On the role of entrainment at the grey zone scales

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What is meant by grey zone

- Processes are partly resolved, partly sub-grid scale – the notion of grid-box averaging operator changes.
- Well known example of precipitating convection, with the “worst” grid resolution somewhere between 7 and 3 km.
- The limits of grey zone are not settled, it depends on process: scientifically attractive problem and quite desirable one to solve for practical reasons => ALARO 5km project of RC LACE with strong contribution of Belgium.
- ALARO with its 3MT moist physics framework is an example of solution how to tackle the grey zone dilemma. For precipitating convection it is likely one of the most advanced approaches available (ES 0905 Cost action). We have now many operational or pre-operational uses of it in ALADIN and HIRLAM at grey zone scale.
- Examples used in what follows – ALARO/CZ application with 4.7km and 87 levels.

Recall on 3MT algorithm

- 3MT is working alike in the “resolved convection case” *(one consistent call to complex microphysics)* but with sub-grid scale parameterization parts *(still a transport term for deep convective drafts)*:
  - Thermodynamic adjustment, downdraft, mixed cloudiness, …
  - **Entrainment**;
  - **Microphysics**.
- Closure (moisture convergence) gives equation for mass flux, yielding:
  - Detrainment;
  - Cloudiness contributions;
  - Fluxes: precipitation (also evaporation) and transport.

Cascade General layout

(Fix negative contents from advection) $\Big\} \longrightarrow J_\ell^{cor},\ J_i^{cor},\ J_v^{cor}$

$[q_v^*, q_i^*, q_\ell^*] \swarrow$

$\boxed{\text{Resolved cloud fraction}}$

st $\swarrow$

$(f^*$, Radiation)

$\searrow (T_{\rm surf}$, Turbulent diffusion) $\longrightarrow J_\ell^{td},\ J_i^{td},\ J_v^{td},\ J_S^{td}$

$[\cancel{q_v^*}, q_i^*, q_\ell^*, T^*] \swarrow$

$\boxed{\text{Resolved condensation}} \longrightarrow F_{vi}^{st},\ F_{v\ell}^{st}$

$[q_v^*, q_i^*, q_\ell^*, T^*] \swarrow$

isture
onver- $\longrightarrow \boxed{\text{Deep convection}} \longrightarrow F_{vi}^{cu},\ F_{v\ell}^{cu},\ J_v^{cu},\ J_i^{cu},\ J_\ell^{cu},\ J_S^{cu},\ J_V^{cu}$
gence

$[q_v^*, q_i^*, q_\ell^*, T^*] \swarrow$

$$f^{cu} = \sigma_D + \sigma_u,$$

$$\alpha_{\rm cu} = \frac{F_{vc}^{cu}}{F_{vc}^{cu} + F_{vc}^{st}} \longrightarrow f^{eq}$$

$\boxed{\text{Microphysics}} \longrightarrow F_{is},\ F_{\ell r},\ [F_{\ell i}],\ \mathcal{P}_r,\ \mathcal{P}_s,\ F_{rv},\ F$

$F_{hP} \swarrow \quad [q_v^*, q_i^*, q_\ell^*, T^*] \swarrow$

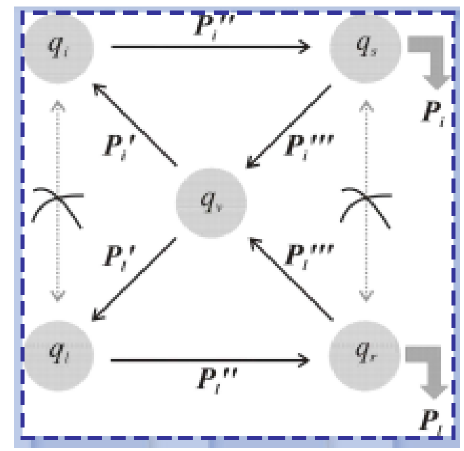
$\searrow \boxed{\text{Downdraught}} \longrightarrow F_{rv}^{dd},\ F_{sv}^{dd},\ J_v^{cu},\ J_i^{cu},\ J_\ell^{cu},\ J_S^{cu},\ J_V^{cu}$

