Introduction

Aerosol Impacts on BL Clouds Observations and Modelling

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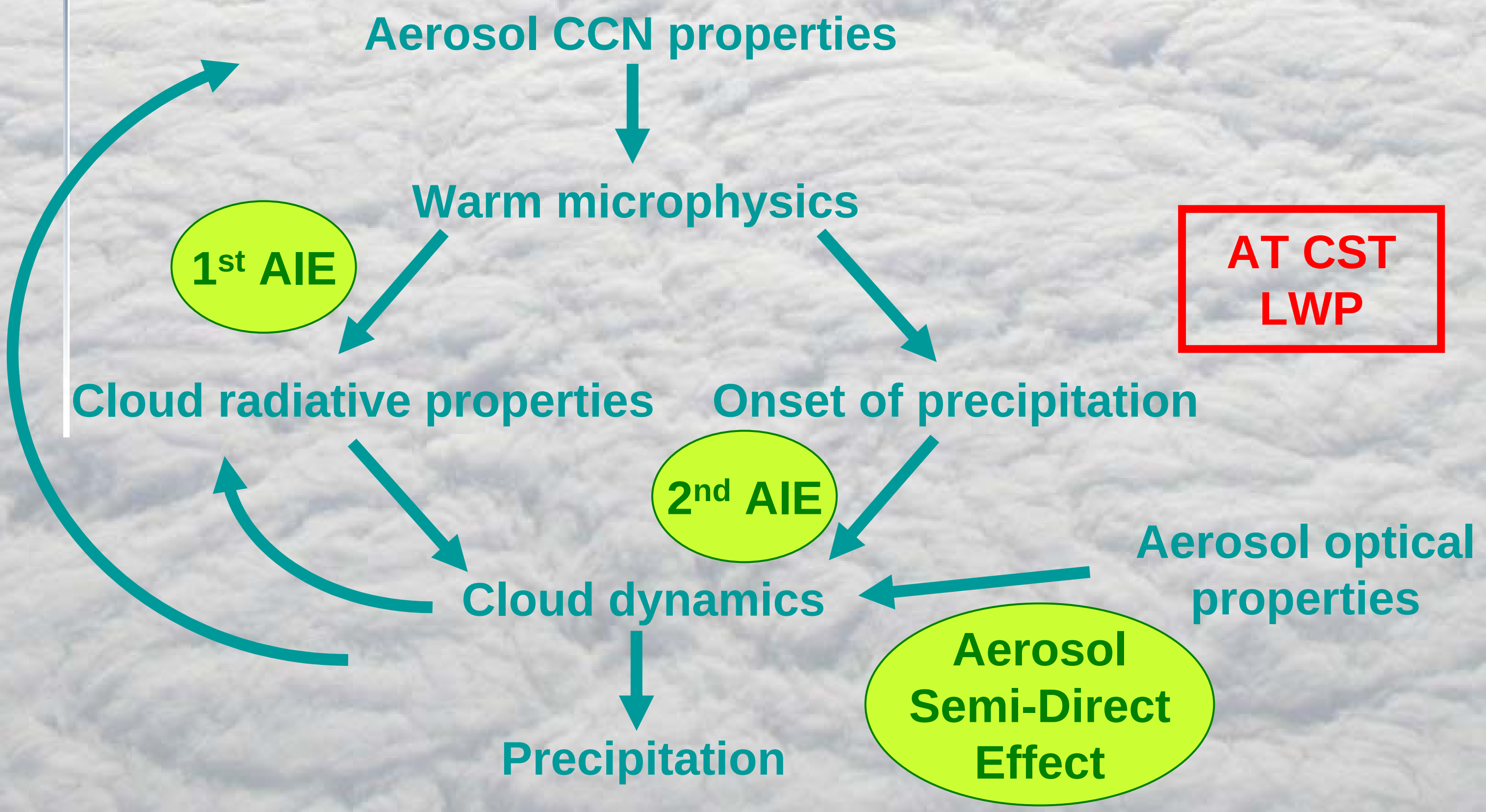
Acknowledgements:
O. Geoffroy, C. Lac, V. Masson, O. Thouron, I. Sandu

