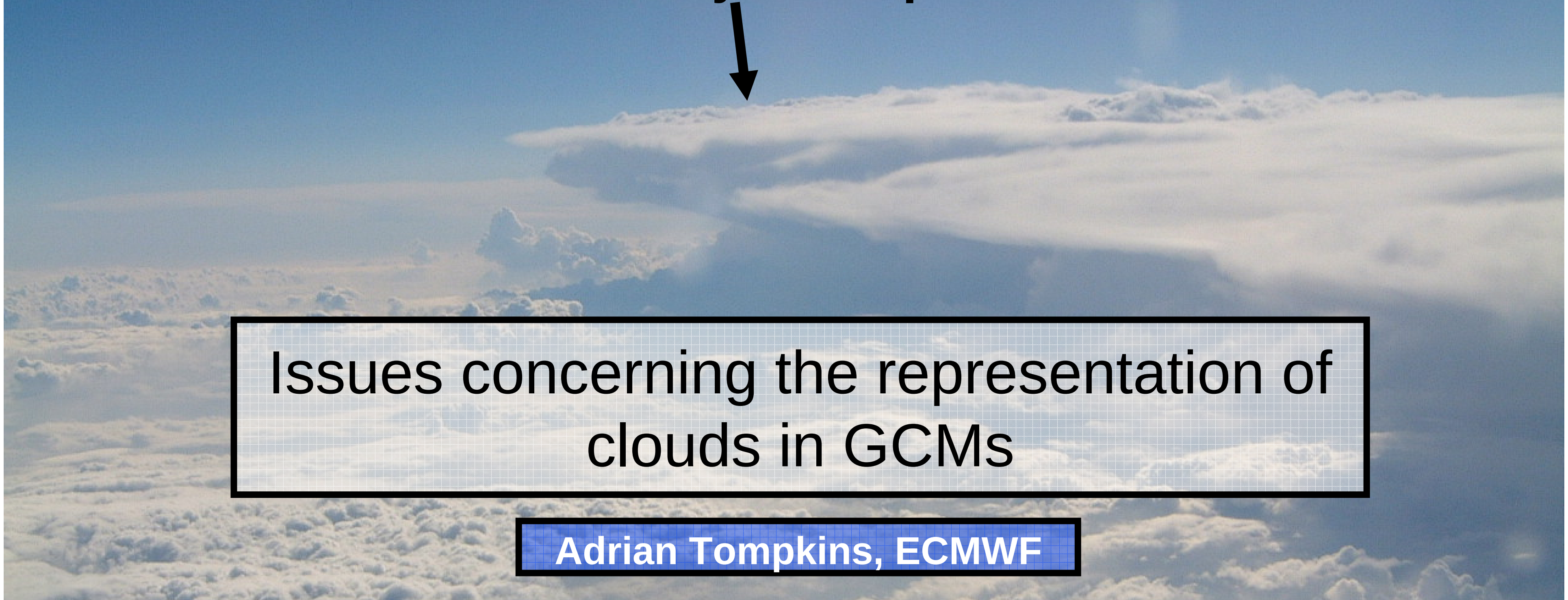
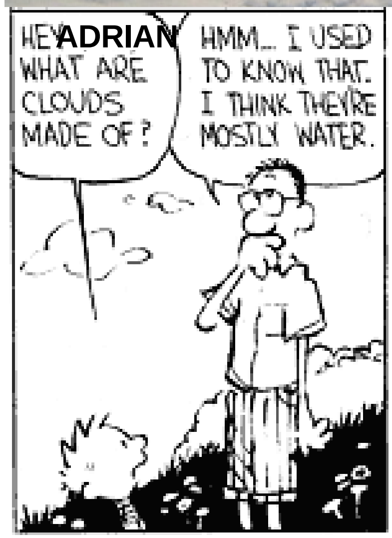
Clouds over Venice: Observations at visible wavelengths from the Ryan Air platform

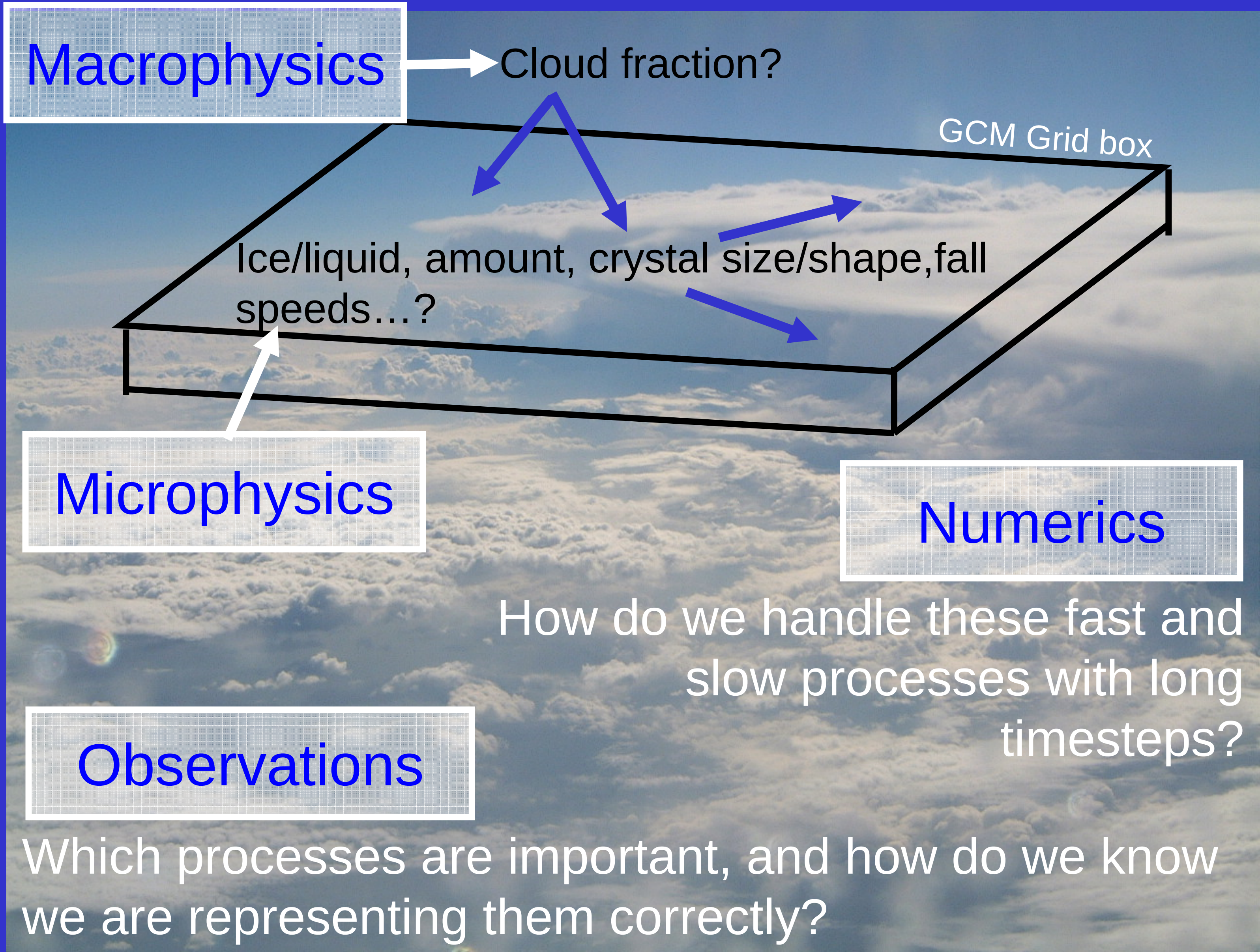


Issues concerning the representation of clouds in GCMs

Adrian Tompkins, ECMWF



The Aim: Represent the “*important*” characteristics of clouds with the smallest number of parameters possible

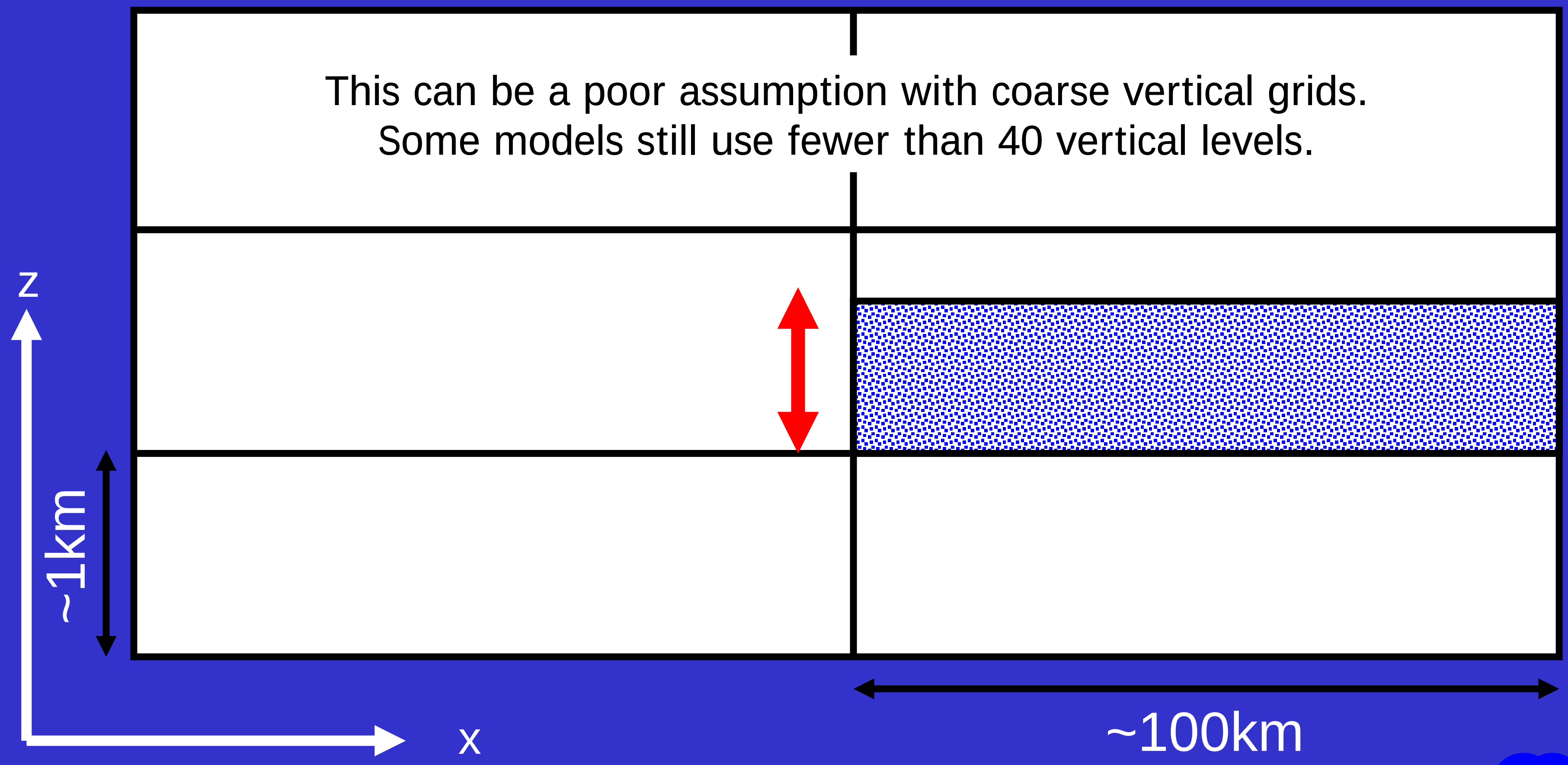


#1 Macrophysical issues

Macrophysical Issues of Parameterization

VERTICAL COVERAGE

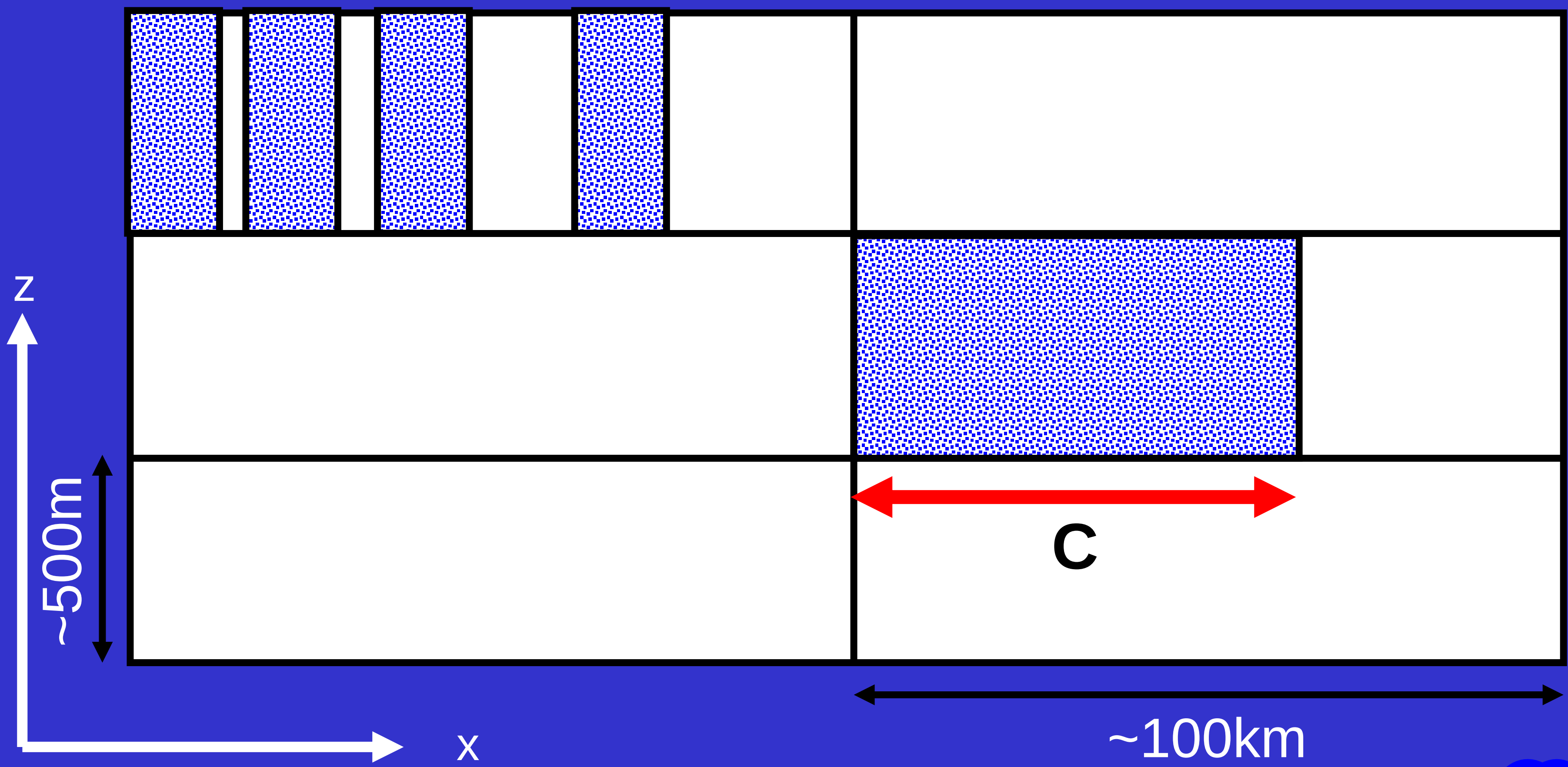
Most models assume that this is 1



Macrophysical Issues of Parameterization

HORIZONTAL COVERAGE, C

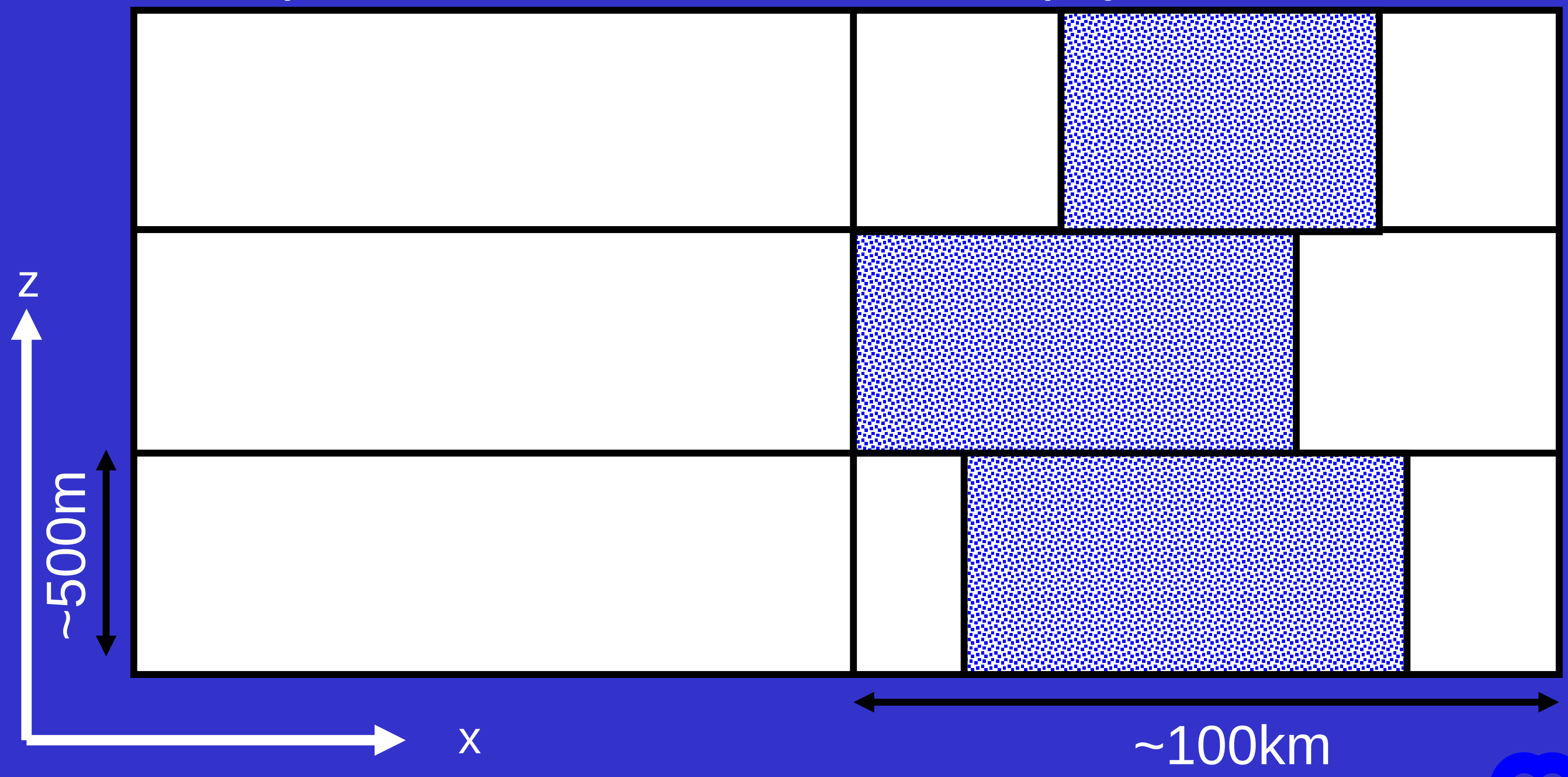
Spatial arrangement?



