Challenges for bridging the gap between theory and parameterisation practice for precipitating clouds. The multi-scale and convective-memory-oriented 3MT approach in ALARO-0.

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(with acknowledgments to D. Banciu, R. Brožková, L. Gerard & J.-M. Piriou)

'CLOUD09' workshop on 'Moist Processes in Future High Resolution NWP/Climate Models'
15/6/09, SMHI, Norrköping, Sweden

First of all, back to another NetFAM workshop (Tartu, January 2005)

Conclusion viewgraph of a talk (Geleyn and Piriou)

Also remember that we had very structuring discussions there on the interplay 'turbulence ⇔ non-precipitating convection ⇔ precipitating convection'

Summary

- The MOCON ⇔ Rainfall link is sufficiently stronger than any equivalent (*at large scale and in a steady environment*) for schemes intelligently based on such a closure to be very robust and applicable even if the balance is less accurate.

- Going further implies to stop thinking large-scale forcing vs. cloud balancing:
  - Introducing a local organisation source of moisture leads to the overall concept of (CAPE- & CIN-dependent) moisture availability;
  - The cloud-stationarity hypothesis might be relaxed;
  - What then really counts is the Bulk Convective Condensation rate (BCC).

- *Bougeault's 85 scheme anticipates such steps, but not enough for 'meso-scale-organised' and/or 'dry environmental' cases.*

M-T roots

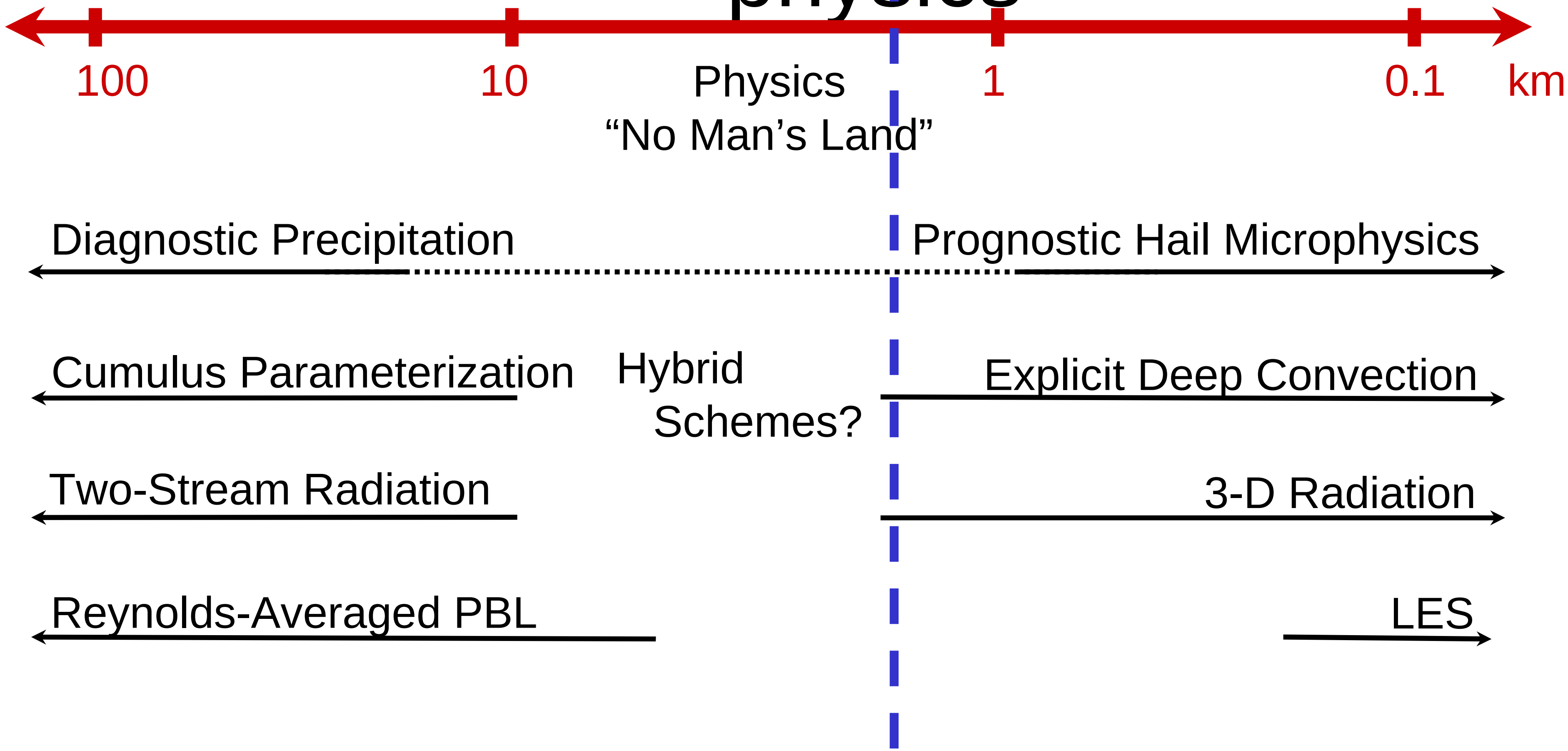
The challenges

Physical origin (for the record)
Scale constraints
Algorithmic constraints
Link with parameterisation paradigms

Physical challenges (for the record)

- Given the central topic of the present talk, we shall assume that these ‘challenges’ are met, at least in the best way currently compatible with the other constraints that we shall study separately.
- They are (principally):
  - The intrinsic complexity of ‘locally acting’ cloud- and precipitation microphysical processes
  - The individual mechanisms of convection triggering, growth and decay
  - The way phase changes modify the complex self-control mechanism of turbulence
  - The feed-back leading to the time- and space configuration of clouds (via radiation, turbulence and 3-phase thermodynamics)

Scale dependency of model physics



(adapted from Klemp 2007, by Seifert [GCSS, Toulouse, June 2008])

The specific case of fully organised convection (1/2)

- The parameterisation schemes of organised convection are mostly just based on a ‘statistical handling’ of the grid-box population of ‘plumes’. And it is indeed a complex issue!
- The shortcomings of this approach if the said population stops to be numerous enough for a true statistical sampling are well understood (so to say, ***1st ‘grey-zone’ syndrome***).
- But there is another problem: the ‘invisible’ return current of any plume with a ‘net ascent’ stretches horizontally on far larger scales. Said differently, the ‘compensating subsidence’ part of the local flow ALWAYS remains a statistical aggregate, EVEN when this is not any more true for the ‘ascent part’ of the grid-box where condensation happens.

The specific case of fully organised convection (2/2)

- And yet parameterisation schemes force us:
  - to treat both aspects in the same conceptual framework;
  - to close the mass-budget independently inside each grid-box.
- Forgetting both issues is the source of the what may be called ***2nd 'grey-zone' syndrome***, far more structural than the first one.
- Additionally, it shall be argued later that the distinction deep/shallow (for convection) might better be linked with the notion of 'net-ascent or not' than with the one of 'precipitating or non-precipitating'.

Algorithmic challenges (*and some way to meet them*) (1/3)

- Addressing grey-zone syndrome N°1 forces to discuss the ‘relevance’ of the dynamically computed ‘large-scale’ vertical velocity. This relevance is quite weak (a mere statistical average) until convective plumes are well ‘resolved’. But it nevertheless controls what is called the ‘large-scale’ part of the condensation processes. **Hence the N°1 syndrome is clearly associated with the arbitrariness of any algorithm separating (in the model) both types of condensation processes.** *This leads to the idea of merging various condensation sources before their handling by a single microphysical computation, in order to ‘iron out’ the issue about ‘which scheme does what’.*

Algorithmic challenges (*and some way to meet them*) (2/3)

- But what about grey-zone syndrome N°2 if using mass-flux-type schemes that separate ‘detrainment’ [difficult to parametrise] and ‘compensating subsidence’ [artificial]? **Seen from this angle, the N°2 syndrome is a consequence of the core hypothesis of ‘classical’ mass-flux schemes that the cloud is in a stationary state.** *Assuming time-evolving properties for the ‘averaged plume’ allows to forget the ‘compensating subsidence’ terms. Even more, adding then ‘memory’ for the cloud area fraction allows to by-pass the parameterisation of detrainment (and puts all the ‘science’ in the parameterisation of entrainment).*

Algorithmic challenges (3/3)

- Assuming that both 'core algorithmic challenges' are met in the way that was just hinted at, does not solve the full problem of moist physics. **It displaces it to less crucial items:**
  - How to handle, under the same hat, the intrinsically differing geometries of 'large-scale' and 'deep convective' clouds?
  - How to deal with the 'memory' of the vertical velocity that, multiplied by the prognostic area fraction, shall give back the mass-flux (that we still need of course)? In more specific terms, how to ensure vertical consistency when each model level has its independent freedom to 'advect' the convective cloud signature?
  - How to parameterise the downdraft part of the problem if convective condensation looses its identity as soon as it is computed?
  - How to modulate the interacting life-cycles of up- and downdraft processes?

Link with 'parameterisation paradigms'

- It is no coincidence that attempting to offer a consistent answer to most of the challenges for the parameterisation of moist physics at resolutions below δx~6km leads to 'shake' a lot of 'long admitted paradigms', namely:
  - Deep and shallow convection are best distinguished by precipitating vs. non-precipitating;
  - There is a unique scale transition between parameterised and resolved deep convection;
  - The characteristic time-scale of microphysics is between the cloud life times associated to large-scale- and convective precipitations;
  - Convective clouds may be considered as 'stationary' items.
- Unfortunately this wide reassessment leads to problems, since quite a lot of 'pet parameterisation pieces' (that one would quite naturally like to preserve) have an explicit or implicit link with those paradigms => need of a global approach (the Modular side of 3MT).