$[q_v^*, q_i^*, q_\ell^*] \swarrow \quad \mathcal{P}_r,\ \mathcal{P}_s \swarrow$

$\alpha_{\rm cu} \longrightarrow$ (Convective/ Resolved) $\longrightarrow \mathcal{P}_r^{cu},\ \mathcal{P}_s^{cu},\ \mathcal{P}_r^{st},\ \mathcal{P}_s^{st}$

Microphysics (1)

- PDF based sedimentation:
  - Statistical handling of fall speeds.
- Thermodynamics:
  - All phase changes go through the vapor phase for budgeting.
- Prognostic species: q_v, q_l, q_i, q_r, q_s (and diagnostic q_g)
- Future version with prognostic q_g is under preparation; graupel is sub-type of snow for thermodynamics.

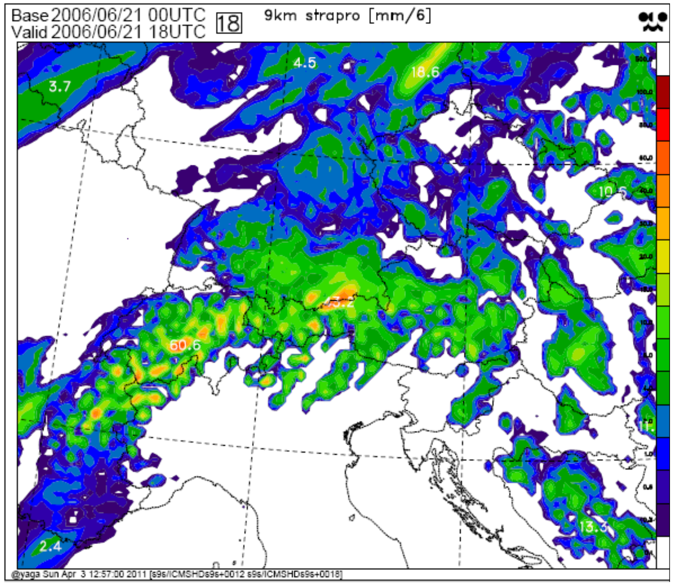


Microphysics (2)

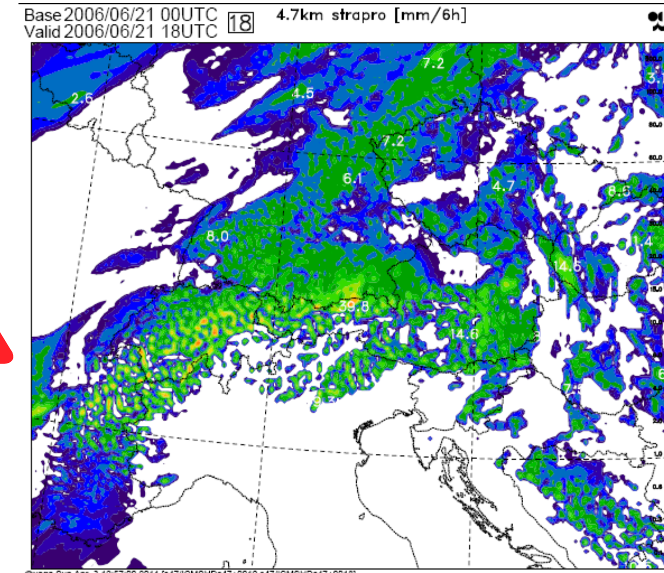
- Processes:
  - Autoconversion including WBF;
  - Collection;
  - Evaporation, melting, freezing.
- Sub-grid geometry of clouds
  - Maximum overlap (like in radiation scheme) => less extreme solution under development;
  - Some processes (e.g. collection, evaporation), depend on combination of categories: cloudy or clear air, seeded from above or not.
- Key component of 3MT: microphysics directly acts on the sum of the two condensation processes (stratiform and convective).