Macrophysical Issues of Parameterization

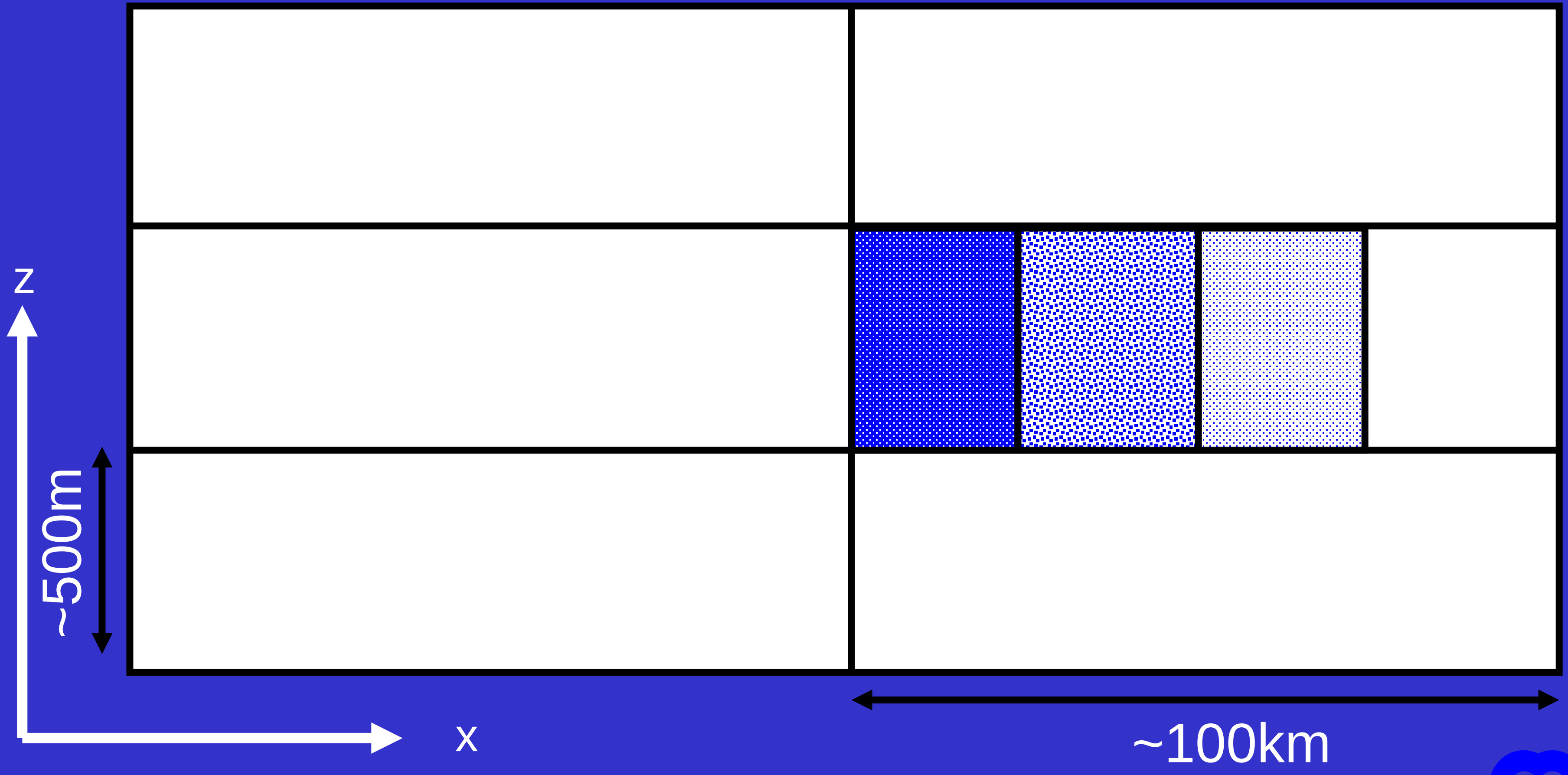
VERTICAL OVERLAP OF CLOUD

Important for Radiation and Microphysics Interaction



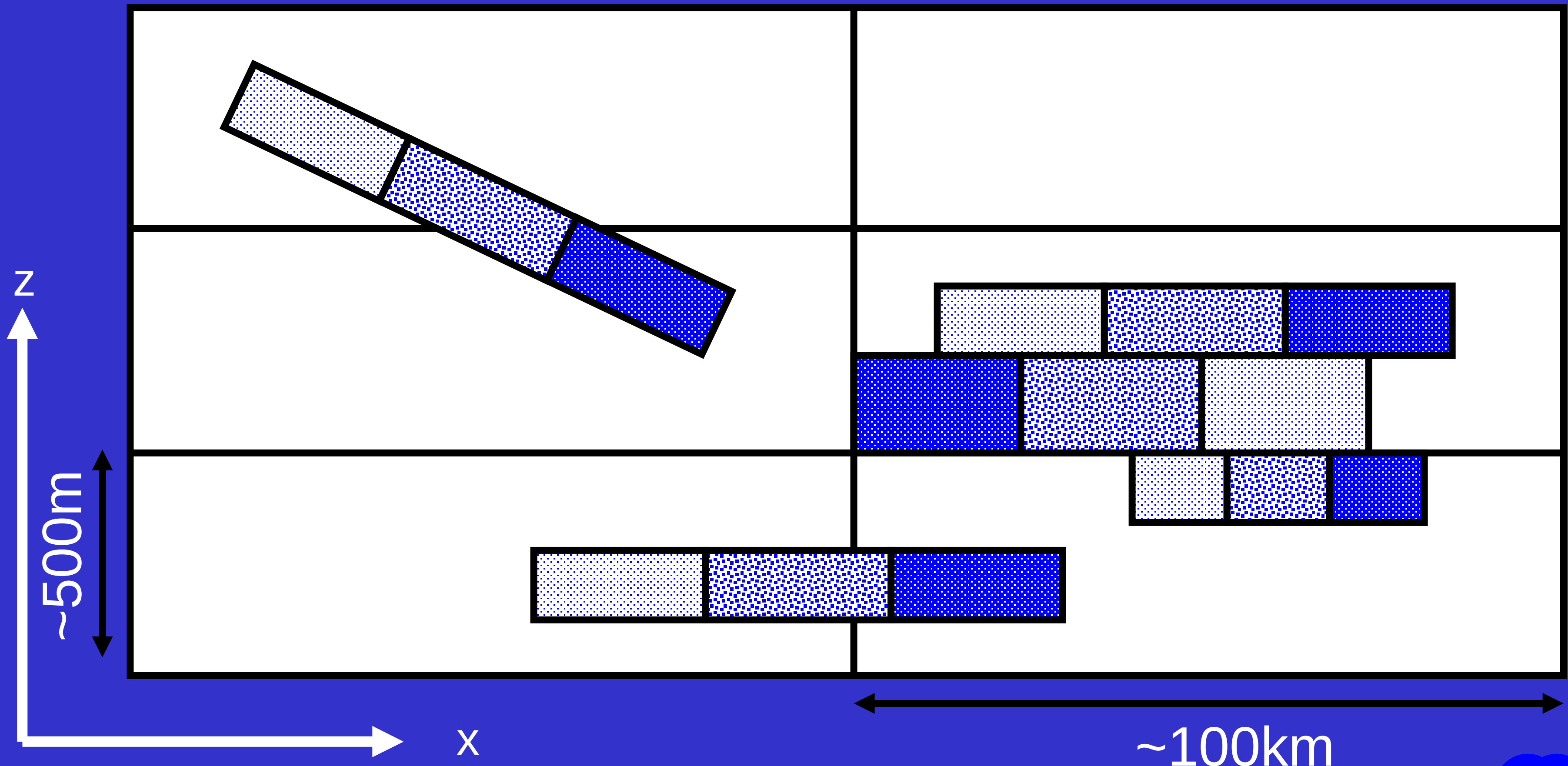
Macrophysical Issues of Parameterization

IN-CLOUD INHOMOGENEITY
in terms of cloud particle size and number



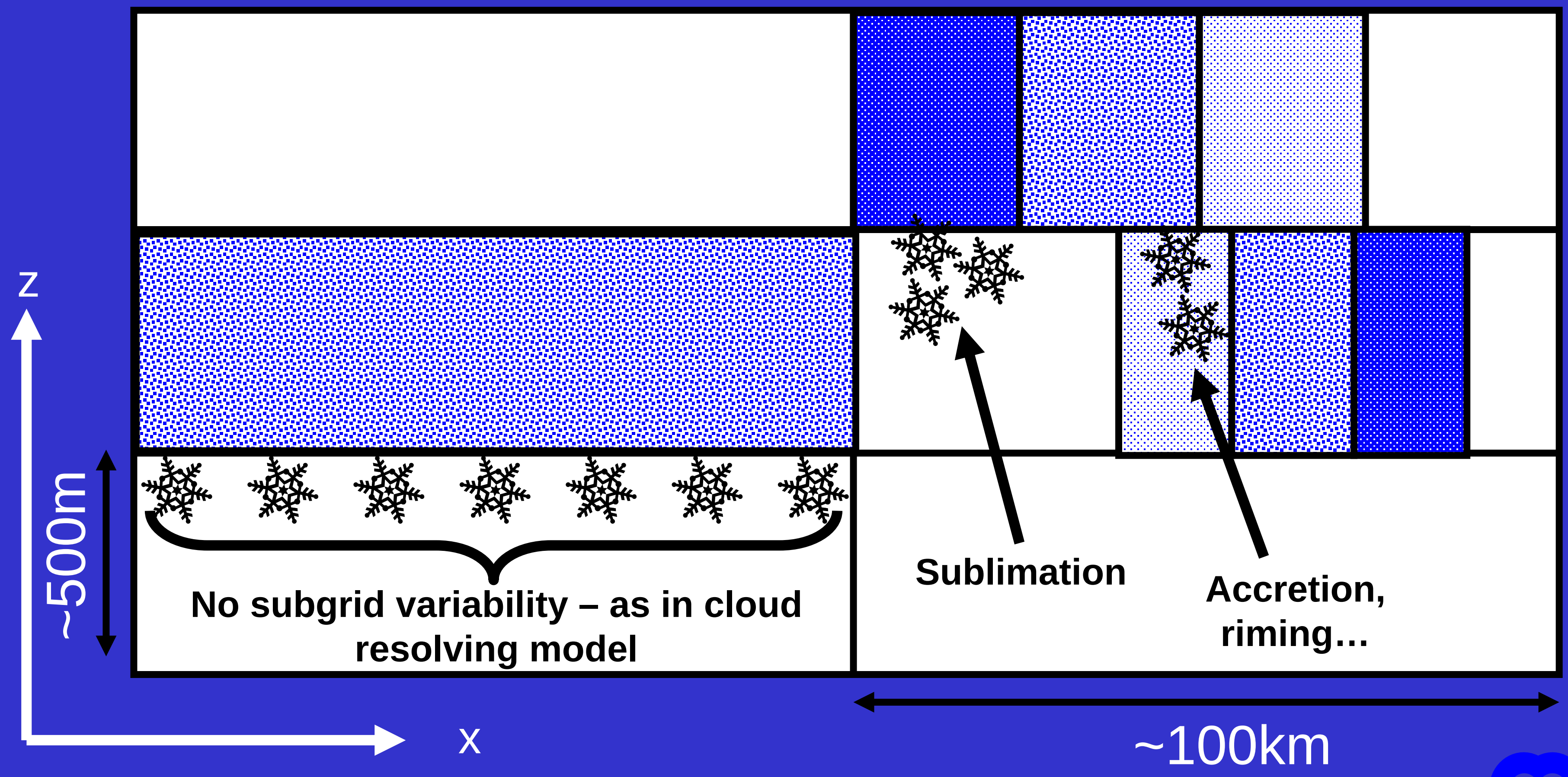
Macrophysical Issues of Parameterization

Just these issues can become a little complex!!!



Microphysical Issues of Parameterization

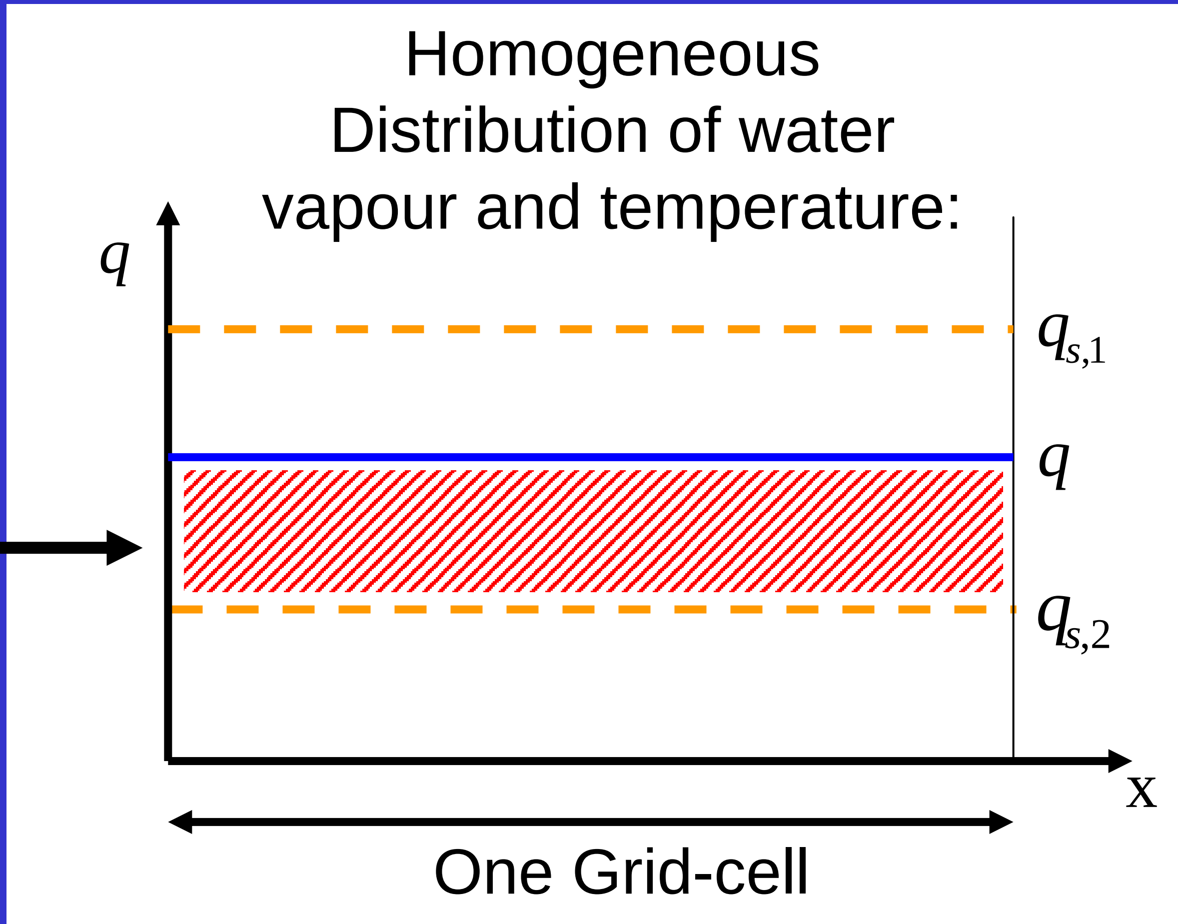
It is clear that MICRO and MACRO physical issues can not be separated



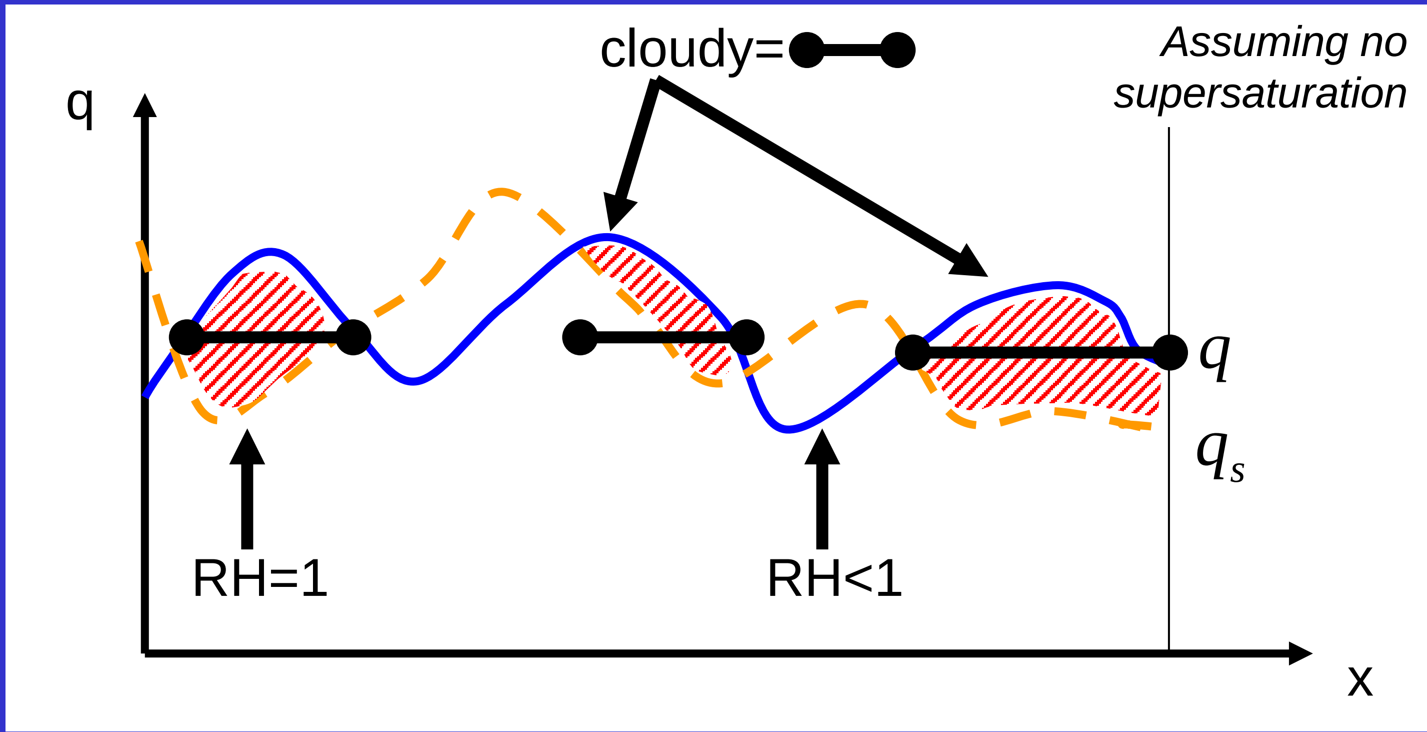
In Large-scale models some subgrid variability assumption is mandatory

Partial coverage of a grid-box with clouds is only possible if there is a inhomogeneous distribution of temperature and/or humidity.

Note in the second case the relative humidity=1 if supersaturation is not permitted

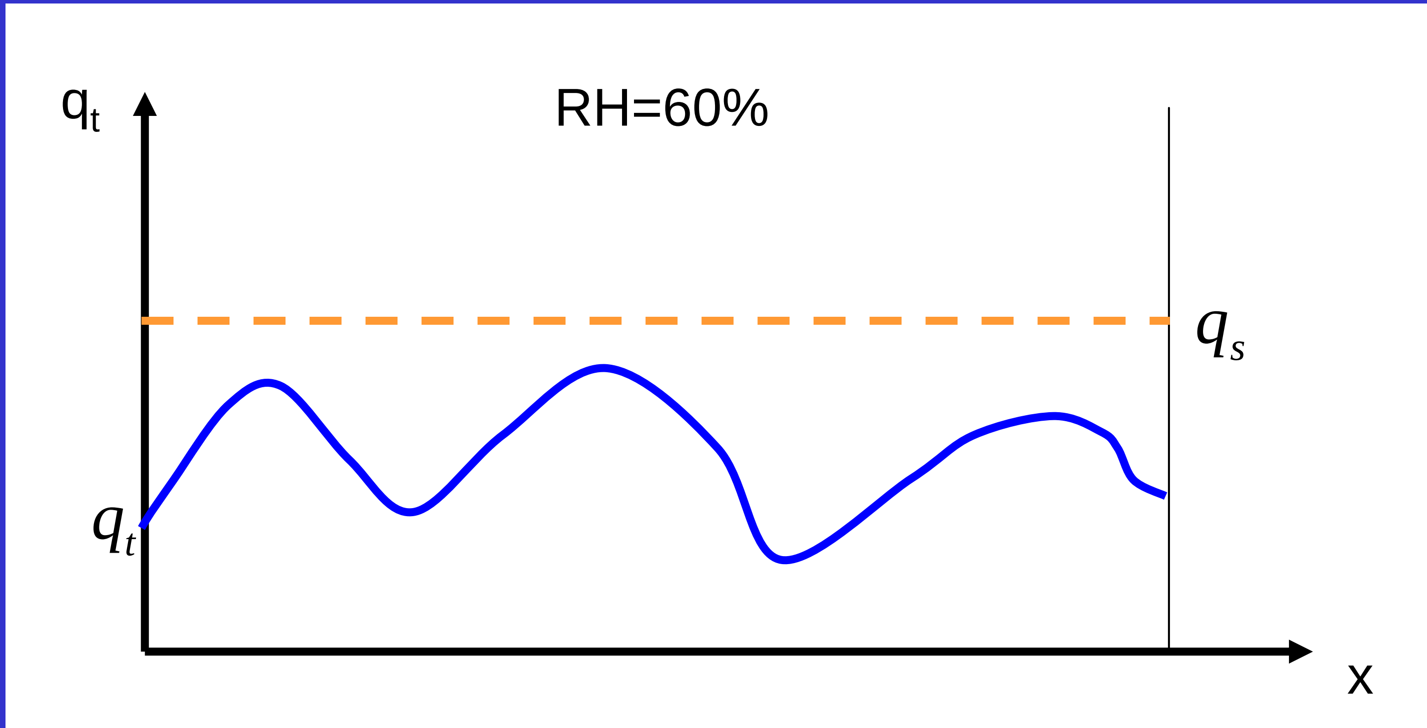


Heterogeneous distribution of T and q

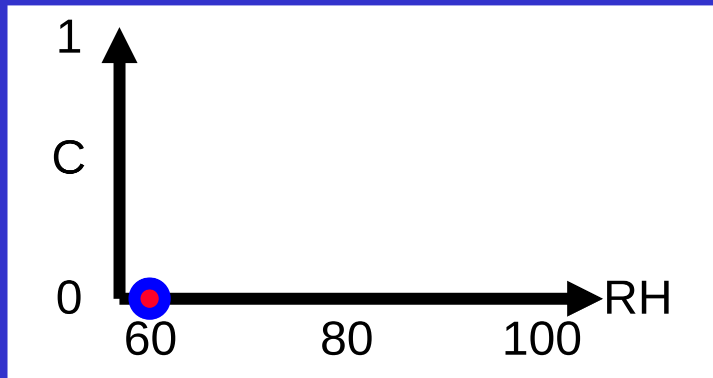


Another implication of the above is that clouds must exist before the grid-mean relative humidity reaches 1

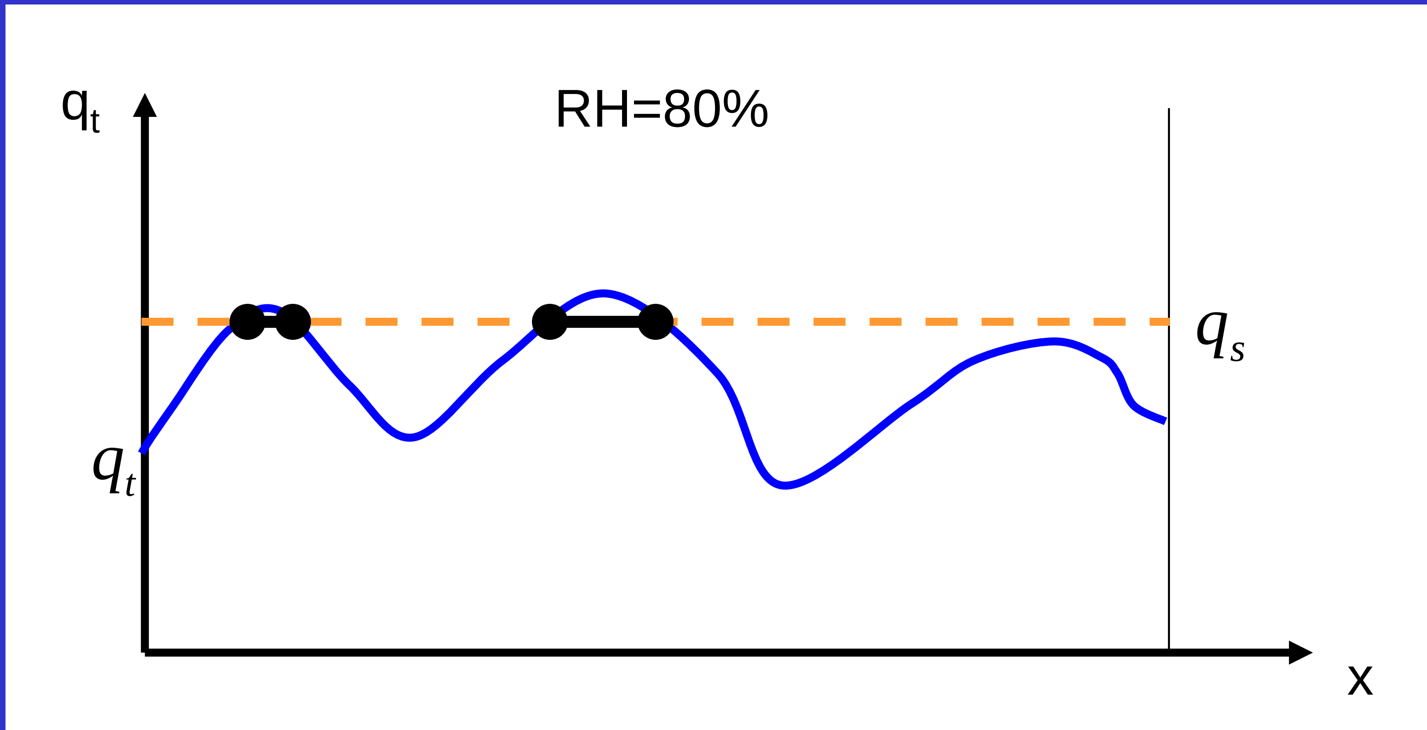
#1 Simple diagnostic schemes: RH-based schemes