Second 'core workshop' on 'Concepts for convective parameterisations in large-scale models'

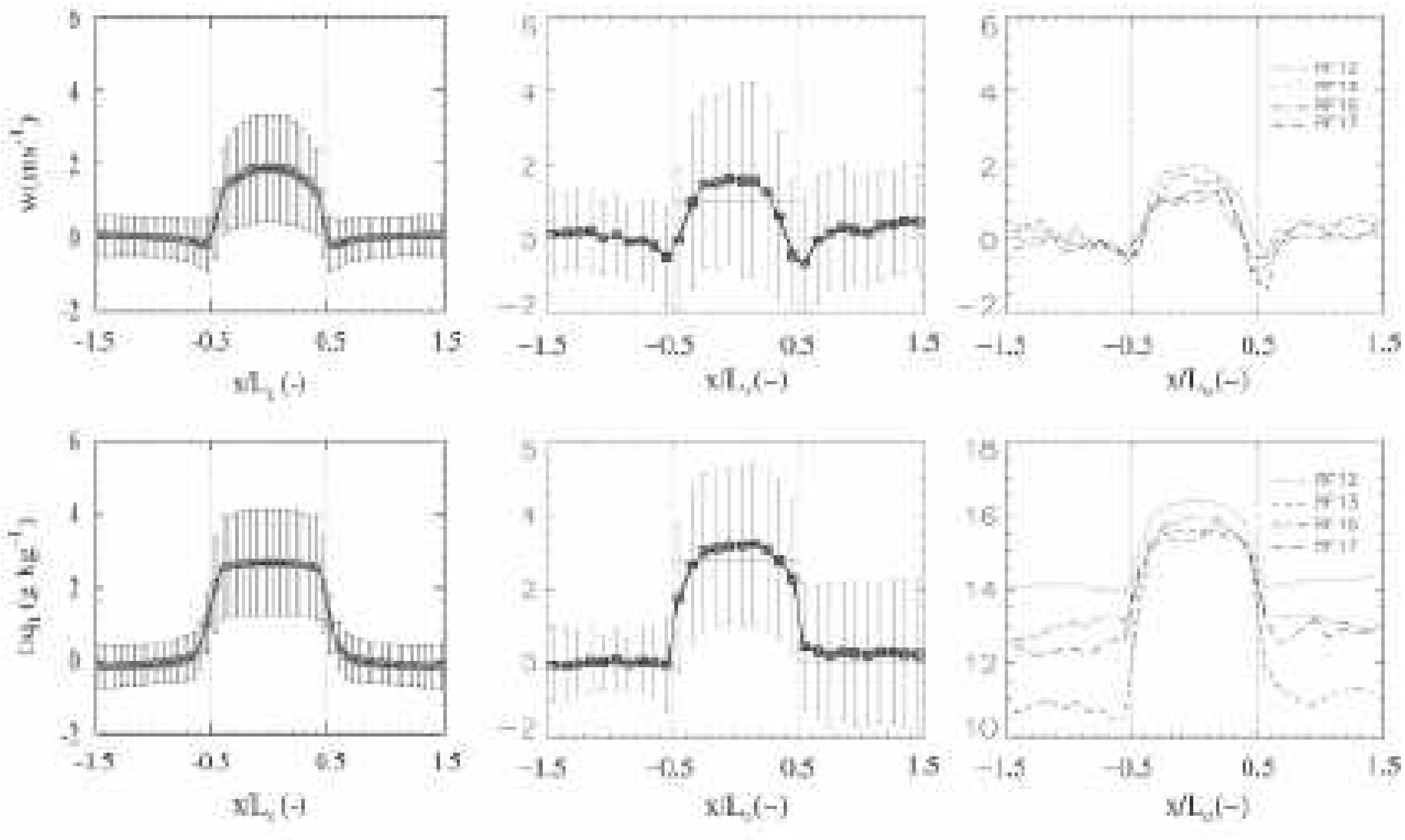
CHMI, Prague, 25-27/03/09

The initiative, the themes
Outcomes/Issues relevant to the present lecture
(totally subjective choice)

Concepts for convective parameterisations in large-scale models

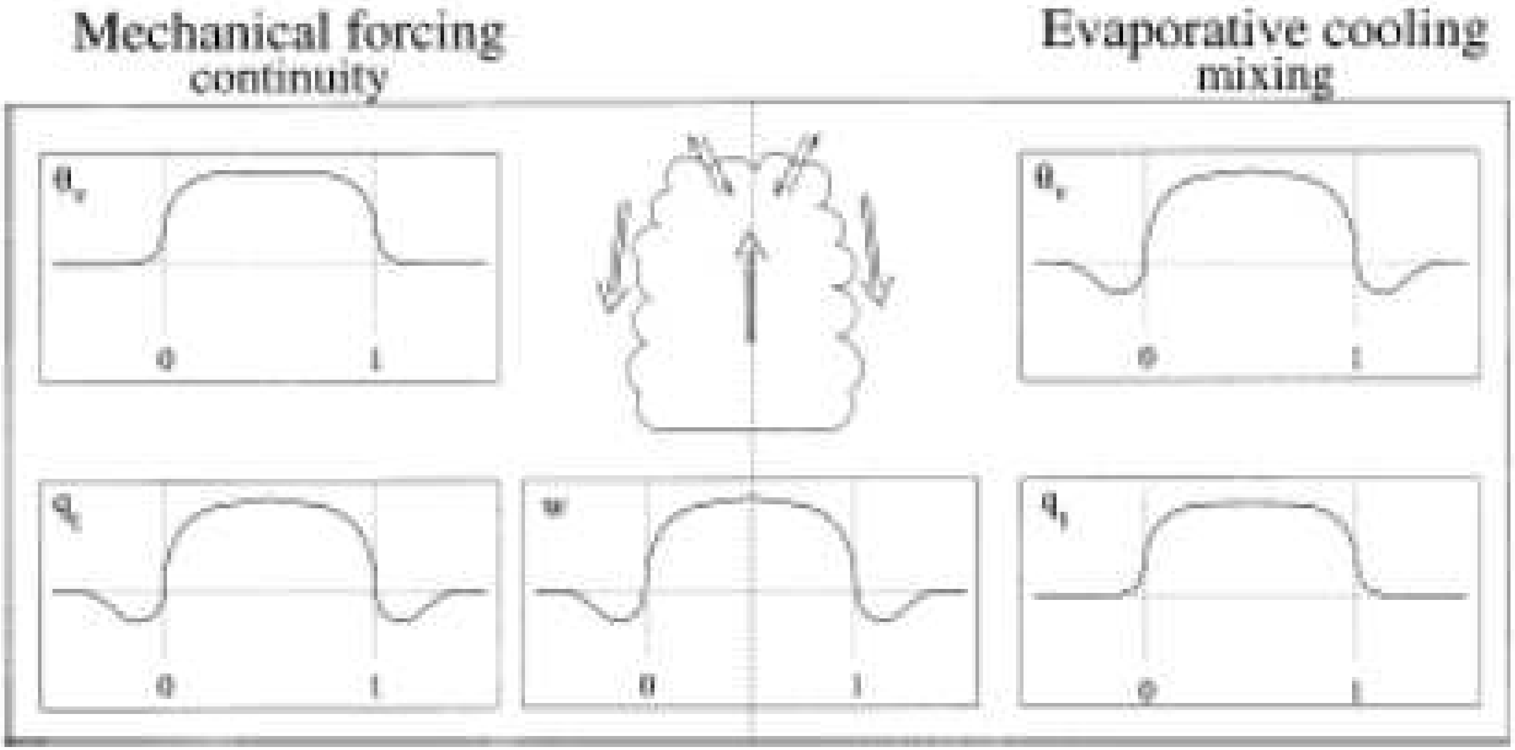
- A truly bottom-up initiative of J.-I. Yano (Météo-France & LMD), J. Quass (MPI Hamburg) & H. Graf (University Cambridge)
- Loose structure, frequent contacts by e-mails, a workshop every year (with strong focus in the theme but total freedom in the running):
  - 2008 Hamburg (physics of plumes)
  - 2009 Prague (entrainment/detrainment)
  - 2010 Warsaw (high resolution issues)
- Search for a more stable framework (COST ?)

