The difficult art of evaluation clouds and convection representation in GCM's

Motivation

Configuration

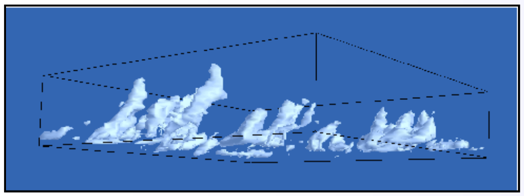
Results

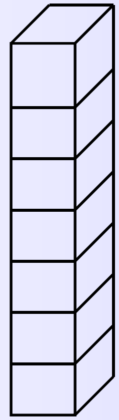
Roel Neggers

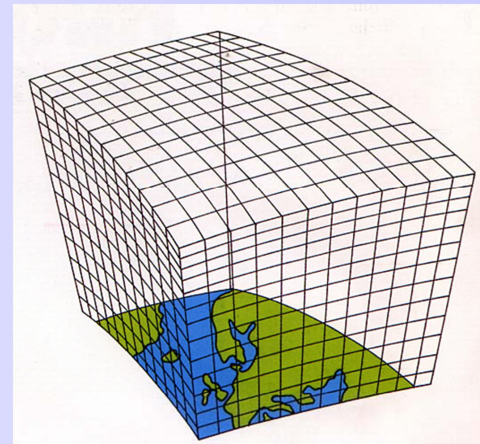
Pier Siebesma

thanks to many others at KNMI

Evaluation Strategy







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

Satellite Data sets

Development

Testing

Evaluation

Potential issues:

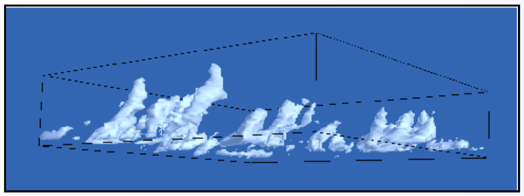
i) How representative are these idealized situations?

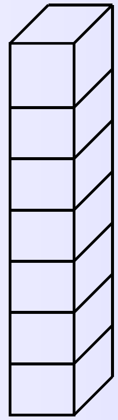
ii) Parameterizations might get calibrated to rare situations

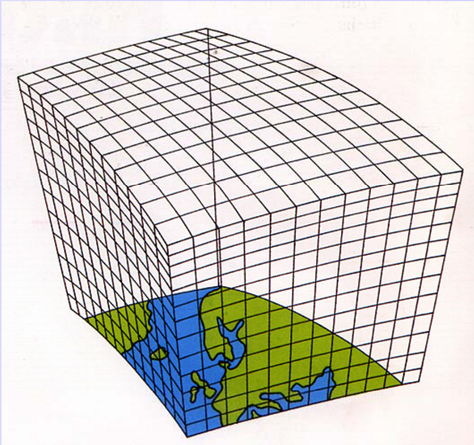
iii) Do the available cases represent those situations where GCMs have most trouble / uncertainty ?

Q: How can we improve/ensure the statistical significance and relevance of SCM simulations?

Can't 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
Satellite Data sets

Development

Testing

Evaluation

Continuous SCM evaluation – The Cabauw SCM Testbed

Purpose:

Daily SCM simulation at Cabauw for long, continuous periods of time

Evaluation of long-term statistics against observational datastreams

The idea

* Short-range (3 day) SCM simulations are generated daily for Cabauw

Method: a combination of prescribed large-scale forcing and
nudging towards a background state (observed/forecast/reanalysis)

* Build up a long (multi-year) archive of simulations

Allows diagnosing monthly/yearly statistics:

i) improved statistical significance (representativeness)

ii) many different weather regimes are automatically captured

iii) a fair comparison with similarly diagnosed GCM statistics

* Comprehensive evaluation of the *complete* parameterized system against Cabauw observations

Covering thermodynamics, momentum, radiation, clouds, soil, etc.

Allows constraining all parameterizations simultaneously

→ should reveal compensating errors in GCMs

The Cabauw site

Operated by KNMI

Operational since 1972

Tower height: 213m

Main scientific goals:
* Atmospheric research (PBL)
* Climate monitoring
* Air pollution monitoring
* Model evaluation

Cabauw is a Cloudnet site

http://www.cesar-observatory.nl/

remote sensing	in situ (in tower)	in situ (ground)
wind profiler	SJAC	2m meteo
CT75 ceilometer	LAS-X	rain gauges
ir-radiometer	optical particle counter	disdrometer
3 GHz radar	FSSP-95	TDR
35 GHz radar	nephelometer	BSRN station
10 GHz scanning radar	sonic anemeter	
backscatter lidar	gas analyzer	
GPS-receiver	aetholometer	
HATPRO MWR	sun photometer	
UV radiometer	humidograph	
scintillometer	wind sensors	
pyranometer	temperature sensors	
nubiscope		

What are the strong points of Cabauw for model evaluation?

* The number of operational instruments

* Continuity of measurement

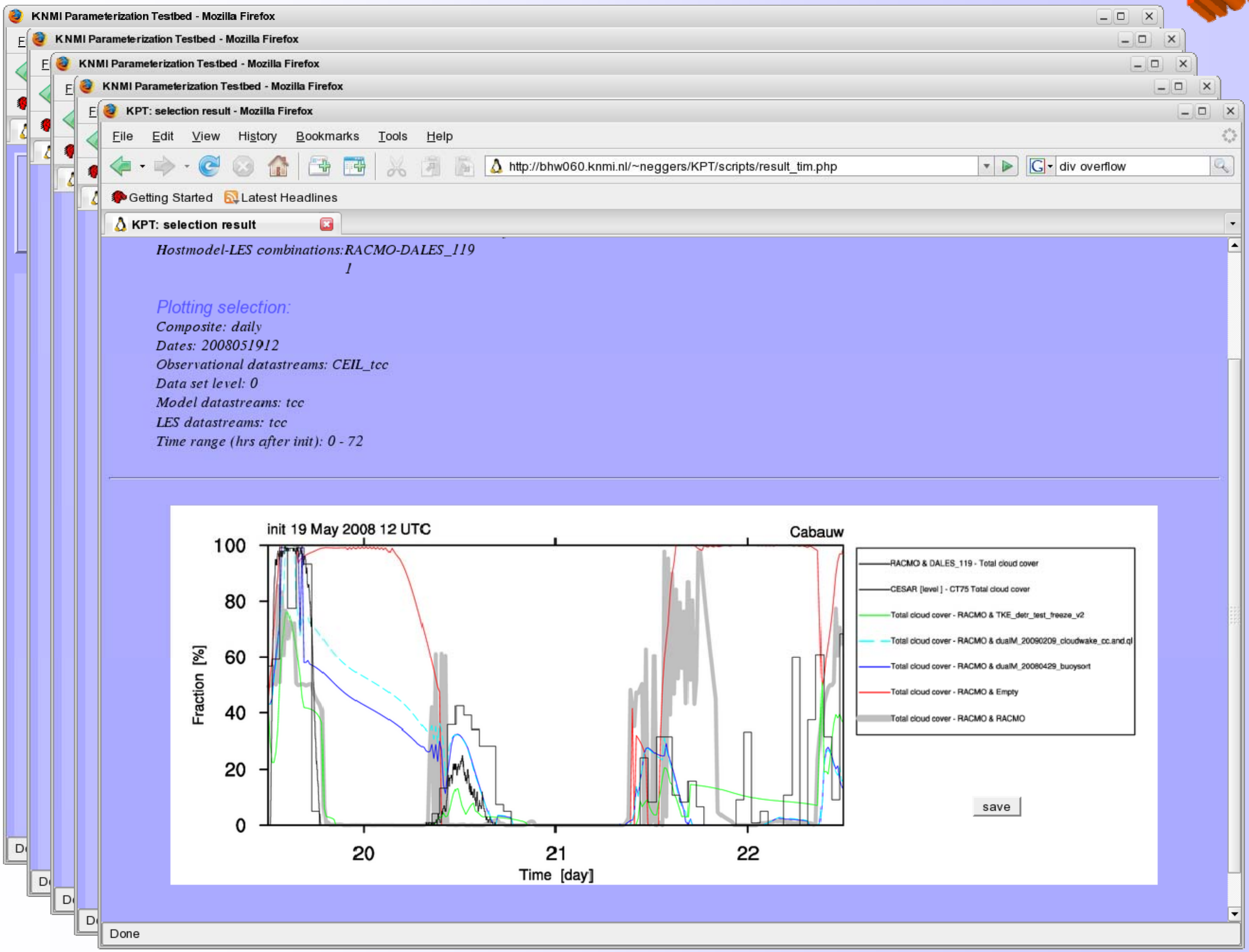
* Long time-coverage

* High sampling frequency

• A well-organized data archive that is easily accessible (CESAR)

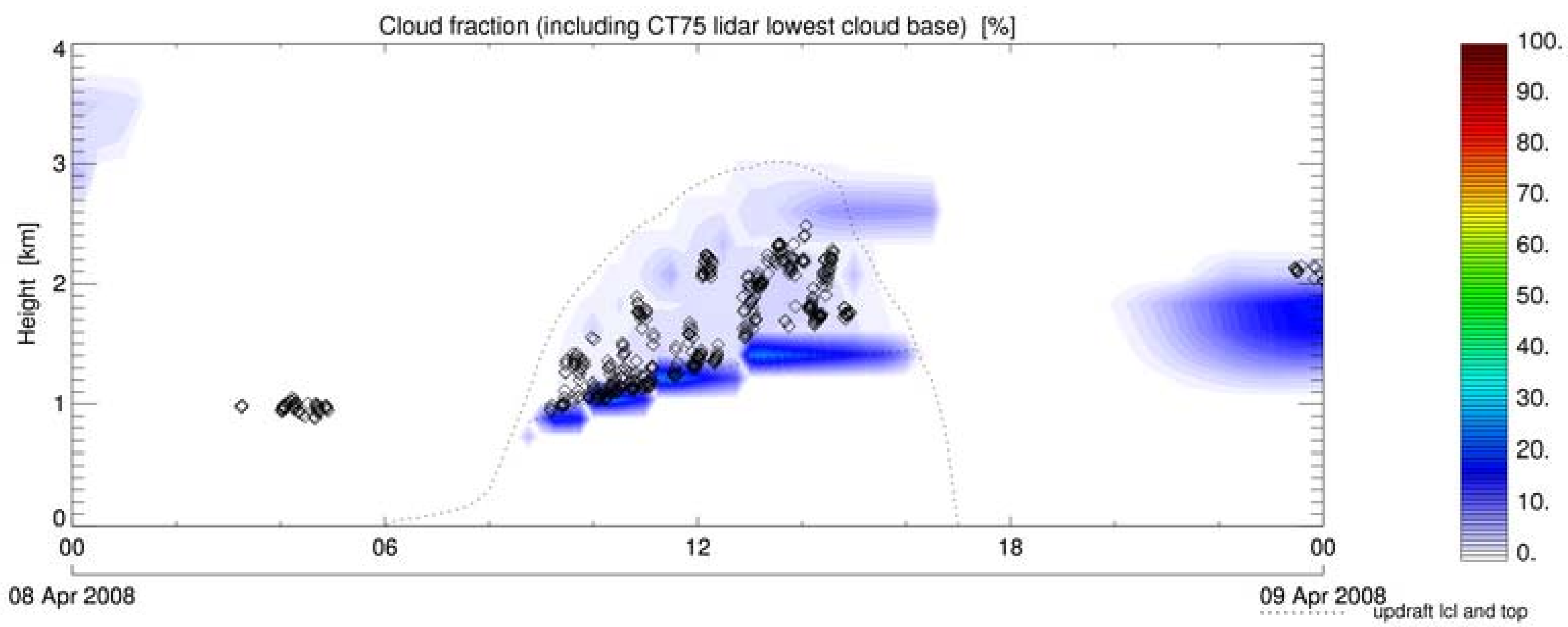
• Web browser to confront models (SCM, LES) with observations

