AN INTEGRATED APPROACH FOR
AEROSOL/CLOUD/RADIATION INTERACTIONS
IN
BOUNDARY-LAYER CLOUDS

ACE-2: 5 co-ordinated field experiments focused on the Aerosol Indirect Effect in Marine BL Clouds

LAGRANGIAN – HILLCLOUD – FREETROP

1997 **CLEARCOLUMN – CLOUDYCOLUMN**

PACE: 4 Experimental ACE-2/CLOUDYCOLUMN Groups

2000-2002 **& 5+2 GCM Modelling Groups**

Worshop on Aerosol/Cloud/Radiation Interactions

24-27 June 2002, Meteo-France Conference Center

EUROCS Meeting 18 December 2002 J. L. Brenguier Météo-France

PACE

Cooperative Study between ACE-2 Experimentalists and GCM Modellers for Testing/Developing GCM Parameterizations on the ACE-2 data set

Meteo-France: J.L. Brenguier

FUBerlin: L. Schüller

U Warsaw: H. Pawlowska

U Wyoming: J. Snider

MPI: J. Feichter

Hadley: D. Roberts

U Dalhousie: U. Lohmann

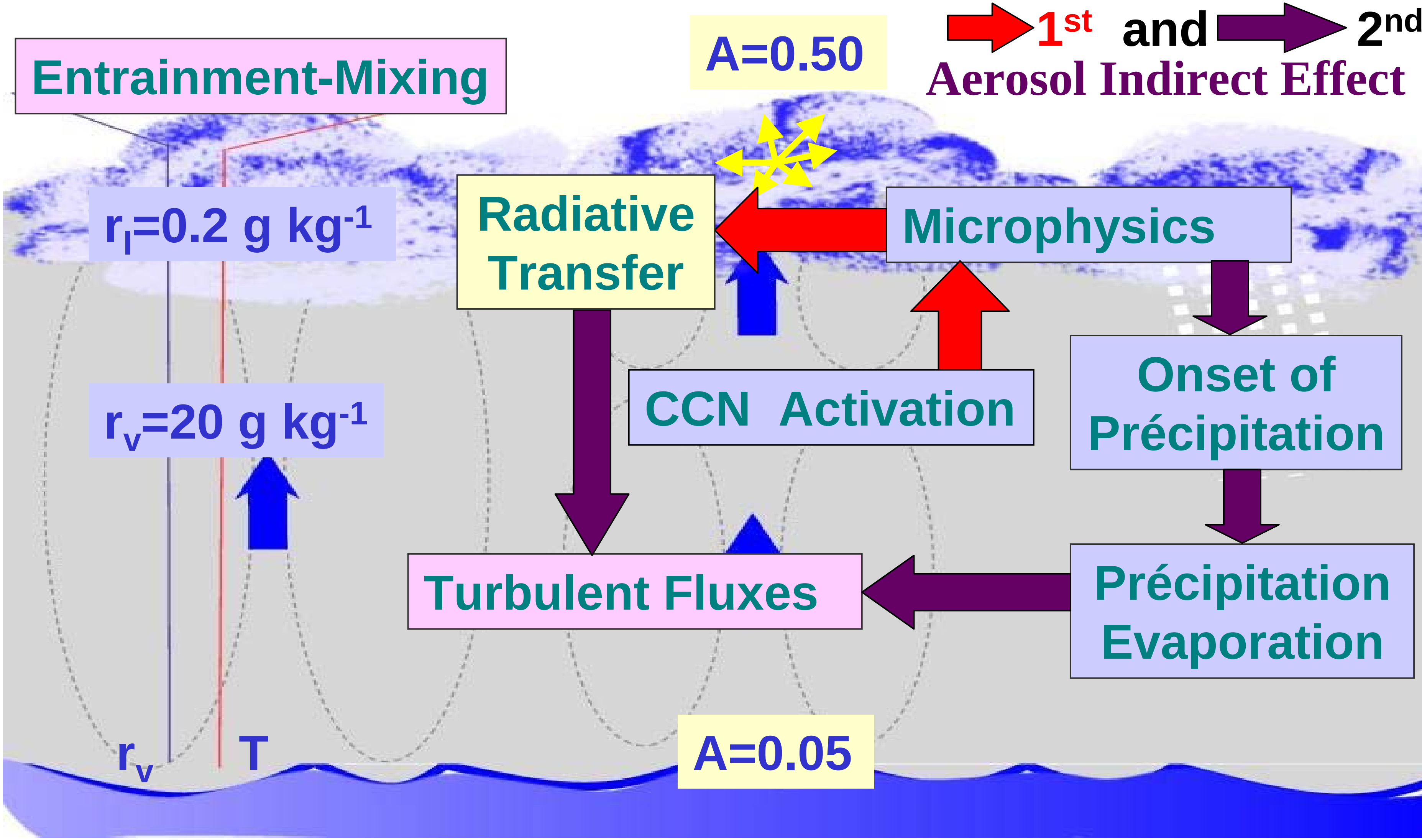
U Columbia: S. Menon

PNNL: S. Ghan

U Michigan: J. Penner

LMD: J. Quaas

Boundary Layer Clouds



1st and 2nd

Aerosol Indirect Effect

A=0.50

Entrainment-Mixing

$r_l=0.2$ g kg^{-1}

$r_v=20$ g kg^{-1}

Radiative Transfer

Microphysics

CCN Activation

Onset of Précipitation

Précipitation Evaporation

Turbulent Fluxes

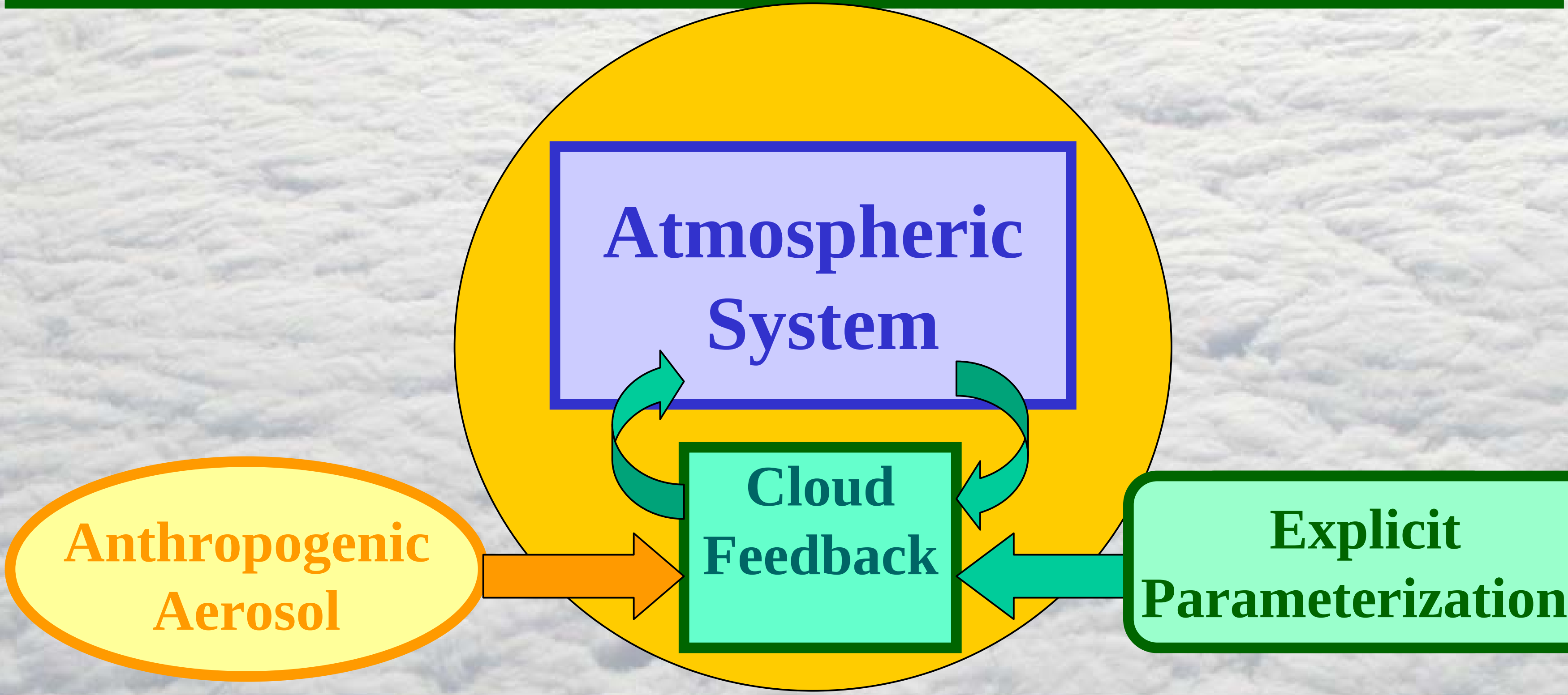
A=0.05

GCM Parameterizations of AIE

CHALLENGE

**TO PARAMETERIZE MODIFICATIONS
OF CLOUD MICROPHYSICS
AND THEIR IMPACT
ON AN ENSEMBLE OF CLOUDS
WITH NO EXPLICIT DESCRIPTION
OF SINGLE CELL PROPERTIES
(horizontal scale larger than ≈20 km)**

