# Scale aware deep convection parameterization

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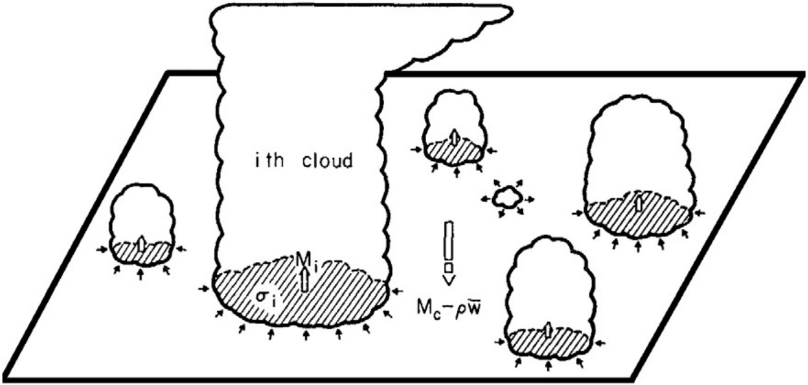
# Convective clouds in a model grid box

Quasi-Equilibrium hypothesis: Large subgrid population, all stages represented, adjusts faster than 'larger-scale' forcing



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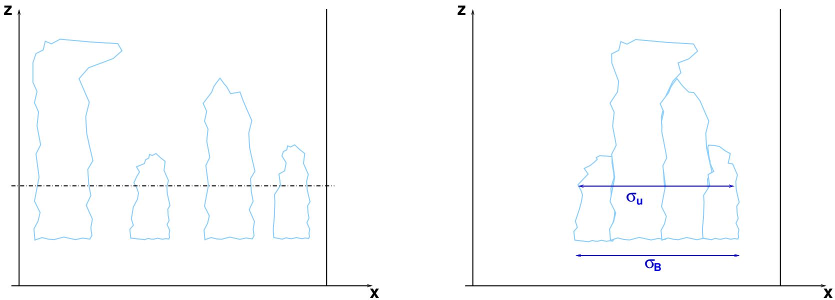
- Grid spacing resolving a phenomenon of size $\ell$: $\triangle x \sim \ell/6$

# Bulk parameterization




Equivalent bulk updraft

$\Rightarrow$ ensemble effect, decreasing together with $\triangle x$

- detrainment profile
- effect on bulk updraft properties: $h_u$ increases upwards
- $\sigma_u$ profile: $\sigma_u = \sigma_B \cdot \nu(z, \sigma_B)$

# Prognostic approach

Why:

- $\Rightarrow$ reduced subgrid variability, short time steps
- $\Rightarrow$ Allows feedback/interaction of other parameterizations:
  Downdraft $\rightarrow$ PBL, cold pools $\rightarrow$ triggering, CAPE
  Downdraft, evaporation $\rightarrow$ entrainment/mixing
  Anvils $\rightarrow$ radiation $\rightarrow$ modified $\psi_e$

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How:

- Updraft velocity equation $\frac{\partial \omega_u}{\partial t} = \text{drag} - \text{buoyancy}$ ($\omega = \dot{p} \approx -\rho g w$).
- Updraft gradual elevation (not in 3MT)
- Closure on base mesh fraction $\sigma_B$: at steady state
  $\rightarrow$ prognostic evolution towards it
- updraft thermodynamical properties: steady-state estimation.

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- Updraft detrains condensates, combined with those from cloud scheme $\rightarrow$ single prognostic microphysics:
  - allows a smooth transition towards fully explicit convection
  - condensates from convection are more localized:
    - equivalent cloud fraction to compute intensive values passing thresholds in microphysics
    - keep memory of 'convective area' to be protected against re-evaporation by cloud scheme next time step – relaxation in time of detrainment area ($\rightarrow$ stratiform cloud)
    - partial cloudiness and overlap rules in precipitation sedimentation

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    - partial cloudiness and overlap rules in precipitation sedimentation
- Separated downdraft scheme computed after microphysics
  - lives independently of subgrid updraft scheme
  - retrospective adjustment of precipitation contents

# 3MT Convection scheme main features

## Handles complementarity, evolution and mesh fraction

- Sequential organization of parameterizations, one single microphysics.
- Cloud scheme prevented to affect condensates in convective part.
- Evolution in time with prognostic variables
- Direct expression of DC effects through convective condensation and transport fluxes.

# 3MT Convection scheme main features

Handles complementarity, evolution and mesh fraction

Ignores direct effects of resolved updraft

- DC scheme ignores $\overline{w}$, assumes $w_e \equiv 0$.
- DC scheme pretends to represent the absolute updraft.

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Protection of convective area hinders explicit representation

- Prevents cloud scheme to evaporate *but also to condense* on convective area

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Moisture convergence closure, no explicit triggering

- Extremely cheap.
- A CAPE closure cannot be used.
- Reducing the forcing at small mesh fraction appears to improve the diurnal cycle (slowing down the onset of convection, hence leaving more CAPE accumulate).

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*but not in a way that the subgrid part would fade out*.