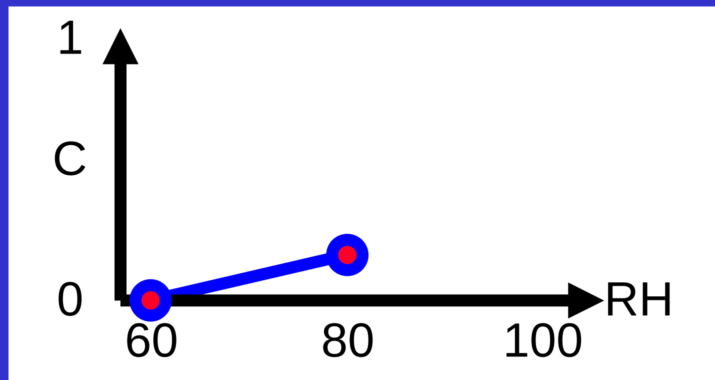
Take a grid cell with a certain (fixed) distribution of total water.
At low mean RH, the cloud cover is zero, since even the moistest part of the grid cell is subsaturated



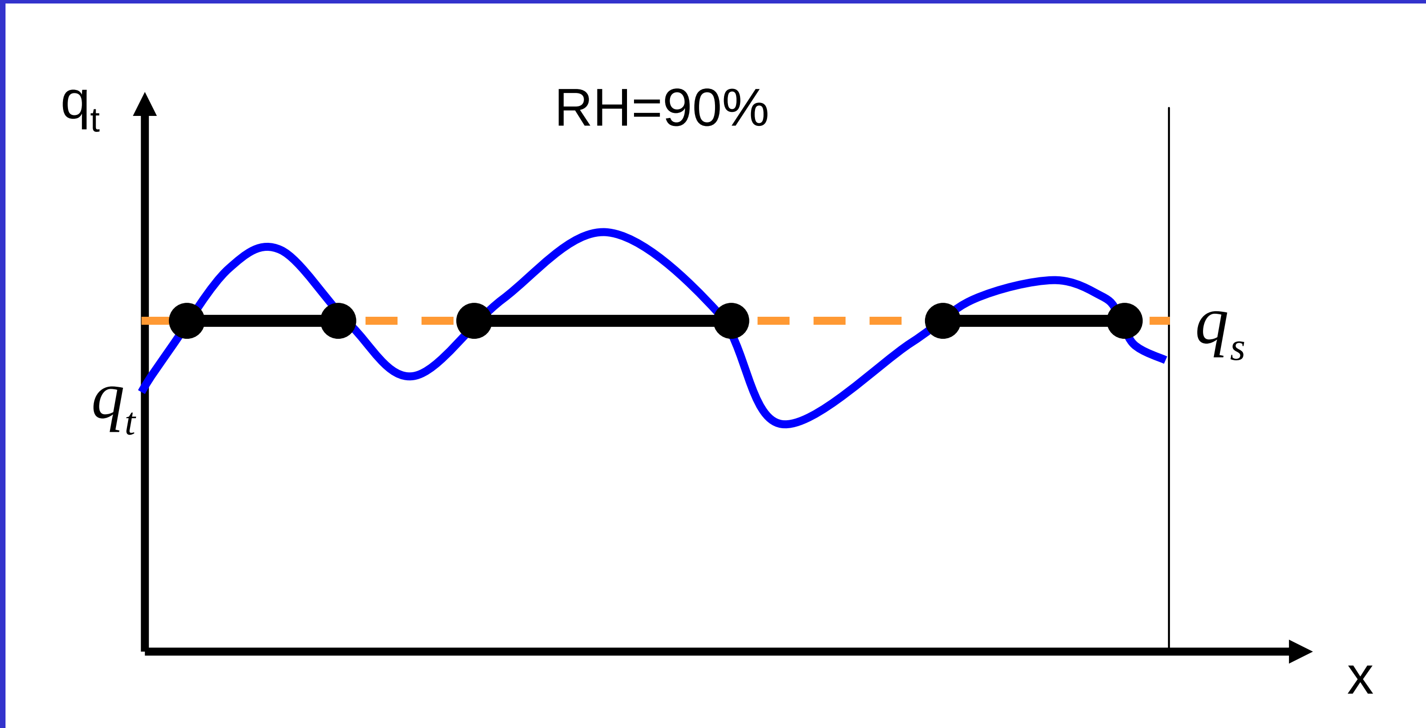
#1 Simple diagnostic schemes: RH-based schemes



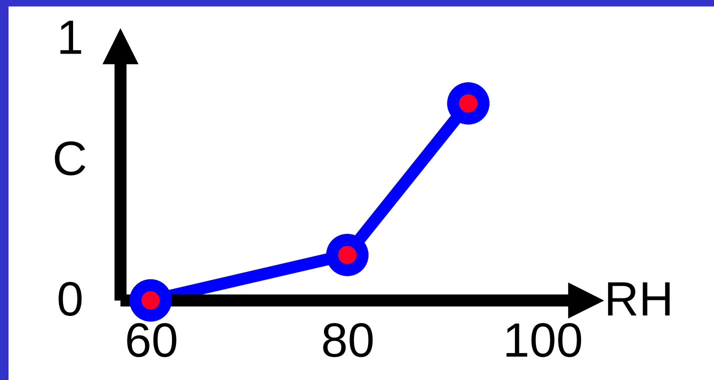
Add water vapour to the gridcell, the moistest part of the cell become saturated and cloud forms. The cloud cover is low.



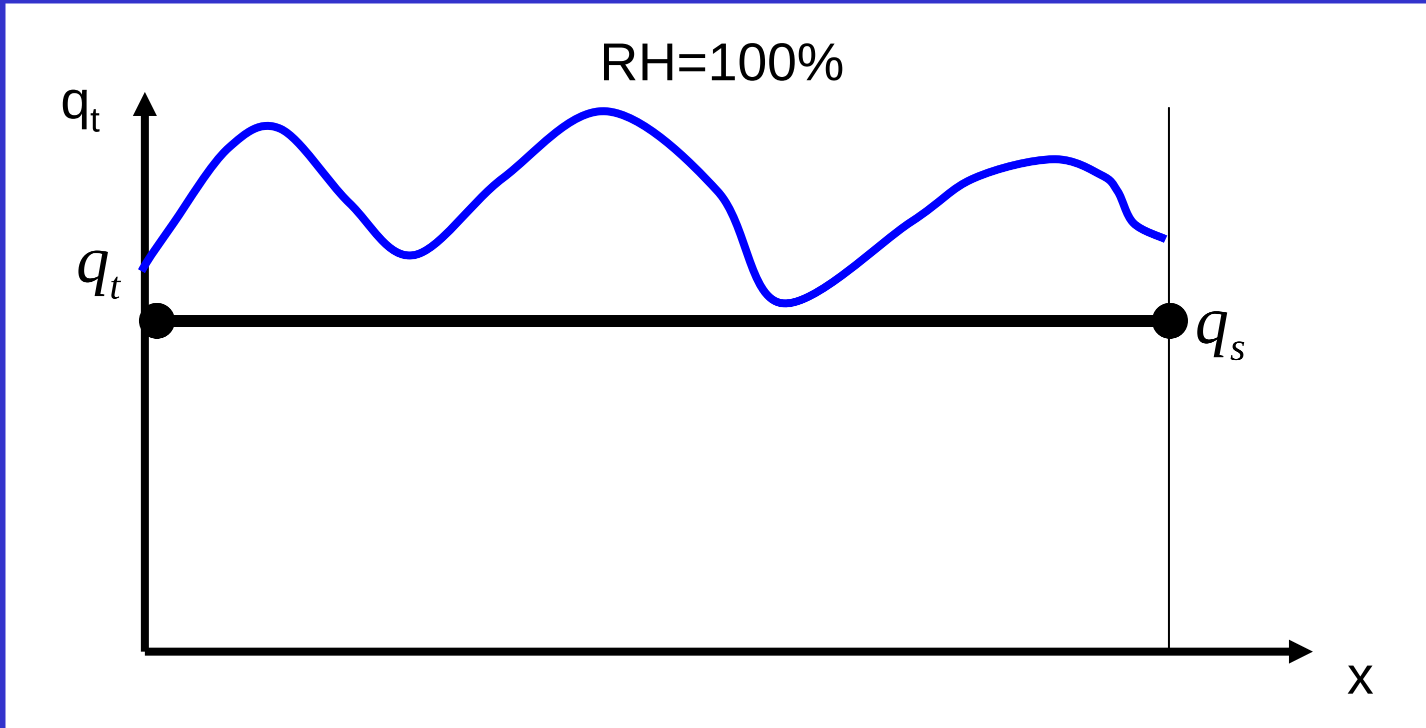
#1 Simple diagnostic schemes: RH-based schemes



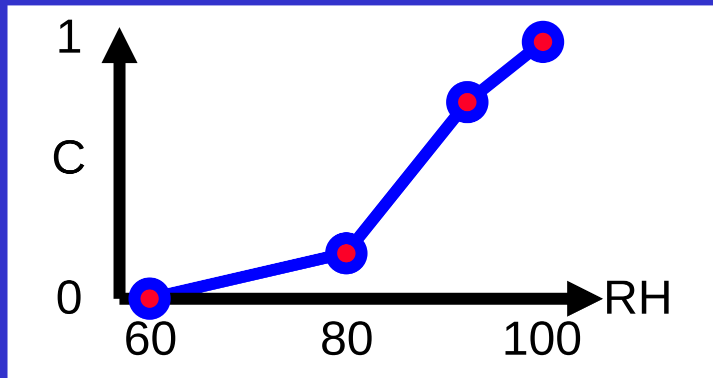
Further increases in RH increase the cloud cover



#1 Simple diagnostic schemes: RH-based schemes



The grid cell becomes overcast when RH=100%, due to lack of supersaturation



Diagnostic Relative Humidity Schemes

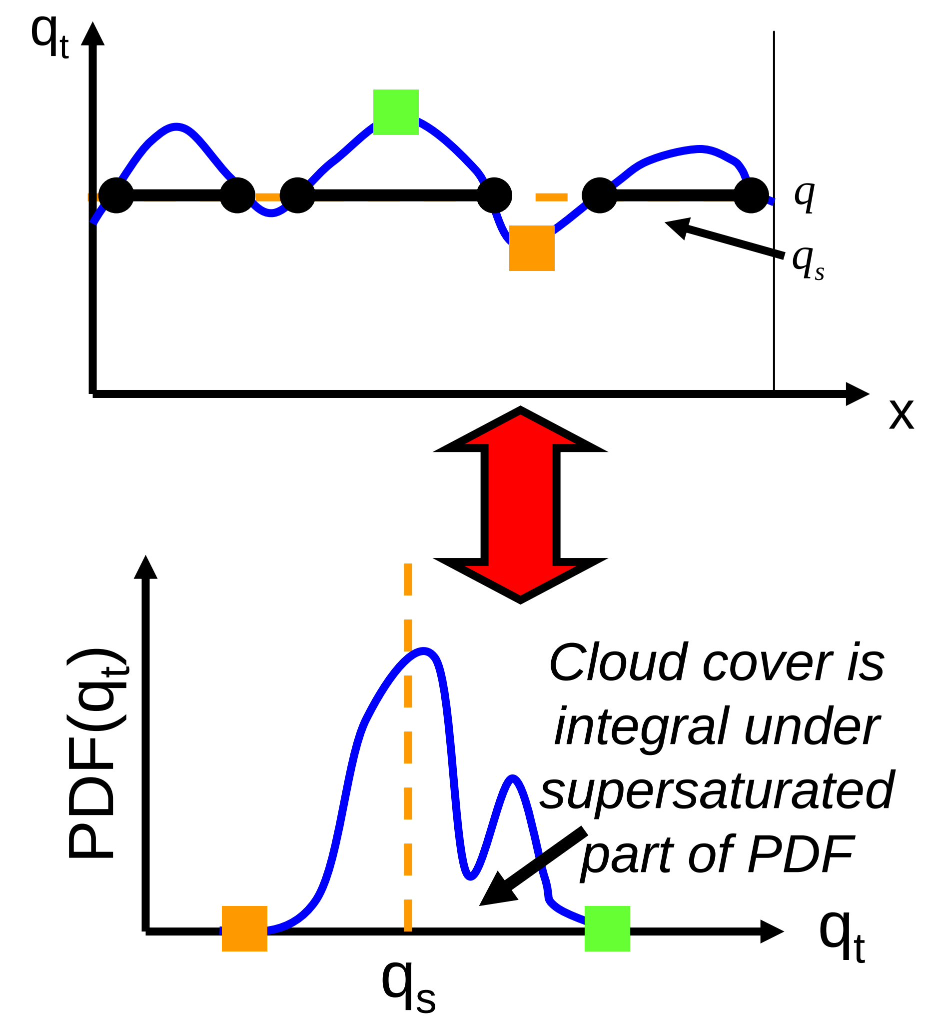
- Cloud cover not well coupled to other processes
- In reality, different cloud types with different coverage can exist with same relative humidity. This can not be represented

Statistical Schemes

These explicitly specify the probability density function (PDF) for the total water q_t (and sometimes also temperature)

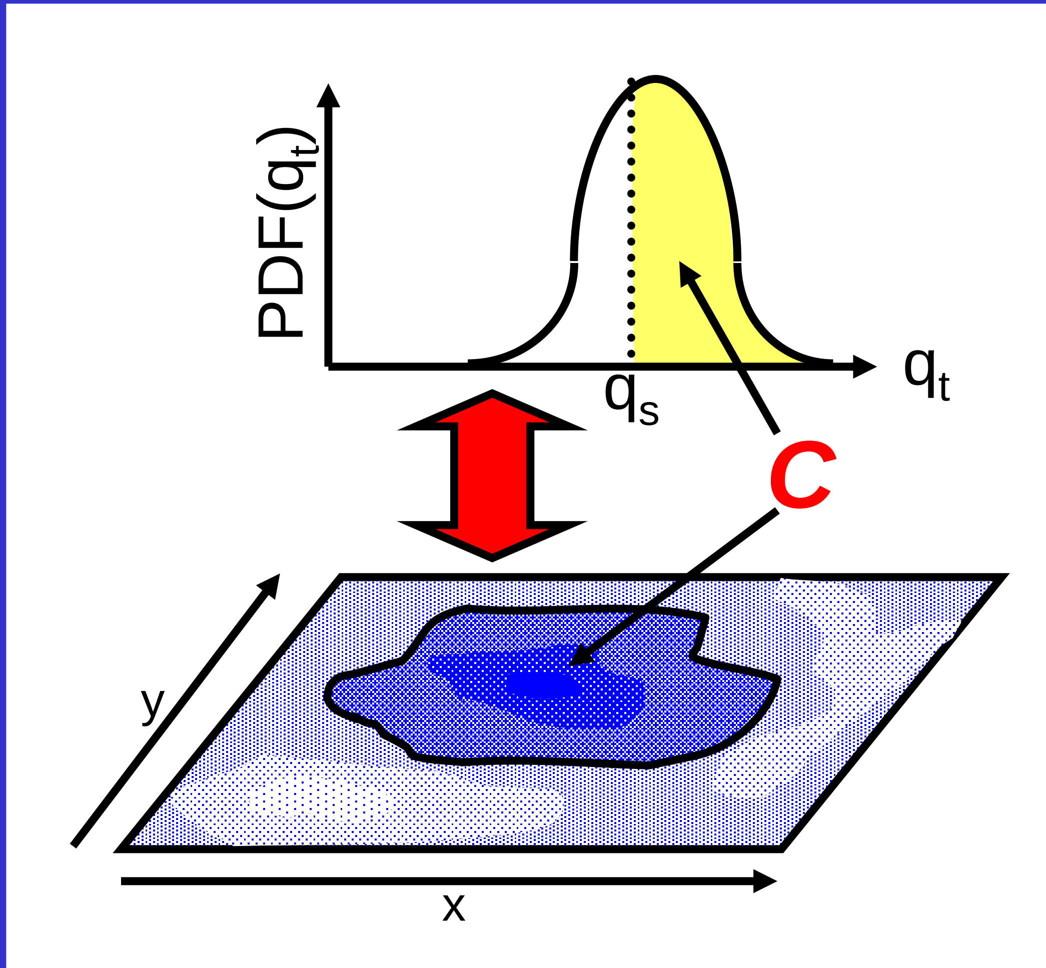
$$C = \int_{q_s}^{\infty} PDF(q_t)\,dq_t$$

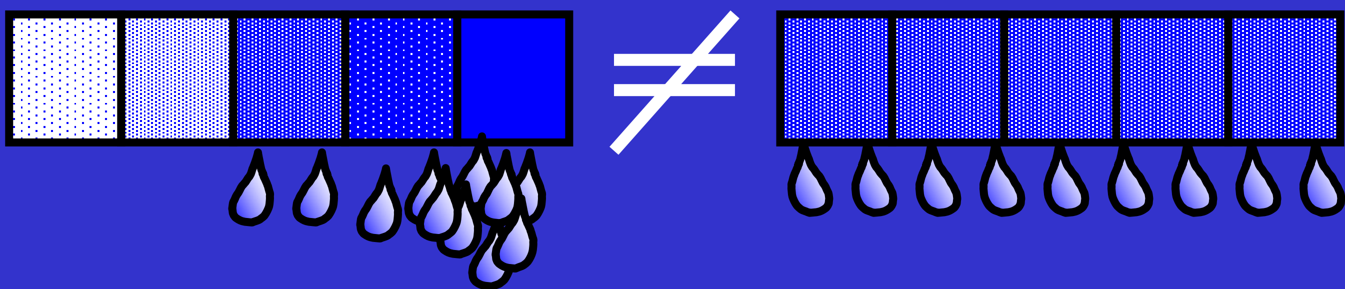
$$q_c = \int_{q_s}^{\infty} (q_t - q_s)\,PDF(q_t)\,dq_t$$



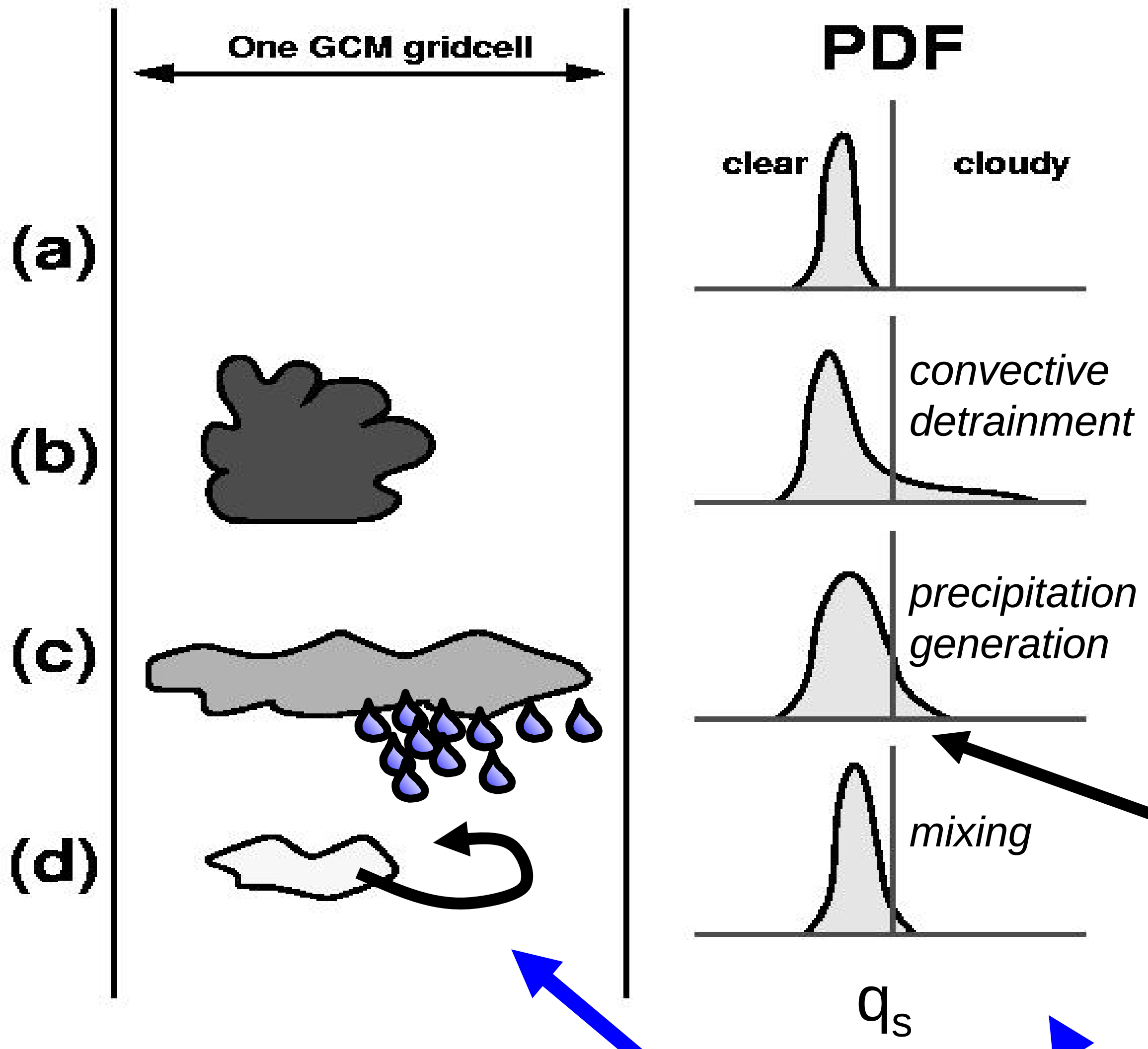
Statistical Schemes

- Knowing the PDF has advantages:
  - More accurate calculation of radiative fluxes
  - Unbiased calculation of microphysical processes
- Location of clouds within gridcell unknown