Grey zone study – influence of prognostic microphysics

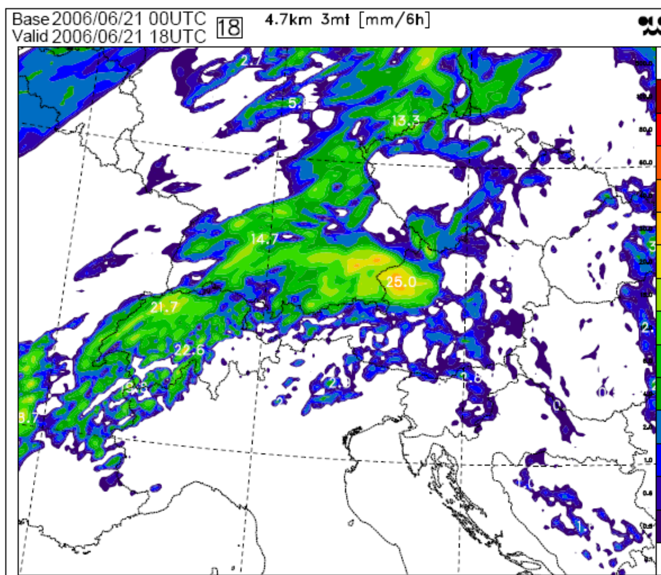
9km old diagn. convection

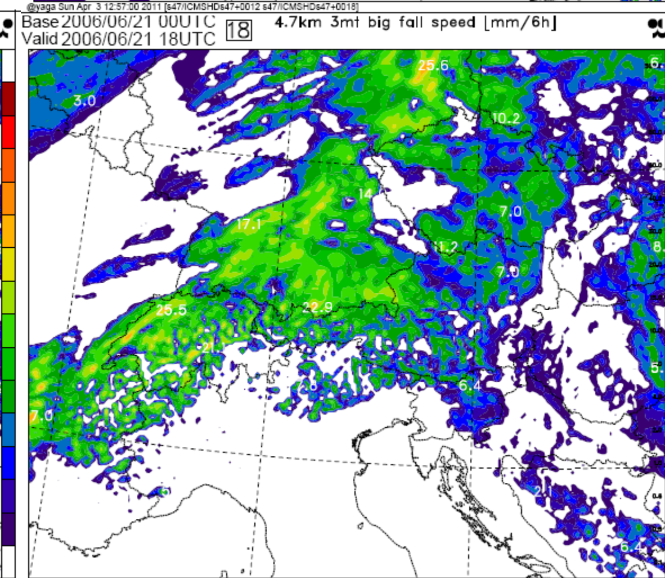


4.7km old diagn. convection



4.7km with 3MT
Left: standard
Right: infinite fall speed of precipitation





Entrainment – starting point (1)

- Entrainment is parameterized in the same way as in the old diagnostic moist deep convection scheme (ACCVIMP/ACCVIMPD):

$$\lambda_u = \lambda_n + \left(\lambda_x - \lambda_n\right)\exp\left(-\lambda_x^{3/4}\lambda_n^{1/4}\left(\phi - \phi_b\right)\right) \qquad \lambda_d = const$$

units: kg/J ≈ $0.1\ m^{-1}$

$$\lambda_n = \frac{1}{1/\mathbf{E_n} + \boldsymbol{\alpha} I_b} \qquad \lambda_x = \frac{1}{1/\mathbf{E_x} + \boldsymbol{\alpha} I_b}$$

E_n, E_x and α are tuning parameters; I_b is vertically integrated buoyancy of undiluted ascent.

Entrainment – starting point (2)

- Modulation of entrainment by **α** simulates a positive feed-back: potentially more buoyant updrafts feel less the mitigating effect of entrainment.
- Another allowed modulation of entrainment profile should reflect variability in sub-grid population (buoyancy sorting). It is simulated through a modification of the geopotential thickness in the computation of moist adiabatic ascent.

$$\Delta\phi' = \Delta\phi \Big/ \left\{ 1 + \nu \frac{\phi - \phi_b}{\phi_t - \phi_b} \max\left(0, h_{undl} - h_u\right) \right\}$$

with tuning parameter **v**

(ν and α are acting in opposite directions, but for distinct processes).

We have 4 tuning parameters for entrainment parameterization: E_n, E_x, α, and ν.

Entrainment – starting point (3)

- Basic lessons of operational tuning steps:
  - When going to 3MT one needs strong increase of entrainment (more than doubling) via all four parameters. This brings the entrainment rates closer to observed/LES values.
  - Recent retuning following changes in downdraft parameterization and mesh size going from 9km to 4.7km: **α** is then the lead parameter that allows coping with changes in thermodynamic profiles.
- Up to now we stayed in a static view of parameterizing λ_u.