Issue N°1: convective clouds have a ‘shell’ of subsident motions, driven by evaporation at the cloud edges



Heus and Jonkers, 2003

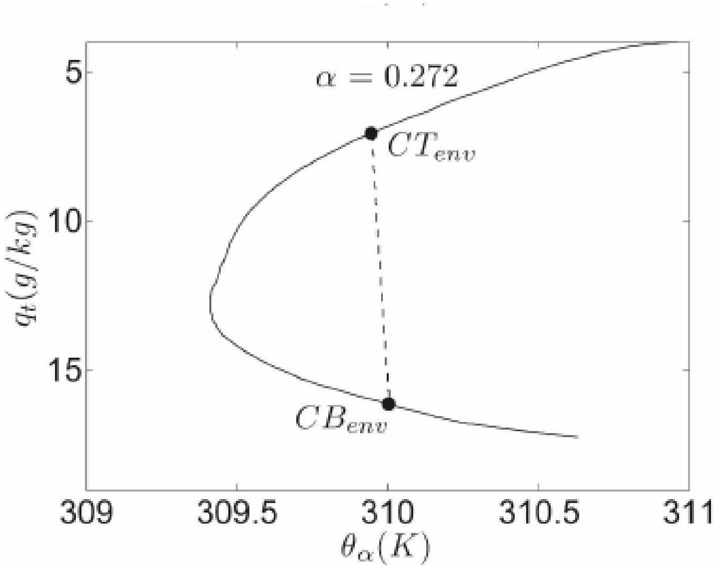
Issue N°1: for small clouds (=shallow?) this leads to deconnection from the 'larger scales'

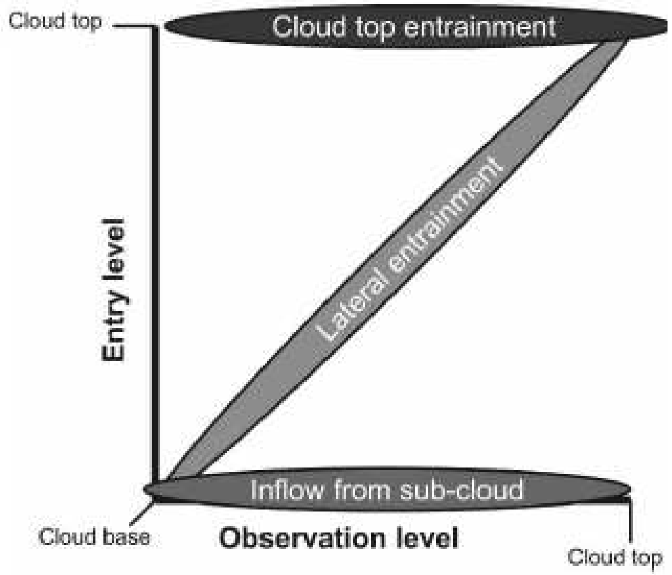


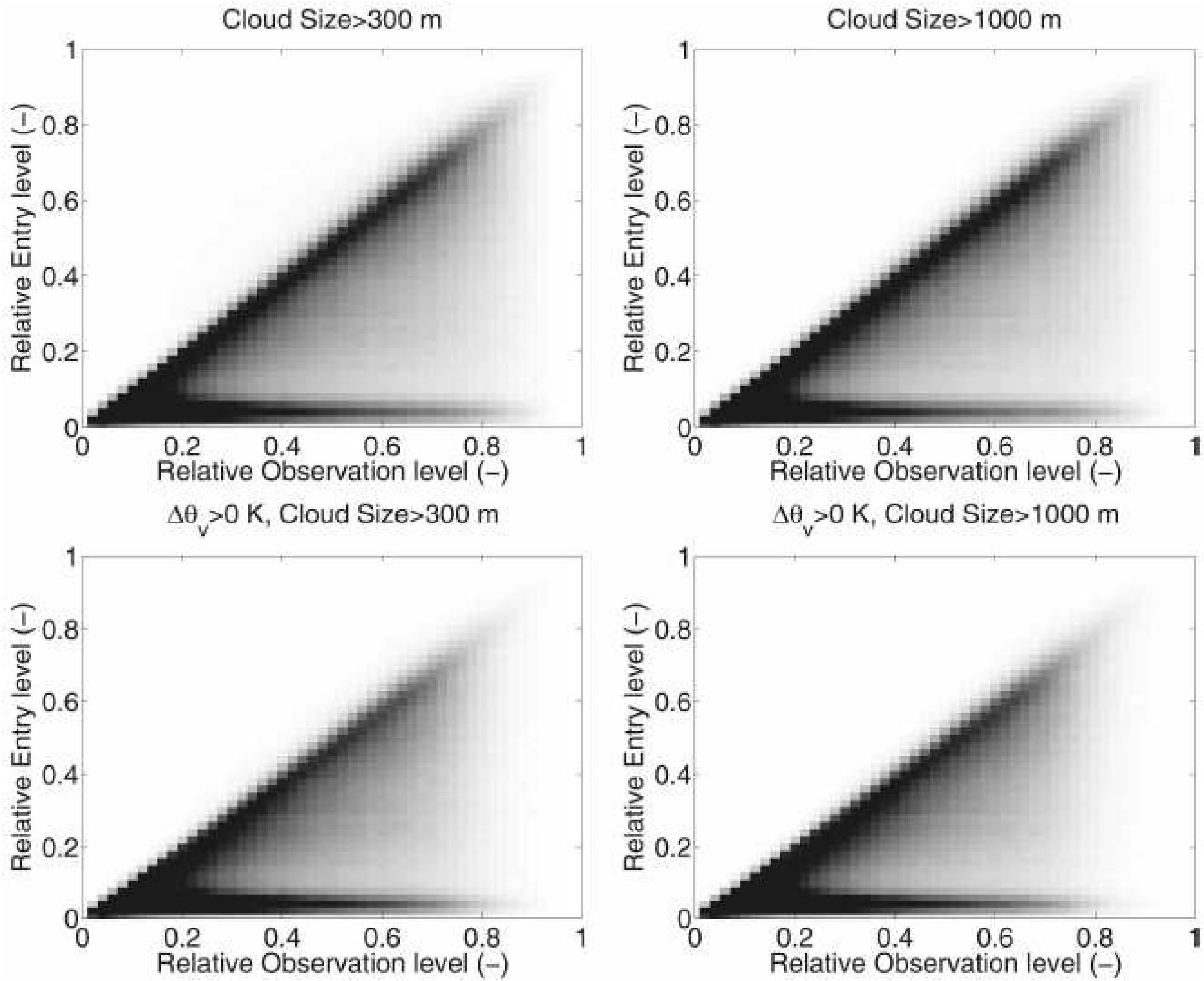
Rodts et al., 2003

Issue N°2: Despite the 'mixing line' arrangement of cloud samples, the famous 'cloud top entrainment' seems to be a hoax

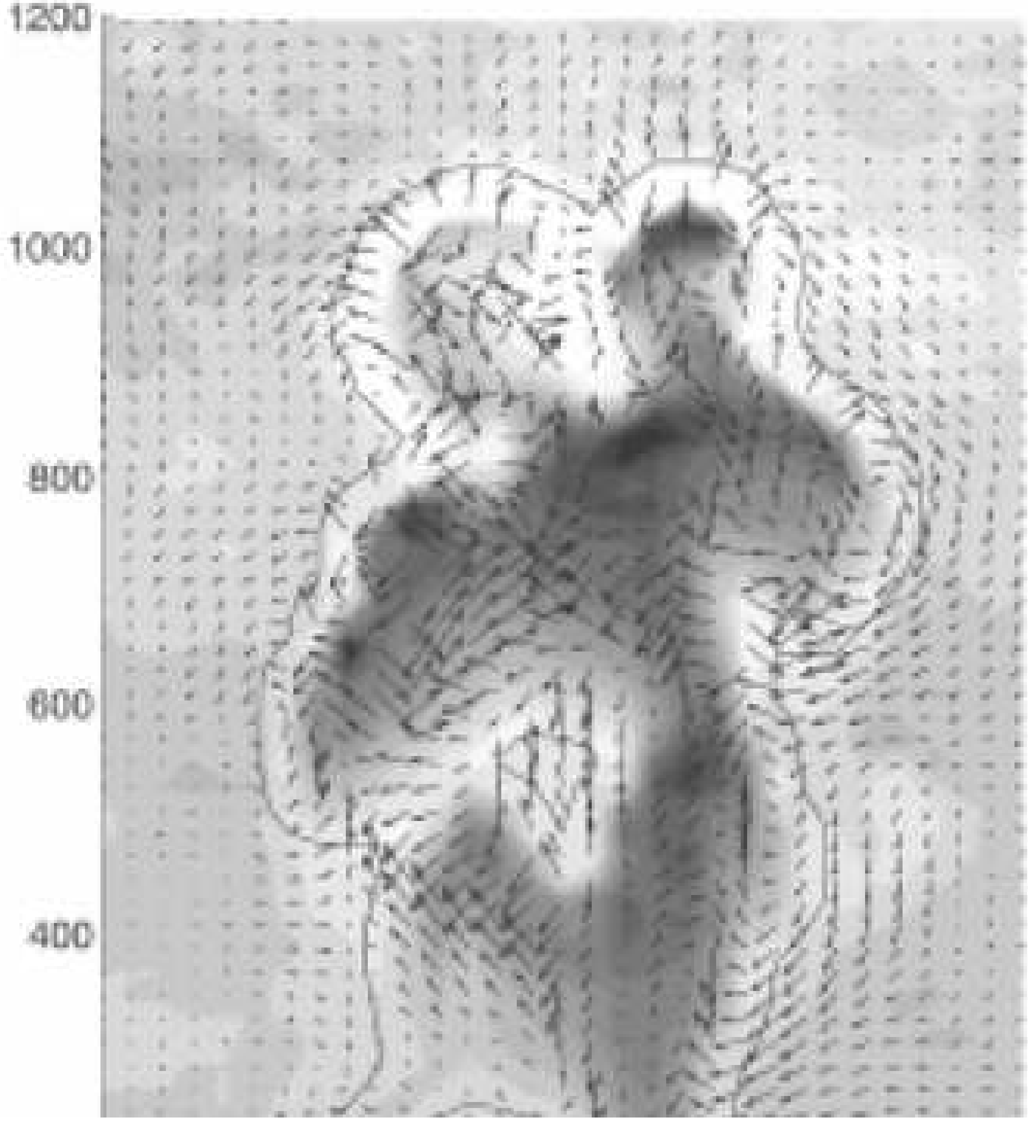
Heus et al., 2008







Issues N°1/2: visualisation in LES



Issue N°3: Towards a Unified Description of Turbulence and Shallow Convection (D. Mirovov)

Quoting Arakawa (2004, The Cumulus Parameterization Problem: Past, Present, and Future. *J. Climate*, **17**, 2493-2525), where, among other things, "Major practical and conceptual problems in the conventional approach of cumulus parameterization, which include artificial separations of processes and scales, are discussed."

