The effect of a simple homogeneous ice nucleation on the ECMUF model

or "progress (or lack thereof) in the representation of ice physics in the IFS"

<u>Aim of this presentation</u>: To outline some of the complexity of implementing even a simple microphysics into a large-scale model with fractional cloud cover

<u>Contents</u>:

(1) Simple supersaturation scheme

(2) SCM and 3D results

(3) Future and outlook

Adrian Tompkins, ECMUF, UK

<u>With many thanks to Klaus Gierens, DLR</u>

Much of this talk also inspired by

Ulrike Lohmann and Bernd Karcher

with thanks to Klaus…

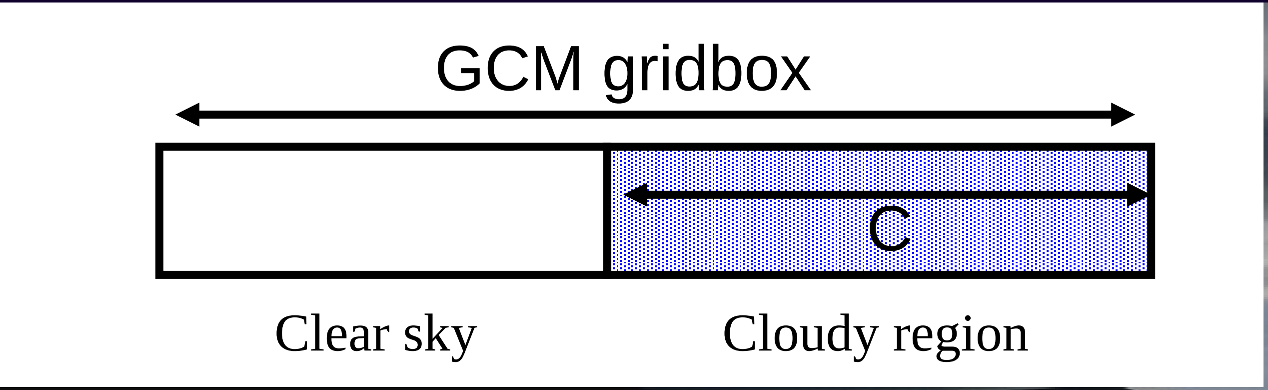
Current ECMWF cloud schemes

	Forecast Scheme	Analysis Scheme
Prognostic Variables	T, q_v, q_{cl}, C	T, q_v
	Sources and sinks from VDF, convection, radiation, dynamics…	**Statistical diagnostic scheme with convective source term**

Neither Scheme allows for supersaturation

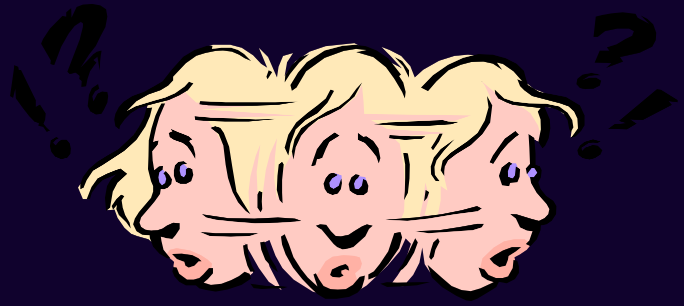
1. Approach

- **We are interested in representing supersaturation**
- **1st attempt, include simple parameterization in existing ECMWF cloud scheme**
- **Desires:**
  - Supersaturated clear-sky states with respect to ice
  - Existence of ice crystals in locally subsaturated state

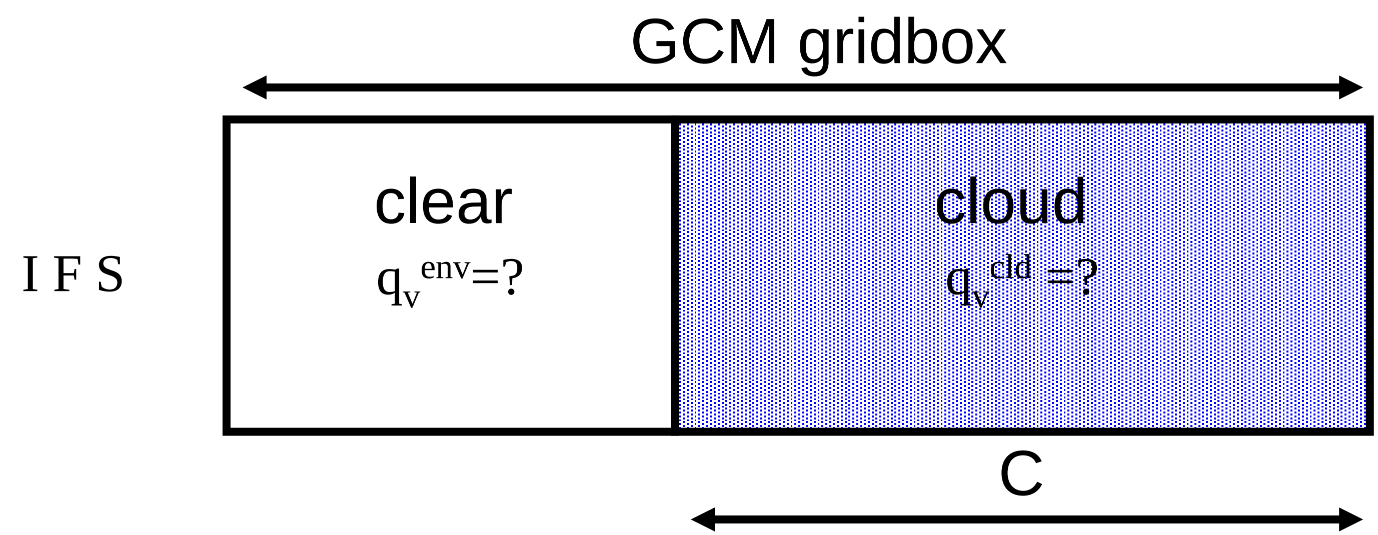


1. Approach

- **Desires:**
  - Supersaturated clear-sky states with respect to ice
  - Existence of ice crystals in locally subsaturated state
- **<u>Not possible</u> to model sublimation and nucleation timescales without either**
  - (a) Additional prognostic equation(s), or
  - (b) Simplifying assumptions
- **What does this mean?**



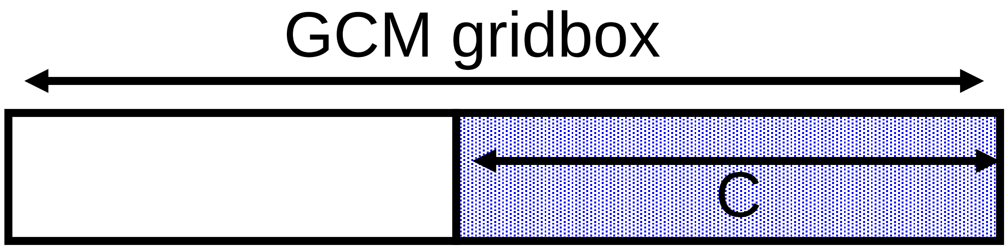
Unlike “parcel” models, or high resolution LES models, we have to deal with subgrid variability



Three items of information: q_v, q_i, C (vapour, cloud ice and cover)

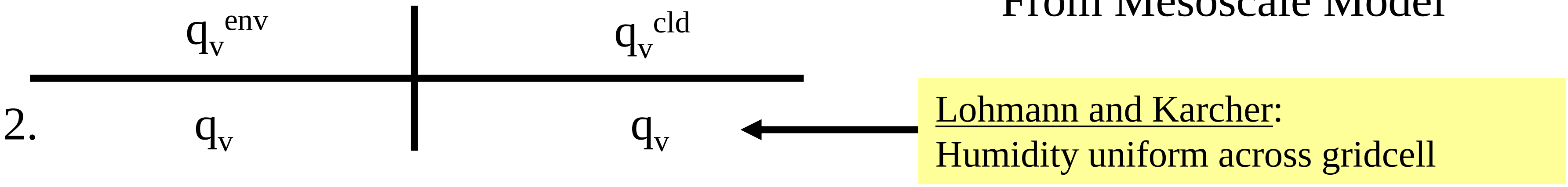
- We know: q_c occurs in the cloudy part of the gridbox
- We know: The mean in-cloud cloud ice
- What about the water vapour? In the bad-old-days was easy:
- Clouds: $q_v^{cld}=q_s$
- Clear sky: $q_v^{env}=(q_v-Cq_s)/(1-C)$ (rain evap and new cloud formation)

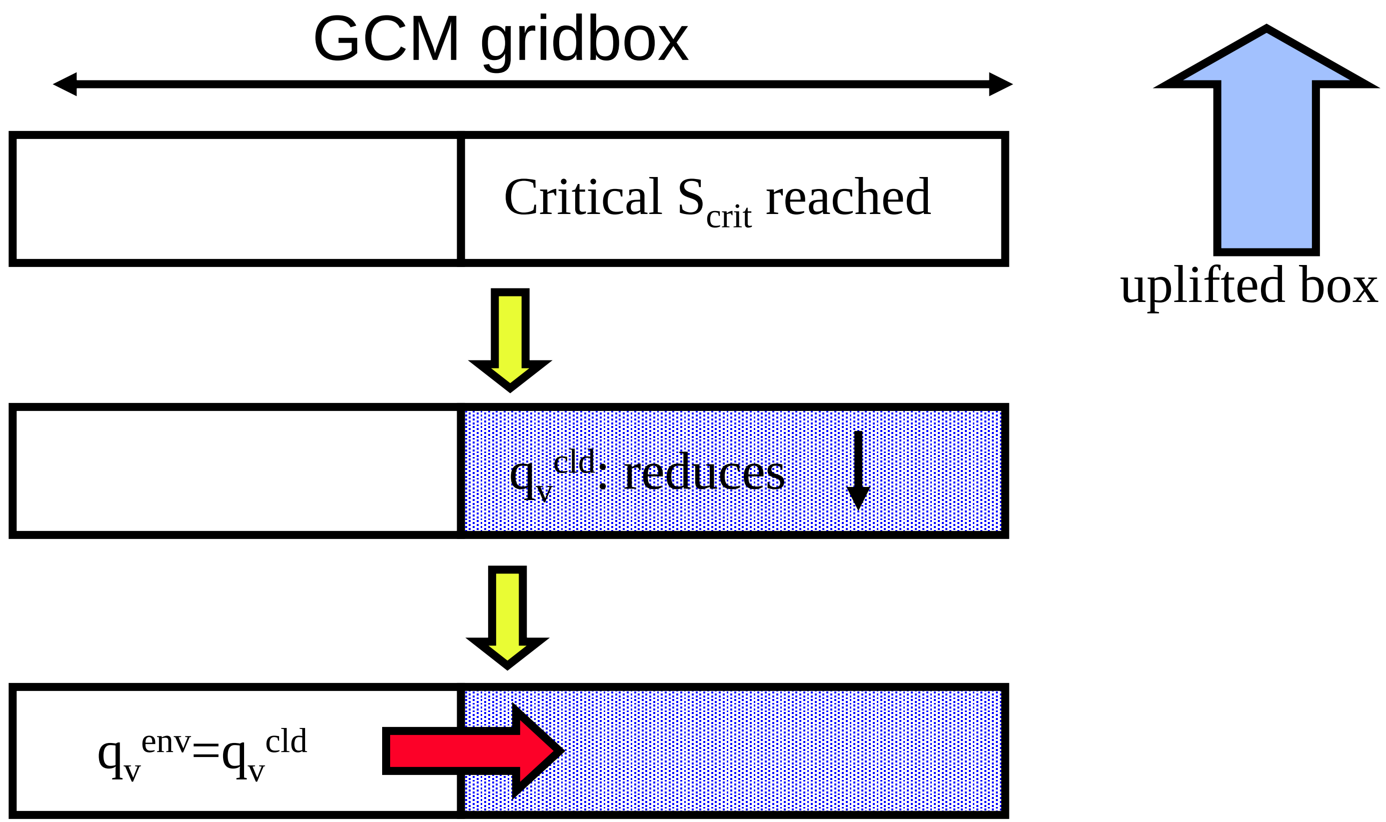
The good-new-days: assume no supersaturation CAN exist



	q_v^{env}	q_v^{cld}	
1.	$(q_v - C q_s)/(1-C)$	q_s	The bad old days No supersaturation
2.	q_v	q_v	Lohmann and Karcher: Humidity uniform across gridcell
3.	$q_v + q_i$	$q_v - q_i(1-C)/C$	Klaus Gierens:Humidity in clear sky part equal to the mean total water
4.	$(q_v - C q_s)/(1-C)$	q_s	My assumption: Hang on… Looks familiar???