Review of past activities

Comments & Recommendations

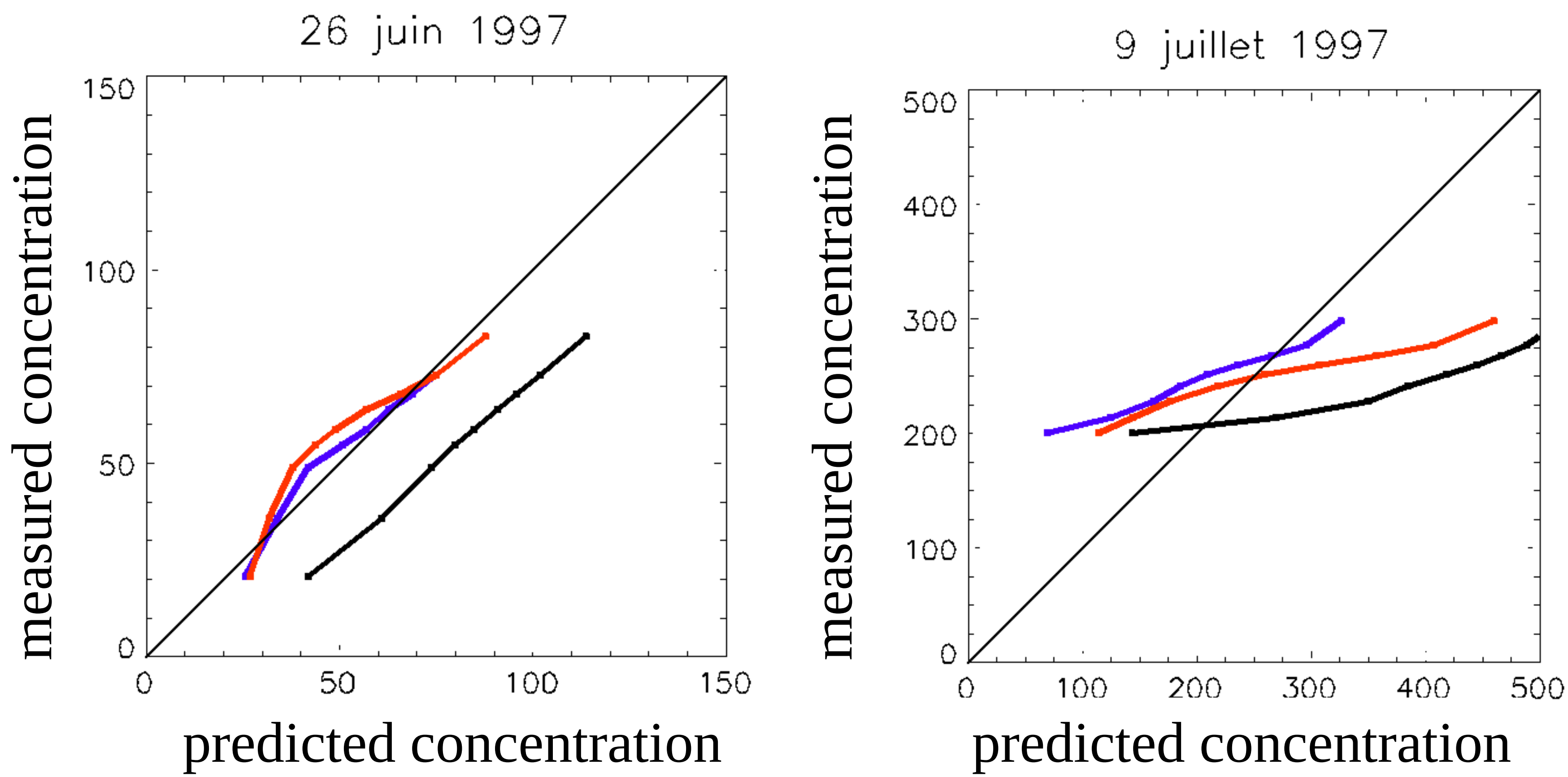
Physical Processes and Feedbacks

Background



CCN Activation

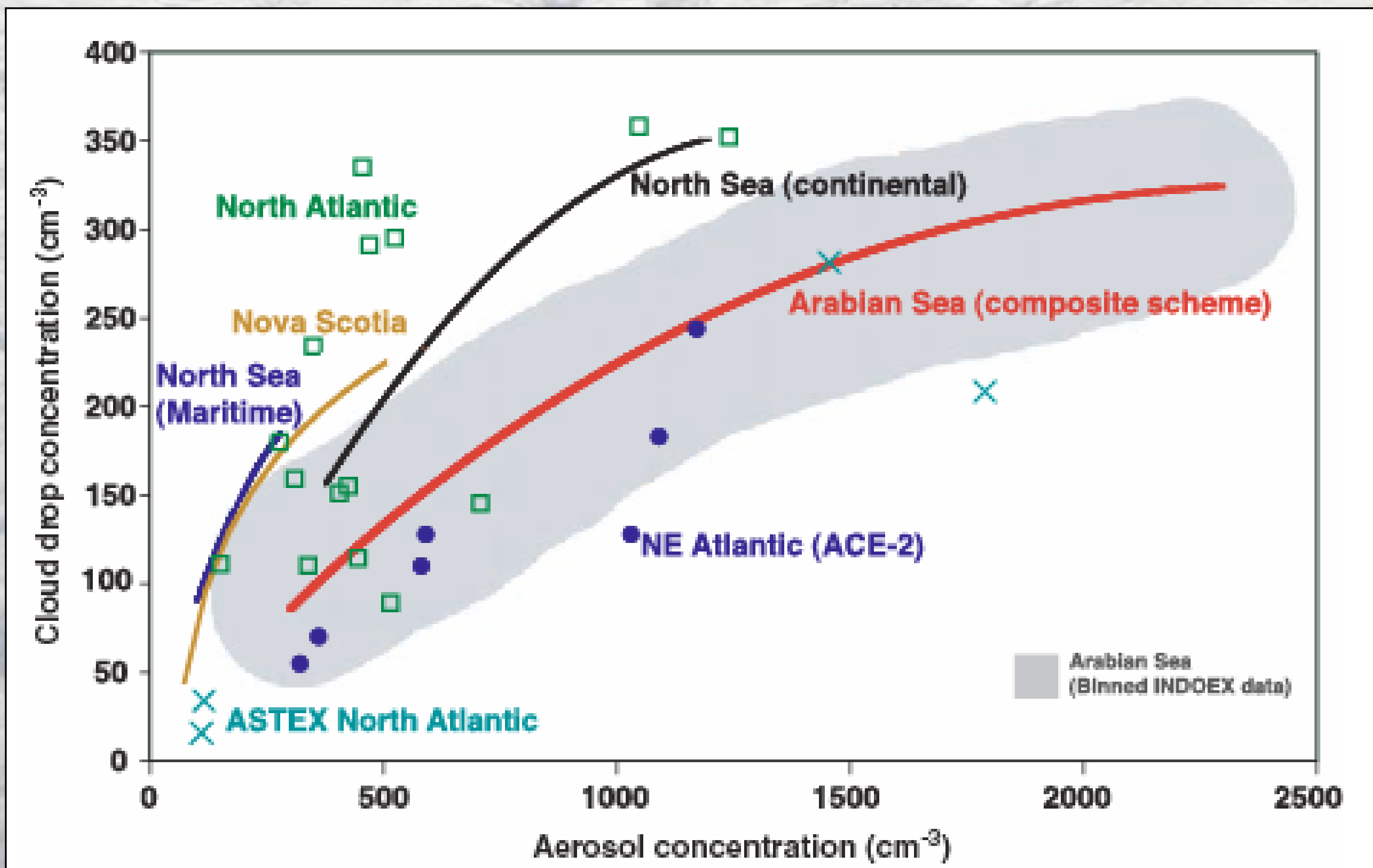
Droplet concentration predicted for the 10% percentiles
of the measured w frequency distribution
against the 10% percentiles
of the measured droplet concentration frequency distribution



Snider et al. 2000

CCN Activation

Review of past activities



Ramanathan et al., 2001

CCN Activation

Comments
&
Recommendations

Both natural and anthropogenic aerosol produce CCNs.

Increasing the number concentration of CCNs generally yields to an increase of the CDNC, though not proportional !

CCN properties are well understood and well simulated when the aerosol chemical composition is known.

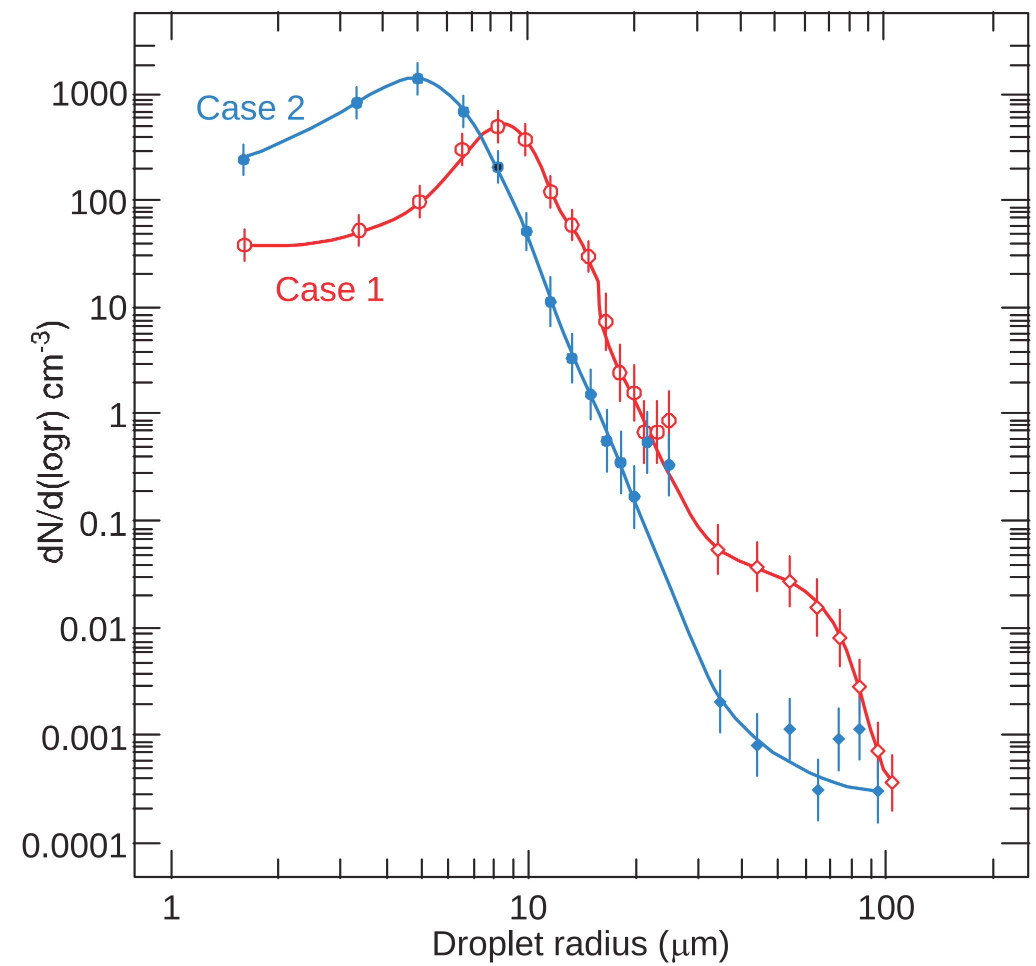
Organic matter however modifies significantly the CCN properties of the aerosol, and the impacts are not well understood.

In the prediction of CDNC from aerosol properties, most of the uncertainty arises from the vertical velocity.

How does CCN activation impact cloud microphysics ??

Aerosol CCN Properties → Warm Microphysics BL Clouds (short time scale)

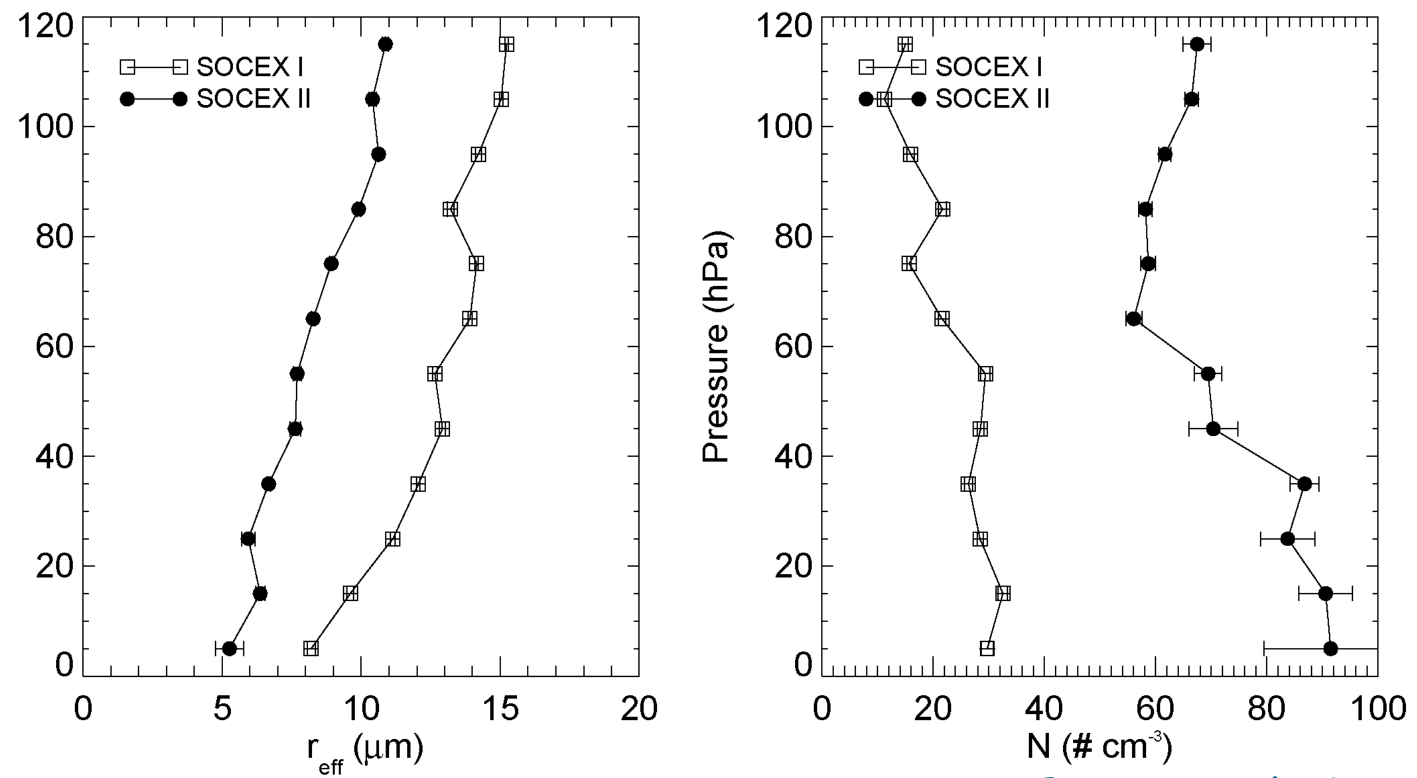
Review of past activities



Garrett and Hobbs, 1995

Aerosol CCN Properties → Warm Microphysics BL Clouds (long time scale)