"It is rather obvious that for future climate models the scope of the problem must be drastically expanded from "cumulus parameterization" to "unified cloud parameterization" or even to "unified model physics". This is an extremely challenging task, both intellectually and computationally, and the use of multiple approaches is crucial even for a moderate success."

The tasks of developing a "unified cloud parameterization" and eventually a "unified model physics" seem to be too ambitious, at least at the moment.

However, a unified description of boundary-layer turbulence and shallow convection seems to be feasible. There are several ways to do so, but it is not a priory clear which way should be preferred (see Mironov 2009, for a detailed discussion).

Issue N°3: Towards a Unified Description of Turbulence and Shallow Convection – Possible Alternatives (D. Mironov)

- ***Extended mass-flux schemes*** built around the top-hat updraught-downdraught representation of fluctuating quantities. Missing components, namely, parameterisations of the sub-plume scale fluxes, of the pressure terms, and, to some extent, of the dissipation terms, are borrowed from the ensemble-mean second-order modelling framework. (ADHOC, Lappen and Randall 2001)

- ***Hybrid schemes*** where the mass-flux closure ideas and the ensemble-mean second-order closure ideas have roughly equal standing. (EDMF, Soares et al. 2004, Siebesma and Teixeira 2000)

- ***Non-local second-order closure schemes*** with skewness-dependent parameterisations of the third-order transport moments in the second-moment equations. Such parameterisations are simply the mass-flux formulations recast in terms of the ensemble-mean quantities!

Issue N°4: Geometry of clouds and rain (1/4)

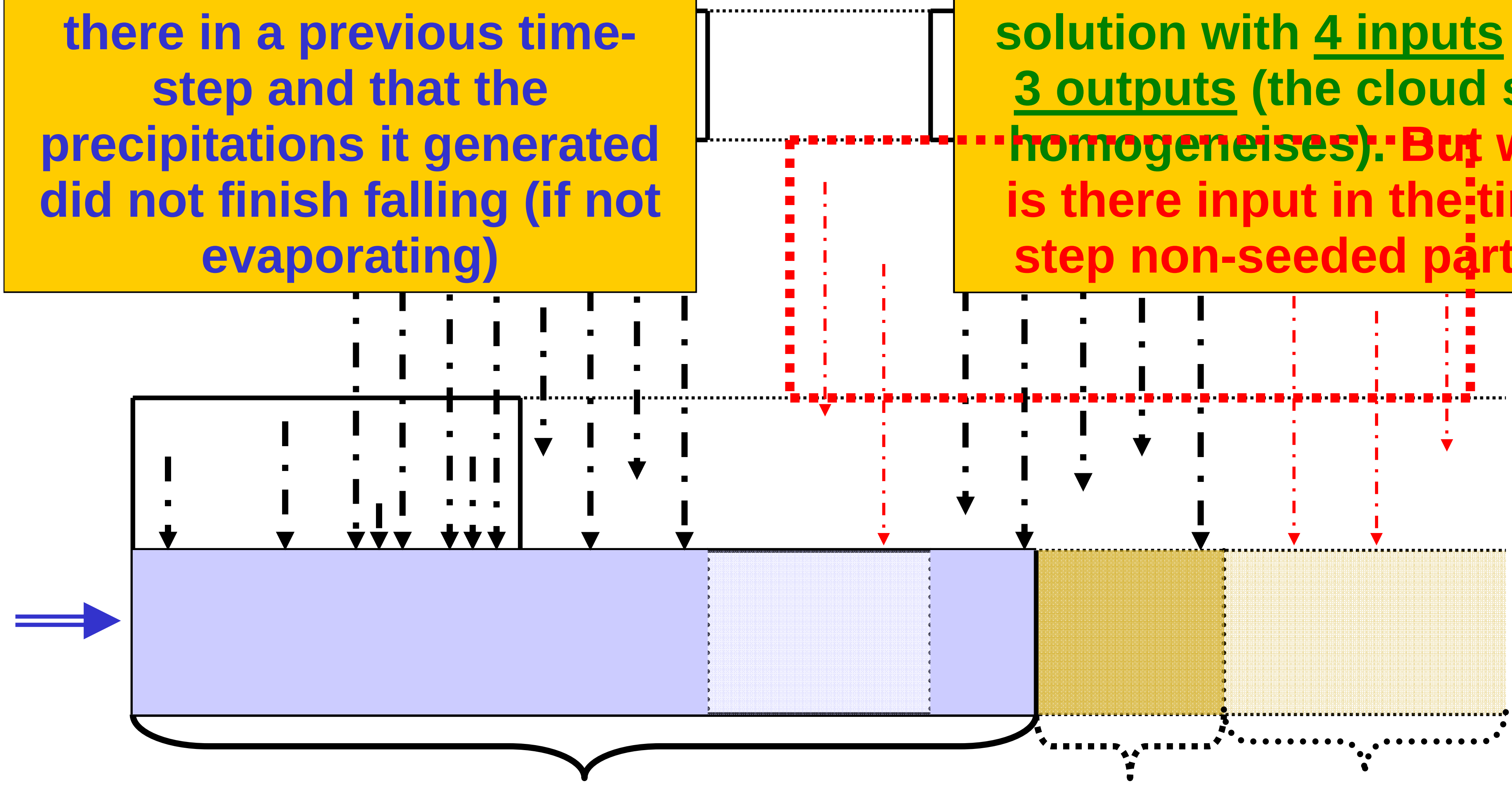
- Microphysics:
  - Processes of collection, evaporation and melting/freezing of falling precipitations depend on:
    - Cloudy or clear-sky environment locally and above;
    - Whether considered parcel is ‘seeded’ or not.
  - Why: because sub-grid convective clouds cannot be represented by mean grid values
  - How: the ‘process’ routines are called for geometrical categories, as needed.

Geometry of clouds and rain => how to find an algorithm to describe this kind of facts?

Geometry of clouds and rain (3/4)

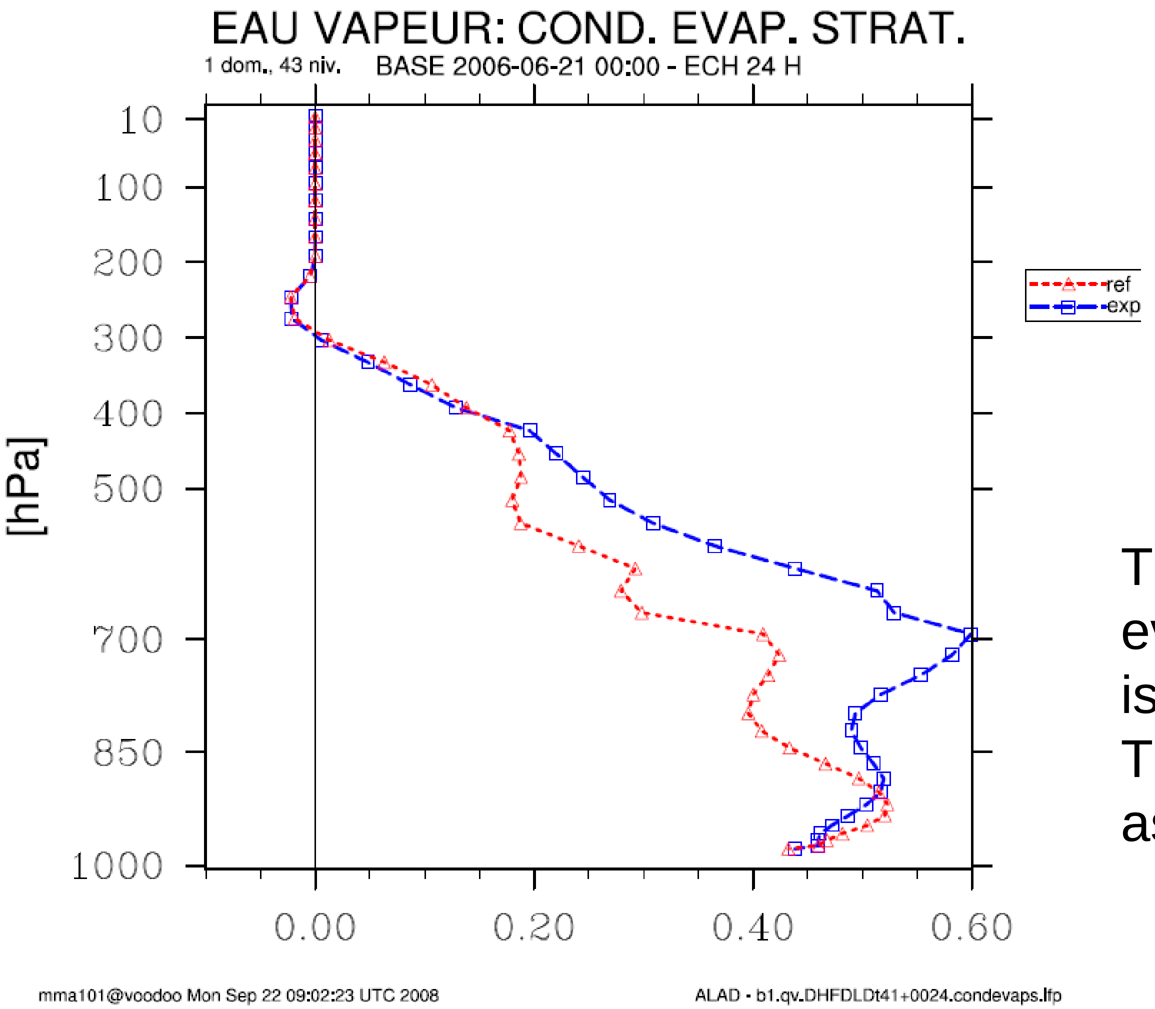
Because there was a cloud there in a previous time-step and that the precipitations it generated did not finish falling (if not evaporating)

This is now the correct solution with <u>4 inputs</u> and <u>3 outputs</u> (the cloud still homogeneises). But why is there input in the time-step non-seeded parts ?