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- guess mesh fraction
- plume model: build entraining and braked ascent
  - turbulent mixing TENTR (deep) or TENTRX (shallow), GENVSRH dependence on RH, braking TUDFR, mass coefficient GCVALBU
  - reference properties
  - actual CSD properties: $T_u, q_u, q_{cu}$, buoyancy, $\omega_u^\diamond$
  - assumptions on normalized ud area profile $\nu \Rightarrow$ organized entrainment

| NFSIG | $\nu = \sigma_u/\sigma_B$ |
|---|---|
| 0 | 1 |
| 2 | $(1 - [\max(0, 2z-1)]^2[1 - \min(1, 2\sigma_B)^2])$, with $z = \frac{p_b - p}{p_b - p_t}$ |

  Organized entrainment limited by GCVENDYMX
  - assumption on hanging $\leftrightarrow$ detrained condensates (ECMNP/ECMNPI)
  - criterion to continue ascent: upwards velocity, MoCon (if LCVGQ=T)

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- final updraught mass flux,
- Horizontal momentum profile (TUDGP)
- Condensation fluxes with freezing/melting correction (NIMELIT), transport fluxes, detrainment area evolution GCVTAUDE

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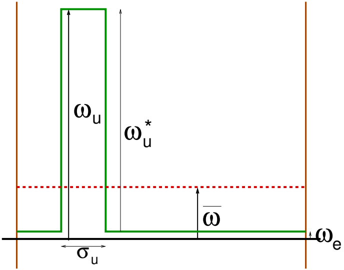


$$\overline{w} = \sigma_u w_u + (1-\sigma_u) w_e$$

actual updraft environment at rest $w_e \approx 0$ (compensating subsidence distributed over wider area)

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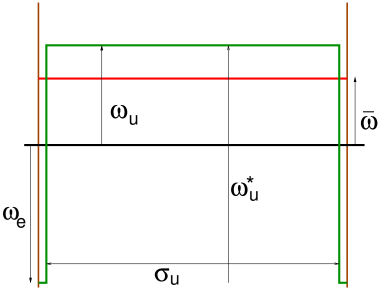


$$\overline{w} = \sigma_u w_u + (1 - \sigma_u) w_e$$

large downwards $w_e$ to fulfill geometrical constraints
no physical meaning (should induce strong adiabatic heating)

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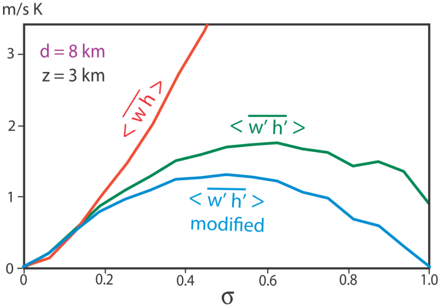

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  - Must account for $\overline{w}$ in $w_u$ equation.

# Perturbation approach

Complemetary subgrid draft (CSD)

Gerard (2015), to appear in Mon. Wea. Rev.

$$\psi_j^\diamond = \psi_j - \overline{\psi}, \qquad\qquad \sigma_u \psi_u^\diamond + (1-\sigma_u)\psi_e^\diamond = 0$$

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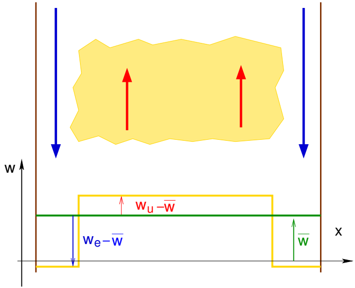

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- Perturbation draft is a *closed circulation* in the grid column
- Formal derivation from anelastic equation
  - Perturbation updraft properties account for mesh fraction, for grid-column environment vertical lapse rate.
  - Distinction between organized entrainment and turbulent mixing.

# Plume model

Perturbation updraft properties

$$\frac{\partial \psi_u^\diamond}{\partial p} = \frac{\Lambda_u'}{(1-\sigma_u)}\psi_u^\diamond + \frac{1}{\triangle p}\Big[[\delta\psi_a - \triangle\overline{\psi}\Big],$$

$$\Longrightarrow \qquad \psi_u^\diamond = \psi_b^\diamond \exp\Big(\frac{\Lambda_u'\triangle p}{1-\sigma_u}\Big) + \frac{(1-\sigma_u)}{\Lambda_u'(-\triangle p)}\Big[\delta\psi_a - (\overline{\psi}^l - \overline{\psi}^{l+1})\Big](1-\exp\Big(\frac{\Lambda_u'\triangle p}{1-\sigma_u}\Big))$$

Prognostic vertical perturbation velocity equation

$$\frac{\partial \omega_u^\diamond}{\partial t}\Big|_{sg} = \Lambda_w(\omega_u^\diamond)^2 - \underbrace{\omega_u^\diamond}_{c/\delta t}\frac{\partial \omega_u^\diamond}{\partial p} - \underbrace{\Big(\frac{\partial\overline{\omega}}{\partial p} - \overline{\omega}\frac{d\ln\rho_0}{dp}\Big)}_{d/\delta t}\omega_u^\diamond - \underbrace{\alpha_b\rho_0 g^2\frac{T_{vu}^\diamond}{\overline{T_v}}}_{B}$$

$\delta\psi_a$: either $\delta q_{ca}$ net condensate production or heating.
$\Lambda_u'$: turbulent mixing and organized entrainment.
$\Lambda_w$: drag, turbulent mixing and organized entrainment.

# ETR closure: eddy transport reduction

- Arakawa & Wu 2013: eddy transport is a fraction of the value producing full adjustment $(\overline{w'h'})_E$ responding to grid-scale destabilization:

$$\overline{w'h'} = (1-\sigma_u)^2(\overline{w'h'})_E, \qquad \overline{w'h'} = \sigma_u(1-\sigma_u)(w_u - w_e)(h_u - h_e)$$

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  - mean grid-box $\overline{\psi}$ substantially departs from real environment $\widehat{\psi}$
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$\Rightarrow$ Possible mixed closure, e.g. CAPE at small $\sigma_B$, MoCon at large $\sigma_B$

... and ETR can help to combine them

# CAPE closure formulation

- Approximation of larger-scale environment:

$$\mathrm{CAPE} = -R_a \int_{p_b}^{p_t} (T_{vu} - \hat{T}_v) \frac{dp}{p} \approx -R_a \int_{p_b}^{p_t} \frac{(T_{vu} - \overline{T}_v)}{(1 - \sigma_B)} \frac{dp}{p}$$

