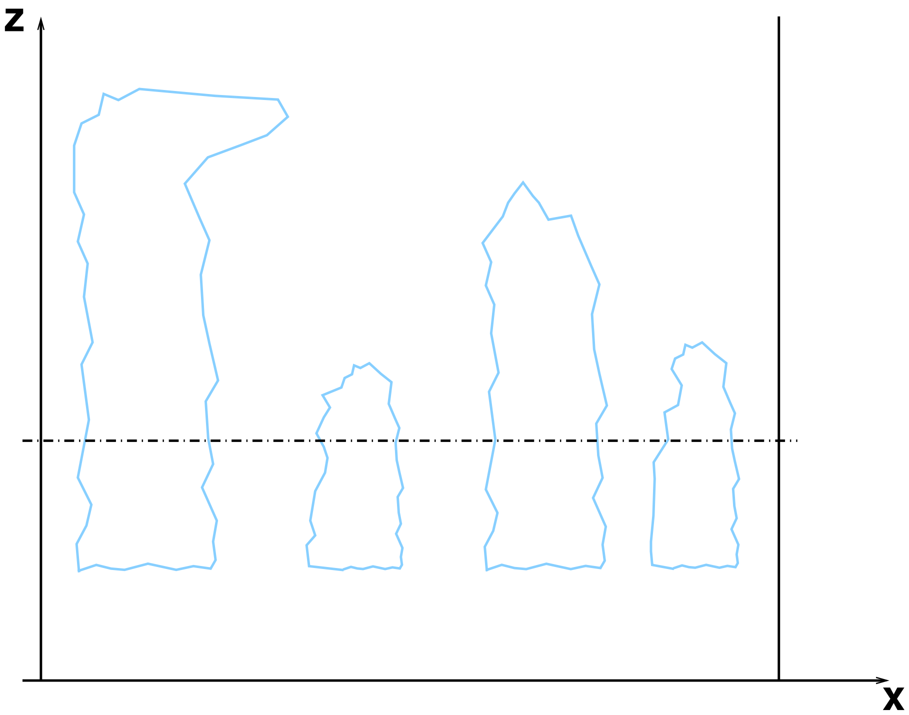
Representing deep convection at ‘high’ resolution

Luc Gerard

12 May 2014

RMI

Subgrid variability



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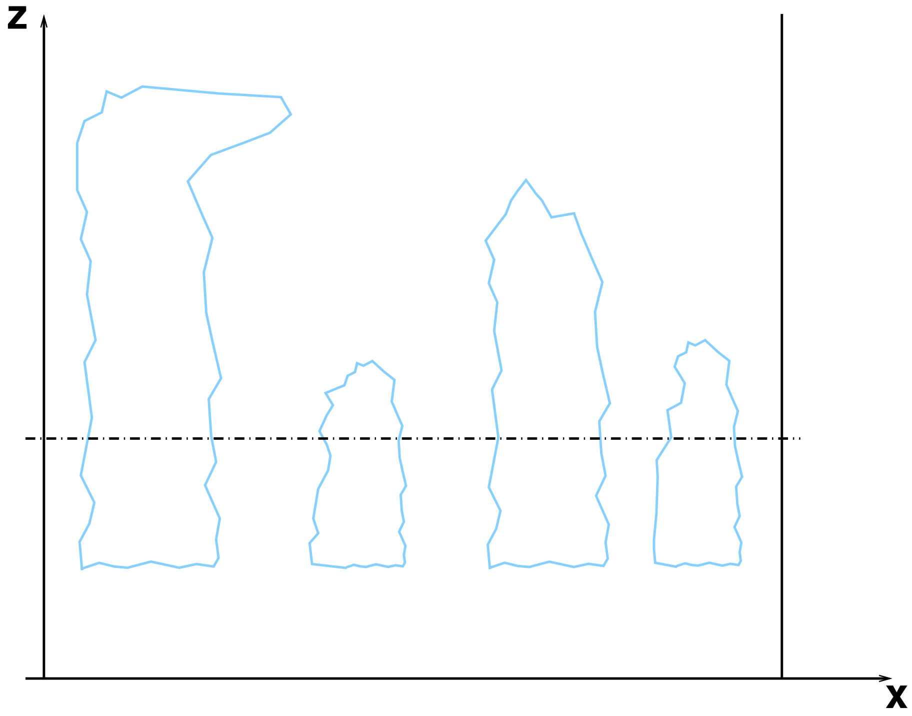

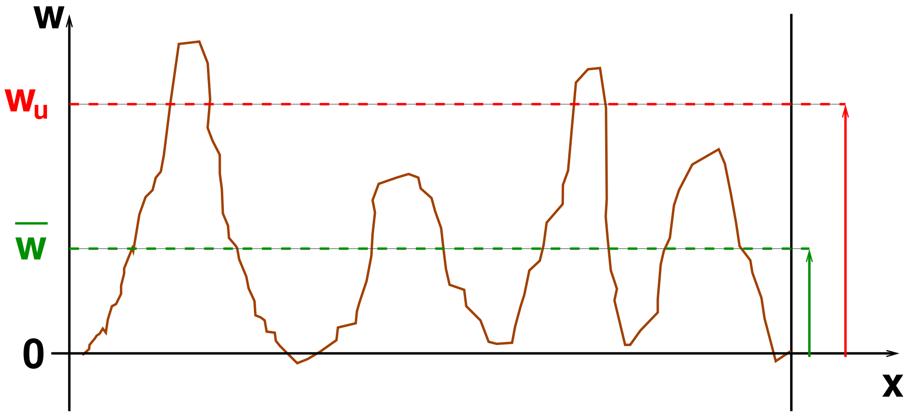

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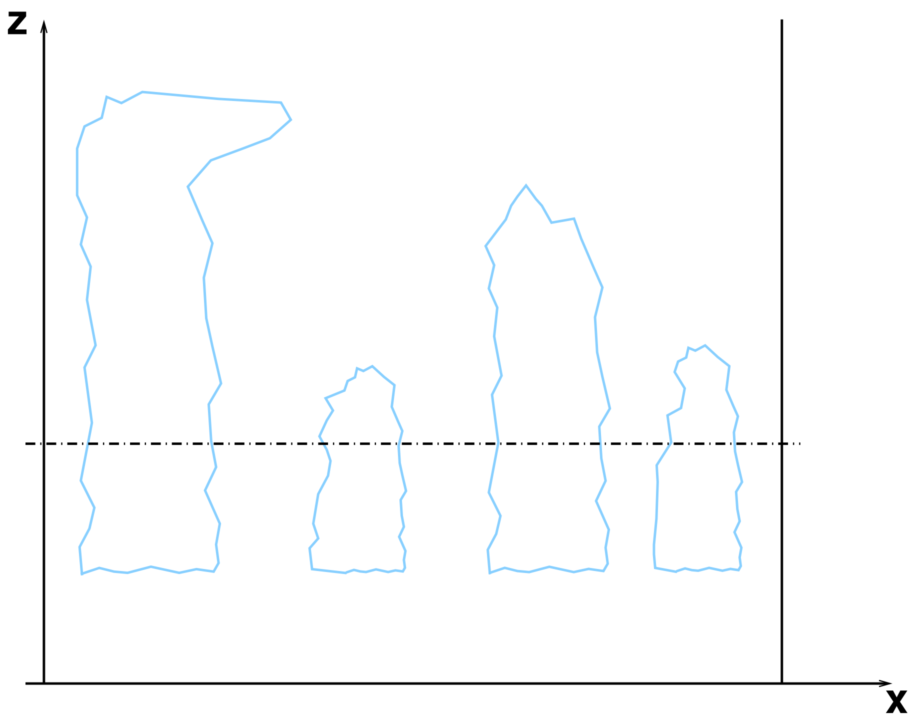