Random overlap of parts separated by clear air, maximum overlap of adjacent parts (schematic view)

Geometry of clouds and rain (4/4)



Two options are currently coded:

- Maximum overlap of clouds (more realistic) – reference;
-Random overlap of clouds – exp 1

The impact (here shown for evaporation of falling species) is not negligible.
The problem cannot be treated as linear.

Issue N°5: entrainment

- Seems to become the 'core' topic of 'parameterisation' (in opposition to modelling).
- Several parallel attempts:
  - More physically based prescription (P. Bechtold, ECMWF)
  - Try to go back to some basic equations (De Rooy & Siebesma)

$$\varepsilon_{\exp} = \frac{\alpha B}{w_c^{\ 2}} - \frac{1}{w_c}\frac{\partial w_c}{\partial z} \qquad and \qquad B(\varepsilon, w_c)$$

$$M = a_c w_c \qquad and\ be\ brave\ enough\ to\ trust\ your\ 'a_c'?$$

  - Try adding some 'external' physics in this crucial part of the parameterisation (ALARO => cold pool mechanism).

validation

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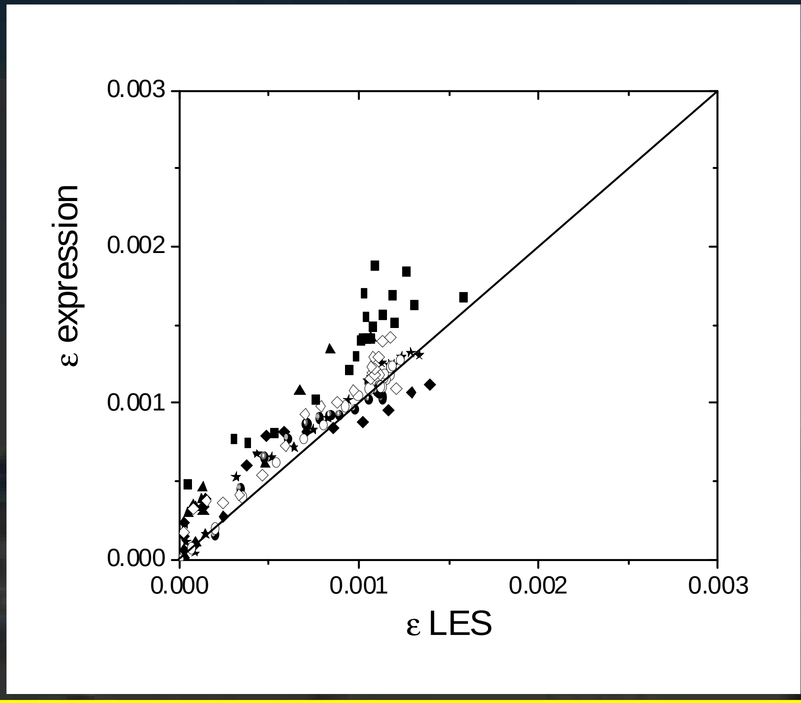
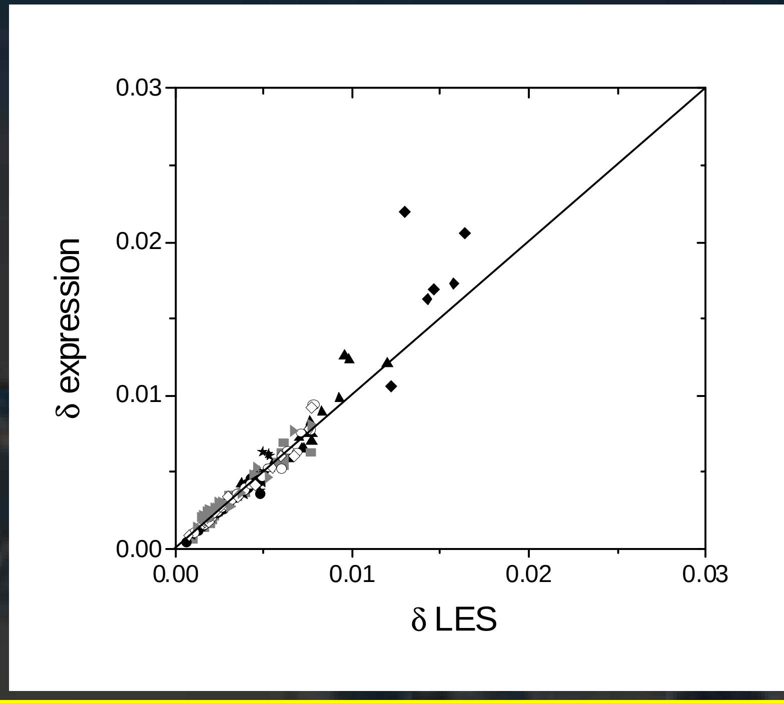
ARM





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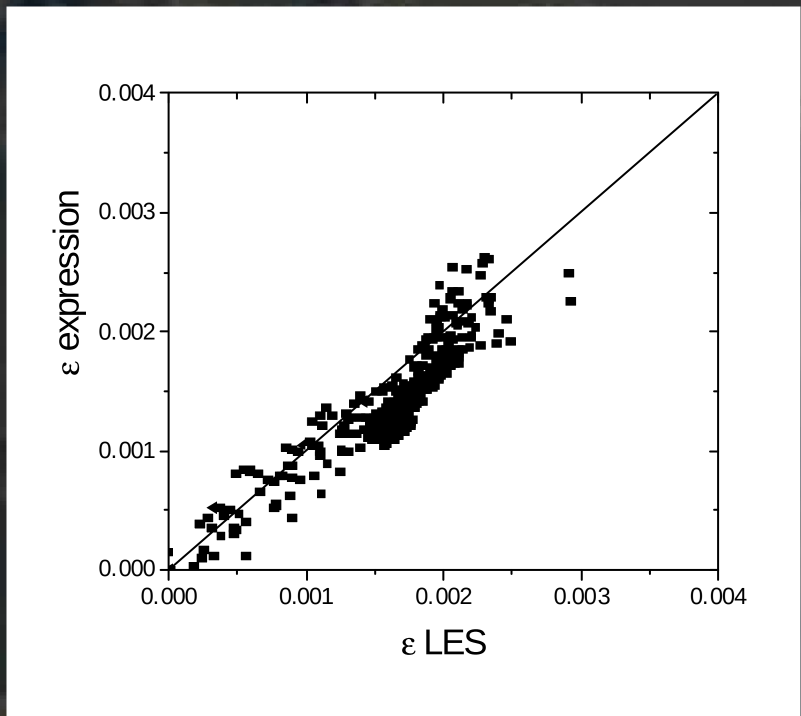

