The role of ARM data in improving the ECMWF boundary layer scheme

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ECMWF

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Various ways to evaluate an operational forecast model

Issues concerning the model physics

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Improvements

Outlook

How to evaluate an operational forecast model?

GCM: resolved & unresolved (sub-grid) scales

↓

Physical process evaluation can be done in two modes:

3D

Forecasts and climate runs

Process is interactive with the larger scales (dynamics)

Provides info about location and frequency of occurrence

1D

At physics level

In controlled conditions

Increased transparency

A roadmap to model improvement

3D Identification of problem: bias, location, and frequency of occurrence
* Evaluation against station timeseries / remote sensing datasets
* At many locations (global coverage)

↘

1D Process studies: which model component is responsible?
* Idealized case studies based on observational data
* Supplemented by CRM/LES results
* Continuous forcings datasets

↘

Model development Improving the parameterizations

↙ ↗

1D Revisiting the idealized cases
* sensitivity tests / equilibrium studies
* feedbacks between model components (compensating errors)

↙ ↗

3D Forecasts and climate runs
* global impacts

Recent results at ECMWF

what: Cloudy boundary layers - Shallow cumulus convection

where: ARM SGP : Continental transient shallow cumulus
Subtropical Trade-winds : Marine steady state shallow cumulus

how: 3D Forecast evaluation against ARM SGP datasets

1D Idealized CRM/LES cases

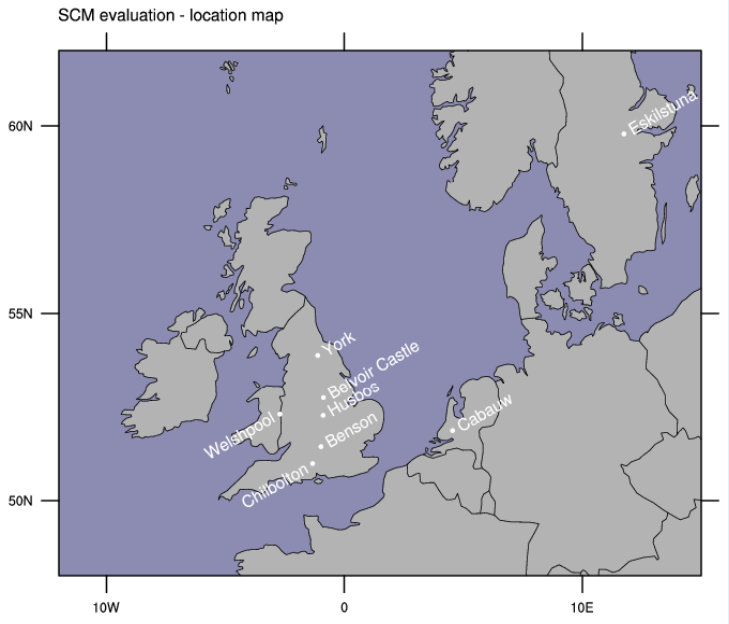
Continuous forcings datasets

Automated daily SCM evaluation at various ARM sites 

Automated daily SCM evaluation

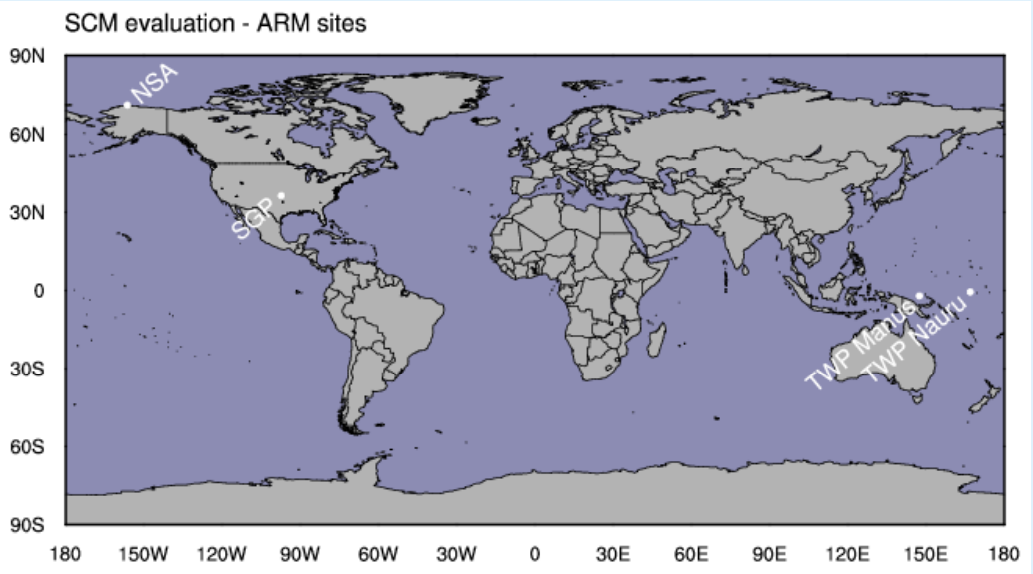
Method:

* SCM runs are performed *daily* at various locations where measurements are available (ARM, CloudNet)
* Large scale forcings are obtained from 2-day forecasts, starting from the 00 UTC analysis
* Different versions of the 1D model are compared



Benefits:

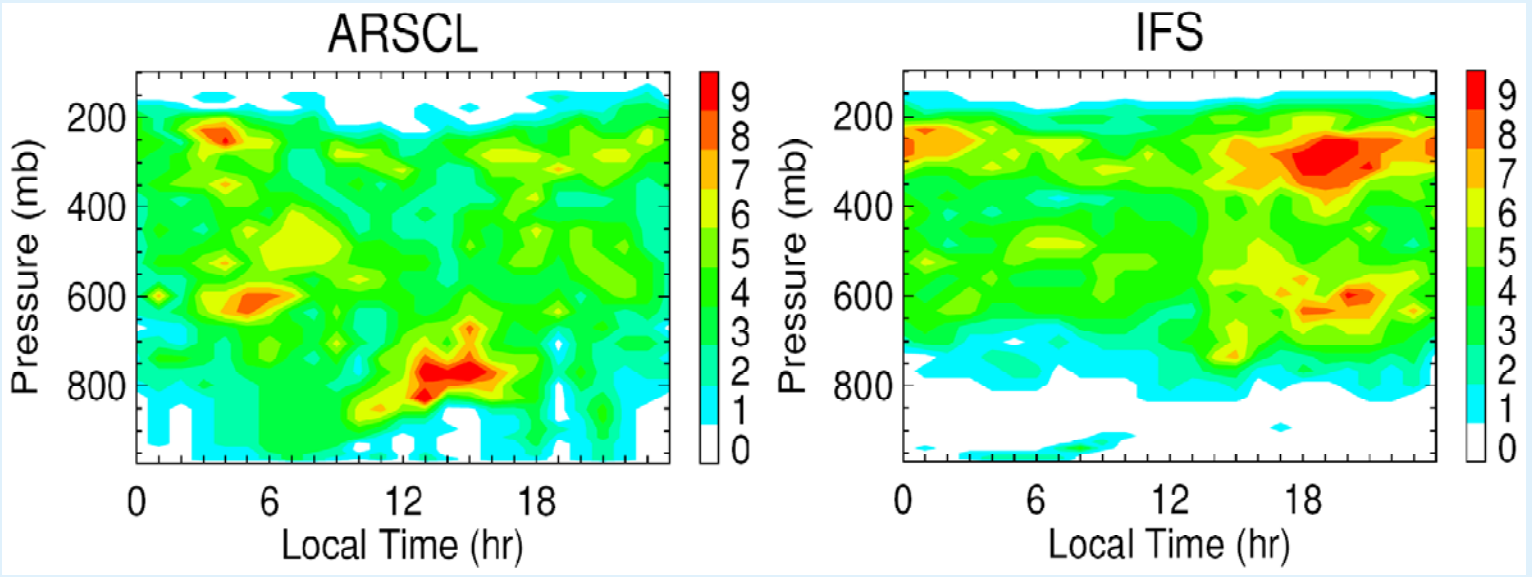
* every day is a new PBL scenario
* automatic generation of a case archive
* provides detailed diagnostics about model physics
* acts as an *"early warning system"* in the model development stage
* runs can be used as local 1D forecasts



Required: fast (ideally instant) availability of measurements of 1st order PBL parameters, such as cloud boundaries, LWP/IWP, surface meteorology, etc.

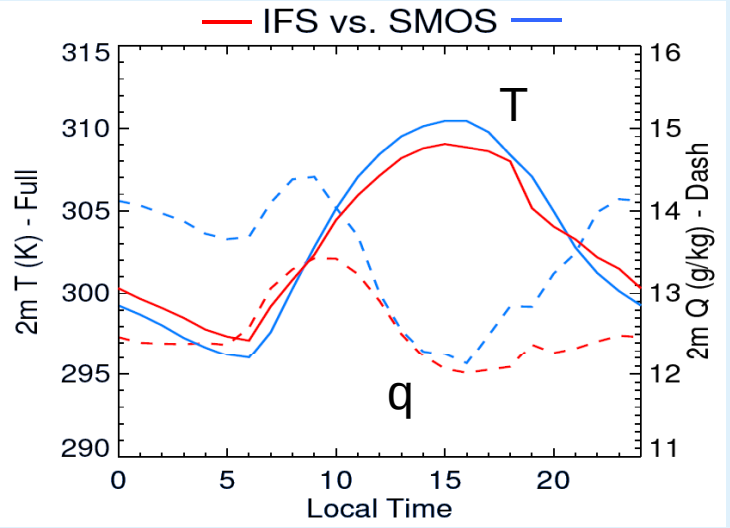
Identified issues

Summertime shallow cumulus at ARM SGP in 18-42 hr forecasts of the ECMWF Integrated Forecasting System (IFS)