From Mesoscale Model





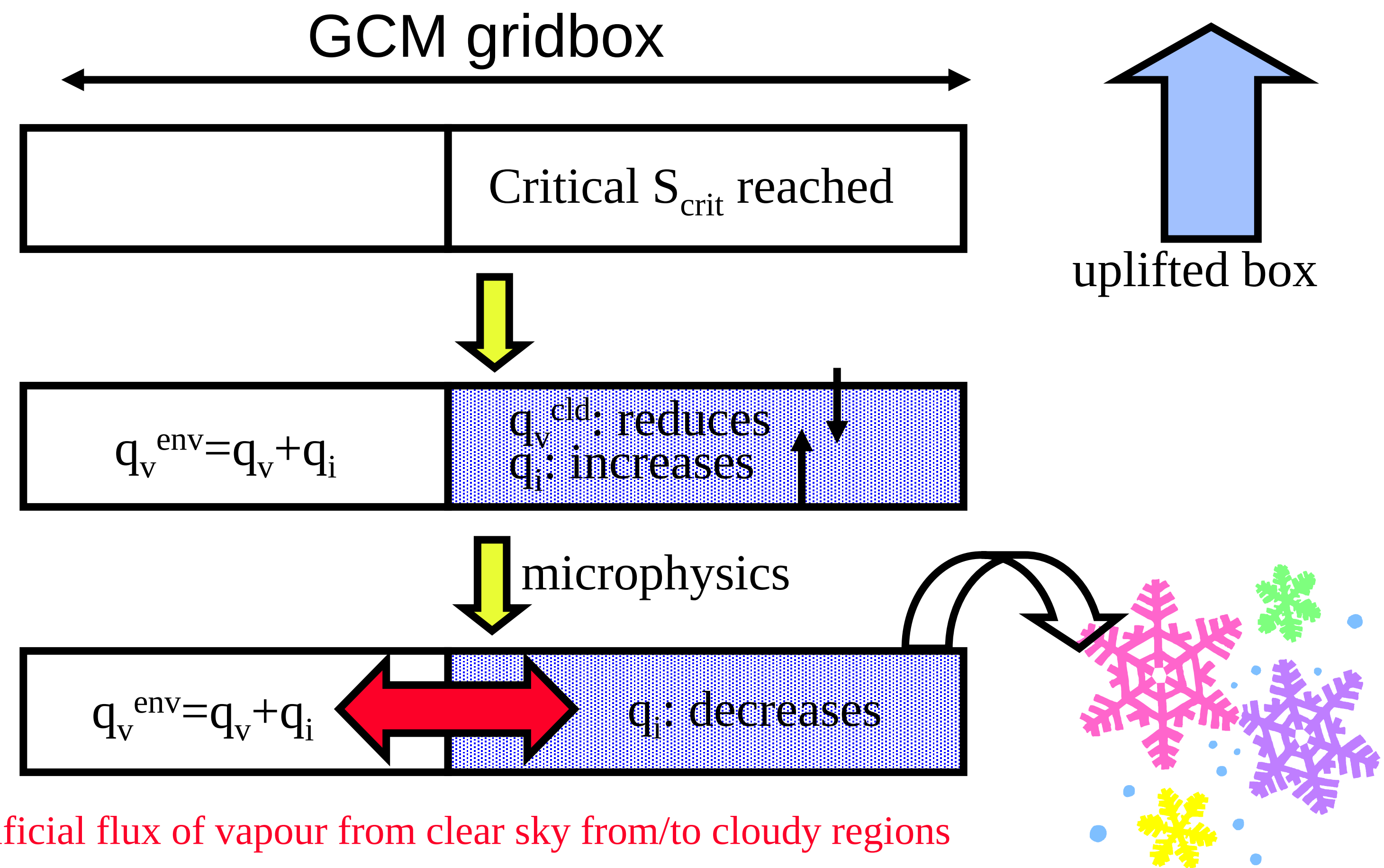
Artificial flux of vapour from clear sky to cloudy regions

Assumption ignores fact that difference processes are occurring on the subgrid-scale, and amounts to an “all-or-nothing” scheme

From Box Model

	q_v^{env}	q_v^{cld}
3.	q_v+q_i	$q_v-q_i(1-C)/C$

<u>Klaus Gierens</u>:Humidity in clear sky part equal to the mean total water



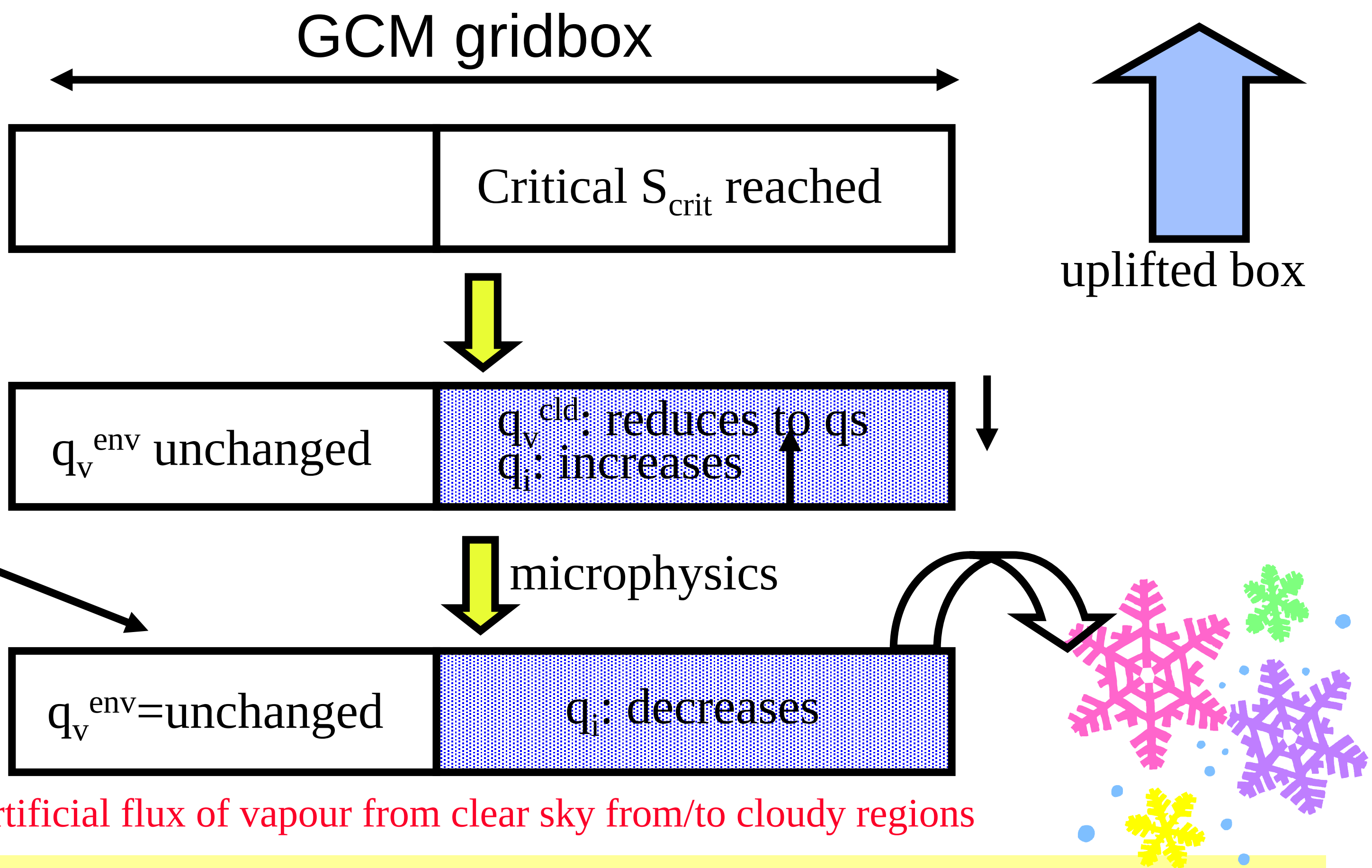
Artificial flux of vapour from clear sky from/to cloudy regions

Assumption is valid in absence of microphysics (i.e. box model). Any changes due to microphysics implies an artificial horizontal flux

	q_v^{env}	q_v^{cld}
4.	$(q_v - Cq_s)/(1-C)$	q_s

<u>My assumption</u>: Hang on… Looks familiar???

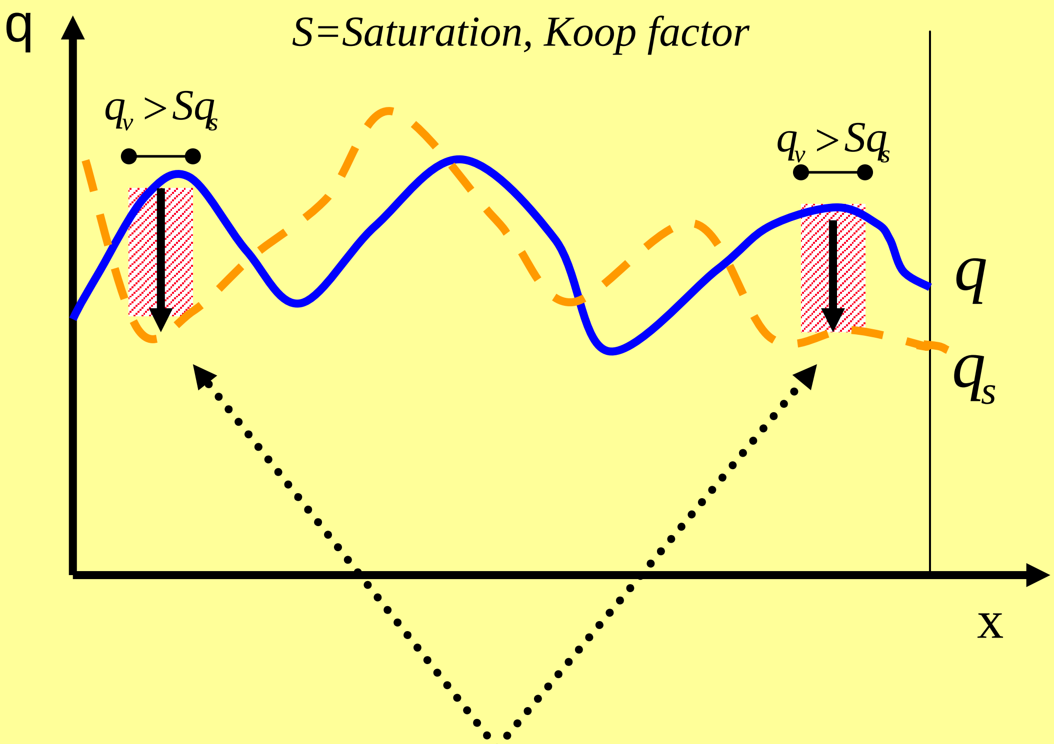
Difference to standard scheme is that environmental humidity must exceed S_{crit} to form new cloud



No artificial flux of vapour from clear sky from/to cloudy regions

Assumption seems reasonable: BUT! **<u>Does not allow nucleation or sublimation timescales</u> to be represented, due to hard adjustment**

Justification



Assumption is that this adjustment timescale is fast (KG=900s) compared to GCM timestep (900-3600s) therefore allowing diagnostic relationship can be used