Review of past activities

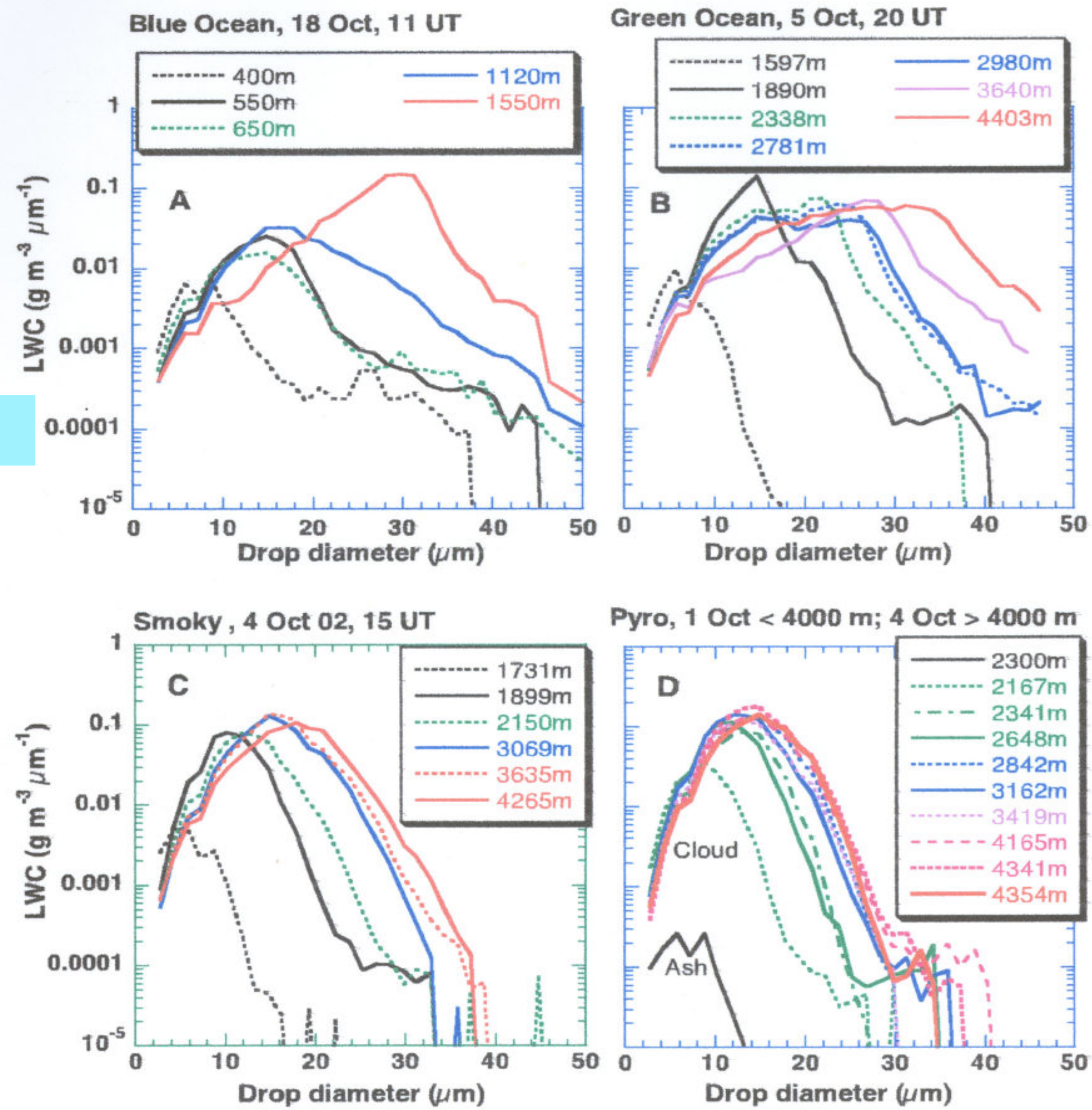


Boers et al., 1998

Review of past activities

Aerosol CCN Properties

Warm Microphysics
Deep Convective Clouds
(short time scale)



Andreae et al., 2004

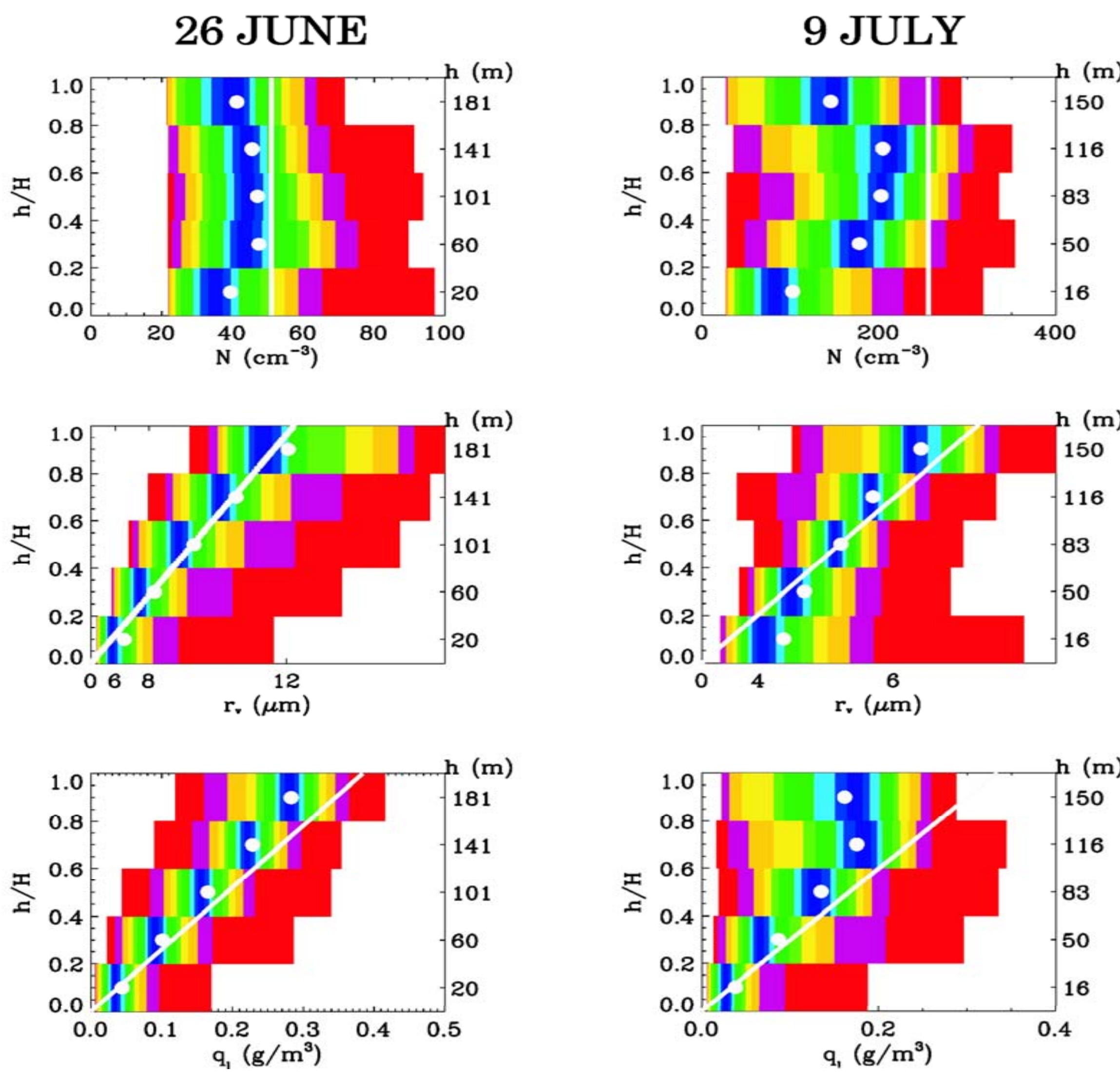
Review of past activities

Aerosol CCN Properties

Warm Microphysics

Boundary Layer Clouds

(short time scale)



Brenguier et al., 2003

Aerosol CCN Properties

↓

Warm Microphysics

Comments
&
Recommendations

The impact of CCN on warm cloud microphysics is known since the pioneering work of Gunn and Phillips [1957], Squires [1958], Squires and Twomey [1961], Warner [1968] and Warner and Twomey [1967].

Recent field (airborne) experiments have improved our knowledge of the relationship between aerosol CCN properties and CDNC, and of additional physical processes that may modulate the impact on cloud microphysics (entrainment-mixing, precipitation scavenging)

Review of past activities

Warm microphysics

1st AIE

Cloud radiative properties

Conover, 1966; *Coakley et al.*, 1987; *Radke et al.*, 1989; *King et al.*, 1993; *Ferek et al.*, 1998; *Ackerman et al.*, 2000; *Durkee et al.*, 2001; *Hobbs and Garrett*, 2000

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Warm microphysics

1st AIE

Cloud radiative properties

Comments & Recommendations

Ship tracks are obviously characterized by a higher CDNC than the environment.