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- Cape relaxation (sole updraft)

$$\frac{\partial \text{CAPE}}{\partial t}\Big|_{\text{ud}} = -\frac{\text{CAPE}}{\tau}, \qquad \tau \propto \text{turnover time-scale} \sim \frac{H}{\langle w_u \rangle_H}$$

$$\frac{1}{R_a} \frac{\partial \text{CAPE}}{\partial t}\Big|_{\text{ud}} \sim \int_{p_b}^{p_t} \frac{\partial \overline{\mathrm{T_v}}}{\partial t}\Big|_{\text{ud}}$$

$$= \underbrace{\sigma_B \int_{p_t}^{p_b} \left\{ \nu \omega_u^{\diamond} \frac{\delta q_{ca}}{\triangle p} (L k_s - k_q) \right\} \frac{dp}{p}}_{\text{subgrid ud cond}} \underbrace{- g \int_{p_t}^{p_b} \frac{\partial F_{cs}}{\partial p} f(\overline{\omega}) (L k_s - k_q) \frac{dp}{p}}_{\text{resolved ud cond}}$$

# Moisture convergence closure formulation example

$$\sigma_B \int_{p_b}^{p_t} \nu(\omega_u^{\diamond} + \overline{\omega}) L \delta q_{ca} = \int_{p_b}^{p_t} L \left[ \text{mocon} - g \frac{\partial J_q^{\mathrm{tur}}}{\partial p} \right] dp$$

where moisture vertical turbulent diffusion flux $J_q^{\mathrm{tur}}$ includes shallow convection transport (BL scheme).

$\Rightarrow$ Closure preferred where shallow convection detected.

# Physically based generalized mixed closure

2(3) different closures : CAPE or Moisture ? or Eddy Transport Reduction ?

$\Rightarrow$ 2 or 3 different scaling for a same reality

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A single coefficient $\alpha$ modulates the forcing
from 100% Moisture ($\alpha$ =1) to 100% CAPE ($\alpha$ =0) :

$$\underbrace{\sigma_B(U - \alpha N)}_{\text{subgrid ud consumption}} + \underbrace{R}_{\text{resolved condensation}} = (1-\alpha)\underbrace{\frac{B/\tau}{(1-\sigma_B)}}_{\text{CAPE forcing}} + \underbrace{\alpha M}_{\text{MoCon forcing}}$$

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Modulation coefficient given by the ratio of Moisture forcing to the total forcing when using an estimate $\sigma_M$ obtained by a third closure (ETR):

$$\alpha = M \Big/ \left\{ M + \frac{B/\tau}{(1-\sigma_M)} \right\}$$

# Steady-state closure selection

| LCAPE | LCVGQ | |
|---|---|---|
| F | F | ETR closure |
| T | F | CAPE closure |
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| NCLOMIX | formula |
|---|---|
| 1 | (1) and $\sigma_M = 0$ |
| 2 | (1), $\sigma_M$ from ETR |
| 3 | (2), $\sigma_M$ from ETR |
| **4** | shallow: (1), $\alpha = 1$; deep: (2) |

# Prognostic closure

- GCVTAUSIG$<0$: extension from the moisture-convergence closure relation

$$(\sigma_B^+ - \sigma_B^-)\Big\{\int_{p_b}^{p_t} \nu(h_u - h_e)dp + \alpha_k \int_{p_b}^{p_t} \nu \frac{(\omega_u^{\parallel})^2}{2\rho_0^2 g^2} dp\Big\} = (\sigma_B^{\parallel} - \sigma_B^+)\delta t \int_{p_b}^{p_t} \nu\, \omega_u^{\parallel} L_u \delta q_{\mathrm{ca}}$$

$\alpha_k \equiv$ GCVKSKV $\sim 3$ ratio of total to vertical kinetic energy of the DC cells

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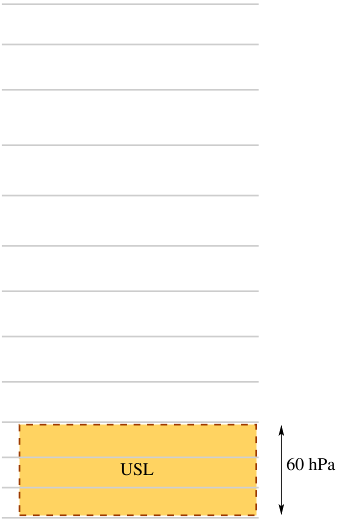
The prognostic relation is also the base for the stochastic closure.

- GCVTAUSIG$=\tau_\sigma > 0$: relaxation towards $\sigma^{\parallel}$.

# Triggering (LUSL=T)

- Updraft source layer (Kain & Fritsch): gtrgdpmix



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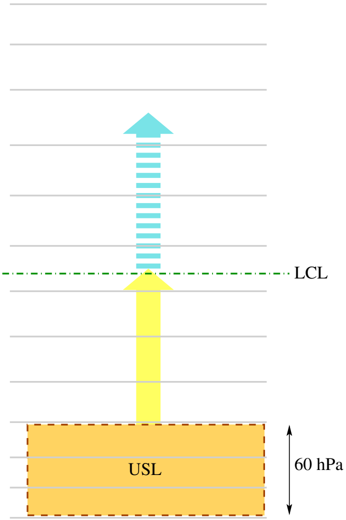

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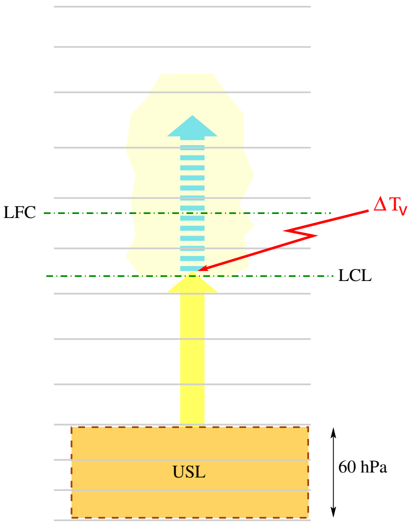