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

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U. Lohmann

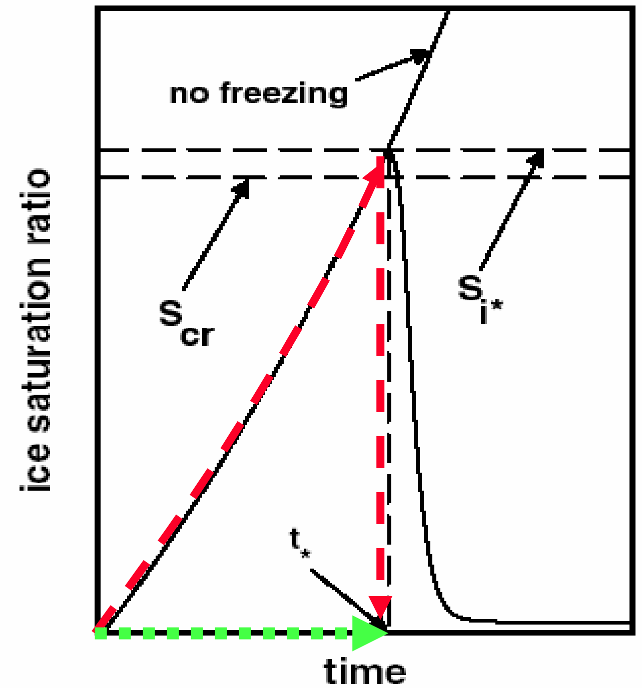


Figure 1. Temporal evolution of the ice saturation ratio in a uniform vertical ascent. Curve labeled "no freezing" neglects ice particle formation, in which case S_i grows exponentially in the rising air parcel. If ice particles form and grow above a critical value S_{cr}, the saturation ratio reaches a maximum value S_{i*} and falls off rapidly due to depletion of the available water vapor. If the air parcel continues to rise after S_i passes its maximum, S_{i*} may exceed S_{cr} by several percent, and S_i approaches a limiting value slightly above unity; otherwise, S_{i*} is approximately equal to S_{cr}, and S_i relaxes to unity. According to numerical simulations, the difference between S_{i*} and S_{cr} is much smaller than the threshold saturation ratio S_{cr}, and the relaxation time is much smaller than t_*.

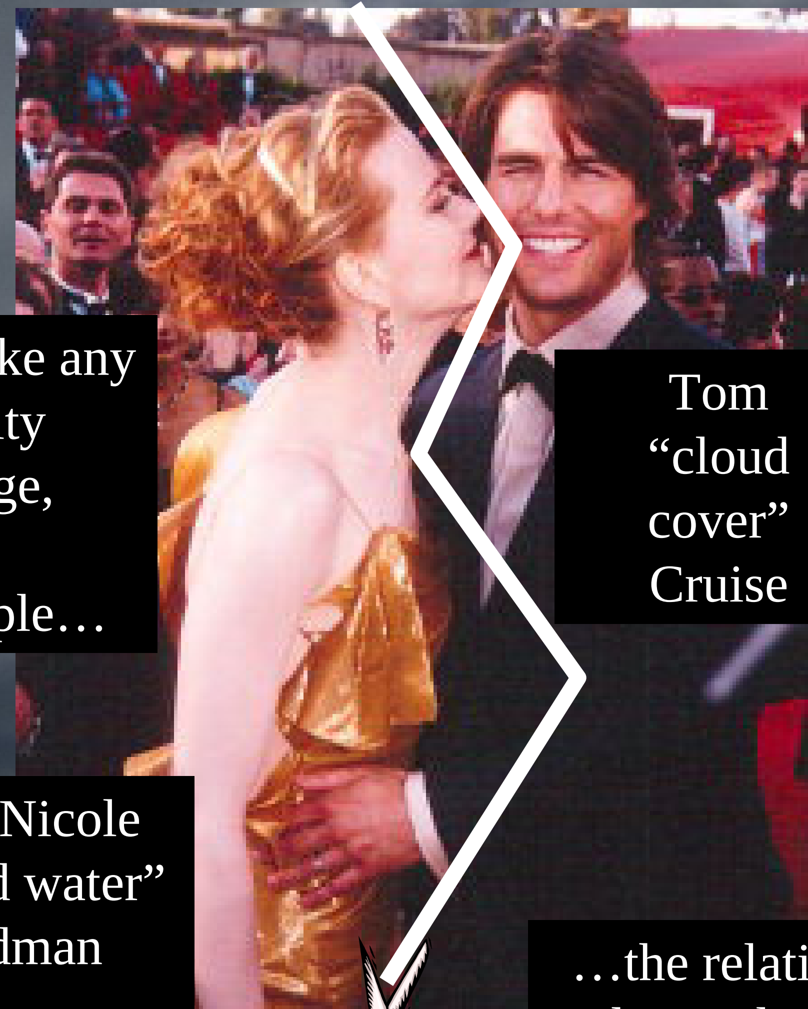
To summarize the scheme

$q_v^{env}=(q_v-Cq_s)/(1-C)$: Note changes in C and q_v must be self-consistent

A cloud scheme can be like…

And just like any celebrity marriage,

for example…



Tom “cloud cover” Cruise

And Nicole “cloud water” Kidman

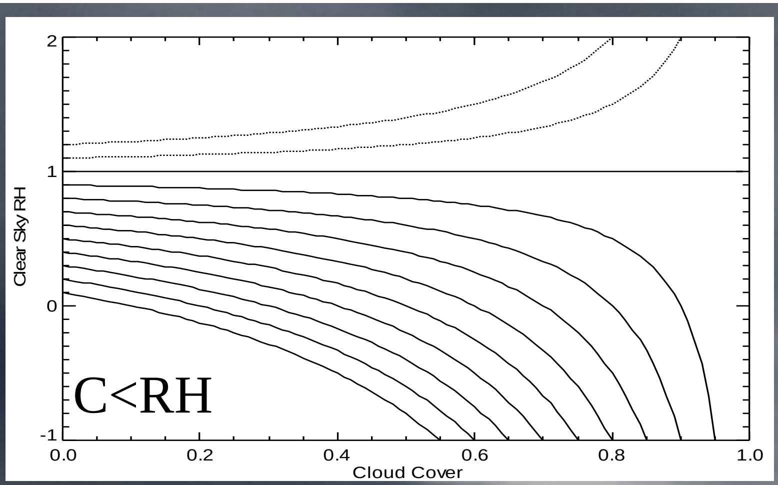
…the relationship is doomed to failure

How is this manifested?

- **The most obvious examples are**
  - $q_i=0$ when $C>0$
  - $C=0$ when $q_i>0$
  - $C=q_i=0$ when $q_v>q_s$
- **How often does this happen? More than you care to wish!**
- **(All) Schemes are full of “clean ups”, “tidy ups”, “safety check”, “clipping”**
- **The more complicated a schemes becomes, the more likely these problems arise, and the more serious their impact**
- **Advantage of statistical schemes: end products are constrained 2b self-consistent**

Even if C>0 and q_i>0 can have inconsistency

Tompkins $RH_{env}=(RH-C)/(1-C)$

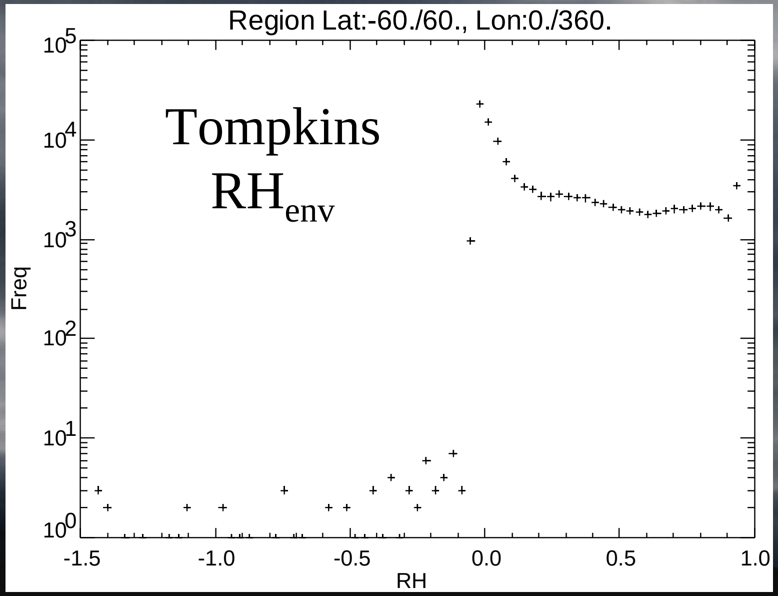


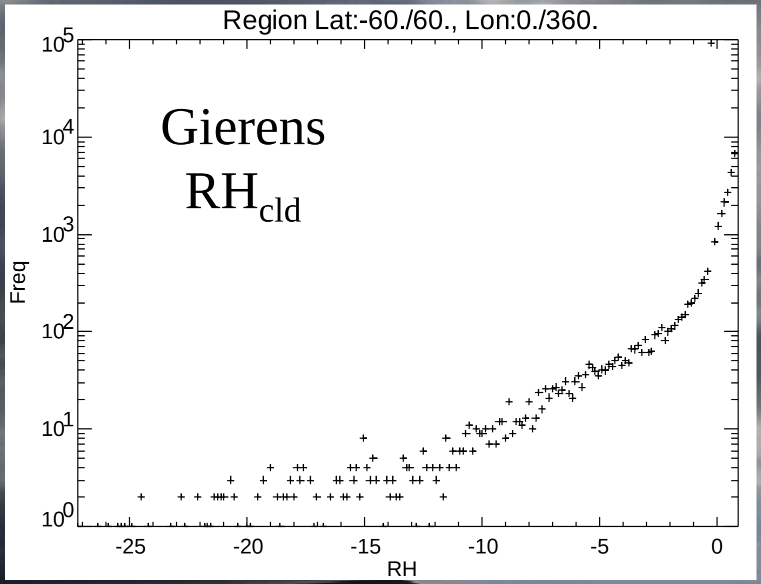
Likewise for Klaus' form for in-cloud RH

$RH_{cld}=RH - q_i(1-C)/(q_s C)$

How often does this happen?