Testbed infrastructure: the interactive browser



Individual cases

Example: a diurnal cycle of shallow cumulus convection



◇ : CT75 lowest cloud base

Evaluation strategy

1) Statistically identify a problem in a GCM

Long-term GCM statistics guide the evaluation effort

3D

2) Assess if the problem is reproduced by the corresponding SCM

Exactly matching the GCM statistics (monthly/yearly means)

3) If so, identify which individual days contribute most to the error

Selected individual cases are guaranteed to matter

1D

4) Study those days in great detail, using a variety of statistical tools

5) When the cause is identified and understood, formulate a solution

6) Re-simulate and re-evaluate the modified SCM

7) Rerun the GCM including the improved physics

3D

Example

Addressing a summertime diurnal warm bias over land in a GCM

An issue encountered during the implementation of a new shallow cumulus scheme into the ECMWF IFS

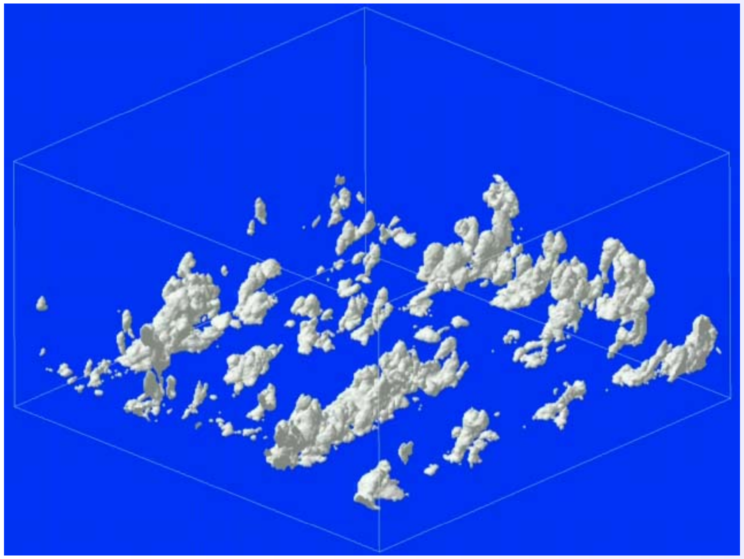
EDMF-DualM

Eddy Diffusivity Mass Flux scheme

Teixeira and Siebesma, AMS BLT proceedings, 2000
Siebesma et al., JAS 2007

Dual mass flux framework

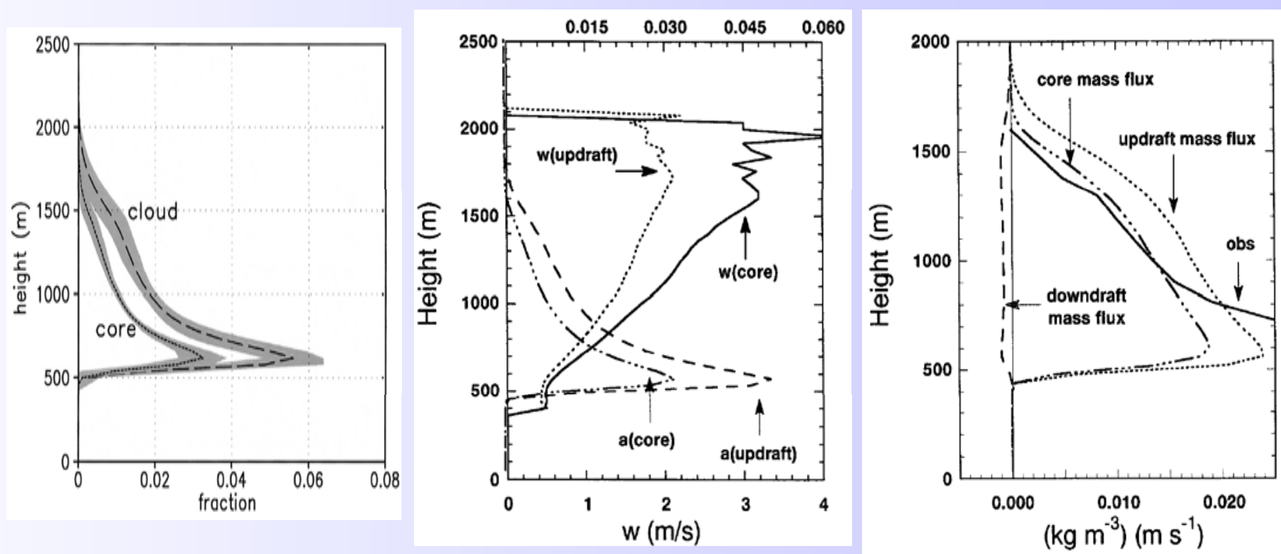
Neggers et al., JAS 2009, June issue



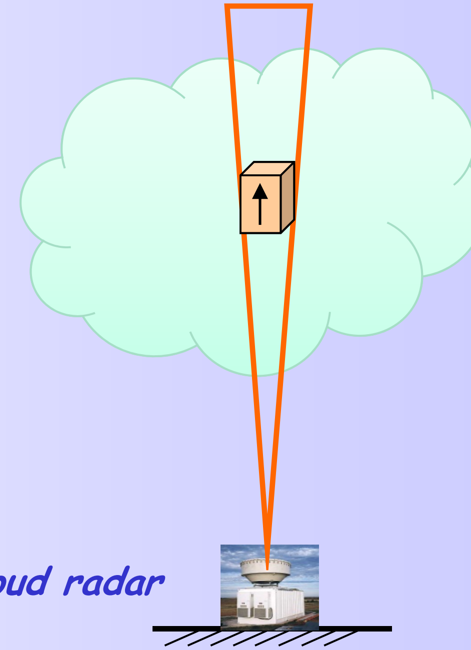
LES: "clouds in silico"

Convective Mass flux decreasing with height

mass flux = updraft cloud fraction * updraft velocity

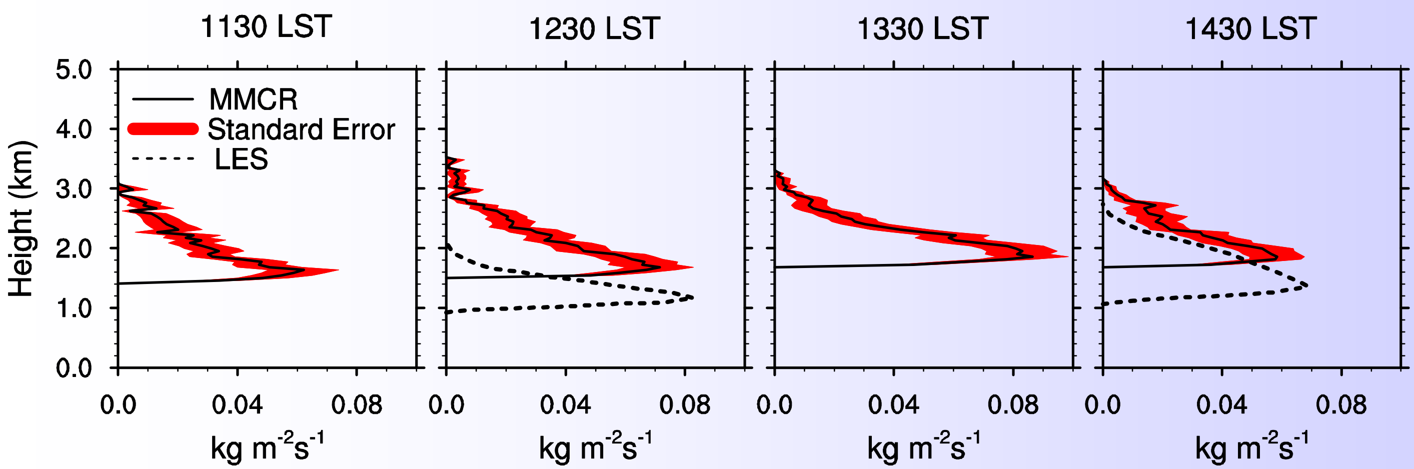


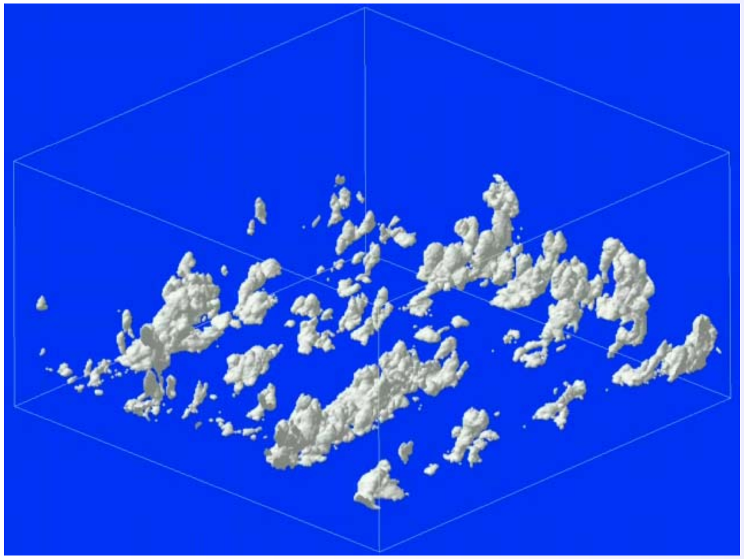
Recently validated for “Clouds in vivo” (Zhang, Klein and Kollias 2009)



ARM mm-cloud radar

*Updraft mass flux = updraft fraction * updraft velocity*

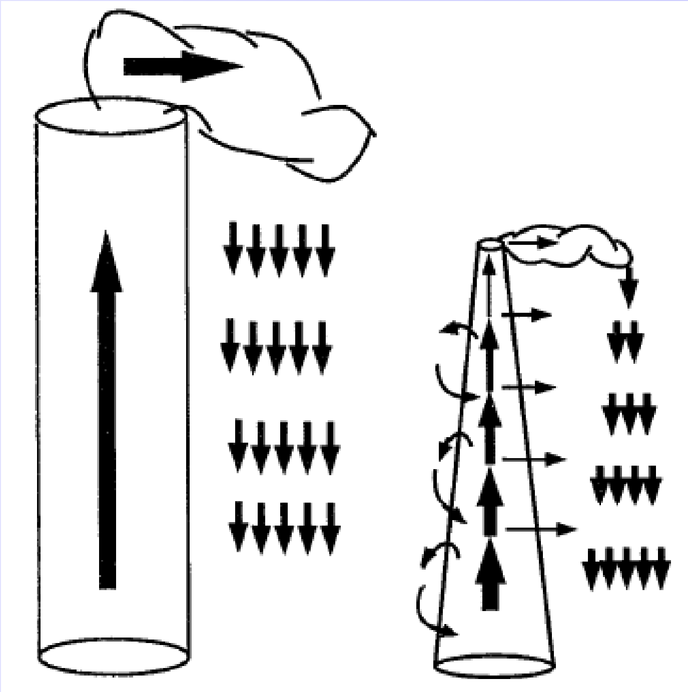




LES: “clouds in silico”

clouds “in vivo”