CLOUD PARAMETERIZATION IN GCM



Atmospheric System

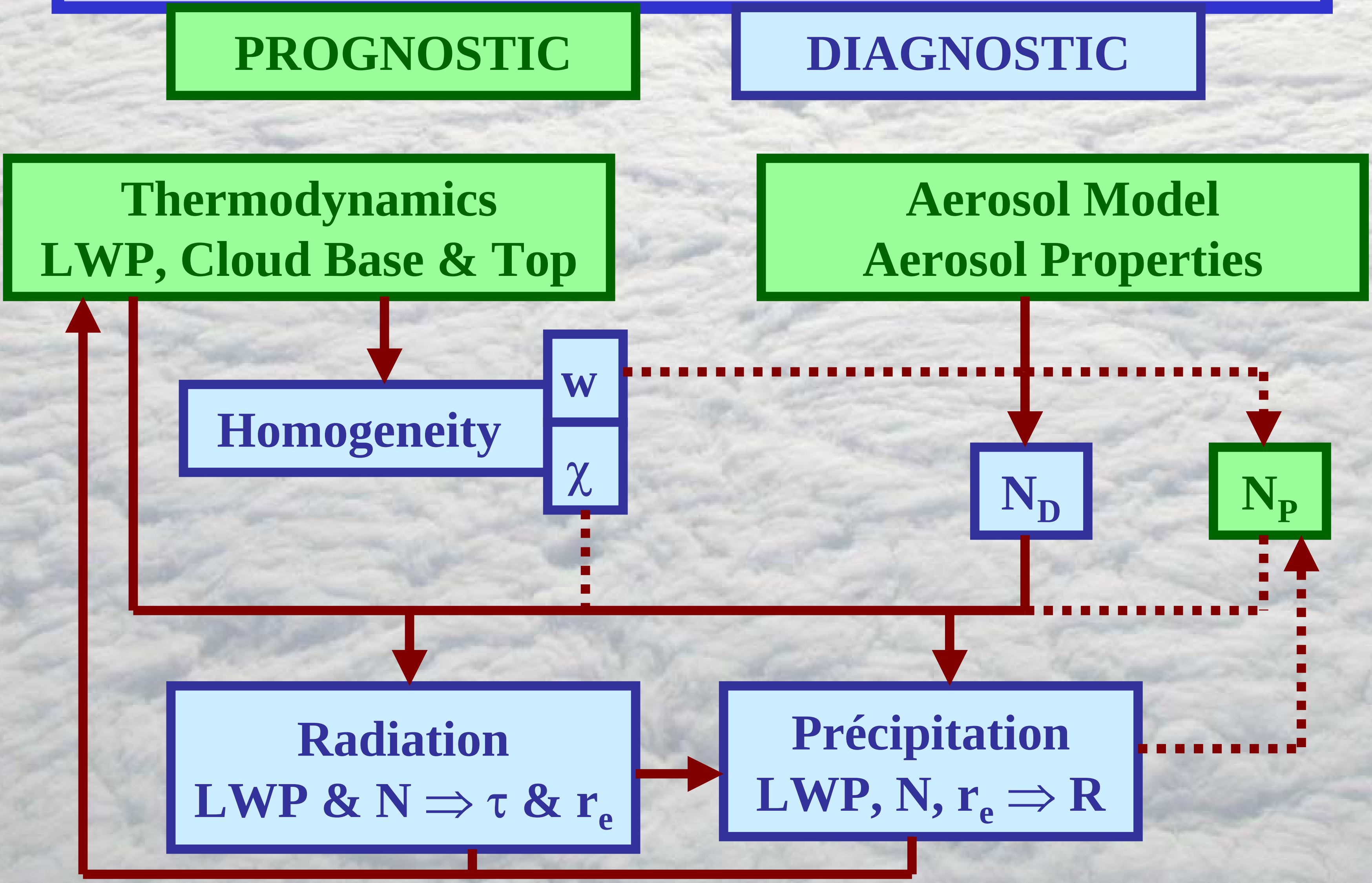
Cloud Feedback

Anthropogenic Aerosol

Explicit Parameterization

The aerosol indirect effect reflects modifications of the cloud microphysics, that shall thus be parameterized explicitly: aerosol activation, rain formation, evaporation, radiation

GCM Parameterizations of AIE



PROGNOSTIC

DIAGNOSTIC

Thermodynamics
LWP, Cloud Base & Top

Aerosol Model
Aerosol Properties

Homogeneity

w

χ

N_D

N_P

Radiation
LWP & N $\Rightarrow \tau$ & r_e

Précipitation
LWP, N, $r_e \Rightarrow$ R

ACE-2 DATA BASE

What is unique ?

Measurements at a scale well suited to GCM (60 km)

Most extensive data set (3.5 h, ~800 km)

First Campaign with independent and collocated measurements of cloud microphysics and cloud radiative properties

Limitations !

Not suited for diurnal cycle (obs at noon local)

AEROSOL/CLOUD/RADIATION INTERACTIONS IN GCMs

1 - PHYSICAL PROCESSES (1st AIE)

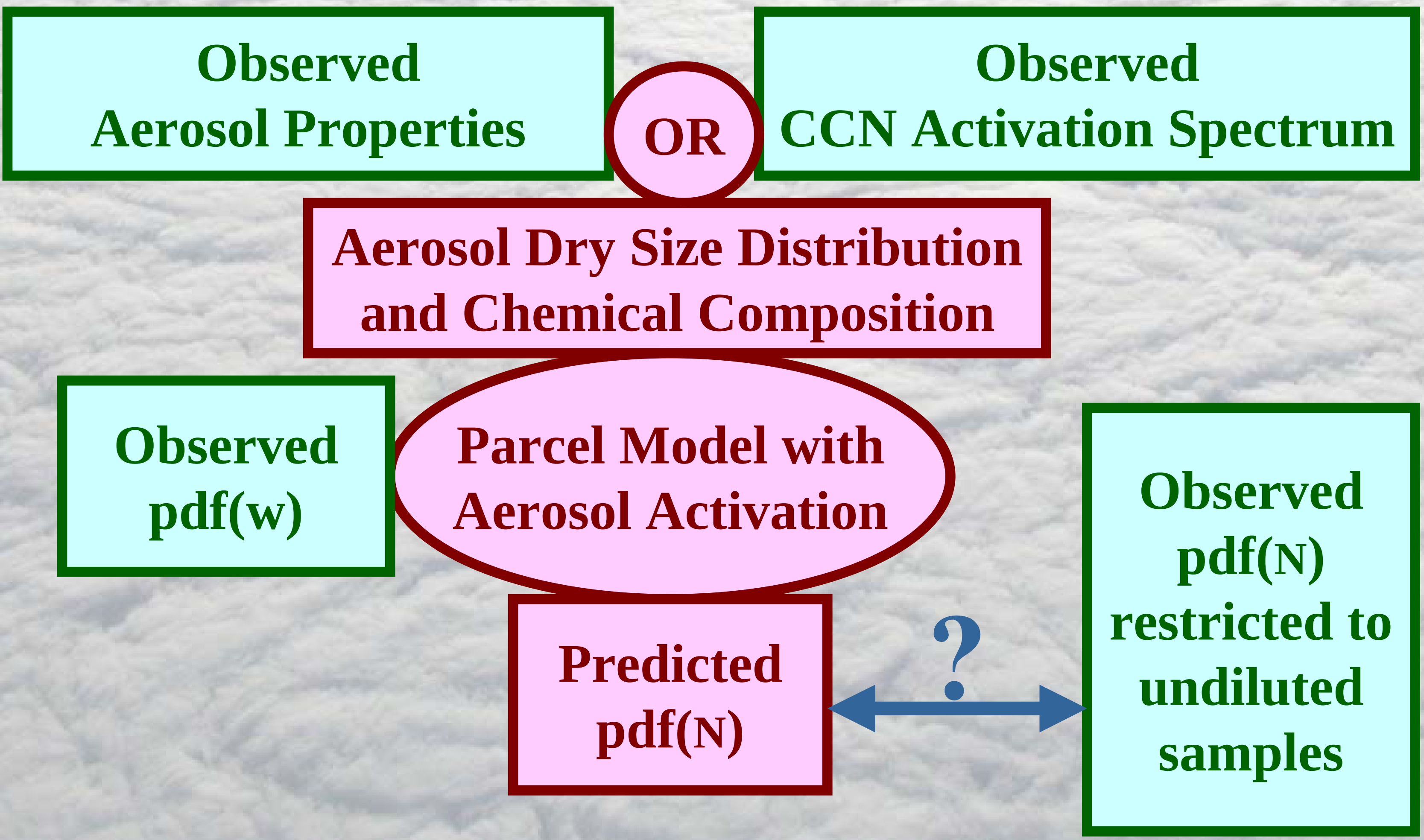
- *a -Aerosol Activation*
- *b -Radiative Properties*

2 - CRM versus GCM PARAMETERIZATION of PRECIPITATION (2nd AIE)

3 – « N » DIAGNOSTIC versus PROGNOSTIC

1 - PHYSICAL PROCESSES

Closure Experiment on Aerosol Activation



Observed
Aerosol Properties

OR

Observed
CCN Activation Spectrum

Aerosol Dry Size Distribution
and Chemical Composition

Observed
pdf(w)

Parcel Model with
Aerosol Activation

Predicted
pdf(N)