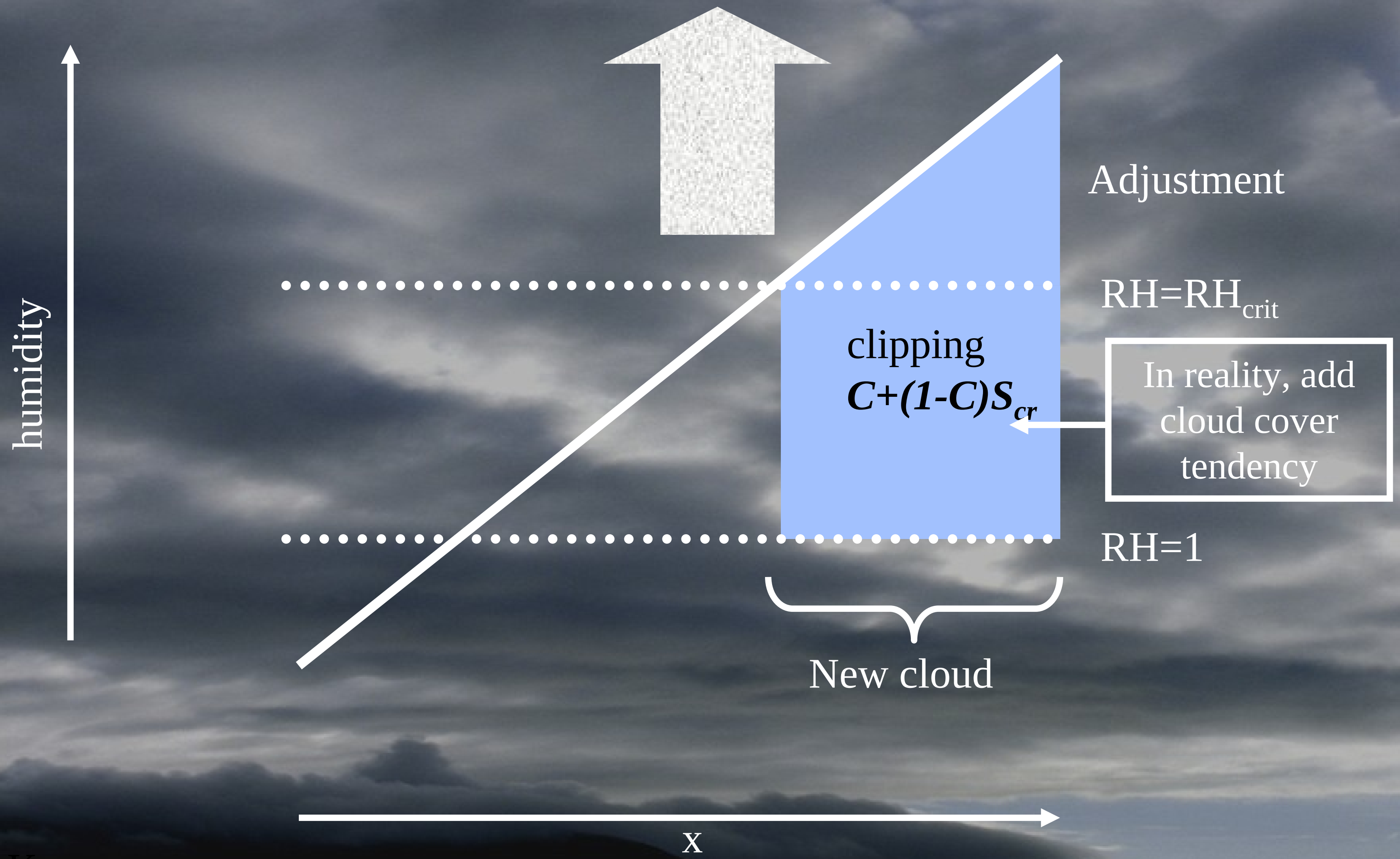
T95 200 hPa 5 day





inconsistent with microphysics

New parameterization

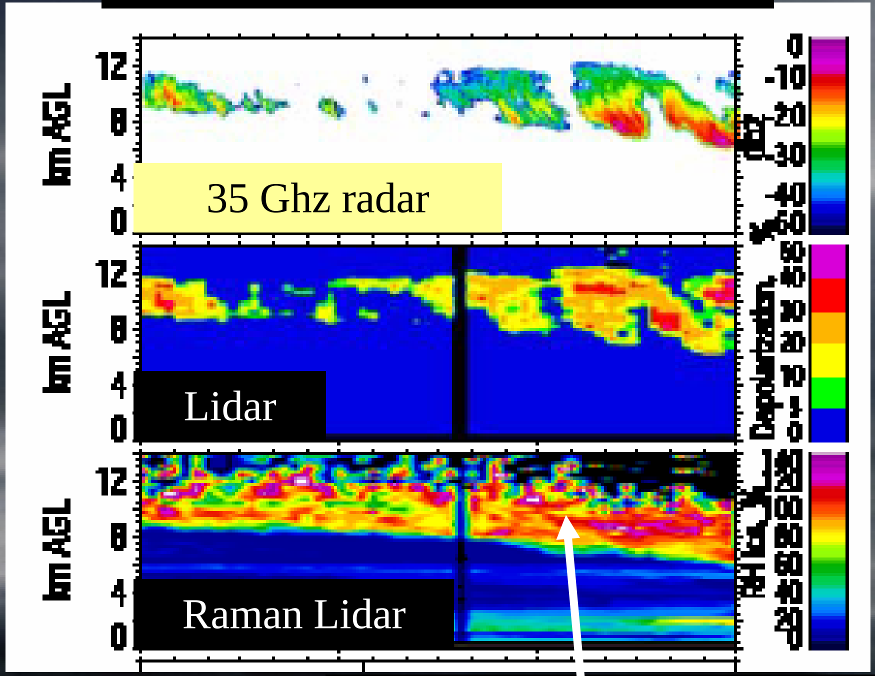


K

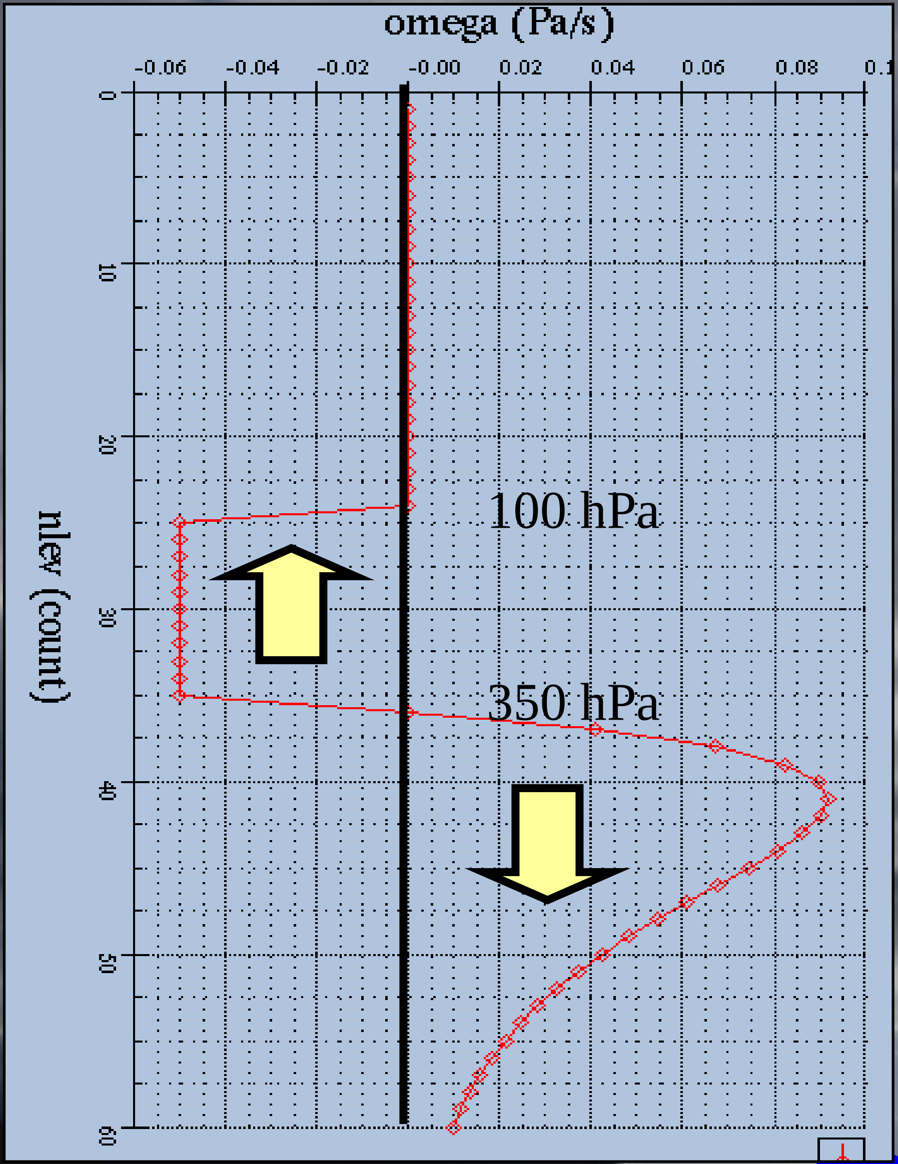
Single column model run

- Test out in idealized cirrus case
- Initialize dry atmosphere
- Uplift between 100 and 350hPa, subsidence below

