Improvement of ECHAM parameterizations during the EUROCS period

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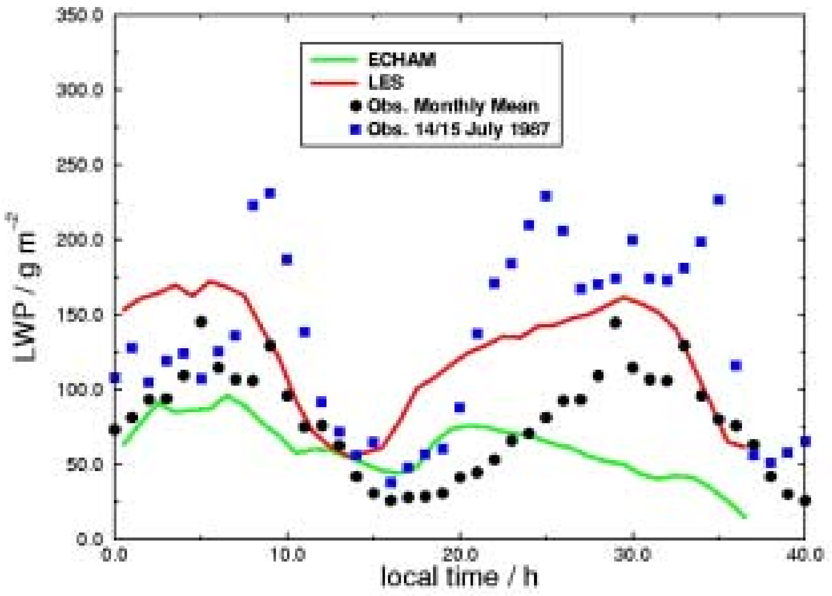
Outline

- Introduction
- Report of work on:
    - Cloud scheme
    - Cumulus scheme
    - Radiation scheme
    - Diffusion scheme
- Conclusions

Motivation

- Sub-grid scale processes need to be parameterized in GCMs and CTMs
- Boundary layer structure is not well represented

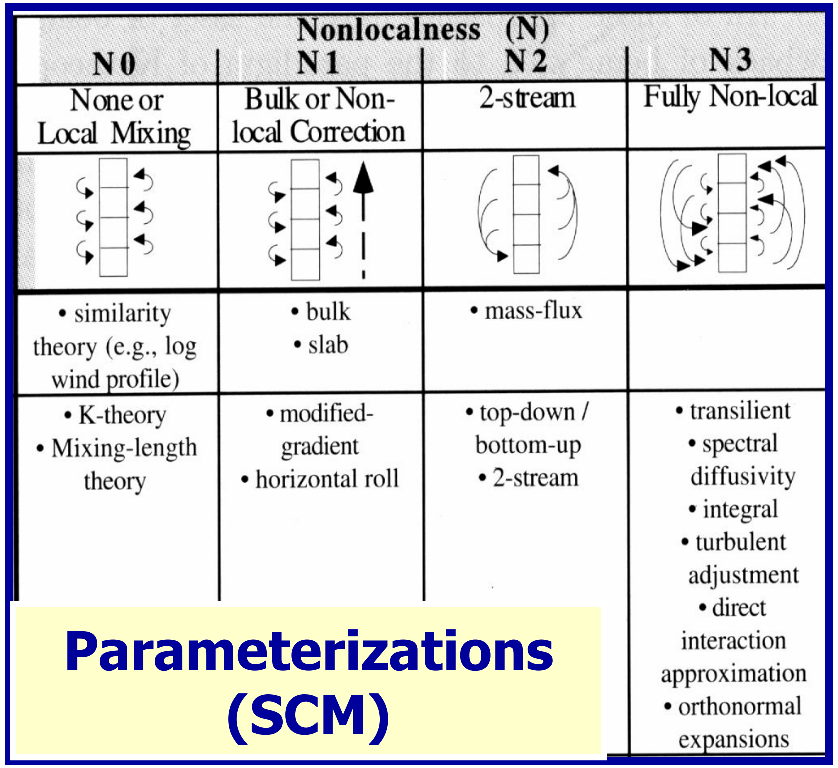


Diurnal variation of LWP (FIRE)

Strategy

Observations

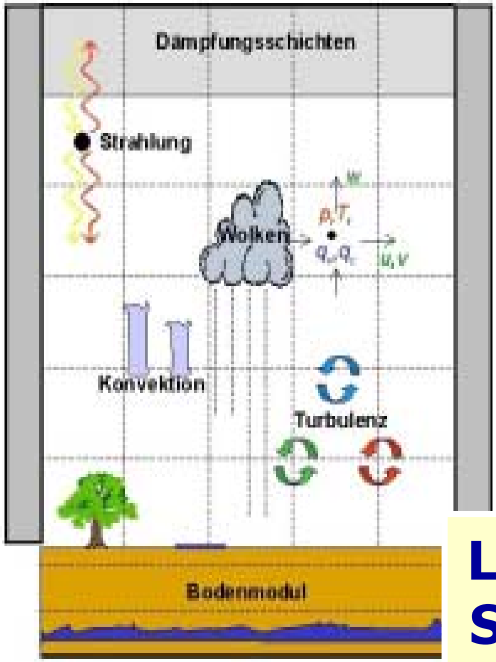
Climate Model (GCM)



Nonlocalness (N) N 0	N 1	N 2	N 3
None or Local Mixing	Bulk or Non-local Correction	2-stream	Fully Non-local
• similarity theory (e.g., log wind profile)	• bulk • slab	• mass-flux	
• K-theory • Mixing-length theory	• modified-gradient • horizontal roll	• top-down / bottom-up • 2-stream	• transilient • spectral diffusivity • integral • turbulent adjustment • direct interaction approximation • orthonormal expansions

Parameterizations (SCM)

Large-Eddy Simulations



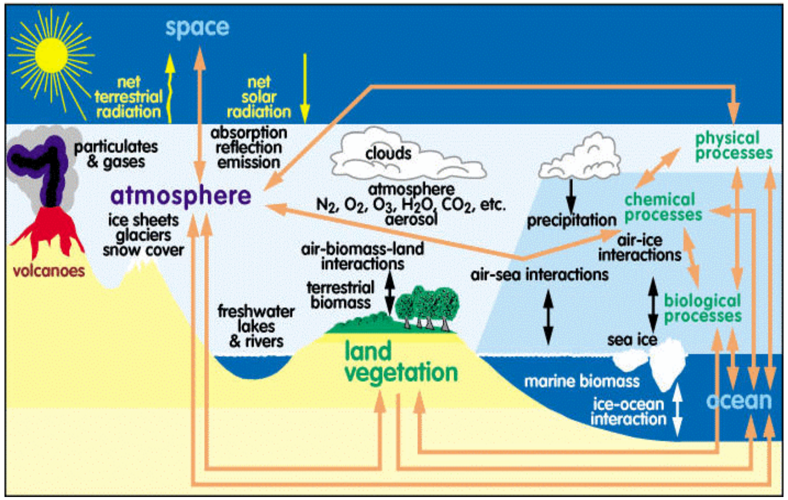
How can CRMs/LES be used to improve Large-Scale Models?