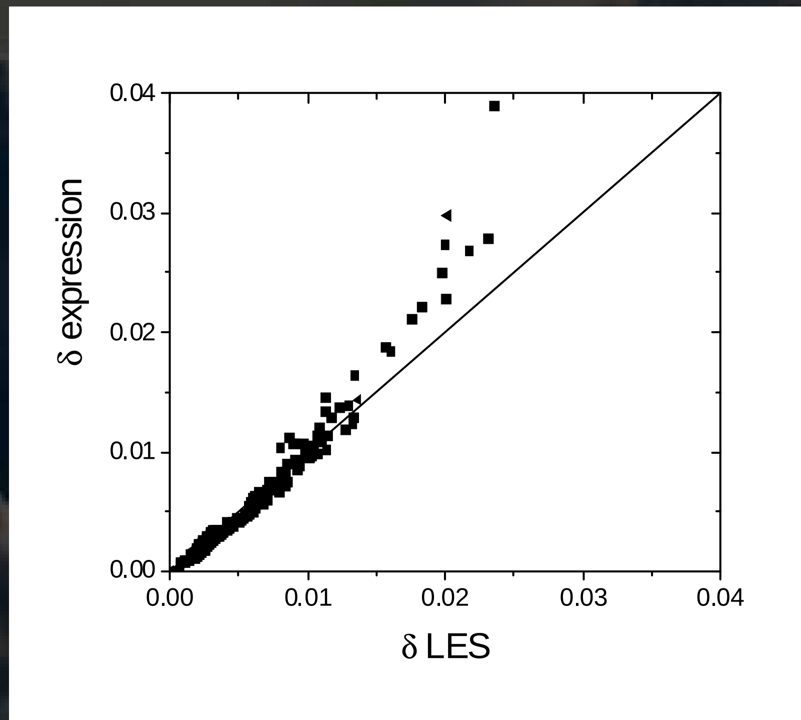

ARM

validation

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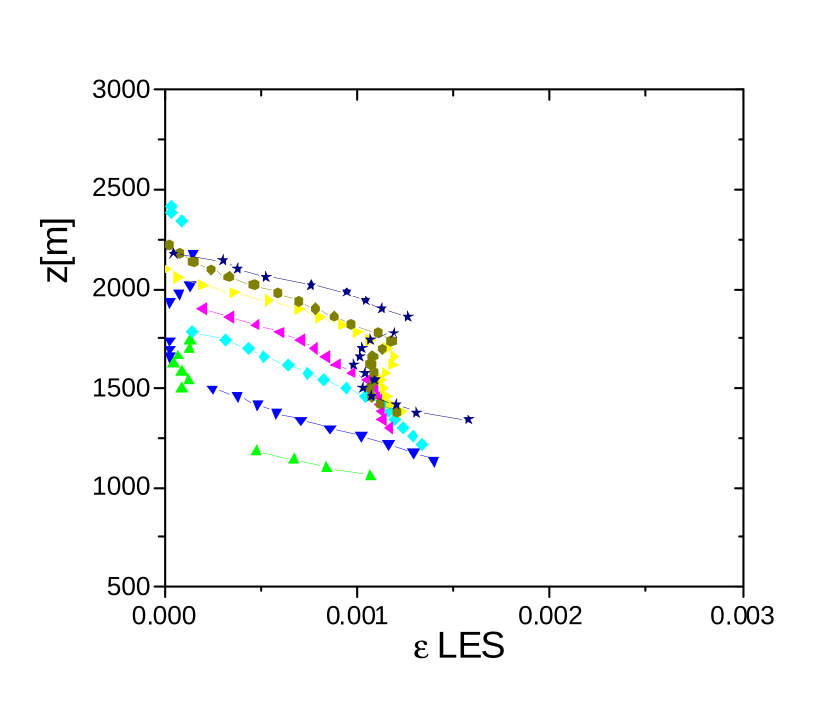
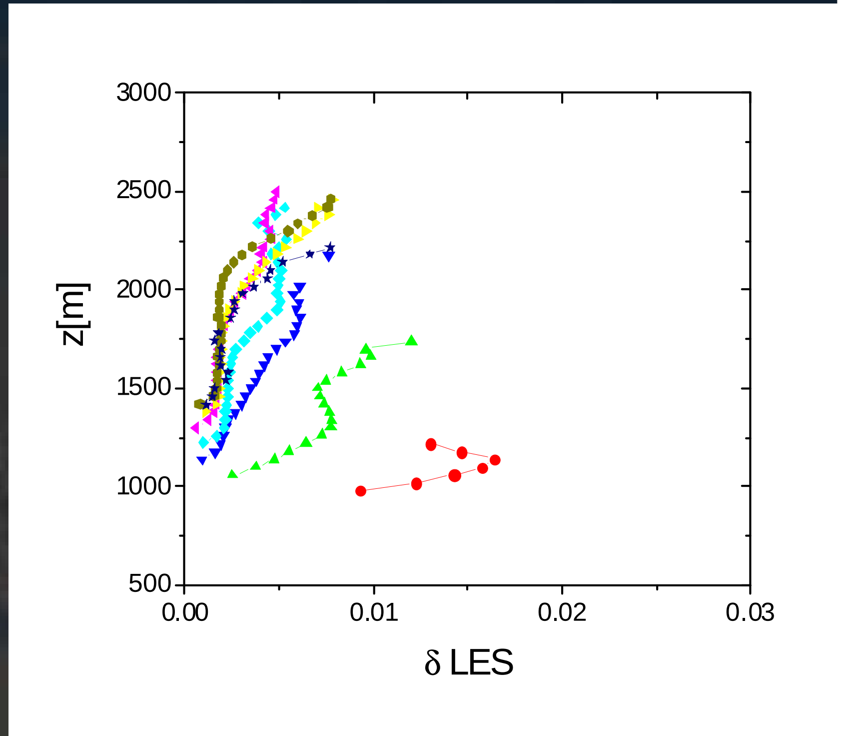
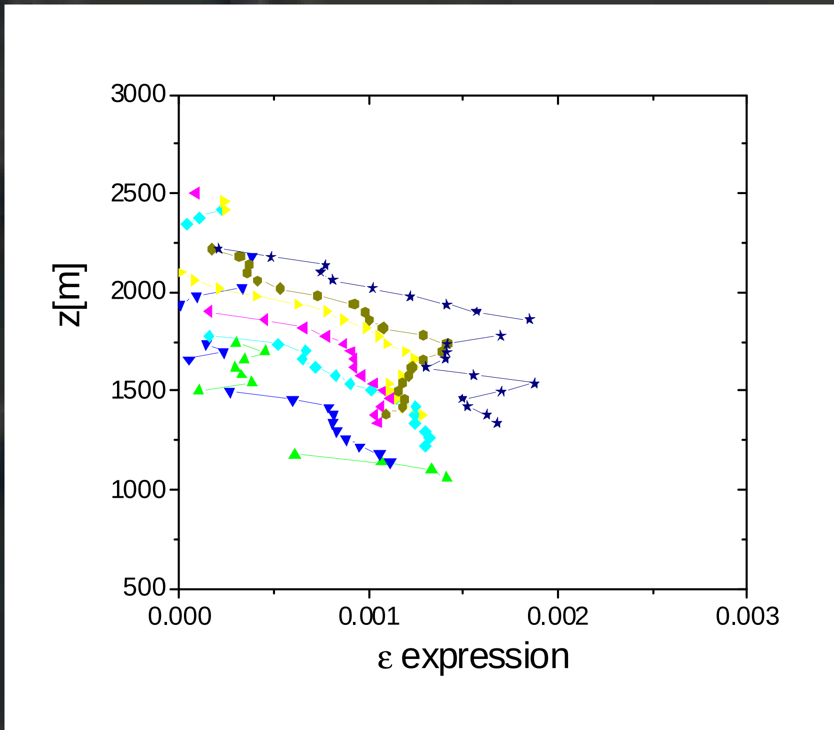
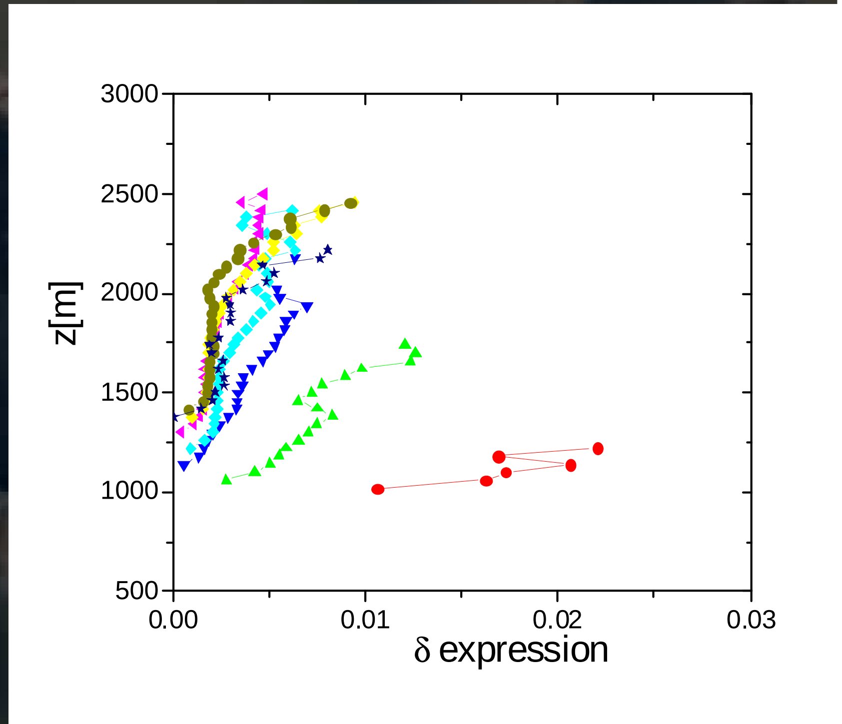
LES
(Best estimate)





expression





Some ideas/results about 3MT

Main choices
Implementation characteristics
Grey-zone results

3MT, the acronym

- Three ideas/concepts:
  - ***M***odular, because of the ALARO-0 effort made in order to stay compatible with a general phys-dyn interfacing while searching proximity with the AROME concepts (R. Brozkova, I. Stiperski, J.-F. Geleyn, B. Catry, D. Banciu);
  - ***M***ulti-scale, because a great deal of the architectural constraint comes from the ‘grey-zone’ oriented work, initiated in 2001 by L. Gerard;
  - ***M***icrophysics & ***T***ransport, to underline the decisive catalysing role played by the central proposal of J.-M. Piriou’s PhD work, made in 2004.

Microphysics AND Transport (M-T)

- It is the basic idea behind all what follows.
- Allows to rethink around two trivial facts:
  - ‘Detrainment’ here = ‘Entrainment’ somewhere else.
  - ‘Cloud+precipitation microphysics’ is anything but instantaneous (fall speed of drops ~ propagation speed of convective structures).

CONSEQUENCES

- 3MT gets away from assumptions of a stationary cloud (neither in size nor in properties).
- 3MT fully takes into account the fact that microphysics has a rather long lag-time and is not only happening ‘within the drafts’.