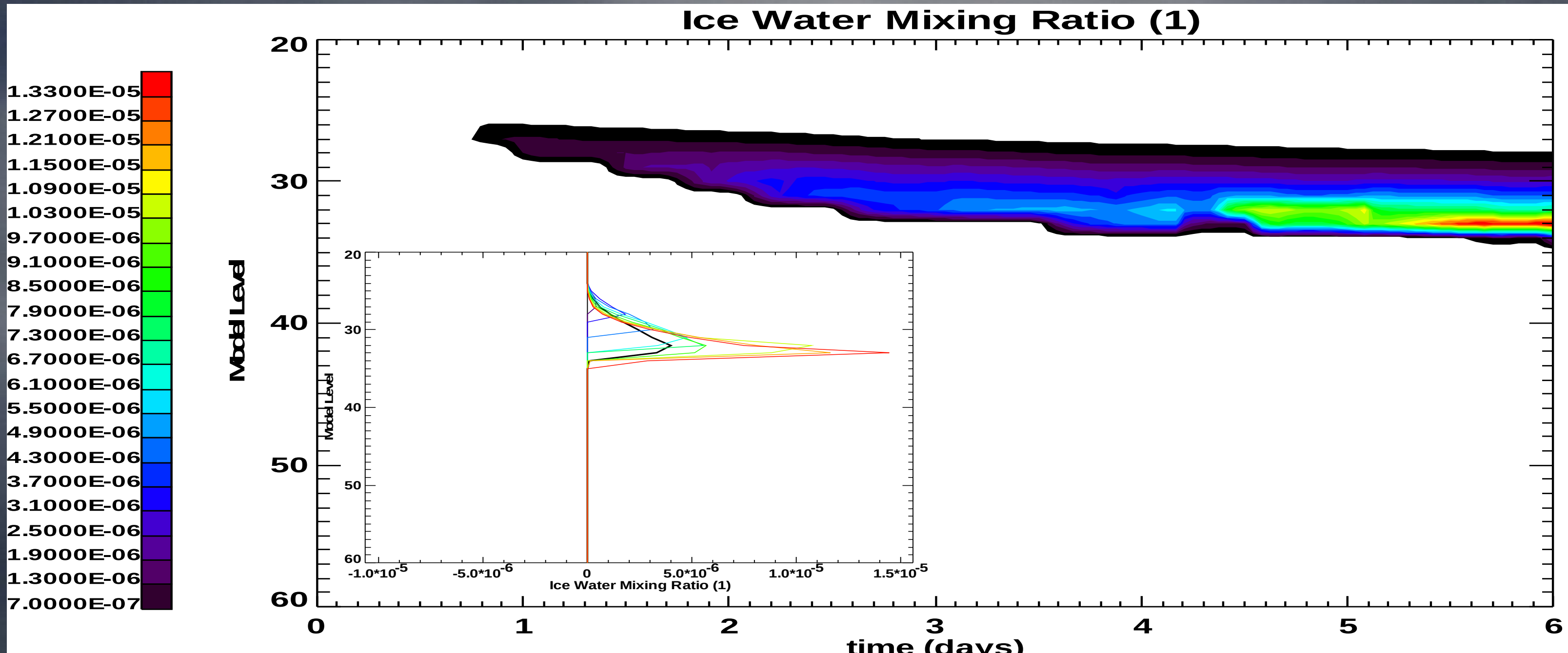
From Comstock et al. GRL 2004



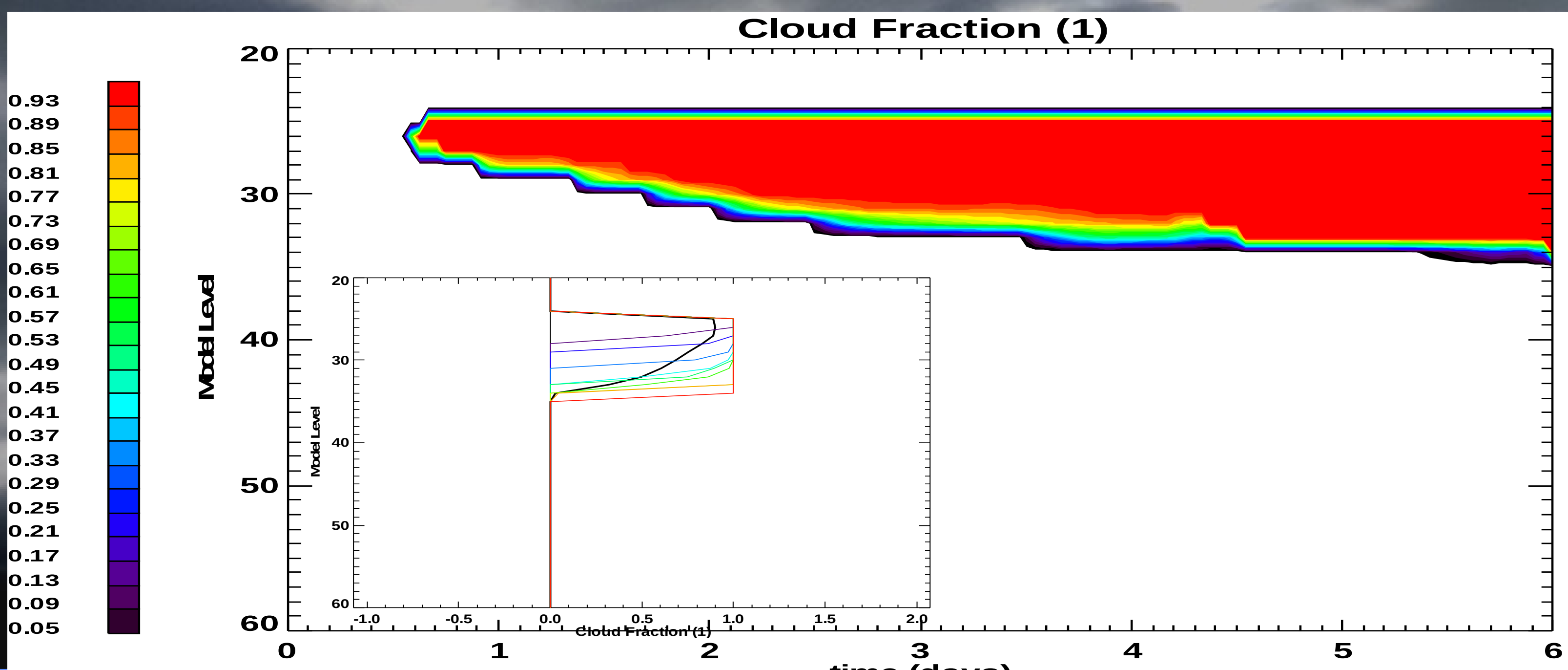
Note variability



Control

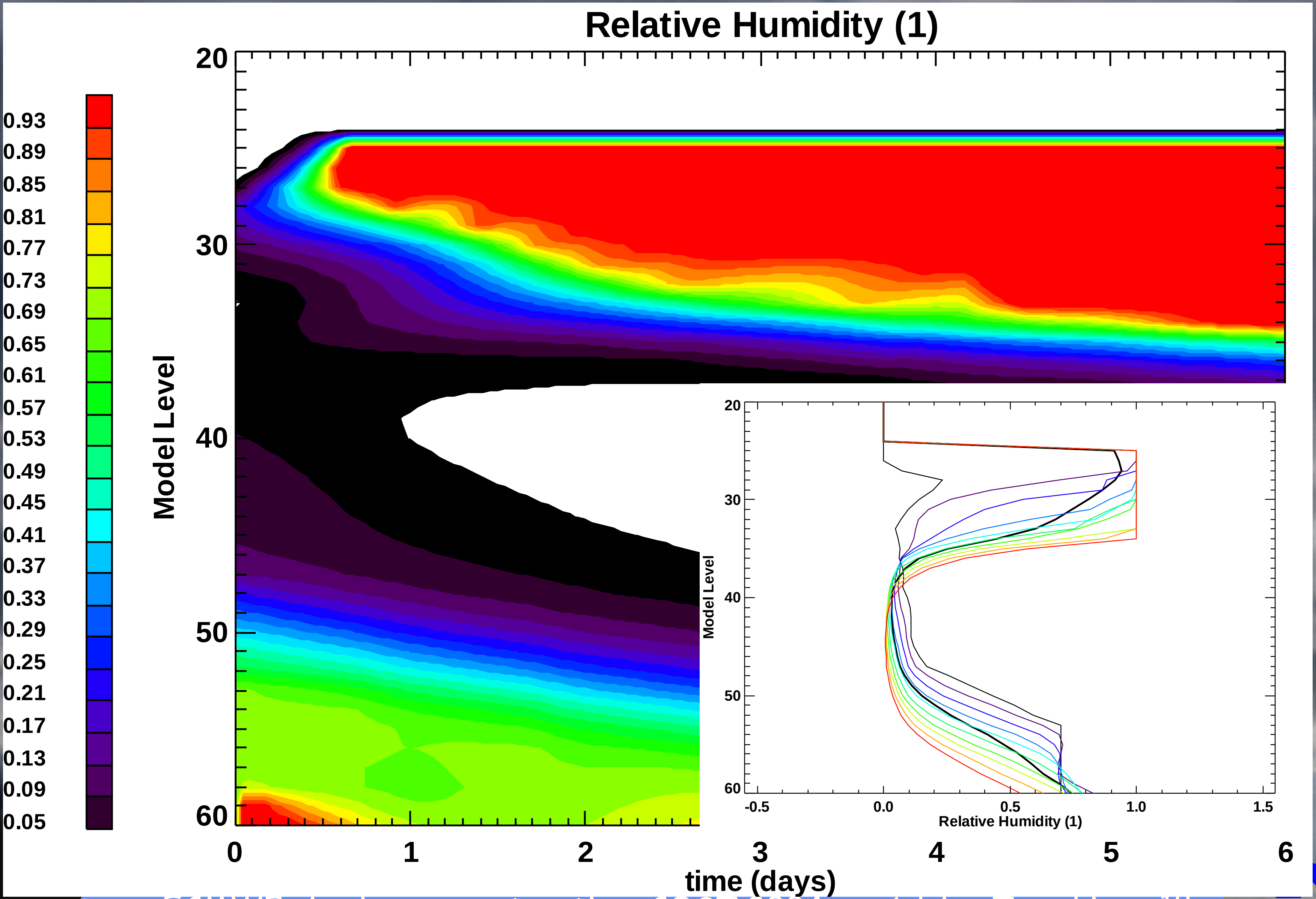


Ice Water Mixing Ratio (1)
1.3300E-05
1.2700E-05
1.2100E-05
1.1500E-05
1.0900E-05
1.0300E-05
9.7000E-06
9.1000E-06
8.5000E-06
7.9000E-06
7.3000E-06
6.7000E-06
6.1000E-06
5.5000E-06
4.9000E-06
4.3000E-06
3.7000E-06
3.1000E-06
2.5000E-06
1.9000E-06
1.3000E-06
7.0000E-07
Model Level
time (days)
Ice Water Mixing Ratio (1)

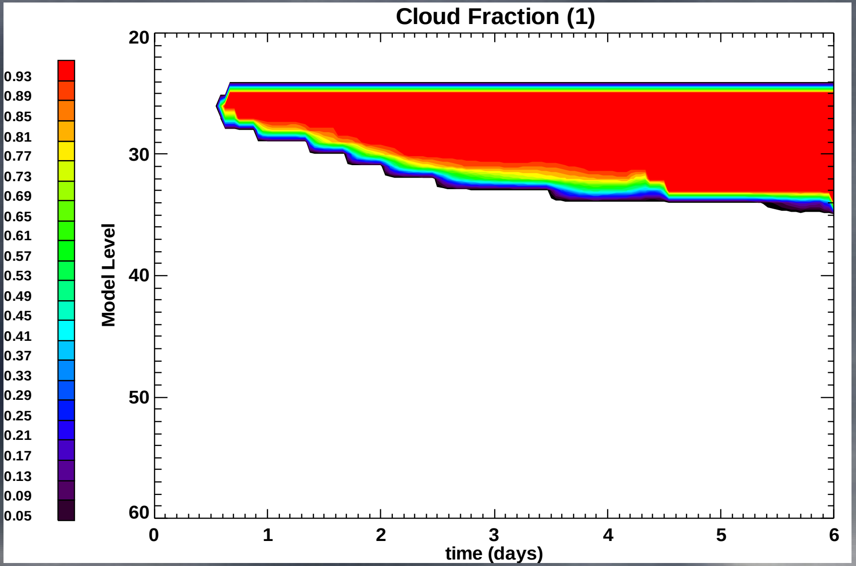


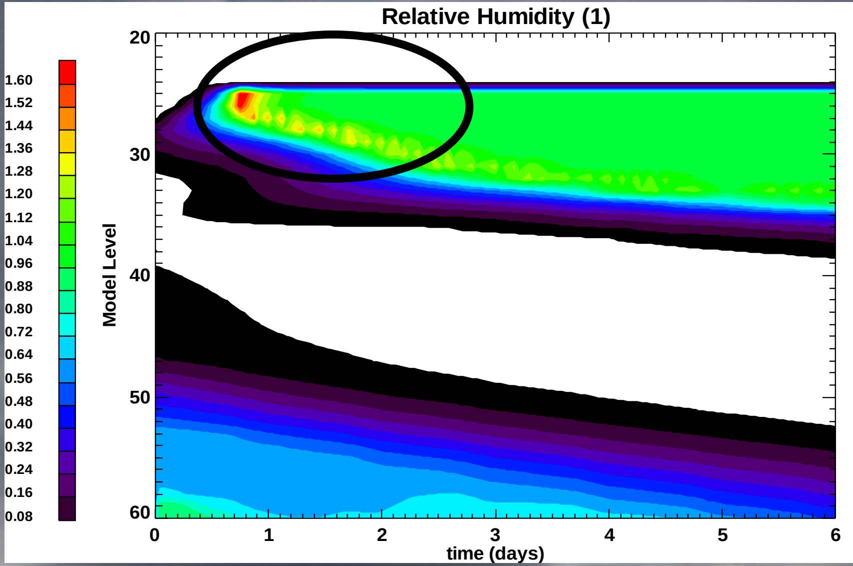
Cloud Fraction (1)
0.93
0.89
0.85
0.81
0.77
0.73
0.69
0.65
0.61
0.57
0.53
0.49
0.45
0.41
0.37
0.33
0.29
0.25
0.21
0.17
0.13
0.09
0.05
Model Level
time (days)
Cloud Fraction (1)