- Advance the understanding of the physical processes
- Evaluate and improve methods of representing shallow clouds
    - Produce comprehensive 4-D data sets using LESs
    - Use of LES data sets to investigate deficiencies in GCMs using the Single Column Model (SCM) version as a test bed
    - Correct and improve parameterizations

Tool: ECHAM4

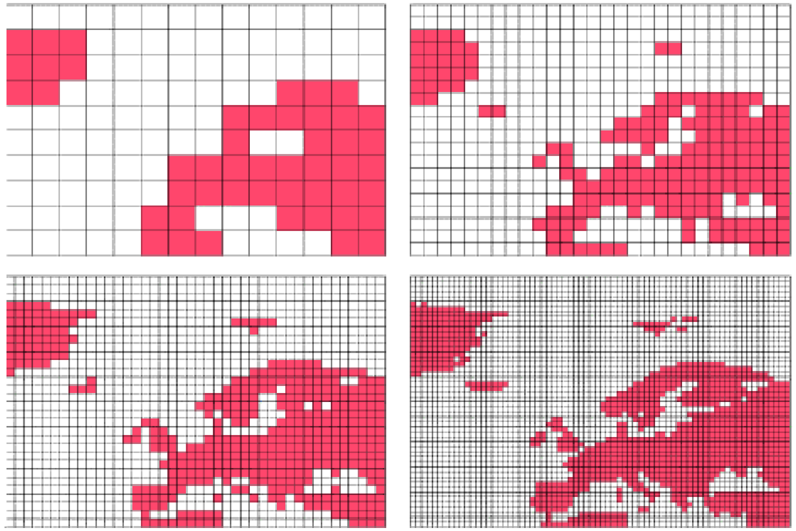
ECHAM is an AGCM

- 19/40-level hybrid sigma-pressure coor.-sys.
- Prognostic variables: Vorticity, divergence, log. of sfc. Pressure, temperature, spec. humidity, liquid water content



Relevant parameterizations:

- TKE-l turbulence boundary-layer scheme
- Cumulus convection is treated with bulk mass flux scheme
- Relative humidity cloud scheme
- Sundquist type large-scale precipitation formulation

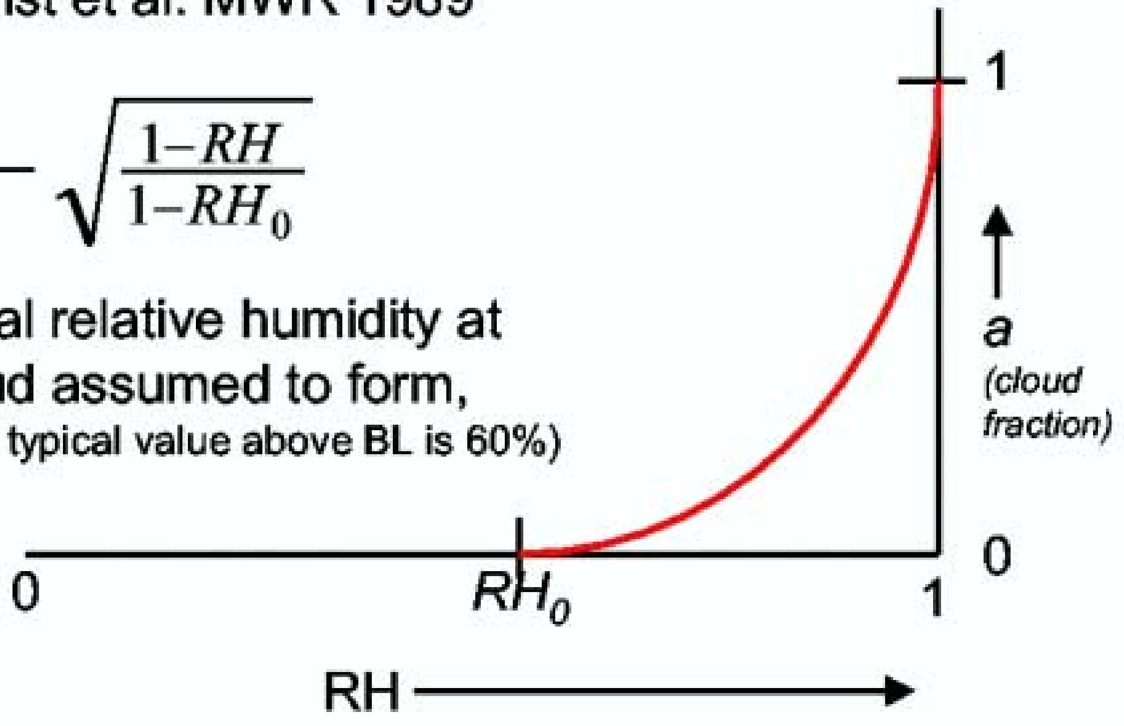


Diagnostic cloud scheme (I)

- Many schemes, from the 1970s onwards, based cloud cover on the relative humidity (RH):
- E.g. Sundqvist et al. MWR 1989

$$a = 1 - \sqrt{\frac{1 - RH}{1 - RH_0}}$$

RH_0 = critical relative humidity at which cloud assumed to form,
(function of height, typical value above BL is 60%)



Diagnostic cloud scheme (II)

Advantage:

- Better than homogeneous assumption, since cloud can form before grids reach saturation

Disadvantage:

- Cloud cover not coupled to other processes

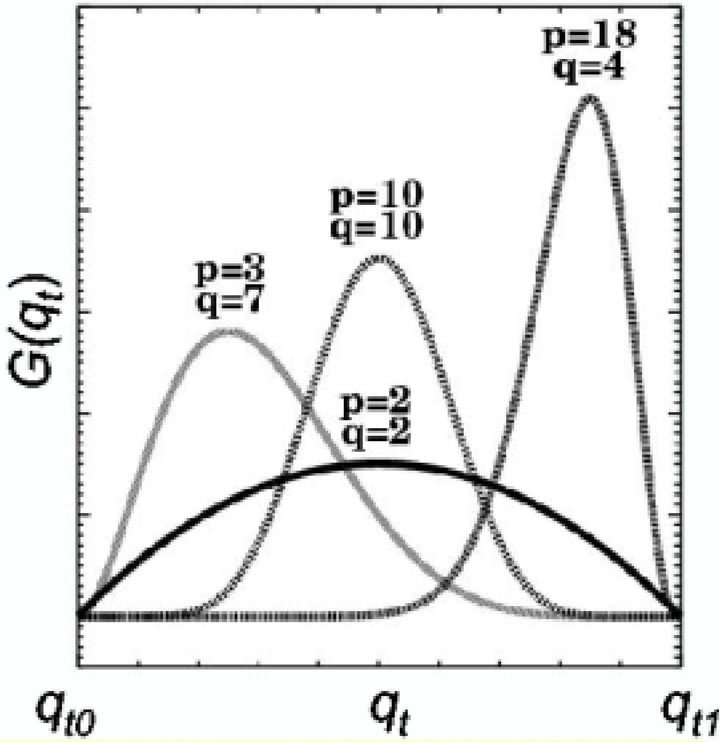
Prognostic statistical scheme (I)

