ARM-GEWEX Cloud System Studies (GCSS)

Collaborations:

Past-Present-Future

A. Pier Siebesma

siebesma@knmi.nl

chair GCCS

KNMI, De Bilt, The Netherlands

Technical University Delft

Multiscale Physics Group

Delft, The Netherlands

Photo courtesy Bjorn Stevens

Topics

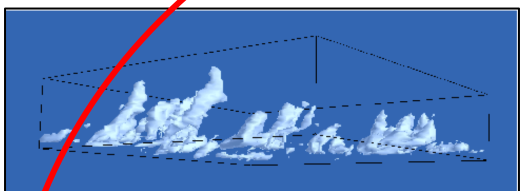
- Introduction to GCSS activities
- Examples and Results for parameterization development in the past.

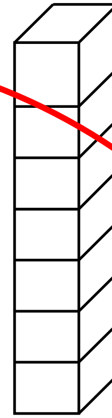
  (has it made a difference?)
- Past and Present Collaborations and results between ARM and GCSS
- The Future: How can we do better?

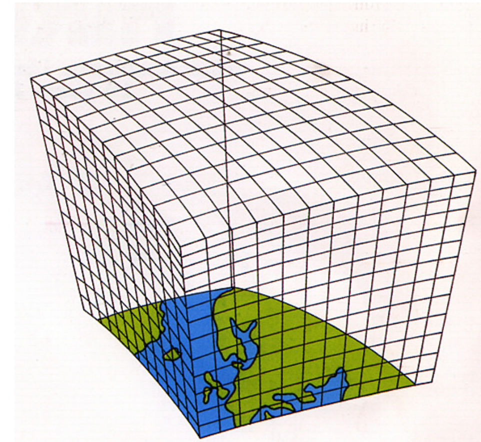
Objective of GCSS

GCSS is developing improved parameterizations of cloud systems for climate models and numerical weather prediction models by improving our understanding of the physical processes for all the climate relevant cloud types

(Simplified) Working Strategy of GCSS







Large Eddy Simulation (LES) Models

Cloud Resolving Models (CRM)

Single Column Model

Versions of Climate Models

3d-Climate Models

NWP's

Observations from
Field Campaigns and/or
Observational sites (ARM)

Global observational
Data sets

Development

Testing

Evaluation

Organization of GCSS

Traditionally organized thematically in working groups around different cloud types:

(1) boundary layer clouds,
(2) cirrus,
(3) extra tropical cloud systems
(4) deep convective cloud systems
(5) polar clouds

New Croscutting Working Groups:

(1) Pacific Cross-section (cloud evaluation of GCM's)
(2) Cloud Climate Feedback (CFMIP)
(3) Microphysics
(4) Metrics of climate models

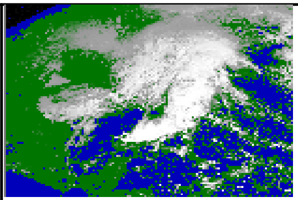
DIME : Data Integration for Model evaluation

http://gcss-dime.giss.nasa.gov/

GCSSDIME

GEWEX Cloud System Study

Data Integration for Model Evaluation



Boundary Layer Cloud Working Group

- FIRE Marine Stratus
- ASTEX
- ARM-1997 SGP IOP
- ATEX
- DYCOMS-II
- CROSS-PAC (EUROCS)
- EPIC 2001
- GPCI
- RICO

Cirrus Cloud Working Group

- FIRE I Cirrus
- FIRE II Cirrus
- ICE-89
- EUCREX-93
- EUCREX-94
- ARM-1994 SGP IOP
- CRYSTAL-FACE

Extratropical Layer Cloud Working Group

- ARM-2000 SGP IOP
- WISP
- CFRP III
- CASP II
- FRONTS 92
- FASTEX
- GALE
- BALTEX

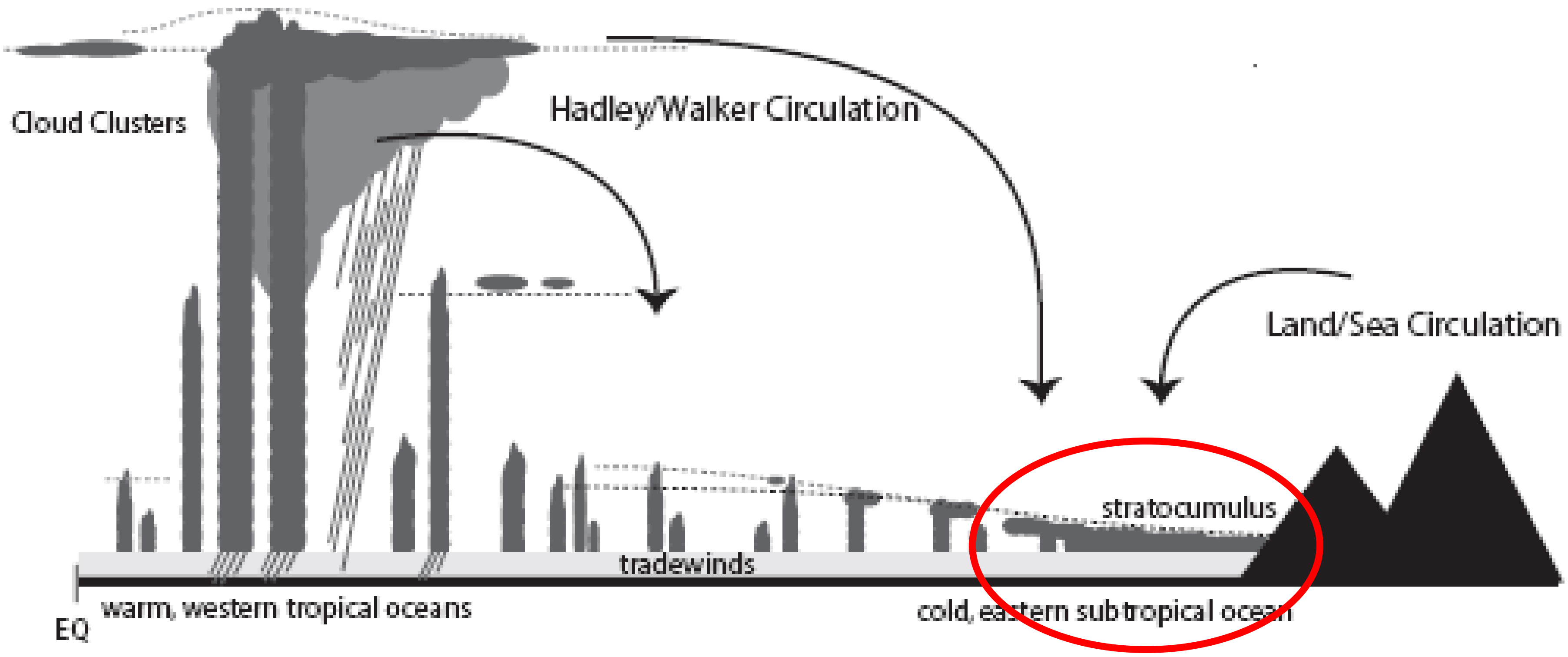
Deep Convective Working Group

- GTE/TRACE-A
- TOGA/COARE
- ARM-1997 SGP IOP
- CROSS-PAC (EUROCS)
- LBA
- CRYSTAL-FACE

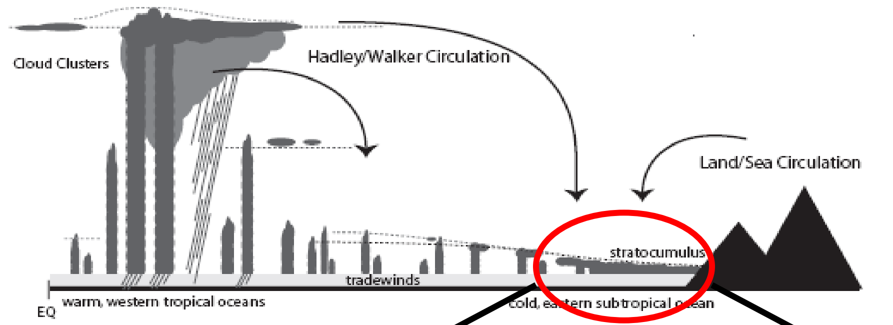
Polar Cloud Working Group

- ARCMIP
- BASE
- SHEBA
- CEAREX
- LEADEX
- AOE 2001
- M-PACE

Some Key (sub)-tropical Cloud-types that have been studied in GCCS



Stratocumulus (1)



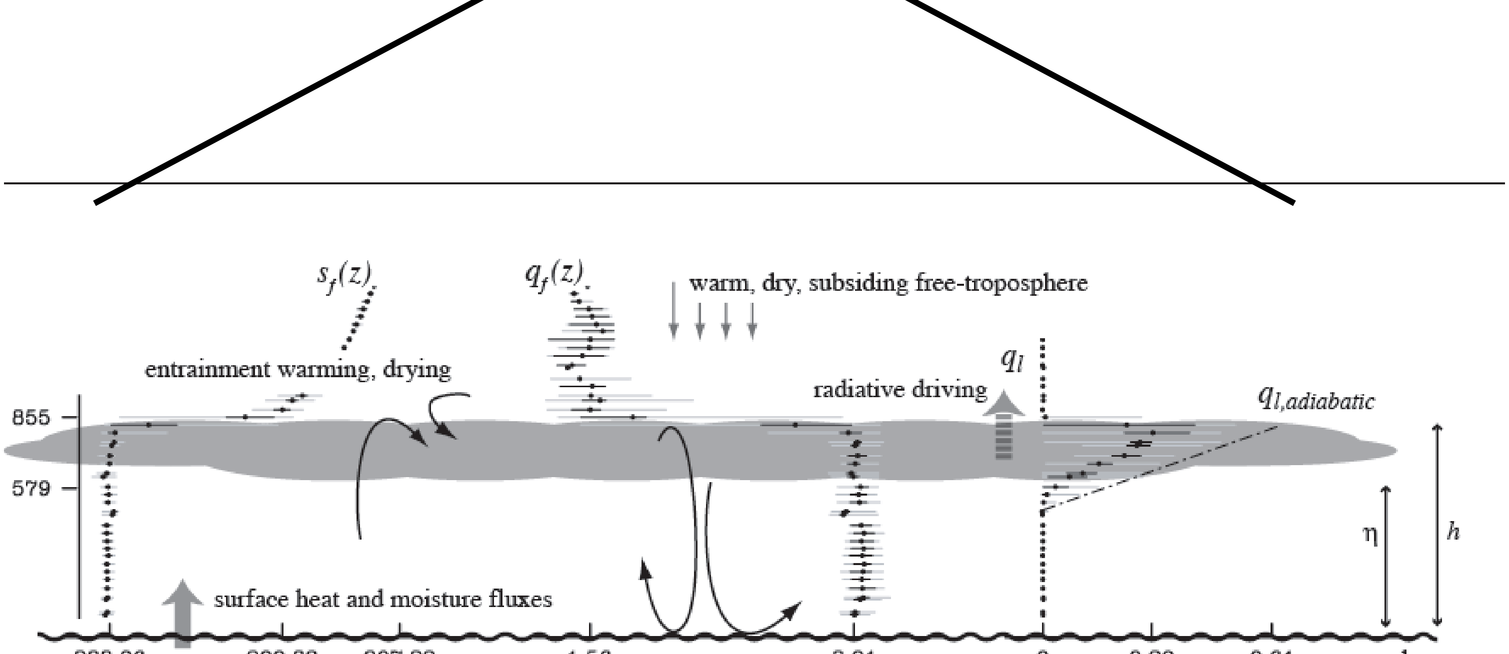


figure : Bjorn Stevens

Stratocumulus (2)

A long history!

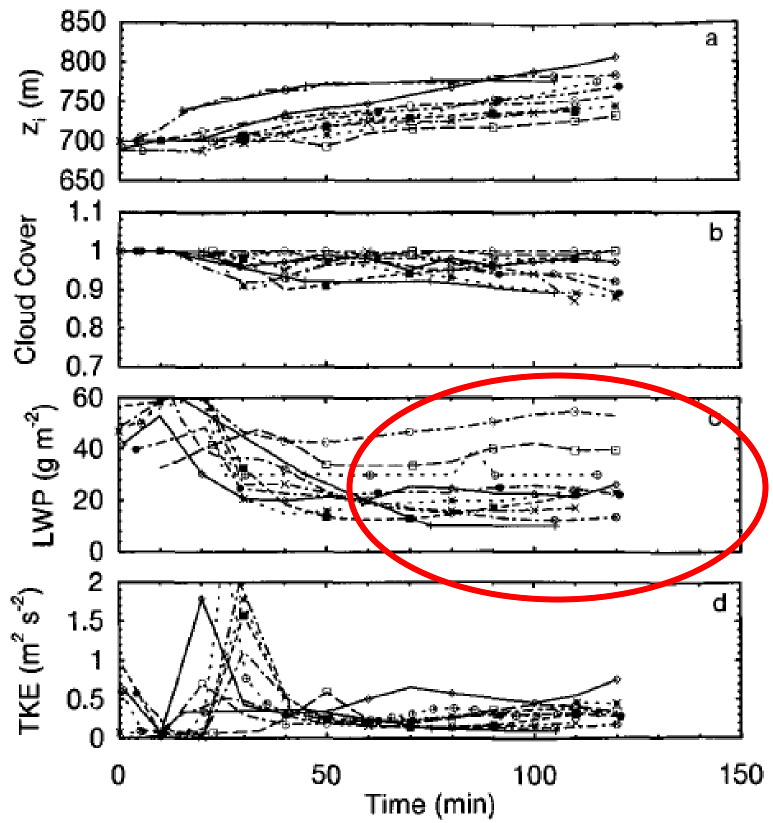
Experiment	Case	year
FIRE	Nocturnal Scu	1994
Idealized Smoke case		1995
ASTEX	Langrangian case	1995
ASTEX	Nocturnal	1996
FIRE	Diurnal cycle	2002
DYCOMSII	Nocturnal Scu	2003
DYCOMSII	Nocturnal Scu Precipitating	2005

Why?

Stratocumulus (3)

Experiment	Case	year
FIRE	Nocturnal Scu	1994
Idealized Smoke case		1995
ASTEX	Langrangian case	1995
ASTEX	Nocturnal	1996
FIRE	Diurnal cycle	2002
DYCOMSII	Nocturnal Scu	2003
DYCOMSII	Nocturnal Scu Precipitating	2005

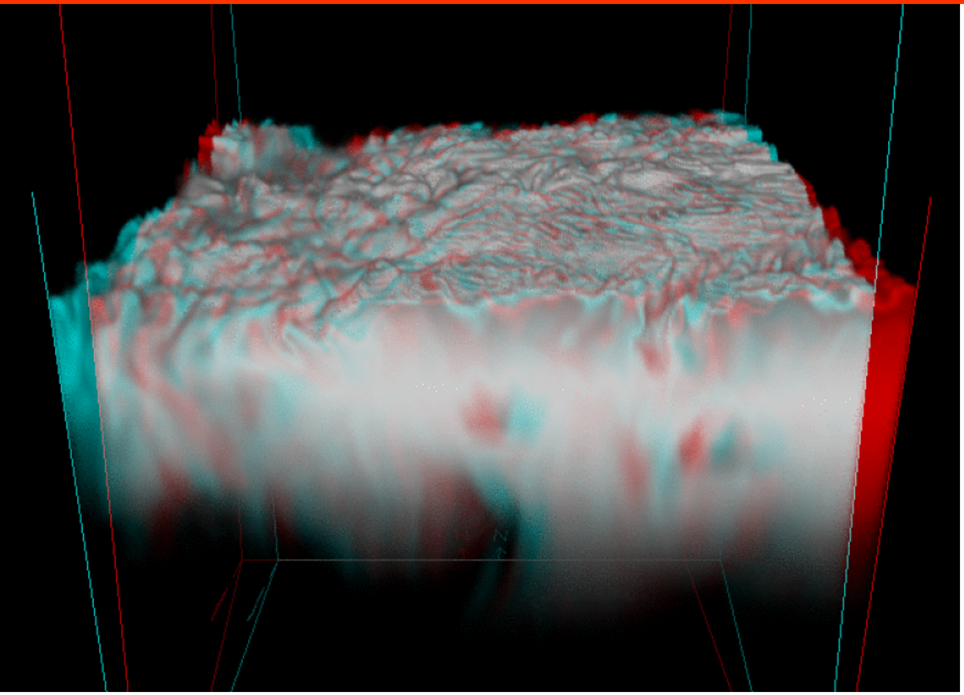
LES Results (first case 1994)



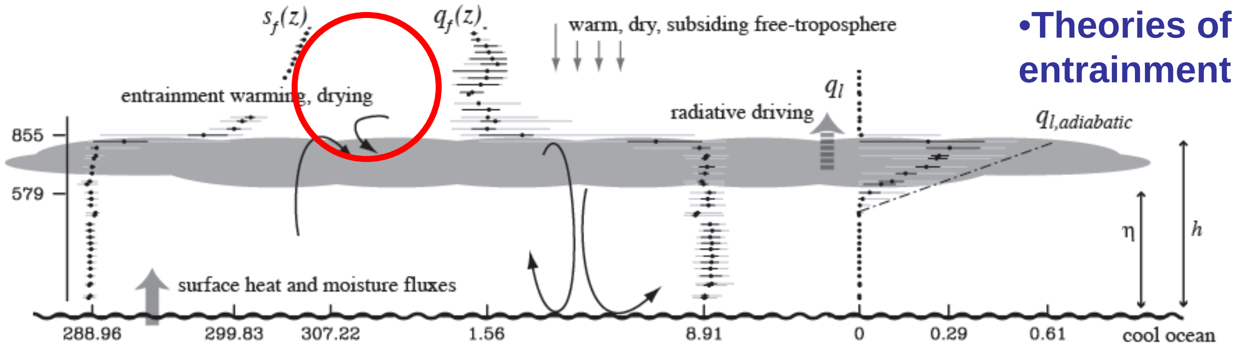
Spread of LWP in LES too large to constrain SCM's and parameterizations due to :

- **case not well constrained.**
- **Numerics and resolution of the LES models not good enough to deal with strong inversion.**

Stratocumulus (4)



Courtesy: Steve Krueger



Era of maturing (1995-2002):

- Better constraint cases
- Improved advection schemes for LES
- Higher Resolution.