Prognostic entrainment

- Proposal of Piriou (2007), worked out by Gerard and Banciu:

$$\lambda_u = \frac{S\lambda_x\left(1-\xi\right)+S\lambda_n\,\xi}{\phi-\phi_{surf}}$$

With tunings $S\lambda_x = 3.$, $S\lambda_n = 0.3$

$$\frac{\partial\xi}{\partial t} = \frac{\kappa_E}{\tau_E}\sigma_D\left(1-\xi\right)^2-\frac{\xi^2}{\tau_E}$$

- Motivation: better diurnal cycle of convection, via improved transition from shallow to deep, following Piriou (2007) and demonstration in 1D case (EUROCS).
- Introduction of prognostic entrainment had weak and unstructured impact, contrary to expectations => need for understanding.

Convective diurnal cycle study

- Period of 21 June to 5 July 2009:
  - Large shallow cyclone in Central Europe, weak frontal activity;
  - Deep convection every day over land – ideal to study diurnal cycle.

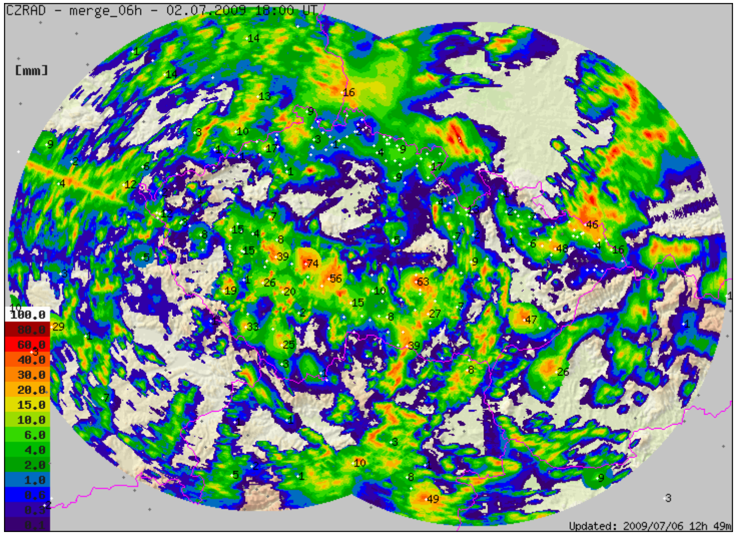
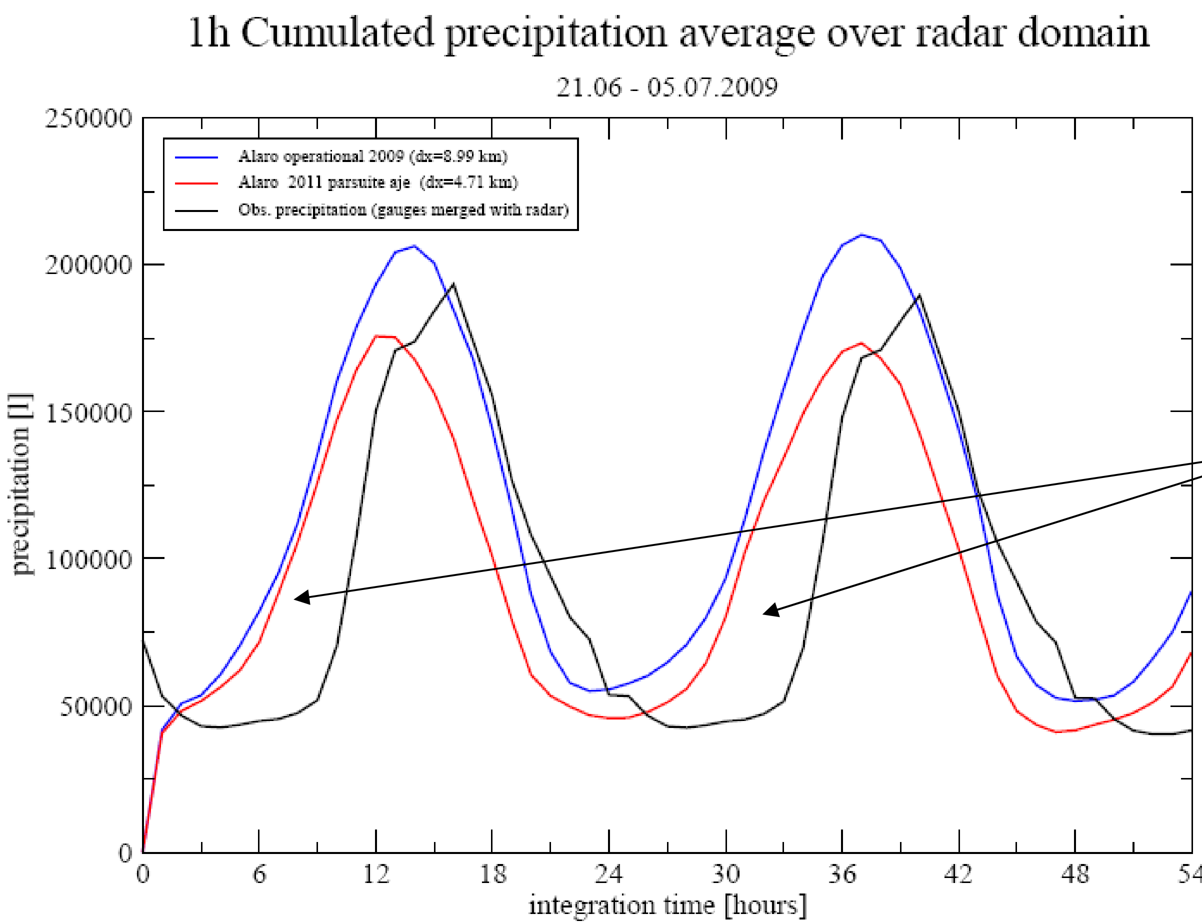