Fundamental difficulty of this approach…



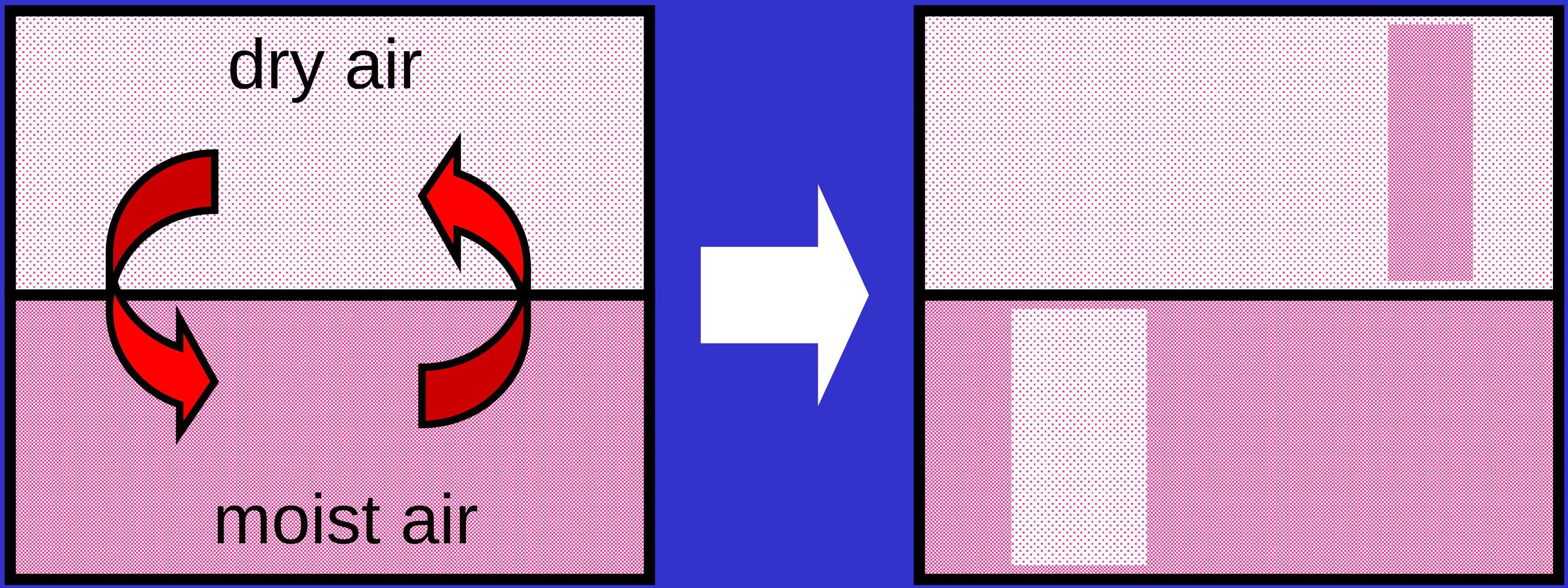
Deriving the effect of these physical processes on the PDF moments

The greater the complexity of the PDF shape, the more moments (either prognostic equations or diagnostic closures) are required to describe it

So what complexity is required?

Example: Turbulence

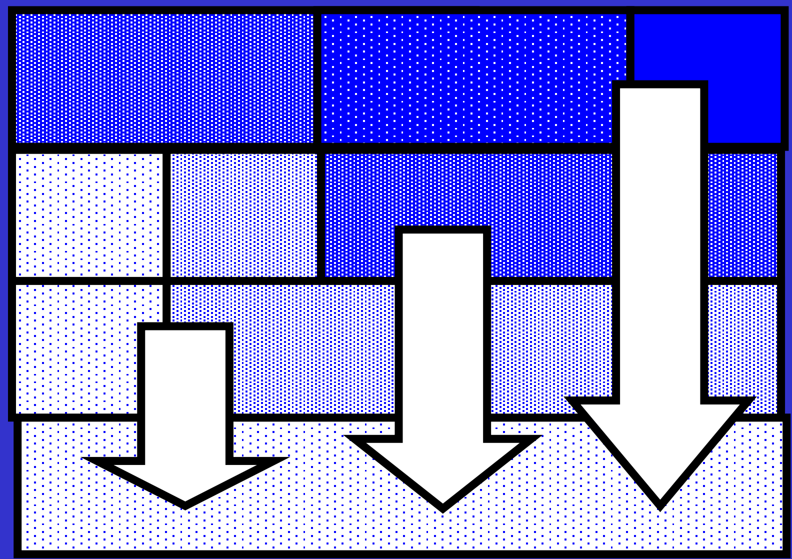
In presence of vertical gradient of total water, turbulent mixing can increase horizontal variability



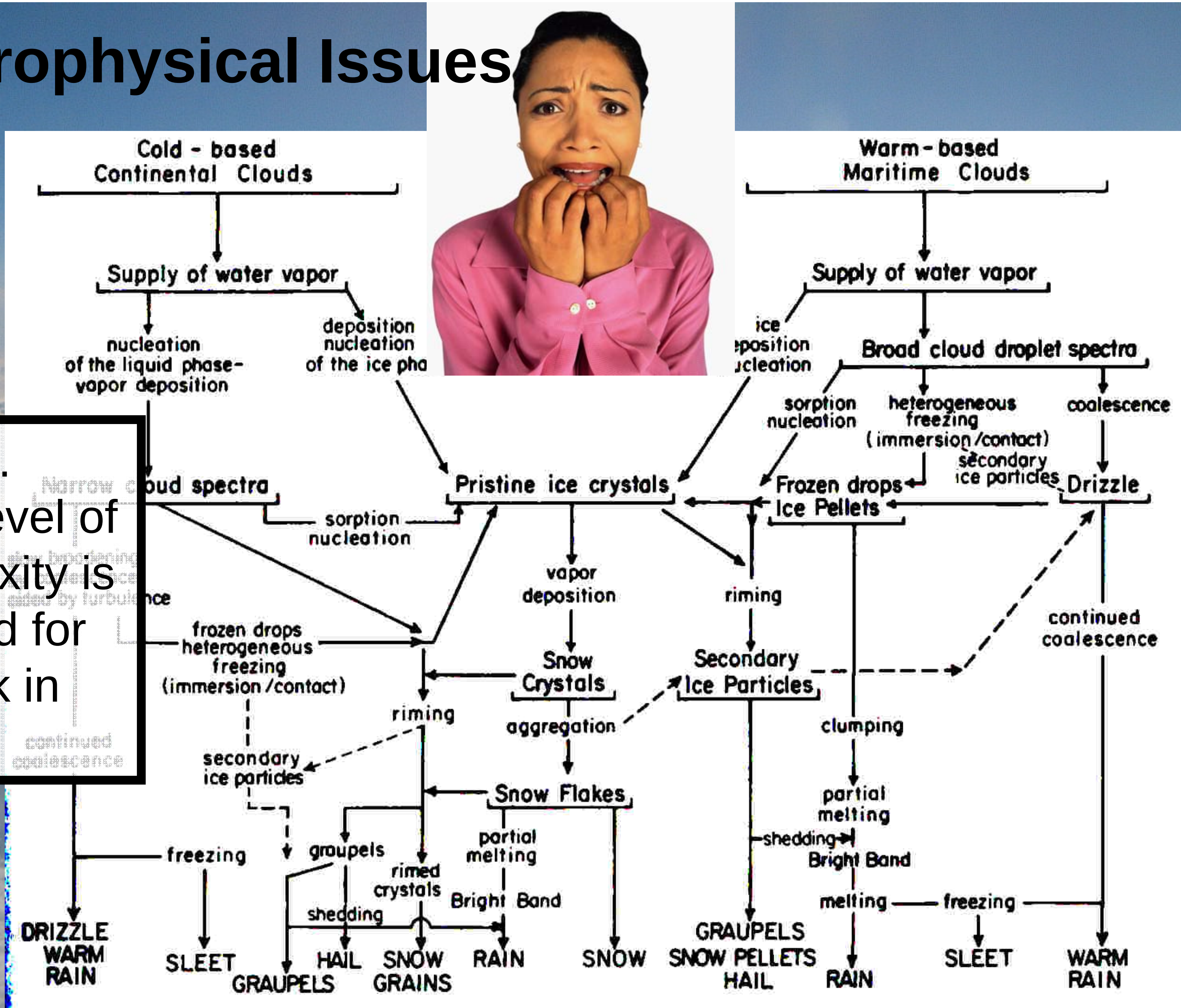
$$\frac{d\overline{q_t'^2}}{dt} = -2\overline{w'q_t'}\,\frac{d\overline{q_t}}{dz}$$

But microphysical terms can be more difficult…

- e.g.: Semi-Lagrangian ice sedimentation
- Source of variance is far from simple, also depends on overlap assumptions



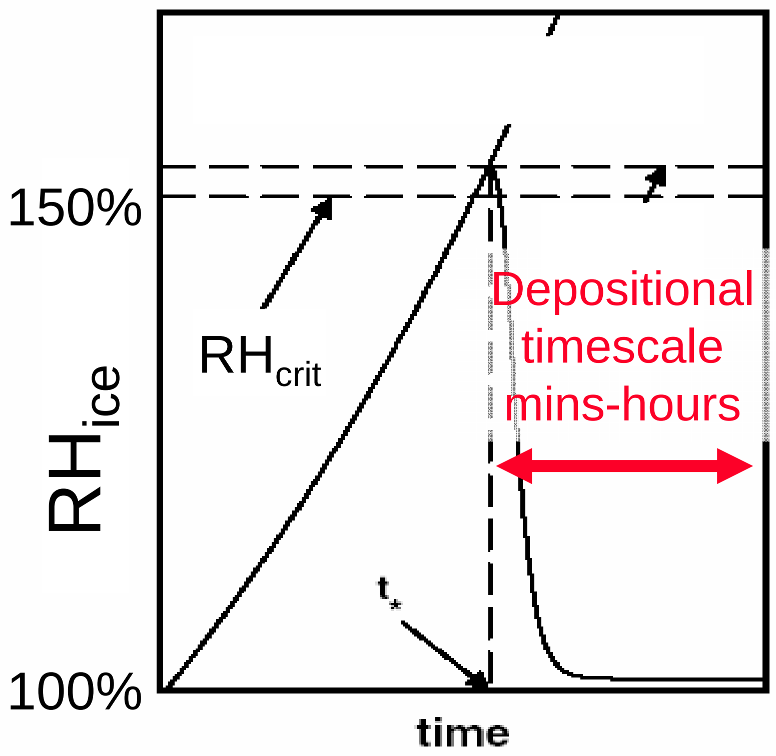
#2 Microphysical Issues



Again…
What level of complexity is required for the task in hand?

Take one example: ice homogeneous nucleation and depositional growth

- Due to relative lack of ice nuclei in the atmosphere, supersaturation with respect to ice is common!
- Threshold for ice nucleation is not q_s^{ice}
- Deposition growth timescale depends on N_i, the number of nucleated ice particles
- Depositional growth timescales may or may not be fast compared to a GCM timestep

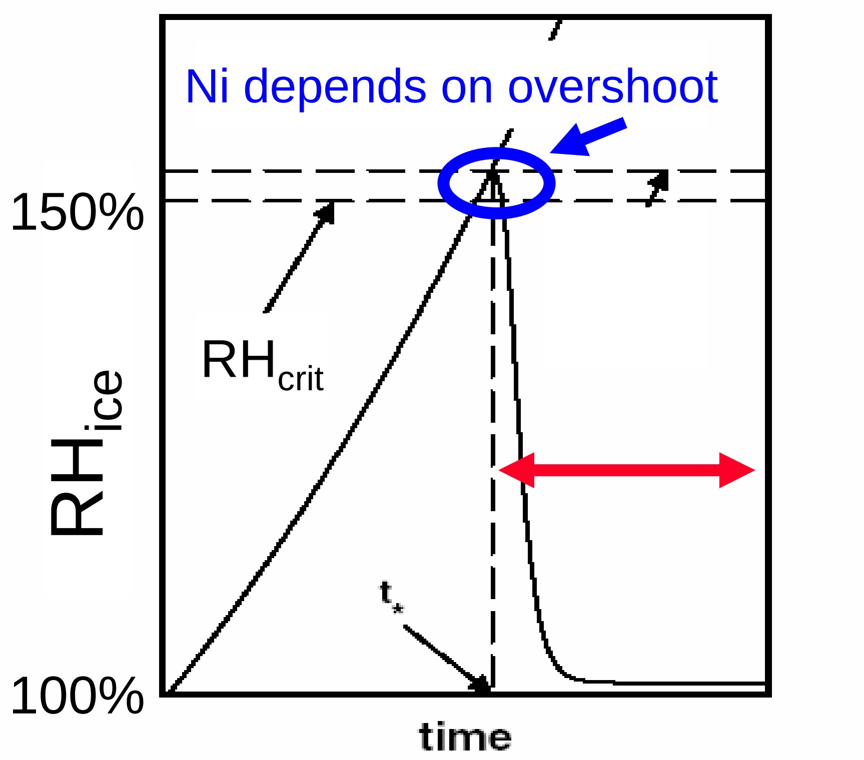


From Karcher and Lohmann

Schematic of evolution of upper air parcel subject to mean ascent

Take one example: ice homogeneous nucleation and depositional growth

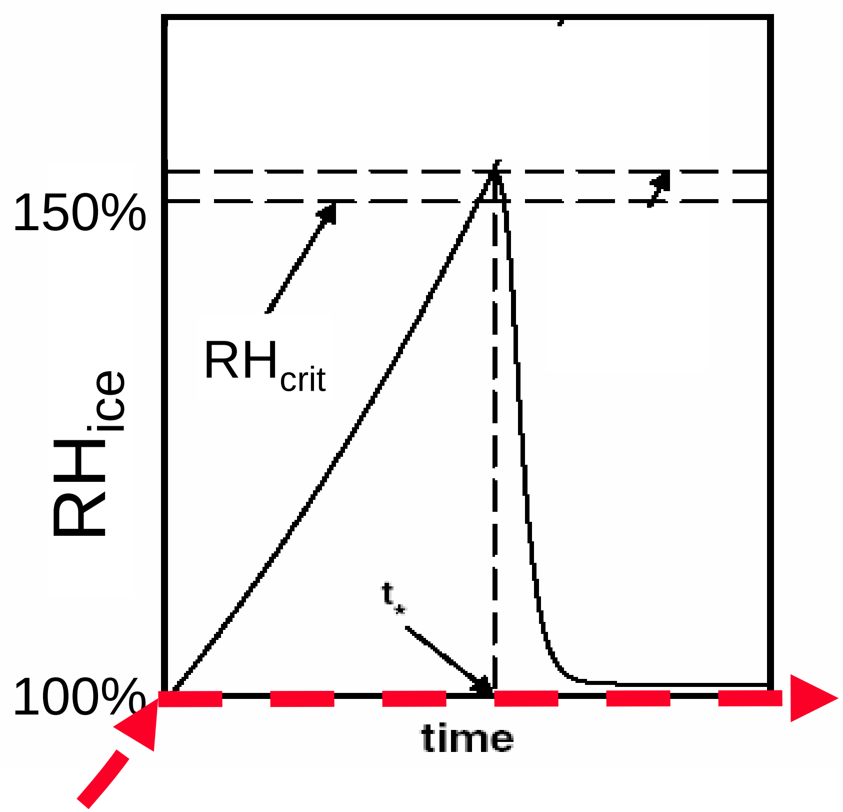
- Ni depends on the period and magnitude of the "overshoot" when RH>RH_{crit} – Not resolved!
- Overshoot depends on vertical velocity spectrum *on the cloud scale*, not the grid-scale



A parameterization of cirrus cloud formation: Homogeneous freezing of supercooled aerosols

B. Kärcher
Deutsches Zentrum für Luft- und Raumfahrt, Institut für Physik der Atmosphäre, Oberpfaffenhofen, Germany

U. Lohmann
Atmospheric Science Program, Department of Physics, Dalhousie University, Halifax, Nova Scotia, Canada

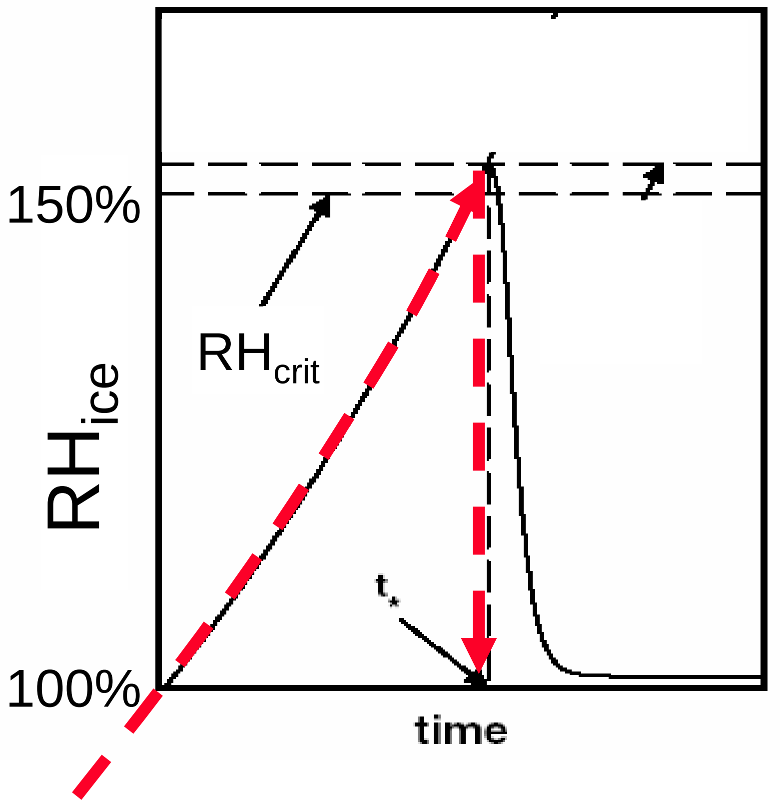


Many GCMs preclude
No supersaturation

ECMWF previous operations
(before 12-9-06)

Assume depositional timescale fast compared to GCM timestep.

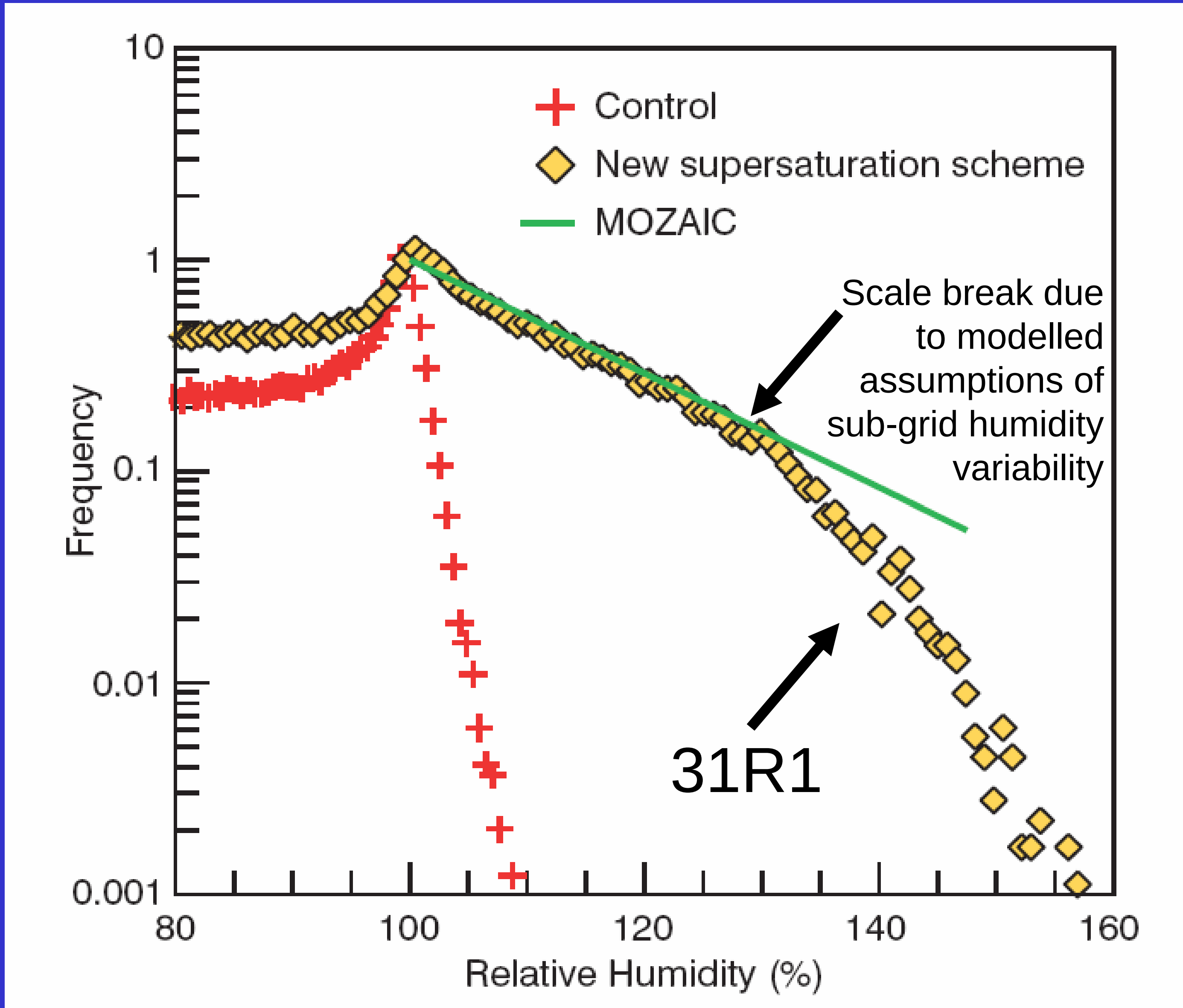
Thus the prognostic approach can be abandoned in favour of a diagnostic adjusment