Making of the theory and Parameterizations:

- Identification of top-entrainment as a key process
- Theories and parameterizations of entrainment.
- Theories of decoupling of Scu./ cloud-top entrainment instability (Randall 1980)

No lack of rules/parameterizations of the entrainment velocity

- Nicholls and Turton (1986)

$$w_e = \frac{2.5AW_{NE}}{\Delta\theta_{v,NT} + 2.5A\left(T_2\Delta\theta_{v,dry} + T_4\Delta\theta_{v,sat}\right)}$$

- Lilly (2002)

$$w_e = \frac{A_{DL}W_{NE,DL}}{\Delta\theta_{v,DL} + A_{DL}\left(L_2\Delta\theta_{v,dry} + L_4\Delta\theta_{v,sat}\right)}$$

- Stage and Businger (1981)
  Lewellen and Lewellen (1998)
  VanZanten et al. (1999)

$$w_e = \frac{AW_{NE}}{T_2\Delta\theta_{v,dry} + T_4\Delta\theta_{v,sat}}$$

- Lock (1998)

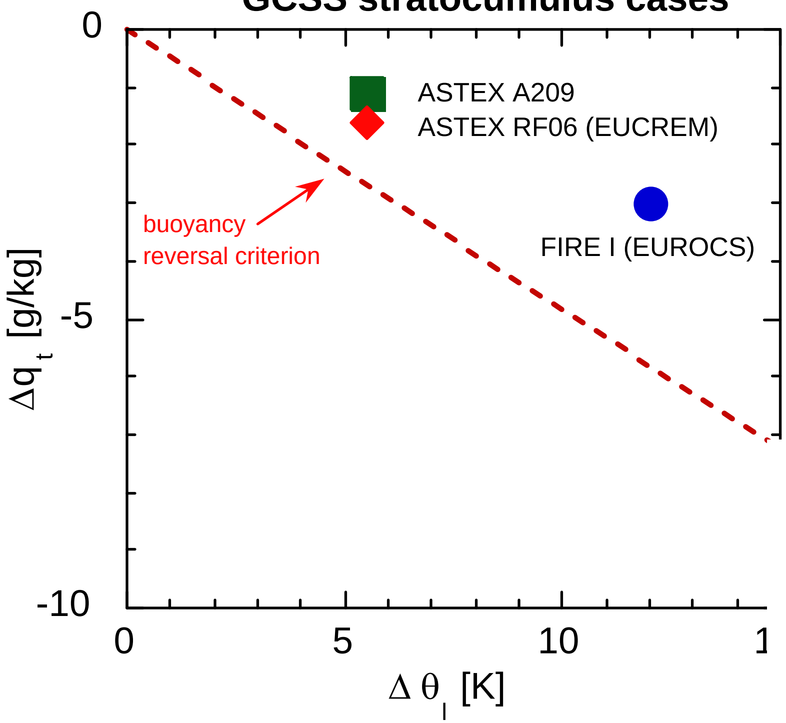
$$w_e = \frac{2A_{AL}W_{NE} + \alpha_t A_W \Delta F_L/\left(\rho c_p\right)}{\Delta\theta_v}$$

- Moeng (2000)

$$w_e = \frac{A_M\overline{w'\theta_l'} + \Delta F_L\left(3 - e^{-\sqrt{b_m L}}\right)/\left(\rho c_p\right)}{\Delta\theta_l}$$

Stratocumulus : Entrianment velocities: Observations vs Parameterizations

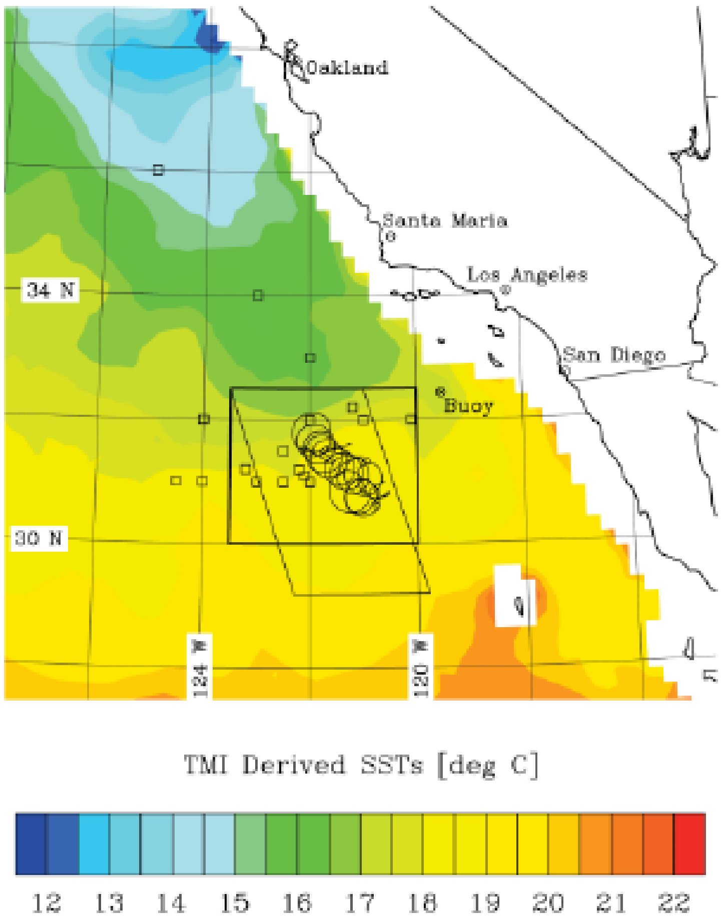
initial jumps for different GCSS stratocumulus cases



Entrainment velocities (cm/s) of 3 GCSS Cases

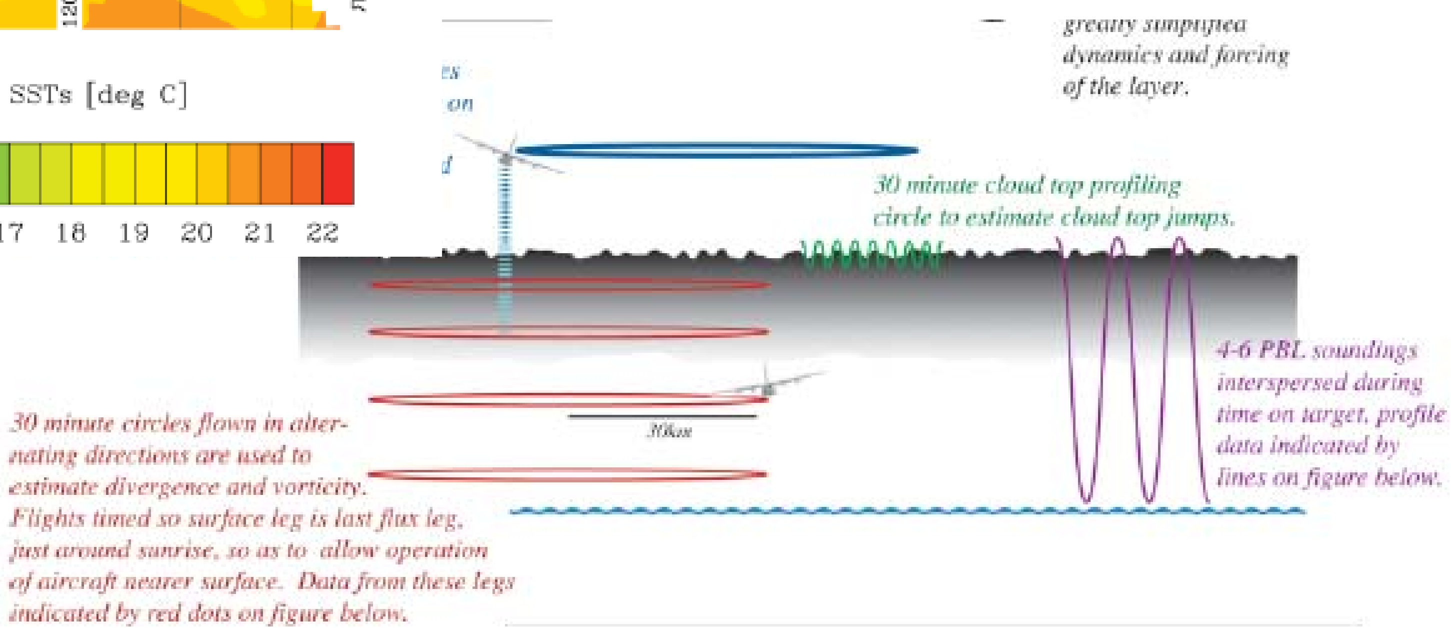
	FIRE	ASTEX A209	ASTEX RF06
Observed	-	1.1±0.5	1.2 ±1
LES	0.58 ± 0.08	1.2 ± 0.3	1.9 ± 0.1
NT	0.38	1.21	1.86
Lock	0.19	0.85	1.13
SB	0.38	0.76	1.18
Moeng	0.57	1.35	1.53
Lilly	0.37	0.99	1.42

Uncertainty in entrainment rate has inspired the GCSS-community to design a special dedicated field experiment to narrow down the uncertainty of this key process

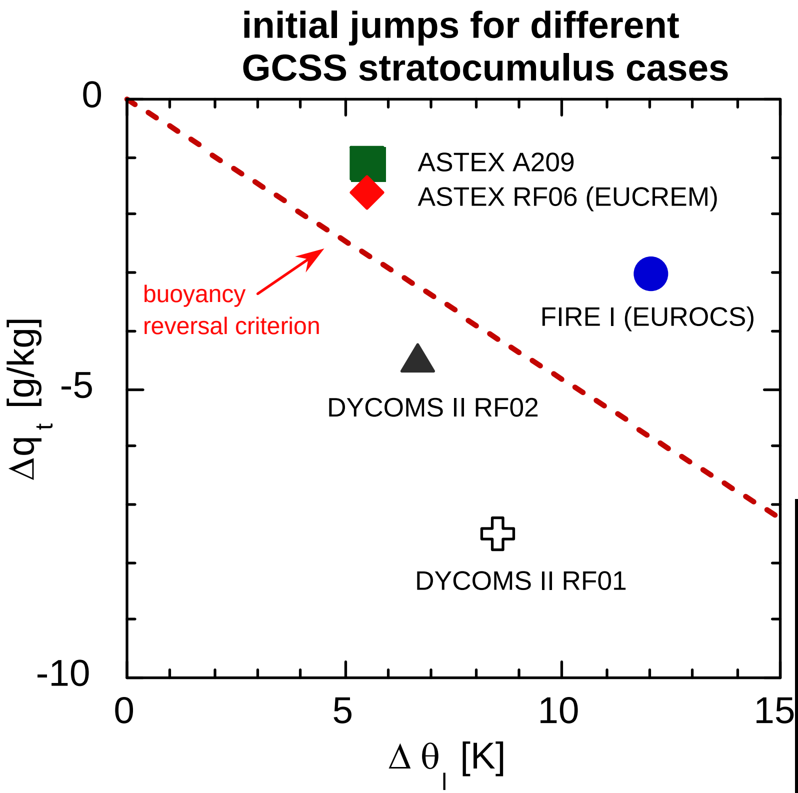


DYCOMS II

B. Stevens et al. BAMS 84 (2003)



Incorporating DYCOMS results: narrowing down parametrizations!



Entrainment results (cm/s) of 4 GCSS Cases

	FIRE	DYCOMS RF01	ASTEX A209	ASTEX RF06
Observed	-	0.38 ± 0.1	1.1±0.5	1.2 ±1
LES	0.58 ± 0.08	0.50 ± 0.09	1.2 ± 0.3	1.9 ± 0.1
NT	0.38	0.72	1.21	1.86
Lock	0.19	0.33	0.85	1.13
SB	0.38	0.88	0.76	1.18
Moeng	0.57	0.69	1.35	1.53
Lilly	0.37	0.78	0.99	1.42

Did it made a difference?

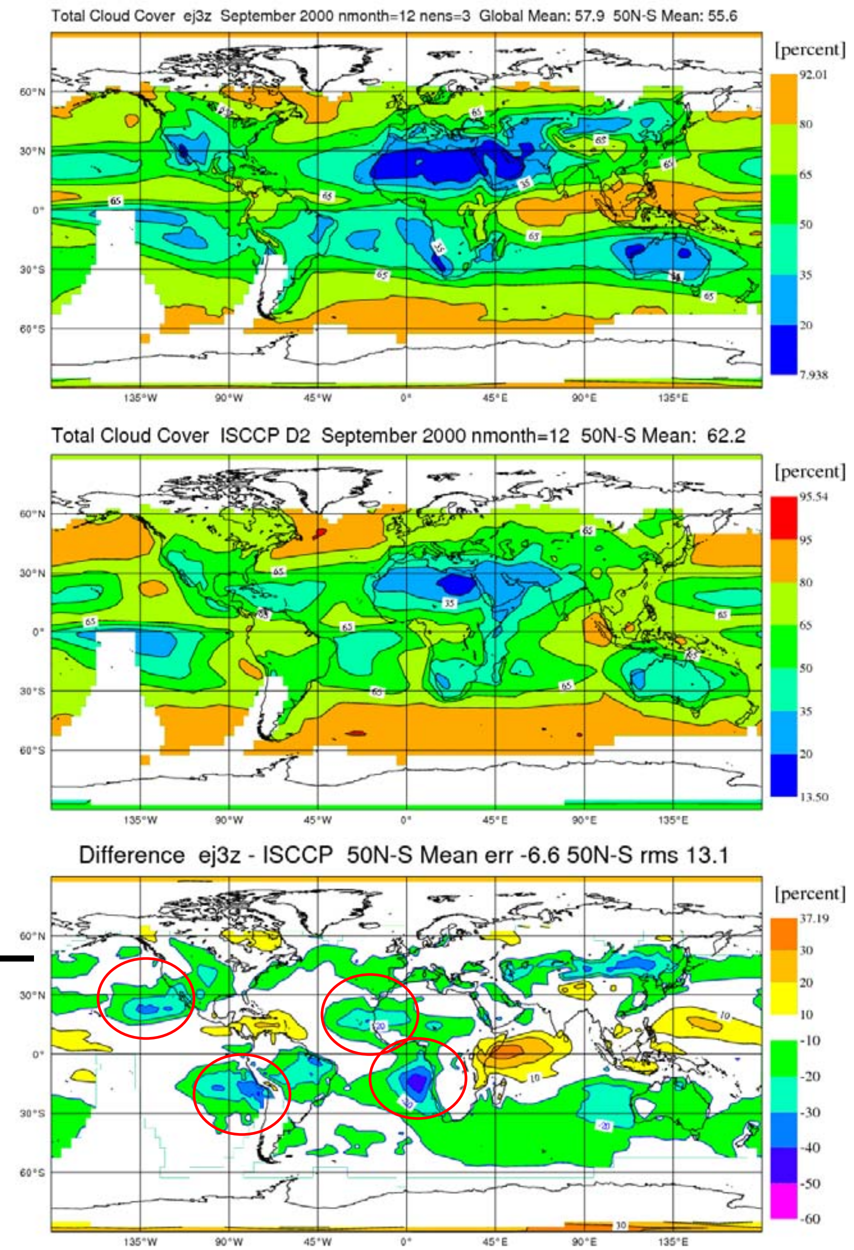
Yes, especially for those operational centres that actively participated in this process: i.e. ECMWF, Met. Office, Meteo France.

Example:

ECMWF: cloud fraction climatology

2002: underestimation of Scu

(general GCM-problem)

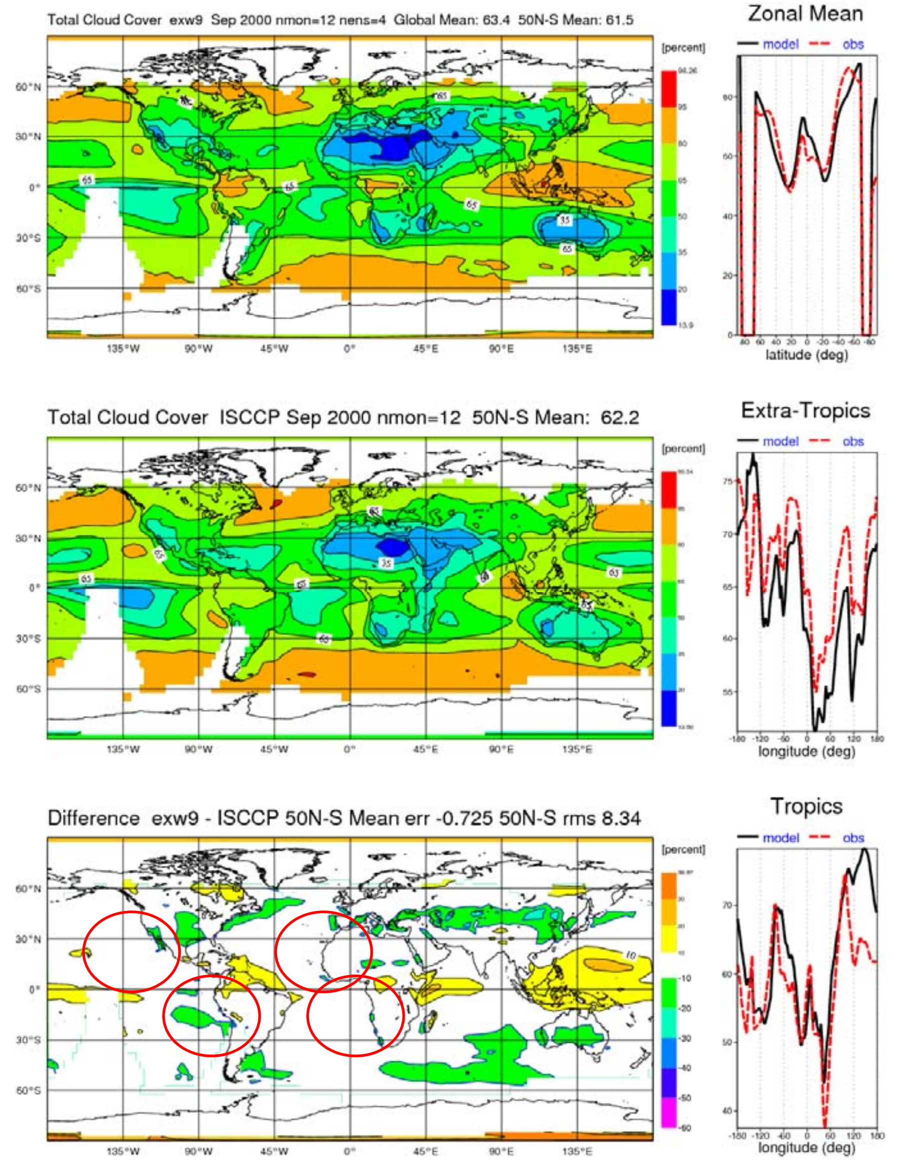


model - obs

Courtesy: Martin Kohler

Did it made a difference?