- Scheme was developed by Tompkins (JAS 2002)
  - Prognostic equations are introduced for the variance and the skewness of the total water PDF
  - These, in conjunction with the grid mean cloud vapour amounts, specify both the shape and width of the PDF, allowing the cloud cover to be diagnosed

Prognostic statistical scheme (II)

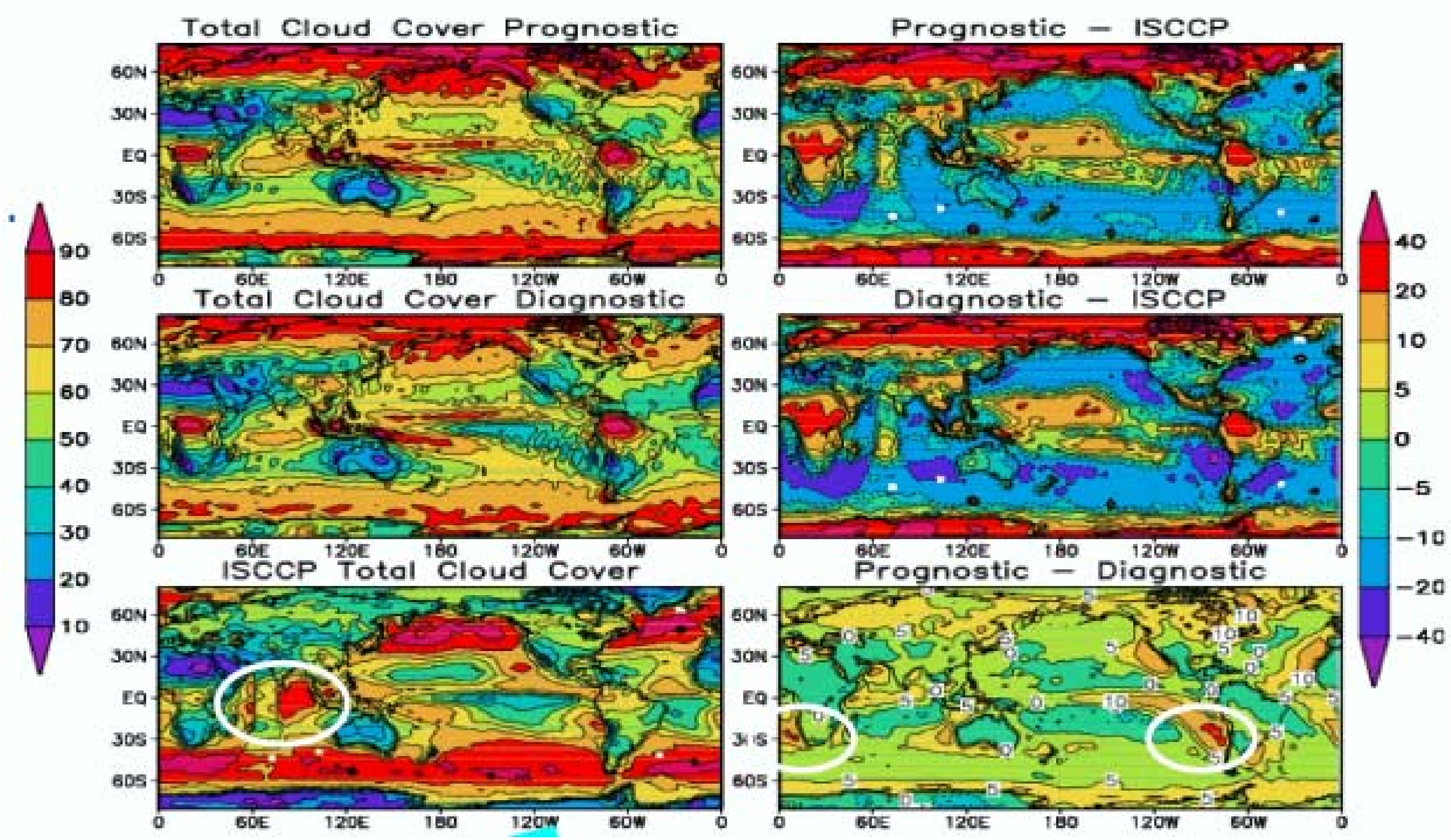
- Scheme uses the Beta distribution for q_t variability
- Justified from use of CRM data (observations agree-ish)
- Temperature variations are ignored.

- POSITIVE / NEGATIVE SKEWNESS POSSIBLE, also SYMMETRIC
- LIMITED FUNCTION
- UNIMODAL



$$G(q_t) = \frac{1}{B(p,q)} \frac{(q_t - q_{t0})^{p-1}(q_{t1} - q_t)^{q-1}}{(q_{t1} - q_{t0})^{p+q-1}}$$

Prognostic statistical scheme (III)



Cumulus scheme

Idea: Treat cloud fields as an idealized prey-predator dynamical system

- Assumption: The driving force for convective clouds is atmospheric instability

- While processes like radiation, advection, ... can create instability (export entropy) clouds are responsible to restore the state of maximum entropy