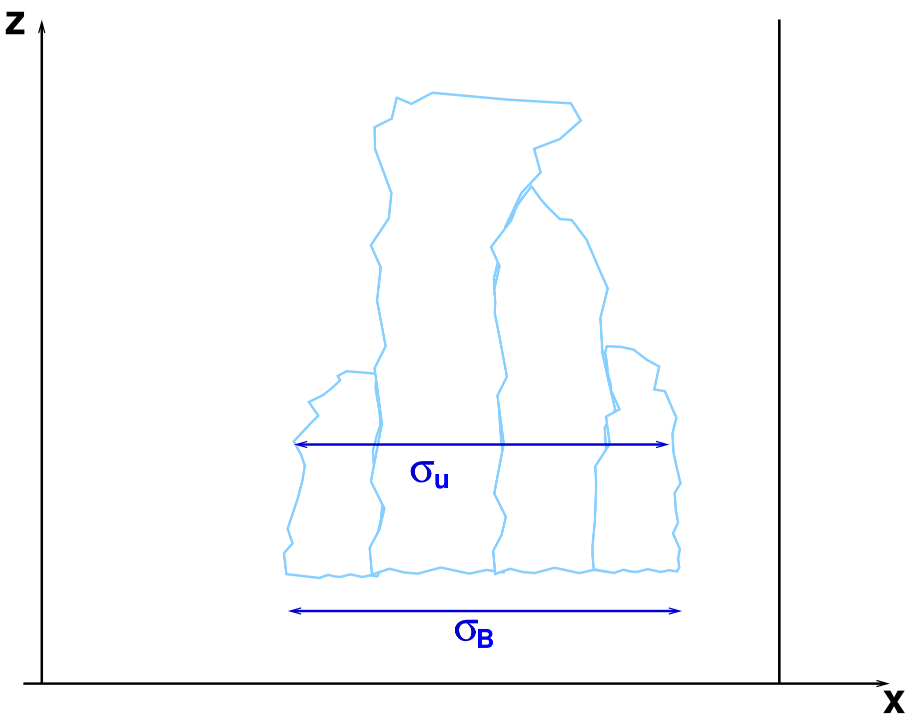

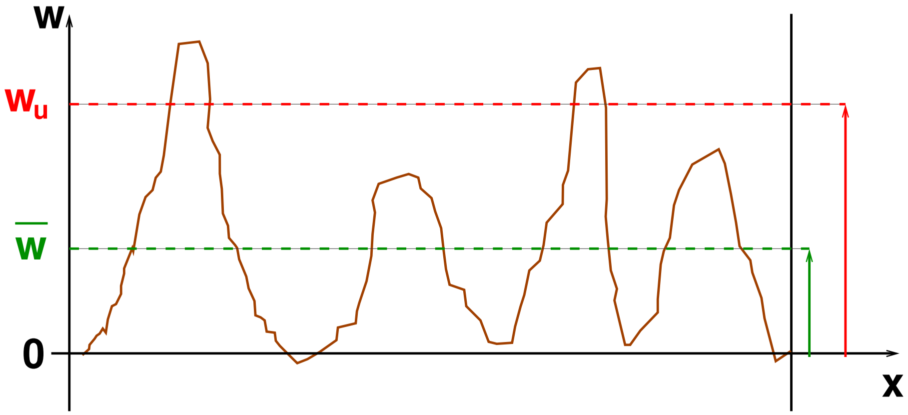

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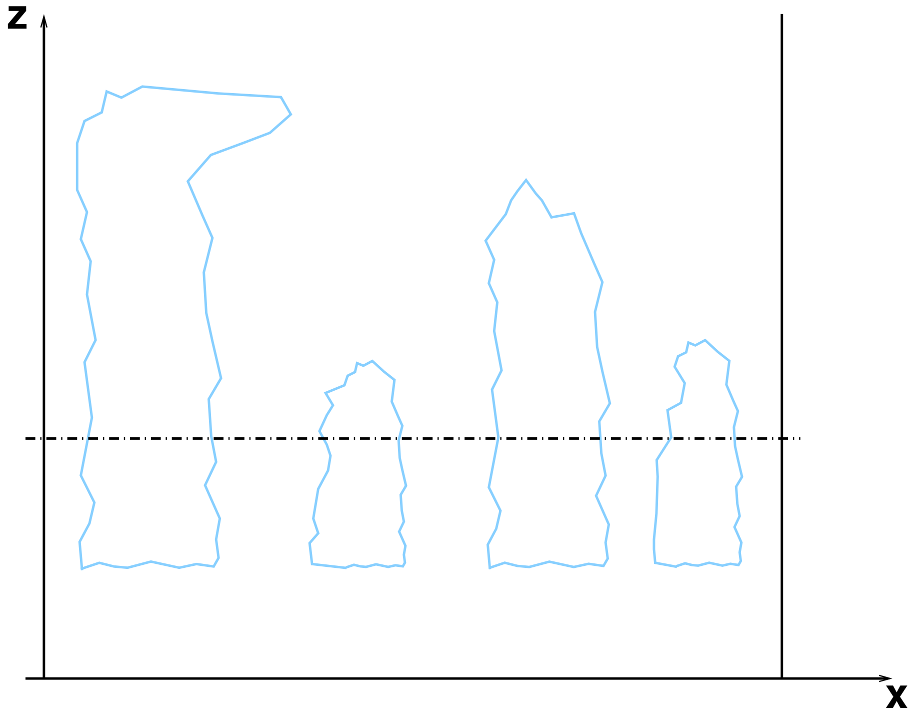

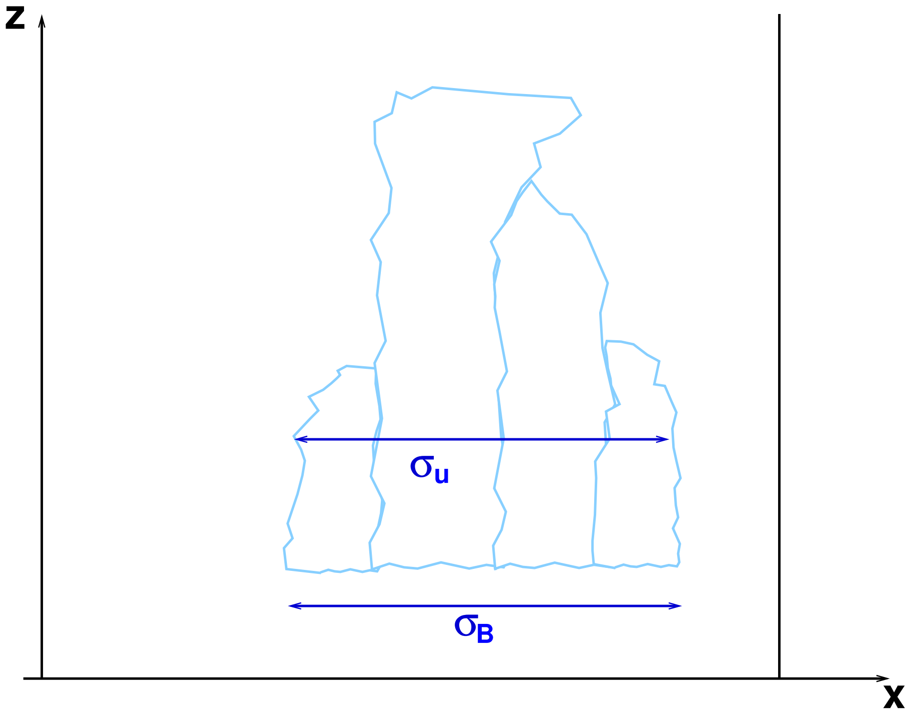

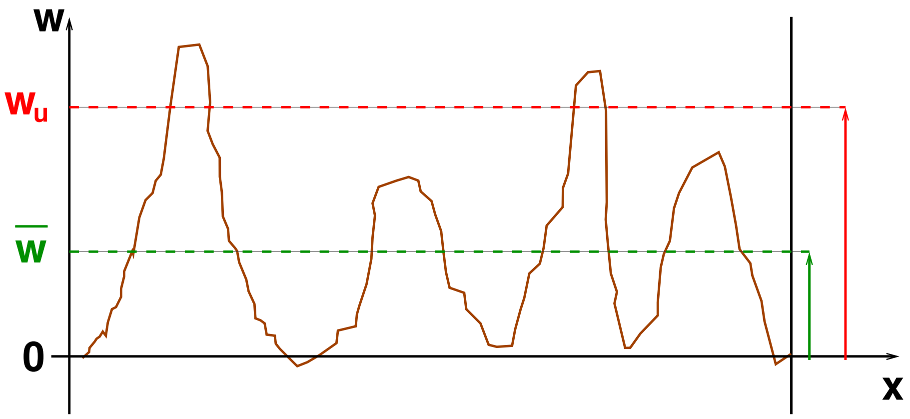

$$
\begin{aligned}
\overline{\psi} &= \sum_u \sigma_i \psi_i + \sum_e \sigma_j \psi_j \\
&= \sigma_u \psi_u + (1-\sigma_u)\psi_e
\end{aligned}
$$