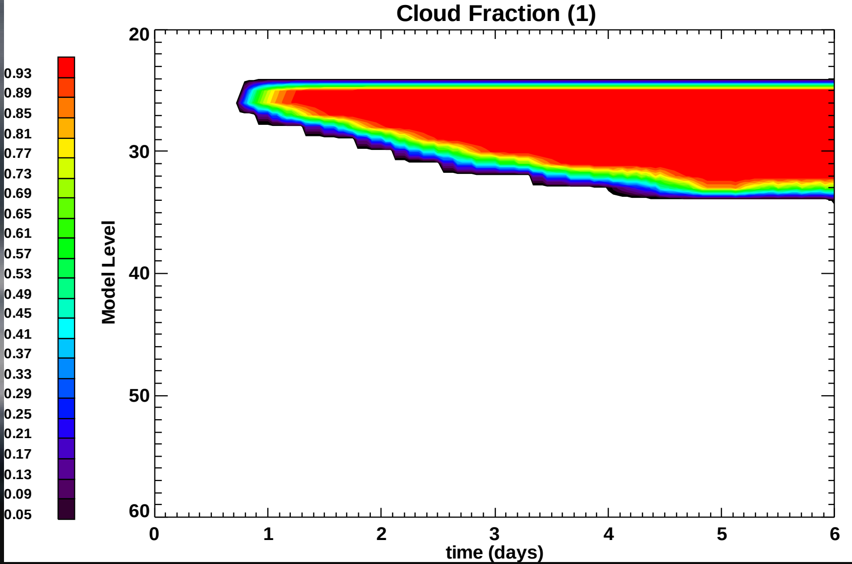
Standard model results: RH

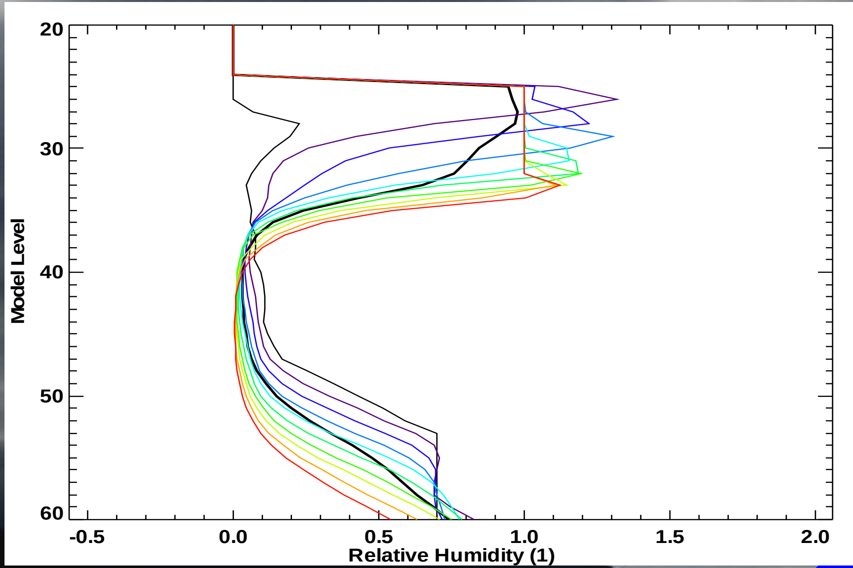


New parameterization





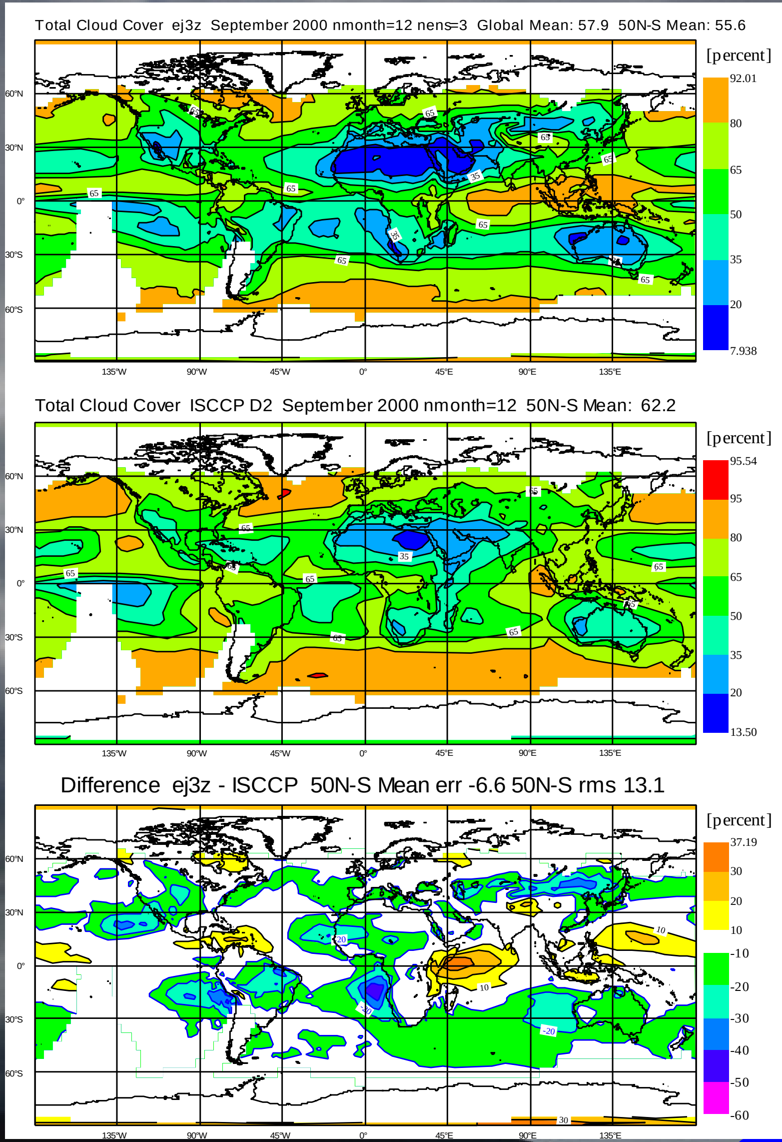


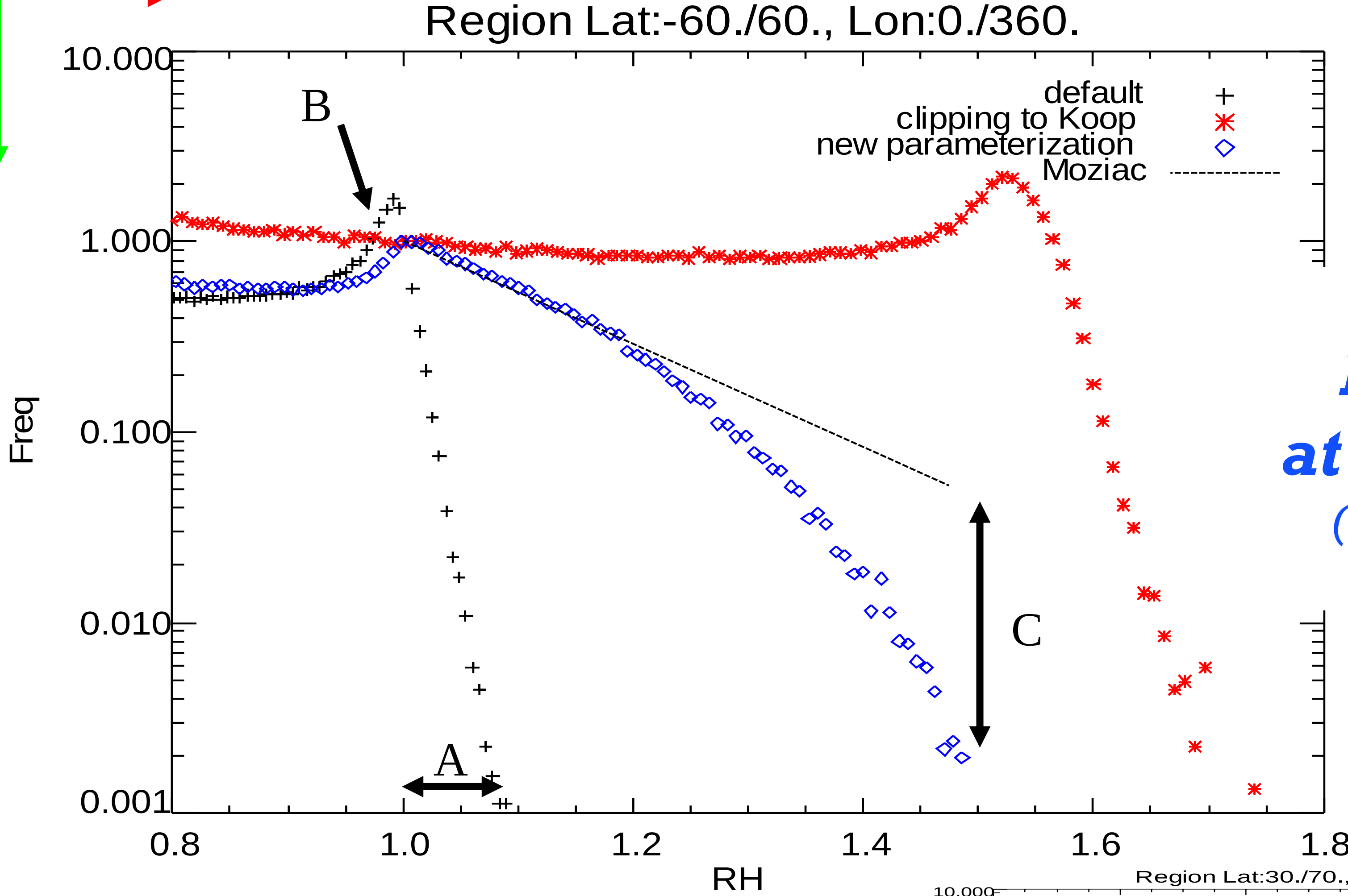


3D tests

- Test out in single forecast at T95, L60 resolution, 13 months from Aug 2000 cycle 28r3.
- Run control, variations on new parametrization
- Note: Without clipping super-saturations of up to 8000%: Numerics

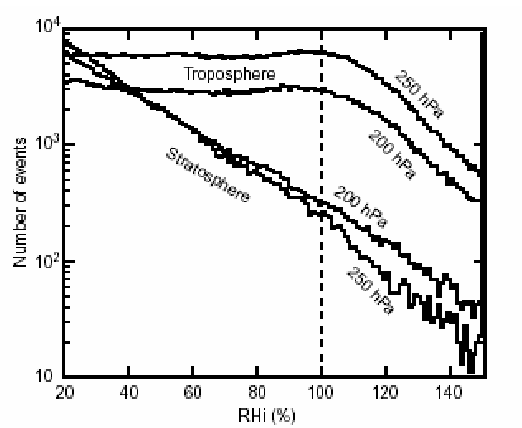
Control TCC version ISCCP



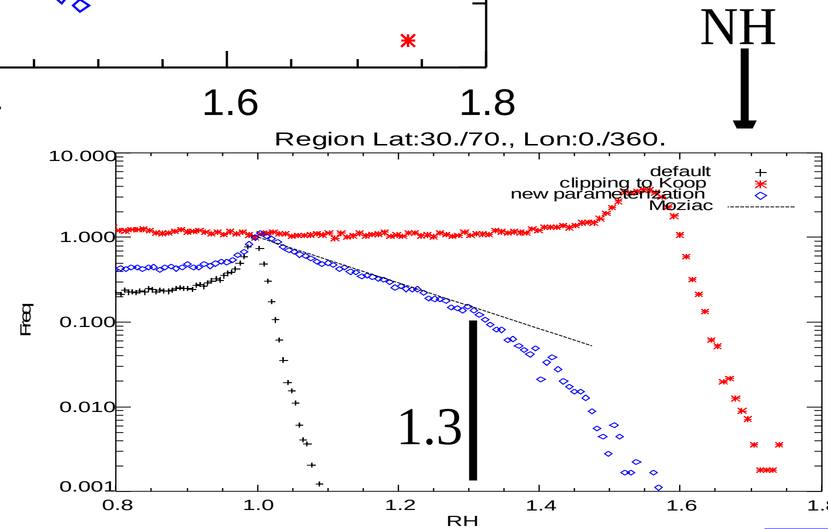


RH PDF at ~ 250hPa

(one month)