Illustration of afternoon convective activity, July 2, 2009: CZ radar estimation of precipitation combined with gauges, for 6h interval between 12-18h

For the study hourly precipitation estimates are available for the whole period.

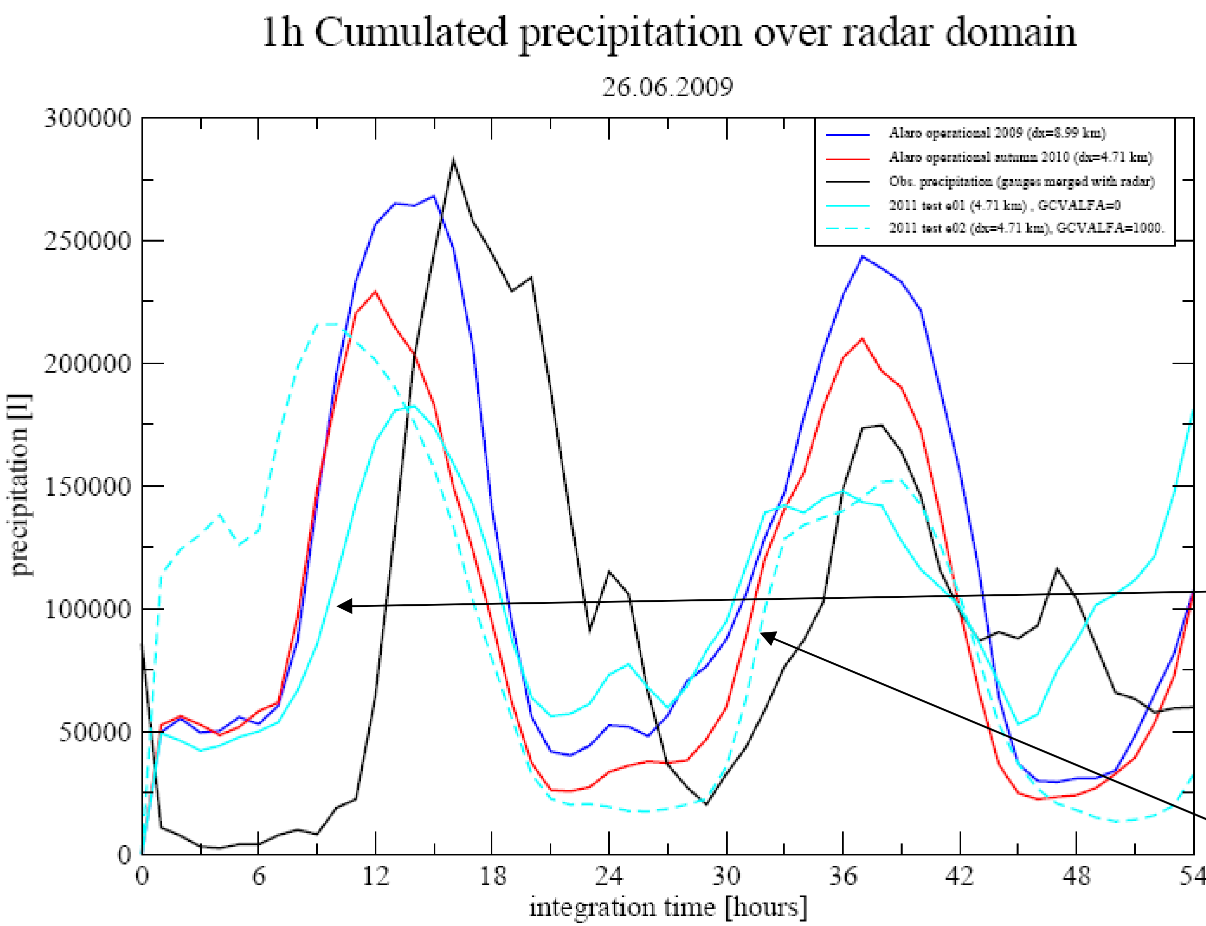
Results with original formulation of mixing – the static one