Yes, especially for those operational centres that actively participated in this process: i.e. ECMWF, UK Met. Office, Meteo France, NCAR



Example:

ECMWF: cloud fraction climatology

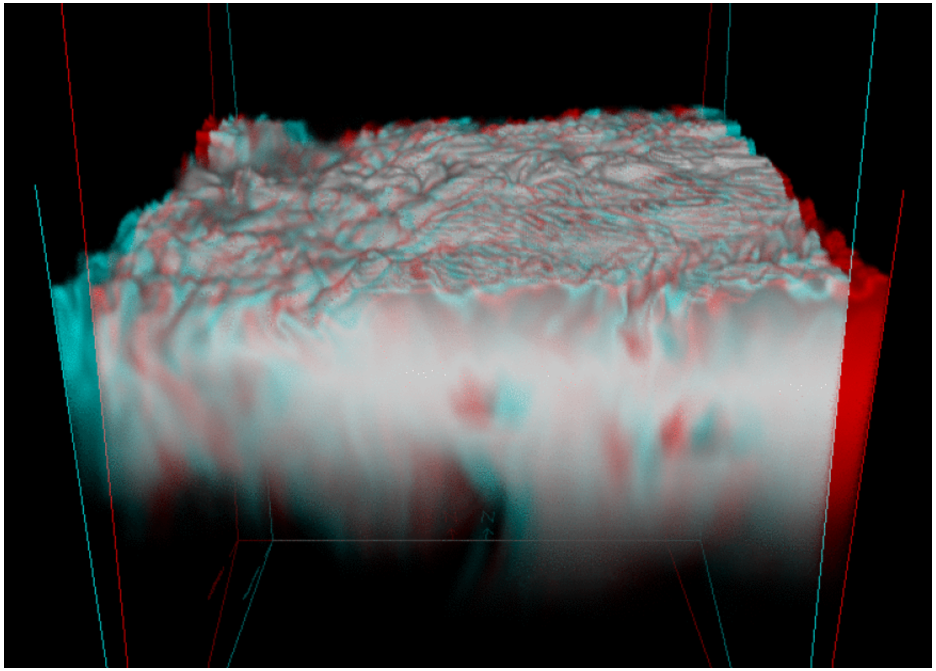
2007: Scu underestimation problem resolved.

model - obs ←

But more modeling centers should invest more on this!!!

Lessons to be learned!!

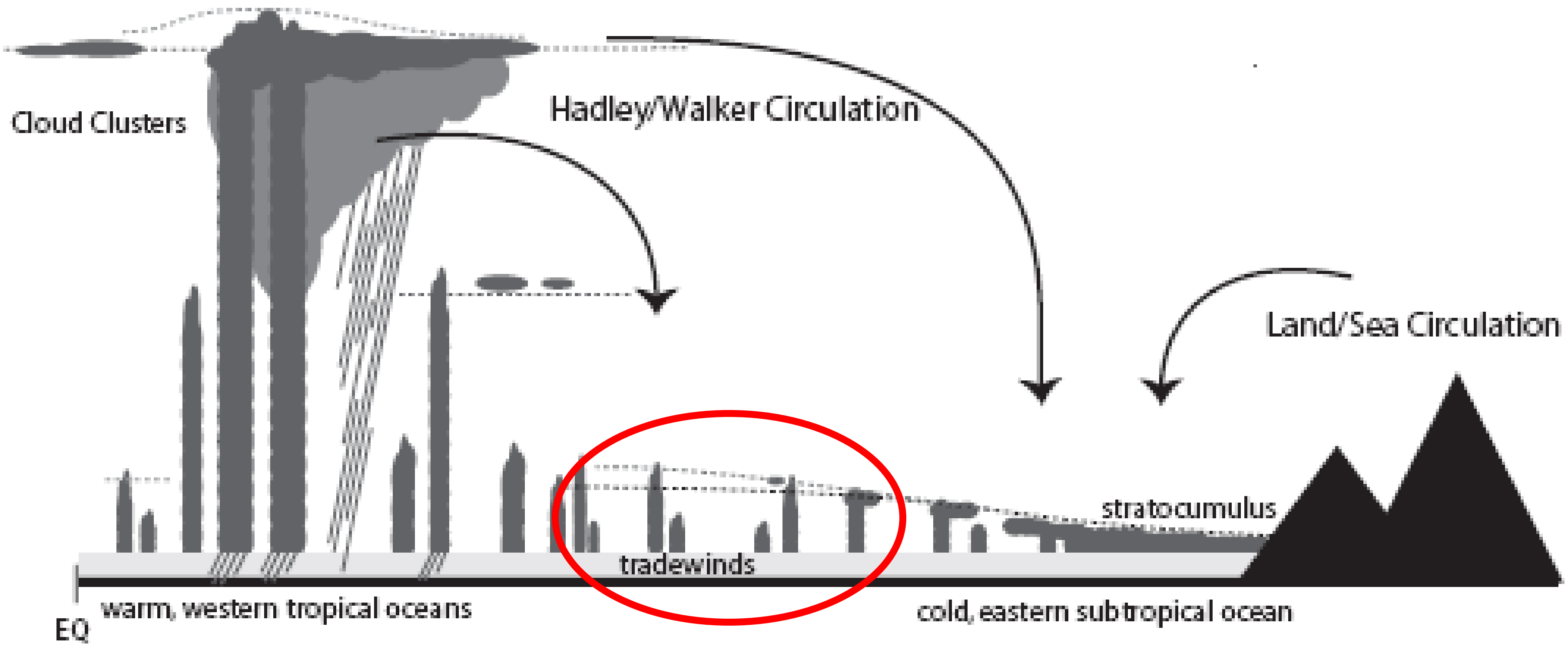
- use observations and models to identify the weak spots (top-entrainment)
- advance theories to improve representation (entrainment closures)
- design critical field experiments (DYCOMS)
- Implement the findings in Large-scale models (ECMWF)
- Critically evaluate the result on a global scale (ISSCP,CERES,SSMI)



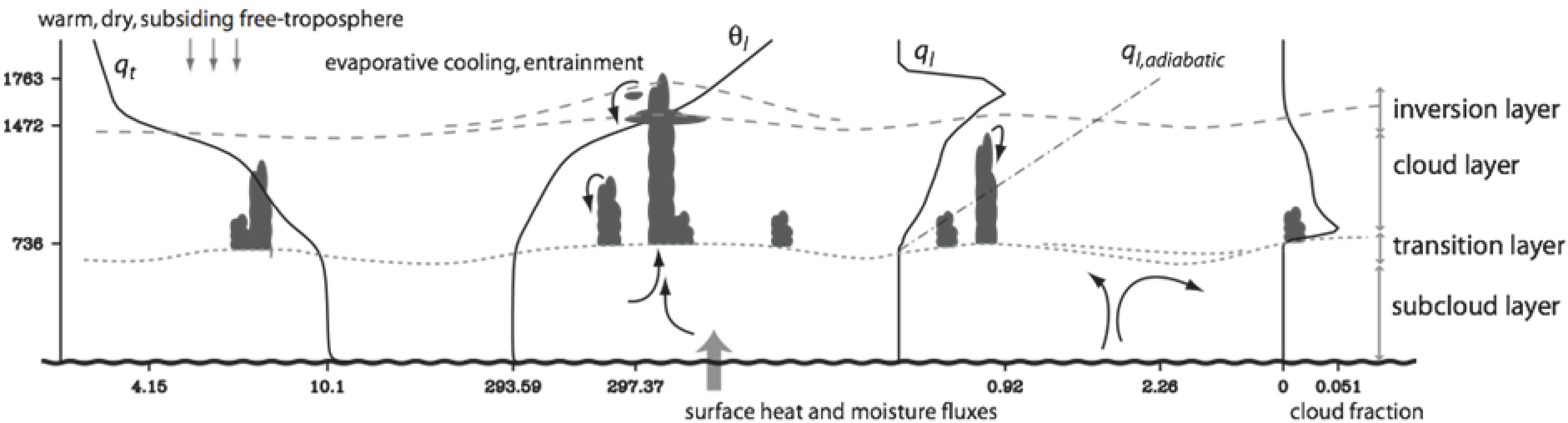
LES results

S. Krueger, Univ of Utah

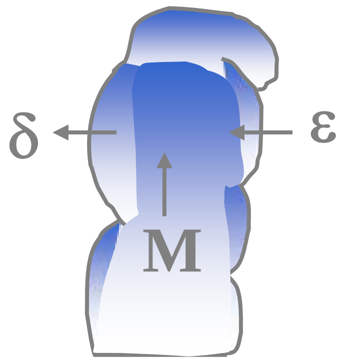
Key Cloud-types that have been studied in GCCS



Shallow Cumulus: Characteristics



Convective Transport in Shallow Cu usually parameterized using the mass flux approach:



$$\partial_t \phi|_{\text{clouds}} = -\partial_z F^\phi$$

$$F^\phi = \frac{M}{\rho}(\phi^c - \phi).$$

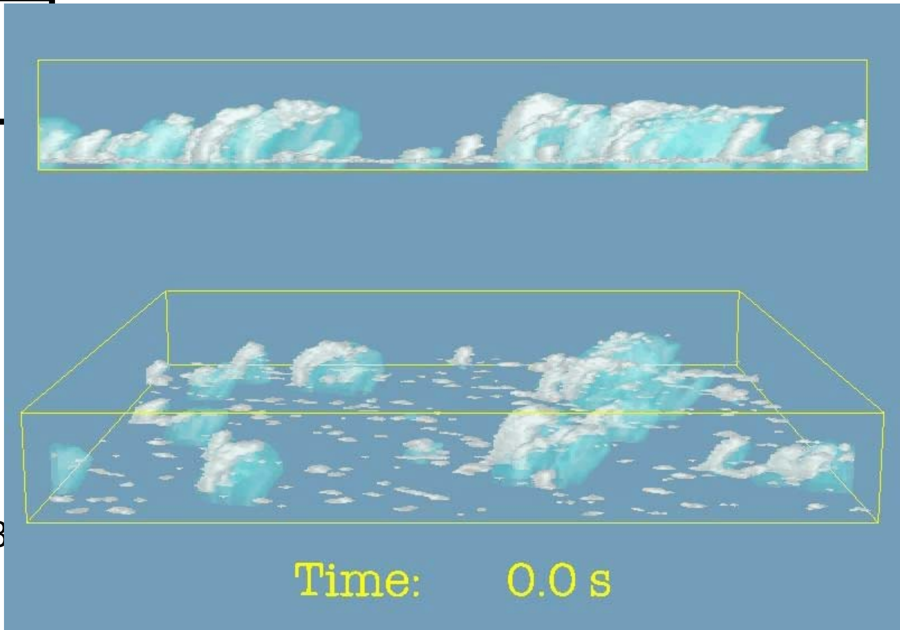
$$\partial_z M = (\epsilon - \delta)M$$
$$\partial_z \phi^c = -\epsilon(\phi^c - \phi).$$

Shallow Cumulus (2)

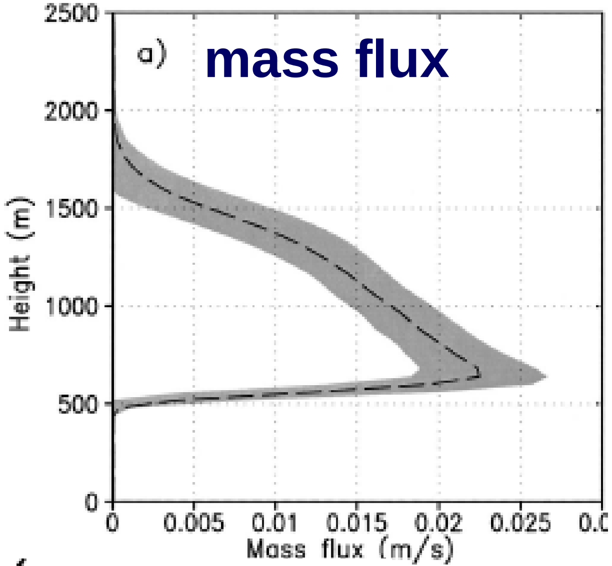
Shorter history:

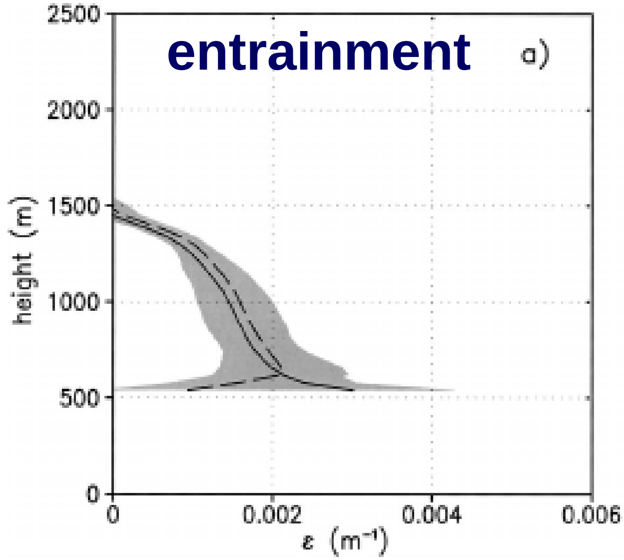
Experiment	Case	year
BOMEX	Steady state Trade wind cu	1997
ATEX	Trade wind cu topped with Scu	1998
ARM **(June 1997)**	Diurnal Cycle Cumulus	2000
RICO	Precipitating trade wind cu	2006

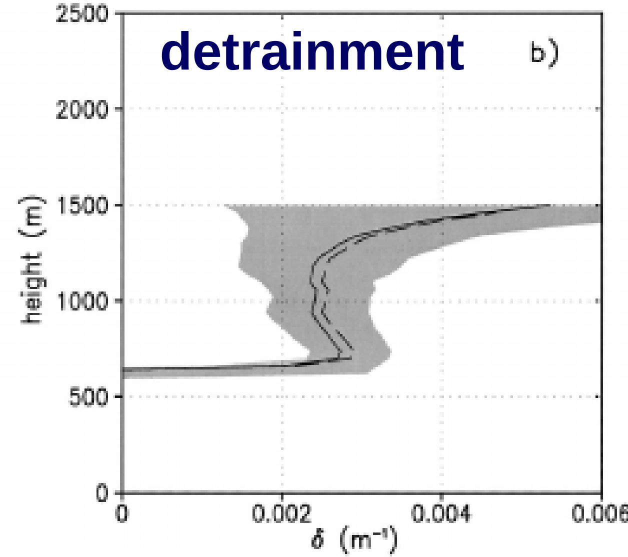
LES: RICO

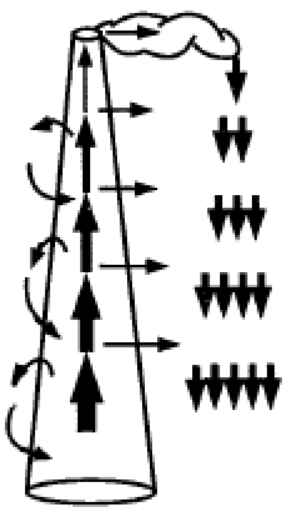


Steady State shallow cumulus (BOMEX). LES results:









Main Results:

1. Lateral entrainment and detrainment rates typically of the order of 10^{-3} m^{-1}
2. Detrainment rates typically larger than entrainment rates or
3. Mass flux decreases with height

Siebesma and Cuypers JAS 95

Siebesma 1998

Grant and Brown QJRMS 1999

Gregory QJRMS 2000

Neggers et al JAS 2002

ARM 97-diurnal cycle of shallow cu

Shorter history:

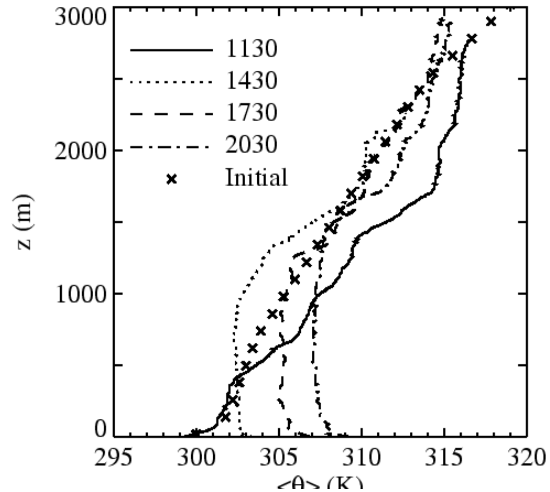
Experiment	Case	year
BOMEX	Steady state Trade wind cu	1997
ATEX	Trade wind cu topped with Scu	1998
ARM **(June 1997)**	Diurnal Cycle Cumulus	2000
RICO	Precipitating trade wind cu	2006

THEME: Can the findings of the steady state marine trade cu (BOMEX) be translated to the (much harder) diurnal cycle of shallow cu such as observed at the ARM SGP June 21 1997

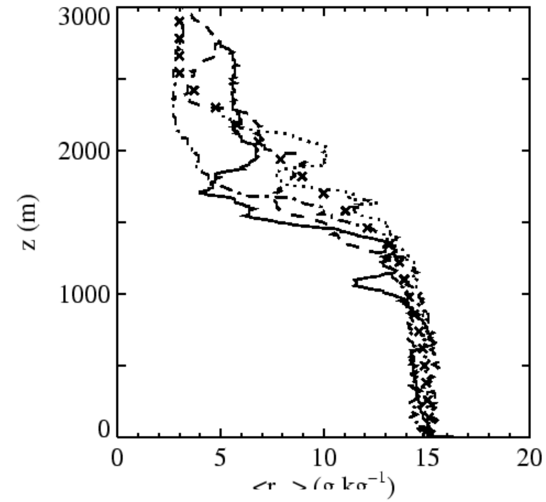
ARM data used to set up the case.