Effects of small grid boxes

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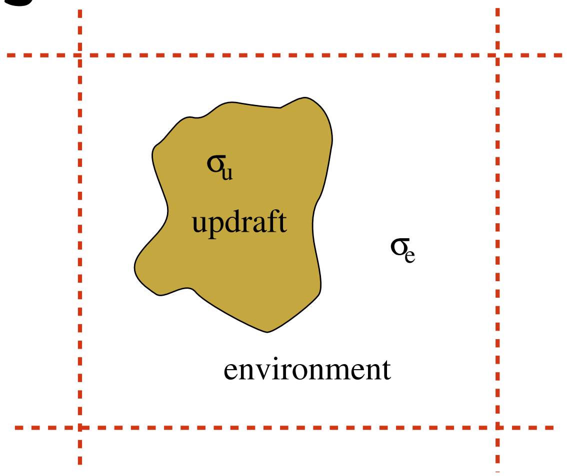

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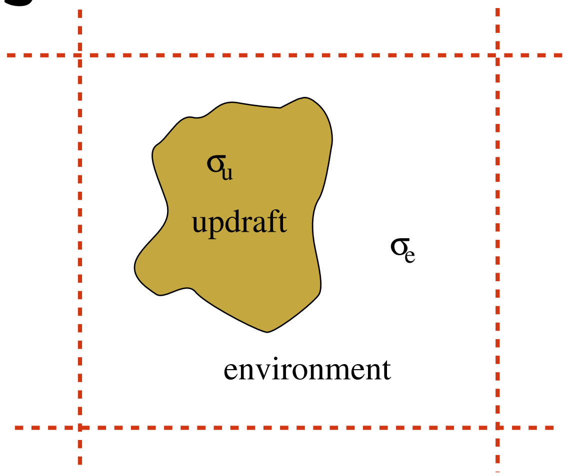

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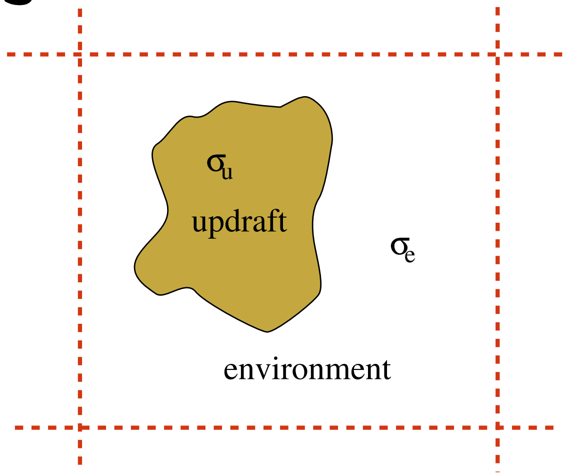

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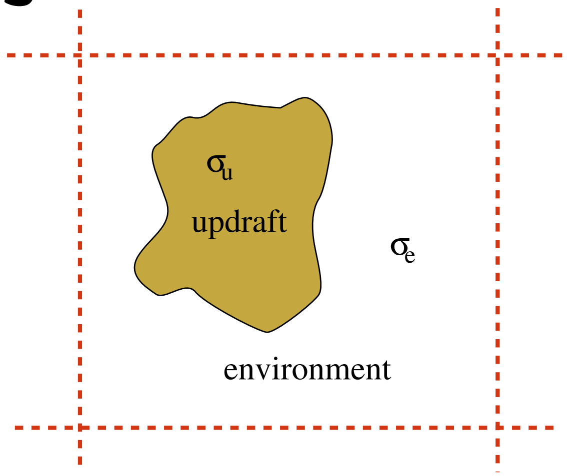

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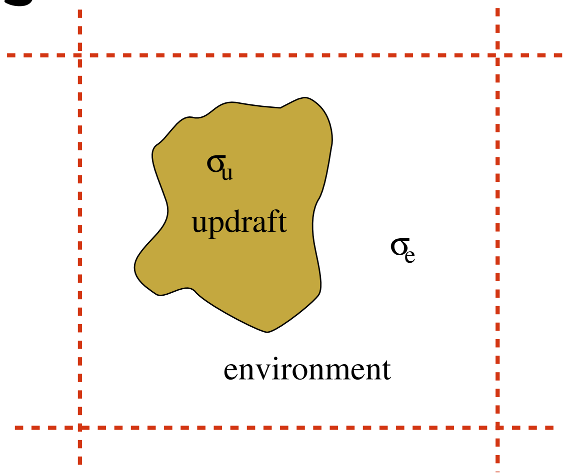

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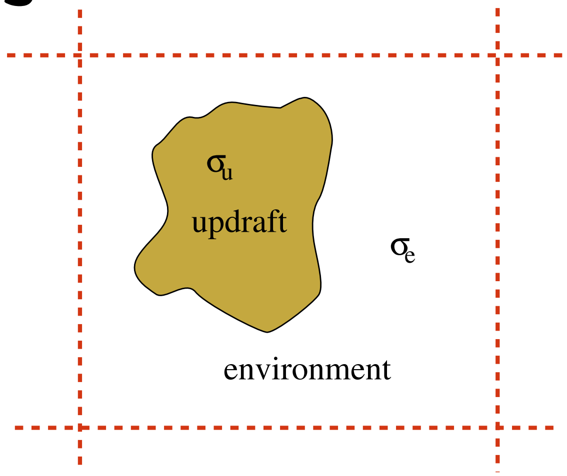

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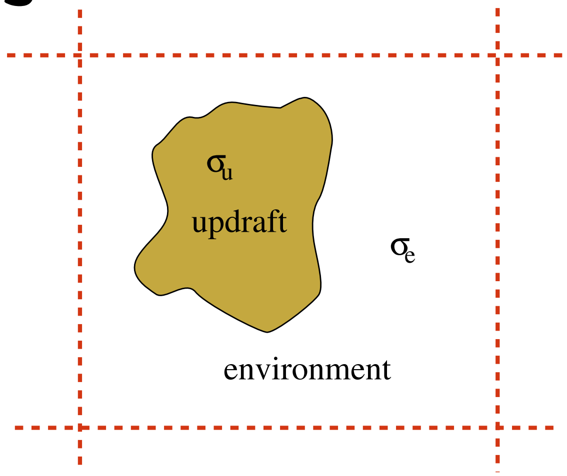

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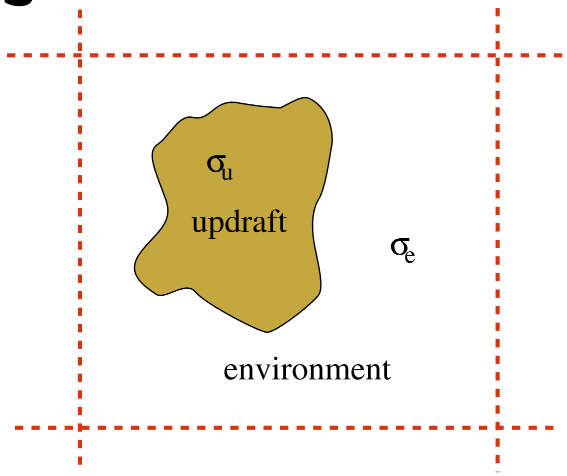

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    + modification of $\overline{\psi}$ → Cloud scheme

Statistical Cloud scheme

The Cloud scheme makes an instantaneous diagnostic at a given model level, assuming some distribution of water and temperature over the grid-box area.