Model concept

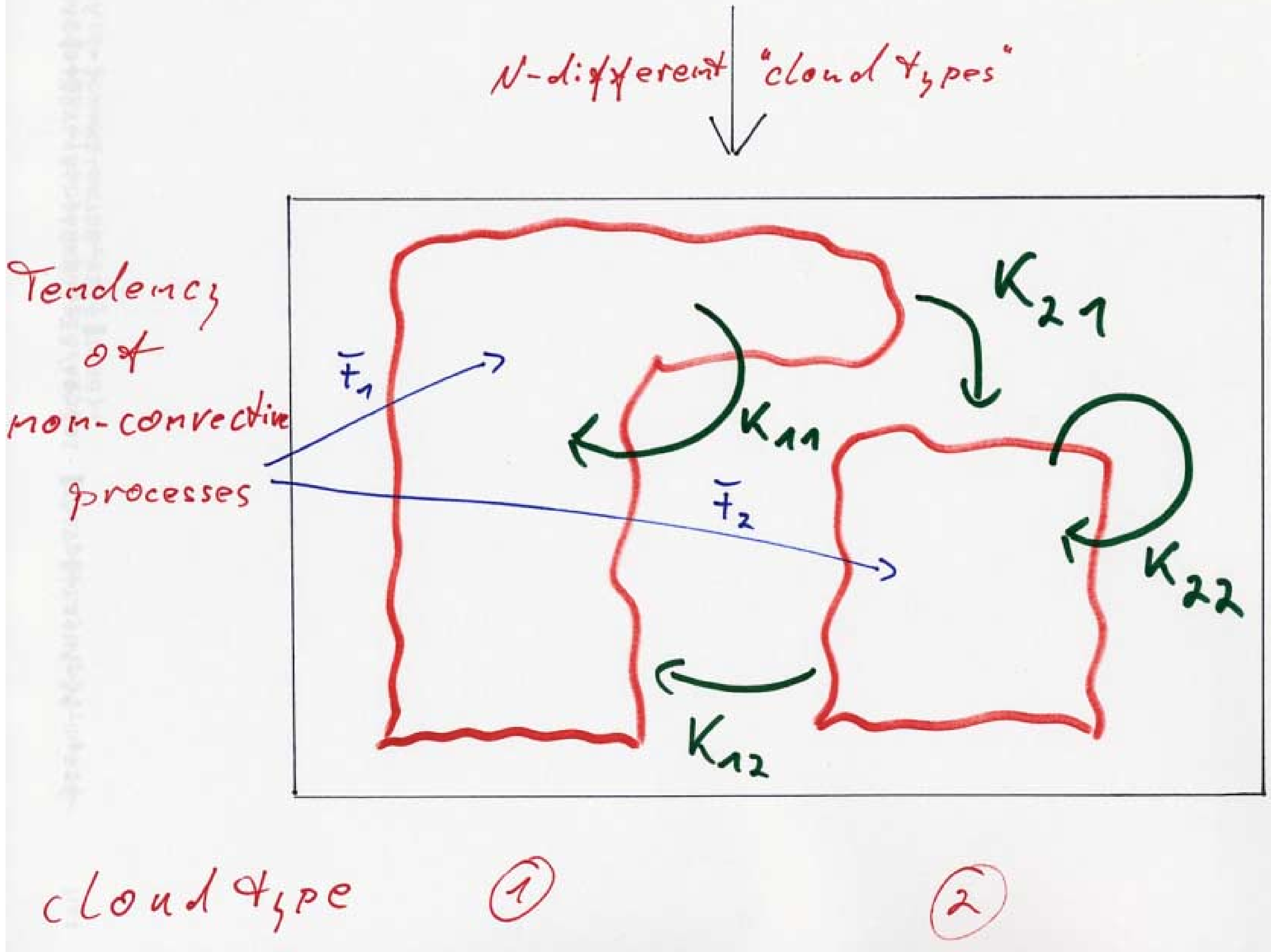
- Use a 1-d cloud model to define an ensemble of different cloud types
- Calculate the effect of
  - the non-convective processes on each cloud type and
  - each cloud type on the environment and therefore on each other cloud type

  - Solving the Lotka–Volterra equation where N different cloud types refer to N different species and where the rate of *CAPE* supply from non-convective processes refers to the food for the species [convective cloud field]

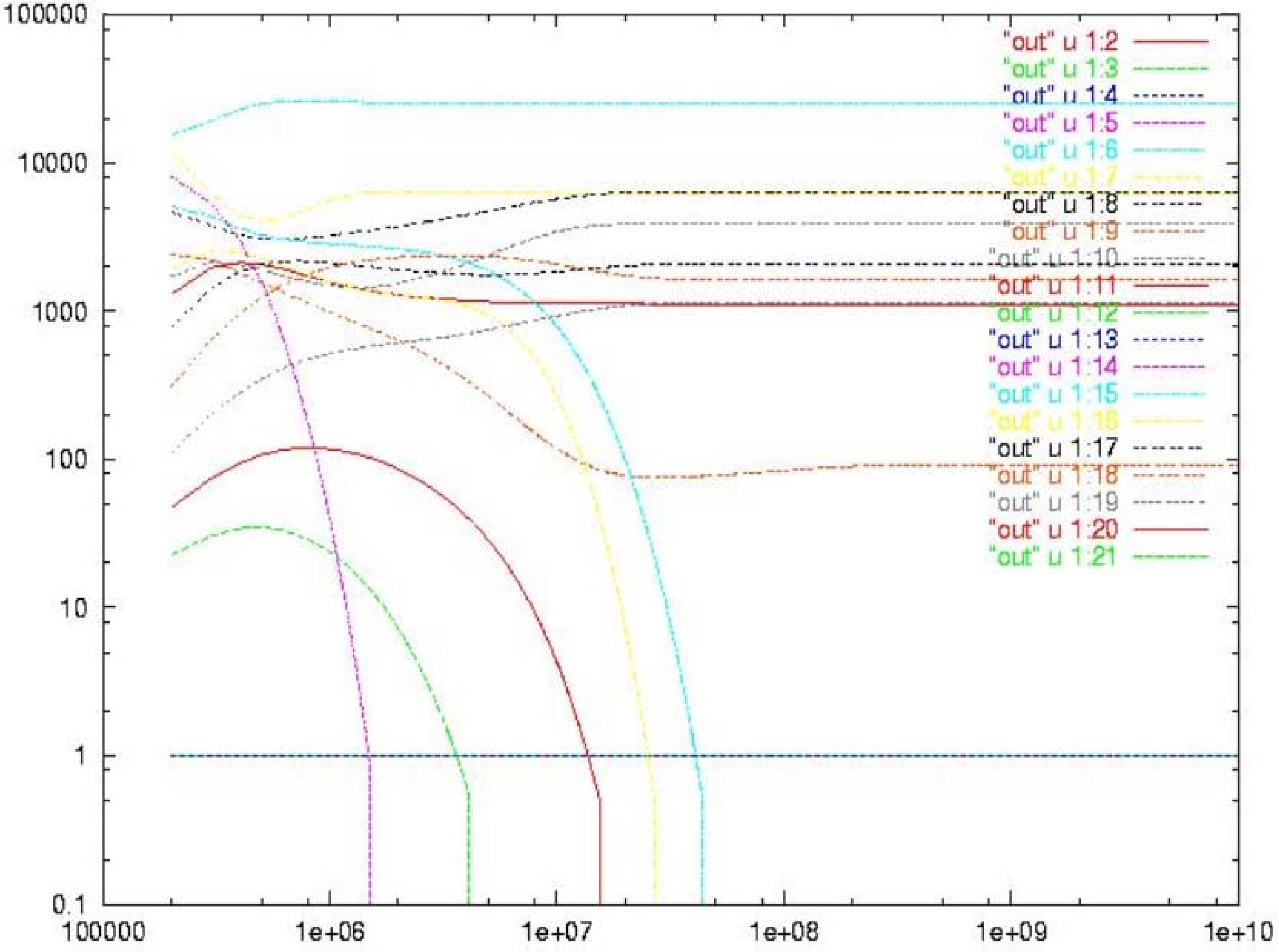
$$\frac{dx_i}{dt} = \sum_{j=1}^{N} K_{ij} x_i x_j + F_i x_i$$