Are they brighter because of higher CDNC and smaller droplets at constant LWP, hence a higher optical thickness, or also because they are thicker ?

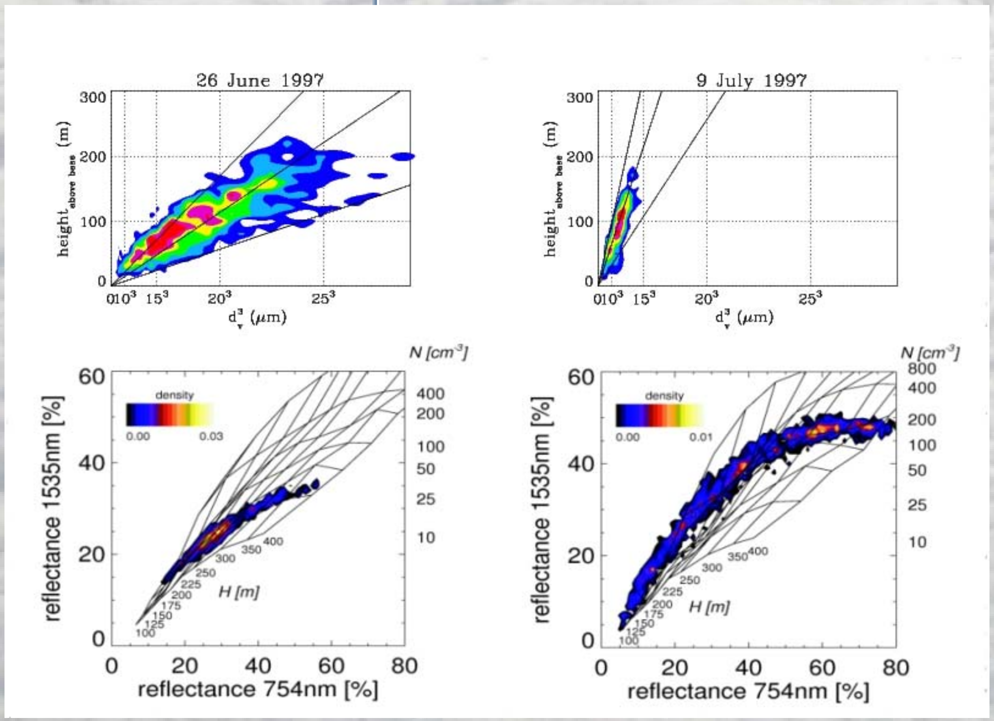
In situ measurements are contradictory !

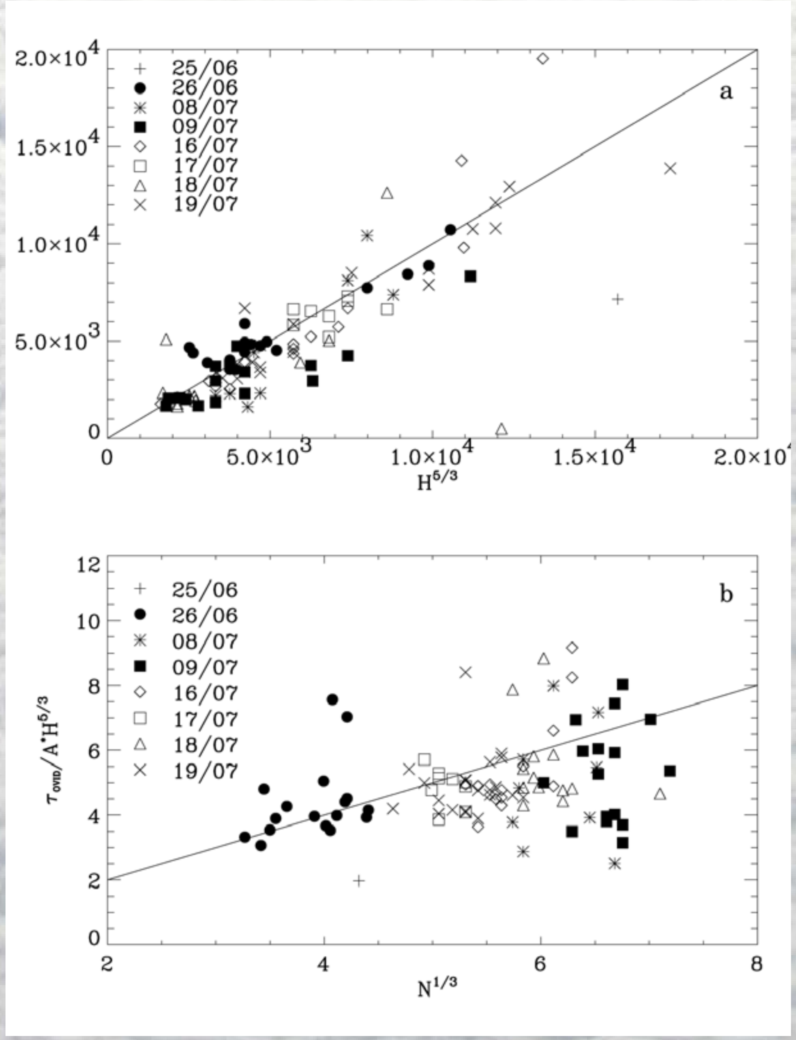
Warm microphysics

1st AIE

Cloud radiative properties

Review of past activities





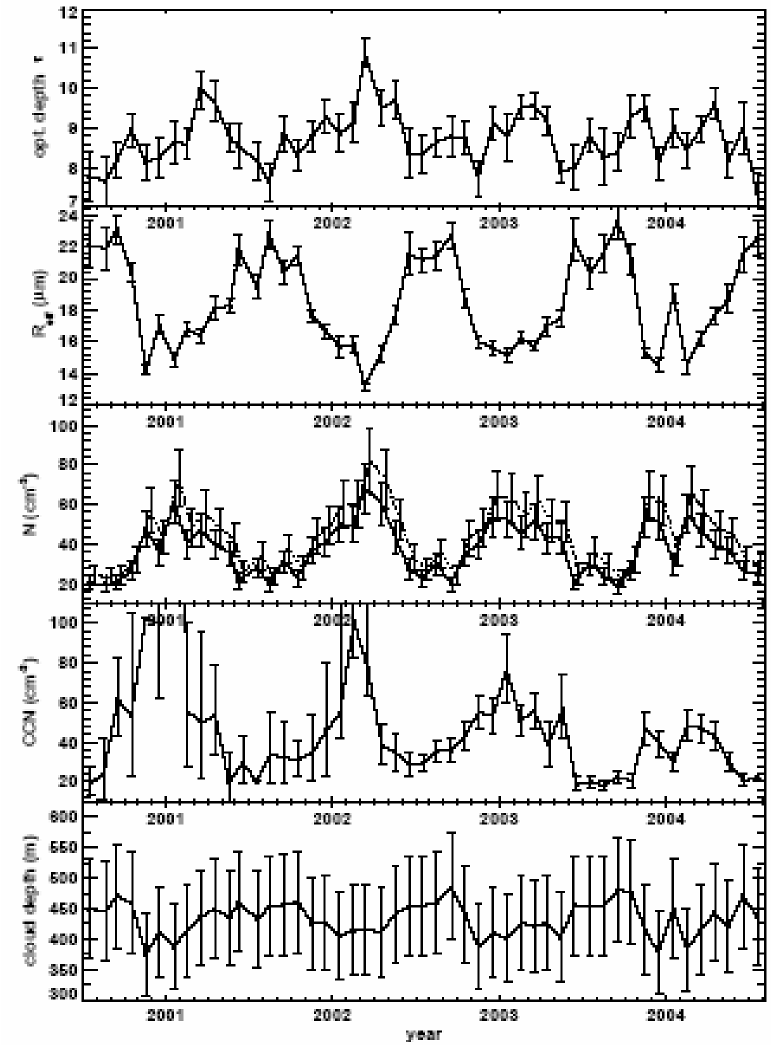
Pawlowska and Brenguier, 2000 (top-left) and Schüller et al., 2003 (bottom-left); Brenguier et al., 2000 right)

Warm microphysics

1st AIE

Cloud radiative properties

Review of past activities



[*Boers et al., 2006*].