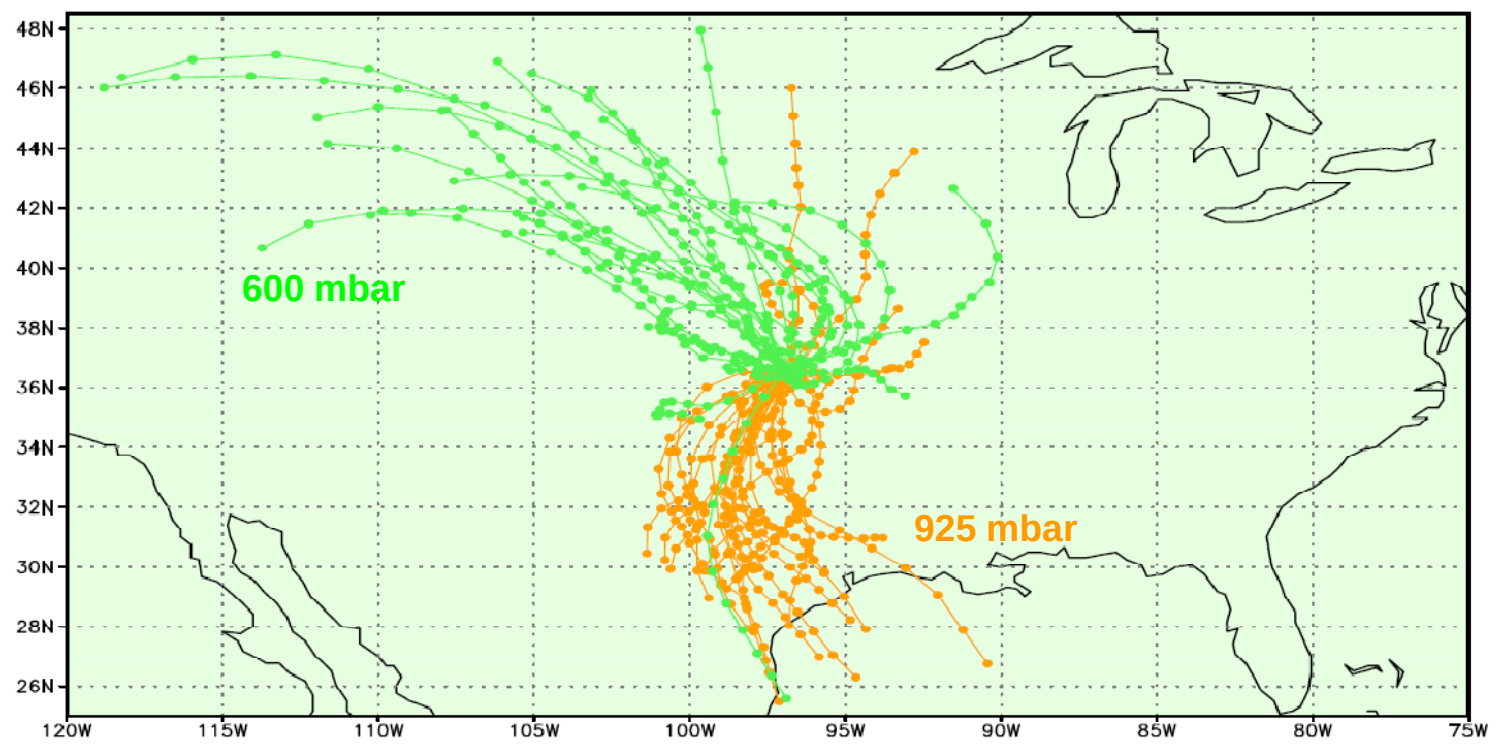
Lack of low clouds

Structural dry bias at low levels



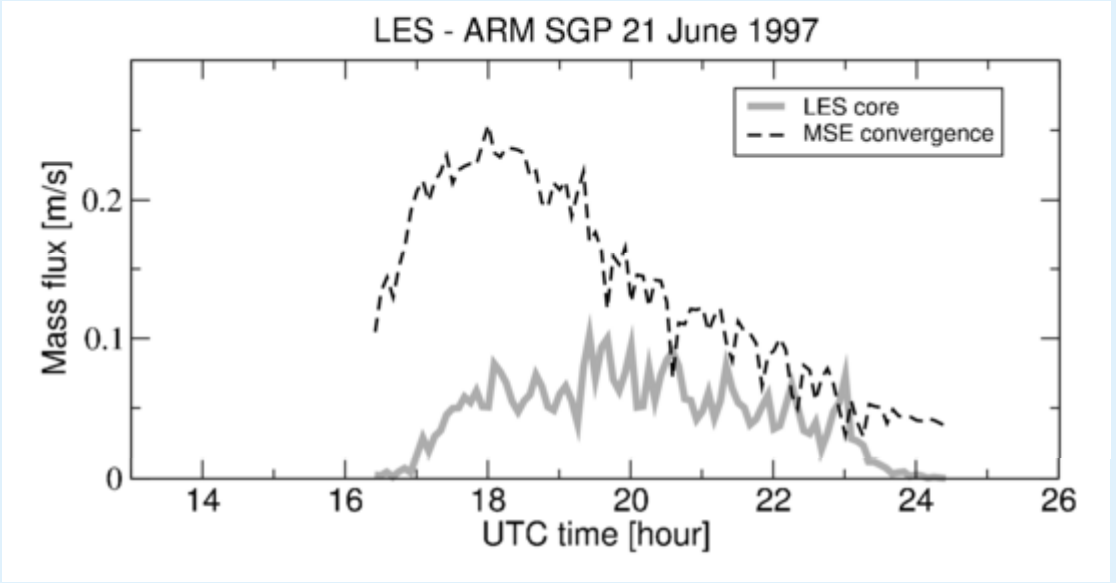
Too vigorous mixing upstream from SGP?