Siebesma & Holtslag ‘96



old new

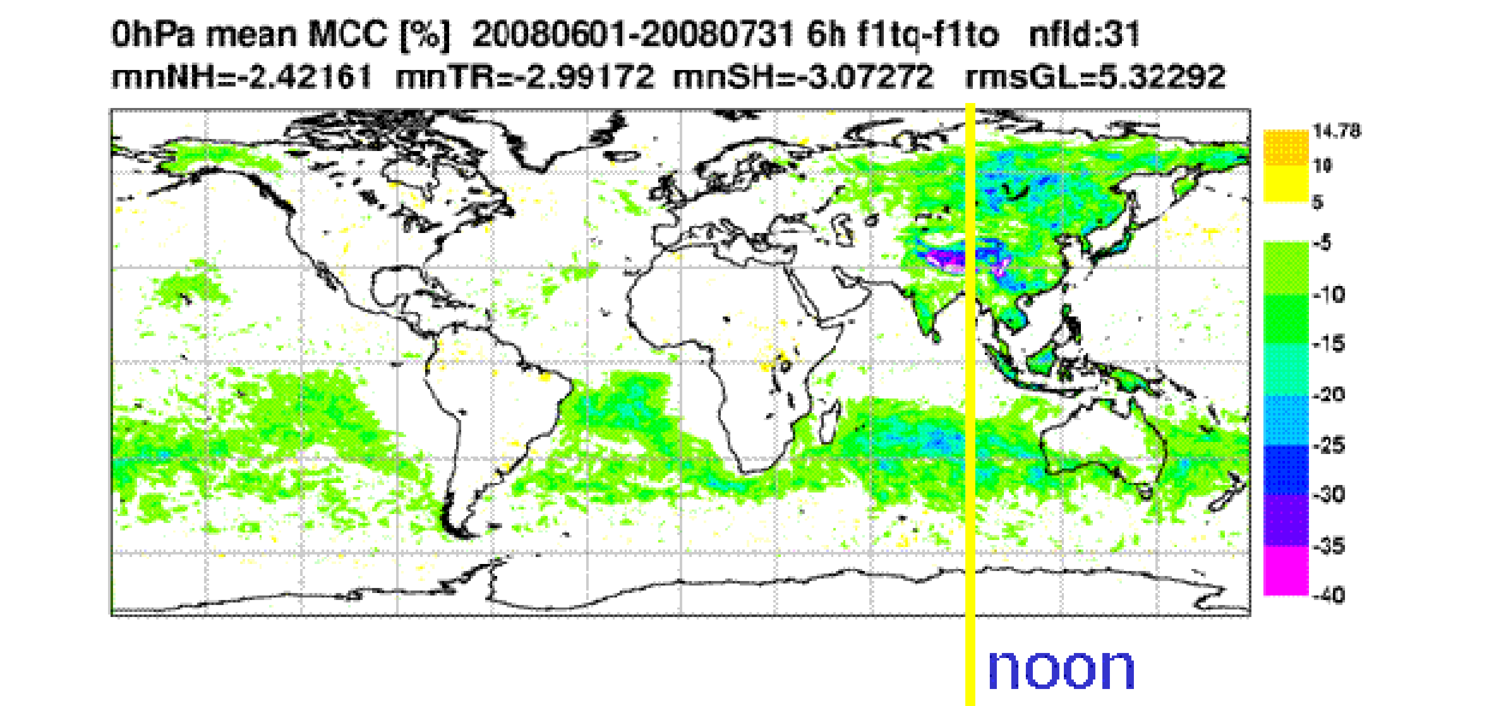
Implication for new EDMF scheme:

“flexible decreasing mass flux”

Step I: The GCM problem

ECMWF IFS difference in summertime diurnal cloud cover
between CY32R3 + EDMF-DualM and CY32R3

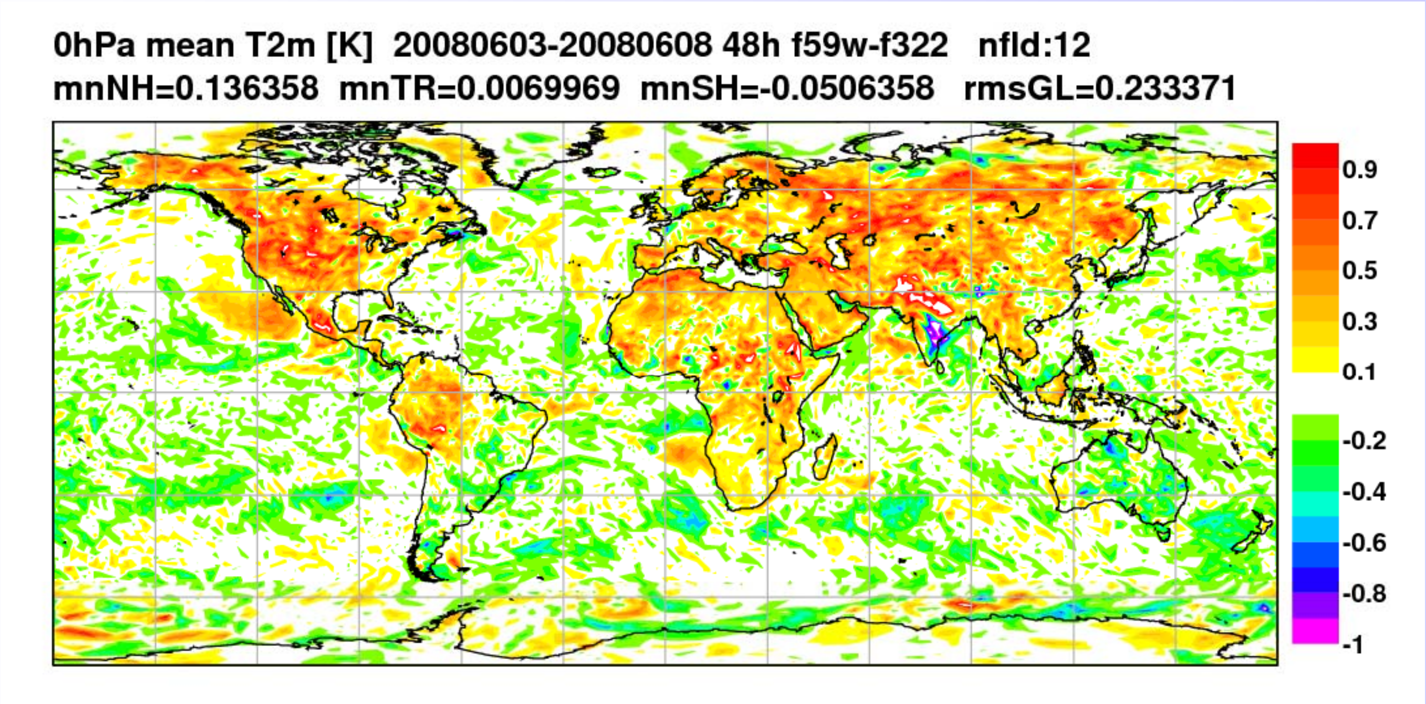
free climate run, June-July 2008



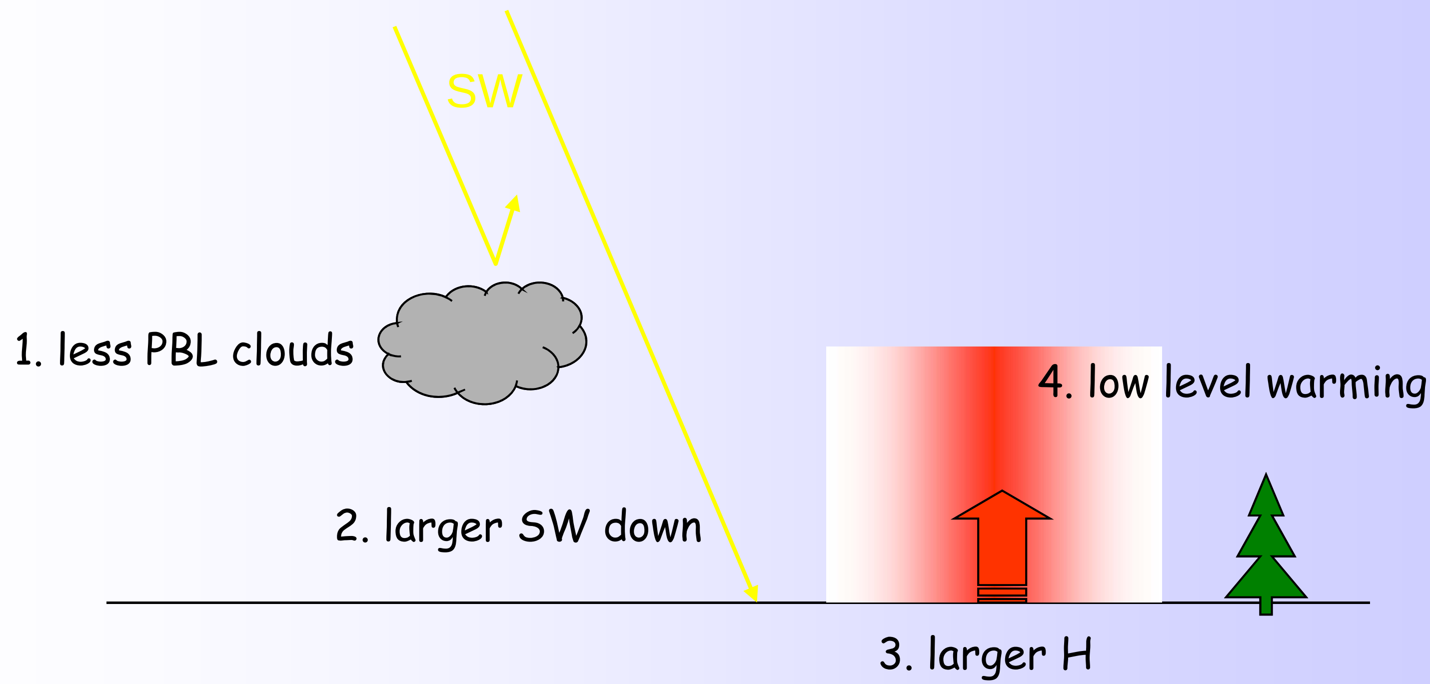
Thanks to Martin Köhler, ECMWF

A difference in daily mean 2m temperature over land

free climate run, June-July 2008

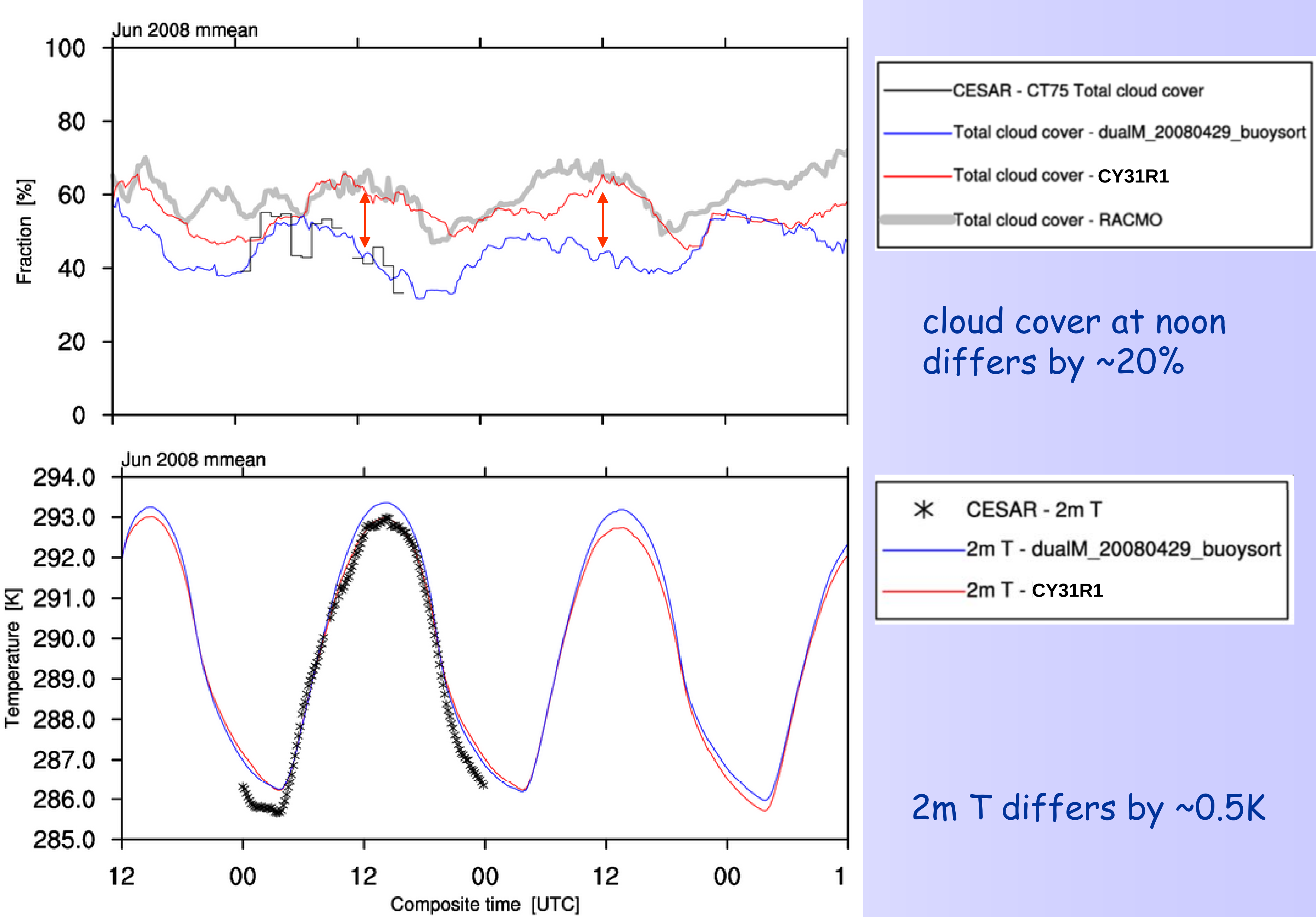


Hypothesis:



Q: can the Cabauw SCM Testbed provide some evidence?