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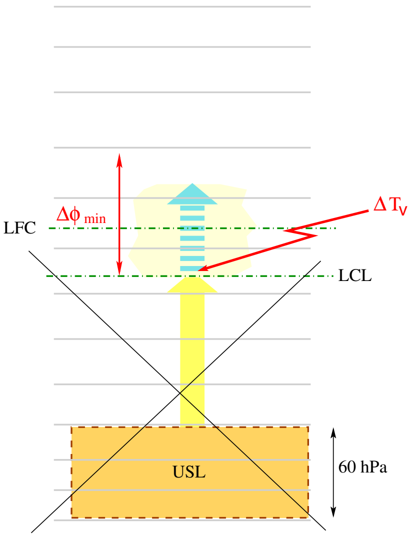

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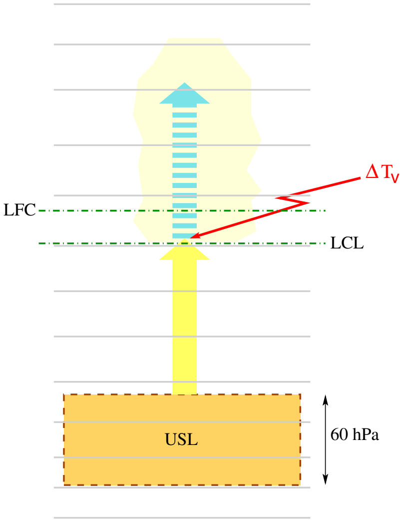


USL Ascent:

- physical point of view;
- independent of vertical discretization;
- full control on triggering: buoyancy kick ($\overline{w}$, TKE, dd history...);
- iterative $\rightarrow$ can be expensive.

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$$\triangle T_{v,\mathrm{kick}} = \min(T_1, \triangle T_{v,cin}, \triangle T_{v,LCL} + \triangle T_{v,RC})$$

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$$\triangle T_{v,RC} = \gamma_{cs}(\triangle T_{F_{cs}} - T_0),$$

    $\triangle T_{F_{cs}}$= mean $(L/c_p \triangle F_{cs})$ in layer $\triangle p_x$ starting at surface
    check sufficient condensation in 300hPa above LCL ($\alpha_{LCL} T_0$)

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  - More classical triggering (CGTRC='KF') modified Kain-Fritsch criterion: $\gamma_{kf} \equiv$ gtrkgain, $w_0 \equiv$ gtrkthrs, $z_0 \equiv$ gtrkthck, $\alpha_{LCL} \equiv$ gtrbrc

$$\triangle T_{v,KF} = \left[\gamma_{kf}\left(\overline{w}_{LCL} - w_0 \min(1, \frac{z_{LCL}}{z_0})\right)\right]^{1/3}$$

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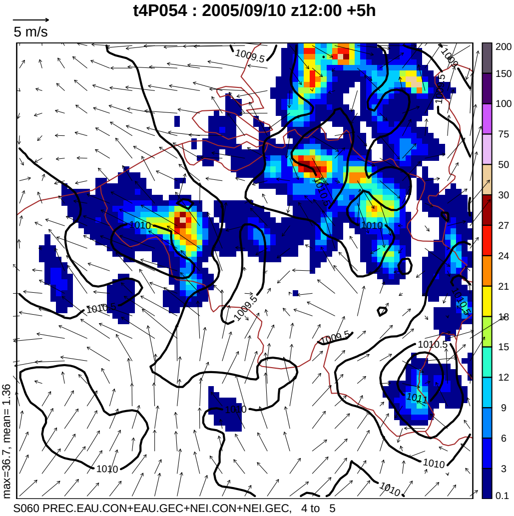
- Shallow cloud diagnostic (LCVSHCU=T): $\triangle \phi_{\mathsf{min}} \equiv$ gtrgdphimn never reached, while other criteria fulfilled:
  - select the USL yielding the deepest cloud
  - use tripled turbulent entrainment in plume model
  - Pure moisture convergence closure (with contribution from vertical turbulent moisture flux including shallow vertical transport).

# Behavior in 3D model

1-h rain



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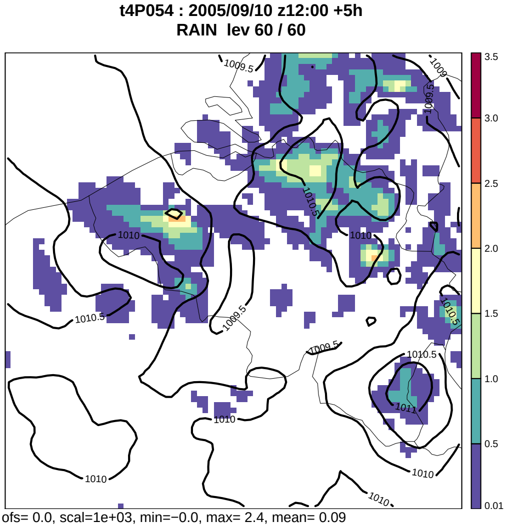
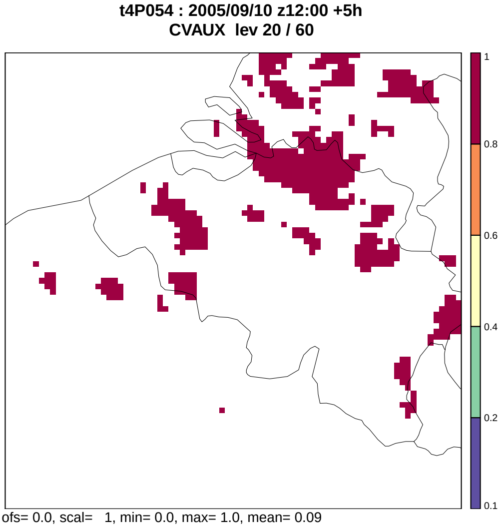
instanteneous rain