1-dimensional

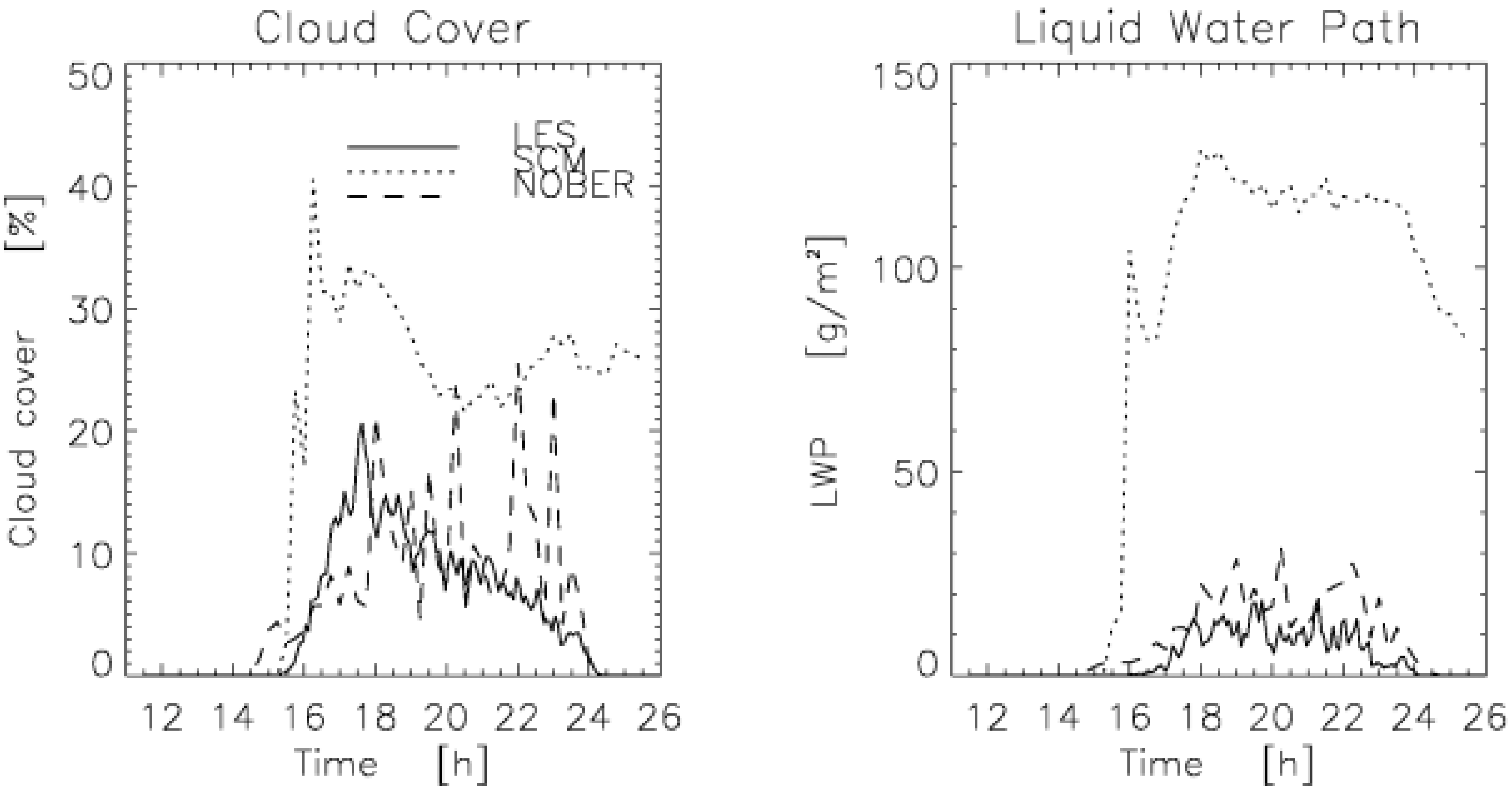
cloud model



Iteration of Lotka-Volterra equation



Time series of cloud cover and LWP



Advantages and drawbacks

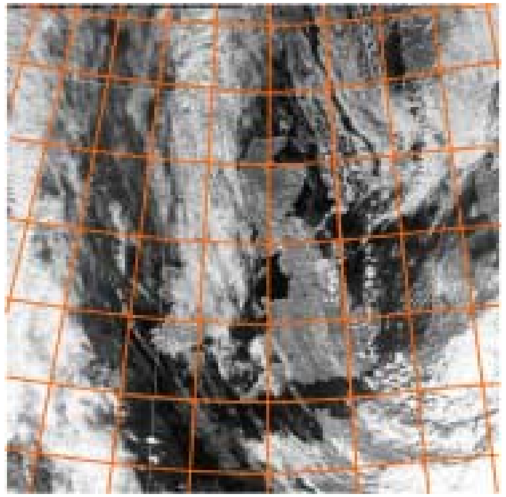
- A self consistent theoretical based approach that resolves at least some features of sub-grid variability of convective cloud fields
- Consideration of a spectrum of different clouds instead of one averaged cloud
- More information (cloud cover of different cloud types, ...) for validation available
- The model closes the gap between very complex and time consuming cloud resolving models and very idealized and simplified convection parameterizations
- Very time consuming compared to simpler parameterisation schemes

Radiation Scheme (I)

Goal:

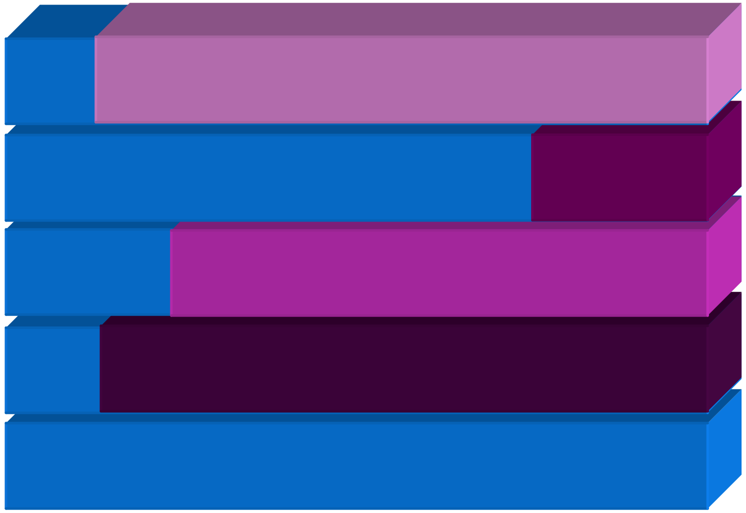
Development of a radiative transfer parameterization in the ECHAM5 model which accounts for the effect of horizontal sub-grid scale cloud variability

Radiation scheme (II)

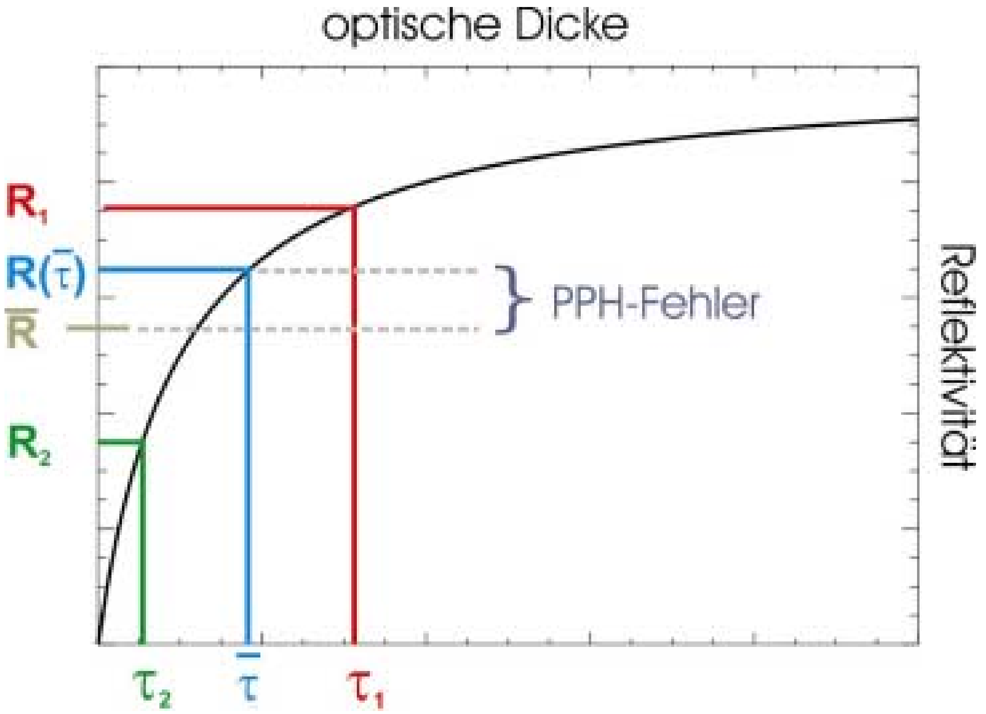


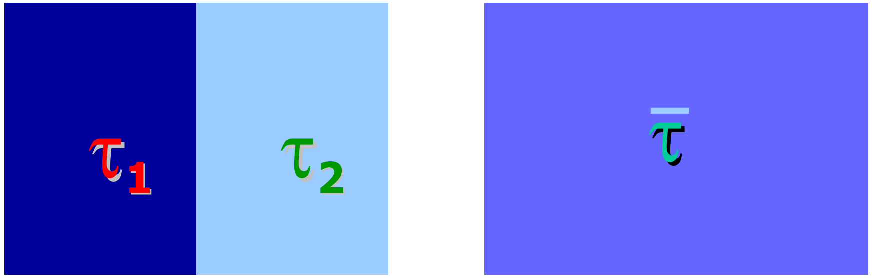
ECHAM4 uses
plan-parallel homogeneous (PPH)
approximation for clouds:

Mean liquid water path and cloud cover in each layer



PPH-Error





- Reflectivity R (Transmissivity T) is a concave (convex) function of the optical depth τ

$$\bar{R}(\tau) \le R(\bar{\tau})$$

$$\bar{T}(\tau) \ge T(\bar{\tau})$$

Radiation Scheme (III)

Basis:

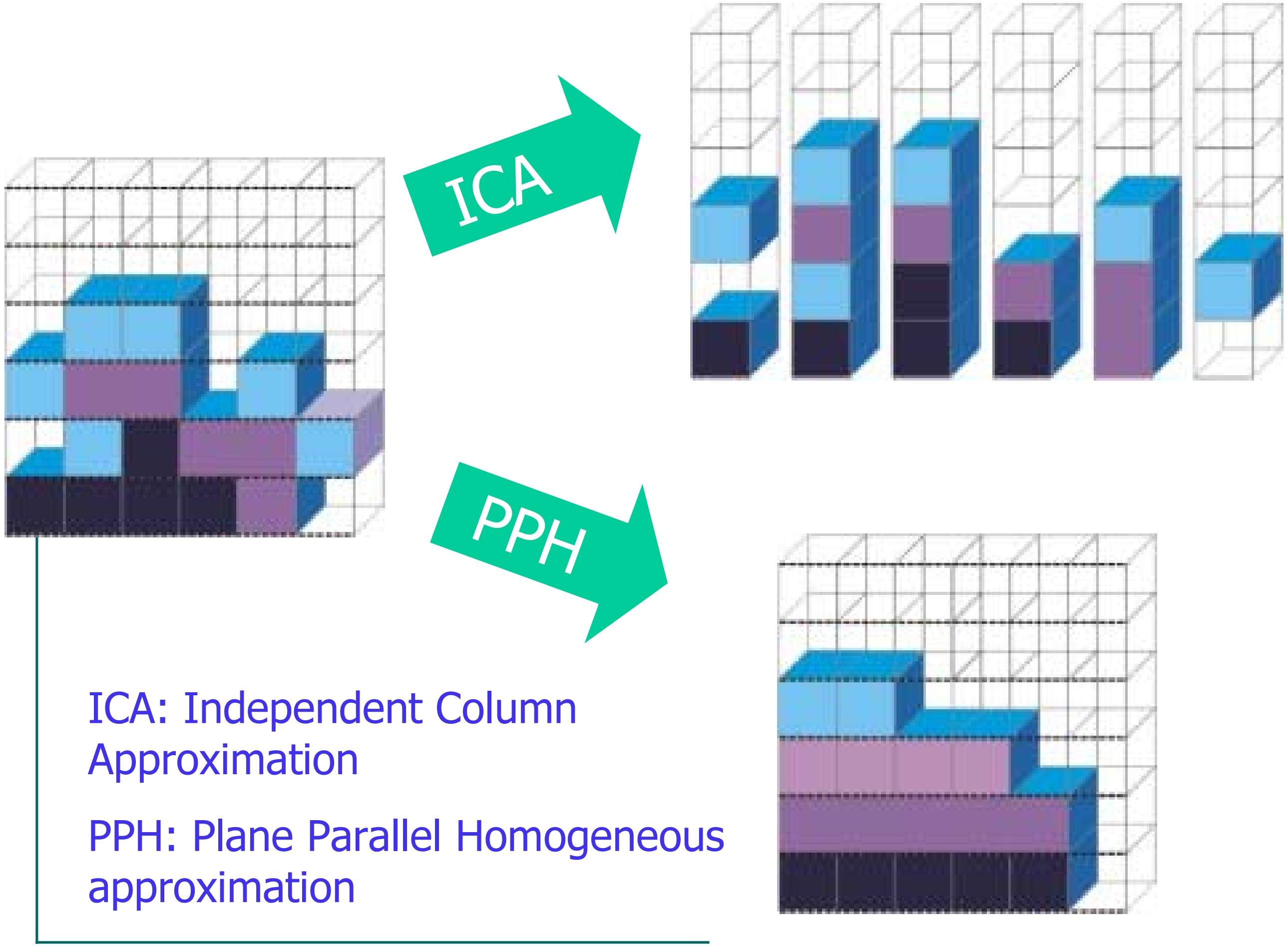
Effective Thickness Approach (Cahalan, 1994): Optical thickness of clouds is reduced by a correction factor χ