Initial Profiles:

TEMPERATURE



HUMIDITY

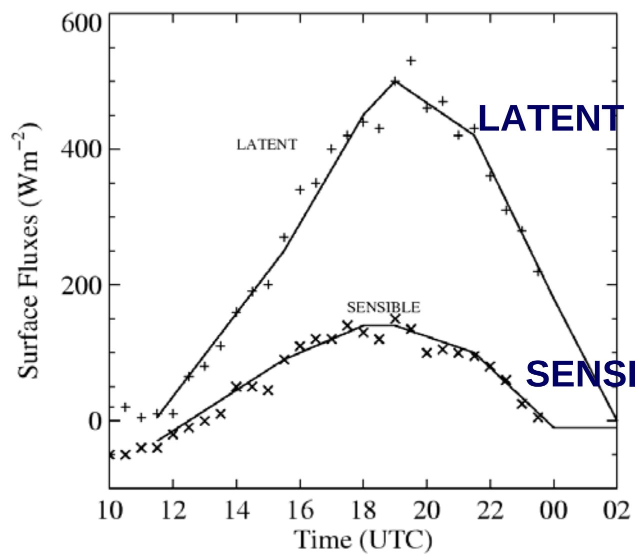


LS-Forcings

Radiation

(Not shown)

Surface Fluxes:



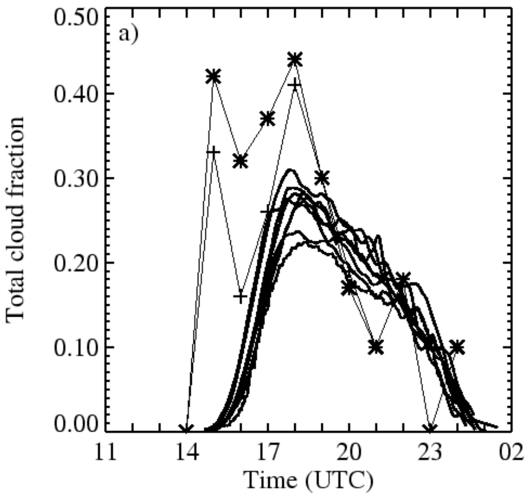
LATENT

SENSIBLE

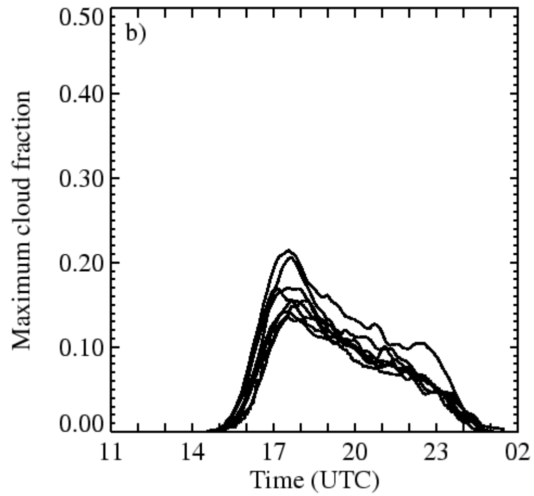
For details see: A.R. Brown et al. Q.J.Met.Soc. 128, 1075-1094 (2001)

LES results vs ARM data of cloud relevant time series

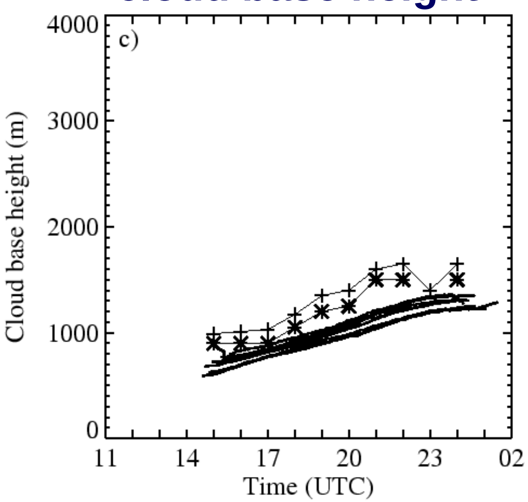
cloud fraction



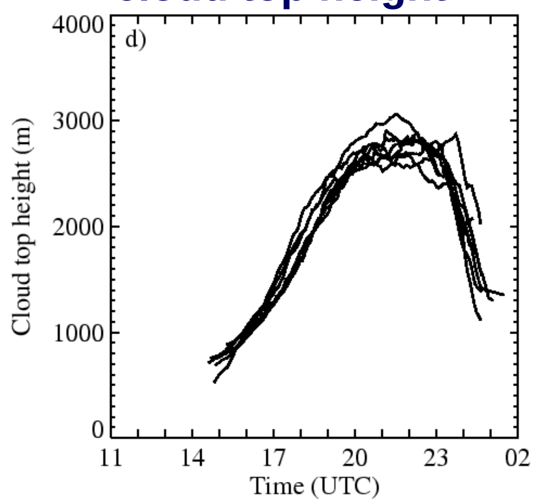
maximum cloud fraction



cloud base height



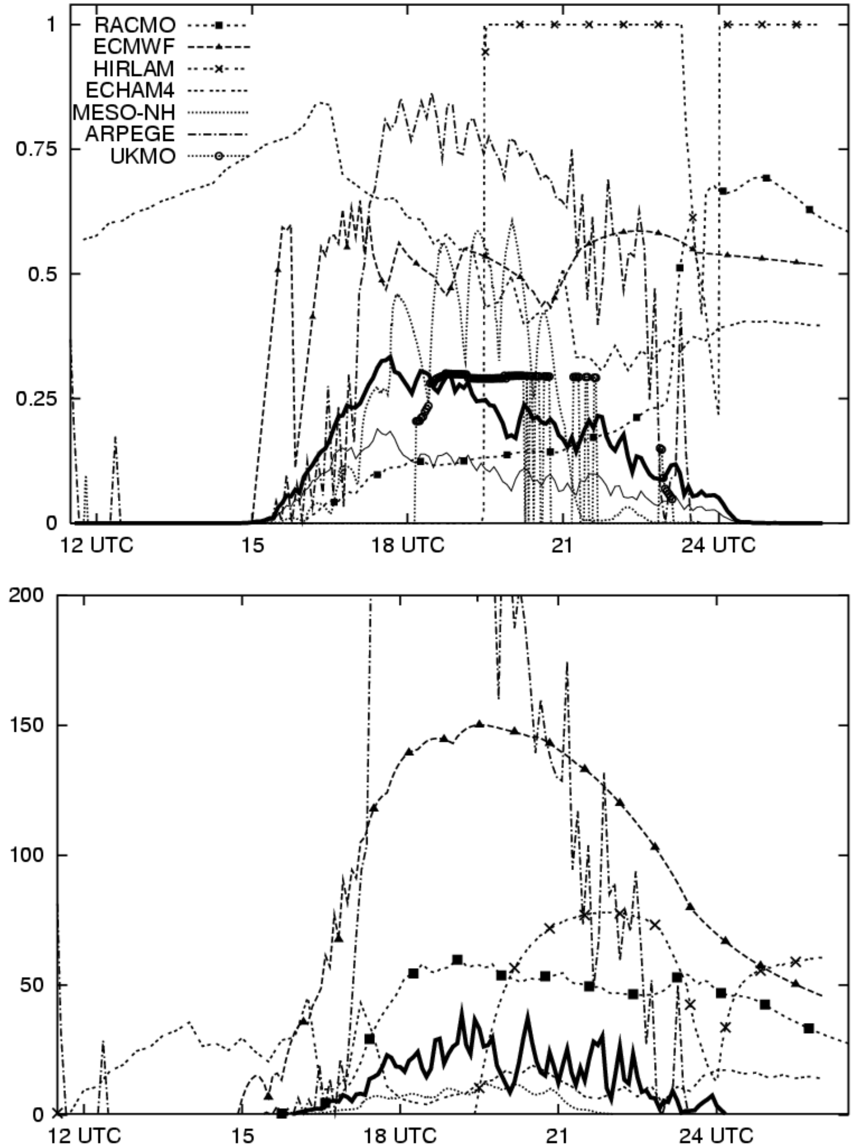
cloud top height



Good agreement with obs given the “idealized”set up of the case.

Allowed the use of the LES data sets to design further parameterizations for GCM’s.

Single Column Model (SCM) versions of GCM's



Strong overestimation of cloud fraction and liquid water path.

due to:

- **Interaction BL-scheme/convection scheme.**
- **Mass flux closure.**
- **Entrainment/detrainment parameterizations.**
- **cloud scheme**

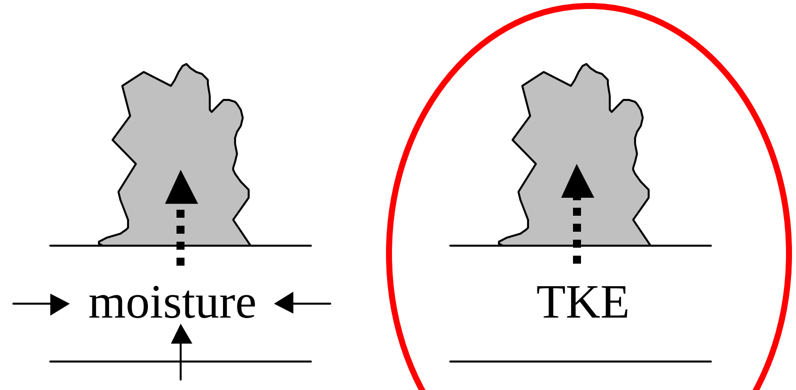
Lenderink et al.: QJRMS 2004

ARM-08

Parameterization improvements:

cloud base mass flux M_b :Mass flux closure

Coupling of M_b to *sub-cloud* layer

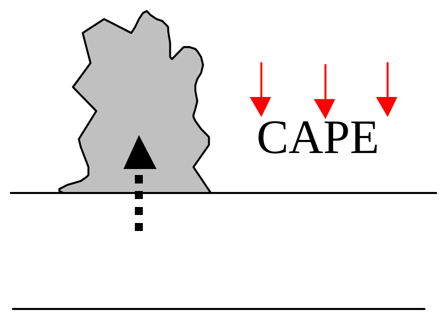


$$M_b^{\,c} = \gamma \; a_b^{\,c} \; w^*_{sub} \approx 0.03 w^*_{sub}$$

Grant 2001 QRMS

OR:

Coupling of M_b to *cloud* layer



Detailed comparisons of SCM with LES indicate that shallow cu is driven by the subcloud layer and that a TKE-type of closure is a superior closure.

Neggers et al 2002 MWR

Summary

- ARM observations succesfully used to set up the shallow cu case and to assess the credibility of the LES results.

- LES reproduced the shallow cumulus convection remarkably well.

- Challenging case for parameterizations as they have to go through a number of stages:

  Stable => dry convective BL => Cu topped BL => Stable

- Parameterization behaved remarkably bad for such a relative simple case.

- A number of GCM's has adressed this and improved substantially on this cloud type (notably: ECMWF, MetO and CCM).

Summary

- **ARM Observations used to set up the case and to assess the credibility of the LES results.**

- **LES reproduced the shallow cumulus convection remarkably well.**

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  Stable => dry convective BL => Cu topped BL => Stable

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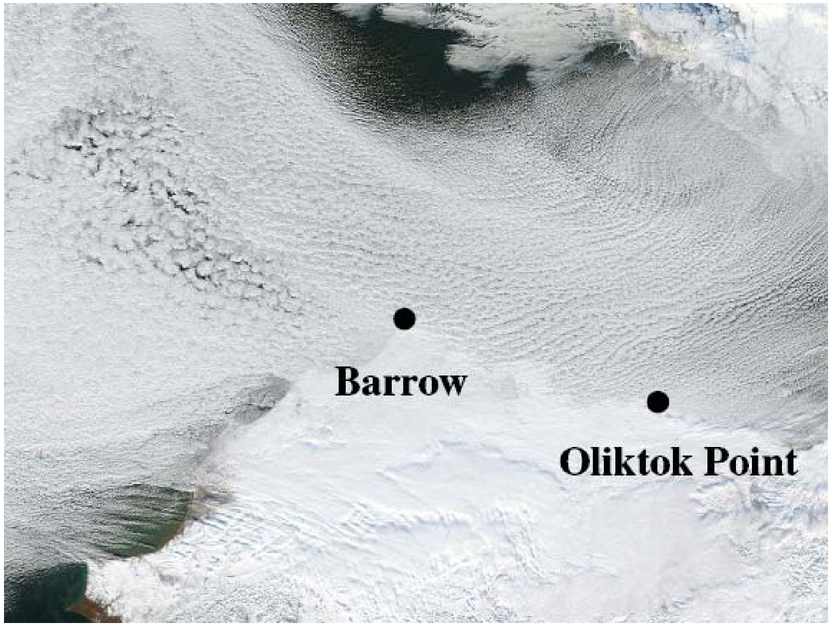
GCSS intercomparisons of other cloud types based on ARM observations

- Polar Clouds
- Deep Convection
- Cirrus

Current Intercomparison case of the Polar Clouds Working Group

A GCSS/ARM Intercomparison for M-PACE ; Steve Klein and Renate McCoy



Cold-air outbreak mixed-phase stratocumulus

Goals:

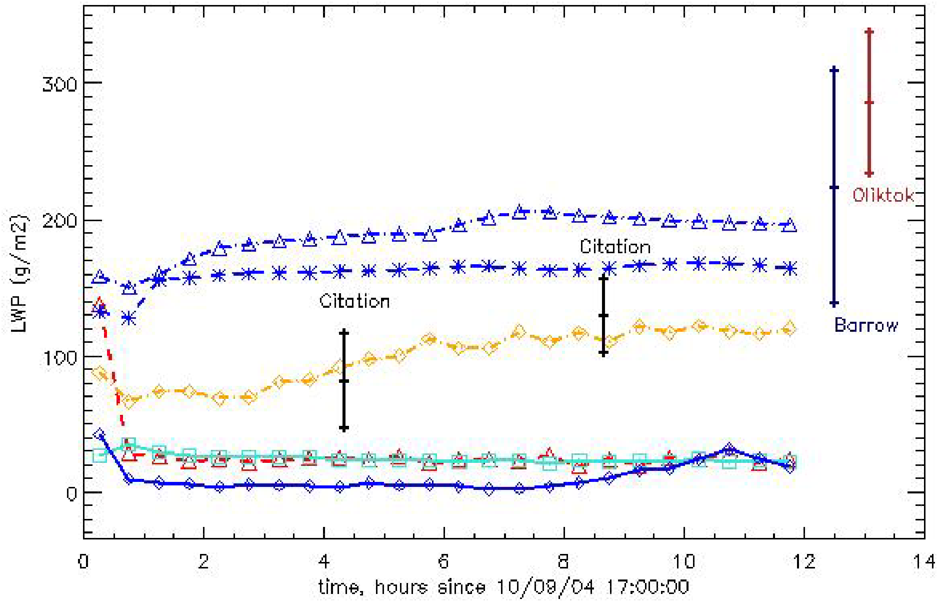
- Document the current state of mixed-phase cloud microphysics in models
- Understand differences between models and observations in their simulations of mixed phase cloud microphysics
- Spur improvements in the representation of mixed phase cloud microphysics in climate and cloud resolving models.