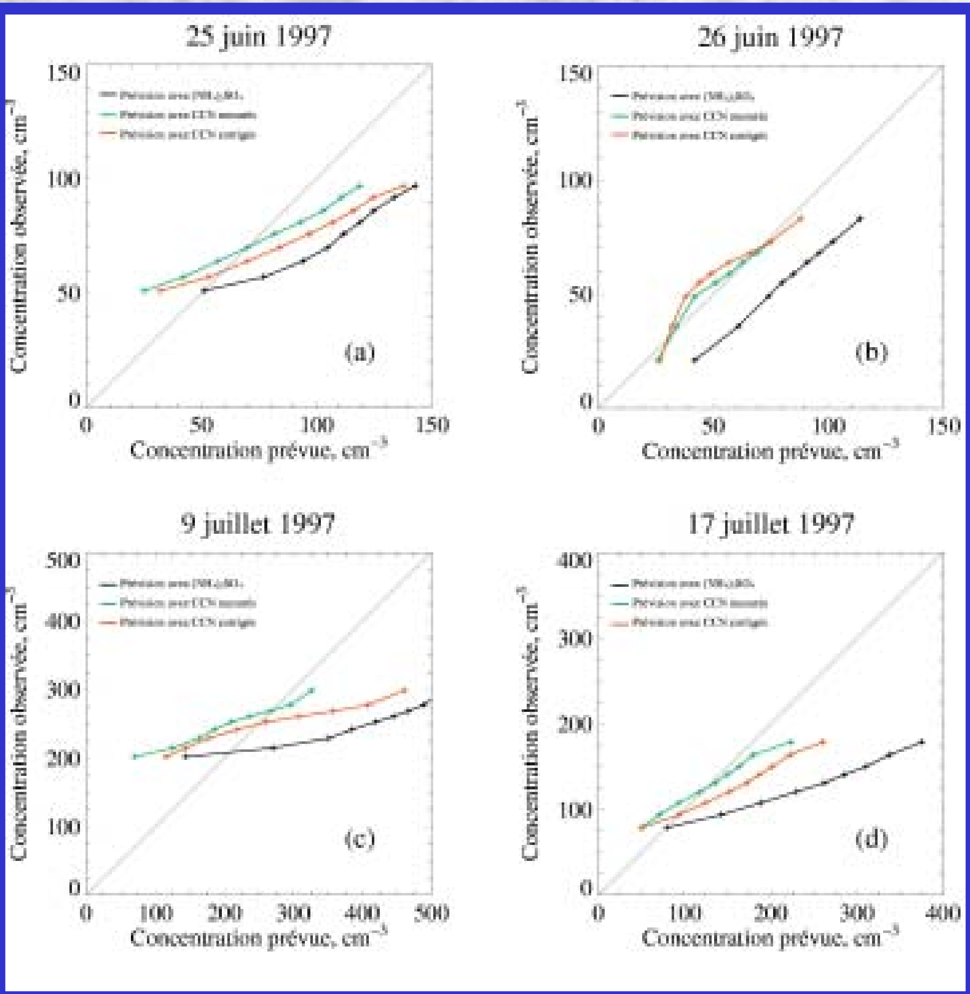
?

Observed
pdf(N)
restricted to
undiluted
samples

1 - PHYSICAL PROCESSES

Closure Experiment on Aerosol Activation

J. Snider and S. Guibert



Comparison of the 10 % percentiles of the observed N freq. distribution and that predicted from the 10% percentiles of the observed vertical velocity freq. distribution.

Parcel model initialised with

- **observed aerosol properties (black)**
- **aerosol derived from obs. CCN activation spectra (red and green)**

1 - PHYSICAL PROCESSES
Closure Experiment on Aerosol Activation
CONCLUSION

Predicted mean N is overestimated with respect to observed mean N

Predicted pdf(N) is broader than the observed pdf(N)

Origin of the bias:

- Aerosol (soluble fraction, mixing state, etc)

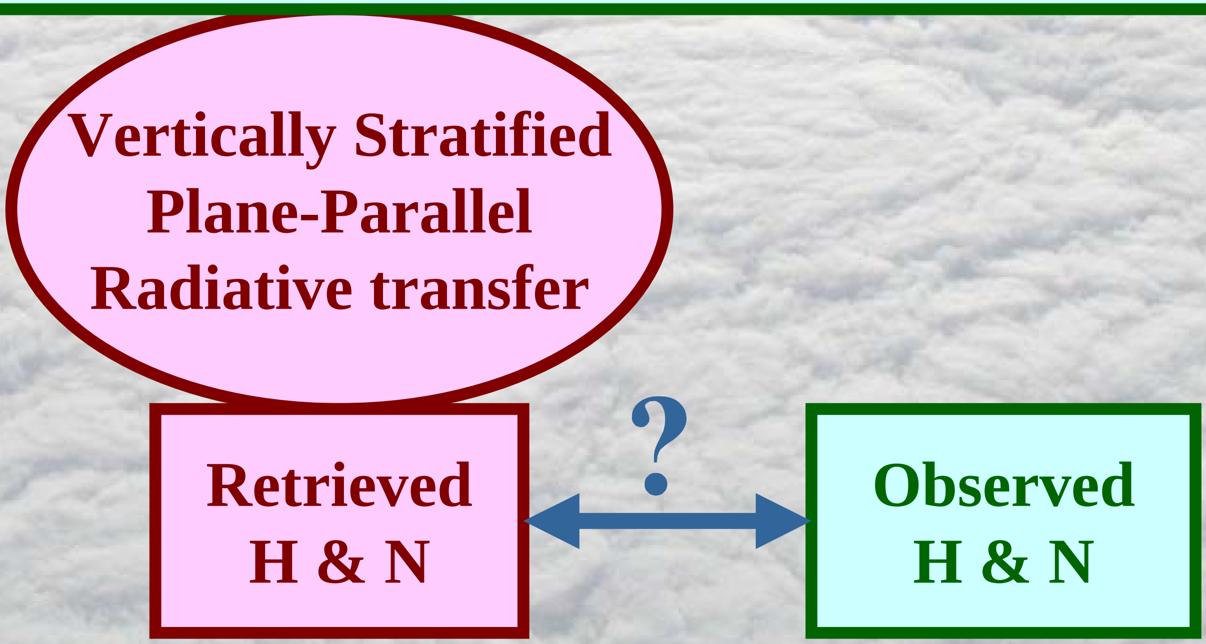
- Presence of large particules

- Biased measurements of w

1 - PHYSICAL PROCESSES

Closure Experiment on Radiative Transfer

Observed Radiances in Visible and Near Infra-Red Channels



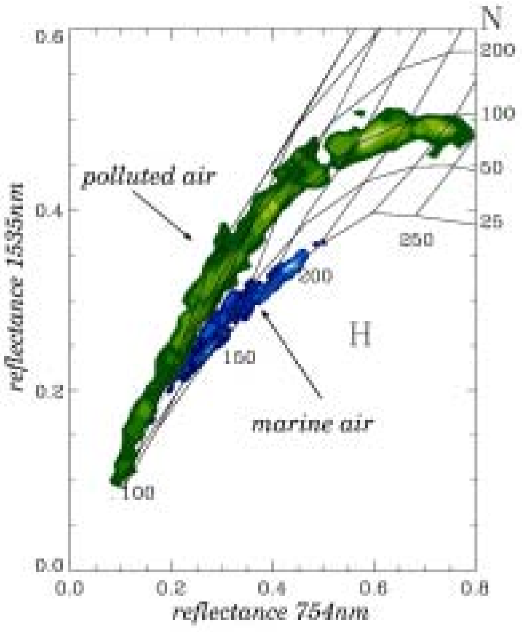
Vertically Stratified Plane-Parallel Radiative transfer

Retrieved H & N

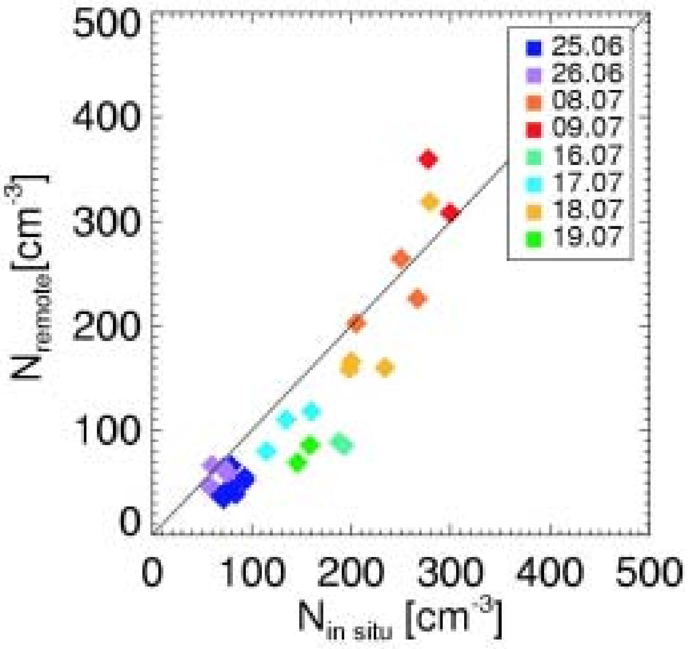
?