One key equation

$$\frac{\partial \sigma_{up}}{\partial t} + \overline{\omega}\frac{\partial \sigma_{up}}{\partial p} = \frac{\partial M_c}{\partial p} + E - D \qquad (M_c = -\omega_c \sigma_{up})$$

- **If we set**
  - M_c from two independent prognostic equations for ω_c and σ_{up}
  - σ_{up} as constant (in the cloud) along the vertical => 2D-only closure
  - E from 'something' (see elsewhere in the presentation)

- **Then D cannot be 'parameterised'** (overdetermination otherwise) and ***it is obtained from all other computations***. Piriou et al. (2007) showed that it is in fact mainly constrained by the microphysical activity => a justification for using the M-T decomposition.

Time- and space-scale issue

- Basically, 3MT is a way to do ‘***as if***’ deep convection was resolved but ***without*** needing to go to scales where this is true.
- This is thanks to:
  - Prognostic and diagnostic ‘memory’ of convection;
  - A unique micro-physical treatment beyond all sources of condensation.
- But, owing to the peculiar role of entrainment in the M-T concept, this requires to better ***understand*** what one means when ‘specifying’ entrainment in one way or the other.

The nice sides …

- NWP orientation: bulk mass-flux but fully prognostic handling of the mass-flux AND of the 2D closure.
- With M-T, the 2D closure and a prognostic equation for the mass-flux, no need to parameterise anymore detrainment.
- Facility to work on 'modularity for flexibility'.
- One single microphysical-type computation, except for the condensation/re-evaporation, the latter being obtained from the sum of a 'resolved' contribution and of a 'convective' one.
- Lot of freedom for a complex fully prognostic micro-physics => more 'memory' of past convective events.
- The 'cold-pool' effect's parameterisation should happen quite naturally in this framework.

But …

- The handling of the ‘cascade’ (neither sequential nor parallel treatment of individual contributions) is not always easy:
  - Avoiding ‘double-counting’ for updraft and downdraft closure is not trivial;
  - The sedimentation aspect of the downdraft impact must be treated heuristically;
  - In order not to be forced to iterate expensive computations, one must make judicious choices about which information to pass or not to pass to the next time-step (and on how to best use it).
- Not enough effort was devoted to the closure formulation, especially in view of its ‘multi-scale’ impact.
- For a ‘deep’ framework, a vertically constant area fraction for drafts is OK; but this does not hold anymore in the ‘shallow’ case.

3MT, the backbone

Unique vertical loop for the microphysics, made purely ‘local’ thanks to ‘PDF-based sedimentation’ (Geleyn et al., Tellus-A, 2008)

↑ ↑

This ‘microphysics’ is sandwiched between up- et downdrafts’ computations (Gerard, QJRMS, 2007)

↑ ↑

Sequential handling of both condensation sources, but summing of their inputs for a unique‘microphysics’ call (Gerard et al., MWR, 2009)

↑ ↑

Prognostic, barycentric and conservative phys-dyn interfacing (Catry et al., Tellus-A, 2007)

↑ ↑

$M_c^{u/d}(p)$=-$\sigma_{u/d}(p).\omega_{u/d}(p)$, both prognostic (Gerard & Geleyn, QJRMS, 2005)

↑ ↑

Convective equations in Microphysics-Transport form (Piriou et al., JAS, 2007)

↑ ↑

3MT is NOT (only) a deep convection parameterisation scheme (1/2)

- The ‘mass-flux’ part is central to it, but it also has key consequences elsewhere in the moist physics:
  - Organisation of the clouds- and precipitations microphysics (influences the choice of the sedimentation treatment)
  - Algorithmic links between both types of condensation (key role of the ‘cloudy detrained part => **see example**)
  - Hybrid solution (‘cascade’) between parallel & sequential physics upgrades for one time step (avoiding double-counting but preserving conservation laws)
- Apart the prescription/parameterisation of the entrainment rate, all this requires some minimum algorithmic superstructure (which in turn ensures full modularity for the description of ‘processes’)

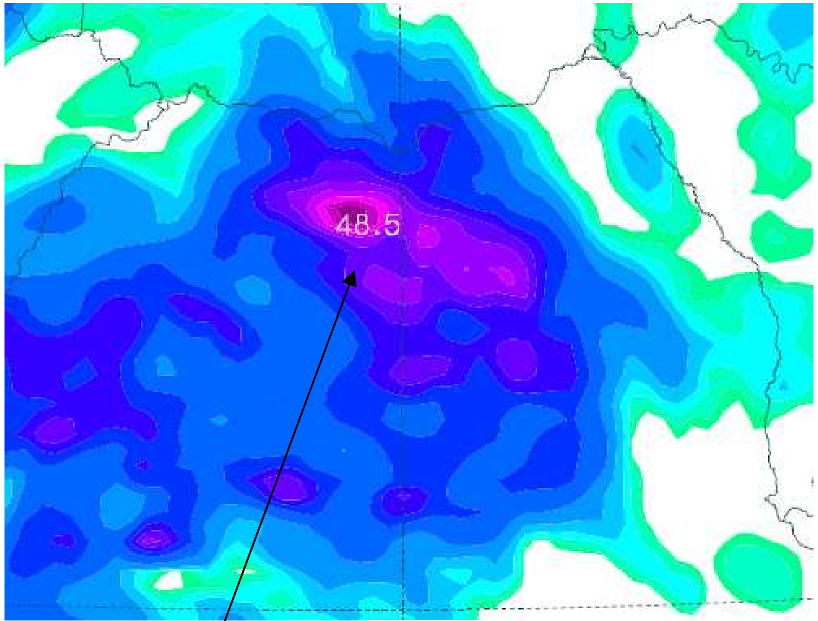
3MT is NOT (only) a deep convection parameterisation scheme (2/2)

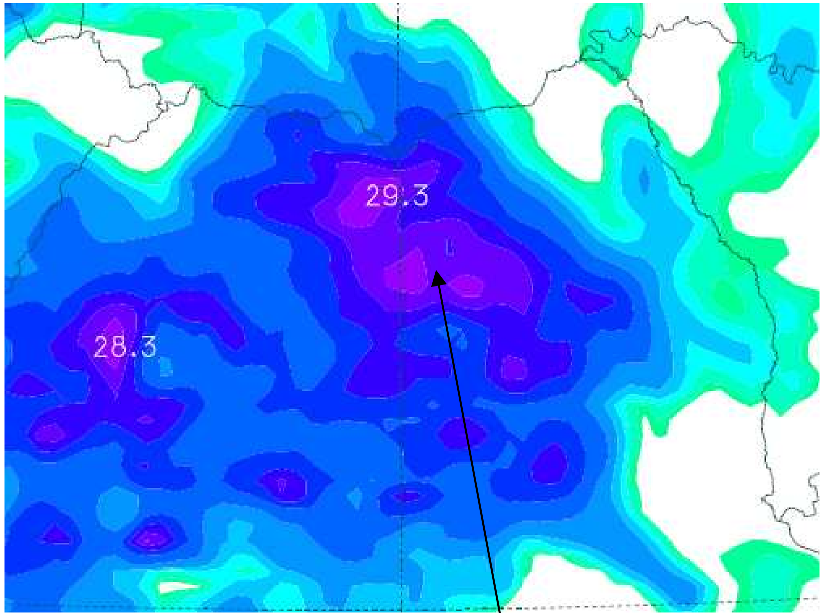
- The spirit of 3MT should in principle allow to treat any kind of convection (precipitating [like up to now], non-precipitating, dry).
- But the link with the 'resolved' condensation requires that the convective part connects the 'thermal' with the environment (Transport = return current outside).
- Hence if the 'shell' approach leads to classify 'shallow' the clouds with full self organisation, those cannot enter the 3MT logic.
- This leads to rather try and treat 'shallow convection' on the turbulent side (the 3rd of Mironov's alternatives: non-local second-order closure).

Adjustment and existing convective clouds (1/2)

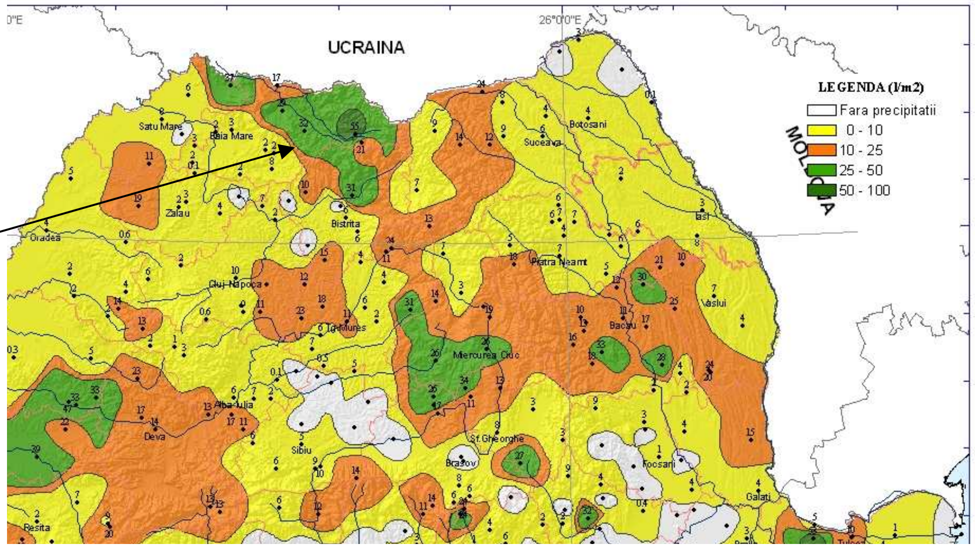
- When parameterised convection is fully prognostic (case of 3MT), associated condensates are not all converted to falling species within the same time-step.
- If nothing is done, adjustment process at the beginning of the next time-step will treat them as mean box values and they will evaporate in surrounding dry air. Contrary to intuition, this has an important feed-back on the convective activity.
- Cure: to introduce an option into the adjustment computation taking into account the existing convective cloudiness.