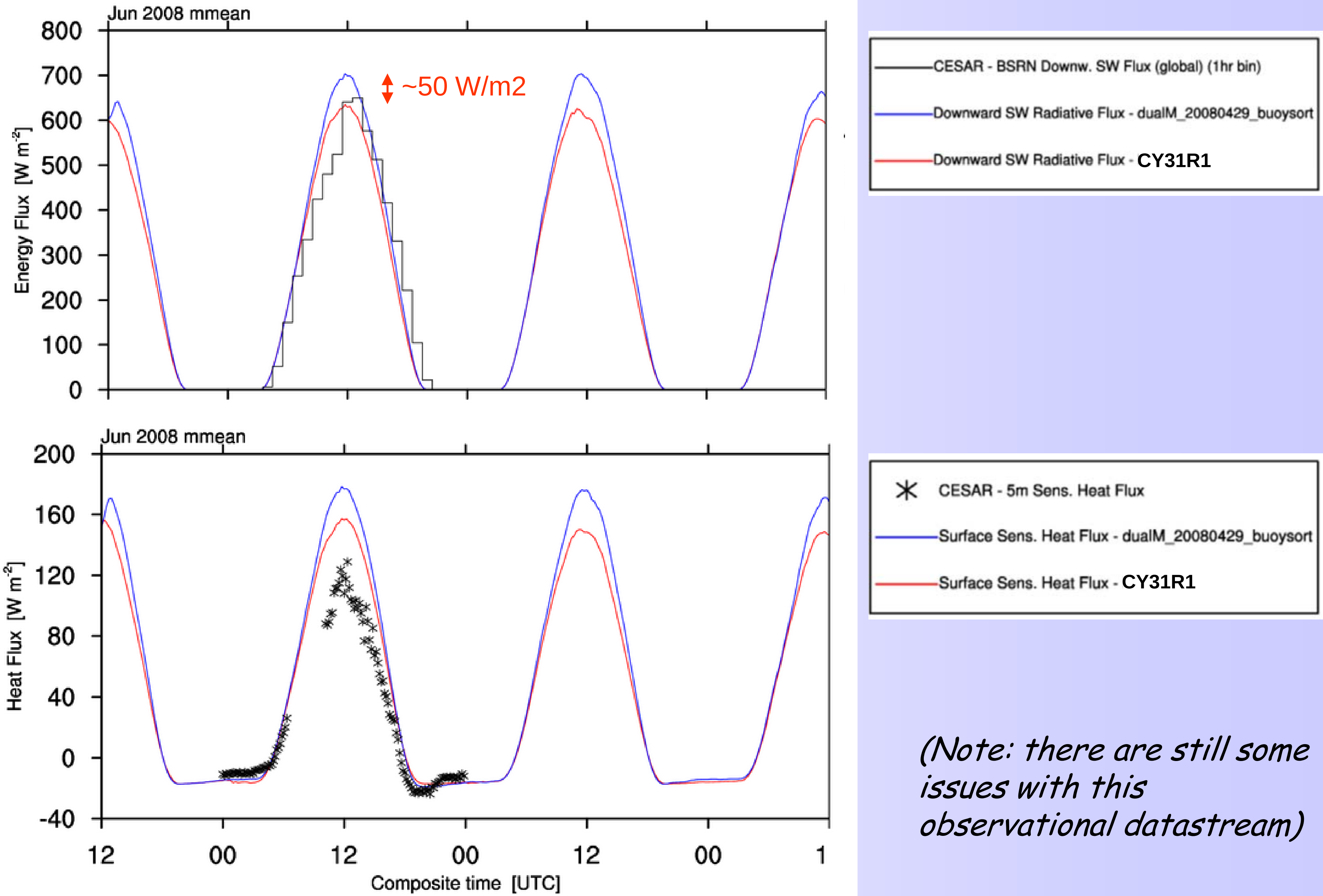
Step II: Do the SCMs reproduce the GCM behavior?



cloud cover at noon differs by ~20%

2m T differs by ~0.5K

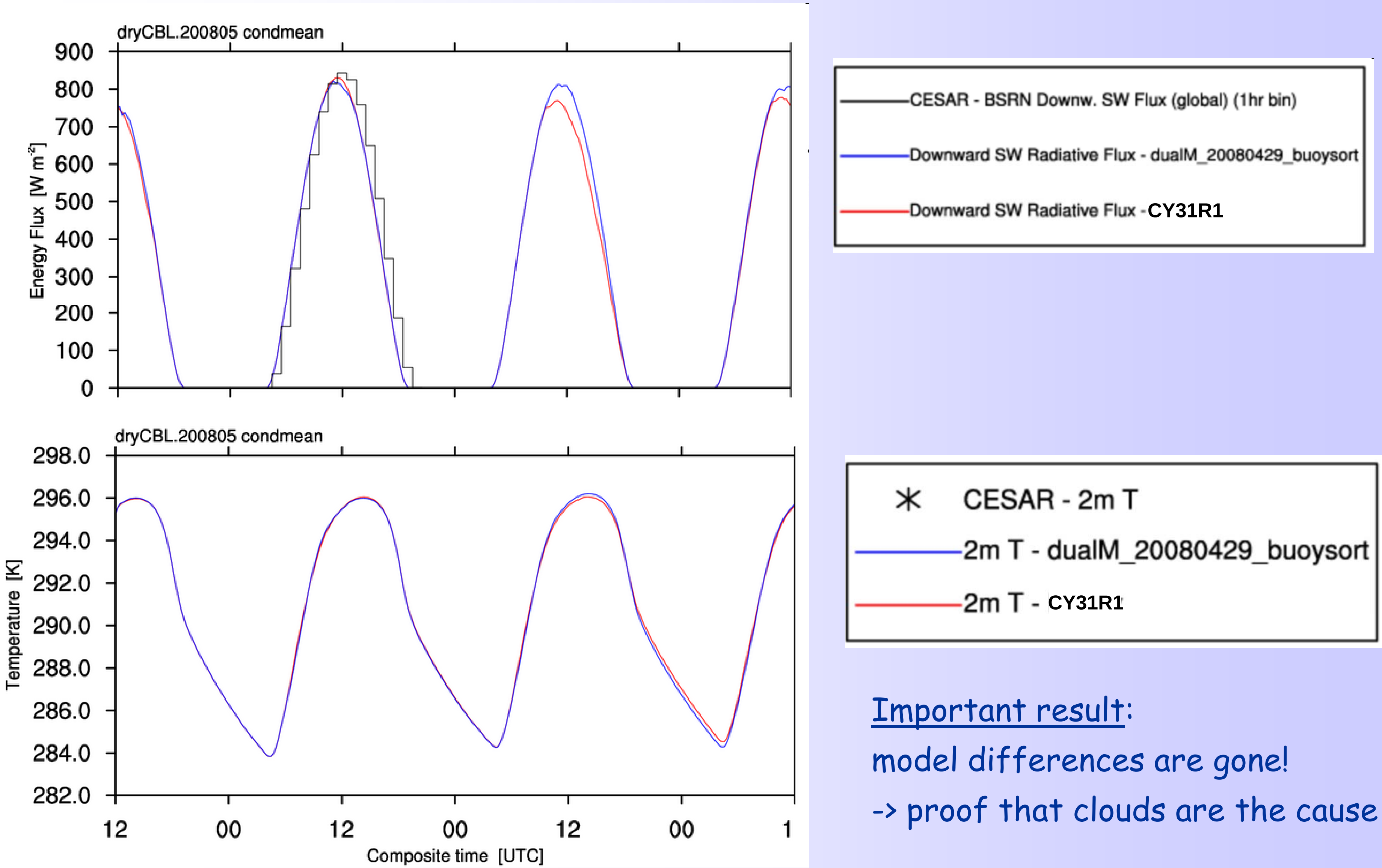
Related monthly-mean differences support our hypothesis



(Note: there are still some issues with this observational datastream)

Step III: Conditional averaging

a) clear convective days in May 2008

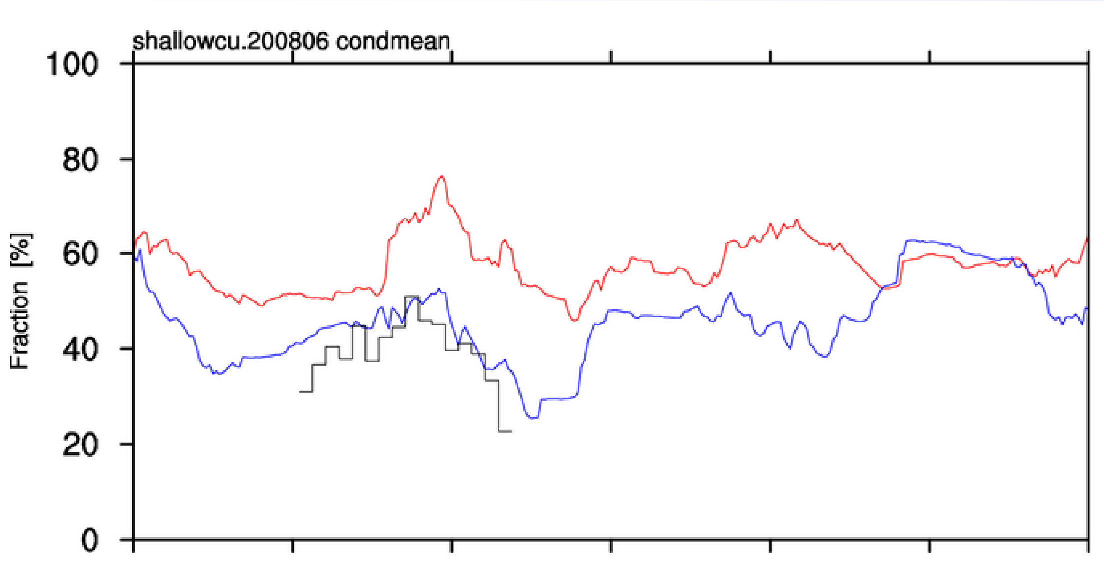


Important result:

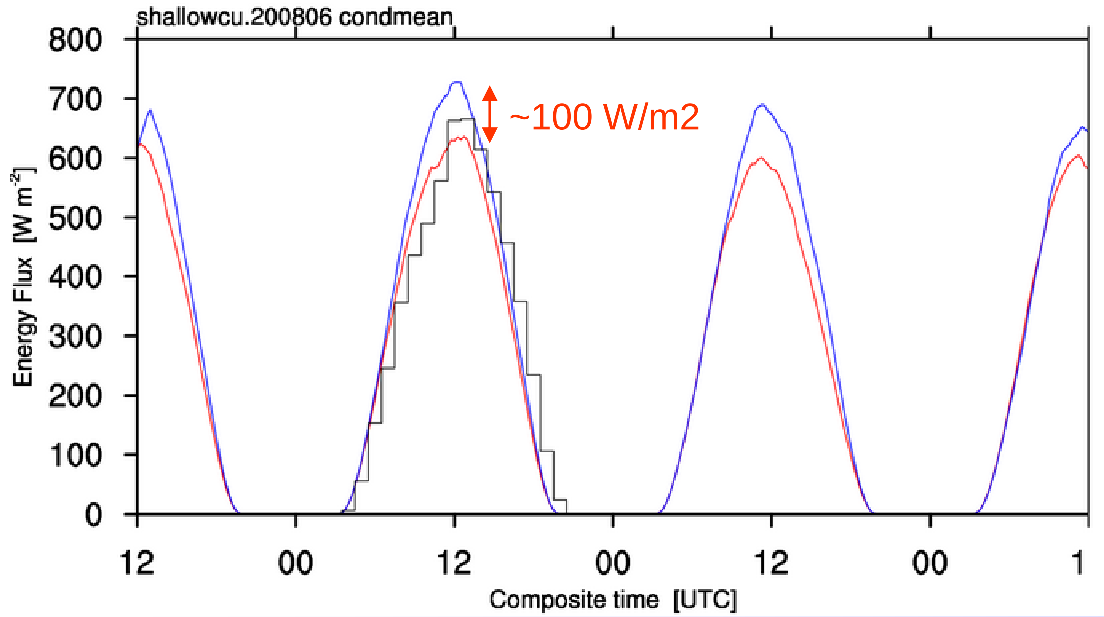
model differences are gone!