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  ...provided assumed distributions more uniform at finer resolution.

3MT choice: towards complementarity and evolution

Aiming at complementarity down to a certain resolution

- Sequential organization of moist parametrizations.

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Aiming at complementarity down to a certain resolution

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- Direct expression of DC effects through convective condensation and transport fluxes.
- Combining condensation from the cloud scheme and the subgrid convective scheme to feed a single microphysics.
- Use of prognostic variables allows a gradual onset of deep convection, leaving time for the feedback of other schemes from one time step to the next: downdraught, microphysics, radiation...

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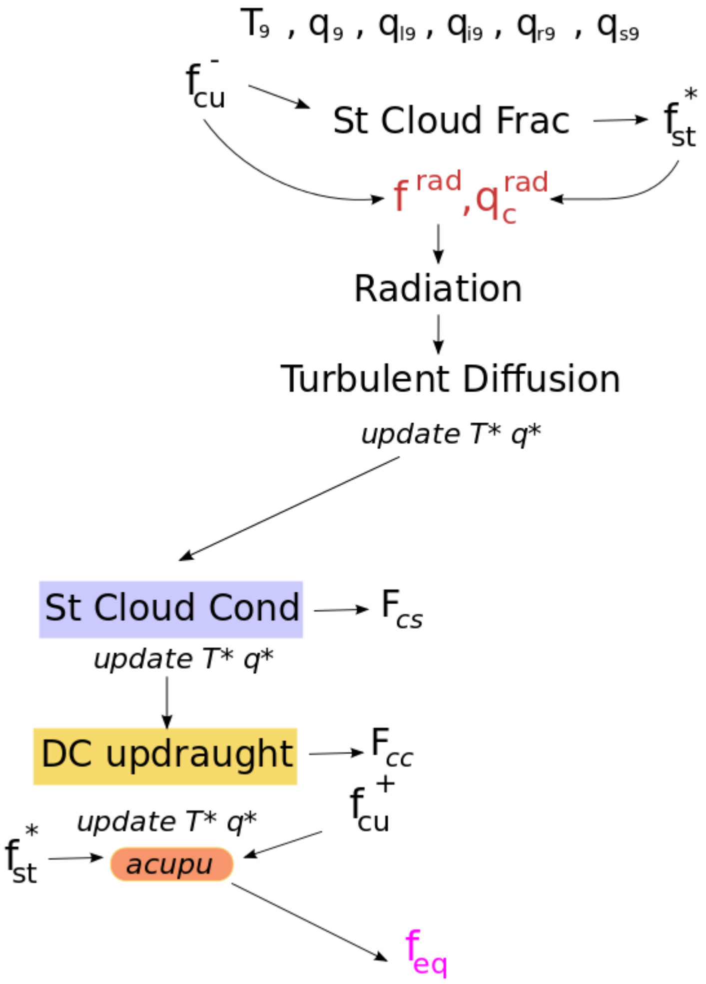
- Interaction between time steps ⇒ protection of convective condensate against re-evaporation in cloud scheme, evolution of a detrainment area gradually turning into stratiform cloud.
- For complementarity, the DC scheme should represent a *complement* to the resolved part of the updraught.

3MT Organization: complementarity



T_9 , q_9 , q_{l9} , q_{i9} , q_{r9} , q_{s9}

f_{cu}^- → St Cloud Frac → f_{st}^*

f^{rad}, q_c^{rad}

Radiation

Turbulent Diffusion

update T q**

St Cloud Cond → F_{cs}

update T q**

DC updraught → F_{cc}

f_{cu}^+

update T q**

f_{st}^* → *acupu*

f_{eq}

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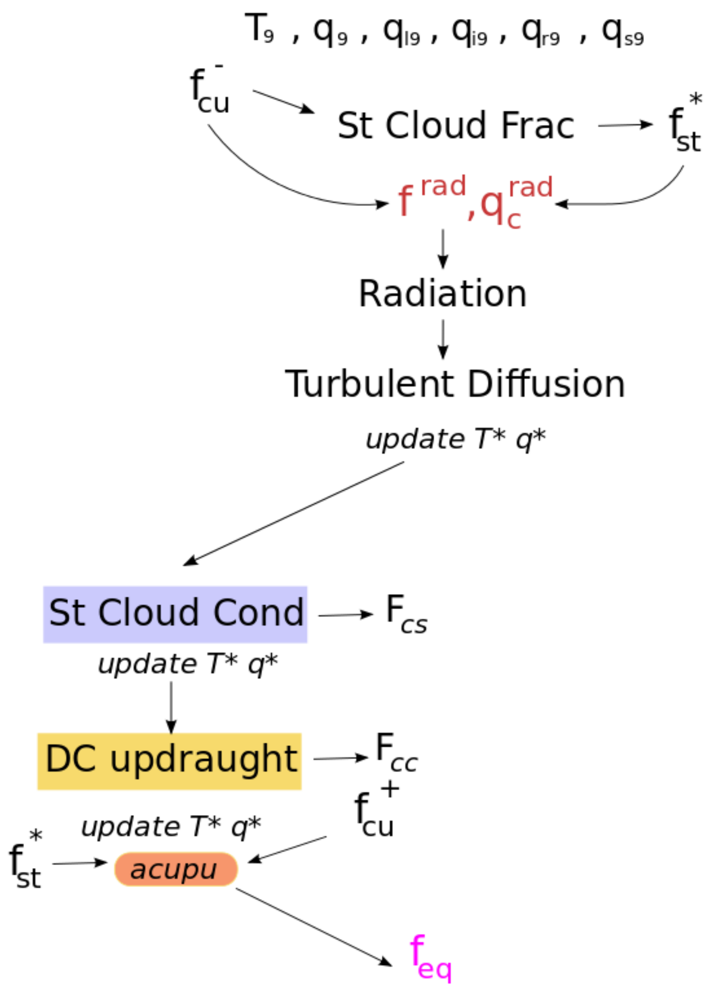

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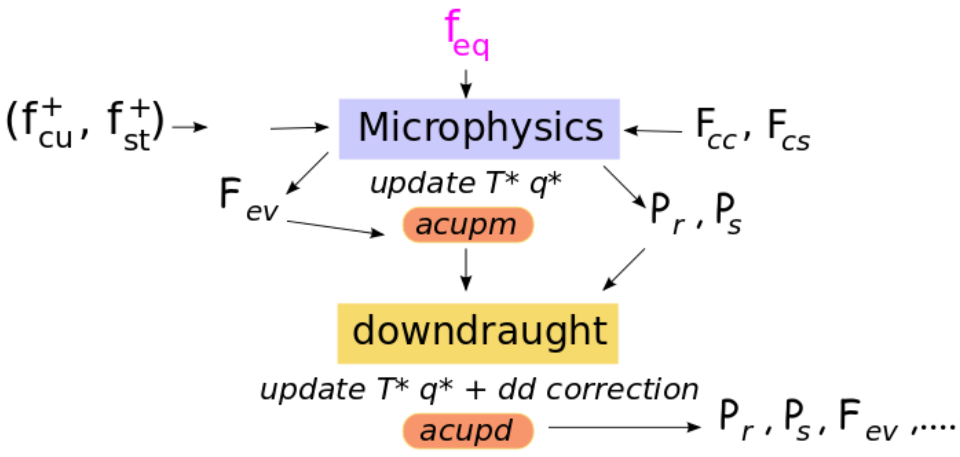


f_{eq}

(f_{cu}^{+}, f_{st}^{+})

Microphysics

F_{cc}, F_{cs}

F_{ev}

update T q**

acupm

P_r , P_s

downdraught

update T q* + dd correction*

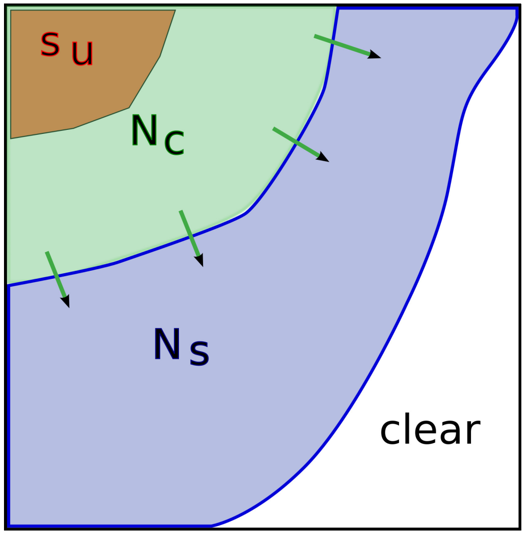
acupd

P_r , P_s, F_{ev} ,....