Backward trajectory analysis in IFS: moist PBL air is advected northward from Gulf of Mexico



1D studies reveal the cause:
The coupling of the convective cloud layer to the subcloud layer

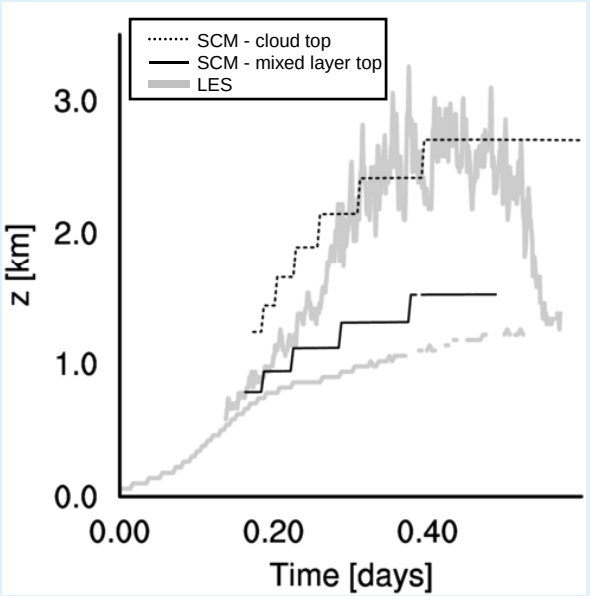
The cloud base mass flux closure relying on moist static energy (MSE) convergence is too aggressive in the early stages of the diurnal cycle

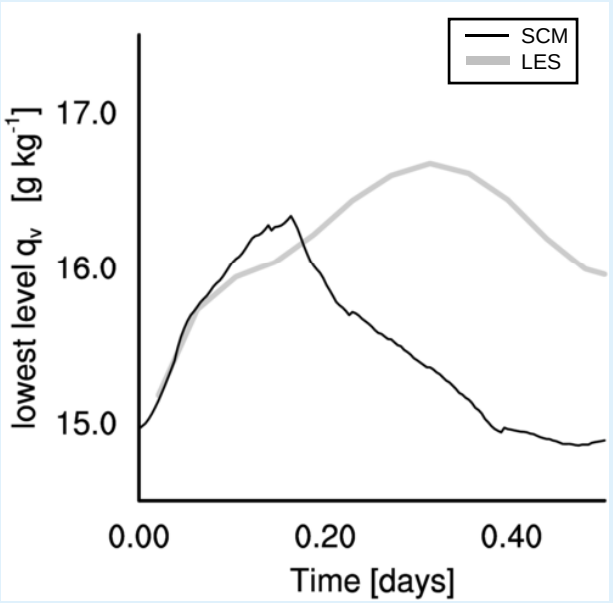


In the SCM this has two important impacts:

- the mixed layer and PBL deepen too fast

- as a result, the subcloud mixed layer warms and dries too much

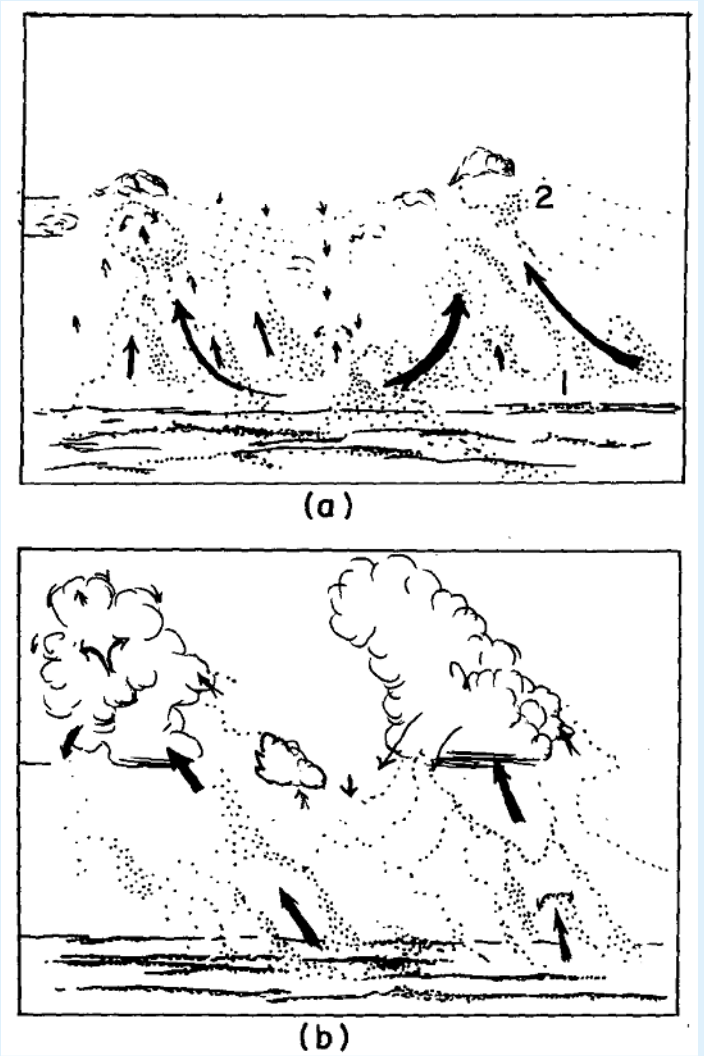




A new boundary layer scheme

Goal:

To enable representation of conditionally unstable cloud layers that are flexibly coupled to the subcloud mixed layer



LeMone & Pennell (1976, MWR)

Enhancing model complexity

I. The Eddy Diffusivity Mass Flux (EDMF) framework

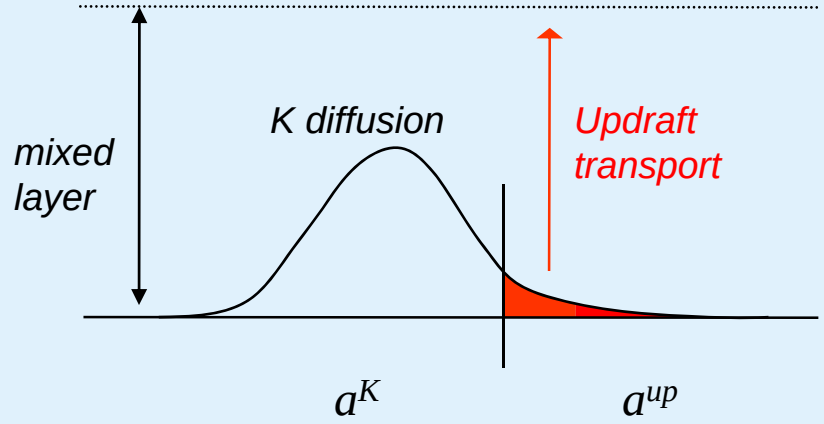
For turbulent transport in well-mixed layers

Siebesma et al. (JAS, in press, 2007)

$$\overline{w'\phi'} = a^K \overline{w'\phi'}^K + a^{up} \overline{w'\phi'}^{up}$$

diffusive flux

advective (mass) flux

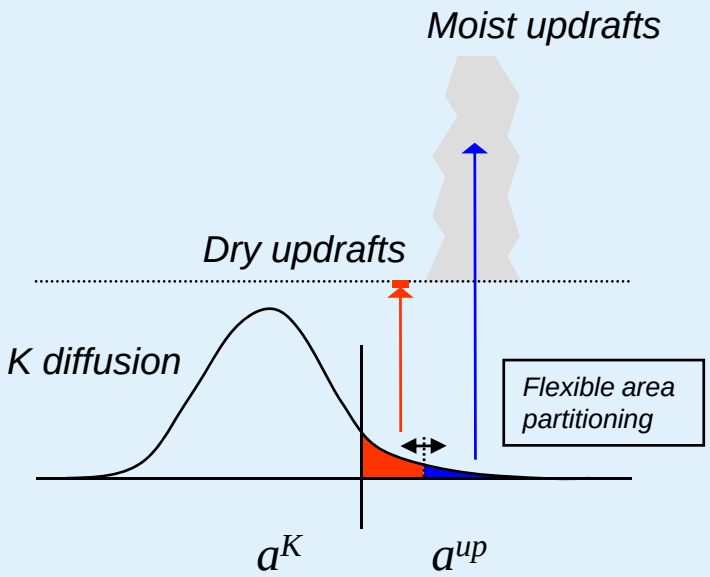


EDMF already represents dry and stratocumulus convection in the currently operational ECMWF forecast model

II. A proposed set of modifications

Enables EDMF to also represent shallow cumulus

(replacing the current shallow cumulus scheme)