-> proof that clouds are the cause

b) shallow cumulus days in June 2008

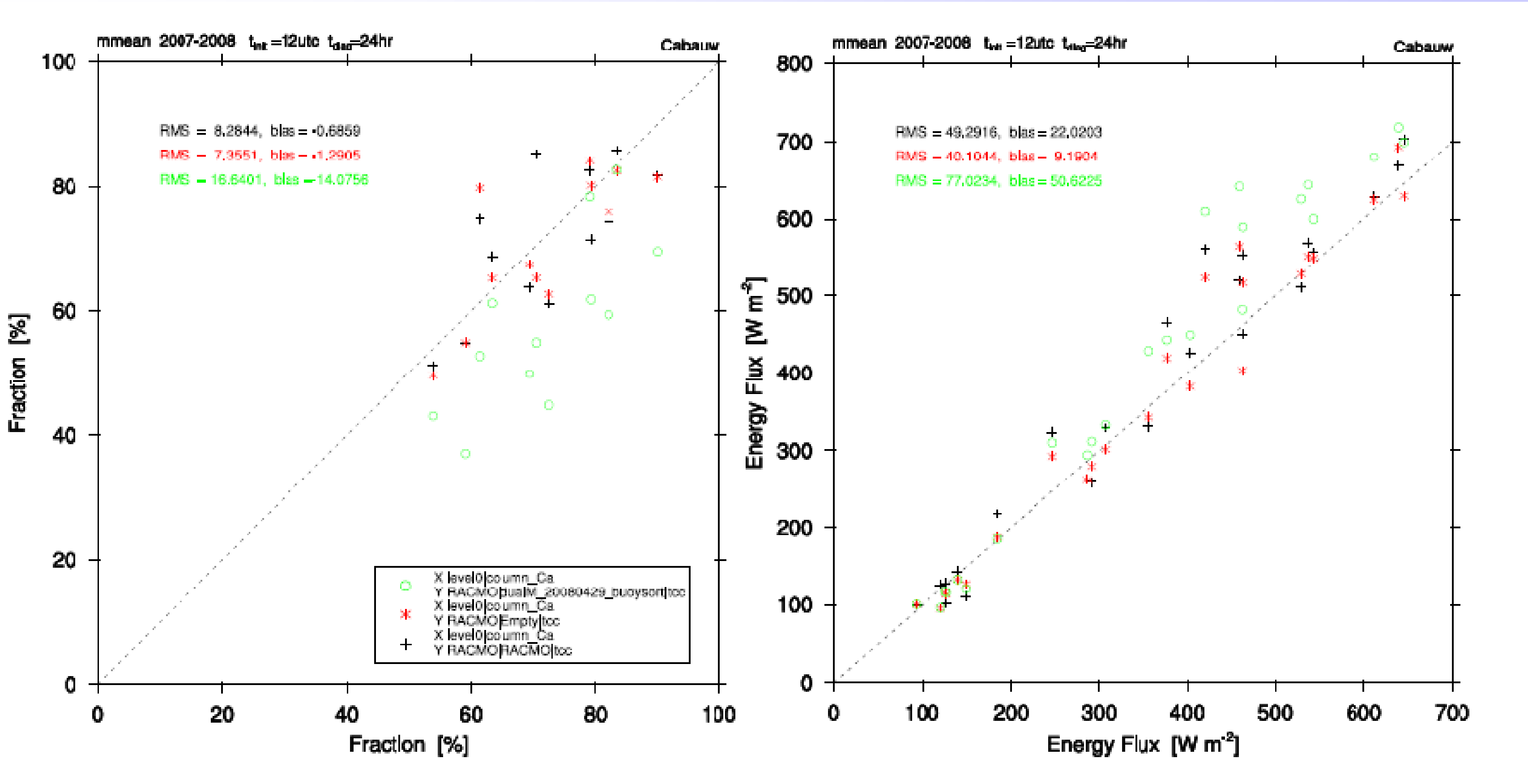


Differences amplify -> this regime is the cause



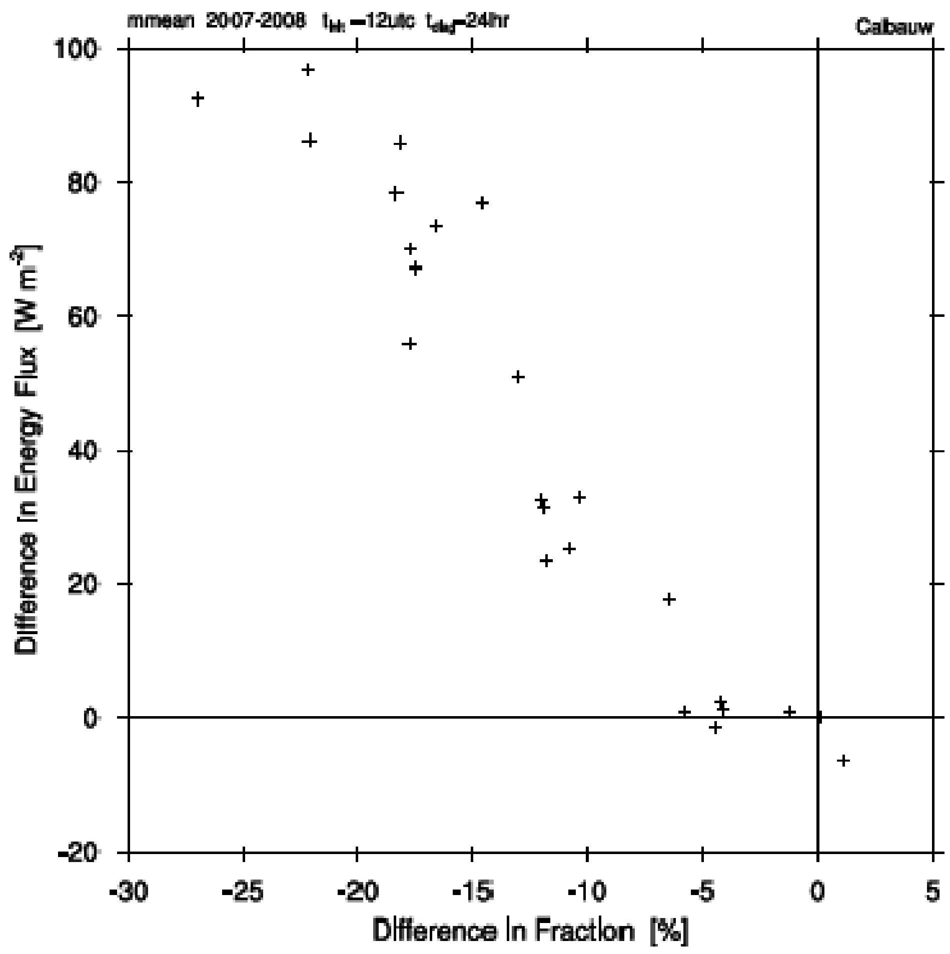
CY31R1 is too optically thick, while DualM is too transparent

c) Scatter plots of monthly mean SW radiation and cloud fraction over 2 years of data.



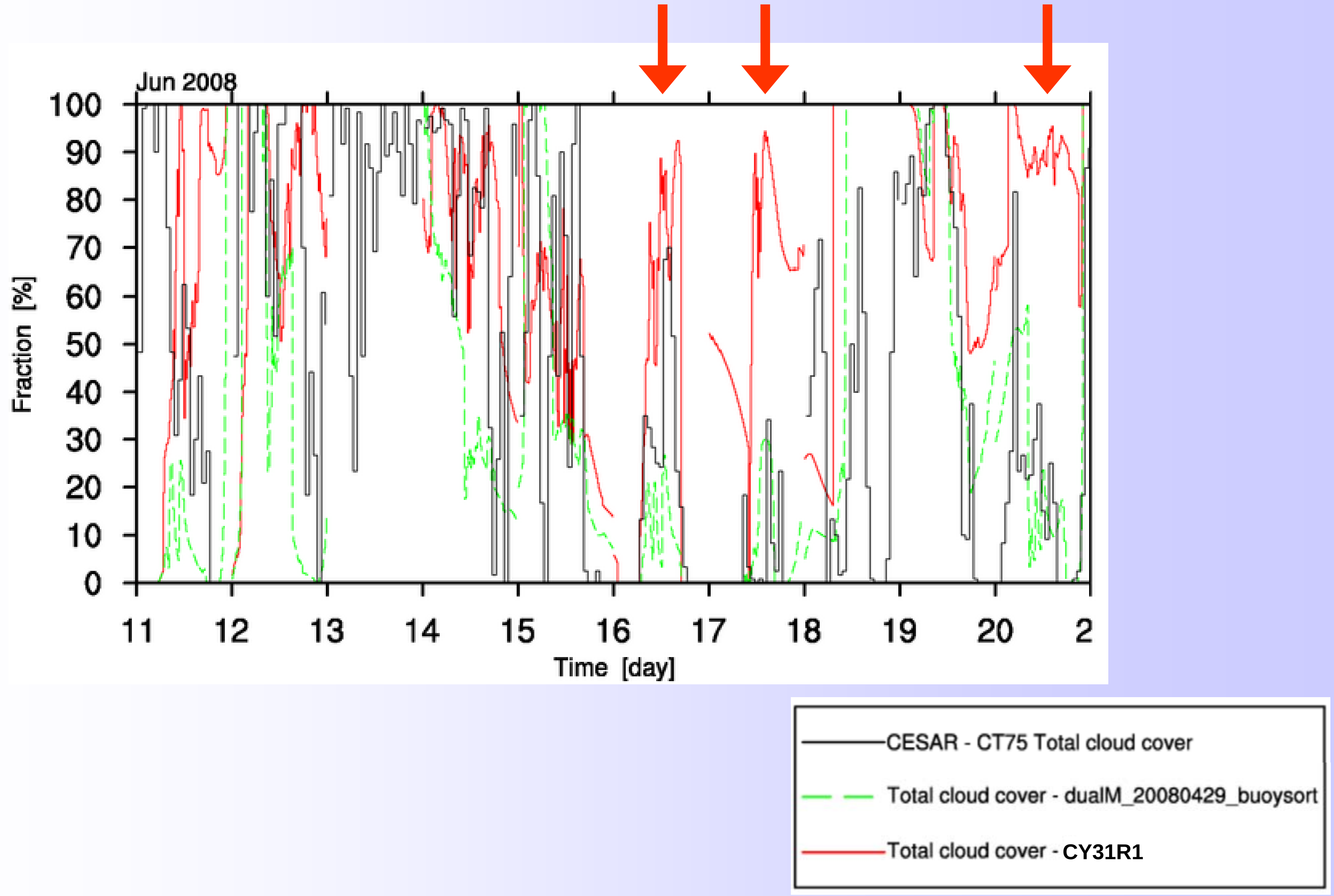
New scheme: too less cloud fraction and too much SW downwelling radiation.

c) Scatter plots of monthly mean model differences of cloud fraction vs downwelling SW-flux.