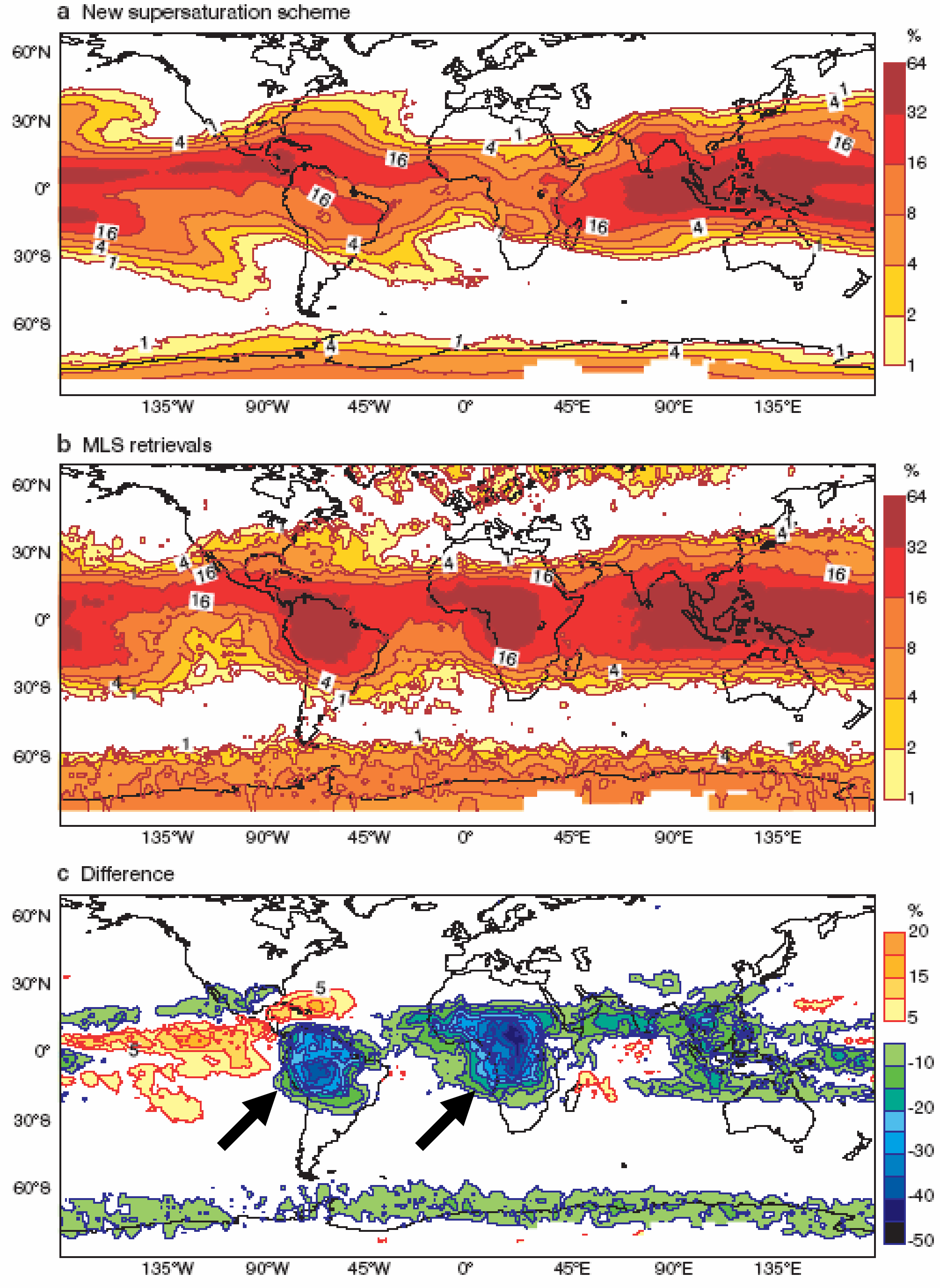
Nucleation threshold modelled, but no deposition growth timescale

ECMWF 31R1
operational 13th Sept 2006

31R1 ECMWF scheme: comparison to Mozaic aircraft data



Comparison to MLS Freq of occurrence of ice super-saturation

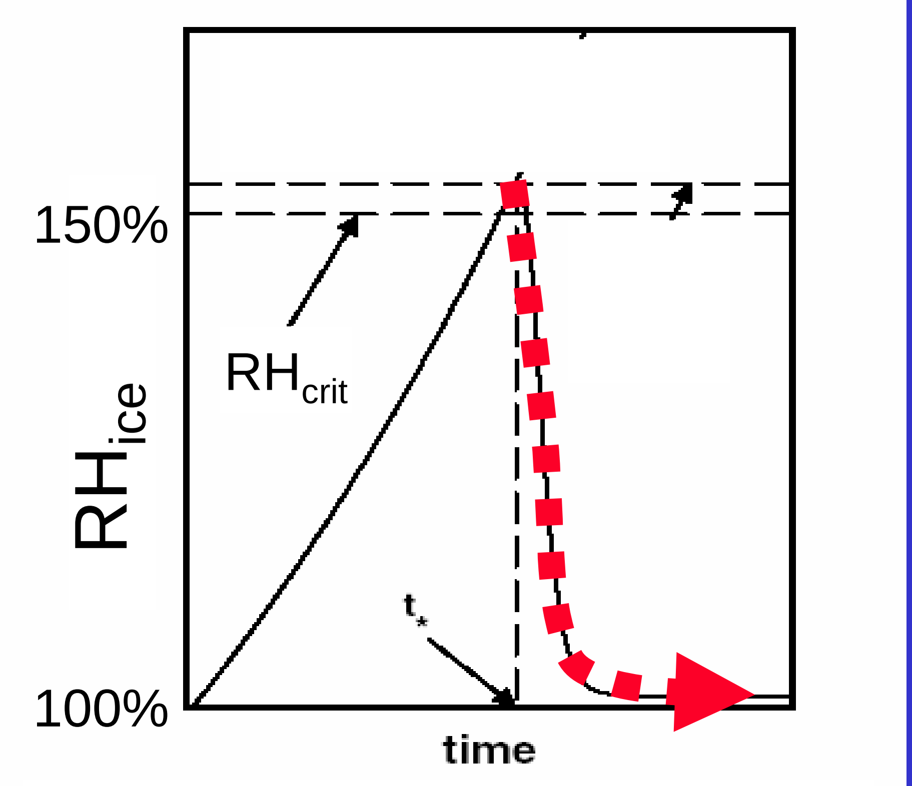


Underestimation of convection over Maritime continents – agrees with other data sources

Ice complications

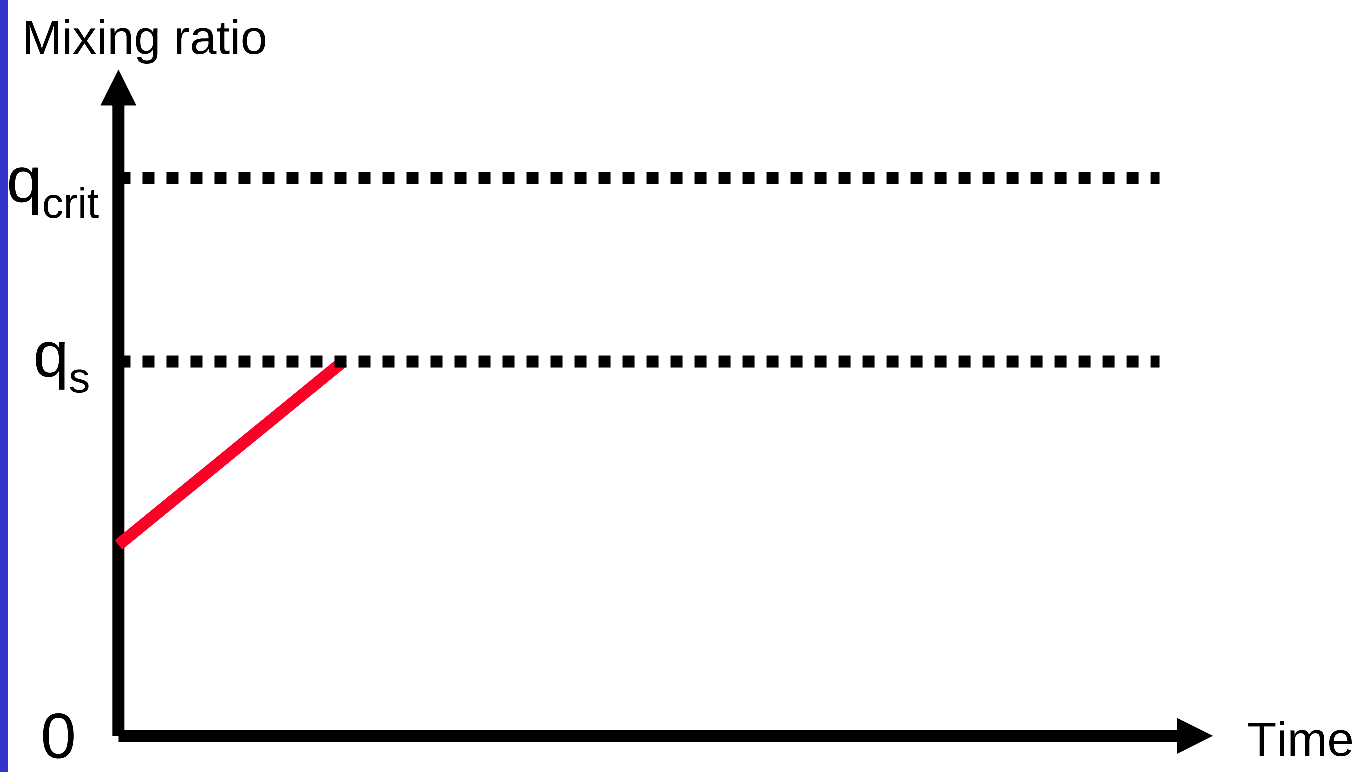
But:

- what if one wishes to model the deposition timescale?
- what are the issues then?



With a homogeneous “CRM” grid box it is not a problem

Gridcell moistening through ascent



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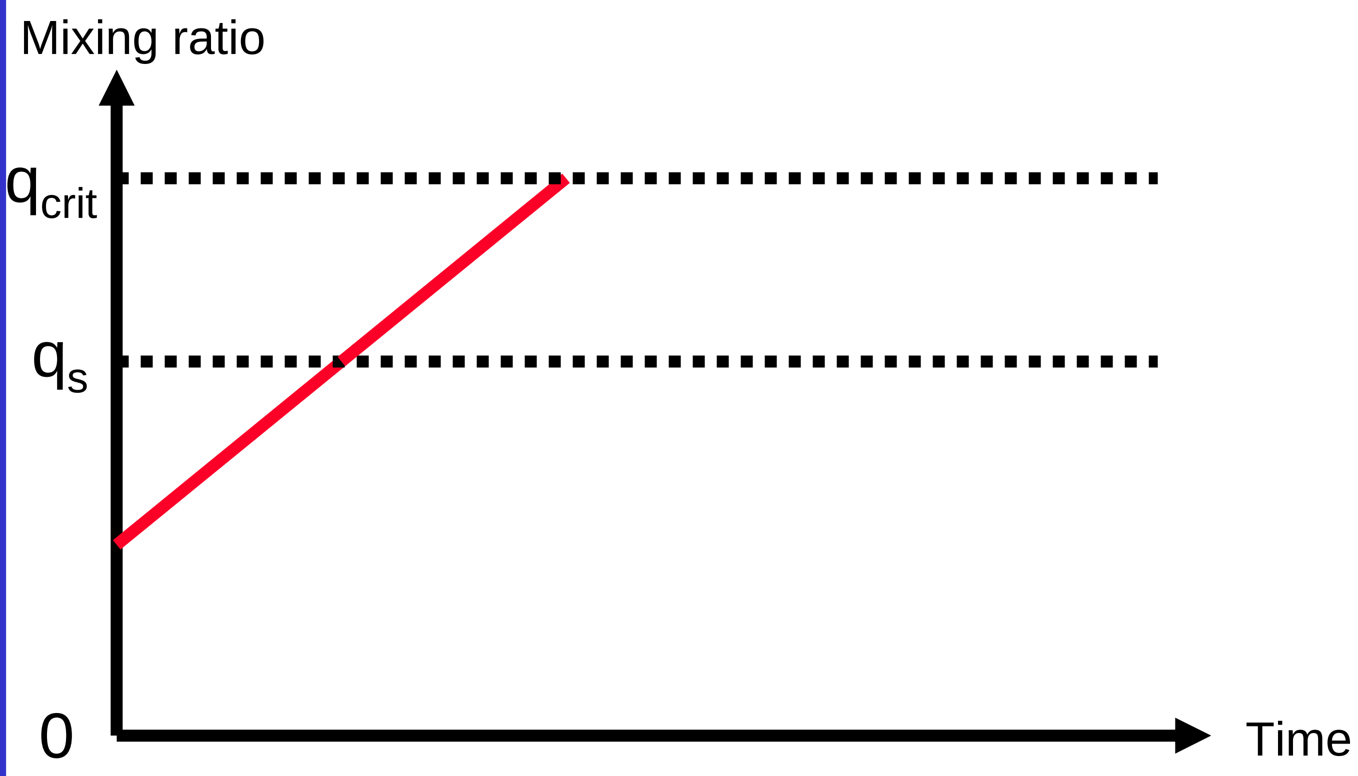

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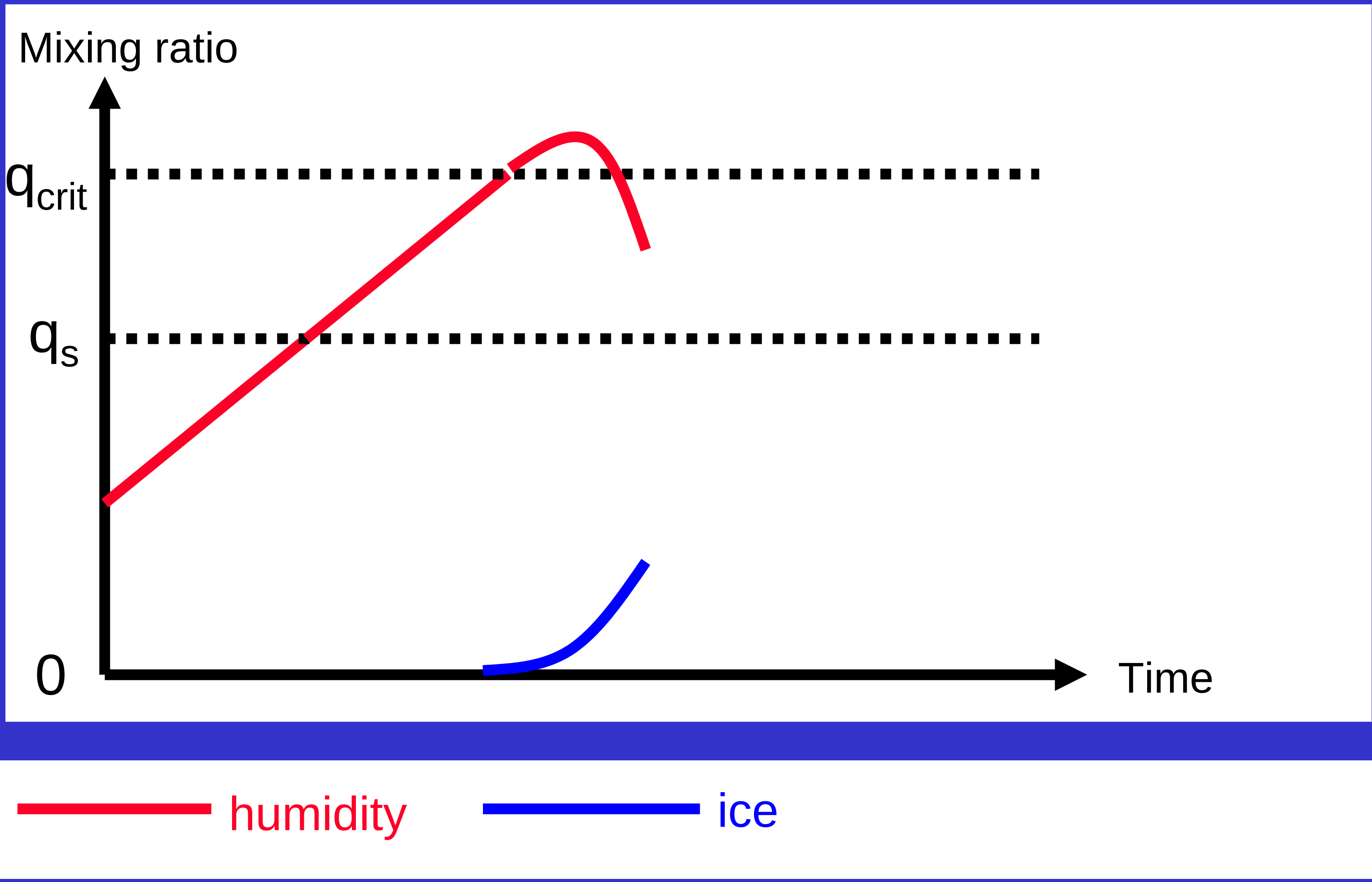

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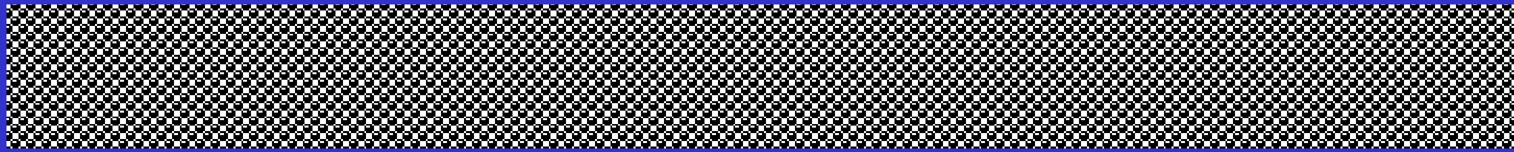
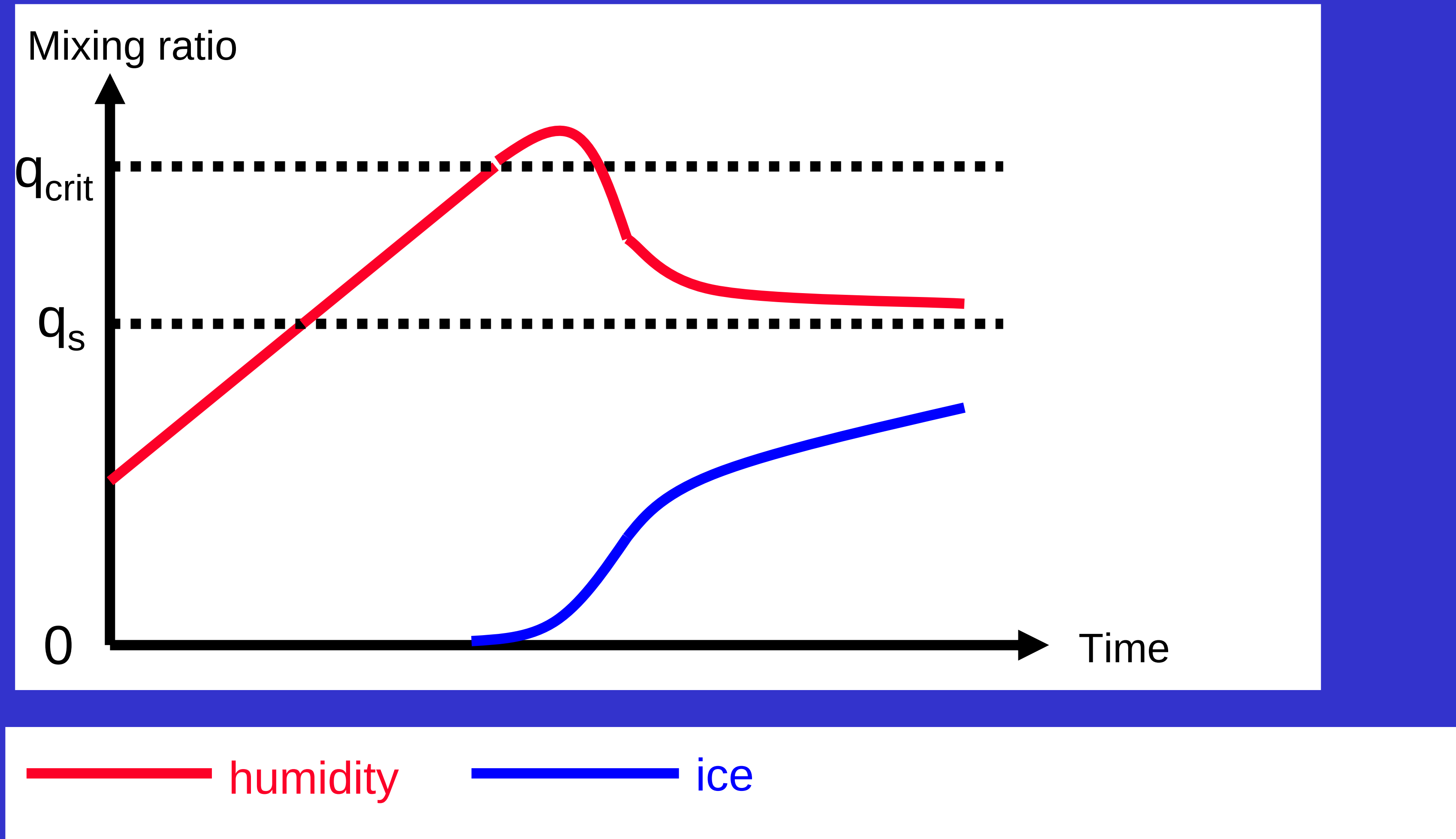
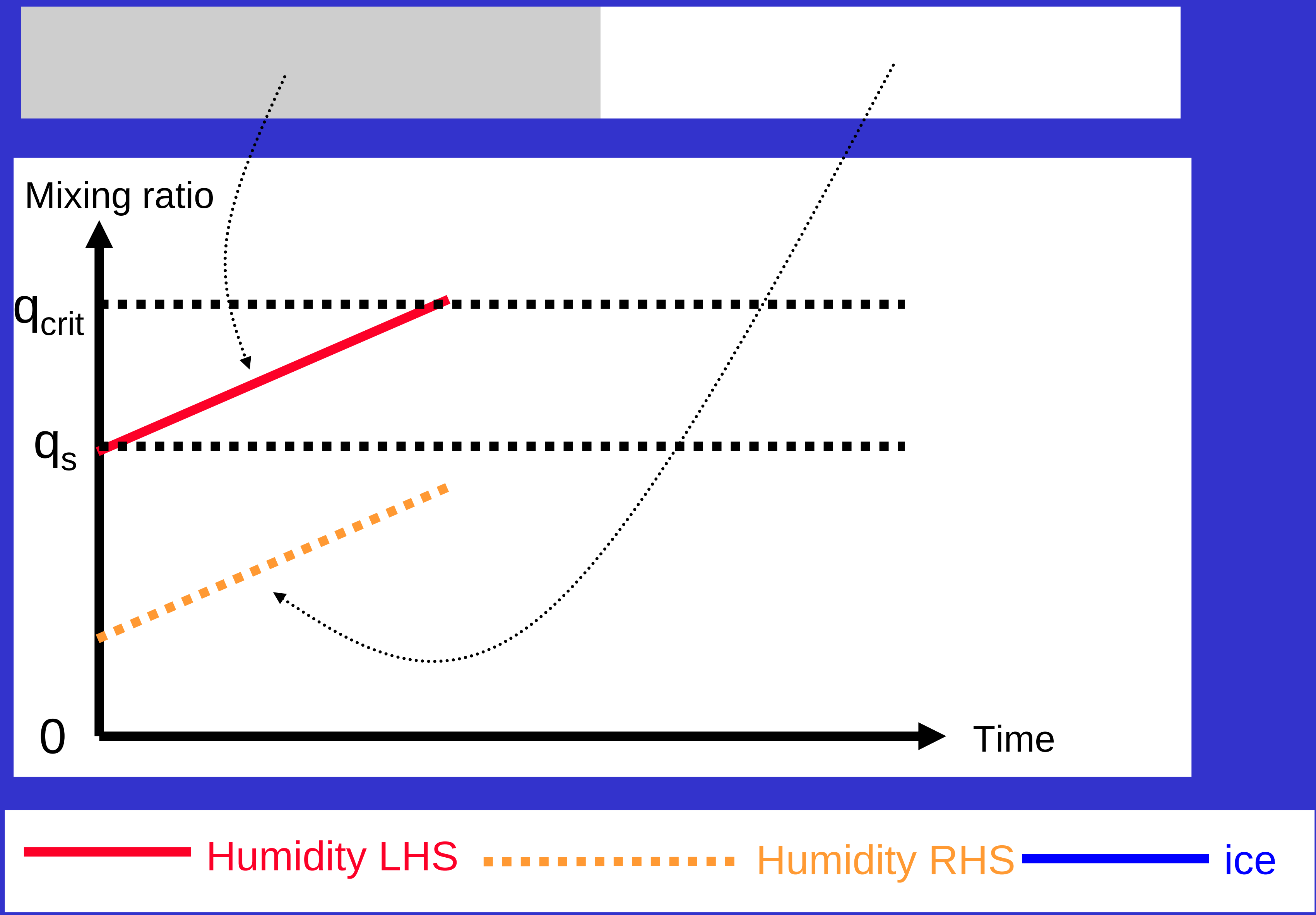