Observed H & N

1 - PHYSICAL PROCESSES
Closure Experiment on Radiative Transfer
L. Schüller



Measured reflectances in VIS and NIR, with H-N grid



Comparison of N_{insitu} with the remotely retrieved values of N

1 - PHYSICAL PROCESSES

Closure Experiment on Radiative Transfer

CONCLUSION

Retrieved and observed mean N agree

Retrieved H (LWP) is overestimated with respect to the observed H (LWP)

Origin of the bias:

- Bias in radiance measurements
- Limitation of the radiative transfer model (3D effects)
- Poor statistical significance of in situ estimations of H (LWP)

2 - CRM versus GCM PARAMETERIZATION OF PRECIPITATION

Detailed microphysics 1 to 3-D (50 to 200 variables)

3-D CRM Runs (diverse conditions)
Tripoli-Cotton, Beheng, Khairoutdinov-Kogan

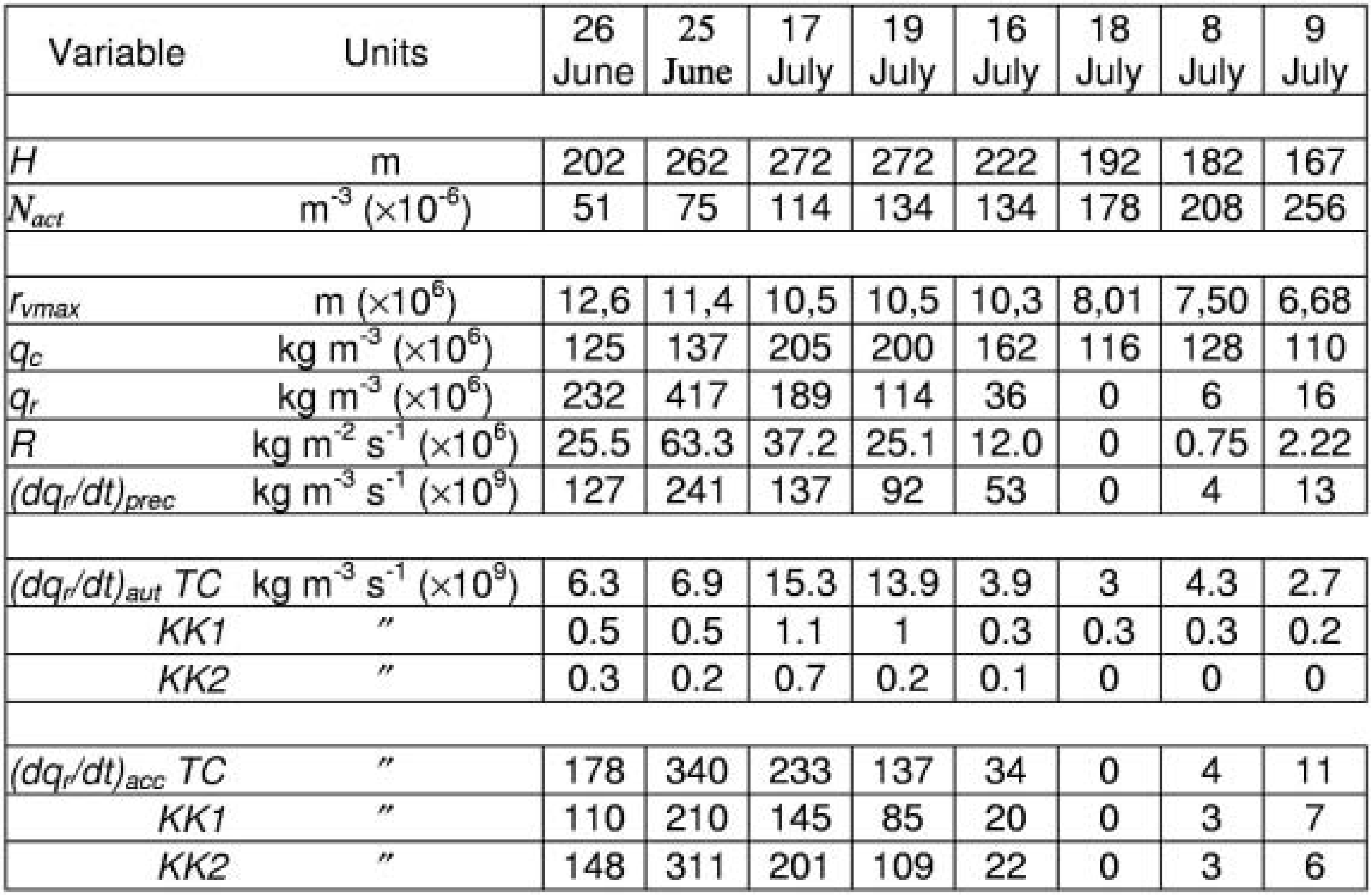
Bulk microphysics for CRM (3 variables: N, q_c, q_r)
Auto-conversion (N, q_c) and Accretion (N, q_c, q_r)

Tuning bulk coefficients to account for GCM grid smoothing effects

Bulk microphysics for GCM (2 variables : N, q_c)
Auto-conversion (N, q_c) (Accretion diagnosed)

2 - CRM versus GCM PARAMETERIZATION OF PRECIPITATION

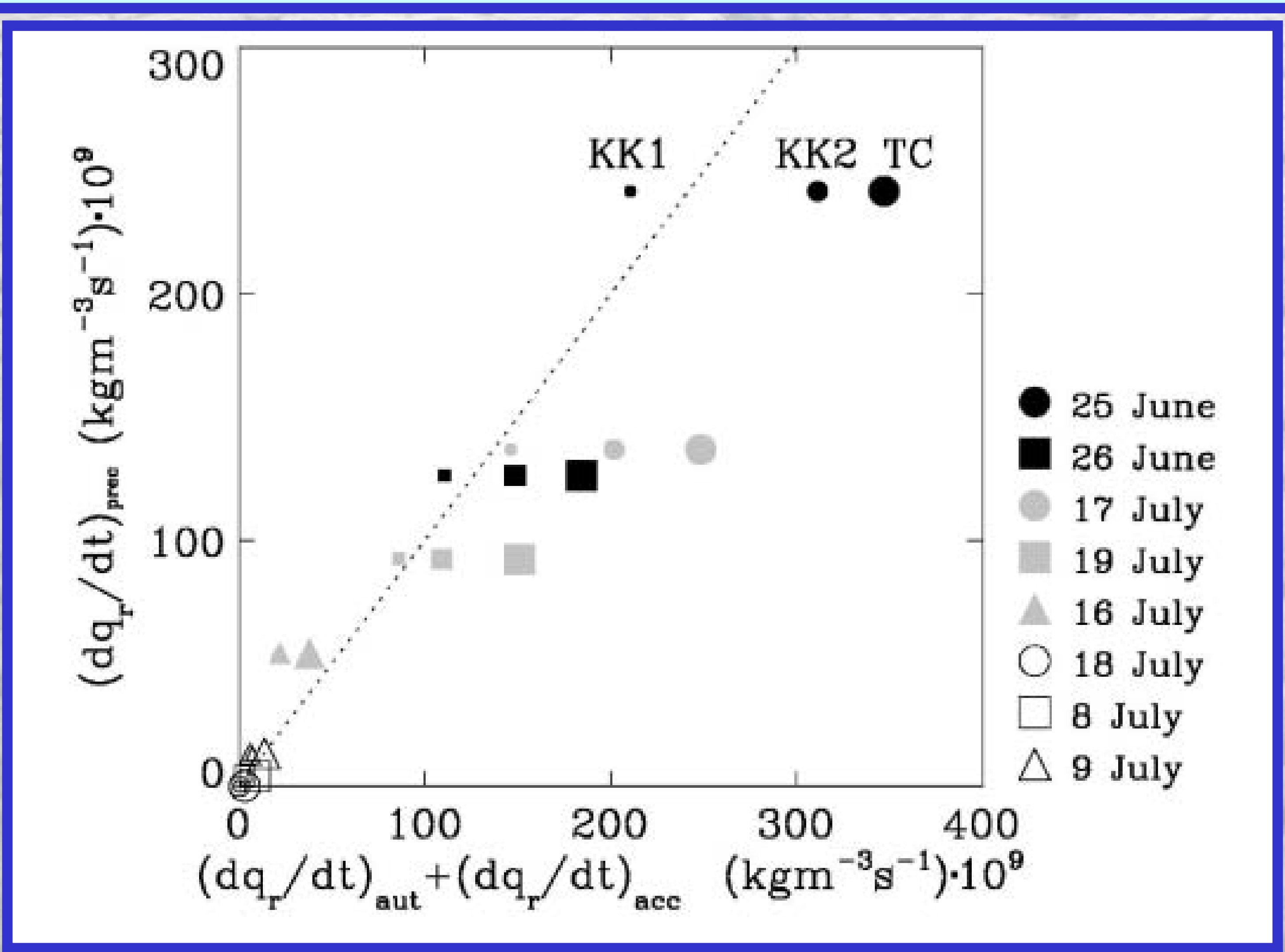
H. Pawlowska



Variable	Units	26 June	25 June	17 July	19 July	16 July	18 July	8 July	9 July
H	m	202	262	272	272	222	192	182	167
N_{act}	m^{-3} ($\times 10^{-6}$)	51	75	114	134	134	178	208	256
r_{vmax}	m ($\times 10^{6}$)	12,6	11,4	10,5	10,5	10,3	8,01	7,50	6,68
q_c	kg m^{-3} ($\times 10^{6}$)	125	137	205	200	162	116	128	110
q_r	kg m^{-3} ($\times 10^{6}$)	232	417	189	114	36	0	6	16
R	kg m^{-2} s^{-1} ($\times 10^{6}$)	25.5	63.3	37.2	25.1	12.0	0	0.75	2.22
$(dq_r/dt)_{prec}$	kg m^{-3} s^{-1} ($\times 10^{9}$)	127	241	137	92	53	0	4	13
$(dq_r/dt)_{aut}$ TC	kg m^{-3} s^{-1} ($\times 10^{9}$)	6.3	6.9	15.3	13.9	3.9	3	4.3	2.7
KK1	"	0.5	0.5	1.1	1	0.3	0.3	0.3	0.2
KK2	"	0.3	0.2	0.7	0.2	0.1	0	0	0
$(dq_r/dt)_{acc}$ TC	"	178	340	233	137	34	0	4	11
KK1	"	110	210	145	85	20	0	3	7
KK2	"	148	311	201	109	22	0	3	6