Opposite choice: separation of processes lcvfirst=T

Maintain a clean separation between deep convection handled by the DC scheme and all other clouds, treated by the Cloud scheme.

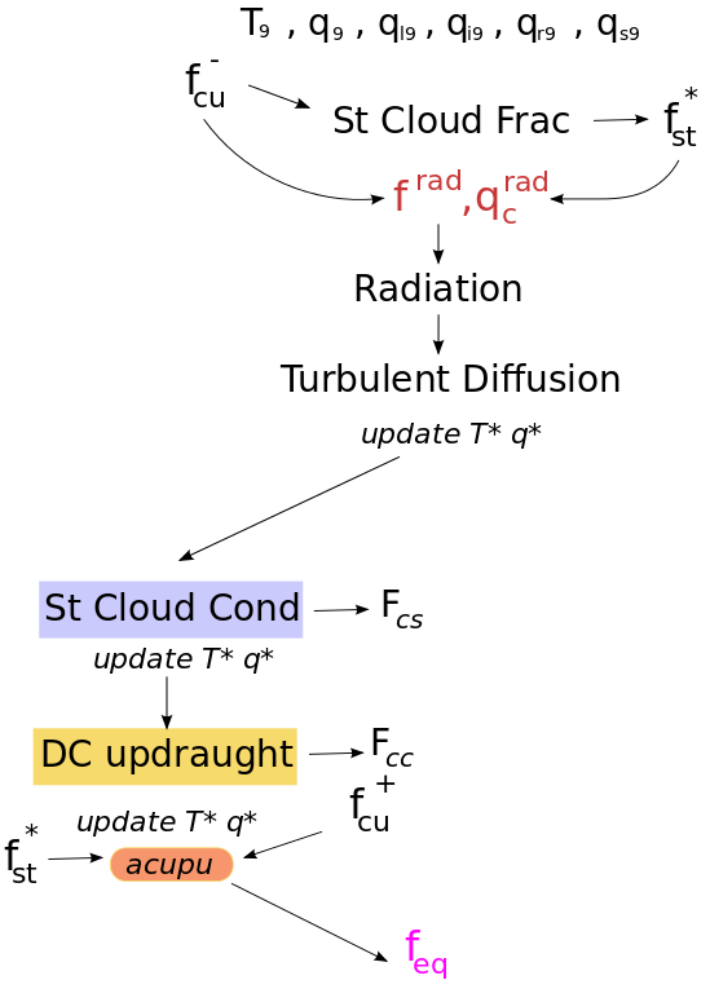
- 2 schemes active at all resolutions, no extinction.
- DC scheme has to be called first *and represent the absolute updraught.*
- Cloud scheme provides a complement for the *non convective area*
- Proves feasible taking advantage of 3MT features:

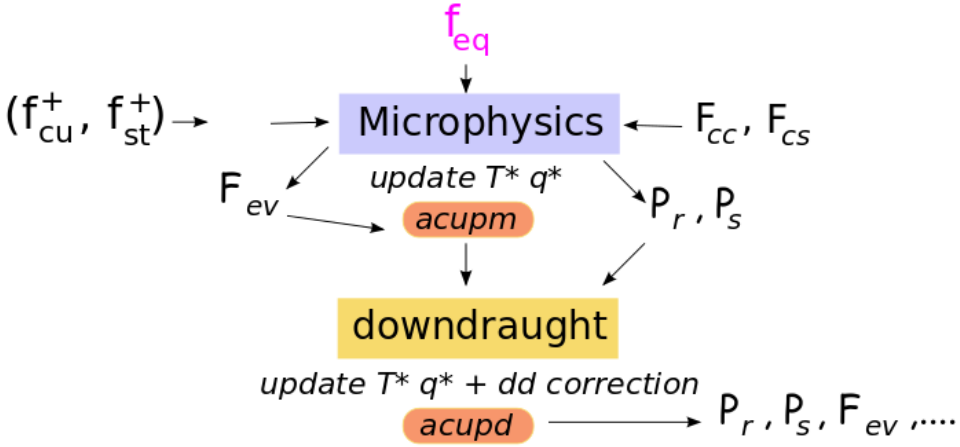


- protection of N_c in acnebcond (lxrvdev=T).
- Gradual conversion of detrainment area into stratiform (relaxation with gcvtaude).