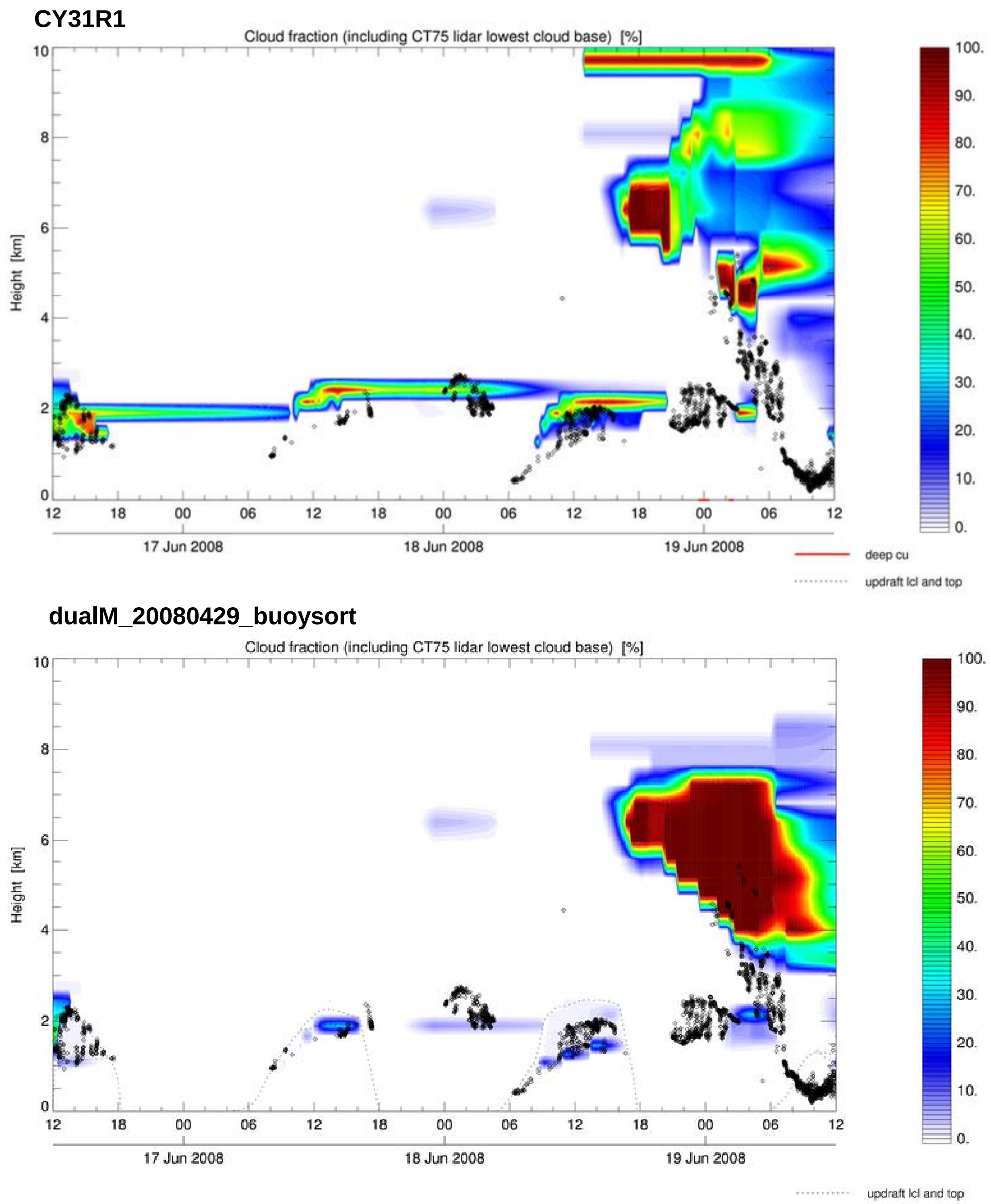
Step IV: Zooming in on single days

Which days contribute most to the monthly-mean differences?

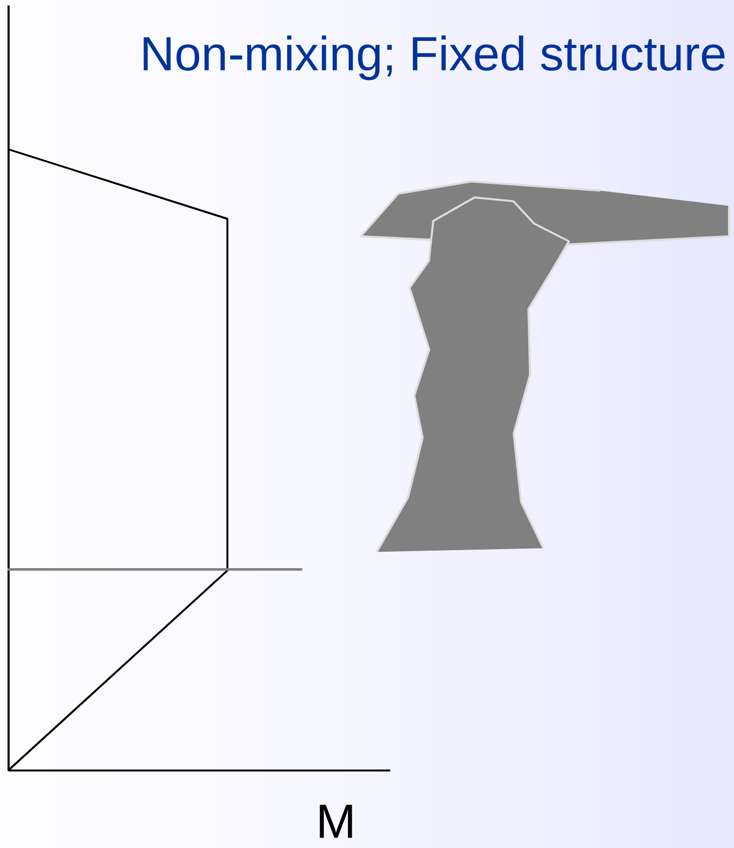


17 June 2008

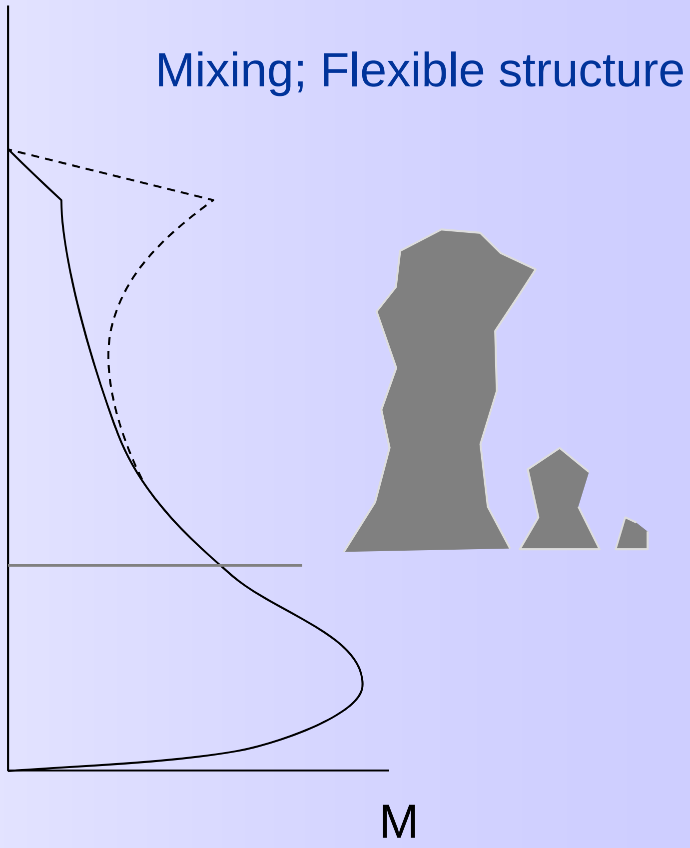
CY31R1 tends to produce anvils at the top of the cumulus PBL



Different tendency to form cumulus anvils is caused by differences in the vertical structure of model mass flux:



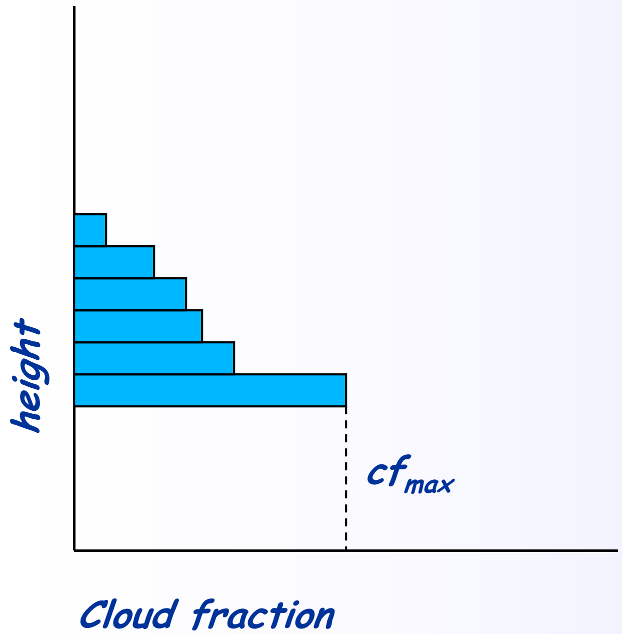
Tiedtke (1989) in IFS



EDMF-DualM

Step VI: Modify SCM

Now that we understand the problem, we can make targeted changes

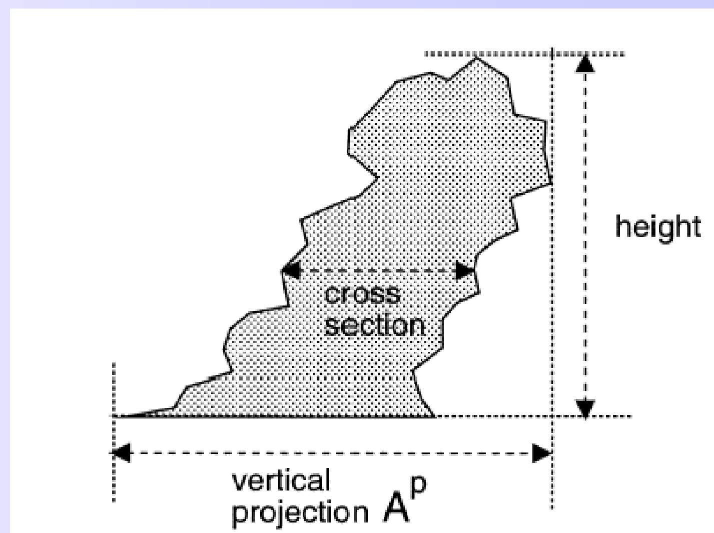


Cloud Overlap functions:

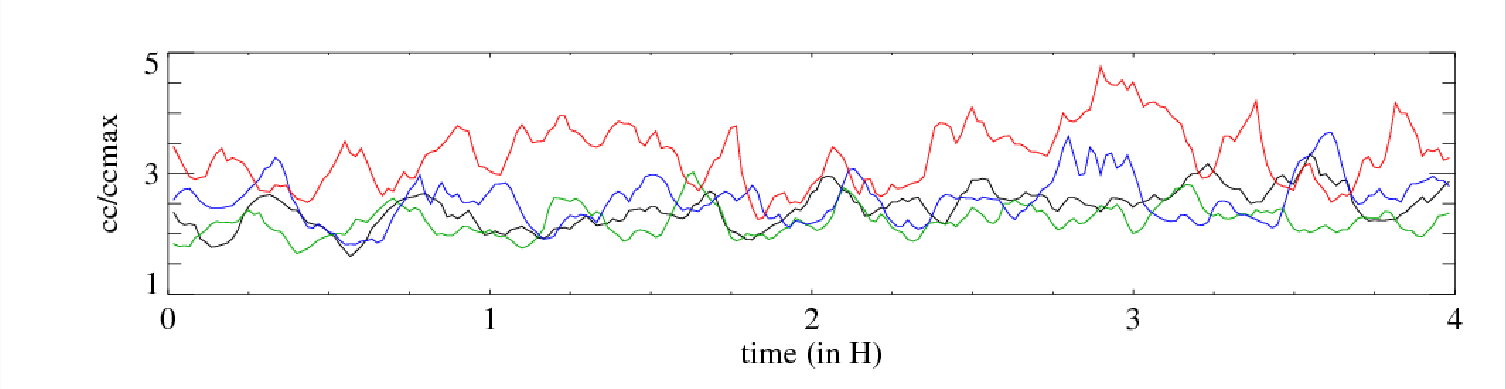
at present maximum overlap for BL-clouds (in each GCM!!)