2 - CRM versus GCM PARAMETERIZATION OF PRECIPITATION

H. Pawlowska



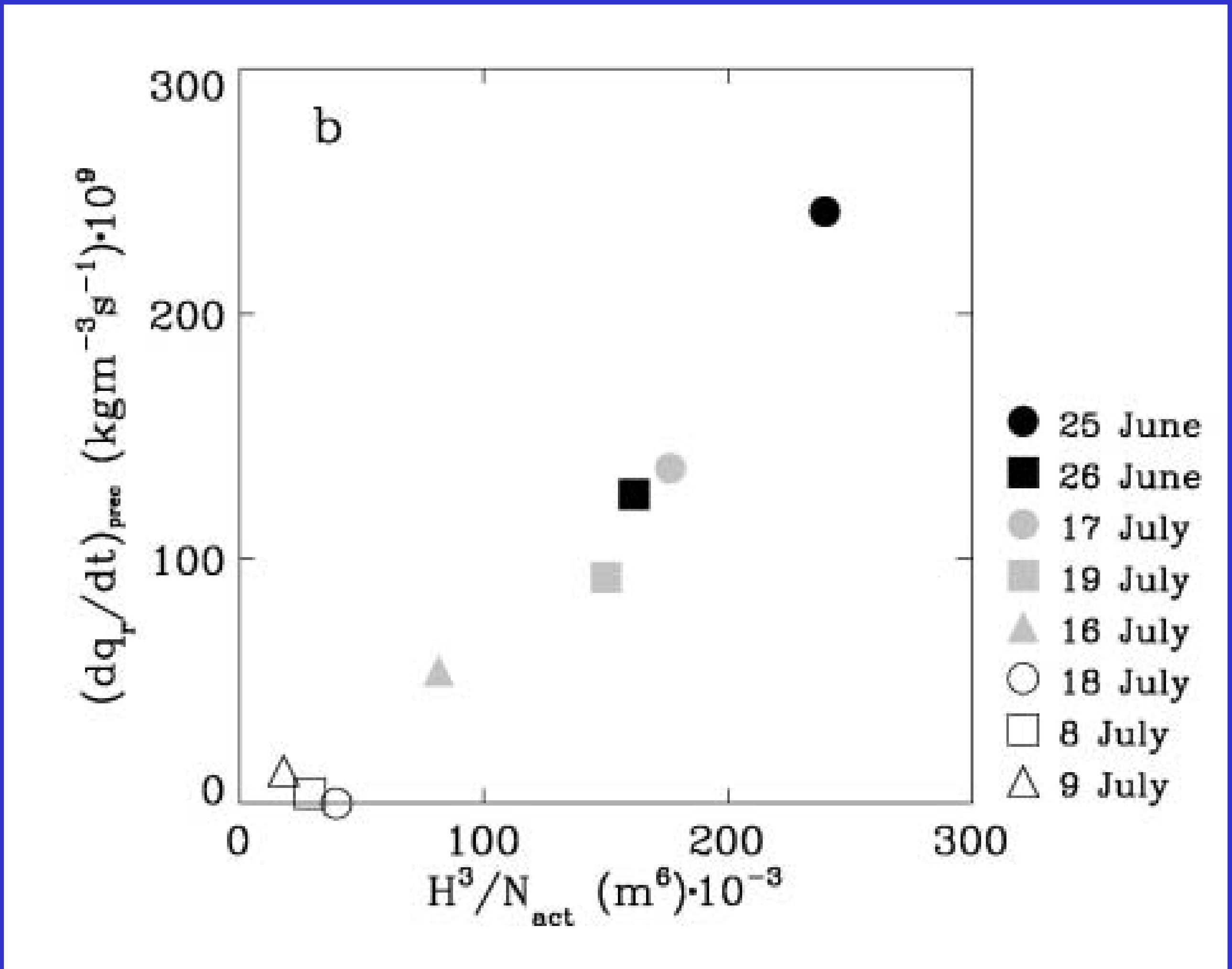
2 - CRM versus GCM PARAMETERIZATION OF PRECIPITATION
CONCLUSION

CRM bulk parameterizations provide good estimate of cloud to rain water conversion, despite non-linearity of microphysical processes and the coarser resolution of GCM compared to CRM

BUT, auto-conversion is less than one order of magnitude smaller than accretion that is not parameterized in GCM

2 - CRM versus GCM PARAMETERIZATION OF PRECIPITATION

H. Pawlowska



Parameterization of precipitation in GCM

Detailed microphysics 1 to 3-D (50 to 200 variables)

3-D CRM Runs (diverse conditions)
Tripoli-Cotton, Beheng, Khairoutdinov-Kogan

Bulk microphysics for CRM (3 variables: N, q_c, q_r)
Auto-conversion (N, q_c) and Accretion (N, q_c, q_r)

3-D bulk CRM Runs (meso-scale)

Bulk microphysics for GCM (2 variables : N, H)
Average precipitation rate from multi-cells in steady state,
with auto-conversion and accretion implicitly included

3 – « N » DIAGNOSTIC versus PROGNOSTIC

For <u>aerosol activation</u> :

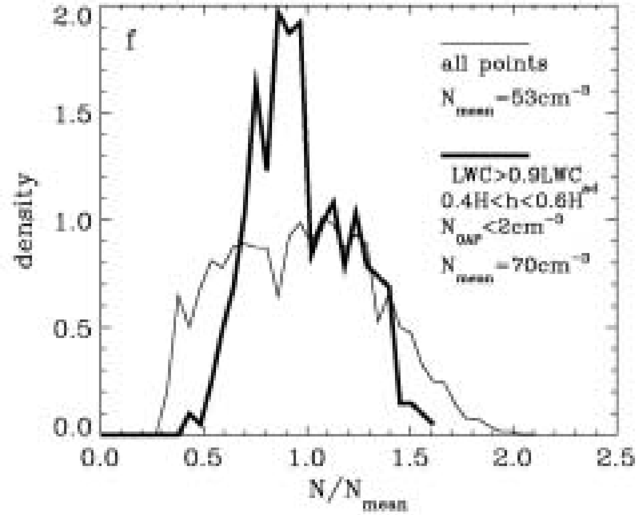
- A <u>diagnostic</u> scheme predicts N_{act} a value that reflects the activation process.

- A <u>prognostic</u> scheme predicts N_{mean} cloud-fraction mean CDNC, that includes the effects of diluting processes after activation (mixing & drizzle scavenging).

$q_c(h) > 0.9\ q_{cad}(h)$

$N_{drizzle} < 2cm^{-3}$

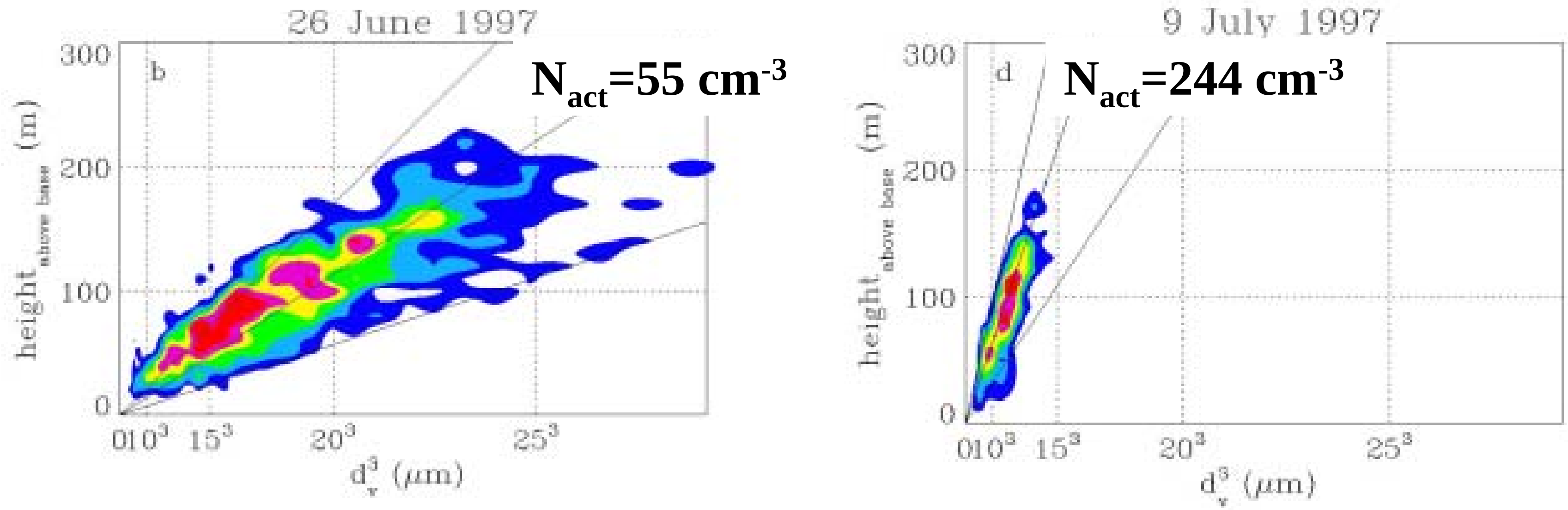
$0.4H < h < 0.6H$



3 – « N » DIAGNOSTIC versus PROGNOSTIC

?? What is the value that determines droplet sizes??