from Gierens et al 99



Comparison to Moziac

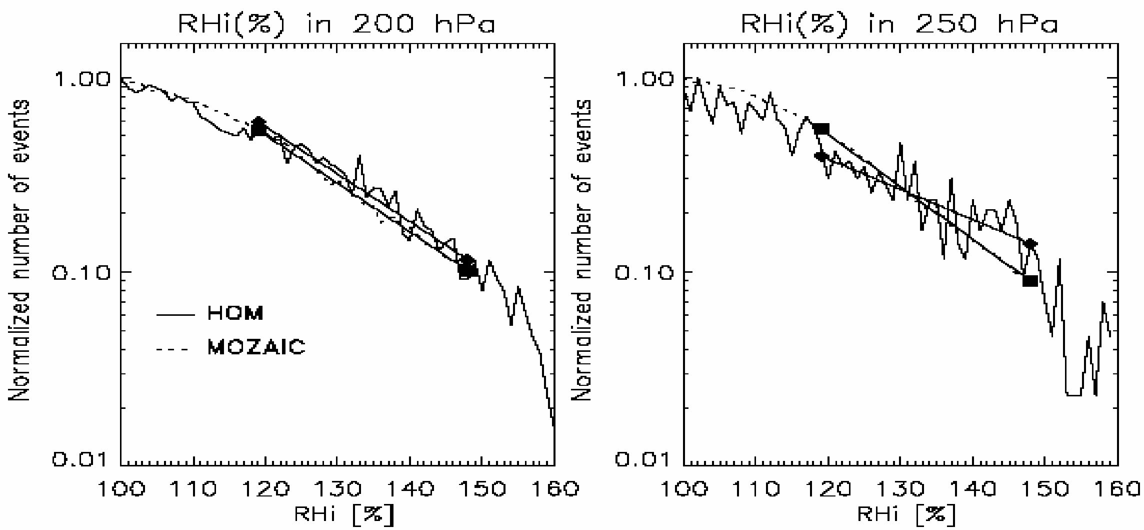
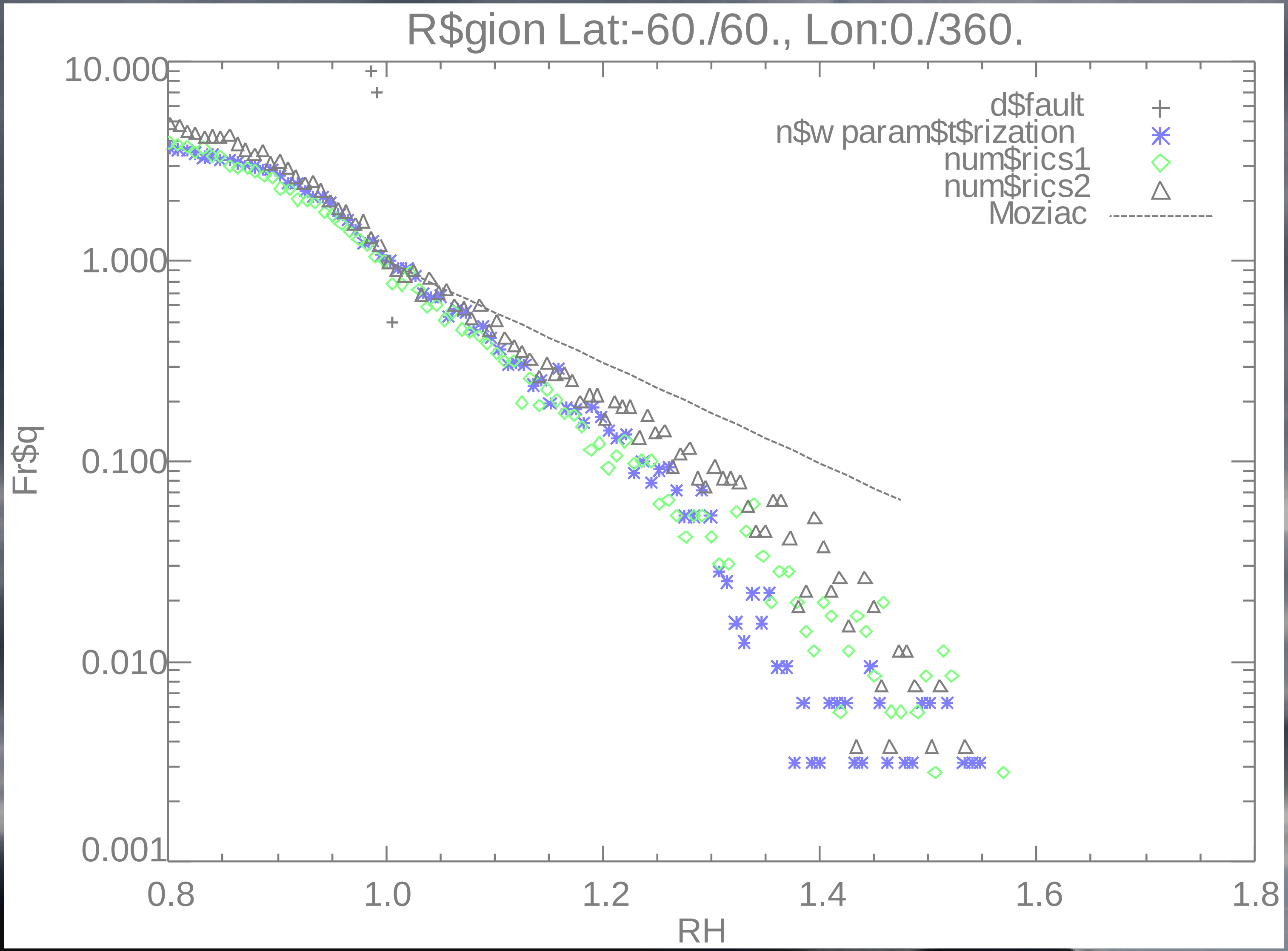


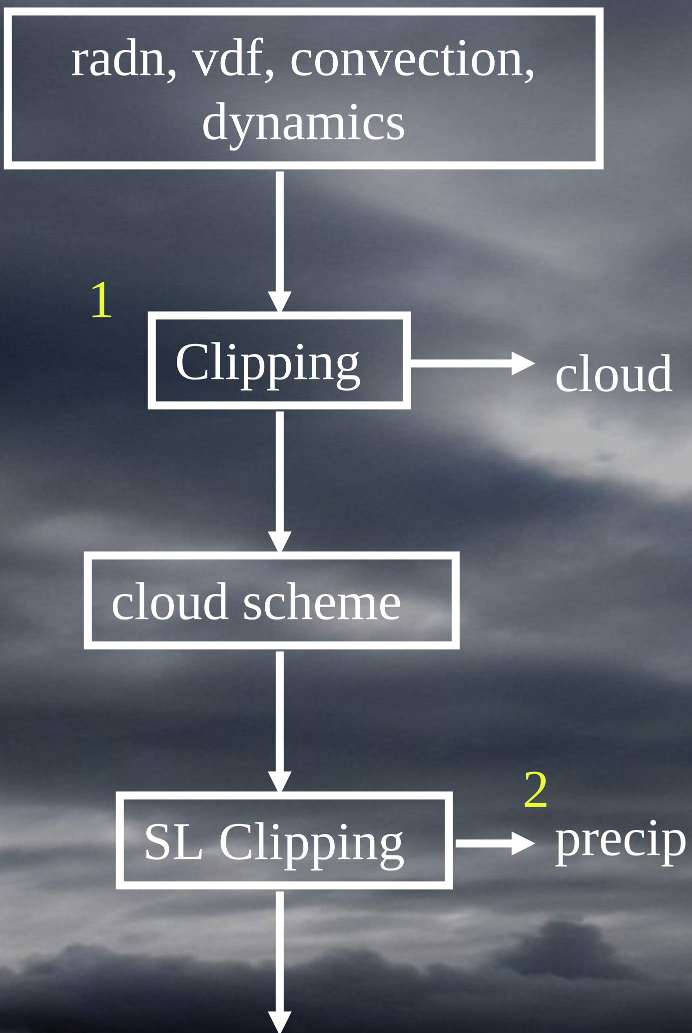
Figure 2. Normalized frequency distribution of relative humidity with respect to ice in two layers centered around 200 and 250 hPa for cloud-free conditions from MOZAIC observations and simulation HOM. The solid lines refer to the slopes summarized in Table 1. See color version of this figure at back of this issue.

- Dependence on subgrid-scale variability assumptions
- Moziac: averaged to 15 km lengths
- ECHAM: effectively neglects subgrid variability
- IFS (T95): starts to limit at 0.8 x Koop (~1.6). I.e. RH= ~1.3
- Both models have results consistent with their underlying assumptions

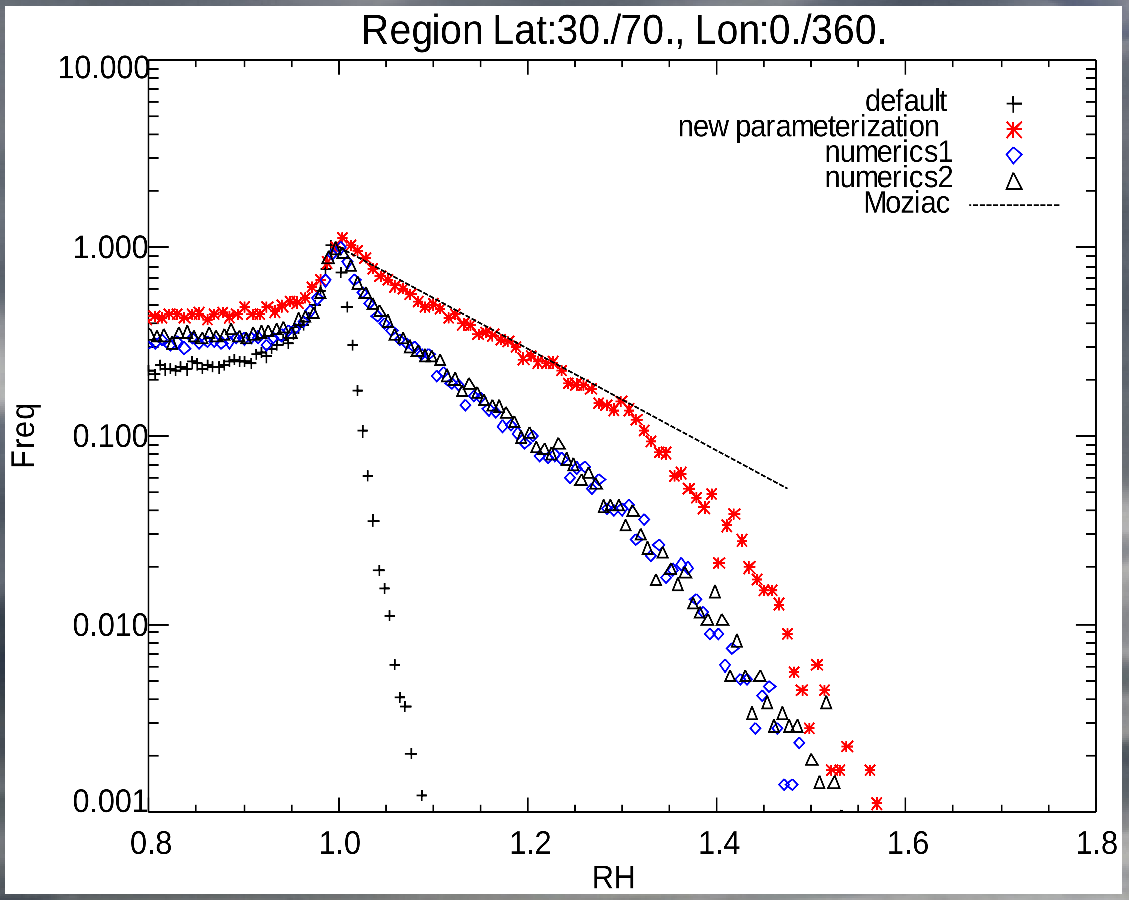
Comparing clear sky distributions only



Numerics



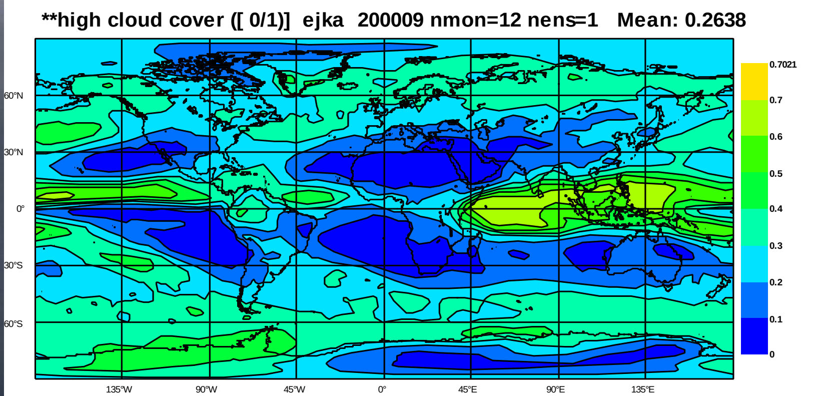
radn, vdf, convection, dynamics
1
Clipping
cloud
cloud scheme
2
SL Clipping
precip