Implies : total cloud fraction $cf_{tot} = cf_{max}$

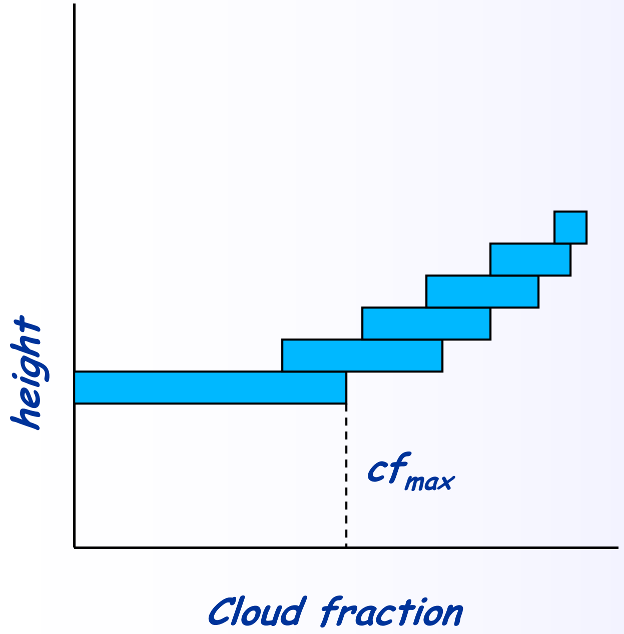
Is this a realistic assumption?



LES revisited:



Time series of the ratio cctot/ccmax for 4 simulation with different shear 0X (black), 1X (green), 2X (blue), -2X (red).



cctot/ccmax = 2~3 depending on shear, depth of cloud layer.

This number is enough to correct the biases in cloud cover and short wave radiation!

Lessons to be learned:

It is possible to reproduce long-term statistics of GCM behavior with continuous daily SCM simulation

Identifying the individual cases that contribute most to the time-mean SCM error ensures we study the most relevant situations

Conditional averaging can be a helpful tool in understanding model behavior

All ingredients (radiation, convection and cloud geometry) usually matters

Be aware of compensating errors (convection scheme vs cloud overlap assumptions in this case). Many GCMs are currently optimized on their radiative properties.

Many of the used information is (roughly) available on new generation satellites except for incloud vertical velocity.

Outlook

Top priority: to make the testbed server publicly accessible

More SCMs

- ✓ ECHAM5
- ✓ HIRLAM/AROME/HARMONIE
- UK MetOffice
- COSMO

More locations

- Cloudnet sites (Chilbolton, Lindenberg), ARM sites

More observational datastreams

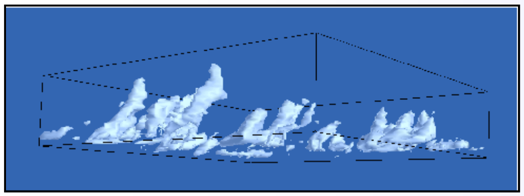
- Nubiscope, UV lidar, soil measurements, profiler

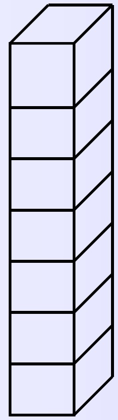
Improved spatial coverage

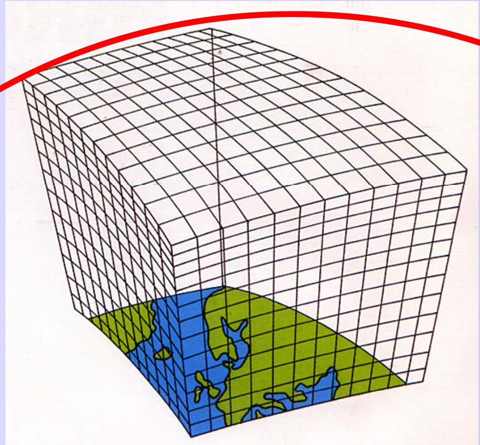
- Surface instrument networks, satellite datasets, scanning radar

Score metrics (RMS, Brier scores)

Evaluation Strategy







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
Satellite Data sets

Development **Testing** **Evaluation**

Observing Trends in Observed Cloudiness and Earth's Radiation budget

Cloud Cover Anomalies

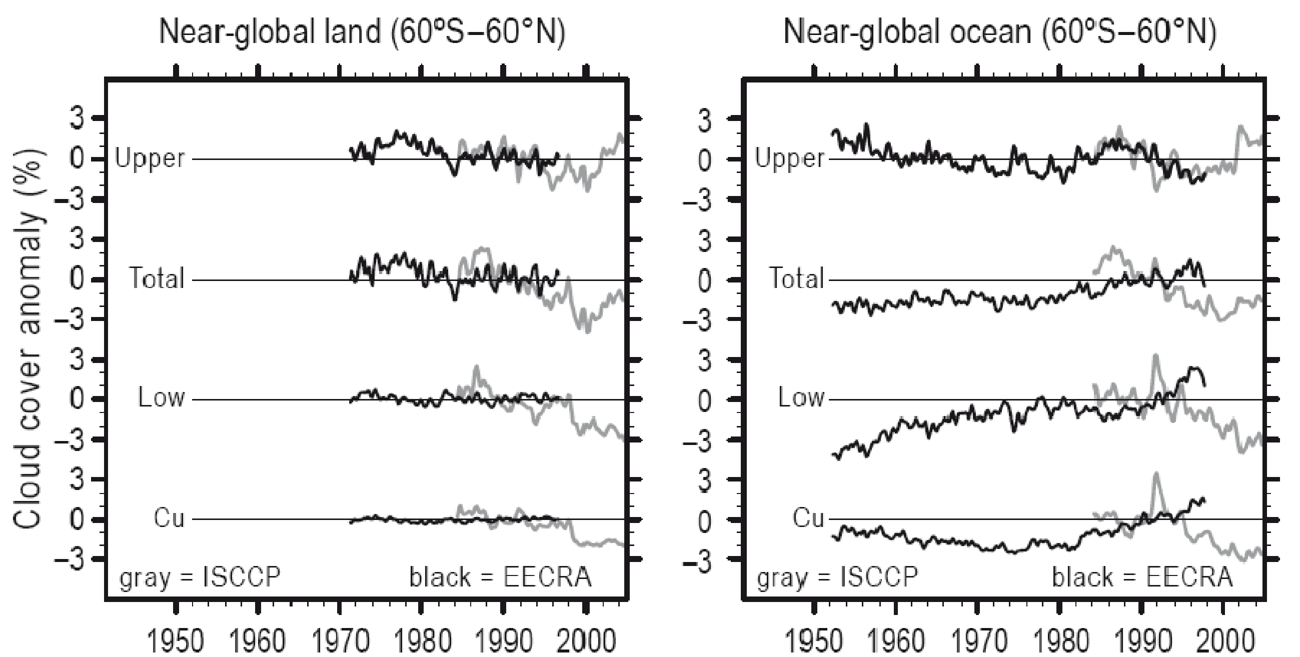
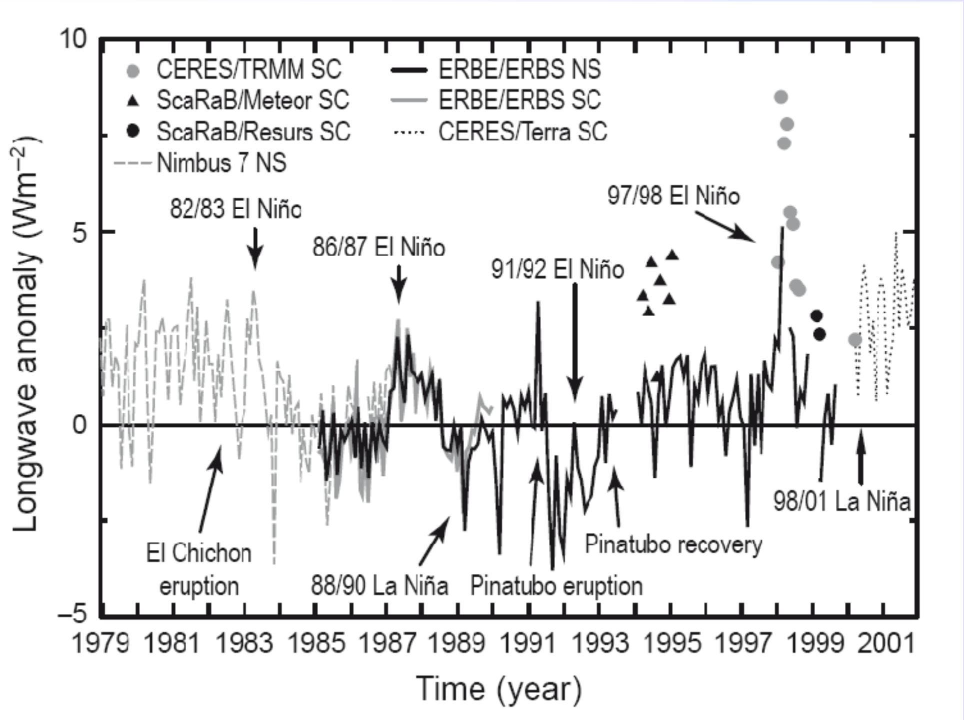


Figure 2.2 Time series of anomalies in total, upper-level, low-level, and cumulus cloud cover from ISCCP satellite (gray) and EECRA surface (black) observations averaged between 60°S and 60°N over land and ocean.

Mainly a task of geostationary satellites.