Alternative Organizations

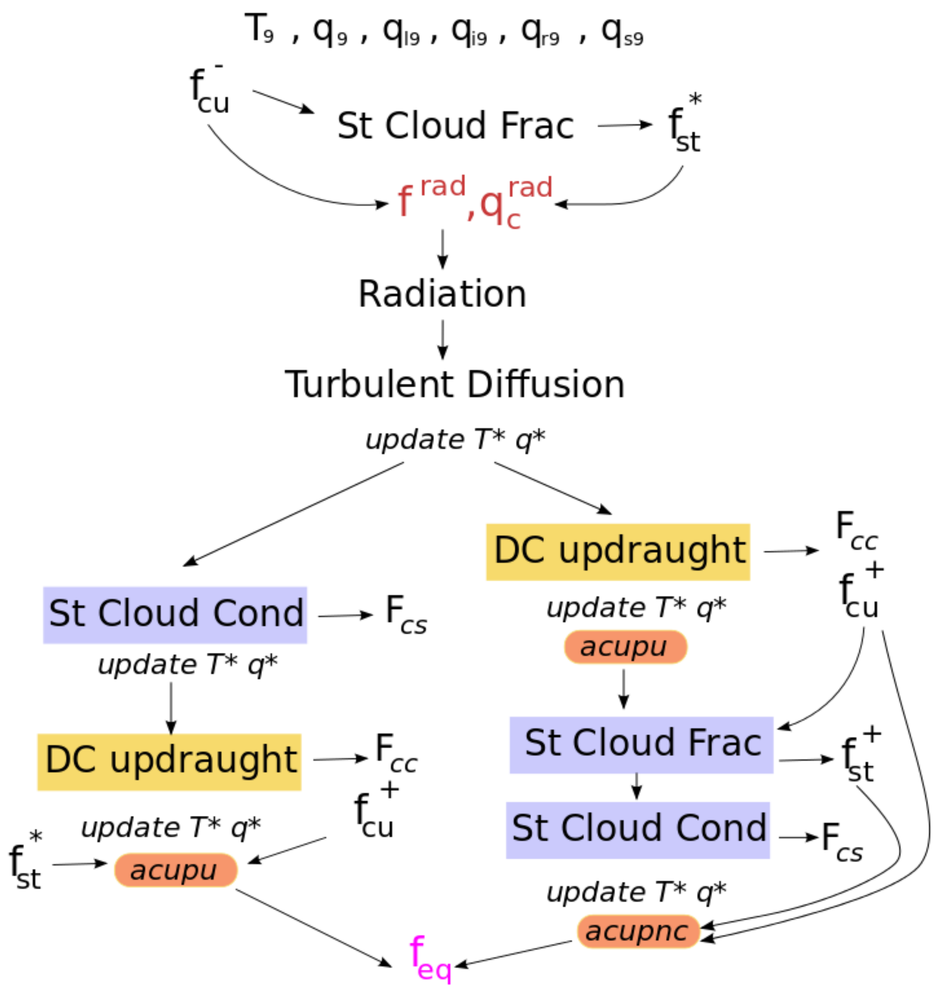
Complementarity of schemes





LCVFIRST=F

Alternative Organizations



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acupnc

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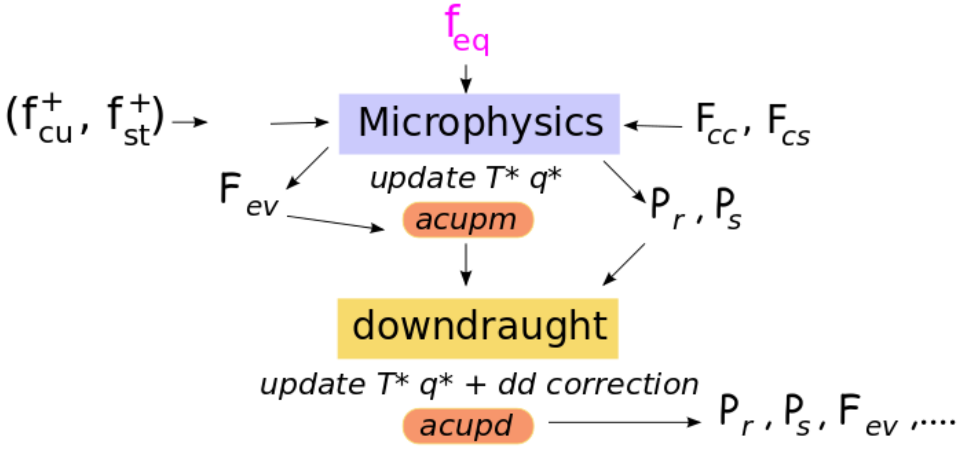

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F_{ev}

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acupm

P_r , P_s

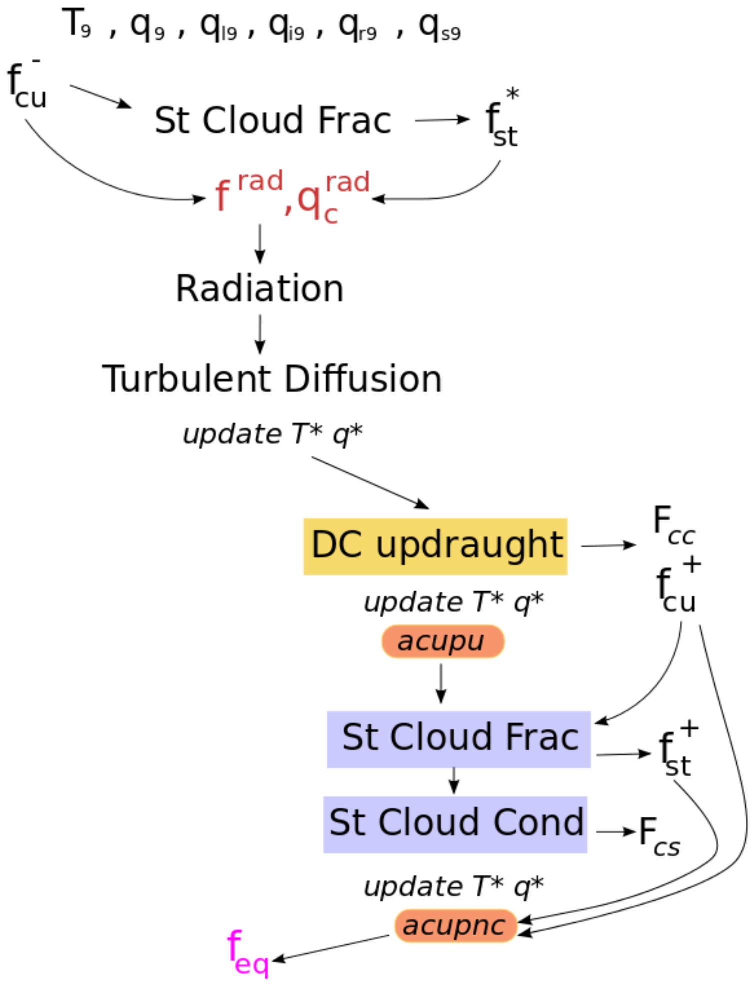
downdraught

update T q* + dd correction*

acupd → P_r , P_s, F_{ev} ,....

Alternative Organizations

Separation of processes



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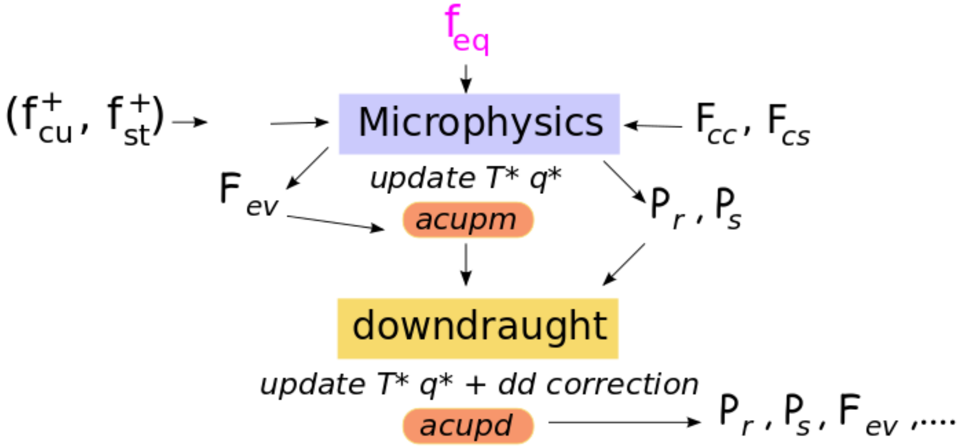

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LCVFIRST=T

3MT DC scheme: accvud

- Evolution in time with prognostic variables
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but not in a way that the subgrid part would fade out.

Complementary subgrid draft scheme: accsu

Aiming at gradual extinction of the subgrid scheme leaving space to the explicit representation of DC.

Principle: acknowledge the fake representation of a resolved updraught and provide a complement to it (pertubation approach).

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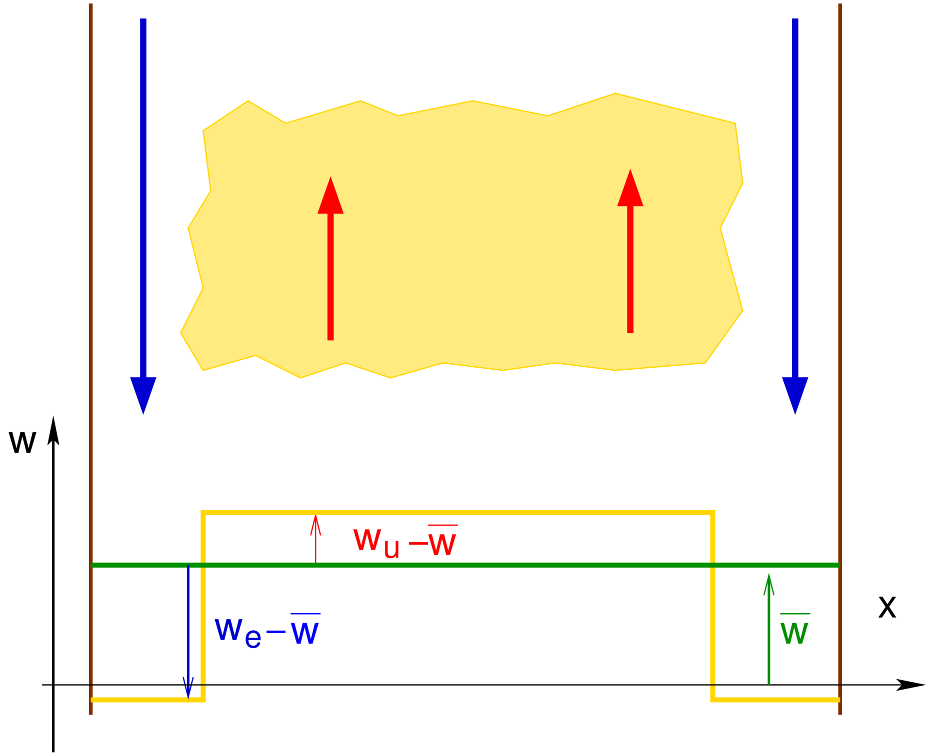

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- Closure relations: extrapolated steady state.
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- Triggering of subgrid scheme $\neq$ triggering of convective updraft
  Need for triggering $\Rightarrow$ cost $\nearrow\nearrow$.