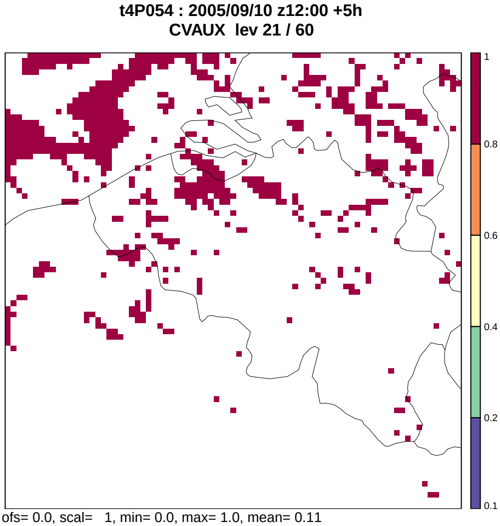
# Behavior in 3D model

Deep cloud

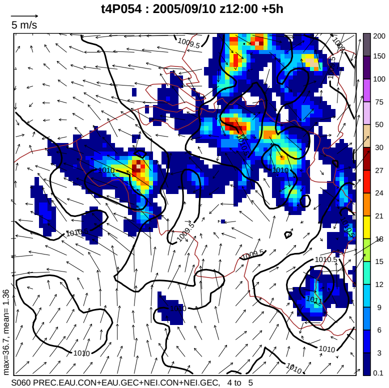


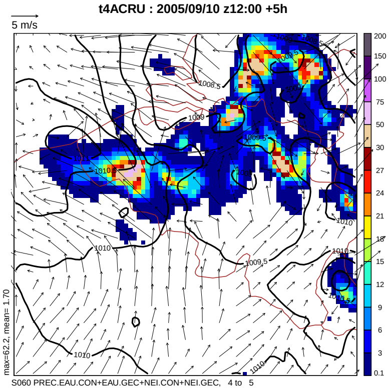
# Behavior in 3D model

Shallow cumulus



# Comparison 3MT/CSD ($\triangle x = 4$km)




CSD

3MT

1-hour accumulated precipitation

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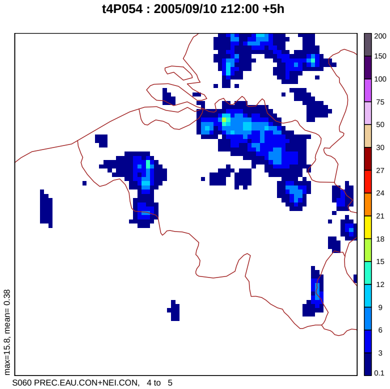
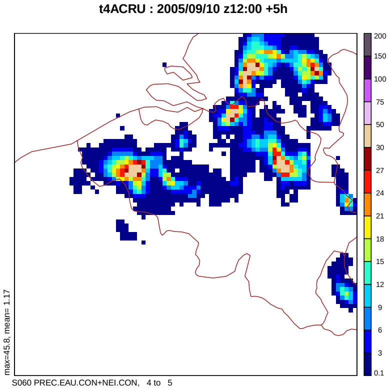


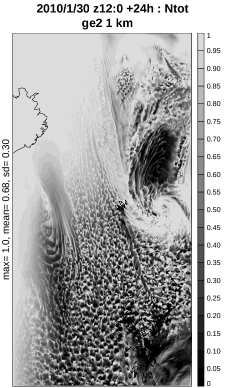




CSD

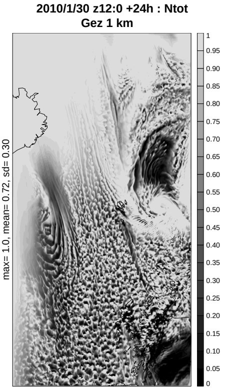
3MT

subgrid part

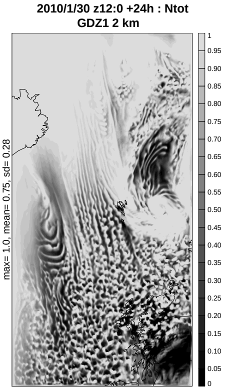
# Test in Alaro-0/1tr - CAOB: Cloudiness

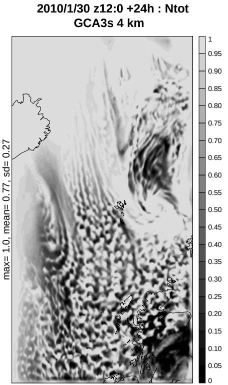



NOCP




CSD



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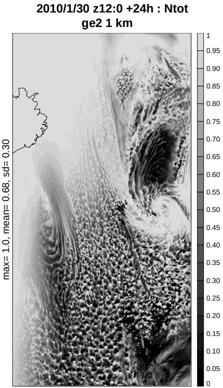


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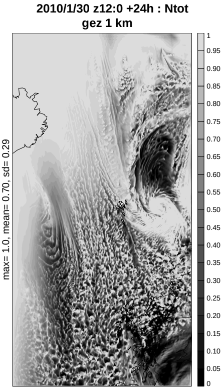
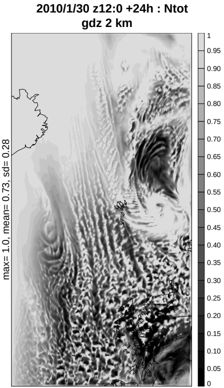
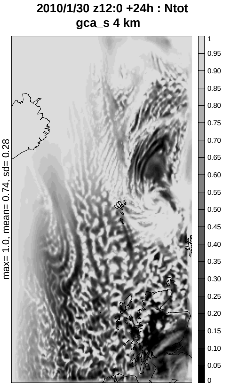