Observing Trends in Observed Cloudiness and Earth's Radiation budget

TOA Longwave anomaly



- ***Trends masked by***
  - ***decadal variability***
  - ***aerosol influences***
  - ***non-compatibility of satellite instruments***

- ***Non-trivial to link eventual trends to cloud effects.***

Observing Trends in Observed Cloudiness and Earth's Radiation budget

Planetary albedo (shortwave effects)

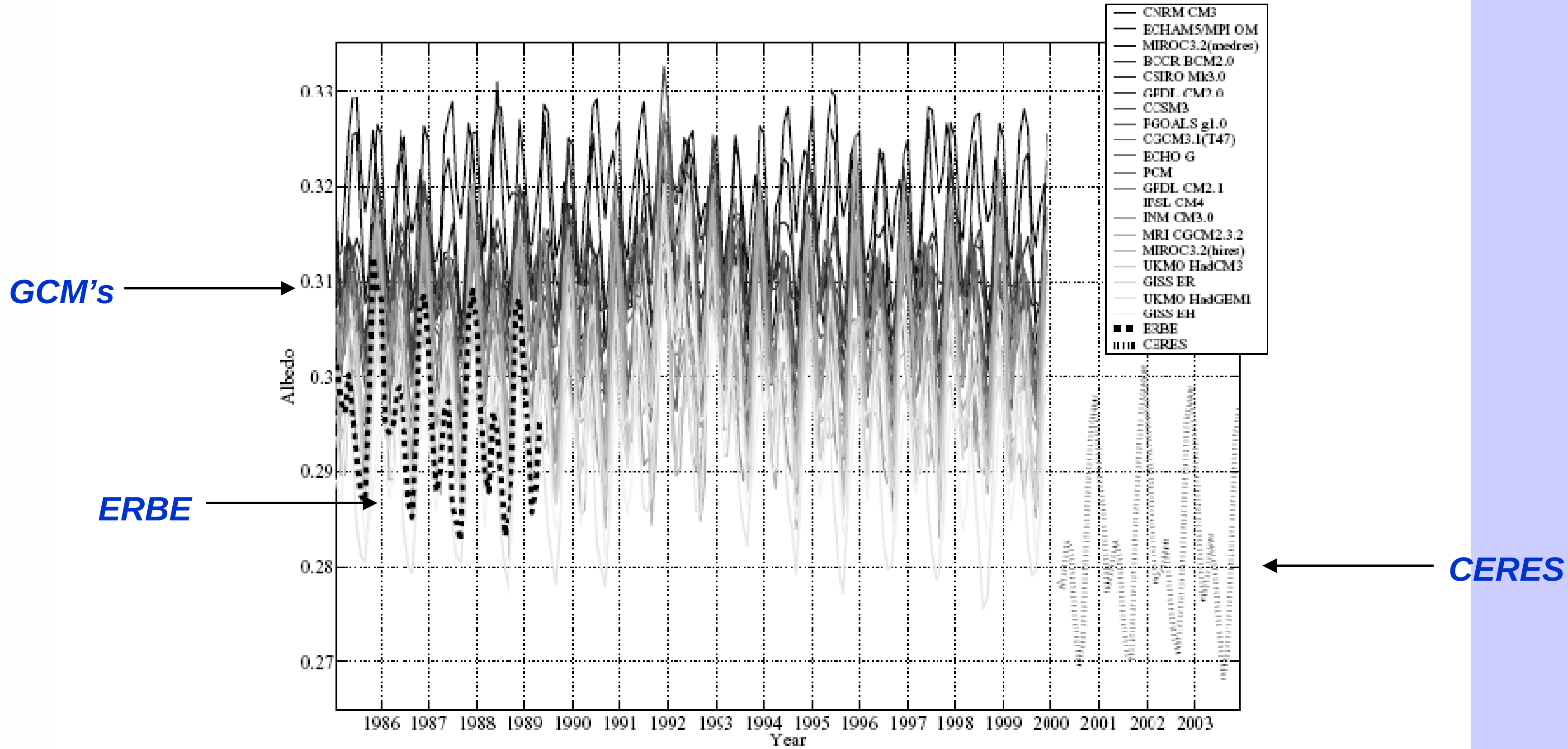


Fig. 1. Global monthly mean albedo time series from 20 GCMs (solid grey lines) compared with ERBE and CERES satellite observations (dashed black lines).

(Satellite) Observational Data Sets for the use of evaluation of GCMs (in a statistical sense)

But….. The correlations of the variability of cloud amount with other fields yield valuable and critical tests for GCMs that are a necessary condition to gain confidence in the predictive power of these models!!

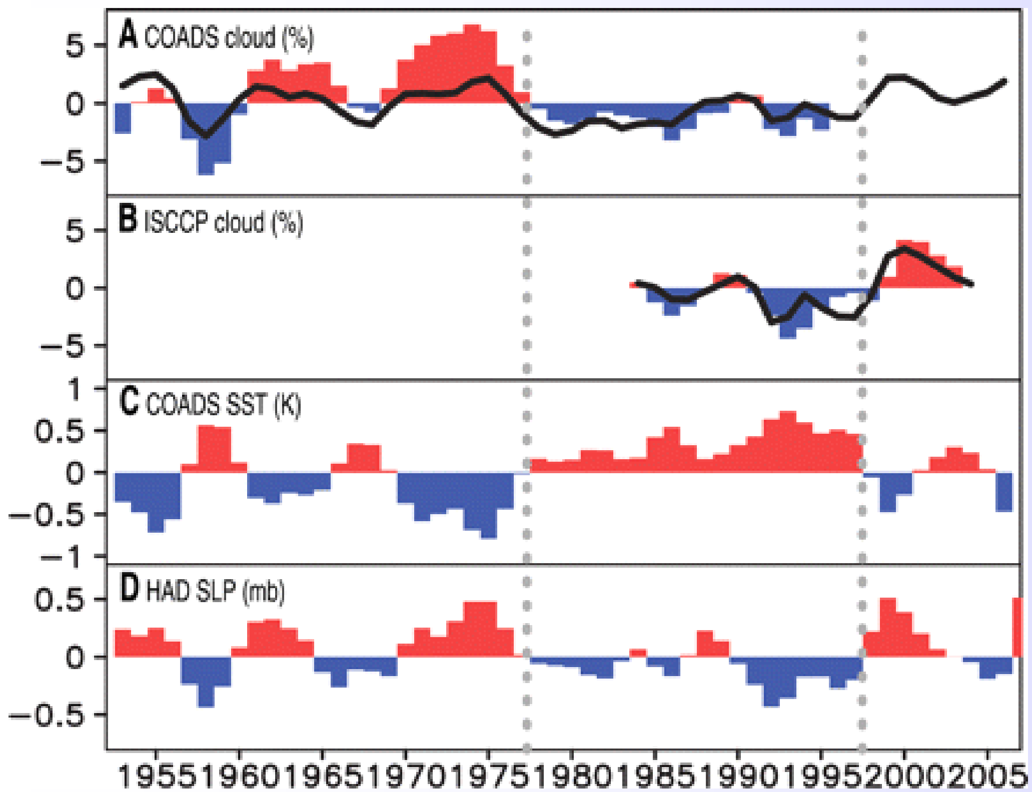


Table 1. Correlation between cloud and various meteorological quantities in the NE Pacific for observations and climate models. For the observations, the ISCCP-corrected and COADS cloud fraction (both total and low-level cloud values are shown) are correlated with observed SST (first column), lower tropospheric stability (LTS, second column), sea-level pressure (SLP, third column), and mid-tropospheric pressure vertical velocity (fourth column). For the models, the total cloud cover is used because the separate low-level cloud cover is not made available in this archive for most models. Models are grouped according to the sign of the correlation (*r*) relative to observations. We only include models for which all diagnostics are available. Statistical significance of the correlation values is calculated with a one-tailed *t* test. Degrees of freedom are derived with the lag-1 autocorrelation. Values that are significant at the 99% level are shown in bold.

	SST	LTS	SLP	ω 500
		Observations		
ISCCP-corrected total	**−0.75**	0.44	**0.80**	0.30
ISCCP-corrected low + mid	**−0.91**	**0.81**	**0.89**	**0.70**
COADS total	**−0.74**	0.35	**0.73**	0.53
COADS MSC	**−0.82**	0.42	**0.74**	**0.70**
		Models with the correct cloud-meteorology relationships		
ukmo_hadgem1	**−0.81**	**0.84**	**0.65**	**0.39**
inmcm3_0	**−0.77**	**0.37**	**0.58**	0.14
		Models that simulate the wrong sign r(cloud, ω 500)		
mri_cgcm2_3_2a	**−0.60**	0.21	**0.35**	**−0.58**
gfdl_cm2_0	**−0.69**	0.06	**0.52**	**−0.42**
ncar_ccsm3_0	**−0.66**	**0.48**	**0.63**	−0.18
		Models that simulate the wrong sign r(cloud, SLP)		
miroc3_2_hires	**−0.91**	**0.54**	−0.03	−0.10
		Models that simulate the wrong sign (or close to zero) r(cloud, LTS)		
cccma_cgcm3_1_t63	**−0.86**	0.01	**0.52**	0.20
cccma_cgcm3_1	**−0.80**	−0.08	**0.35**	−0.14
cnrm_cm3	**−0.73**	−0.24	**0.54**	**−0.54**
ipsl_cm4	**−0.53**	−0.16	0.25	**−0.32**
ukmo_hadcm3	**−0.44**	−0.17	**0.33**	**−0.43**
gfdl_cm2_1	**−0.31**	**−0.38**	0.05	**−0.56**
mpi_echam5	−0.23	**−0.44**	0.06	**−0.70**
miroc3_2_medres	−0.13	−0.00	−0.04	**−0.67**
		Models that simulate the wrong sign r(cloud, SST)		
giss_aom	0.12	**−0.63**	**−0.39**	**−0.67**
iap_fgoals1_0_g	0.22	**−0.43**	−0.24	**−0.89**
giss_model_e_h	0.34	0.10	0.10	**−0.81**
giss_model_e_r	**0.39**	−0.04	0.003	**−0.58**

Observing Trends in Observed Cloudiness and Earth's Radiation budget

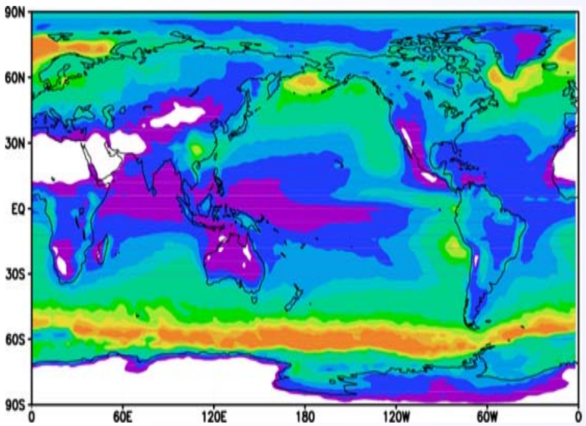
How to ensure continuity in global satellite observations of clouds and radiations?

(How) can accuracy be improved?

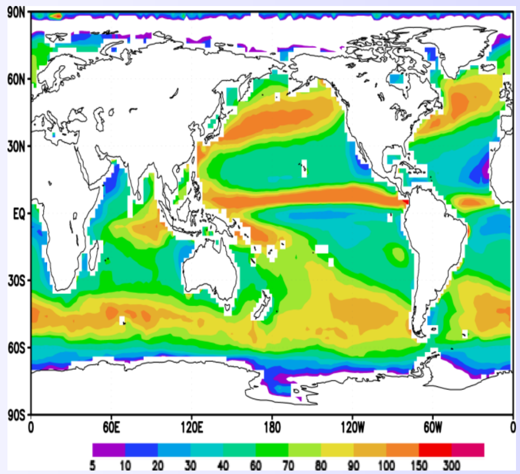
Are we looking at the right fields?

GCM Evaluation with Satellite data

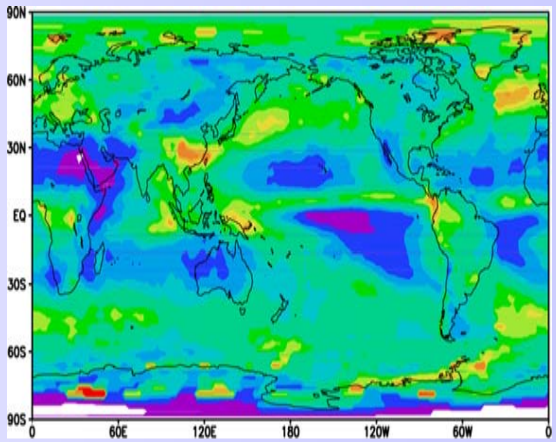
CERES/MODIS LWP

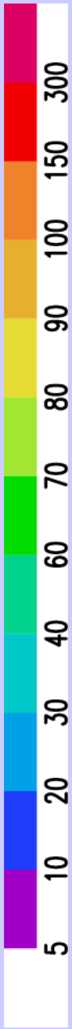


SSM/I LWP



ISCCP LWP





Are satellite simulators the only way out?

Evaluation: diurnal cycle cloud properties
Shouldn't we make more use of geostationary satellites