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Warm microphysics

1st AIE

Cloud radiative properties

Review of past activities

Impact of entrainment-mixing processes

Cloud scene	*CF* %	*LWP* g/m²	*H* m	N_{ad} cm^{-3}	Mixing scheme	A_{Vis} %	*PP bias* %
1	100	83	286	50	homogeneous	**47**	**-2**
					inhomogeneous	**44**	**-8**
				256	homogeneous	**65**	**-2**
					inhomogeneous	**62**	**-7**
				400	homogeneous	**70**	**-2**
					inhomogeneous	**67**	**-6**
2	63	8	76	50	homogeneous	**11**	**-3**
					inhomogeneous	**9**	**-18**
				256	homogeneous	**17**	**-1**
					inhomogeneous	**13**	**-23**
				400	homogeneous	**20**	**-1**
					inhomogeneous	**15**	**-26**
3	50	12	77	50	homogeneous	**11**	**-3**
					inhomogeneous	**9**	**-23**
				256	homogeneous	**17**	**-4**
					inhomogeneous	**12**	**-31**
				400	homogeneous	**19**	**-3**
					inhomogeneous	**14**	**-31**
4	17	12	52	50	homogeneous	**8**	**-1**
					inhomogeneous	**7**	**-11**
				256	homogeneous	**10**	**-1**
					inhomogeneous	**8**	**-17**
				400	homogeneous	**11**	**-1**
					inhomogeneous	**9**	**-19**

Chosson et al., 2006

Warm microphysics

1st AIE

Cloud radiative properties

Comments
&
Recommendations

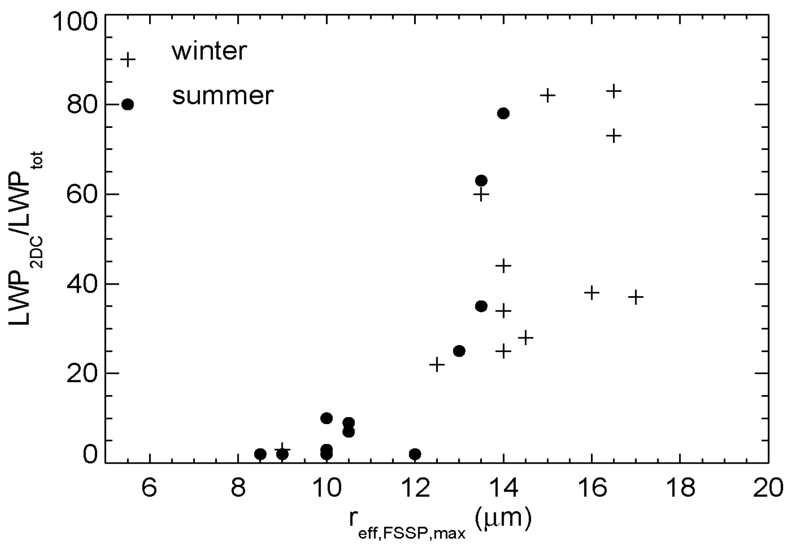
Recent field (1997) experiments have validated the expected (1977) relationship between microphysical changes and cloud albedo change (Twomey hypothesis)

The LWP/CDNC relationship with optical depth/effective radius may be modulated by additional processes such as entrainment/mixing and precipitation scavenging, though their radiative impact is not clear yet !!)

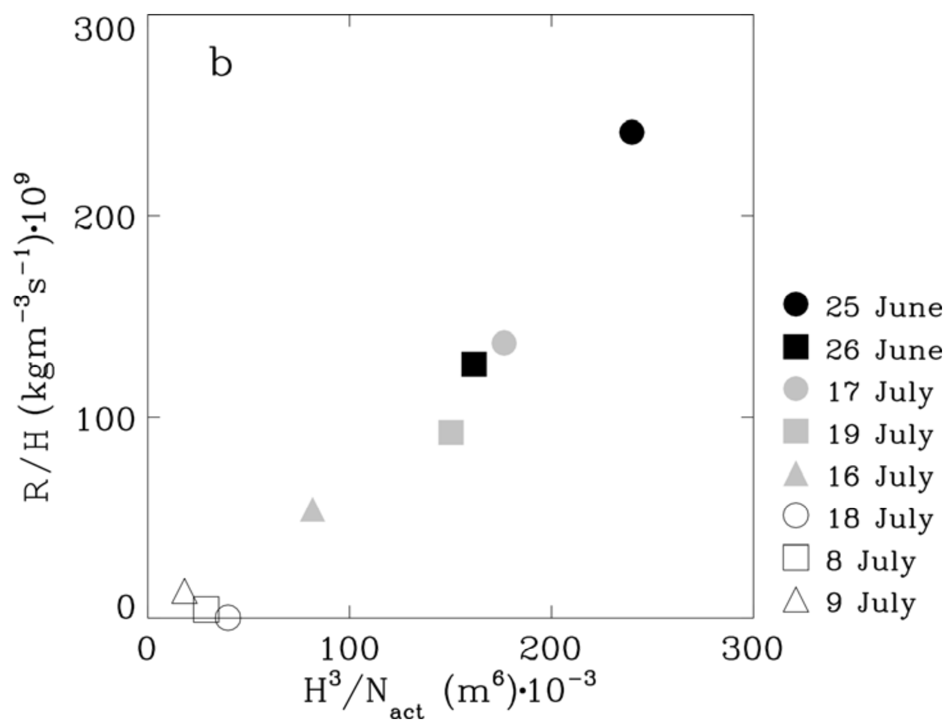
Warm microphysics

Onset of precipitation

Review of past activities



Boers et al., 1998



Pawlowska and Brenguier, 2003

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Warm microphysics

→ **Onset of precipitation**

Review of past activities

At the scale of a cloud system (few tens of km), the precipitation rate scales with the LWP and CDNC

ACE-2 (Pawlowska and Brenguier, 2003)
EPIC (Comstock et al., 2004)
DYCOMS-II (van Zanten et al., 2005)

	N_i (m^{-3}) ($\times 10^{-6}$)		H_i (m)		W_i (kg m^{-2}) ($\times 10^{3}$)		R_i (kg m^{-2} s^{-1}) ($\times 10^{6}$)		Formulation
ACE-2 $i = 1$	N_{act}		H_g		$\frac{1}{2} C_w H_g^{\,2}$		$\langle R \rangle$		$R_1 = 0.3 \cdot 10^6 \cdot \frac{W_1^{\,2}}{N_1} - 10^{-6}$
	min : 51	max : 256	min : 167	max : 272	min : 27	max : 74	min : 0,6	max : 18,6	
EPIC $i = 2$	$\langle N \rangle$		/		$\langle W \rangle$		$\langle R_{base} \rangle$		$R_2 = 24.37 \cdot 10^9 \cdot (\frac{W_2}{N_2})^{1.75}$
DYCOMS-II $i = 3$	$\langle N \rangle$		$\langle H \rangle$		$\frac{1}{2} C_w \langle H \rangle^2$		$\langle R_{base} \rangle$		$R_3 = 21.5 \cdot 10^3 \cdot \frac{W_3^{\,1.5}}{N_3} - 2.3 \cdot 10^{-6}$
	min : 58	max : 254	min : 265	max : 515	min : 70	Max : 265	min : 0,5	max : 19,1	

Warm microphysics

ONSET of precipitation

Comments
&
Recommendations

CDNC obviously affects the ONSET of precipitation

This hypothesis was well established 50 years ago (Fletcher, Squires, and Bowen, 1962)

Recent experiments provide more quantitative assessments of these earlier results

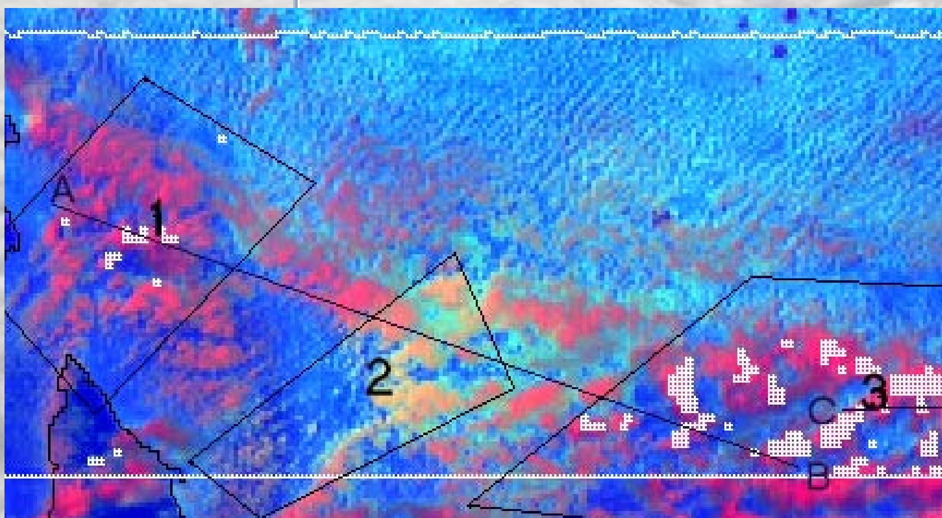
Onset of precipitation

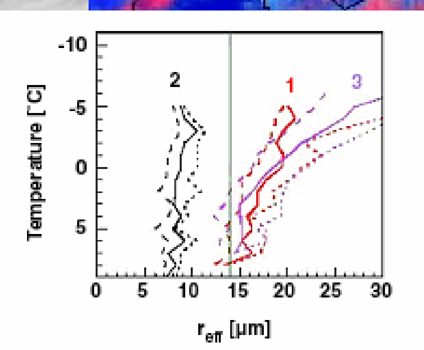
2nd AIE

Cloud dynamics

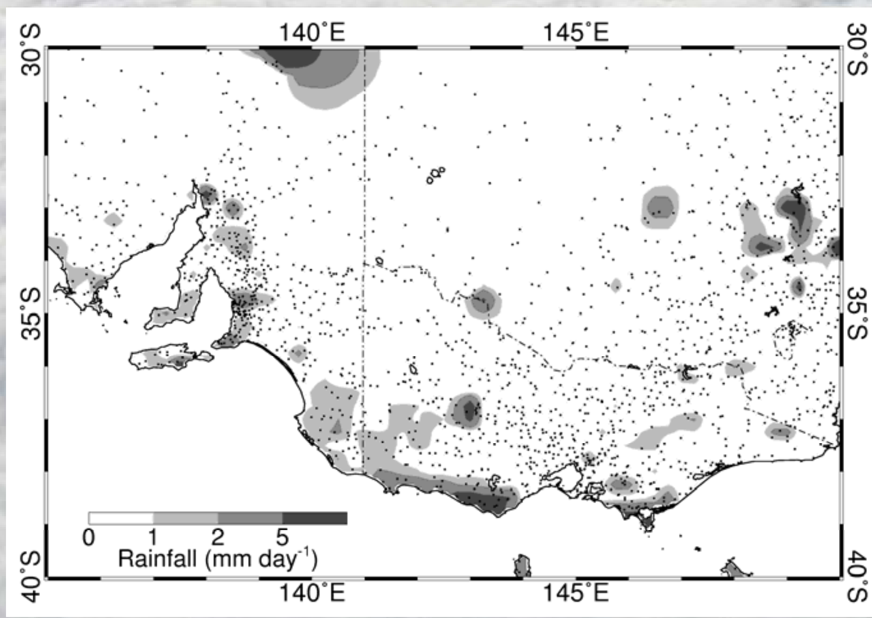
Precipitation

Review of past activities





Rosenfeld, 2000



Ayers, 2006

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Observational studies of the aerosol impact on BL clouds

Comments
&
Recommendations

Observations have clearly established that the aerosol impacts state parameters of the cloud (CDNC, microphysical profiles, albedo).