3MT



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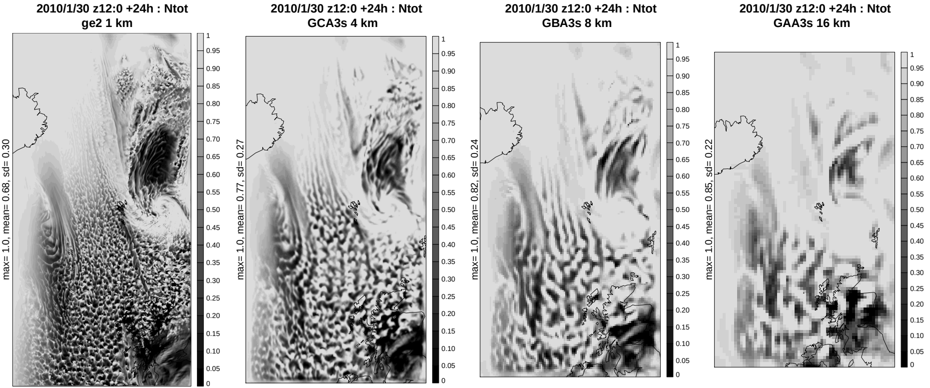


NOCP

CSD

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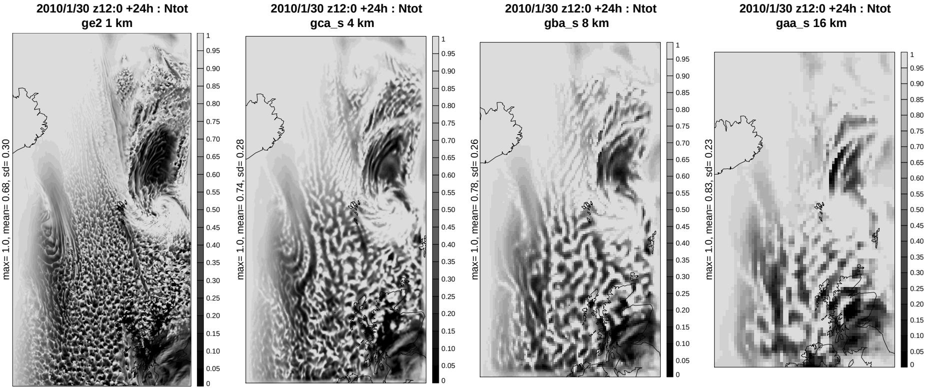


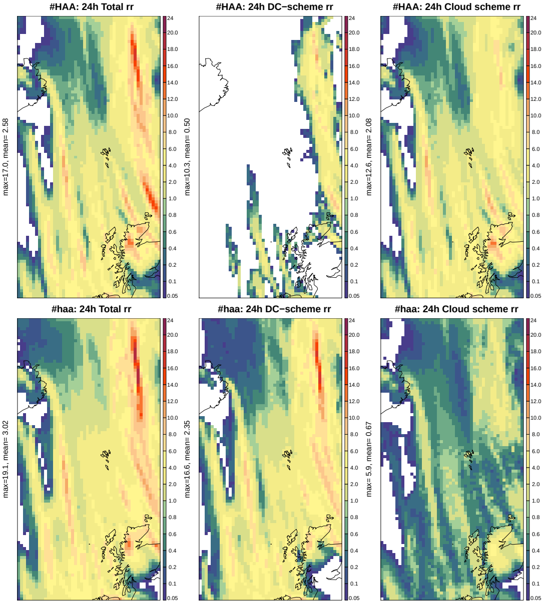

NOCP 3MT

# Alaro-0/1tr: 24-hour accumulated precipitation shares

CSD

$\triangle x = 16$ km

3MT

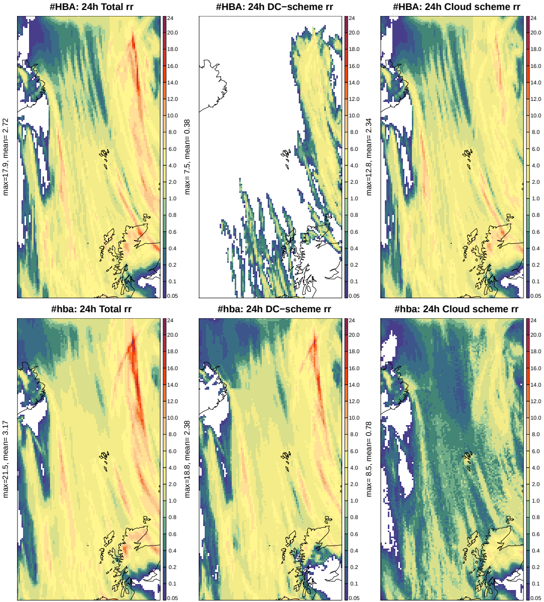


# Alaro-0/1tr: 24-hour accumulated precipitation shares

CSD

$\triangle x = 8$ km

3MT



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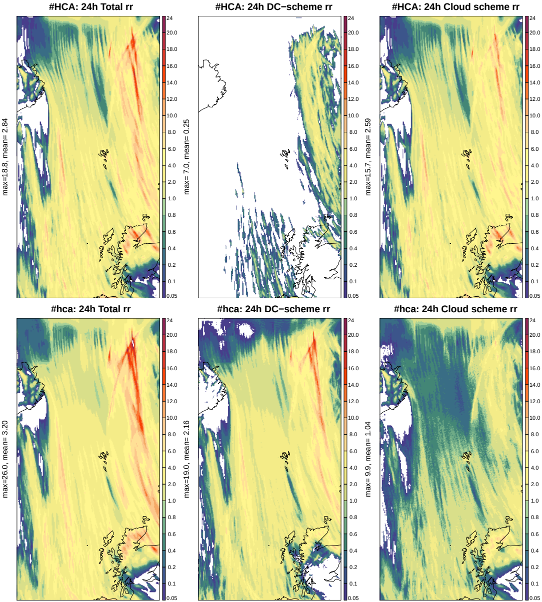
CSD