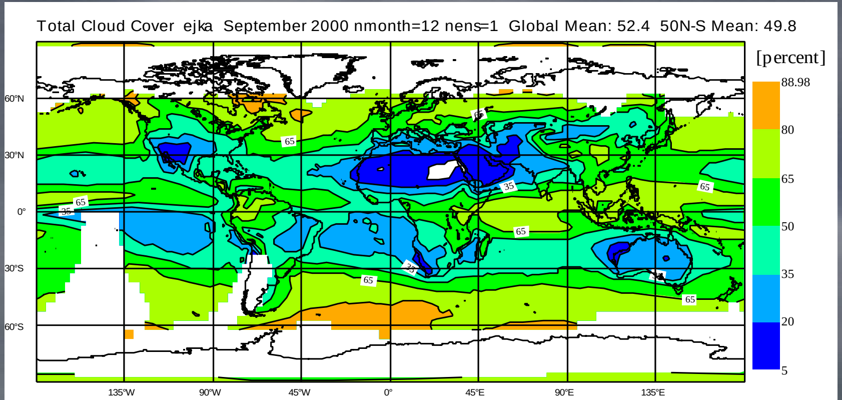


Region Lat:30./70., Lon:0./360.
default
new parameterization
numerics1
numerics2
Moziac
Freq
10.000
1.000
0.100
0.010
0.001
0.8
1.0
1.2
1.4
1.6
1.8
RH

High cloud cover (HCC) | Total cloud cover (TCC)

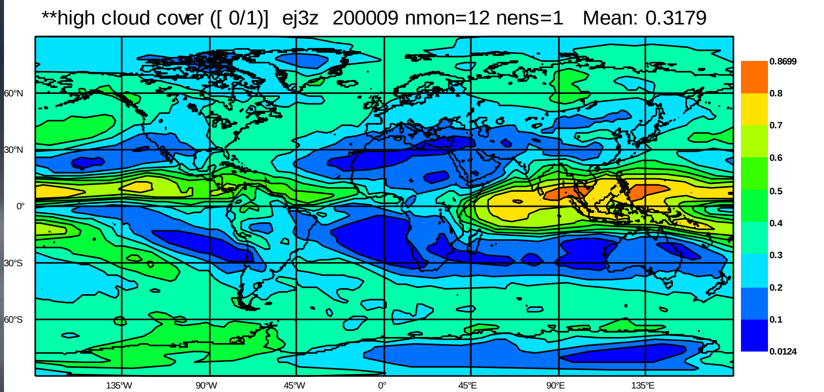
New

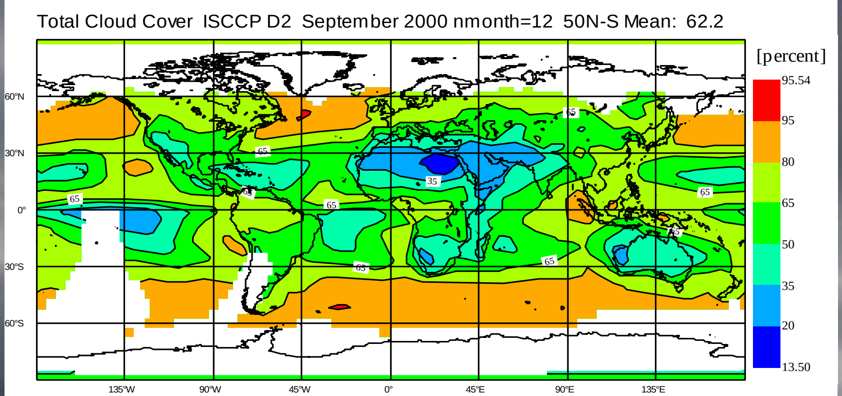




New

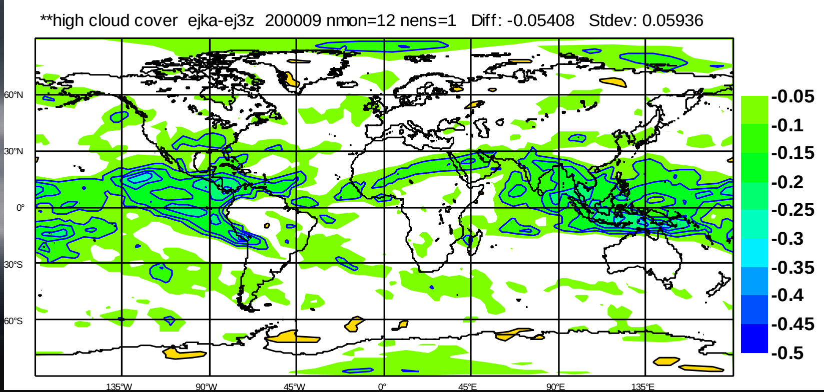
Control

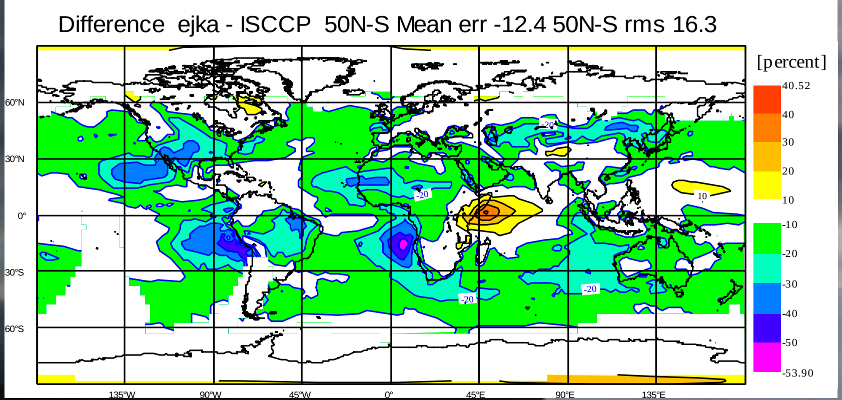




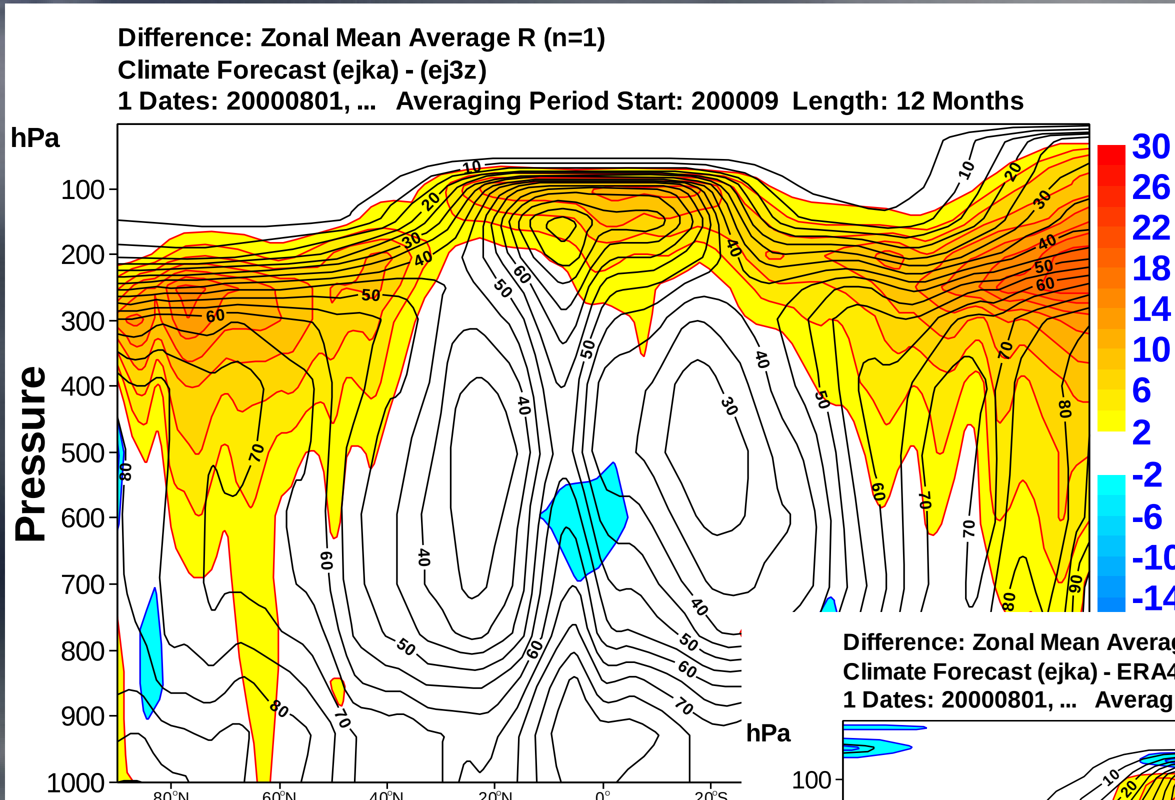
ISCCP D2

Difference

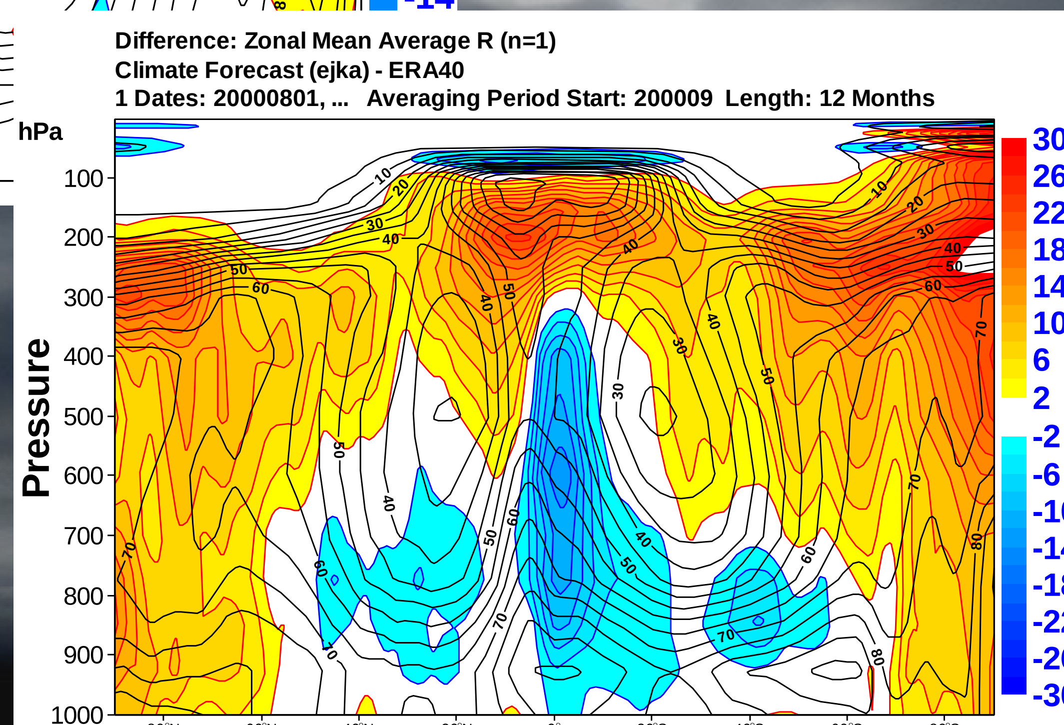




Difference



New-Control RH Difference



New-ERA40 RH Difference

Summary & Future

- Have discussed some of the issues of subgrid-scale variability that arise even when dealing with simple cloud schemes
  - Need: diagnostic assumptions or additional prognostic variable
- Compared the diagnostic approaches used by myself, Gierens and Lohmann/Karcher
- Introduced simple scheme: SCM and 3D, and attempted to interpret the results
- TTT: Test, Tune and Trial the new super-saturation scheme
- Future of the ECMWF cloud scheme: Move towards a prognostic statistical scheme, developing the basic scheme of ECHAM5

- This will require additional prognostic variable if super saturation is to be included in a non-trivial way
- If we assume no super-saturation can exist Can only derive cloud cover C from total water PDF
- In this case an isomorphism exists between any two moments of the PDF, say, variance/mean of total water, and vapour/liquid mmr.
- To represent ice super-saturation still need an additional prognostic equation!