Black: observations
Blue, Red: model
(versions 2009, 2010)

In the model convection starts too early in the morning.

Results with prognostic mixing – limit values



Black: observations
Blue, Red: model
(versions 2009, 2010)

Full light blue: α=0 => strong mixing, between 5.E-06 and 1.6E-04 in the profile;
Dashed light blue: α=big value => almost no mixing

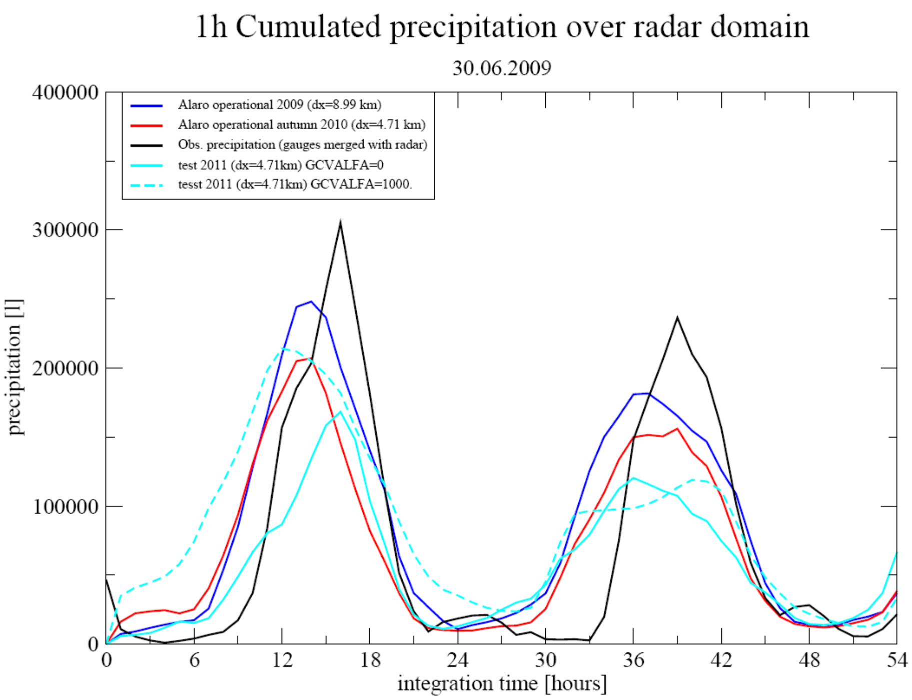
Even with strong mixing convection starts too early.

There is no difference in the timing for the second day

Without entrainment precipitation steadily decrease. With a lot of it, opposite behavior !?

Conclusions, outlook

Previous result rather robust



- Mixing has more influence than microphysics details.
- No way of getting a good diurnal cycle by only modulating entrainment (contrary to 1D controlled tests).
- Need to study closure assumption now, probably.
- Identifying the key ingredient of 3MT's good grey zone behavior is still an independent issue.