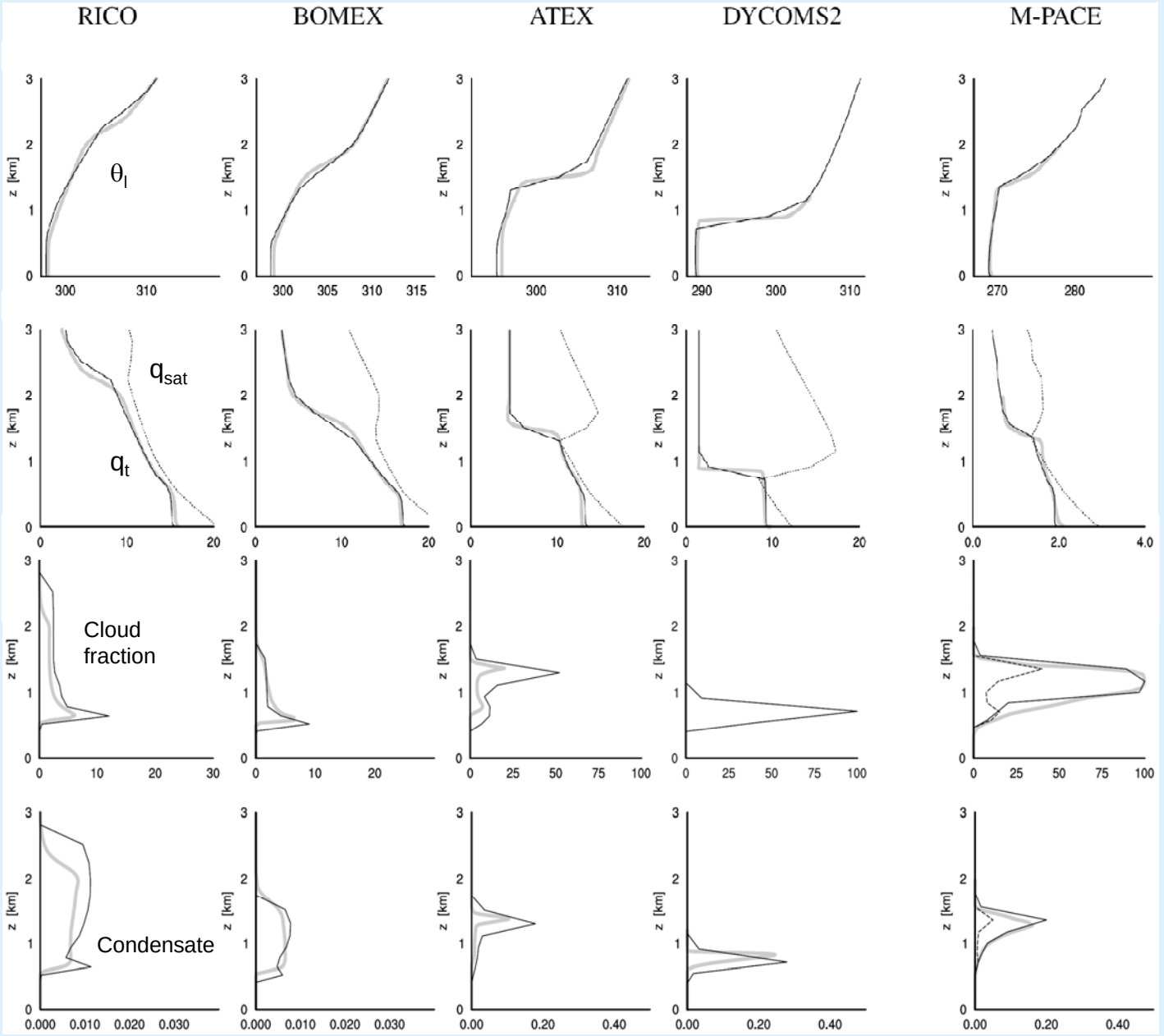


* increased number of resolved updrafts
* flexible area partitioning of the updraft ensemble
  -> determined by moist convective inhibition
  Allows gradual transitions to and from shallow cumulus
* flexible updraft entrainment
  The same entraining plume model is applied to all model updrafts
* flexible vertical structure of cumulus mass flux
  Dependent on inversion stability: a bulk Kain & Fritsch (1990) scheme
  -> to reproduce cloud layers with varying degrees of conditional instability
* top-entrainment efficiency closure at shallow cumulus inversion
  Wyant et al. (JAS, 1997)
* a bimodal statistical cloud scheme within the PBL
  Each EDMF component gets its own independent PDF

So… does it work better?

Step 1: Revisit as many prototype LES/CRM cases as possible

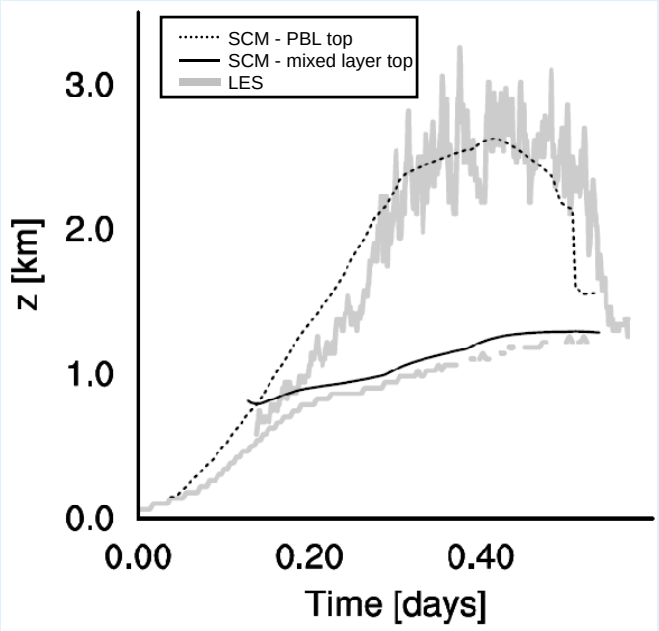
This should be a routine step in model development