There are no convincing observations of an aerosol impact on the cloud life cycle and precipitation.

When different aerosol properties are observed, that necessarily implies different air masses, hence different thermodynamical forcing.

The expected aerosol impacts are smaller than the impacts of thermodynamical forcing changes that are not presently measurable : a 1 % decrease of the relative humidity in the BL makes the different between cloud and no cloud !!

Modelling studies of the aerosol impact on BL clouds

Comments & Recommendations

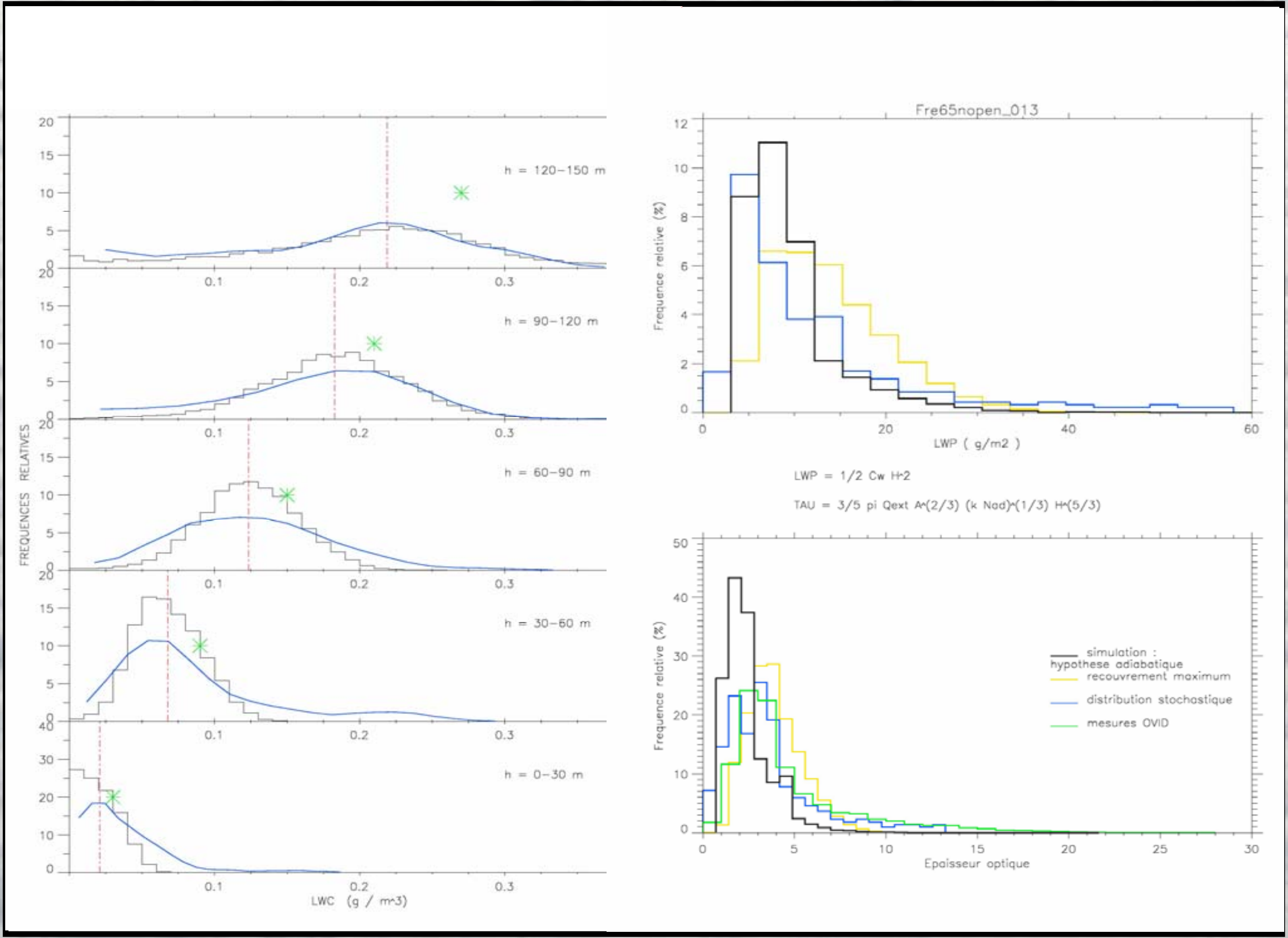
The aerosol impact on BL clouds can be examined using LES models with state-of-the-art parameterizations of dynamics, microphysics and radiation.

The external forcing are not measurable, but they can be tuned for the model to simulate the expected cloud properties.

Tuning LES models

MICROPHYSICS

Review of past activities

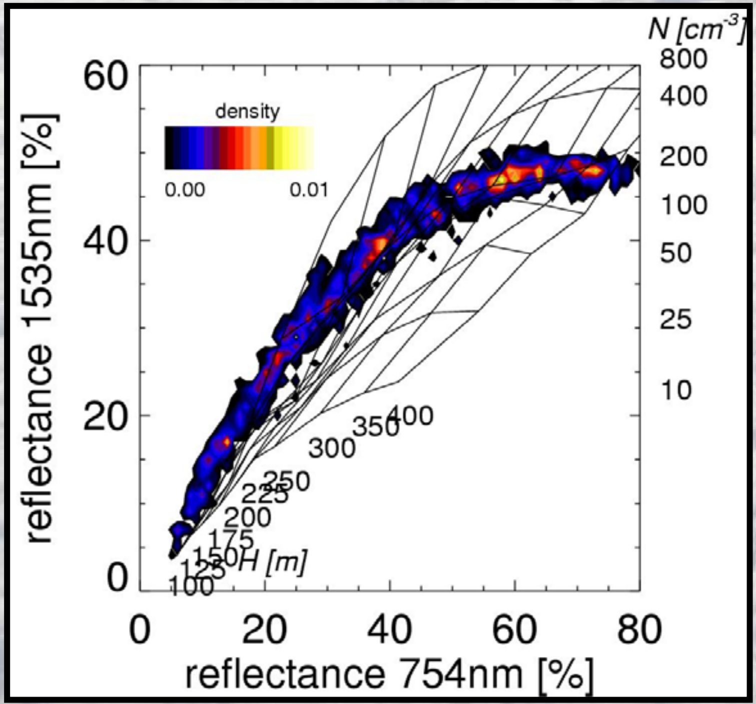


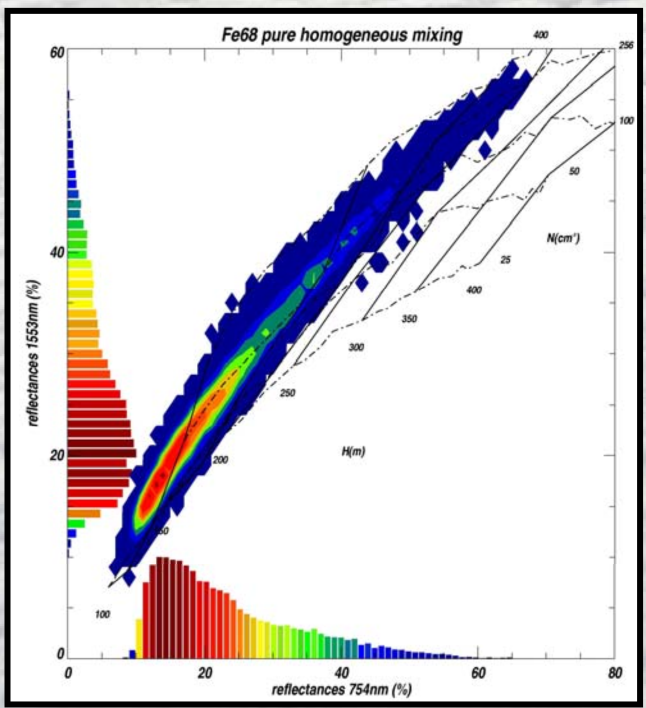
(Chosson et al., 2007)

Tuning LES models

RADIATION

Review of past activities





Measured
(Schüller et al., 2003)

Simulated
(Chosson et al., 2007)

VIS and NIR upward radiances

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LES modelling to explore Aerosol-Cloud Interactions

Review of past activities

The aerosol impact on BL clouds dynamics is not straightforward.