Consider a GCM gridbox with a bimodal distribution of humidity



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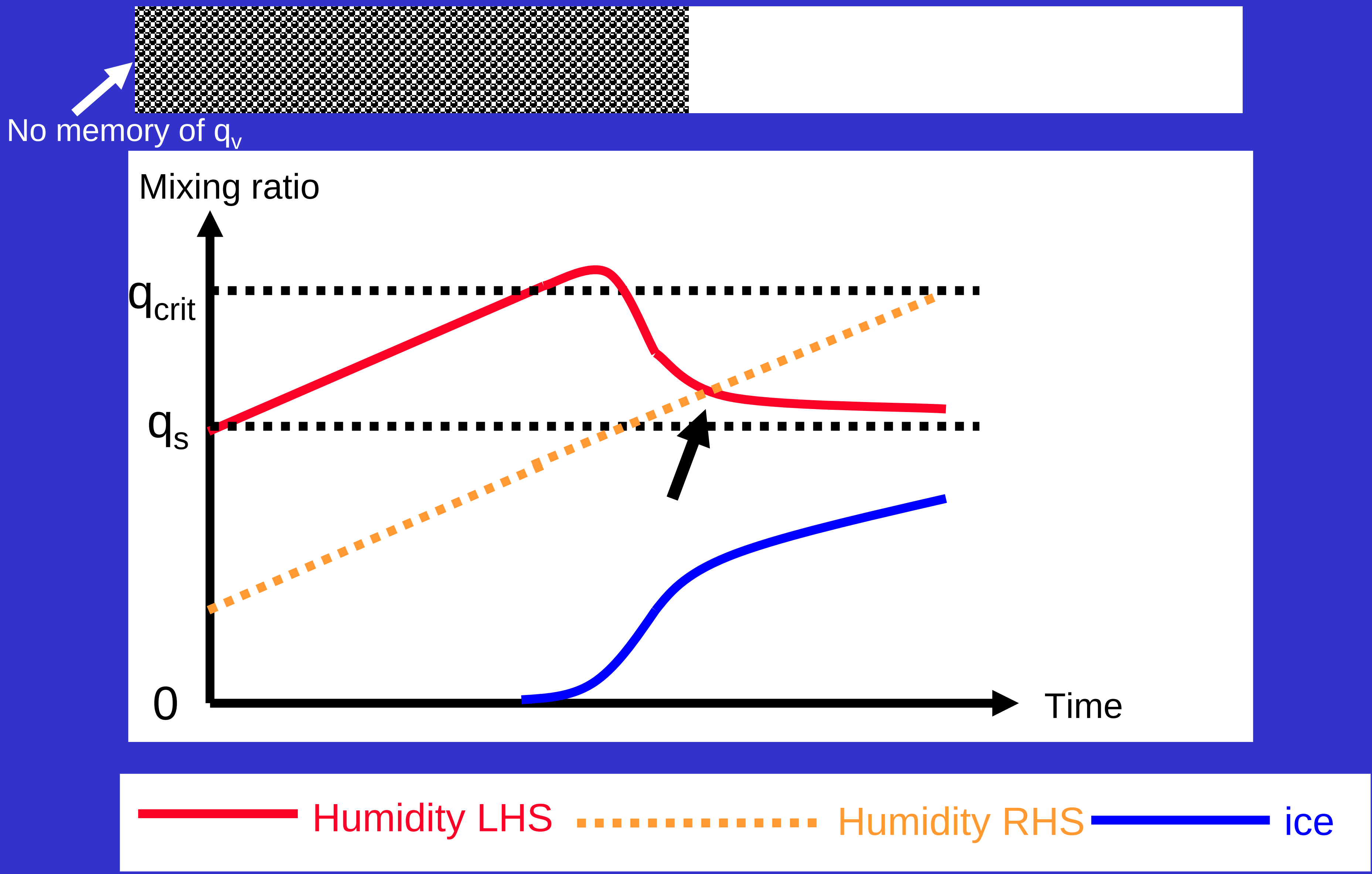

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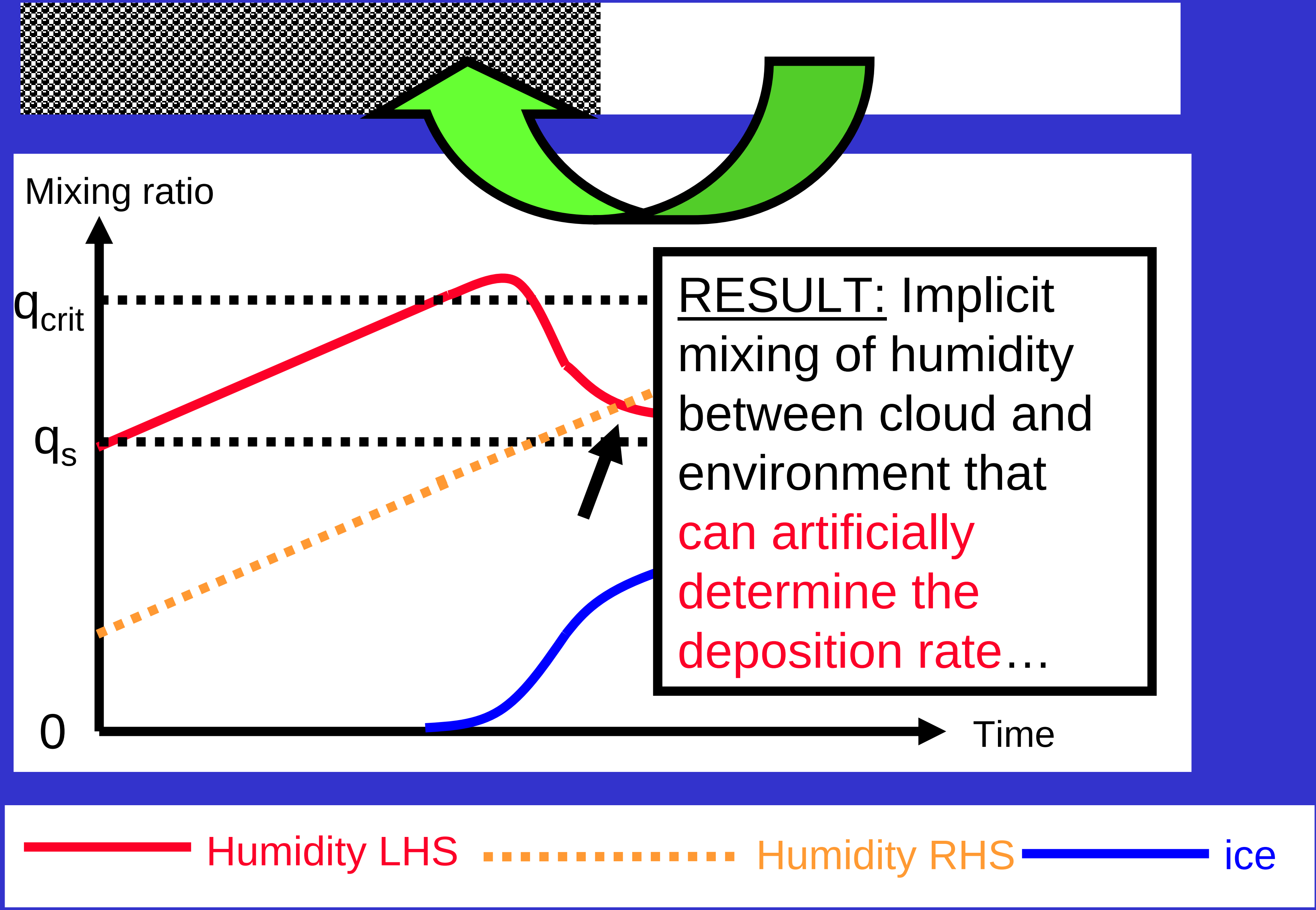


Best approach depends on model requirements:

- Low horizontal resolution
- Long t imesteps

↕

- Model cloud cover? YES
- Model ice deposition? NO

ECMWF CY31R1

- High horizontal resolution
- short timesteps

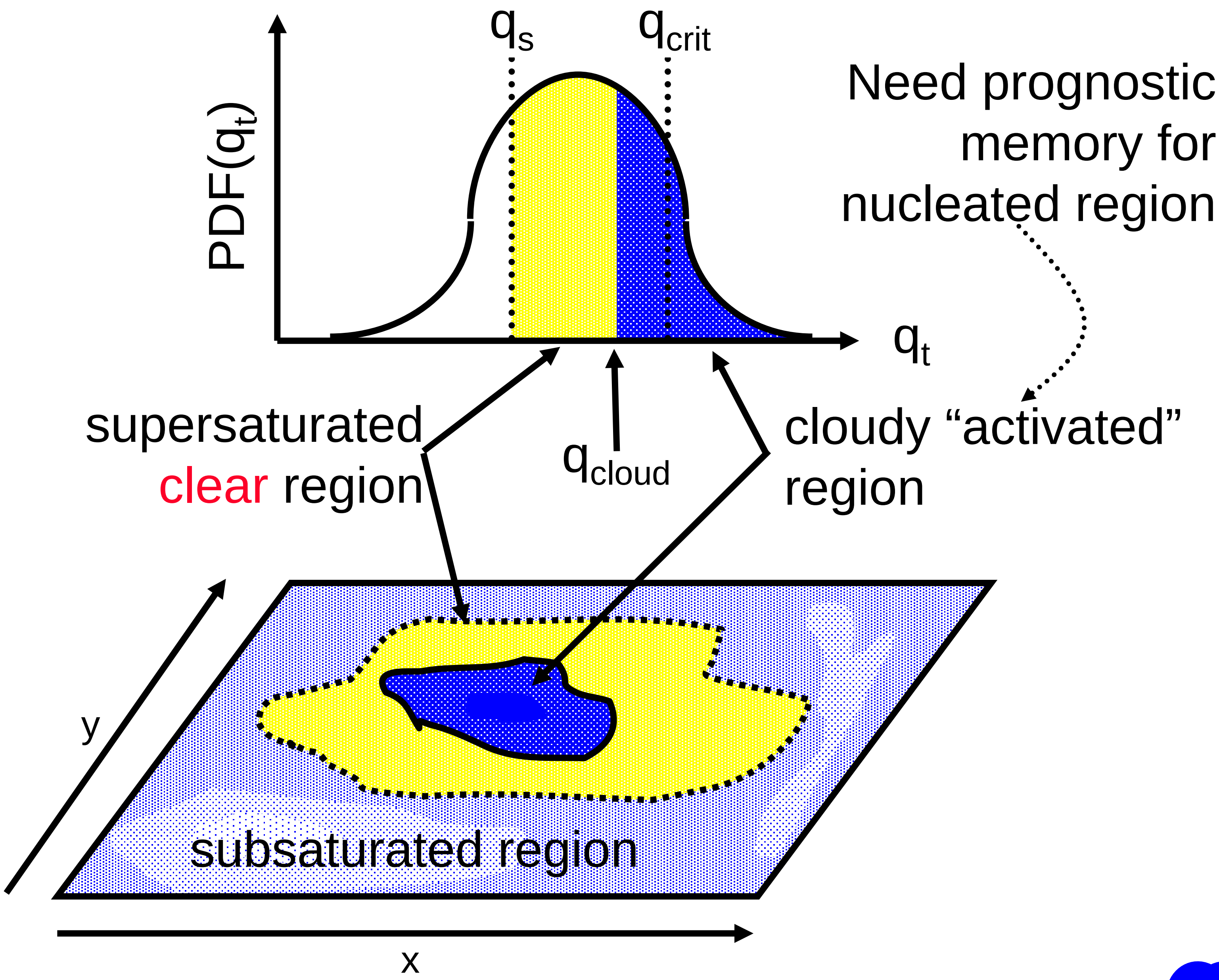
↕

- Model cloud cover? NO
- Model ice deposition? YES

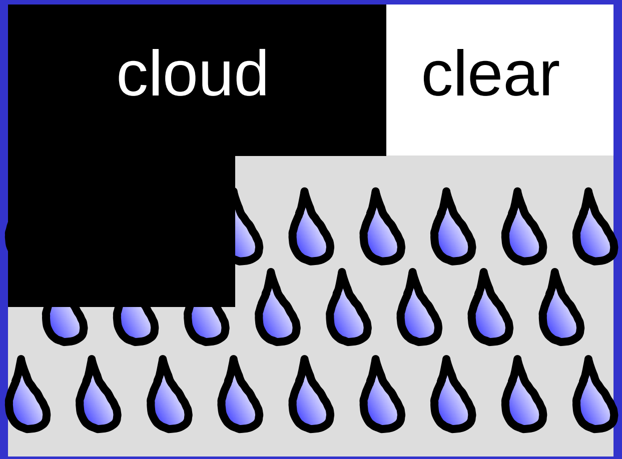
ECHAM 5: Lohmann & Kaecher

Note: Can't do <u>both</u> correctly and simultaneously without adding an additional memory for clear sky humidity: e.g. (1) prognostic in-cloud humidity (2) Statistical PDF scheme

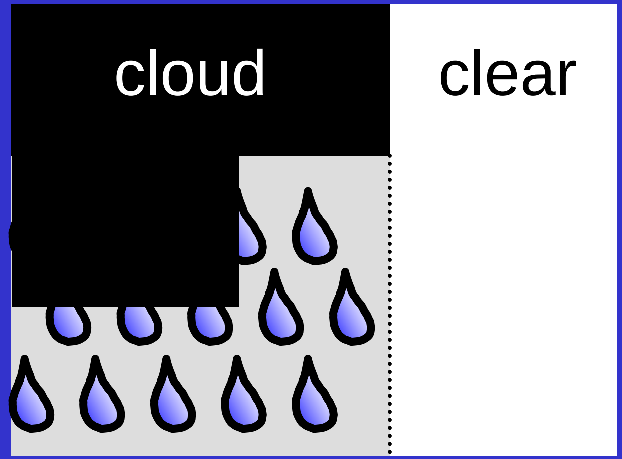
Statistical scheme framework



This issue arises again and again: Rainfall Evaporation



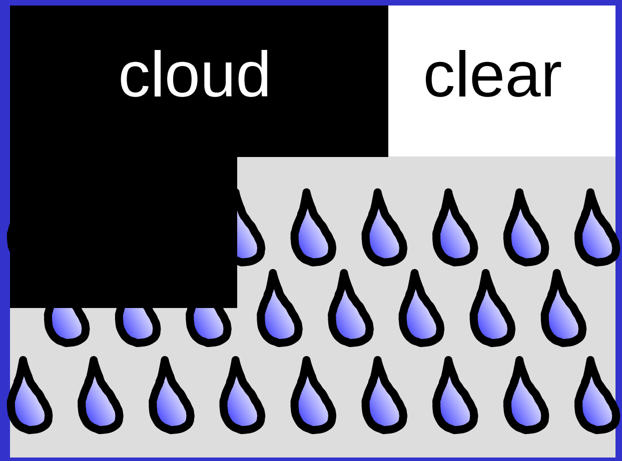
Traditional: Rainfall occupies clear sky fraction



Jakob and Klein 99: Parametrized Rainfall fraction

Again, if no memory for subgrid humidity fluctuations…

This issue arises again and again: Rainfall Evaporation



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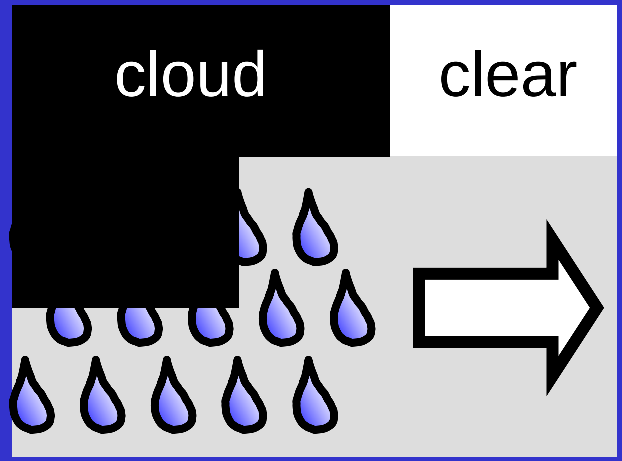


Jakob and Klein 99: Parametrized Rainfall fraction

Again, if no memory for subgrid humidity fluctuations… evaporated rain is spread across gridcell – Solutions only differ since rainfall evaporation is a nonlinear process…

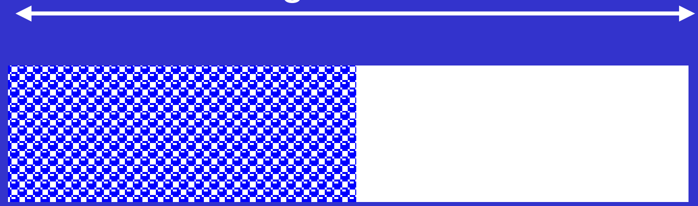
Which is correct?