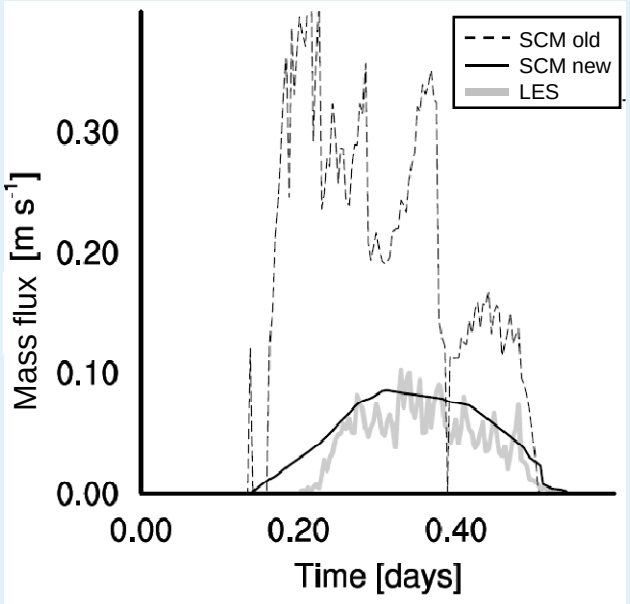


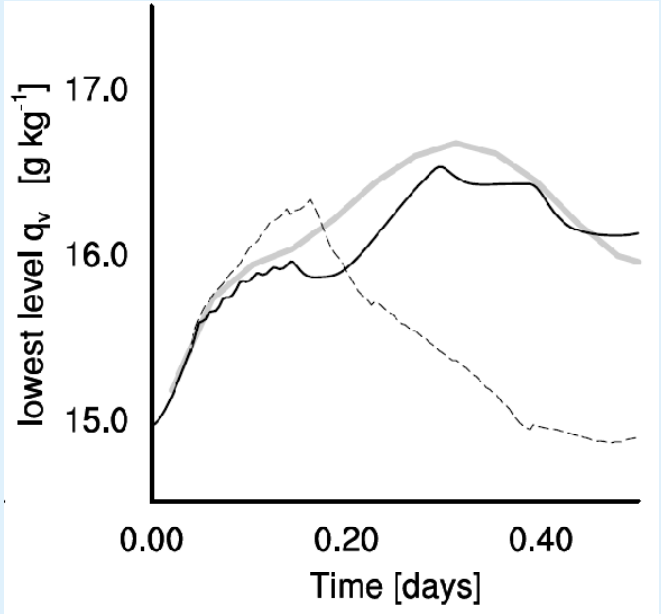
An improved diurnal cycle

Reduced mass flux at cloud onset

More realistic development of low level humidity

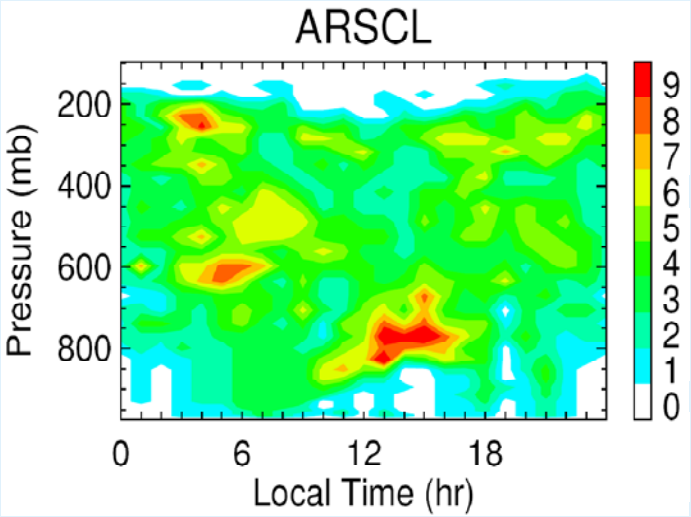






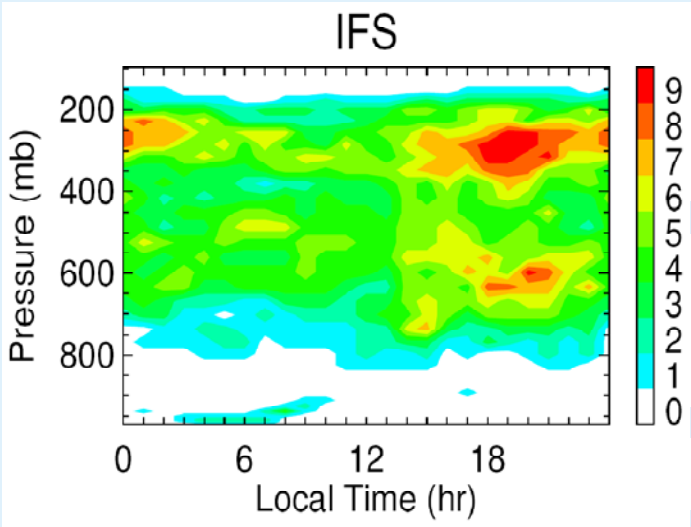
Step 2: back to 3D

Shallow cumulus at ARM SGP in the IFS



old

new



expected soon!