$\triangle x = 4$ km

3MT

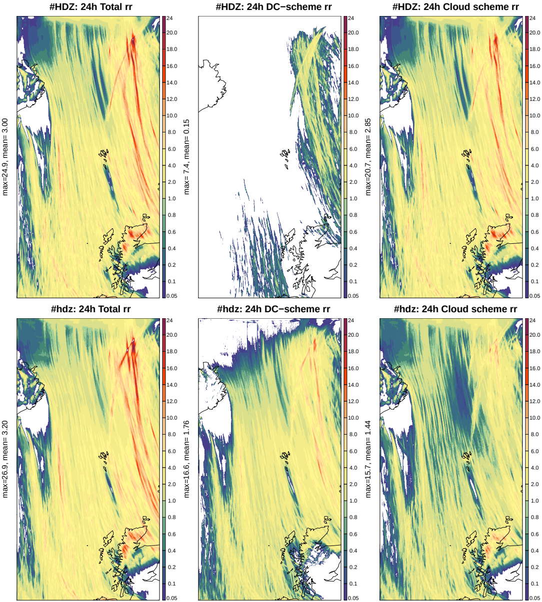


# Alaro-0/1tr: 24-hour accumulated precipitation shares

CSD

$\triangle x = 2$ km

3MT

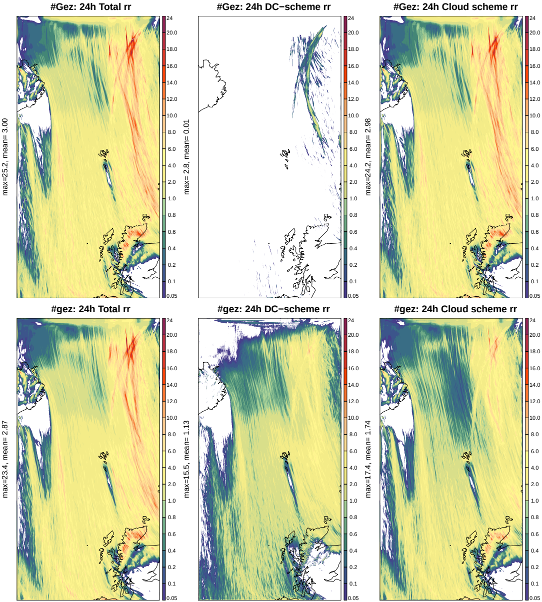


# Alaro-0/1tr: 24-hour accumulated precipitation shares

CSD

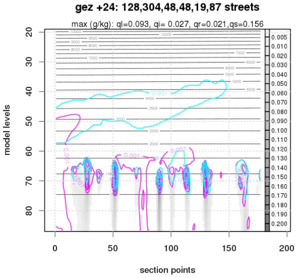
$\triangle x = 1$ km

3MT

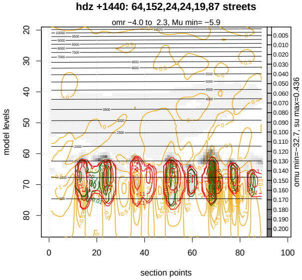


# Vertical (instantaneous) cross section: cloud streets

1km/Ao-0




2km/Ao-1tr

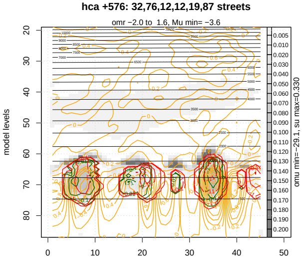



$\overline{\omega}$, $\omega_u^*$

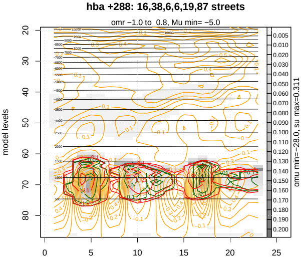
$M_u = \sigma_u \omega_u^*$,

cloud condensates

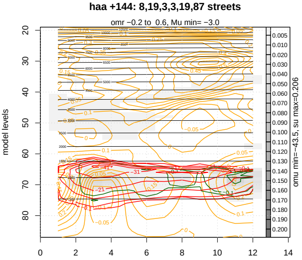
3MT




4km/Ao-1tr



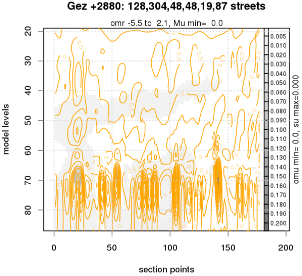

8km/Ao-1tr



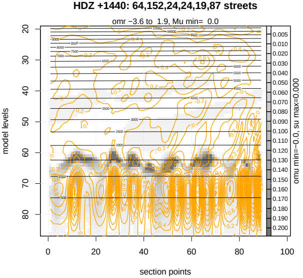

16km/Ao-1tr

# Vertical (instantaneous) cross section: cloud streets

1km/Ao-0

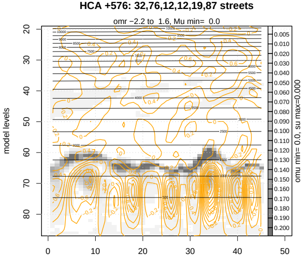



2km/Ao-1tr

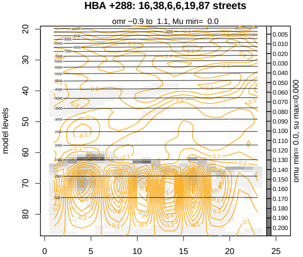



$\overline{\omega}$, $\omega_u^\diamond$
$M_u=\sigma_u\omega_u^\diamond$,
cloud condensates