N_{act} or N_{mean}



N_{act}=55 cm^{-3}

N_{act}=244 cm^{-3}

Droplet mean volume versus height above cloud base

Middle line corresponds to the adiabatic prediction with $N=N_{act}$

3 – « N » DIAGNOSTIC versus PROGNOSTIC

Heterogeneous Mixing

Adiabatic cell

$$q_{cad} = C_w\, h$$

$$r_{vad}(h) = (C_w\, h \,/\, kN_{ad})^{1/3}$$

Sub-adiabatic cell

$$q_c\,(h) = \alpha\, q_{cad}\,(h)$$

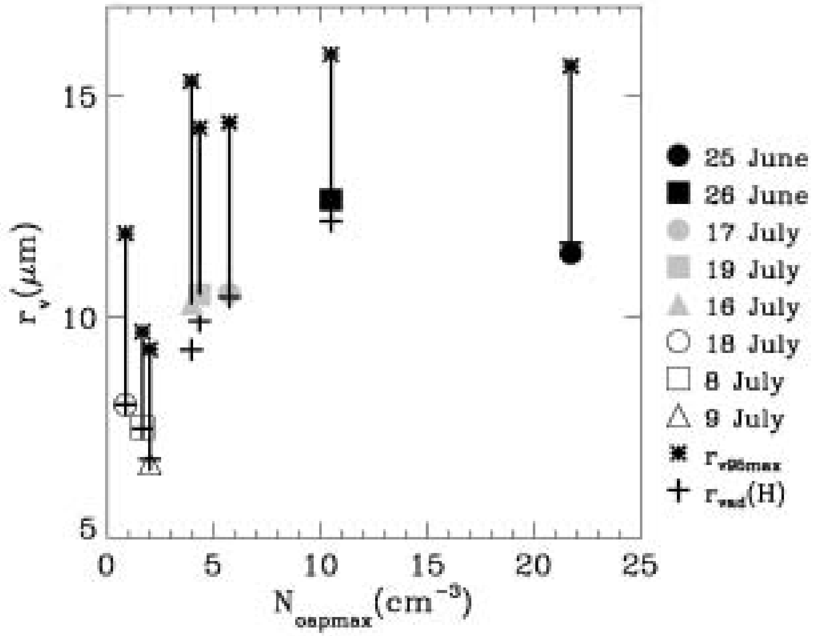
$$N\,(h) = \alpha\, N_{ad}\,(h) \;\&\quad r(h) = r_{vad}(h)$$

3 – « N » DIAGNOSTIC versus PROGNOSTIC

H. Pawlowska

?? What is the value that determines precipitation formation??

N_{act} or N_{mean}



Drizzle concentration N_{OAP} versus droplet radius at cloud top

3 – « N » DIAGNOSTIC versus PROGNOSTIC

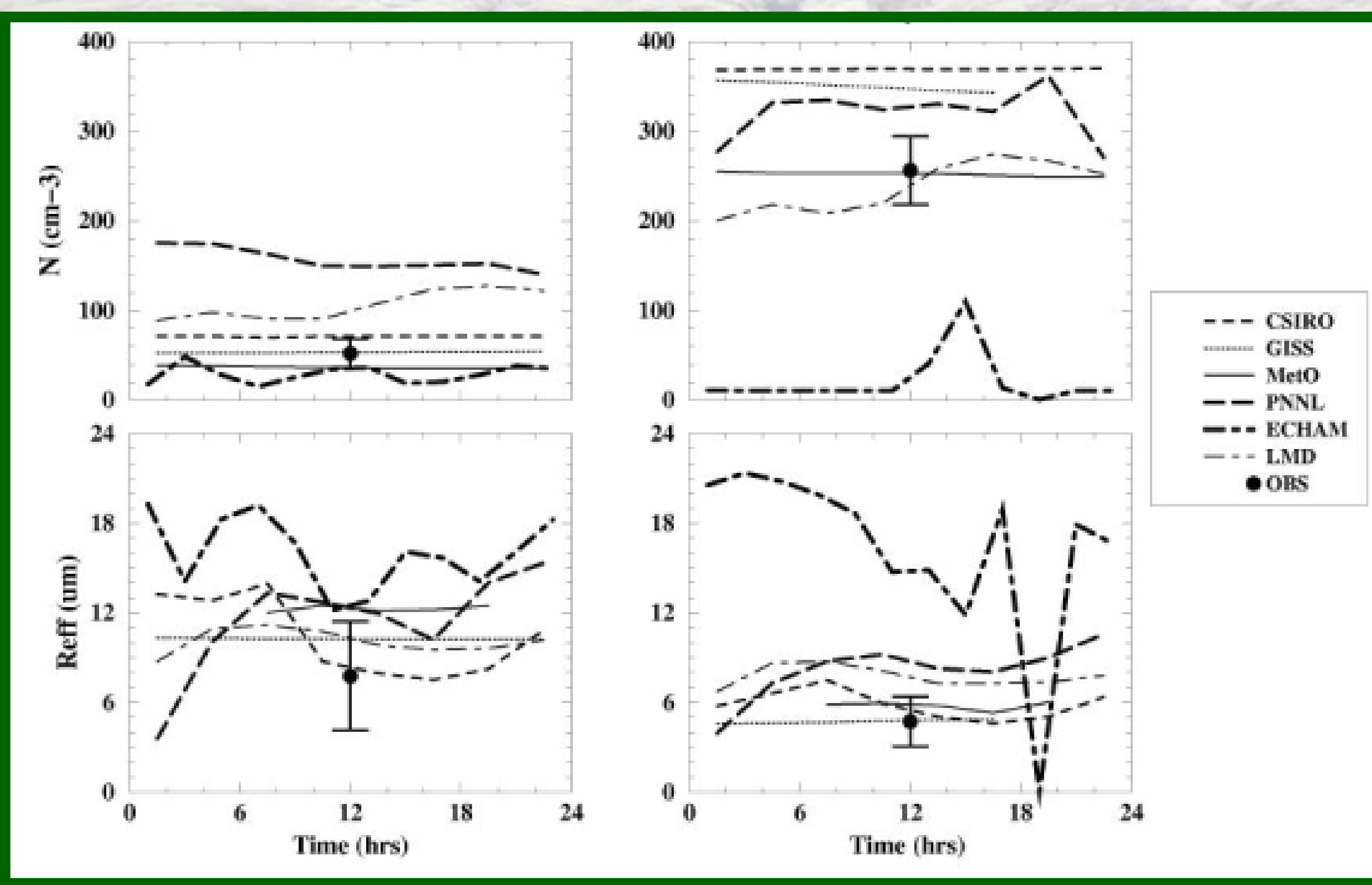
S. Menon et al.

Single column version of 6 GCMs

- **Single time step test of physical process parameterizations at the vertical resolution of the observations (~ 30 m)**
- **Single time step test of physical process parameterizations at the vertical resolution of the GCM (> 100 m)**
- **48 h run at the GCM resolution forced by ECMWF fields, with(out) nudging to observations**