$$\overline{R(\tau)} = R(\chi\overline{\tau}) \qquad , \chi \leq 1$$

Method:

Determine reduction factor for different cloud types using Large-Eddy Simulations and radiative transfer calculations

Experiments ICA — PPH



- ✓ full information about hor. und vert. structure
- ✗ no horizontal flx

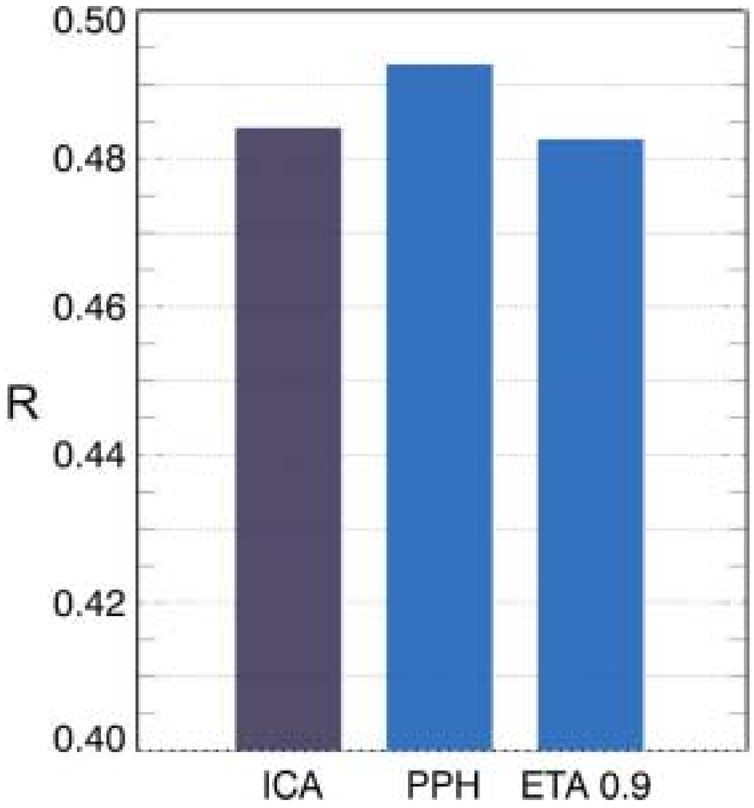
- ✗ no hor. Variability
- ✗ assumption about cloud overlap

ICA: Independent Column Approximation

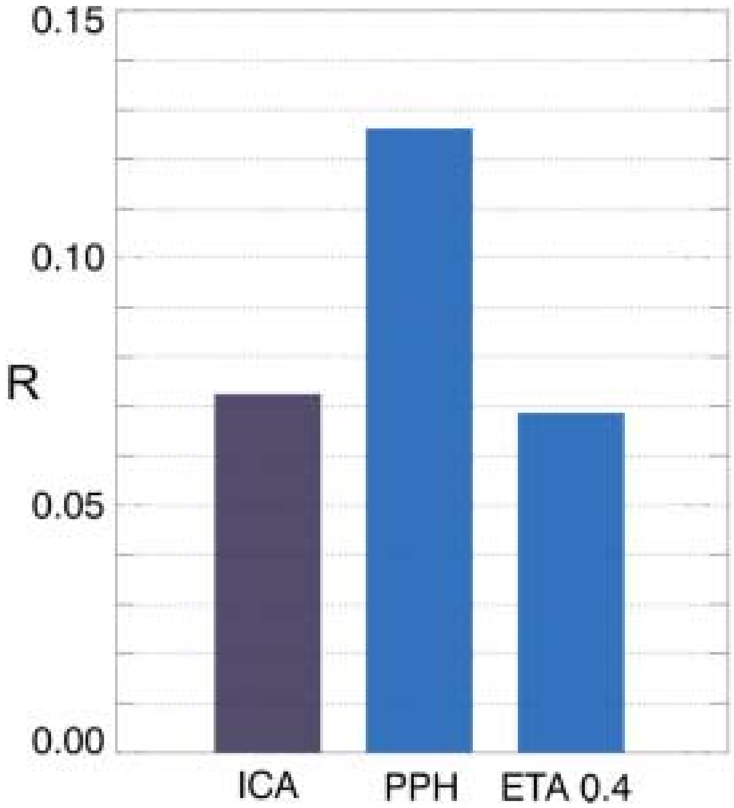
PPH: Plane Parallel Homogeneous approximation