Adjustment and existing convective clouds (2/2)





3MT standard



24h precipitation sum
Courtesy of INMH

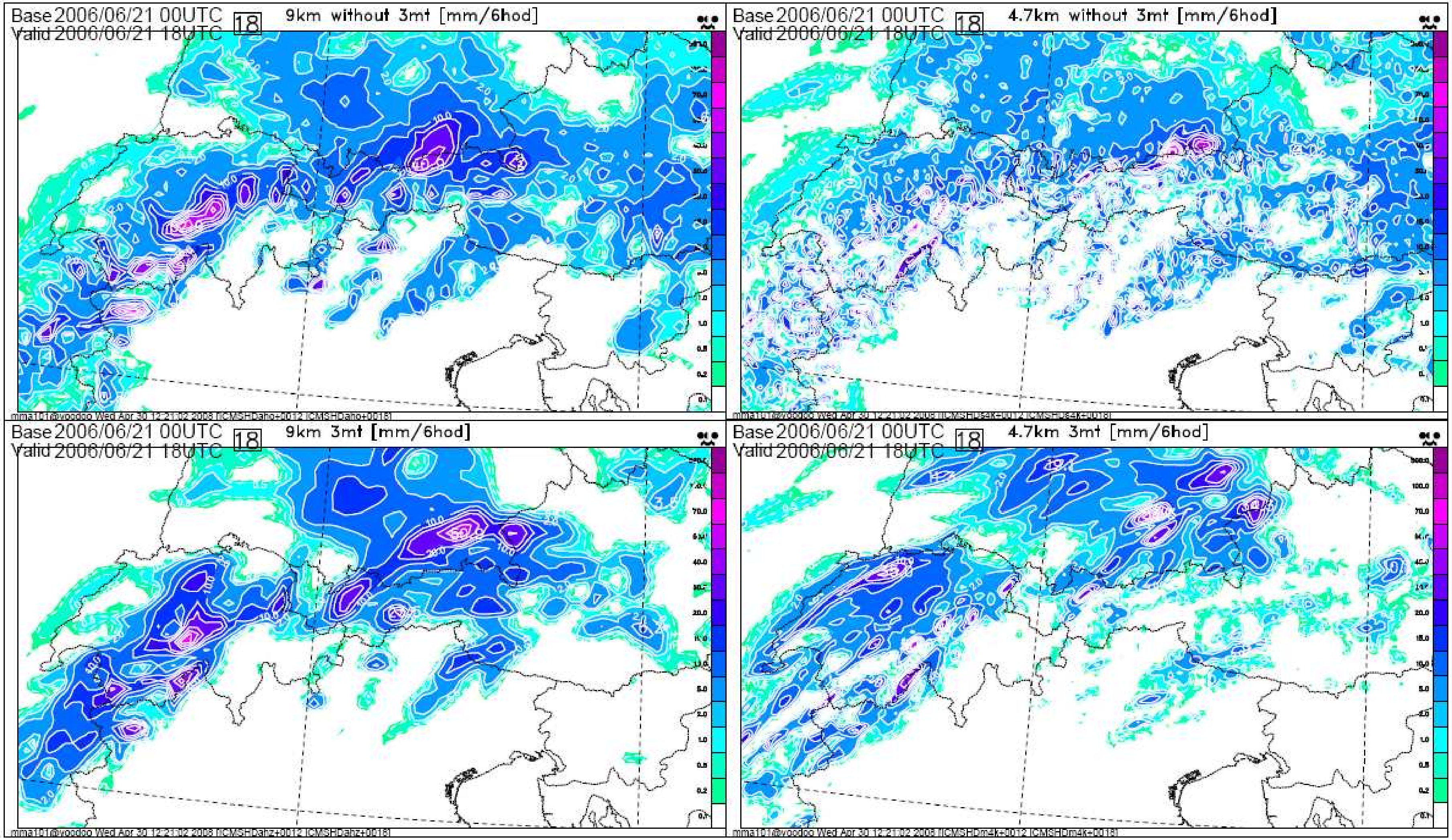
3MT but existing convective condensates are treated as resolved in the new time-step: the squall line structure is smoothed out.

Scalability of precipitation patterns

δx=9.0 km | δx=4.7 km

Without 3MT

With 3MT



3MT’s sampling of the ‘grey-zone’

Diagnostic convection representation incompatible with ‘grey-zone’ scales

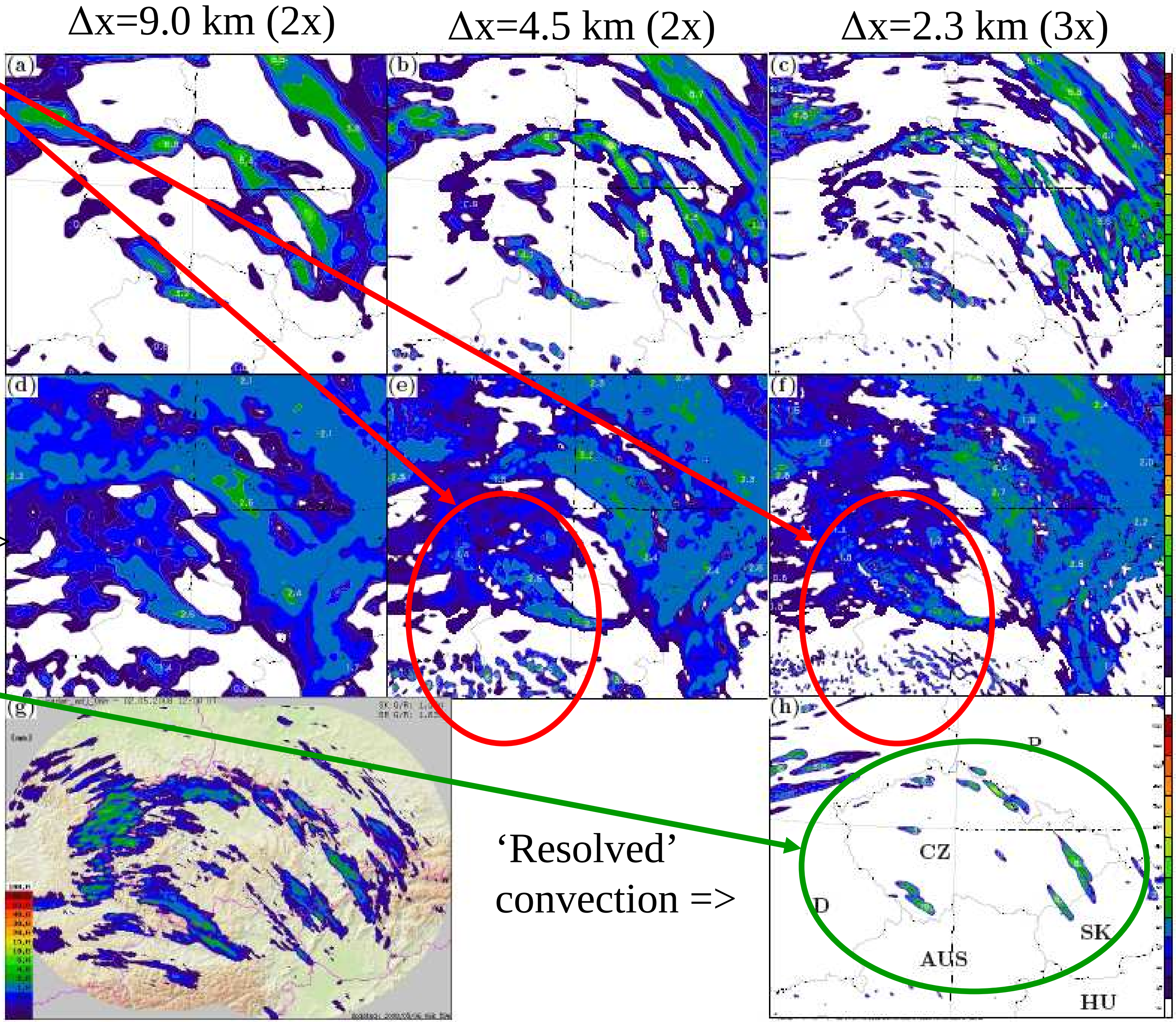
A0 with 3MT =>

A0 without 3MT =>

At least here and then, convection parameterisation is necessary at 2.3 km scale

Observed precipitations =>

‘Resolved’ convection =>



(Still preliminary) lessons

- The core ideas of 3MT (for addressing BOTH aspects of the ‘grey-zone’ syndrome) work rather well.
- There is still quite a lot of work to be done on:
  - Closure;
  - Self-extinction of the purely ‘deep’ part at high resolution;
  - Harmonisation of the various aspects of cloudiness;
  - Prescription/parameterisation of the entrainement rate.
- The implied ‘low-level’ definition of ‘Modularity’ is still creating some controversy.
- The way to address the link with shallow convection is and will remain a hot-topic (this closes the loop with ‘***Tartu***’ => let us make ‘***Norrköping***’ as vivid a remembrance into 4 or 5 years)!