This issue arises again and again: Mixed Phase Clouds

In-cloud humidity

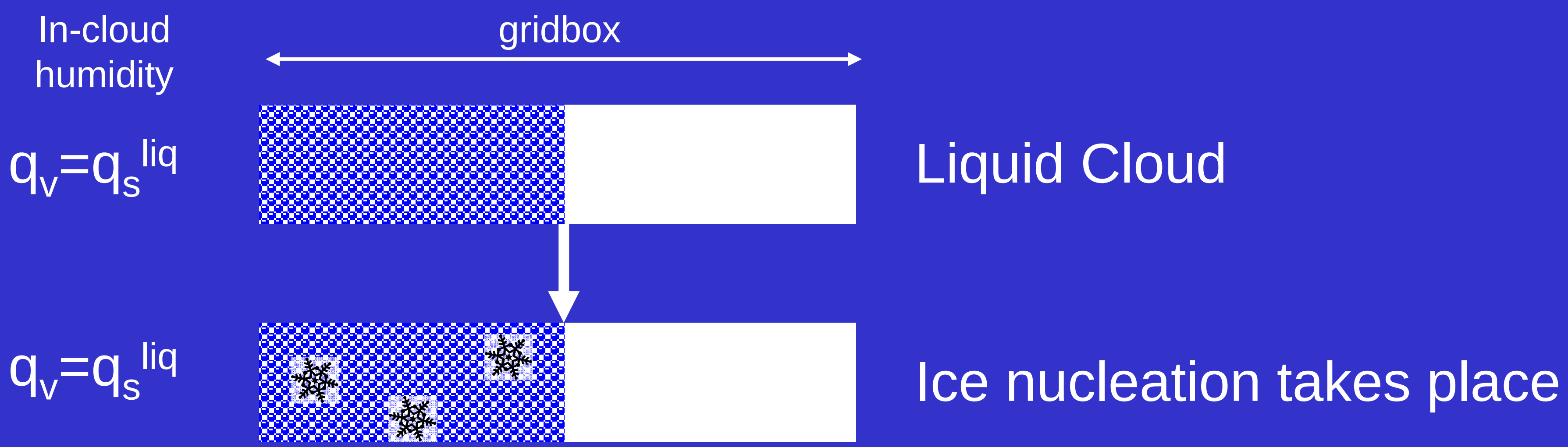
gridbox

$q_v = q_s^{liq}$



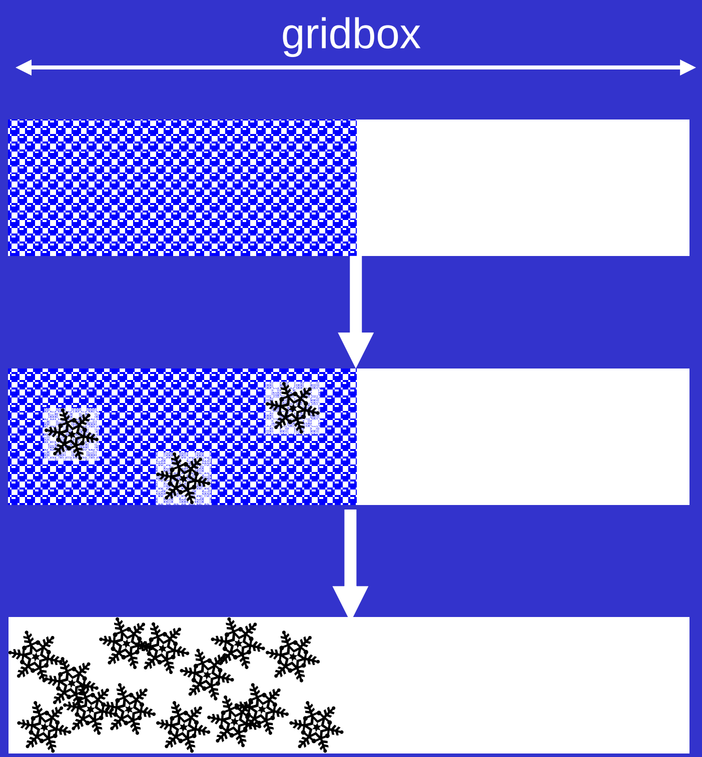
Liquid Cloud

This issue arises again and again: Mixed Phase Clouds



This issue arises again and again: Mixed Phase Clouds

In-cloud humidity



$q_v=q_s^{liq}$ Liquid Cloud

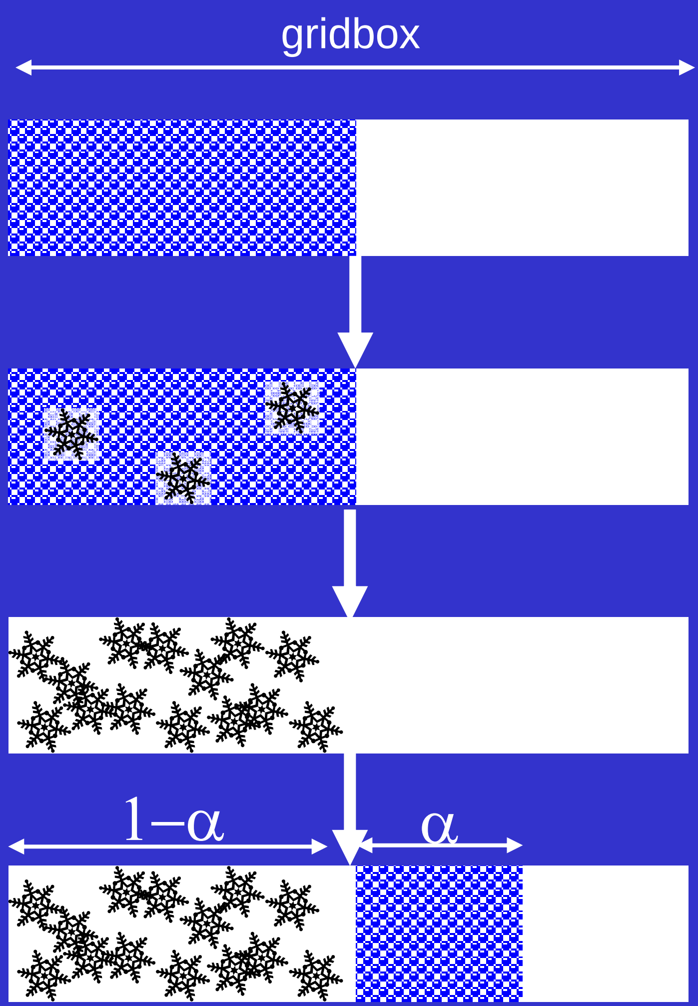
$q_v=q_s^{liq}$ Ice nucleation takes place

$q_v=q_s^{ice}$ Cloud glaciates

(note deposition problem again)

This issue arises again and again: Mixed Phase Clouds

In-cloud humidity



$q_v = q_s^{liq}$ — Liquid Cloud

$q_v = q_s^{liq}$ — Ice nucleation takes place

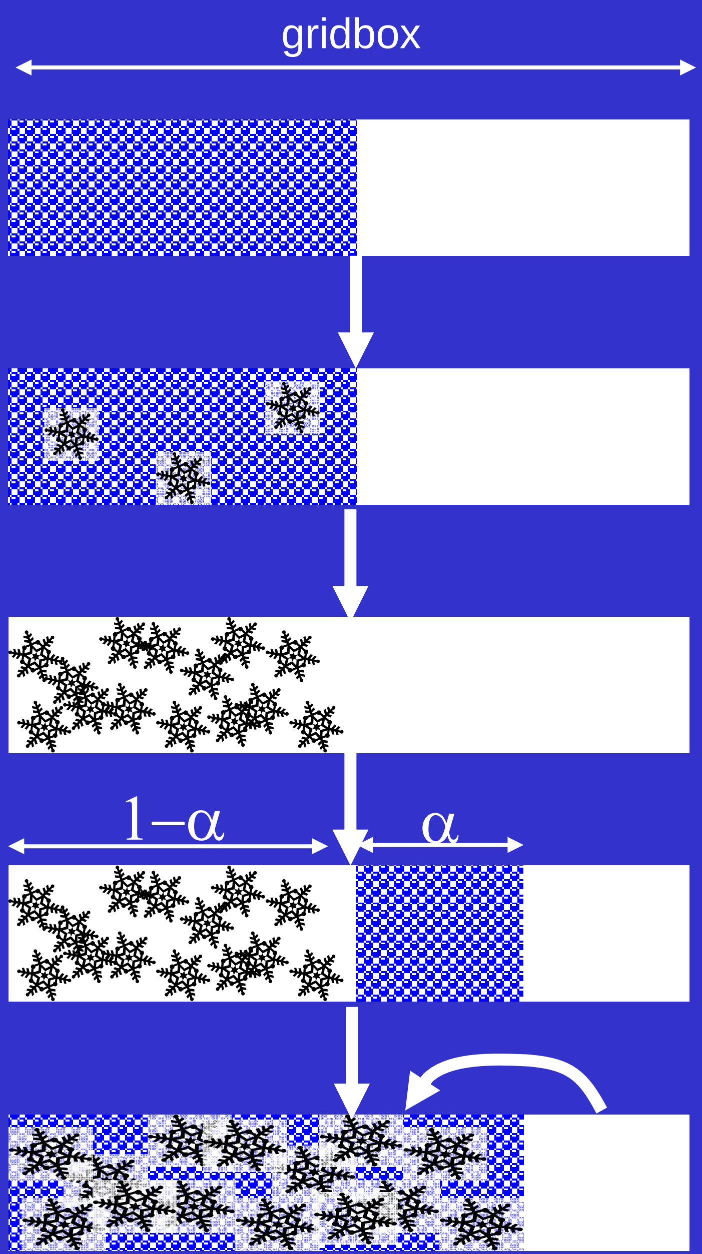
$q_v = q_s^{ice}$ — Cloud glaciates

(note deposition problem again)

$q_v = \alpha q_s^{liq} + (1-\alpha)\, q_s^{ice}$ — Adiabatic cooling produces further condensation

This issue arises again and again: Mixed Phase Clouds

In-cloud humidity



$q_v = q_s^{liq}$ — Liquid Cloud

$q_v = q_s^{liq}$ — Ice nucleation takes place

$q_v = q_s^{ice}$ — Cloud glaciates

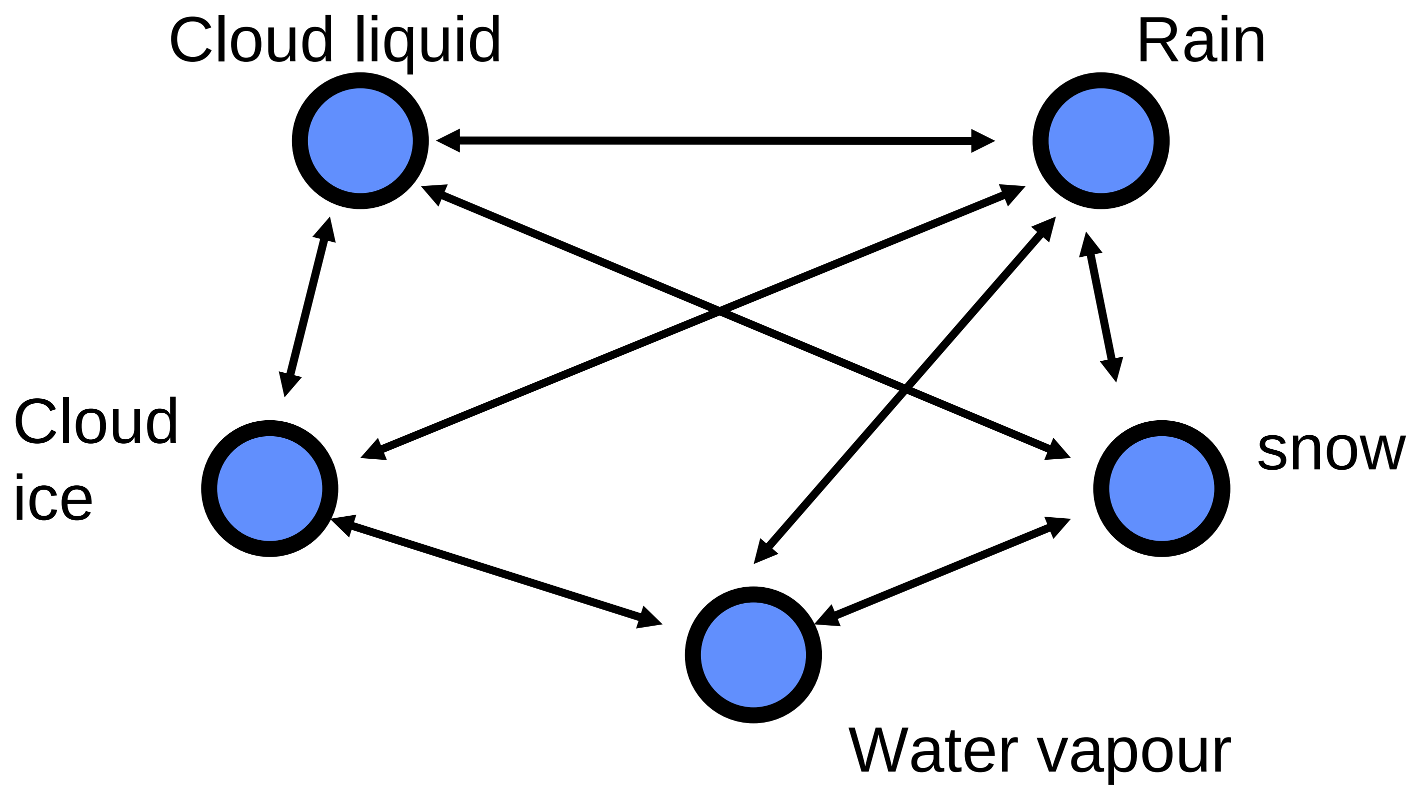
(note deposition problem again)

$q_v = \alpha q_s^{liq} + (1-\alpha)\, q_s^{ice}$ — Adiabatic cooling produces further condensation

$q_v = q_s^{liq}$ — Artificial mixing? In-cloud humidity increases!

#3 Numerics

Multi-phase microphysics with long timesteps



sources/sinks of q_i

$$\frac{\partial q_i}{\partial t} = A_i + \frac{1}{\rho}\frac{\partial}{\partial z}(\rho V_i q_i),$$

i = variable index

Fall speed of q_i

One method: upstream, forward in time implicit solver

n = time level

m = # of microphysical categories

$$\frac{q_i^{n+1}-q_i^n}{\Delta t} = A_i + \sum_{j=1}^{m} B_{ij} q_j^{n+1} - \sum_{j=1}^{m} B_{ji} q_i^{n+1} + \frac{\rho_{z-1} V_i q_{i,z-1}^{n+1} - \rho V_i q_i^{n+1}}{\rho \Delta Z}.$$

Explicit terms

Implicit terms

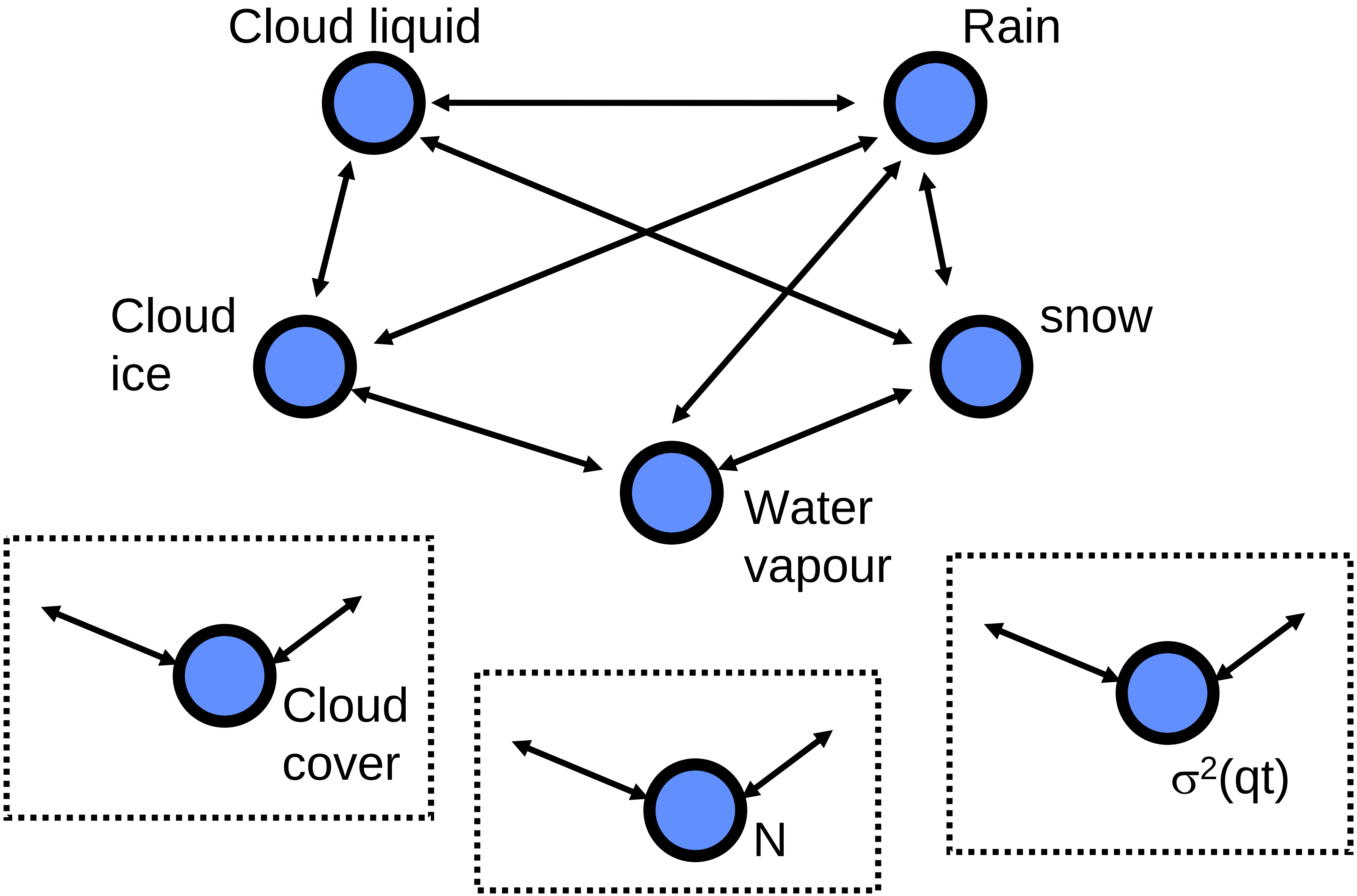
Straightforward to solve resulting matrix equation, fast for small m

Note: $q_i + q_j \Rightarrow q_k$ cross terms neglected…

Numerics

- Implicit methods:
  - Easy to implement
  - Are quite diffusive
- Semi-Lagrangian advection for precipitation
  - Less diffusive
  - More difficult to handle interaction with other fast processes
- Time-splitting methods
  - Allows simple explicit numerical methods
  - Again difficult to handle interaction between fast processes

Multi-Moment Issues,

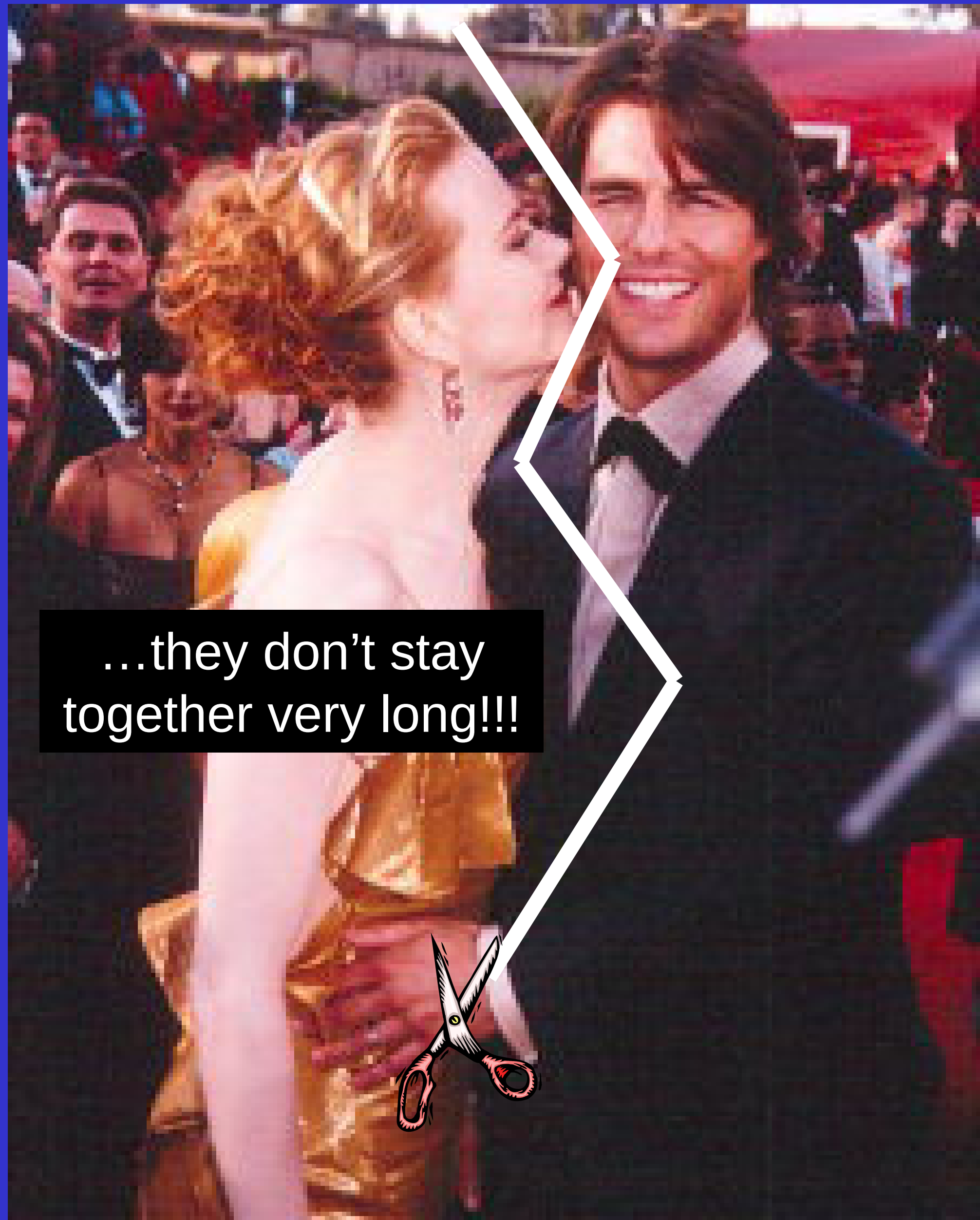


Numerical issues

- Since cloud variables are positive-definite, handling more than 1 simultaneous "descriptor" can lead to conflicting states
- e.g. Cloud cover: Cloud water $q_c = 0$, Cloud cover $C > 0$ or vice versa
- E.g. Statistical Scheme, q_v+q_i and $\sigma^2(q_t)$ indicate clear sky yet $q_i>0$
- Cloud variables are like a celebrities…