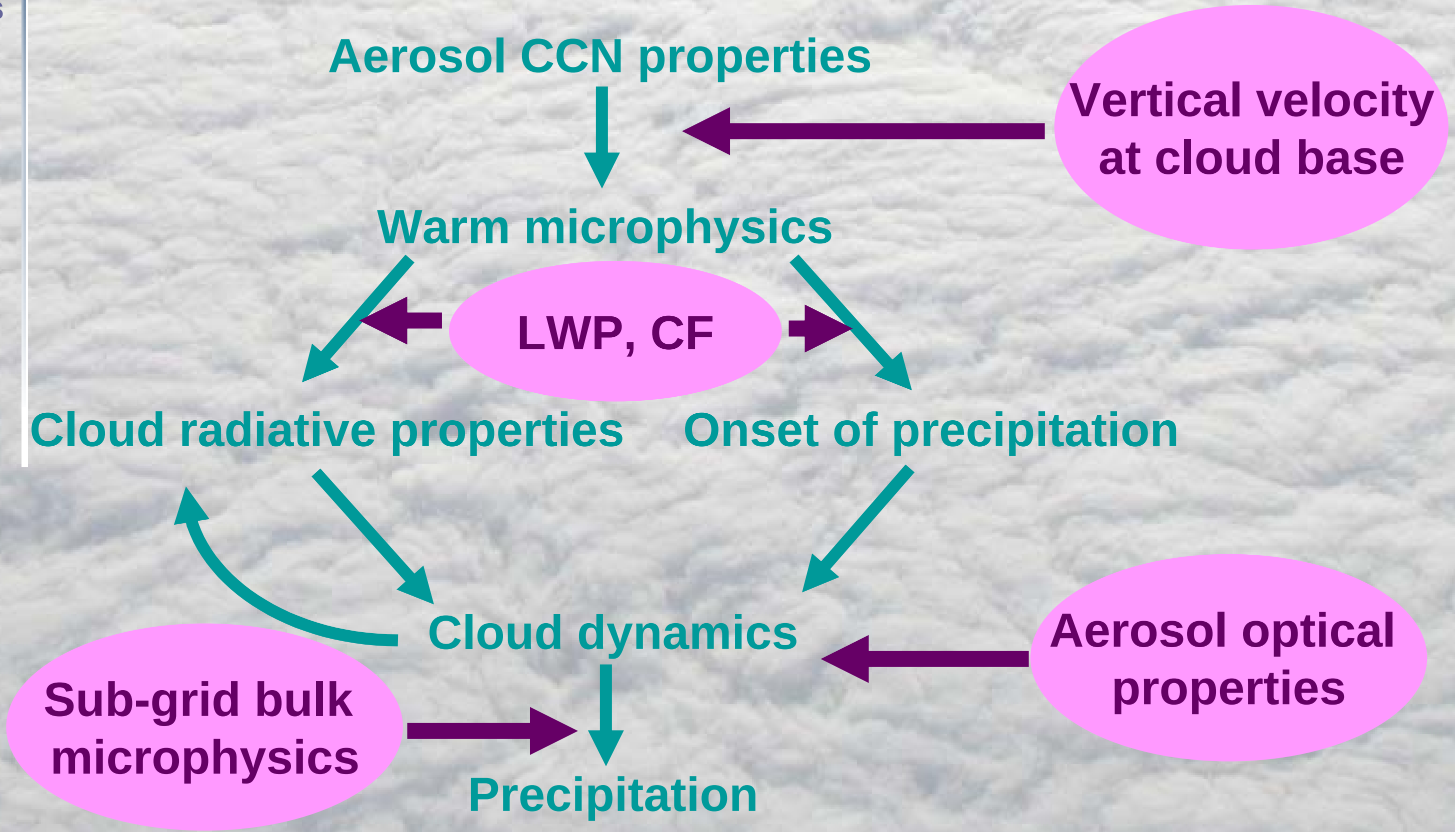
Albrecht (1989) : CDNC ↗ ⇒ droplet size ↘
⇒ precipitation ↘ ⇒ LWP ↗ .

Nighttime :
Ackerman (2004) : CDNC ↗ ⇒ droplet size ↘ ⇒ precip. ↘
⇒ entrainment ↗ ⇒ LWP ↗ or ↘ (depending on LSF).

Diurnal cycle, during nighttime same as Ackerman, but during daytime :
Sandu et al. (2007) : CDNC ↗ ⇒ droplet size ↘ ⇒ precip. ↘
⇒ entrainment ↗ ⇒ LWP ↘ (irrespective of LSF).

LES modelling for the development of GCM parameterizations

Comments
&
Recommendations



Sub-grid bulk microphysics

Comments
&
Recommendations

In bulk parameterizations, the hydrometeors spectrum is reduced to 2 categories : droplets and drops, represented by only 4 (q_c, q_r, N_c,N_r) independent variables.

The collection process is parameterized with two schemes : auto-conversion (collection of droplets to produce drops) and accretion (droplet collection by a drop), and the conversion rates are derived by comparison with solutions of the collection equation. This is valid for scales at which the particles co-exist in the same volume.

Bulk parameterizations have been used in GCMs by tuning the coefficient for increasing the collection efficiency in order to account for the smoothing effect of the coarse resolution.

This may be valid as long as there are no feedbacks on cloud dynamics.

Sub-grid bulk microphysics

Comments & Recommendations

Bulk parameterizations have different number of variables, different limits between droplets and drops, and different way of dealing with the sharp increase of collection at the limit.

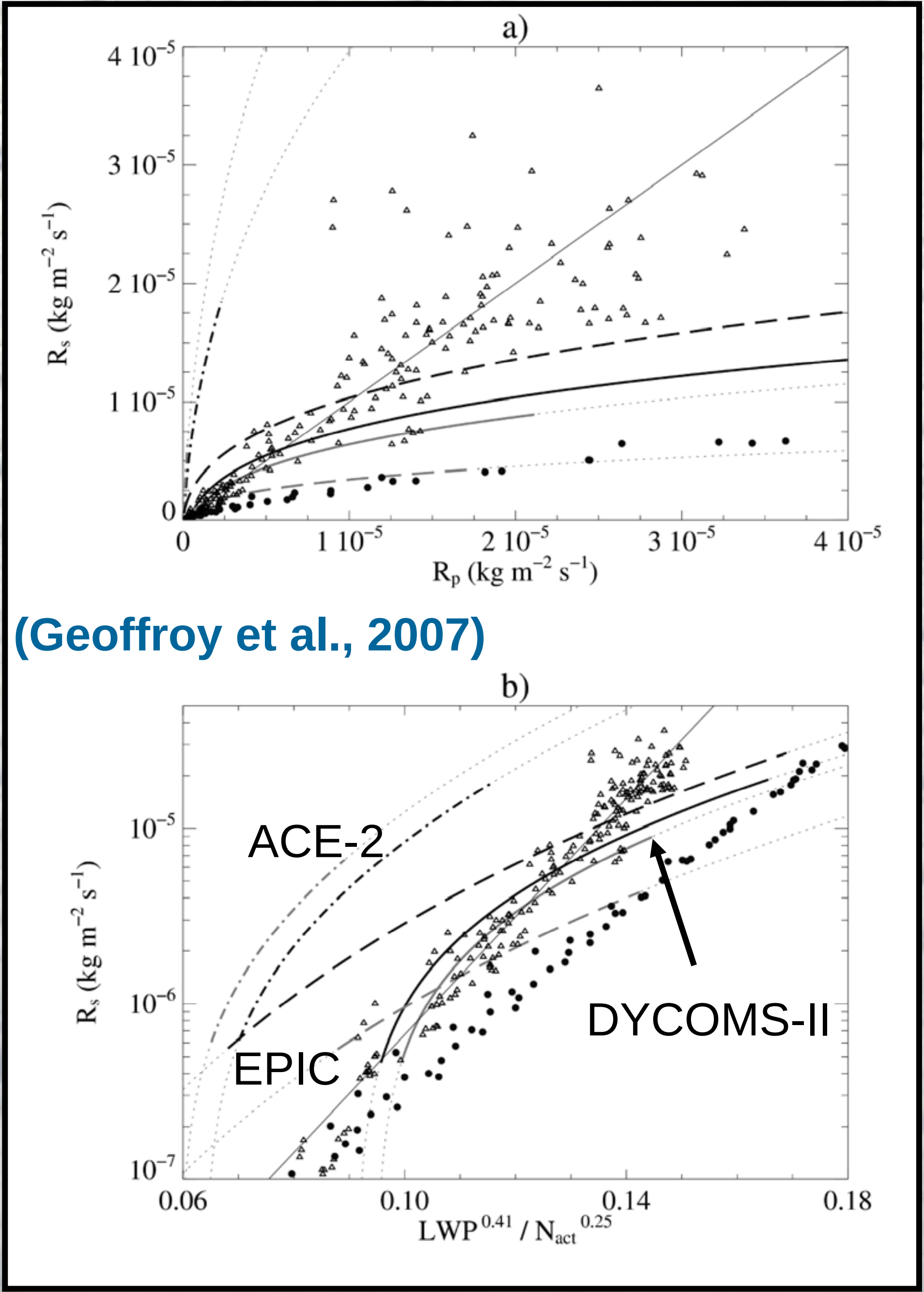
	Number of variables	Limit	Size distribution assumption	Auto-conversion threshold	Threshold applied on	Collision kernel
Berry (1968)	2	~ 40 µm	Gamma law (28 spectra)	none	/	Davis & Sartor (1967)
Kessler (1969)	2	?	monodispersed	Heaviside	q_c	Fixe
Berry et Reinhardt (1974) Ziegler (1985) Cohard et Pinty (2000a)	2 4 4	41 µm	Modifed gamma law (~30 spectra)	Heaviside	A function of r_v et var(x)	Hocking & Jonas (1970)
Sundqvist (1978)	2			Exponential	q_c	?
Manton et Cotton (1977) Tripoli and Cotton (1980)	2		monodispersed	Heaviside	r_v	E_c fixed Stokes velocity
Baker (1993)	2			Heaviside	r_v	E_c fixed Stokes velocity
Beheng (1994)	2	40 µm	Gamma law.	none	/	Hall (1980)
Khairoutdinov et Kogan (2000)	4	25 µm	100000 spectra from bin LES	none	/	Hall (1980)
Seifert et Beheng (2001)	4	~ 40 µm	Gamma law	none	/	Long (1974)
Liu and Daum (2004)	2	20 µm	Gamma law	Heaviside	r_6	Long (1974)

Sub-grid bulk parameterizations for GCMs

Comments
&
Recommendations

LES replicate observational evidences of scaling between precipitation rate, LWP and CDNC.