CSD updraught specific features

- Building the profile
- Closures
  - CAPE closure
  - MoCon closure
  - Prognostic relation
- Output fluxes: transport vs production
- Ancillary refinements
  - rising top
  - Mesh fraction frofile
  - Note on advected prognostic variables
  - Secondary closure vs trusting chance ?
- Triggering

CSD steady-state profile

$$\frac{\partial q_u^\diamond}{\partial p} = -\frac{\partial \overline{q}}{\partial p} + \frac{\Lambda'_u}{1-\sigma_u} q_u^\diamond - \frac{\delta q_{ca}}{\triangle p}, \qquad \Lambda'_u = \Big[\underbrace{\frac{\lambda_u}{\rho_0(1-\sigma_u)}}_{\text{turb mixing}} - \underbrace{\frac{\delta_{oe}}{\sigma_u \omega_u^\diamond}\frac{\partial \sigma_u \omega_u^\diamond}{\partial p}}_{\text{dyn ent}}\Big]$$

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$$\Rightarrow \quad q_u^\diamond = q_b^\diamond e^H + \frac{\delta q_{ca} - (\triangle \overline{q})}{H}(1-e^H), \qquad H = \frac{\Lambda_u' \triangle p}{1-\sigma_u}$$

$\triangle p = p^l - p^{l+1}$.

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$$\Rightarrow \quad q_u^\diamond = q_b^\diamond e^H + \frac{\delta q_{ca} - (\triangle \overline{q})}{H}(1 - e^H), \qquad H = \frac{\Lambda_u' \triangle p}{1-\sigma_u}$$

$\triangle p = p^l - p^{l+1}$.

- δq_{ca}: condensation from $b = l+1$ to l: guess following moist adiabat + correction to maintain $q_u = q_u^\diamond + \overline{q} = q_{\text{sat}}(p, \frac{s_u^\diamond + \overline{s} - \phi_u}{c_p(q_u)})$.

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- In ACCUVD: apply isobaric mixing, followed by return to saturation and moist adiabatic ascent segment.

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$$\omega_u = \omega_u^{\diamond} + \overline{\omega}, \qquad \sigma_u^l = \sigma_B \cdot \nu^l$$

considering effect of *absolute* updraught on *environmental* CAPE.

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considering effect of *absolute* updraught on *environmental* CAPE.
Ensembling effect (NFSIG=2): $\nu < 1$ at the upper part when $\sigma_B < \frac{1}{2}$.

CSD closure: MoCon, prognostic

$$\sigma^{\|}_{Bmoc}\int_{p_b}^{p_t}\nu(\omega_u^{\diamond\|}+\overline{\omega})L\delta q_{ca}=\int_{p_b}^{p_t}L\Big[\mathsf{cvgq}-g\frac{\partial J_q^{\mathrm{tur}}}{\partial p}\Big]dp$$

Prognostic relation:

$$\frac{\partial\sigma_B}{\partial t}\int_{p_b}^{p_t}\Big[\nu(h_u-h_e)+\alpha_k\nu\frac{(\omega_u^{\diamond\|})^2}{2\rho_0^2g^2}\Big]dp=(\sigma_B^{\|}-\sigma_B^{+})\int_{p_b}^{p_t}\nu(\omega_u^{\diamond\|}+\overline{\omega})L\delta q_{ca}$$

while in ACCVUD: use instantaneous $\omega_u^*=\omega_u-\omega_e$:

$$\frac{\partial\sigma_B}{\partial t}\int_{p_b}^{p_t}(h_u-\overline{h})\frac{dp}{g}+\sigma_B\int_{p_b}^{p_t}(\omega_u^{\star})L\delta q_{ca}=\int_{p_b}^{p_t}L\Big[\mathsf{cvgq}-g\frac{\partial J_q^{\mathrm{tur}}}{\partial p}\Big]dp$$

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$$\left.\frac{\partial \omega_u^\diamond}{\partial t}\right|_{sg} = \Lambda_w (\omega_u^\diamond)^2 - \left(\frac{\partial \overline{\omega}}{\partial p} - \overline{\omega}\frac{\partial \ln \rho_0}{\partial p}\right)\omega_u^\diamond - \omega_u^\diamond \frac{\partial \omega_u^\diamond}{\partial p} - \alpha_b \rho_0 g^2 \frac{T_{vu}^\diamond}{\overline{T_v}}$$

$$\Lambda_w = \frac{\lambda_u + \frac{\mathcal{K}_{du}}{g}}{\rho_0 (1-\sigma_u)^2} - \frac{\delta_{oe}}{1-\sigma_u}\frac{\partial \ln(\sigma_u \omega_u^\diamond)}{\partial p} + \frac{\partial \ln \rho_0}{\partial p}$$

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- Gradually rising updraught top (LRITO=T):
  - Memory of previously active levels (from $\sigma_u^-, \omega_u^{\diamond -}$) *and* of fractional path between two levels (scalar)
  - Activity time of each level

Fluxes

- Activity-time of each level: $\chi\delta t \rightarrow$ time-step averages $\widetilde{\sigma} \equiv \chi\frac{\sigma^- + \sigma^+}{2}$.
- Perturbation production-flux: $M_c^\diamond = \widetilde{\sigma_u \omega_u^\diamond}$

  $$\Rightarrow \quad \triangle F_{cc} = M_c^\diamond \delta q_{ca}^{\bar{l}} \qquad (\text{LCVFIRST=F}).$$

- Absolute production flux: $M_c = M_c^\diamond + \chi\widetilde{\sigma_u}\overline{\omega}$

  $$\Rightarrow \quad \triangle F_{cc} = M_c \delta q_{ca}^{\bar{l}} \qquad (\text{LCVFIRST=T}),$$

  $\Rightarrow$ for local mass budget (σ_D).

- Transport flux: $M_t = \frac{M_c^\diamond}{(1-\widetilde{\sigma_u})}$ $\qquad \Rightarrow \quad \triangle J_\psi^{cu} = \frac{1}{g} M_t \psi_u^\diamond$
- ACCVUD: $M_c^\diamond = M_c = M_t = \sigma_u^+ \omega_u^{*+}$

Secondary closure ?

- Ascent: σ_* larger reduces $\psi_u^\diamond$ and $\omega_u^{\diamond\|}$ (reduced buoyancy, increased drag)

- Closure: $\sigma_B^\| \cdot \int ...\omega_u^\|...dp \propto \utilde{\frac{1}{(1-\sigma_B^\|)}} \int T_{vu}^\diamond...dp$

- $\sigma_B^+ \propto \sigma_B^\|$, ω_u^+ reduced by larger σ_B^+

- ACCVUD:
  - assume $\omega_e \sim 0$: requires $\overline{\omega} = \sigma_u \omega_u^*$ that is nearly all the time violated.
  - simpler relations, no dependency of buoyancy on σ_u

- ACCSU:
  - no assumption on ω_e
  - possibility to compute the guess σ_* as a combination of σ_B^- and $\sigma_M = f_\omega(\overline{\omega})$ (GSIGIG $+$ parameters defining f_ω).

DC scheme triggering

When/how and at which level to trigger the updraught ?