Results — ETA

Stratocumulus



Cumulus

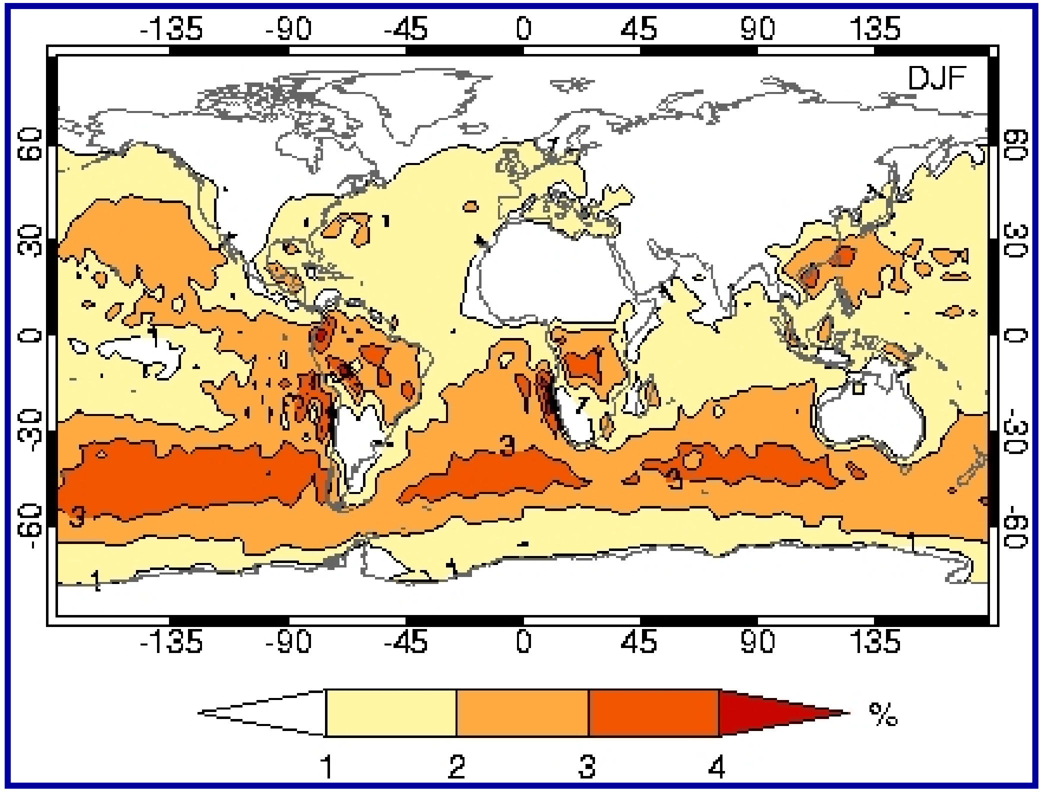


$\chi_{Sc}=0,9$

χ is strongly dependent on cloud type

$\chi_{Cu}=0,4$

Geographical distribution of the mean winter albedo bias due to cloud inhomogeneity



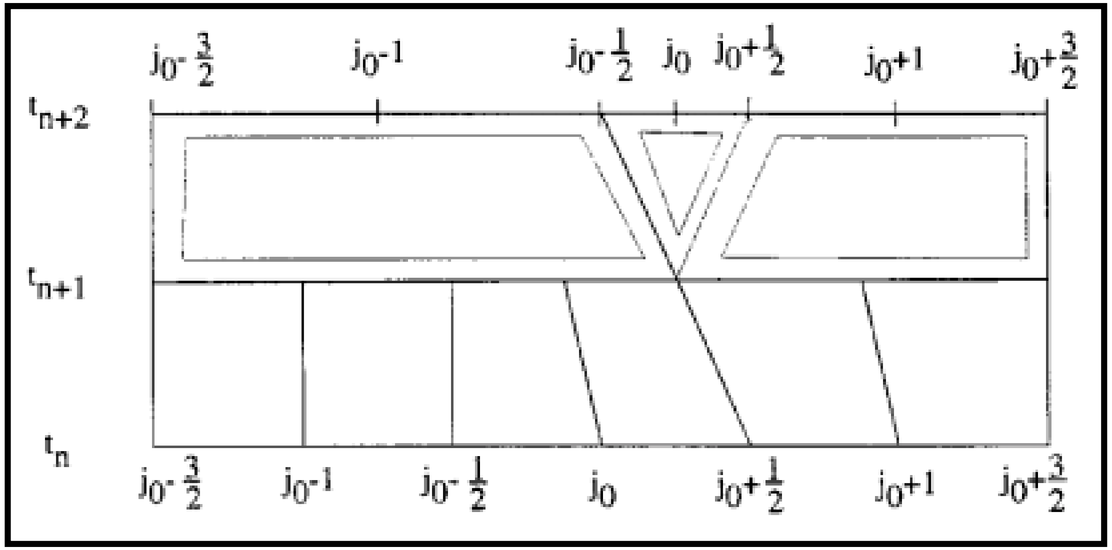
Results:

- Correction factors are in the range 0.4 < χ < 1 for water clouds (depending on LWP), χ = 0.9 for ice clouds
- Albedo is reduced by 1.8 % in the global annual mean (corresponding to an increase of net SW radiation by 6.2 W/m²)

Diffusion scheme

Improvements have been achieved due to:

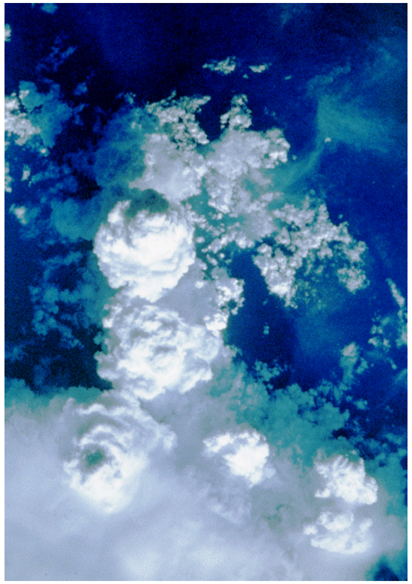
- Adequate treatment of the radiative-diffusive interaction process
- Explicit entrainment parameterization in conjunction with a front tracking/capturing scheme to model the propagation of the phase boundary



Conclusions

- CRMs and LES are the best techniques we have today for studying turbulence and cloud processes
- These tools can be used in developing/calibrating parameterizations for GCMs and NWPs

From Nature



To its

Representation

```
SUBROUTINE  vdiff (kidia,kfdia,klon,klp2,ktdia,klev,klev, &
  &        paclcm,paphm1,papm1,pgeom1,pum1,pvm1,pxm1)

! Description:
!-- Computation of the exchange coefficients
IMPLICIT NONE
! Scalar arguments with intent(In):
INTEGER, INTENT (IN) :: kfdia, kidia, klev, klevm1, klevp1,&
 &   klp2, ktdia, ktrac

DO  jl = kidia, kfdia
         zdu2 = MAX(zepdu2,pum1(jl,klev)**2+pvm1(jl,klev)**2)
         zqmitte = (pqm1(jl,klev)+zqs(jl)*zhsoil(jl))/2.
zmult4 = zfux*zmult5 - 1.
        zcons = zcons12*paphm1(jl,klevp1)/(ptm1(jl,klev)* &
    &          (1.+vtmpc1*pqm1(jl,klev)-pxm1(jl,klev)))
END DO
```