1-D simulations with the same LWP and CDNC underestimate the precipitation rate.



(Geoffroy et al., 2007)

CONCLUSIONS

Comments
&
Recommendations

The impacts of aerosols on cloud dynamics (2nd indirect and semi-direct effects) are not directly observable

The obstacles are very similar to those weather modification has been facing for more than 50 years (WMO reports)

LES models offer a powerful alternative and they show how tightly coupled is the aerosol/cloud system.

To simulate aerosol impacts at the global scale, new (sub-grid) parameterizations of cloud microphysics shall be developed

Any, even small, modification of the life cycle of clouds will have a strong impact on climate, and climate has a strong impact on clouds

What is the main source of cloud life time modifications: aerosol or the climate itself ?????????

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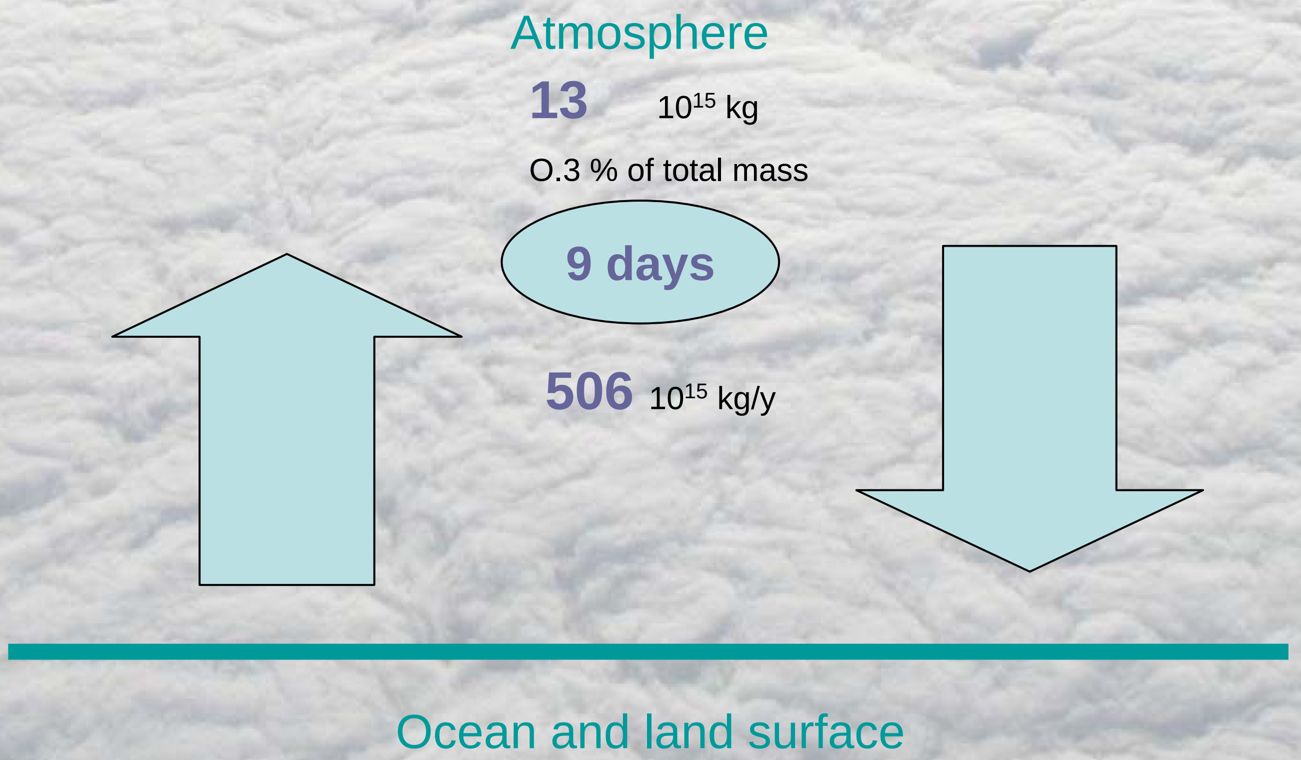
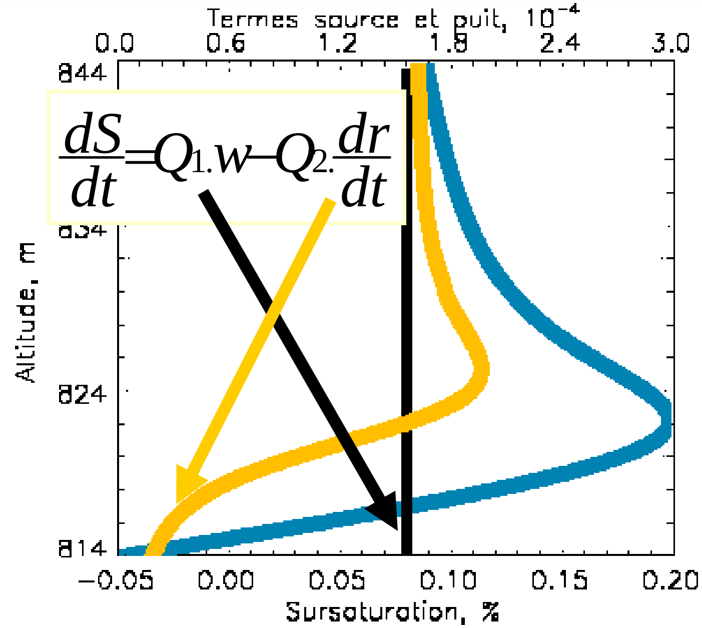
??? HYDROLOGICAL CYCLE ???

Background

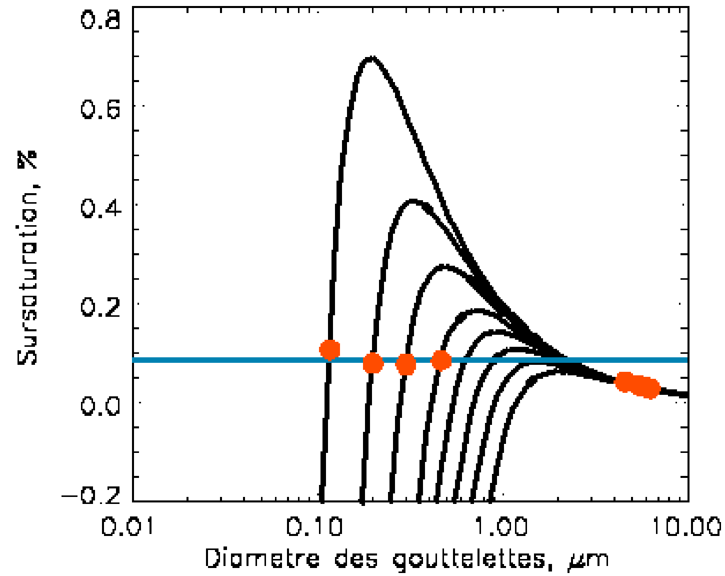


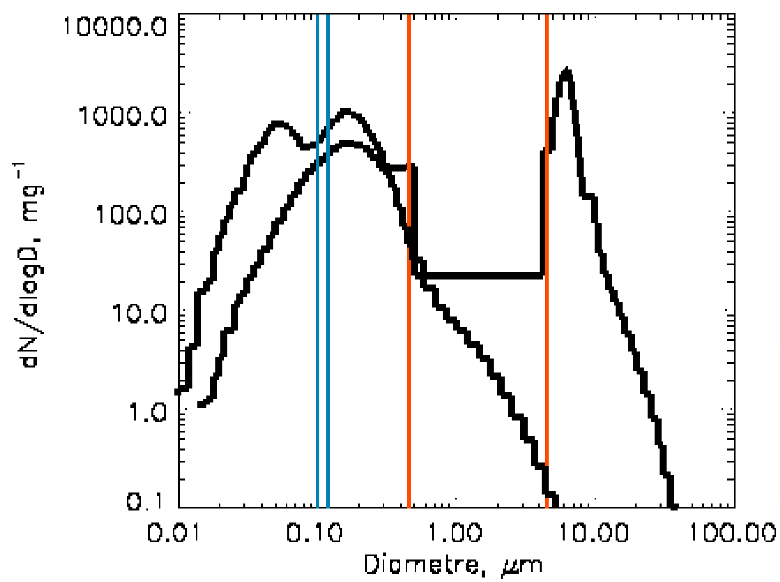
CCN Activation

Background



$$\frac{dS}{dt} = Q_1 . w - Q_2 . \frac{dr}{dt}$$





Dry diameter :
0.102 µm
0.121 µm

$$r\frac{dr}{dt} = \alpha(S - A/r + B/r^3)$$

Guibert et al. 2003