Large Show up:

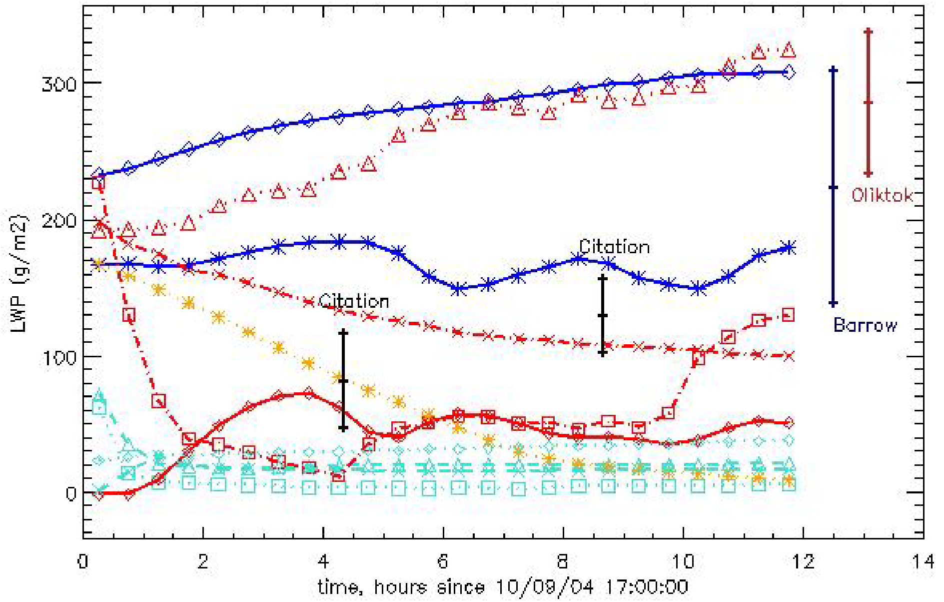
- **17 SCM's**
- **9 CRM's/LES**

Results on LWP

LES/CRM



SCM



Single moment microphysics **Double moment microphysics** **Binned Microphysics**

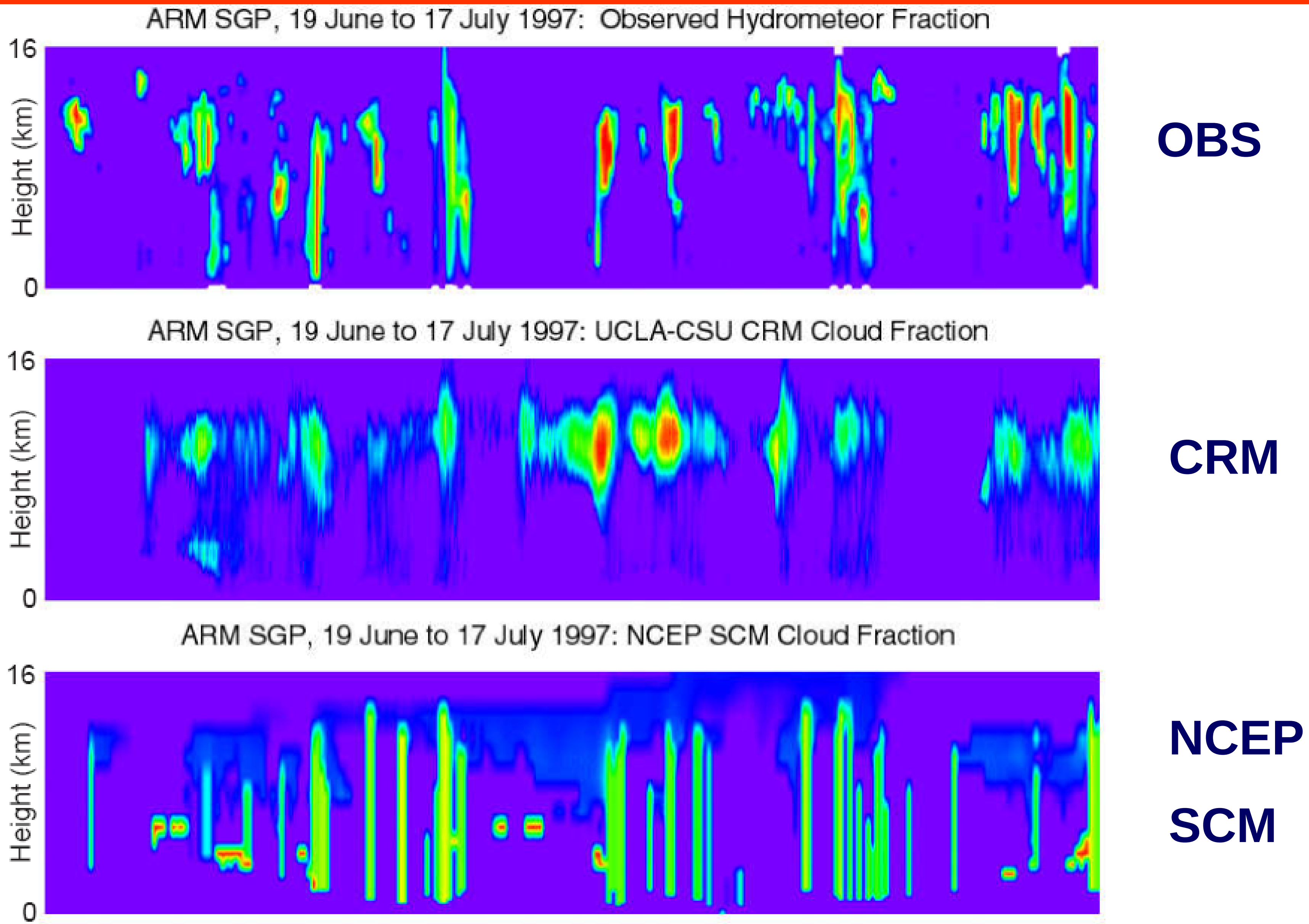
Most models tend to underestimate LWP.

Model behaviour tends to improve with more sophisticated microphysics

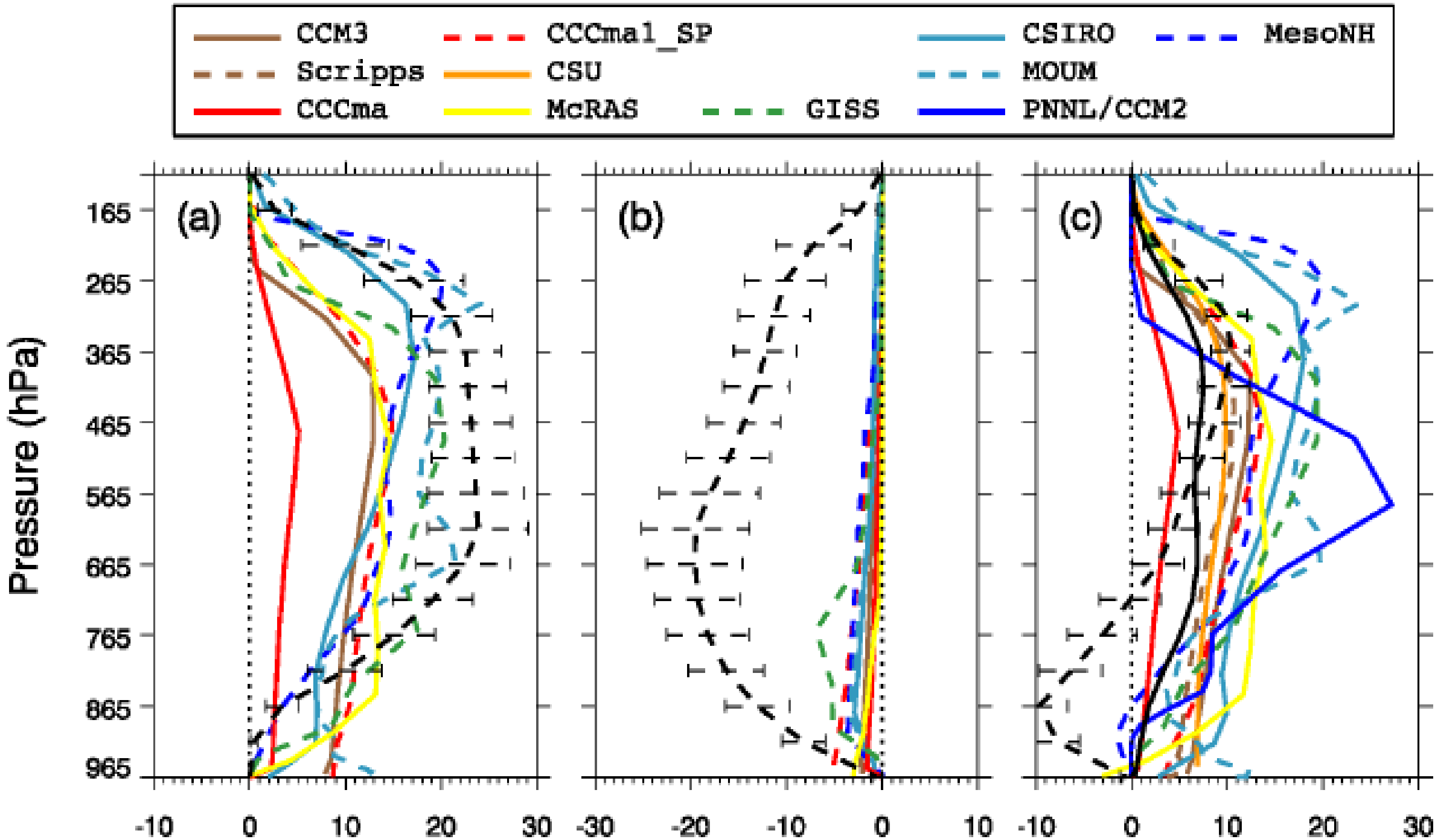
This case is likely to become a classic reference for modelling mixed-phase low clouds

Case 3 of the Deep Convection Working Group

ARM-IOP 1997 period



Allowed a critical evaluation of the mass fluxes in deep convection………..



updraft mass flux Mu

downdraft mass flux Md

total mass flux Mc

Upcoming Theme for the Deep Convection Working Group:

- Origins of the differences between deep convective over land and sea

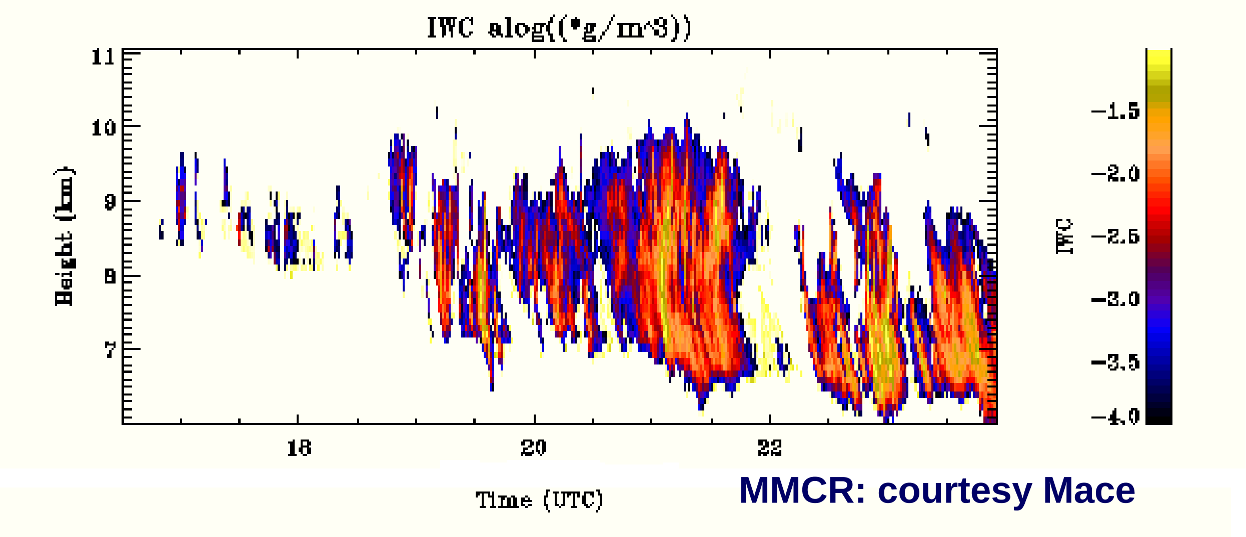
- Observations to be used: TWP-ICE, AMMA, TOGA-COARE.

- Plans will be discussed at the upcoming PAN-GCSS meeting in June, Fra

Current Intercomparison case of the Cirrus Working Group

Case leader: Steven Dobbie

Based on ARM observation at the SGP at March 9, 2000 during the IOP.



MMCR: courtesy Mace

Main Issues:

- **Sedimentation**
- **Micro-physics**

LES and SCM results based on this case will be discussed at the break-out meeting during the PAN-GCSS in Toulouse.

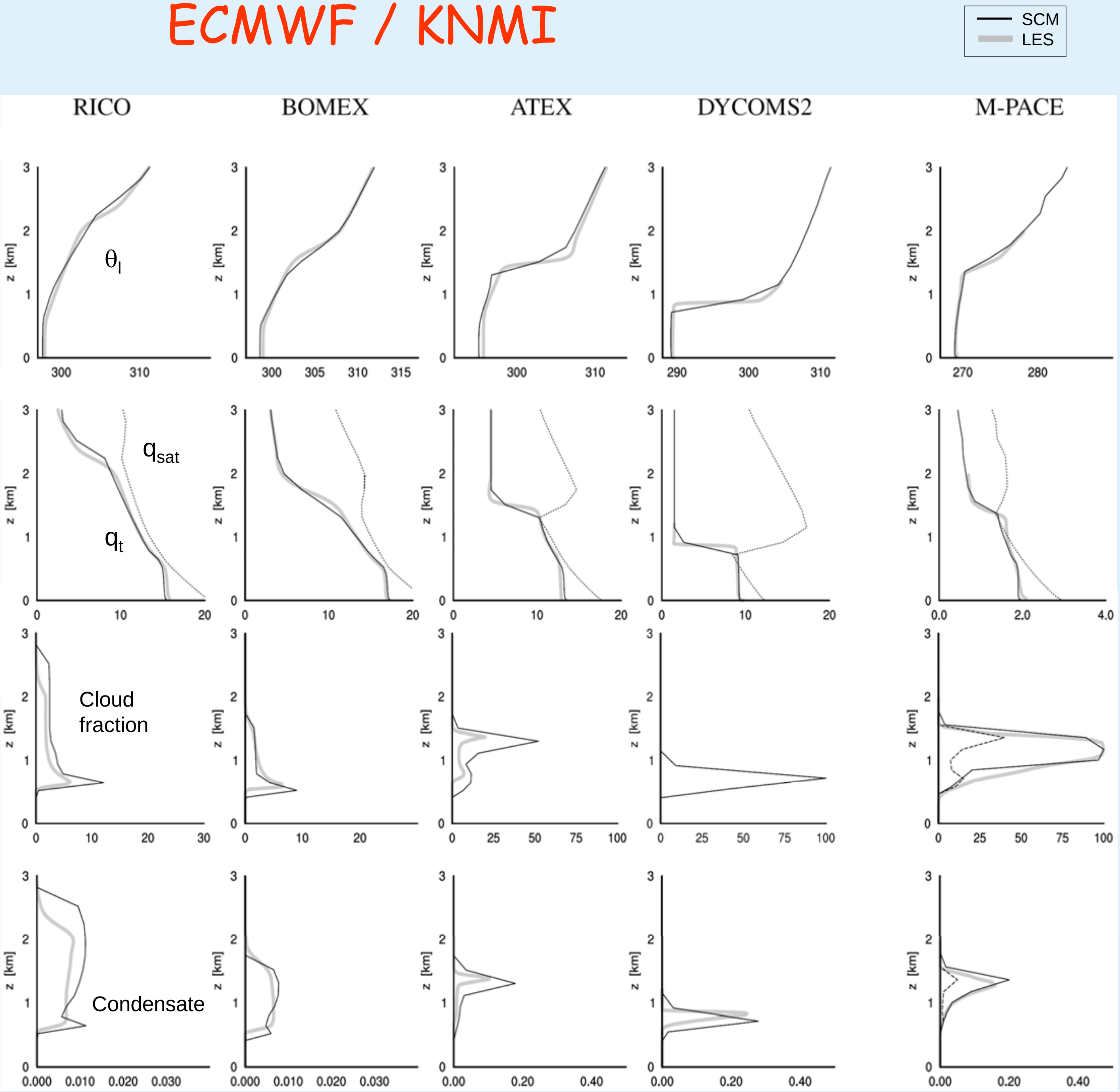
CASE STUDIES

- Case studies have been proven extremely useful in designing and testing parameterizations
- They should be a routine step in any developing parameterization exercise.

ECMWF / KNMI

Evaluate for as many prototype LES/CRM cases as possible

This should be a routine step in model development



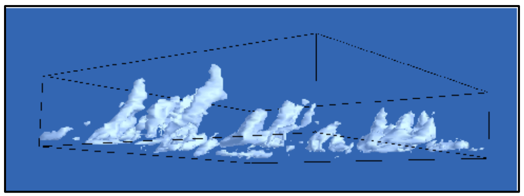
4/3/2008

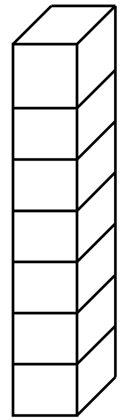
CASE STUDIES

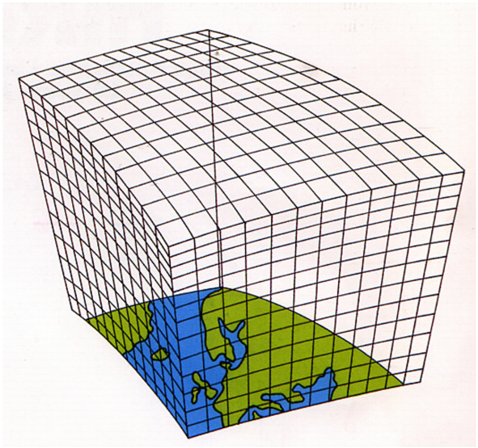
- Case studies have been proven extremely useful in designing and testing new parameterizations
- They should be a routine step in any developing parameterization exercise.

- But… though it is is a necessary step, it is not allways sufficient to certify improvement in the overall performance in the 3d GCM
- And it is not making optimal use of the long observational data records available from the advanced profiling stations (ARM, CLOUDNET)

Can we do more between case studies and global evaluation?







Large Eddy Simulation (LES) Models

Cloud Resolving Models (CRM)

Single Column Model

Versions of Climate Models

3d-Climate Models

NWP's

Observations from

Field Campaigns and/or

Observational sites (ARM)

Global observational

Data sets

Development

Testing

Evaluation

A proposal:

Continuous Model Evaluation at profiling sites:

Thanks to Roel Neggers (KNMI).