3 – « N » DIAGNOSTIC versus PROGNOSTIC

S. Menon et al.



3 – « N » DIAGNOSTIC versus PROGNOSTIC CONCLUSION

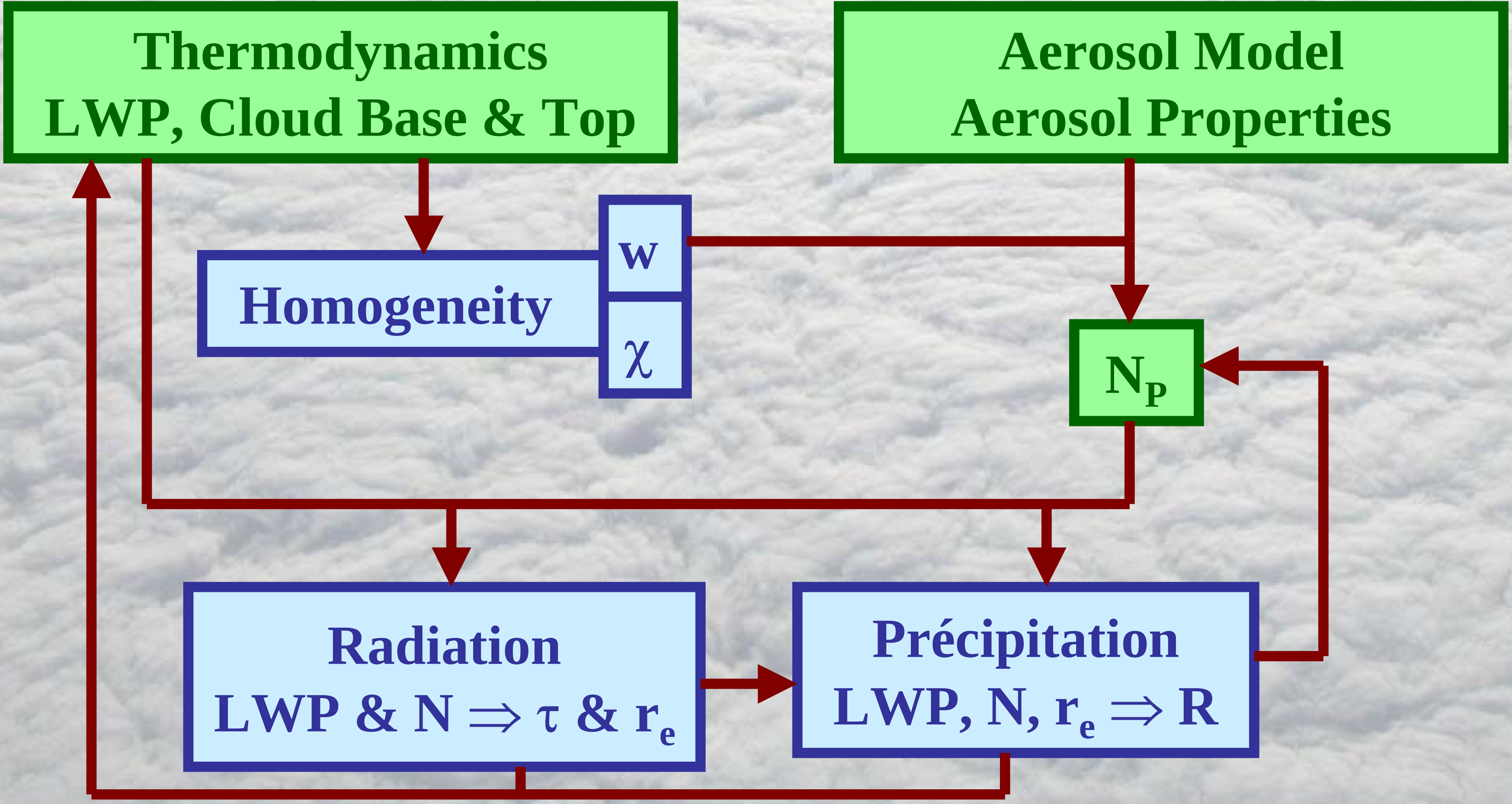
The activation process determines the initial CDNC N_{act}, that is further diluted by mixing and drizzle scavenging. The cloud system mean CDNC N_{mean} is smaller than N_{act}.

COT depends on the droplet radius at cloud top $r_v(H)$ that is determined by N_{act} rather than N_{mean}.

The onset of precipitation is governed by the maximum droplet radius in the cloud layer, i.e. at cloud top $r_v(H)$.