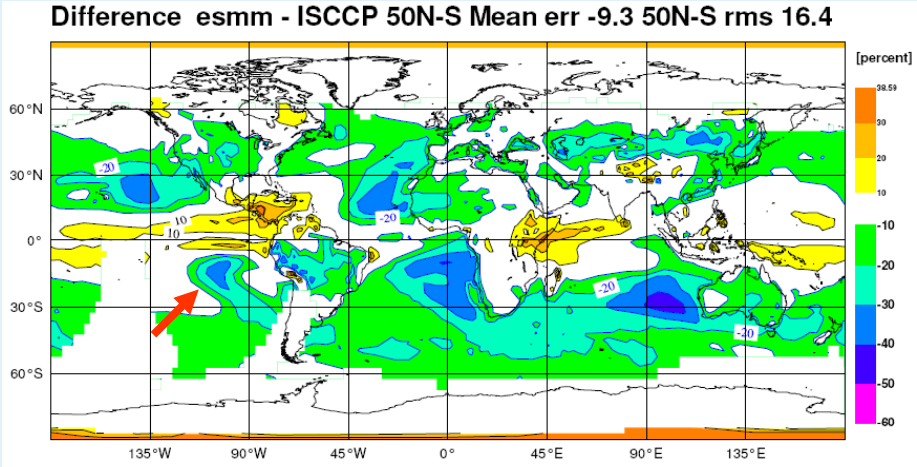
Repairing compensating errors in the IFS

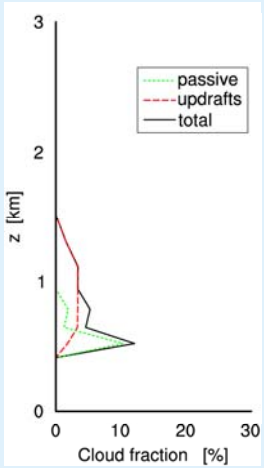
Impacts of the new entrainment efficiency closure for shallow cumulus

1 year climate runs

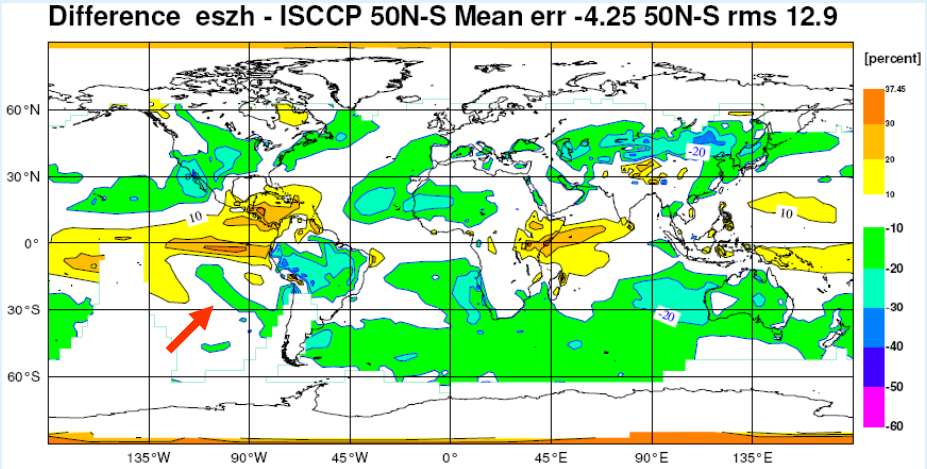
sample at 110W 15S

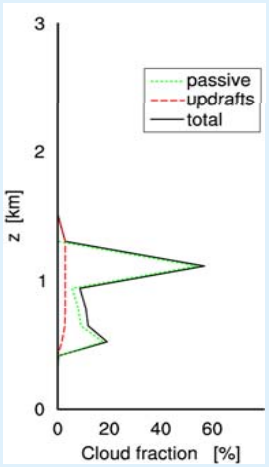
Before





After





Future

Implementation into the operational forecast model
- scheduled late 2007

Unification of the representation of shallow and deep convection
- downdrafts & cold pools

The cumulus updraft precipitation model
- a great source of uncertainty in IFS model climate

Towards a double moment cloud scheme

Ongoing evaluation against ARM data
- both in 1D and 3D mode

ECMWF

ECMWF ARM report series

1. Cheinet, S., A. Beljaars, M. Köhler, J-J. Morcrette and P. Viterbo, 2005:
Assessing physical processes in the ECMWF model forecasts using the ARM SGP observations.

2. Neggers, R. A. J., M. Köhler and A. C. M. Beljaars, 2007:
A dual mass flux scheme for boundary layer convection. Part I: Transport

3. Neggers, R. A. J., 2007:
A dual mass flux scheme for boundary layer convection. Part II: Clouds

Available at *http://www.ecmwf.int/publications/*

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