Purpose:

- To have a case every day
- To expose the parameterization package to all different meteorological conditions.
- To more optimal use the available observational data sets
- To score the physics package.
- To create a meeting place between models and observations

Method:

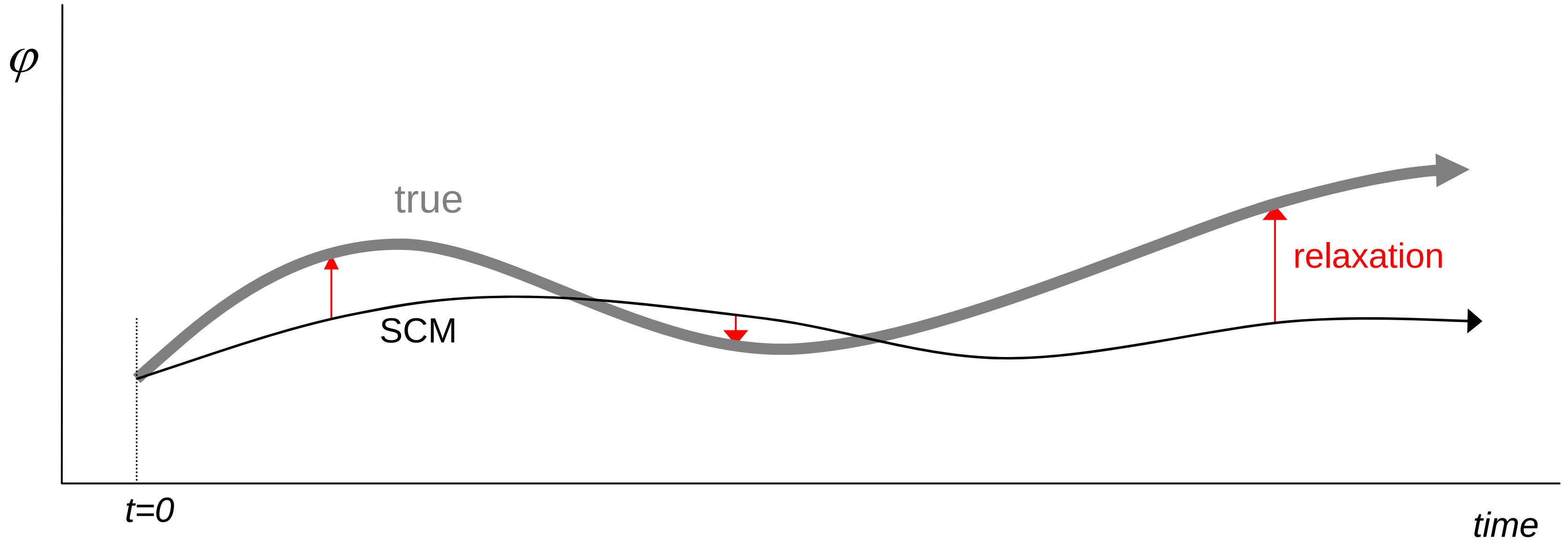
Time-integrate one vertical column of GCM sub-grid physics

Use prescribed large-scale forcings (advection, subsidence, geostrophic wind)

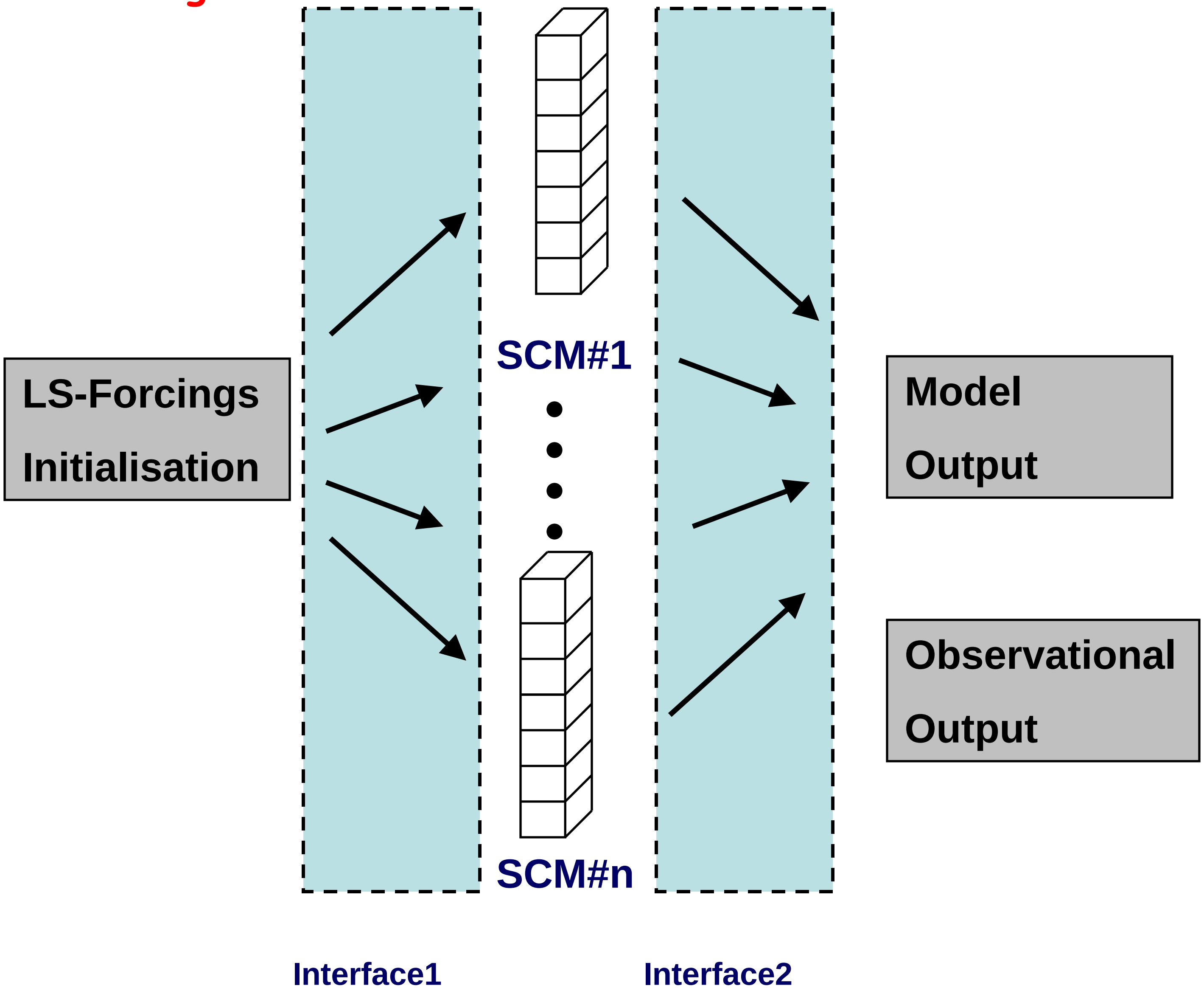
Initialize from observed / GCM-analysis state

Add relaxation towards the mean state (3D model / observed)

- prevents excessive drift
- enough freedom still exists for a unique state to develop
  (dependent on relaxation timescale)



Technical set-up is relatively easy and realised for the Cabauw Profiling station in the Netherlands



Daily automatic evaluation of:

- •Surface fluxes
- •Atm profiles
- •Cloud properties
- •Etc…

RMS Scores are automatically accumulated

Observational datastreams at Cabauw

Class	Instrument	Data-stream	Unit	Status
Surface meteorology		2m T	K	✓
		2m Td	K	✓
		10m wind	m s^{-1}	✓
		Surface precipitation	mm d^{-1}	✓
		Cloud fraction	Octa	✓
Cabauw tower profiles (lowest 200m)		T	K	✓
		q	g kg^{-1}	✓
		U	m s^{-1}	✓
		wT	K m s^{-1}	✗
		wq	kg kg^{-1} m s^{-1}	✗
		wU	m^2 s^{-2}	✗

Class	Instrument	Data-stream	Unit	Status
Ceilometer	CT75	Cloud base height	m	✓
Microwave Radiometer (MWR)	HATPRO	Liquid water path (LWP)	mm	✓
		Water vapour path (IWV)	kg m^{-2}	✓
Surface turbulent fluxes		Latent heat	W m^{-2}	✓
		Sensible heat	W m^{-2}	✓
Surface radiative fluxes		LW down	W m^{-2}	✓
		LW up	W m^{-2}	✓
		SW down	W m^{-2}	✓
		SW up	W m^{-2}	✓
Profiler				✗
Radar				✗

How does it work in practice:

Short-range (3-day) SCM hindcasts for the Cabauw point

Performed _daily_ (fully automated) over 200days now.

Evaluation against near real-time observational data-streams and visualised.

Various scores are calculated to assess model performance

Multiple SCMs are included and inter-compared (ECMWF-branches, RACMO, ECHAM)

Will be further promoted at the PAN_GCSS meeting to get more models in.

Check the website: **www.knmi.nl/~neggers/KPT/archive/index.htm**

We are interested in getting other profiling stations and Models in the system!! (ARM, CLOUDNET).

All this and much more wil be presented and discussed at out 3 annual :

PAN-GCSS Meeting

2-6 June 2008, Meteo France, Toulouse, France

More info on : www.gewex.org/gcss.html

Deadline is next week!!

Thank You!

Examples

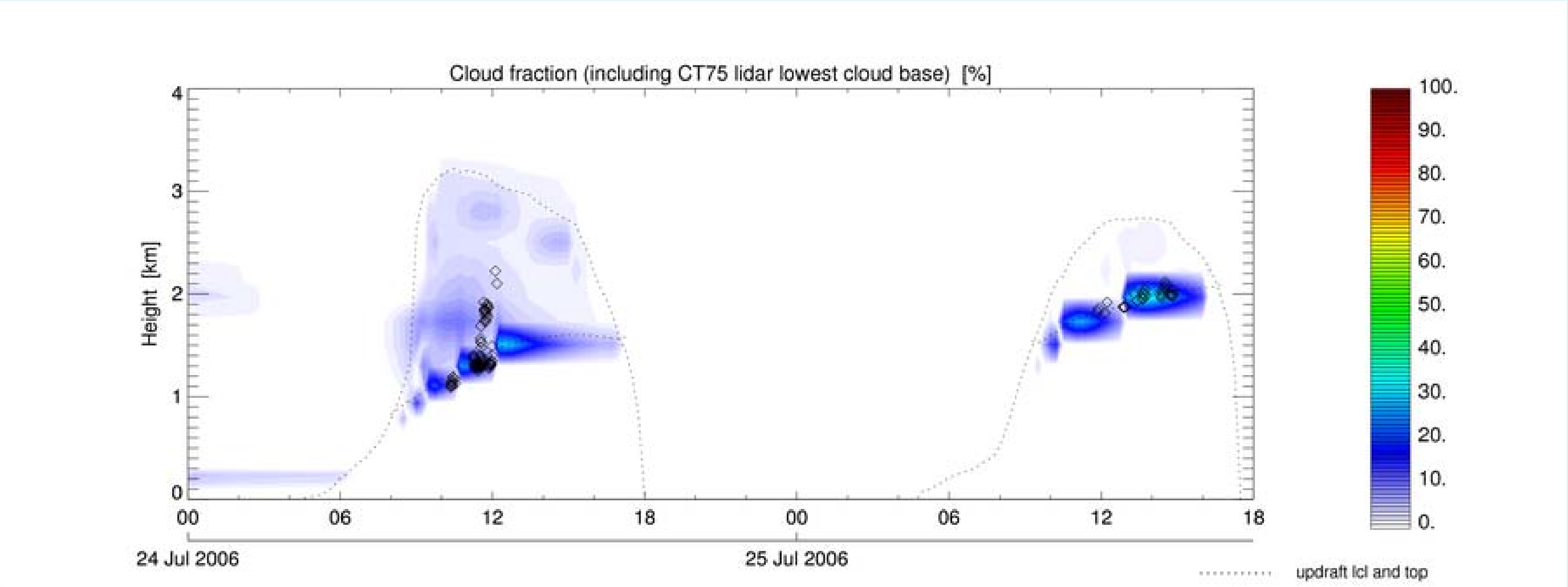
Various weather regimes observed at Cabauw

A showcase of what the SCM testbed offers

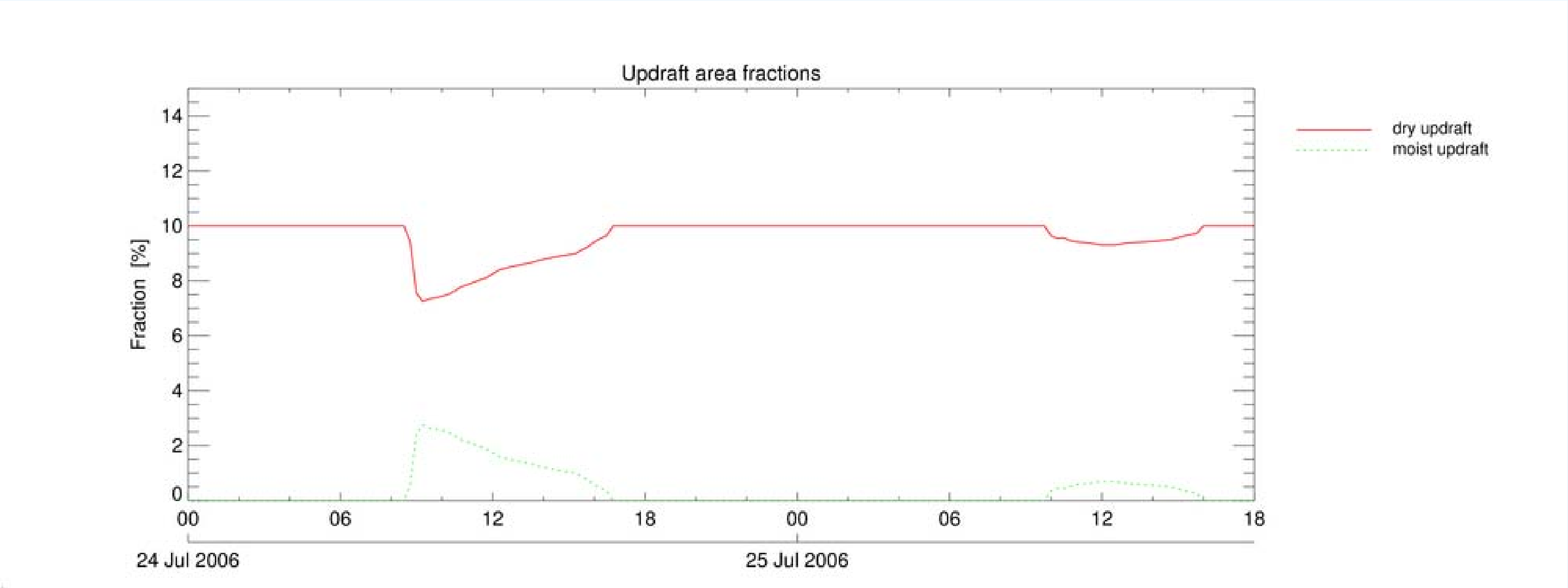
I Shallow cumulus convection

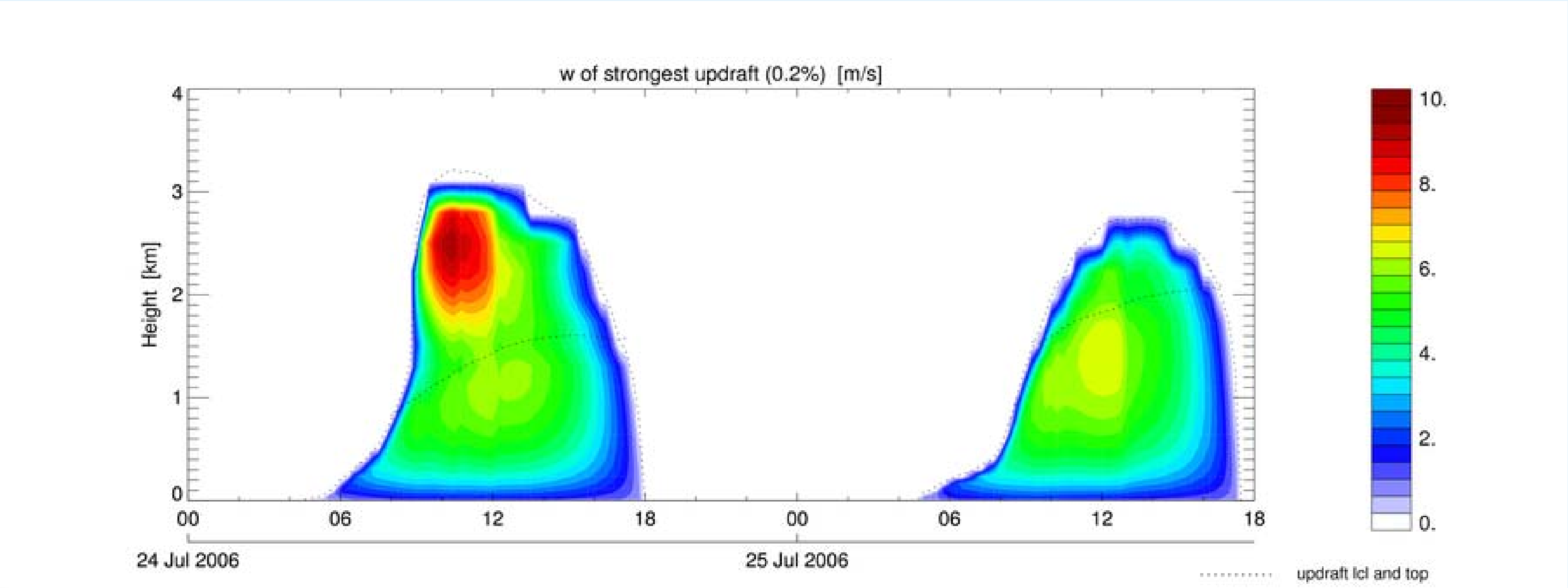
Cabauw, 24 July 2006

Clouds – vertical structure



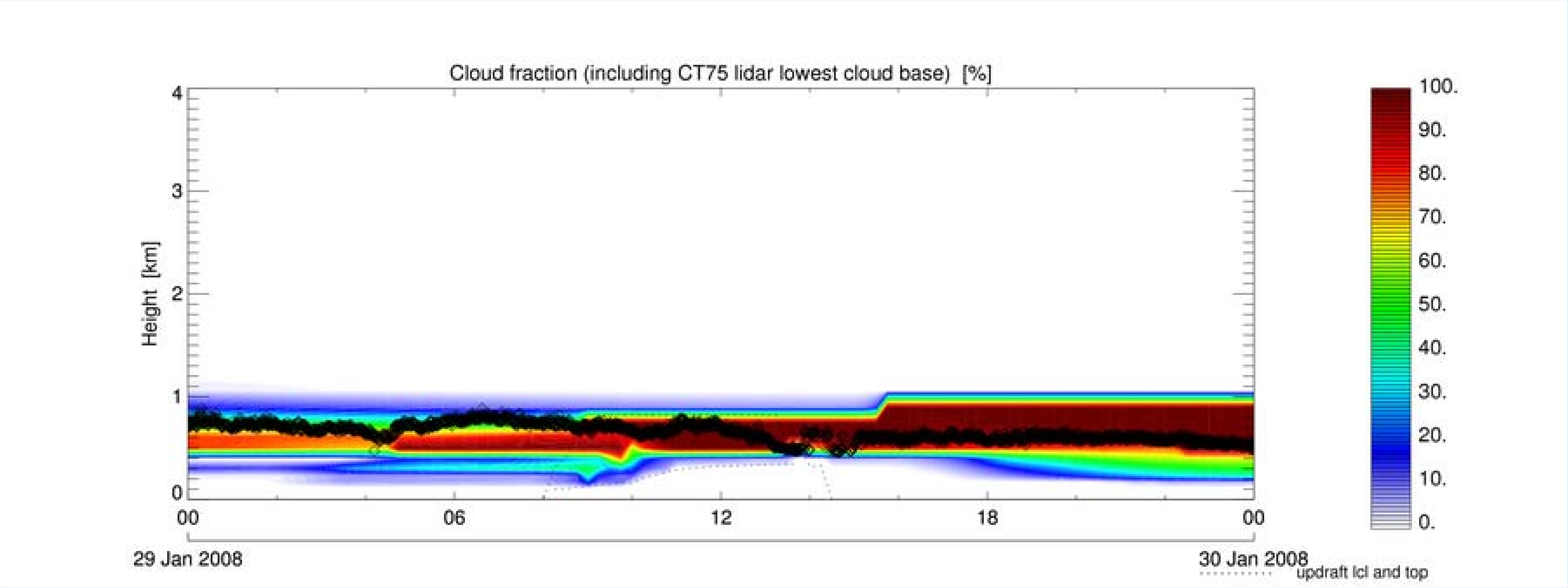
Convective updrafts – fraction, velocity