GCM Parameterizations of AIE

PROGNOSTIC N



Thermodynamics
LWP, Cloud Base & Top

Aerosol Model
Aerosol Properties

Homogeneity

w

χ

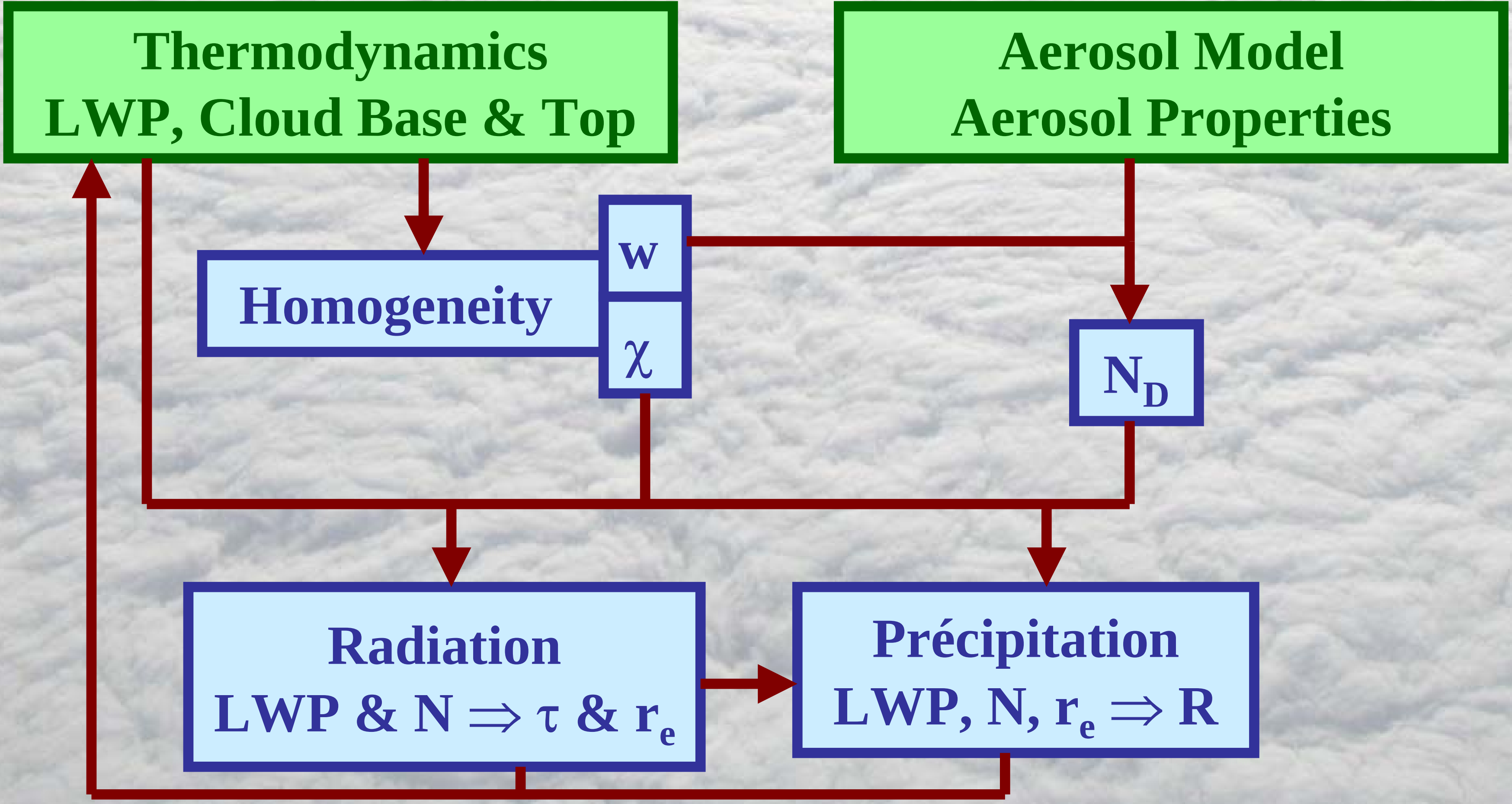
N_P

Radiation
LWP & N $\Rightarrow \tau$ & r_e

Précipitation
LWP, N, $r_e \Rightarrow$ R

GCM Parameterizations of AIE

DIAGNOSTIC N



Thermodynamics
LWP, Cloud Base & Top

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Homogeneity

w

χ

N_D

Radiation
LWP & N $\Rightarrow \tau$ & r_e

Précipitation
LWP, N, $r_e \Rightarrow$ R

State of the art in GCM simulation of AIE

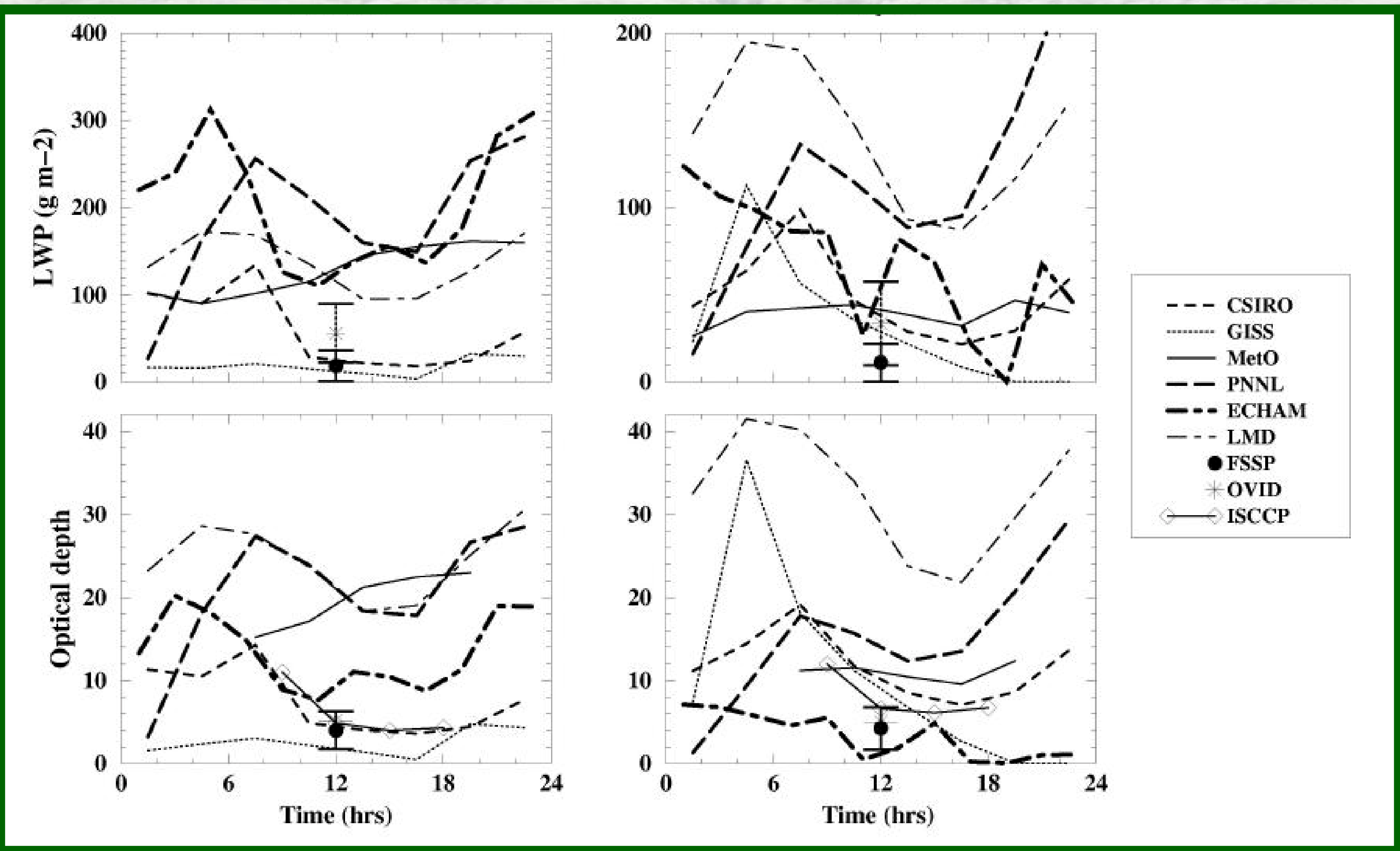
PHYSICAL PROCESSES

- Aerosol Activation: Overestimation by a factor of about 2
- Radiative Transfer: Retrieved H or LWP is overestimated
- Precipitation formation: correctly reproduced by 3-D models

GCM PARAMETERIZATIONS

- Aerosol Activation: Efficient schemes valid for any mixture of aerosol chemical composition
- Radiative Transfer: Efficient schemes for plane-parallel but progress needed for the heterogeneous bias
- Precipitation formation: CRM derived scheme is not suited to the GCM resolution scale

State of the art in GCM simulation of AIE



State of the art in GCM simulation of AIE

CONCLUSION

Most of the uncertainty comes from the coarse representation of thin BL clouds in GCMs

MVDR at cloud top $\propto H^{1/3}$, Optical depth $\propto H^{5/3}$, Precipitation rate $\propto H^4$

Priorities

- **Finer vertical resolution and sub-grid vertical schemes**
- **« GCM Bulk » parameterization of rain formation**
- **Reduce the bias in the prediction of N_{act}**
- **Better understand the heterogenous bias in relation with the second AIE**
- **Parameterizations of the aerosol processing in clouds**

Outcomes of the PACE project

PACE Topical Issue
JGR 2003

Guibert et al. : *Aerosol activation Part I*
Snider et al. : *Aerosol activation Part II*
Zhang et al. : *Aerosol activation parameterization*
Pawlowska & Brenguier : *Precipitation formation*
Schüller et al. : *Radiative tranfer*
Brenguier et al. : *Data base for GCM parameterization and satellite monitoring of the aerosol indirect effect*

Menon et al. : *SCM parameterization tests*

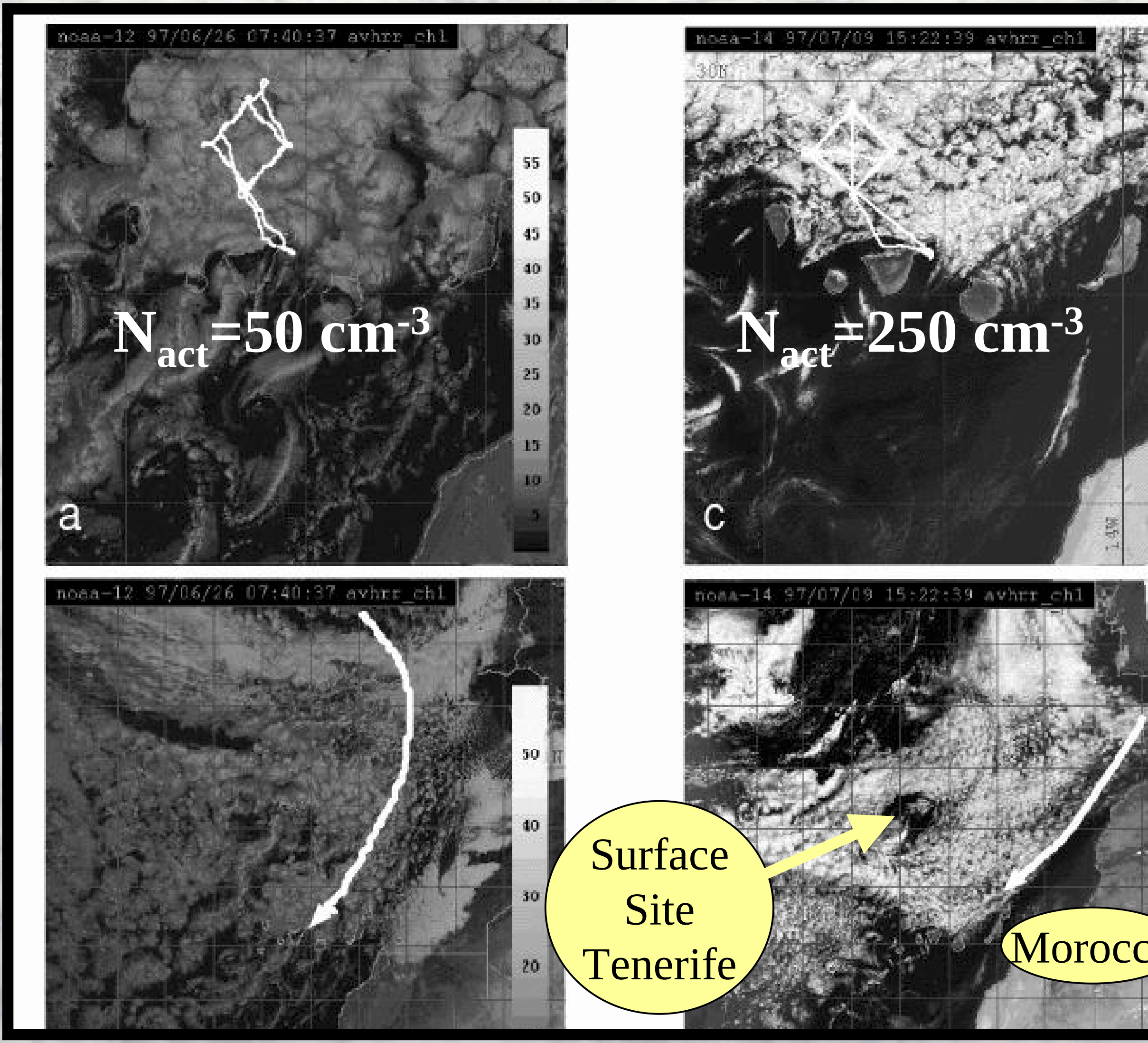
ACE-2 Field Campaign June-July 1997

Experimental Strategy

To select cloud systems with similar LWP and morphology, but with different aerosol prop.

To sample an area of 60 km, about the GCM spatial resolution

To synchronize in situ and remote sensing for column closure experiments



N_{act}=50 cm^{-3}

N_{act}=250 cm^{-3}

Surface Site Tenerife

Morocc

PACE METHODOLOGY

- Series of Closure experiments at a scale relevant to GCM (60 km) on
  - aerosol activation
  - radiative transfer
  - precipitation formation
- Identify variables relevant to GCM parameterization of AIE and establish relationship with physical variables
- Build a data base for initialisation and validation of SCM versions of the GCMs (8 ACE-2 case studies)
- Examine the predictability of the selected variables
- Test parameterizations and examine feedback processes

Workshop on Aerosol/Cloud/Radiation Interactions
24-27 June 2002 Météo-France

I. The aerosol indirect effect on climate
- **I.1. GCM simulations (Chair: J. Feichter & S. Menon)**
- **I.2. Satellite Observations (Chair : W. Rossow and L. Schüller)**
- **I.3. In situ Observations and validation data sets (Chair: P. Siebesma & B. Stevens)**

II. Parameterizations of BL clouds in GCM (Chair: P. Siebesma & B. Stevens)

III. Spatial cloud variability and structures (Chair: A. Illingworth & U. Lohmann)

IV. Physical process parameterizations
- **IV.1. Aerosol activation (Chair: K. Bower & J. Snider)**
- **IV.2. Aerosol transport and transformation (Chair: S. Ghan & G. Feingold)**
- **IV.3. Precipitation formation (Chair: H. Pawlowska & G. Vali)**
- **IV.4. Radiation (Chair: H. Barker & J. Fischer)**

V. Perspective (Chair: T. Choularton & J. Penner)
- **Proposals for future experiments**
- **General discussion and conclusions**

55 Synthetic Presentations + Discussions

F	UK	D	NL	PL	IE	IT	NO	HU	IL	US	CA	JA
43	23	9	6	3	2	1	1	1	1	16	8	3
40 %	20 %	20 %								20 %		