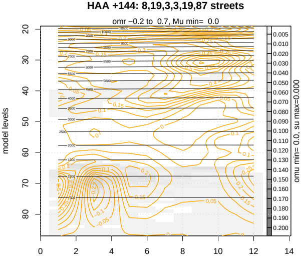
CSD




4km/Ao-1tr



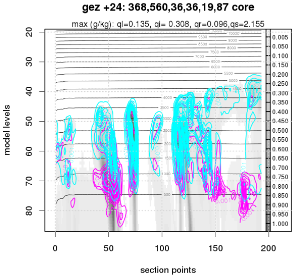

8km/Ao-1tr



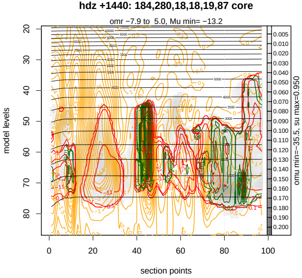

16km/Ao-1tr

# Vertical (instantaneous) cross section: cellular structures

1km/Ao-0




2km/Ao-1tr




$\overline{\omega}$, $\omega_u^*$

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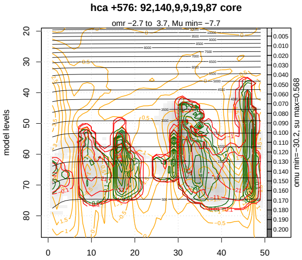
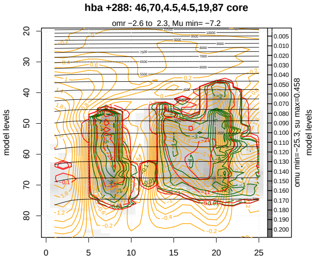
cloud condensates

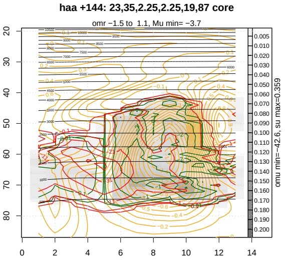
3MT




4km/Ao-1tr



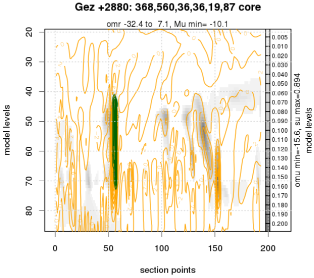

8km/Ao-1tr



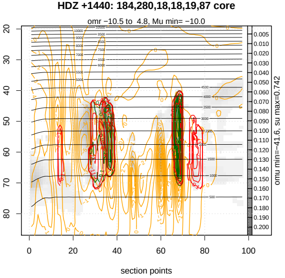

16km/Ao-1tr

# Vertical (instantaneous) cross section: cellular structures

1km/Ao-0




2km/Ao-1tr

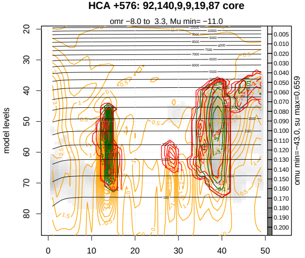



$\overline{\omega}$, $\omega_u^\diamond$

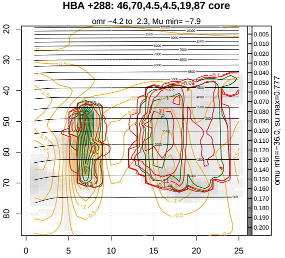
$M_u = \sigma_u \omega_u^\diamond$,

cloud condensates

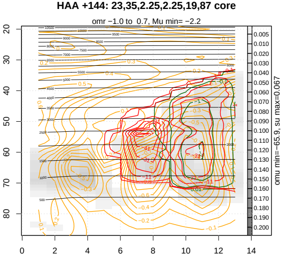
CSD




4km/Ao-1tr




8km/Ao-1tr




16km/Ao-1tr

# Tuning in evolving Alaro versions

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- Multiple interactions between parameterizations require to re-tune at various places.
- Critical Relative Humidity profile:

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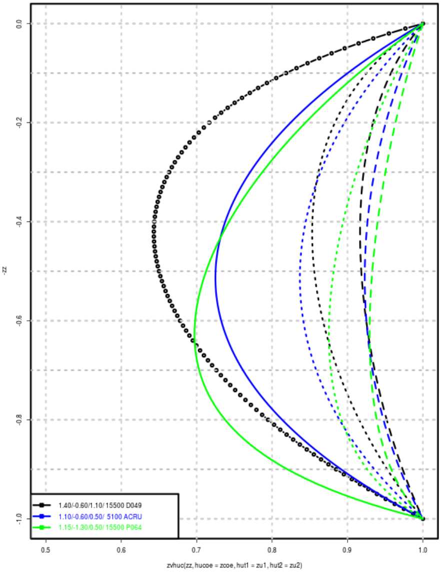

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# Tuning in evolving Alaro versions

- Triggering, updraught tuning appear stable
- Multiple interactions between parameterizations require to re-tune at various places.
- Critical Relative Humidity profile:
- Shallow convection from TOUCANS vs shallow cumuluses in CSD
- Predominance of non-saturated downdraught tuning

# Summary

- CSD produces a gradual transition towards explicit convection
- Essential features are:
  - Sequential physics with feedbacks, e.g. convective area protection, downdraft.
  - Plume model for perturbation-updraft
  - Specific closure formulation
  - Adapted/specific triggering formulation
  - Prognostic updraft evolution (velocity, mesh fraction, rising cloud top).
  - Single prognostic microphysics
- Meso-scale organization not always well rendered at high resolution:
  - tuning of turbulent diffusion has a big impact
  - stochastic components
  - subgrid cold pools parameterization

$\Rightarrow$ more results in next presentation on multi-scale behaviour