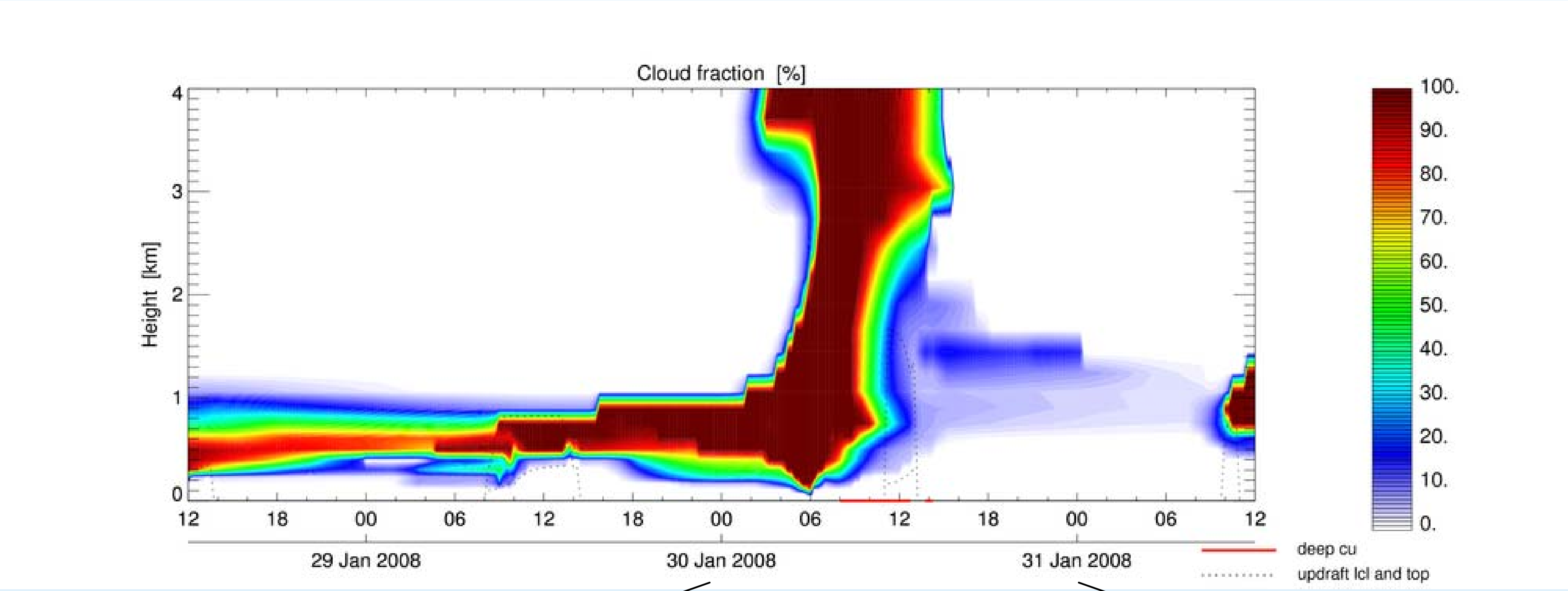
III Stratocumulus

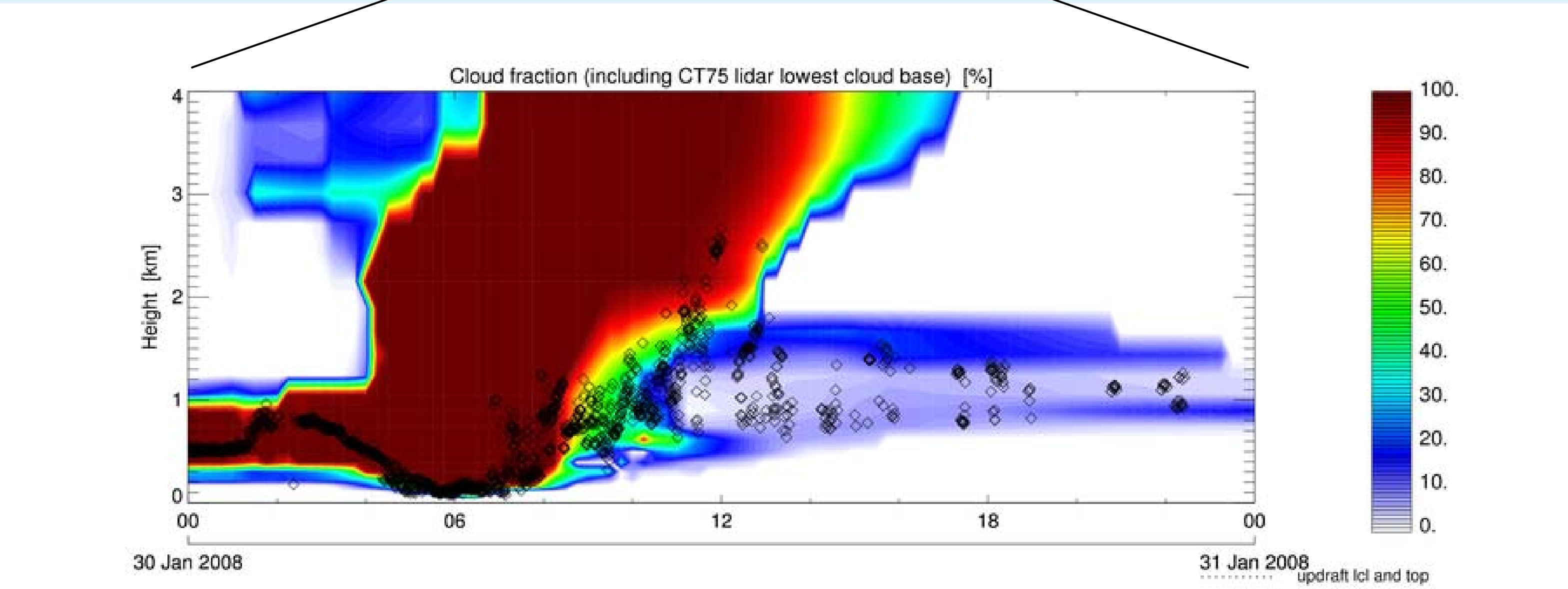
29 january 2008



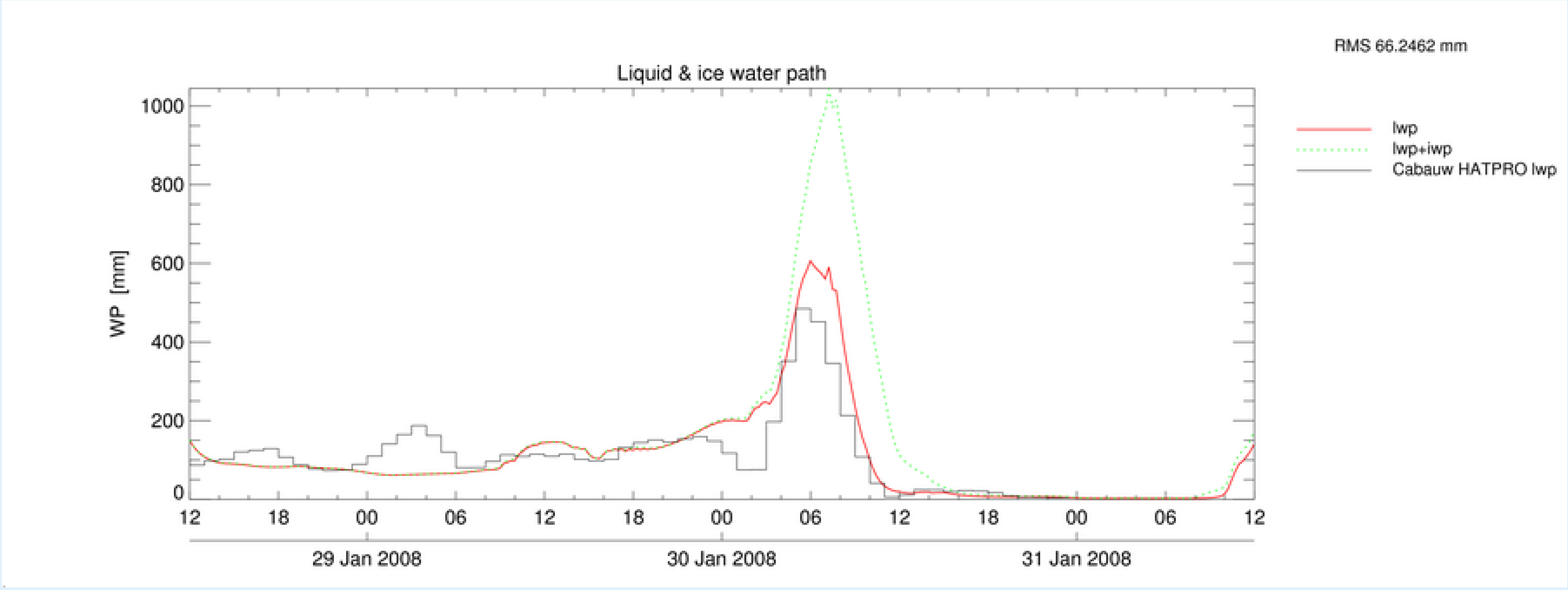
IV A frontal passage

30 januari 2008

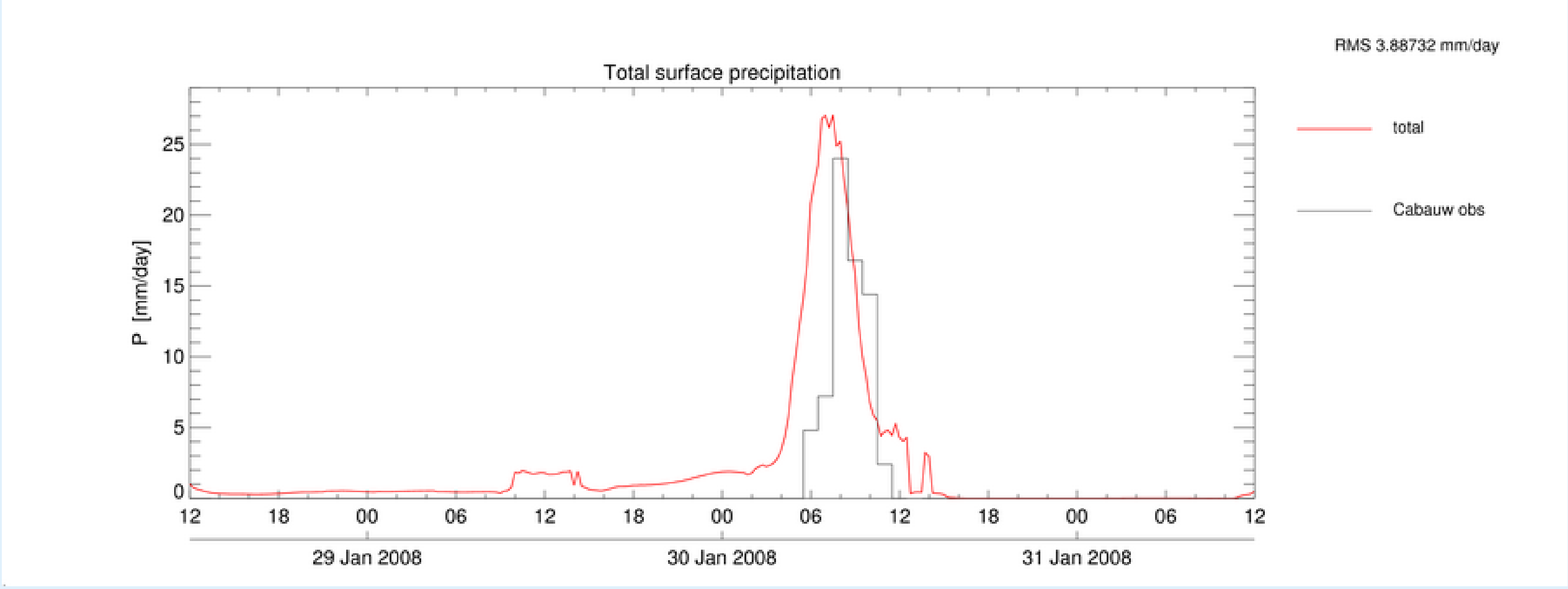


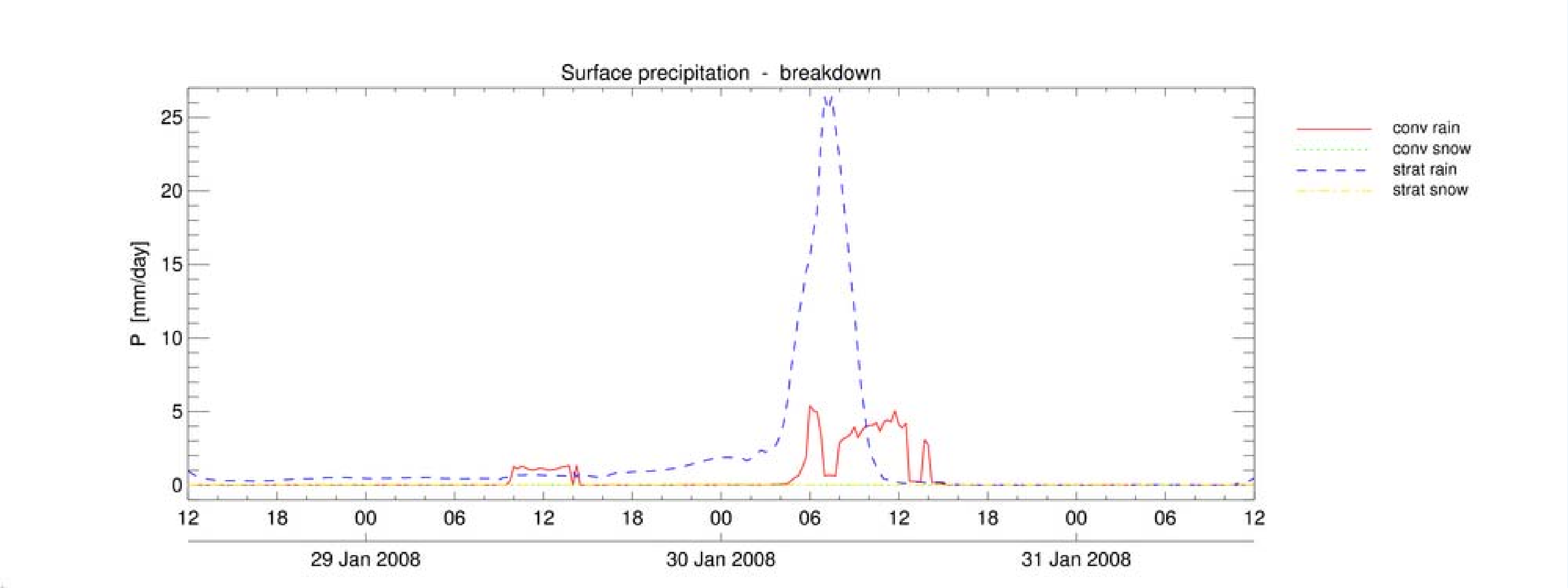


Integrated cloud condensate

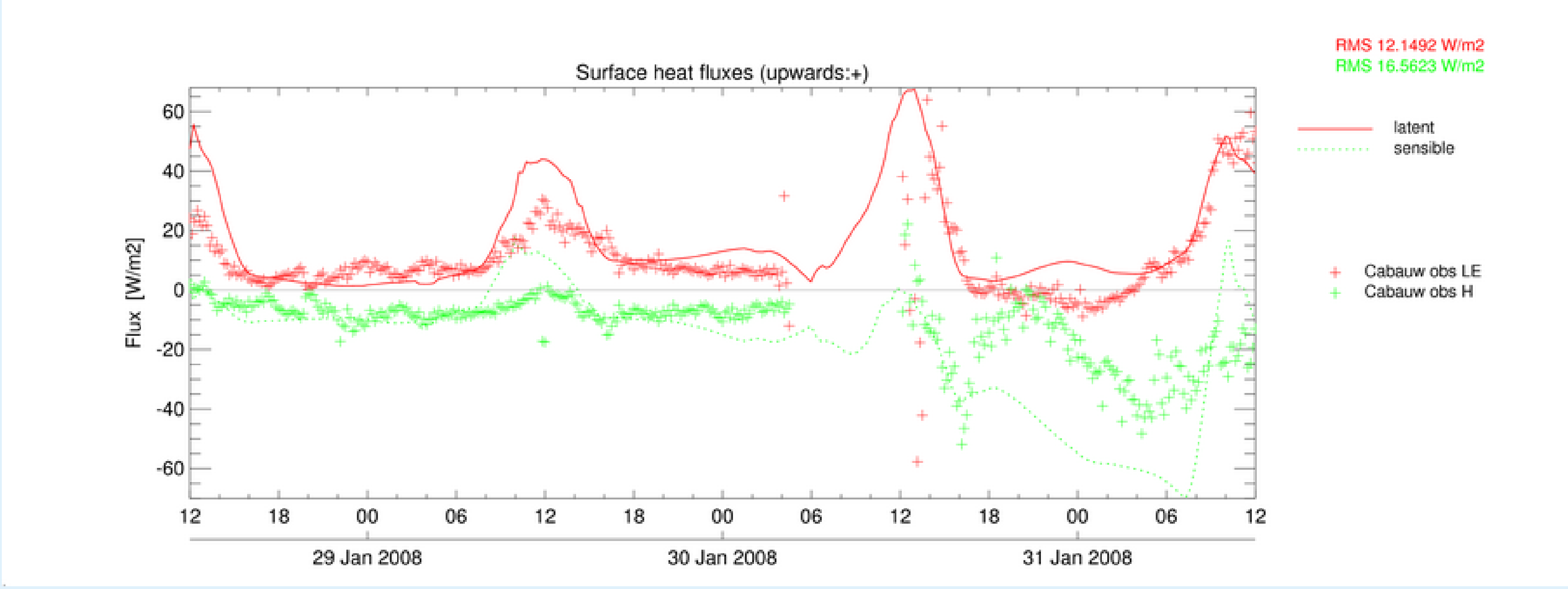


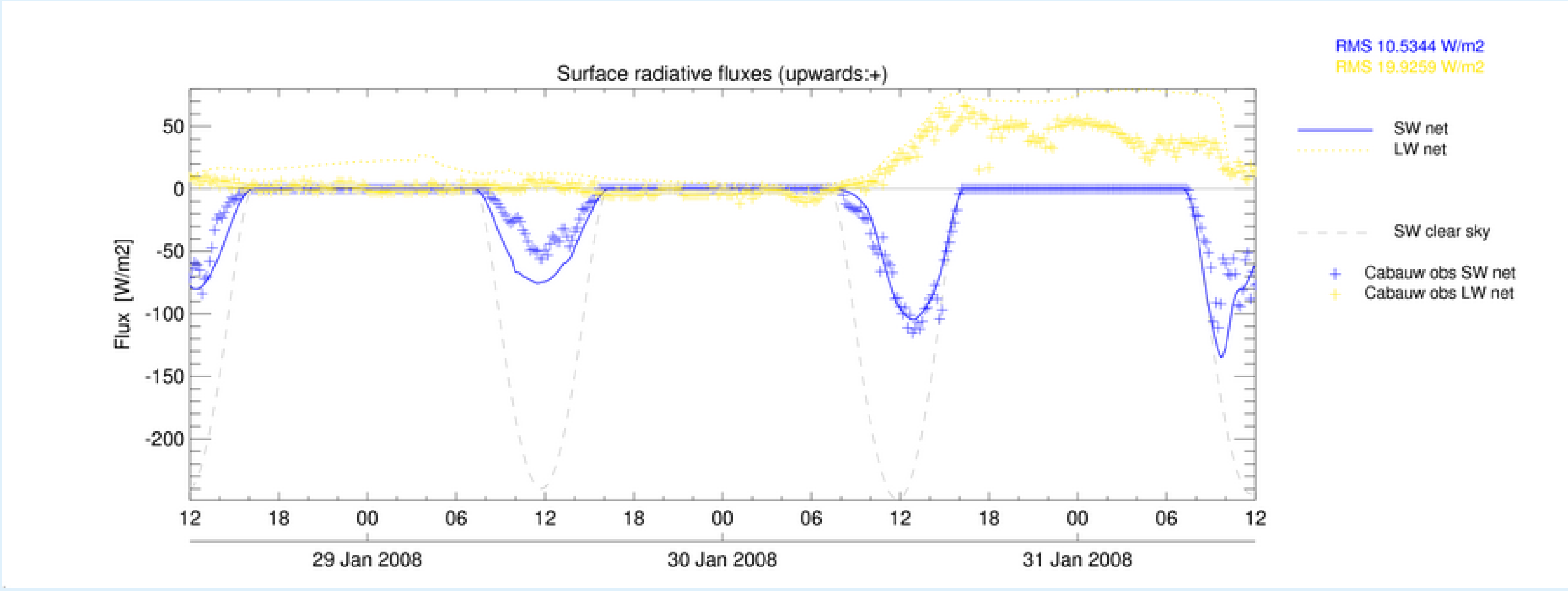
Type of precipitation – stratiform, convective





Surface energy budget



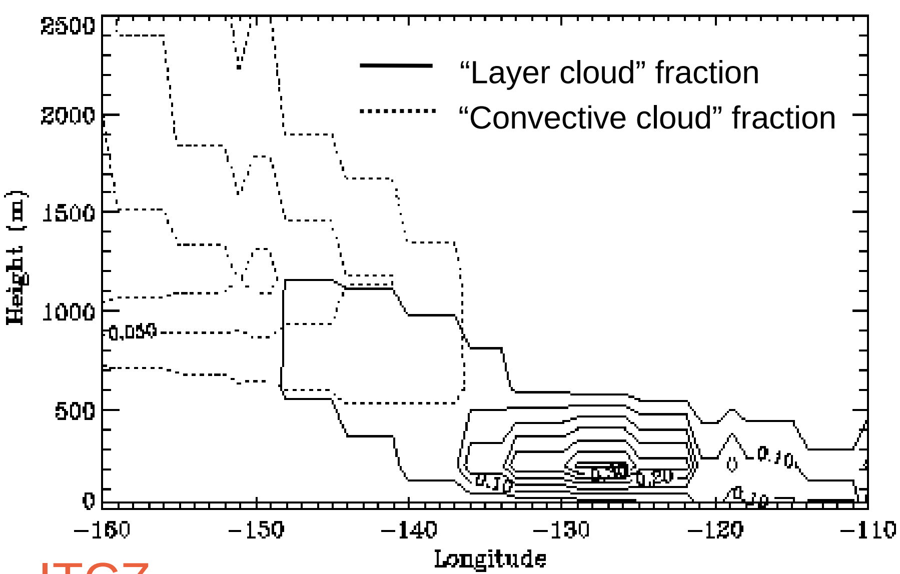


Met Office GCM cloud fractions

EUROCS cross-section – 1998 JJA mean

- HadGAM1 also has a more realistic boundary layer structure, with stratocumulus as opposed to fog

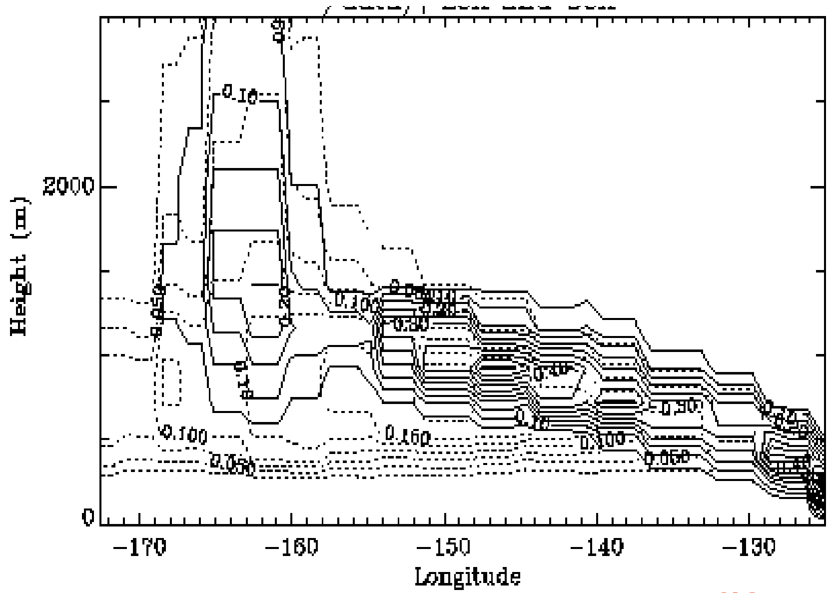
HadAM3



ITCZ

California

HadGAM1



ITCZ

California

Conclusions and Future Plans (Boundary Layer Clouds)

A large participitating community:

1. 12 LES models
2. 17 SCM's from various NWP's, Climate models and Limited Area Models
3. Observational community

A large collection of cases (10+) that serve as a standard testing environment for paramaterization development.

Through a close cooperation between these 3 communities new theories and parameterizations have been developed!

Future plans:

1. Transition from Scu => Cu
2. Construction of a well accessible data base of synthetic LES results
3. More attention to microphysics (see also cros-cutting activities)
4. More attention to GCM-impacts (cloud-climate feedback)

Overall Conclusions

- **GCSS has been succesful in :**

  Bringing communities together (Obs, Data, LES, CRM, GCM)

  Providing parameterization building stones (top-entrainment,lateral entrainment detrainment, closures)

  Organize research around new relevant topics (diurnal cycle deep convection, transition shallow to deep convection, influence environmental RH on convection.