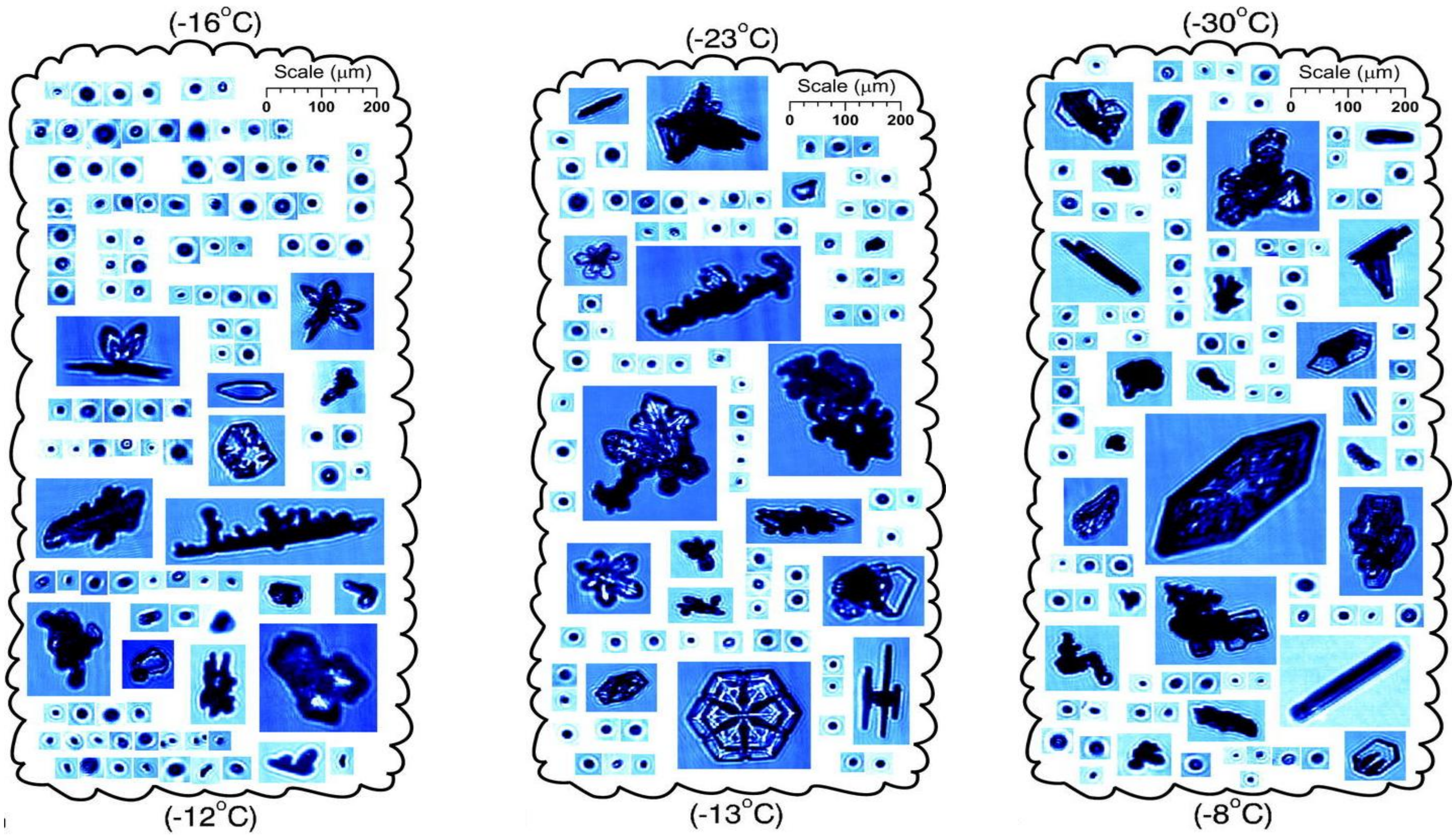
Numerical issues

- Since cloud variables are positive-definite, handling more than 1 simultaneous "descriptor" can lead to conflicting states
- e.g. Cloud cover: Cloud water $q_c = 0$, Cloud cover $C > 0$ or vice versa
- E.g. Statistical Scheme, $q_v + q_i$ and $\sigma^2(q_t)$ indicate clear sky yet $q_i > 0$
- Cloud variables are like a celebrities…



#4 Observations

In-situ aircraft observations

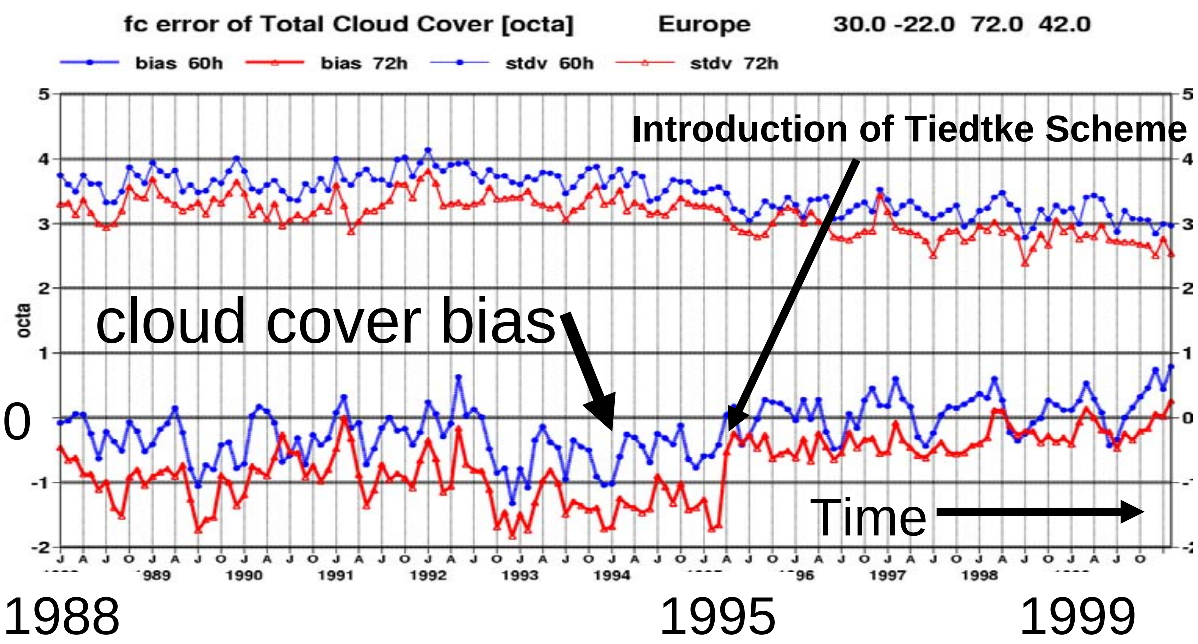


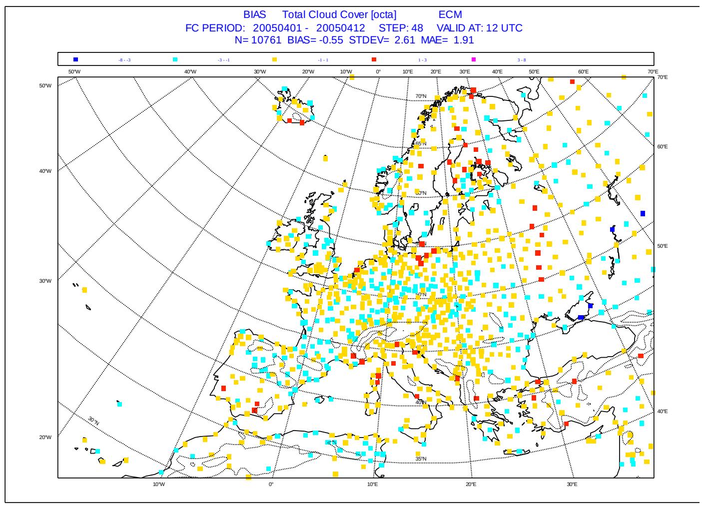
From Fleishauer et al 2002, JAS

In situ observations can give us information concerning:
Ice habits, liquid water and ice amounts, radiative properties, horizontal distributions (mixed phase) etc…
…for isolated snap shots of clouds.

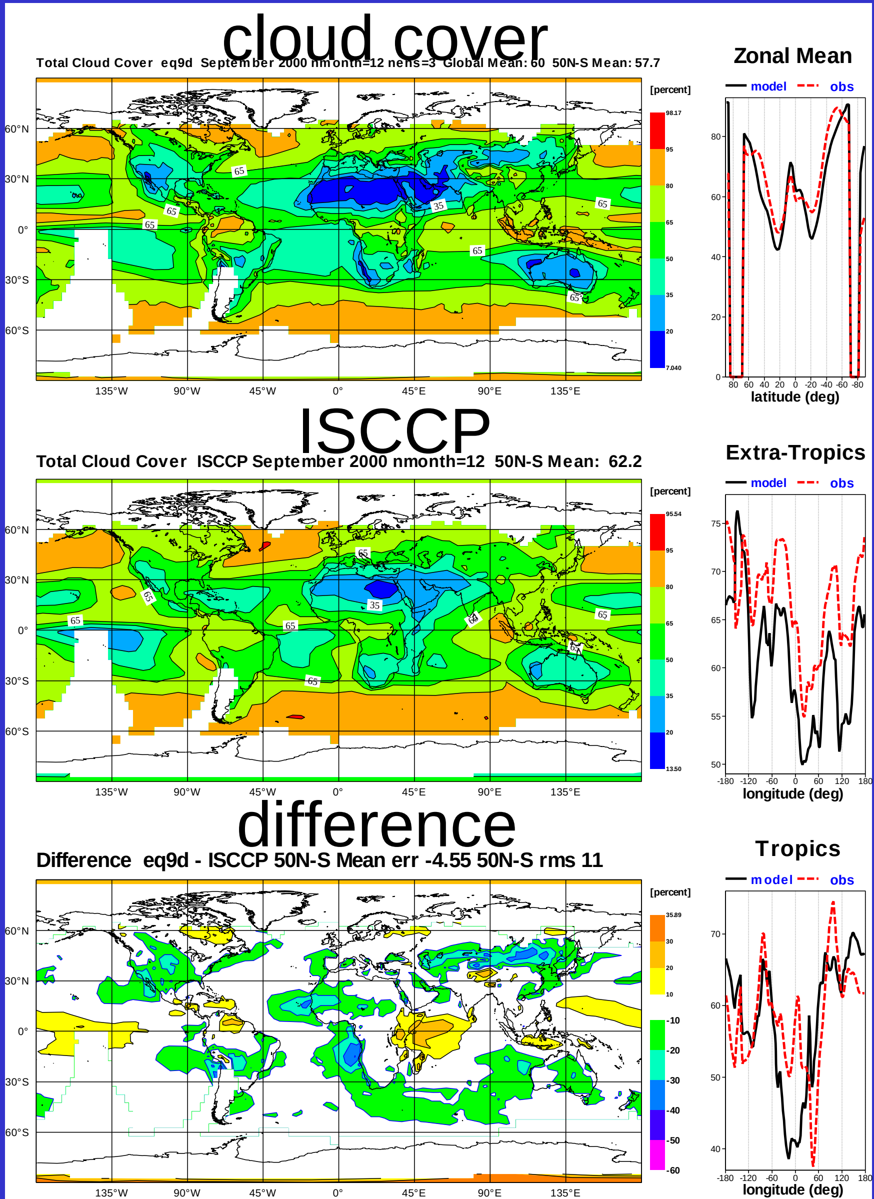
And NWP forecast evaluation?

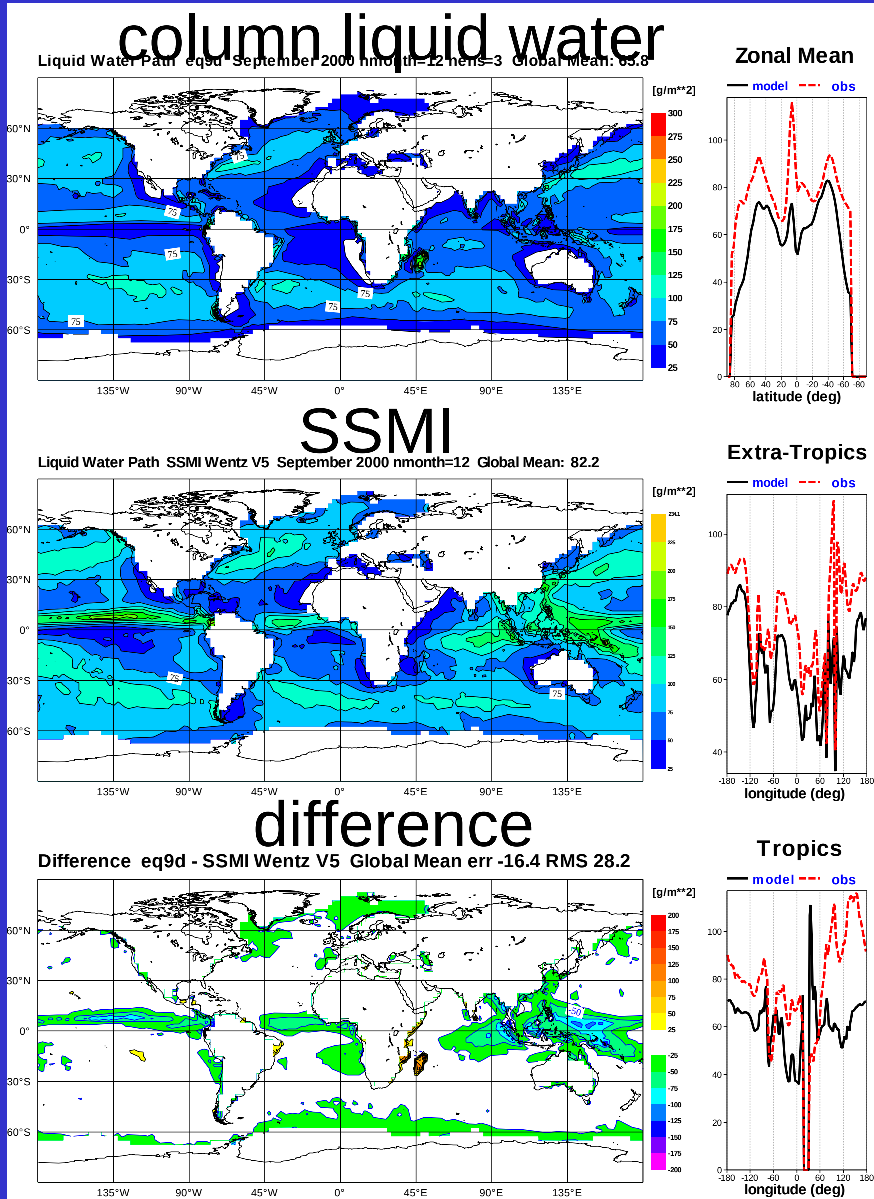
- Differences in longer simulations may not be the direct result of the cloud scheme
  - Interaction with radiation, dynamics etc.
  - E.g: poor stratocumulus regions
- Using short-term NWP or analysis restricts interactions and allows one to concentrate on the cloud scheme





ECMWF also perform 12 month "climate" integrations





Traditionally lack of ice information: MLS and CloudSat

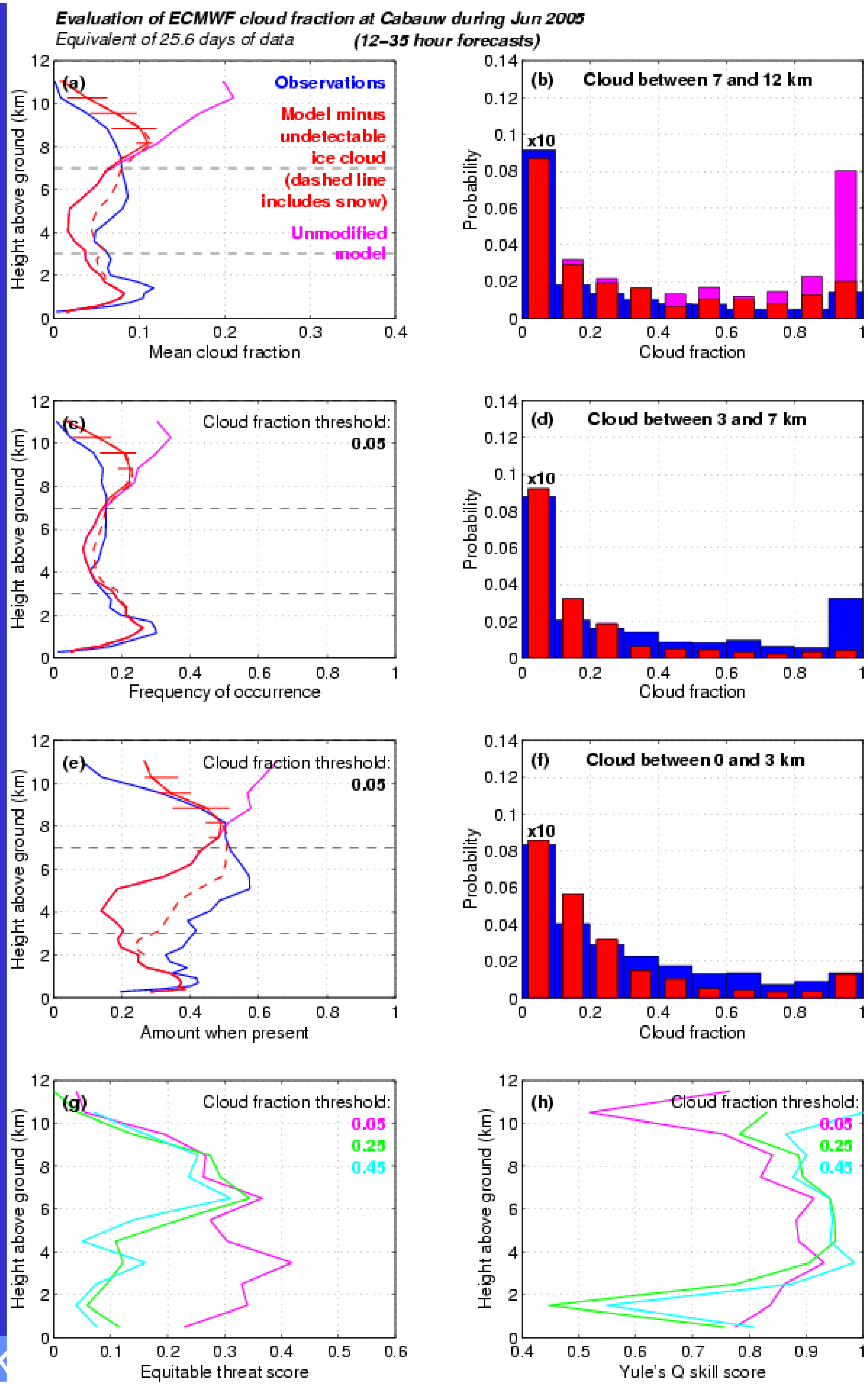
ECMWF climate runs dataset archive

RAIN	GPCP V2	Jan 1979 - Mar 2006 *
	Xie-Arkin	Jan 1979 - Dec 1999
	SSM/I	Jul 1987 – Oct 2003
	TRMM/TMI	Jan 1998 – May 2006 *
Cloud Cover	ISCCP D2	Jul 1983 – Sept 2001
	MODIS	Sept 2000 – July 2001 *
TOA Radiative Fluxes	CERES ERBE NOAA IR	Mar 2000 - Jun 2003 *
TCWV	SSM/I	
	TRMM/TMI	
CIWC	MLS Aura v1.51	Aug 2004 – July 2006*
TCLW (LWP)	SSM/I	
	TRMM/TMI	
TCIW (IWP)	NOAA	1987-1991 (climate)
Surface fluxes	Da Silva climatology	
Surface Winds	SSM/I QUIKSCAT	 Mar 2000-onwards*

- Should such a test become standard?
- Should models be tested in both NWP & climate modes?

Cloudnet Operational Monitoring www.cloud-net.org

- Long term statistics are available comparing to ground-based radar
- This example is for ECMWF cloud cover during June 2005 – 3 operational models are evaluated
- Includes pre-processing to account for radar attenuation and snow
- Important for NWP: is quasi-realtime

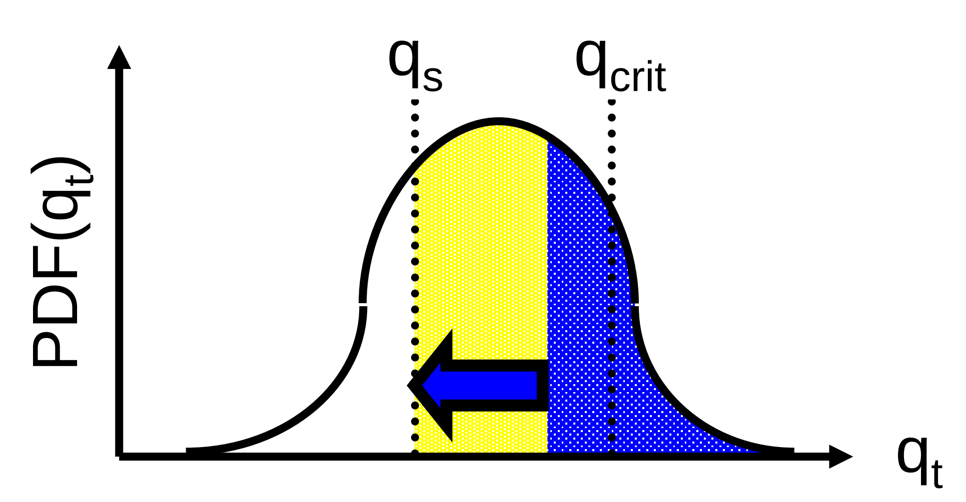


The Future at ECMWF ?

- Future development at ECMWF is likely to take the form of a hybrid scheme
- Prognostic equations for q_v, q_i/q_l, q_t, variance of q_t, but also cloud cover
- There is no redundancy between these variables if supersaturation is allowed
- <u>However, writing sources terms self-consistently for these variables will be difficult</u>

<u>Prognostic Equation Set</u> :

$$q_v$$
$$q_l$$
$$q_i$$
$$\sigma^2(q_t)$$
$$C$$



Outline

- Macrophysical issues
- Microphysical issues
- Numerical issues
- Validation issues
- “ T ” issues

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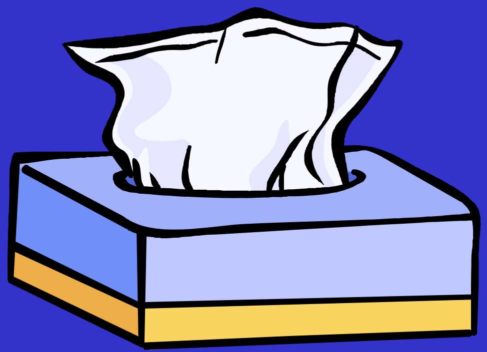

Issues concerning representing clouds in Large-Scale models

- Complex array of microphysical processes: Difficult to observe with cloud chambers and aircraft data.
- Problem made much worse in LS models due to subgrid-scale effects – Impossible to separate mIcro and mAcro-scale physics
- Numerical issues are also important for long timesteps
- Verification of model clouds is also difficult and without consensus especially ice clouds

Specific Questions for this Workshop?

- Microphysical Issues:
  - Which microphysical processes are key for climate/NWP? Esp. Ice?
  - How much complexity is required? E.g. IFS
- Macrophysical Issues:
  - Are statistical cloud schemes the way forward?
  - If yes: What complexity of PDF is required? (Uni/bi/multi modal?)
  - How will we parametrize process influence on PDF moments?
- Numerical Issues: Can we do better than simple implicit methods?
- Observations:
  - Where should our priorities lie with cloud observations?
  - What timeliness is required for NWP?
  - Should models be validated in both NWP modes and Climate modes?
  - How can we best use the observations we already have? Should a centralized database of tests be organised?