But…….. :

Needs direct collaboration with researchers at the operational centers to develop new operational parameterizations

More emphasis on:

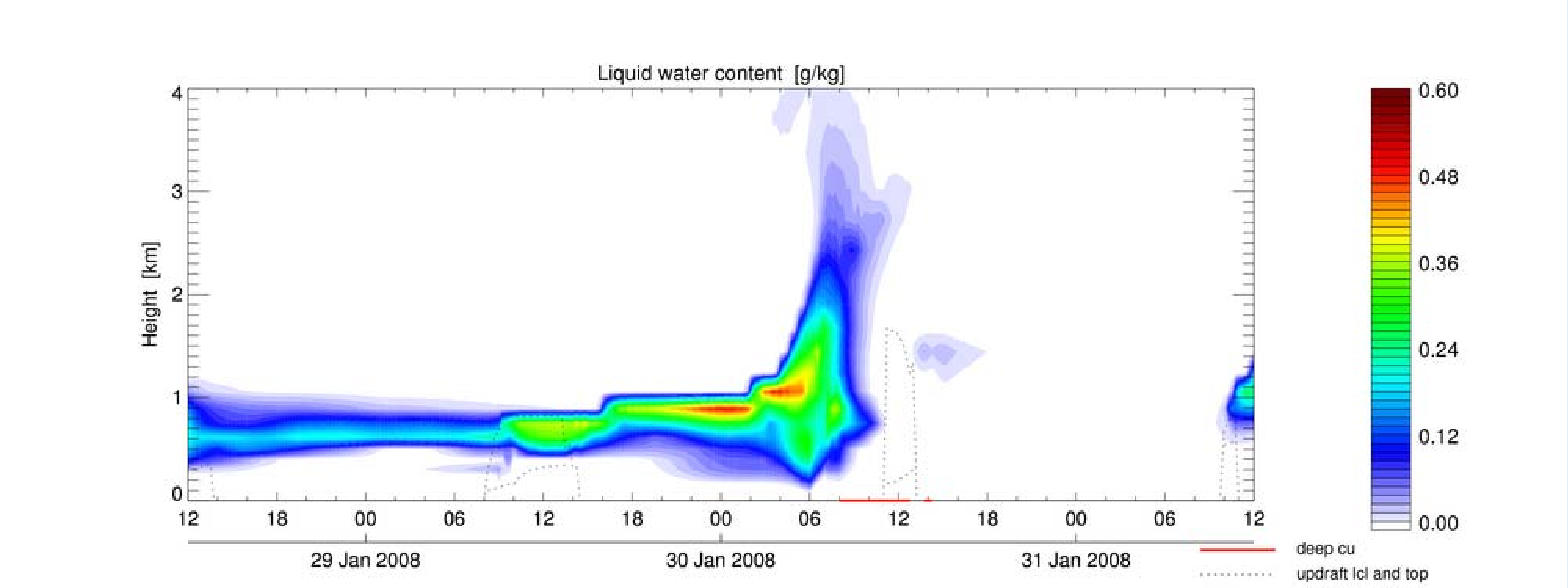
Transition regimes

Microphysics

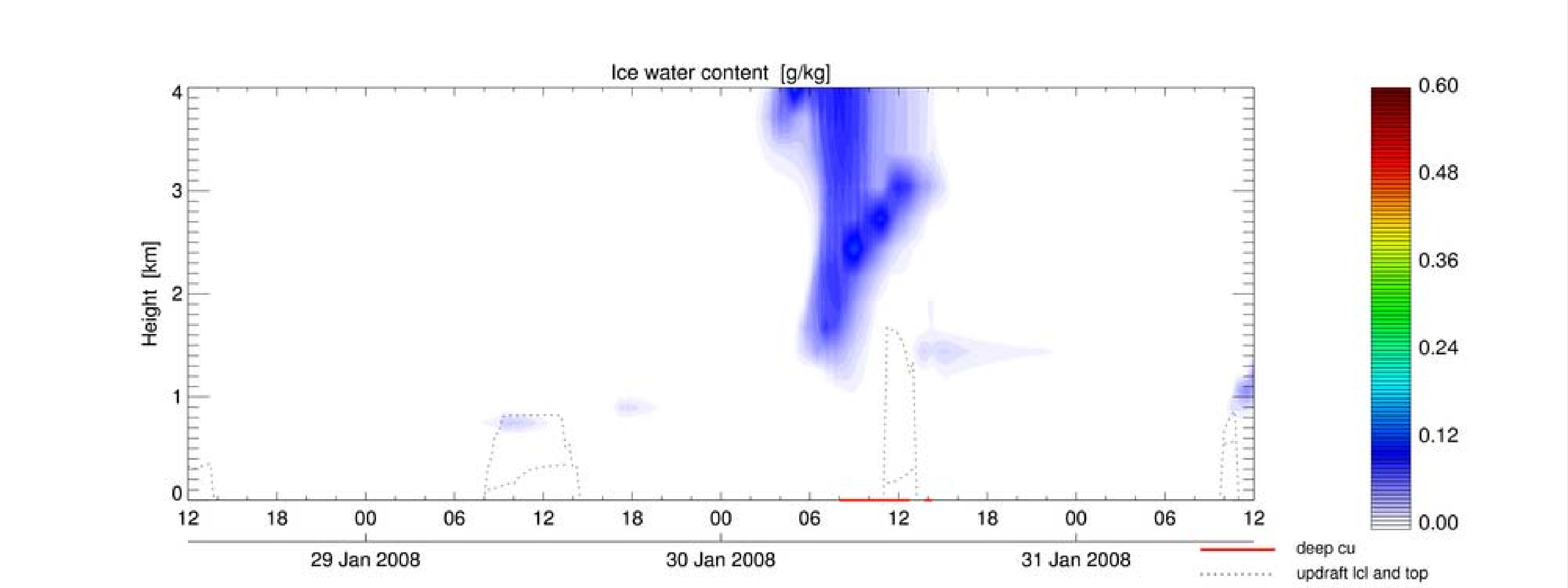
LES/CRM-ensembles

3d GCM's/LAM's evaluaitons (see next presentation)

Cloud phase



Liquid water content [g/kg]
Height [km]
4
3
2
1
0
12
18
00
06
12
18
00
06
12
18
00
06
12
29 Jan 2008
30 Jan 2008
31 Jan 2008
0.60
0.48
0.36
0.24
0.12
0.00
deep cu
updraft lcl and top



Ice water content [g/kg]
Height [km]
4
3
2
1
0
12
18
00
06
12
18
00
06
12
18
00
06
12
29 Jan 2008
30 Jan 2008
31 Jan 2008
0.60
0.48
0.36
0.24
0.12
0.00
deep cu
updraft lcl and top

PAN-GCSS Meeting

2-6 June 2008, Meteo France, Toulouse, France

Special Themes:

- Tropical Convection: (keynote speakers: (Julia Slingo, Brian Mapes)
- New Observations and field experiments: (J-l Redelsperger, J. Teixeira, Pavlos Kolias)
- High resolution modelling on large domains: (M. Khairoutdinov, A. Seifert)
- Cloud climate feedback (S. Bony, M. Webb)

Working Group Meetings:

- BL-Clouds, deep convection, cirrus, polar clouds, extratropical systems
- CFMIP
- Microphysics
- GPCI
- Metrics

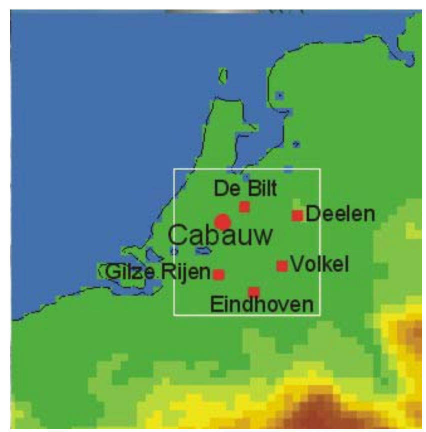
More info on : www.gewex.org/gcss.html

Support from: NASA, NOAA, ESA, NSF, ARM.

How about WCRP:

- Has been set up for the Cabauw site
- Up and running for over 200 days now (a case everyday!!)
- 5 parameterization packages:

  3 different Branches of ECMWF, RACMO, ECHAM
- Will be promoted at the PAN-GCSS meeting in June
- Easy to set up for other sites (ARM, CLOUDNET) with some technical support.
- Please check the website:



ARM-08