Bougeault Ascent:

- progressive, one way
  → very cheap
- quite realistic results
- no control on triggering

DC scheme triggering

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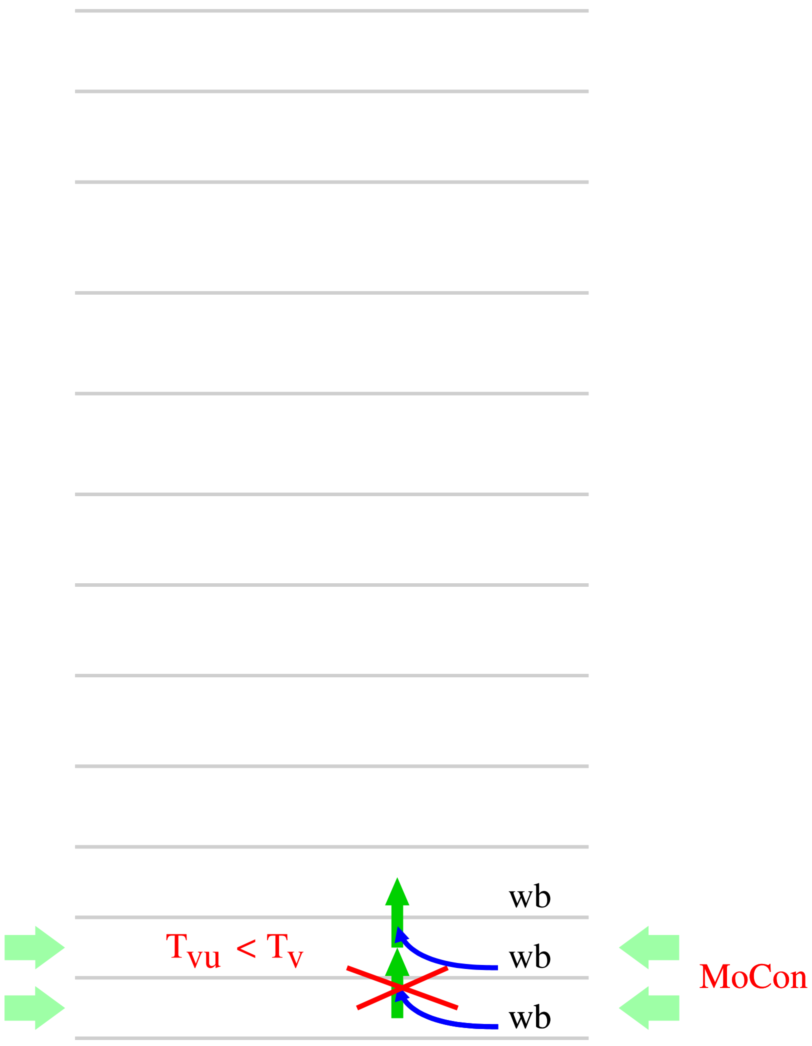

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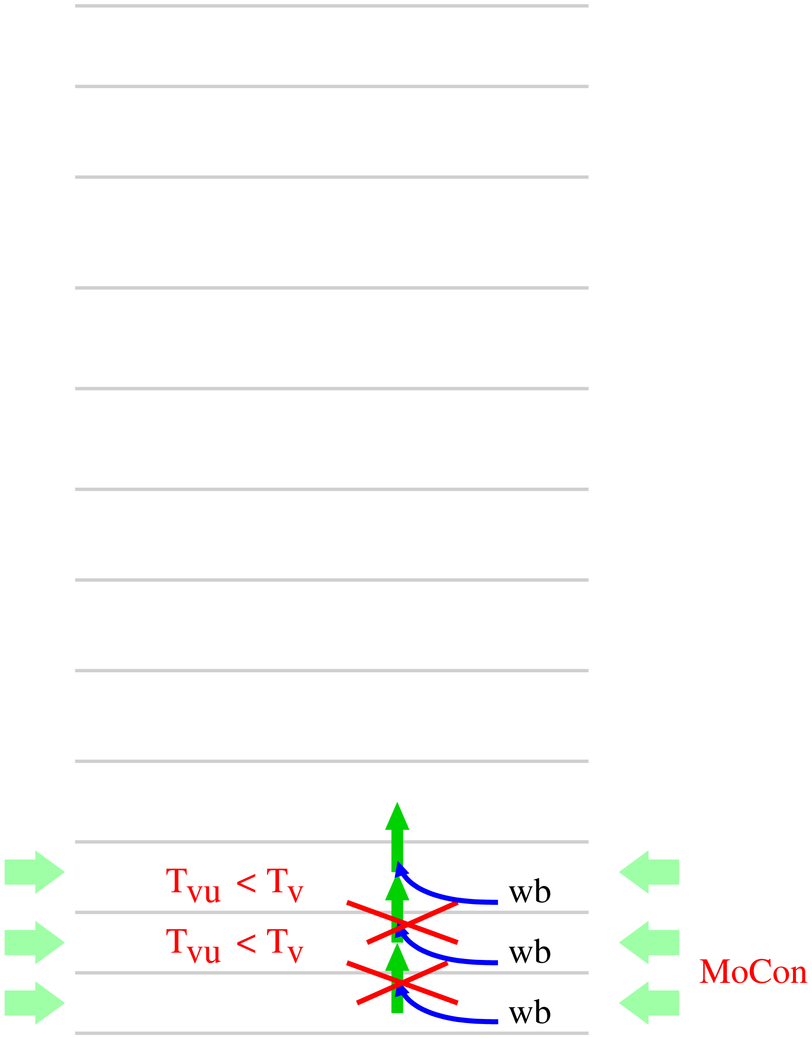

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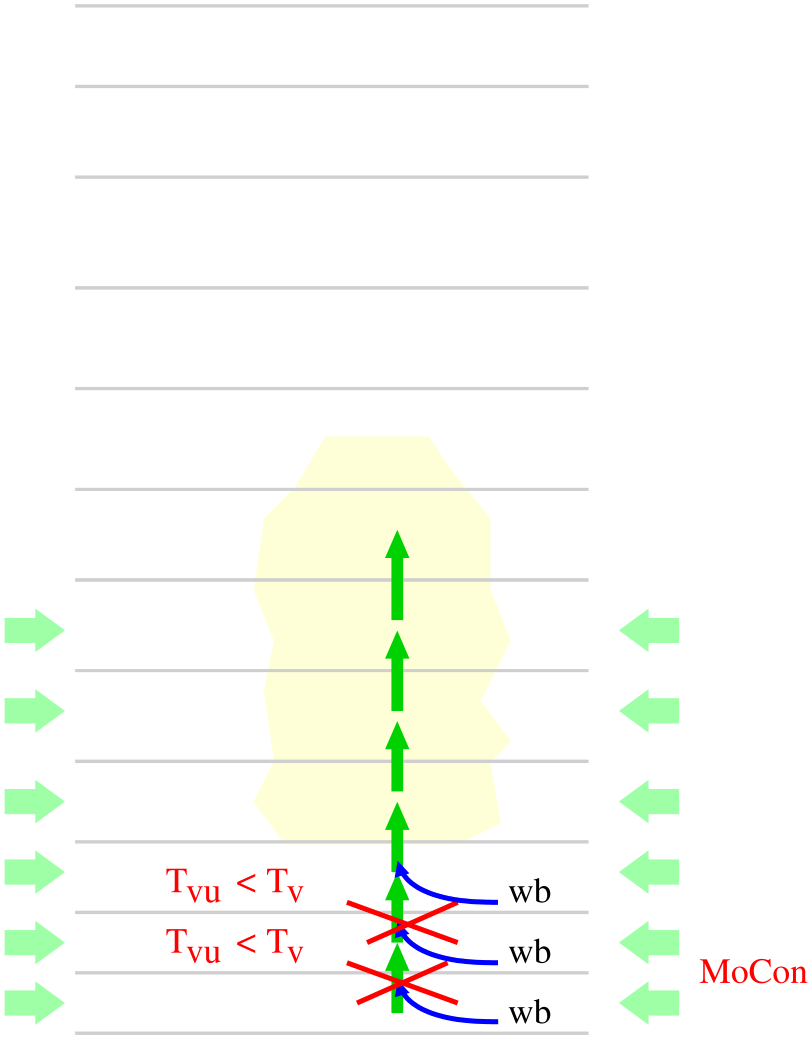

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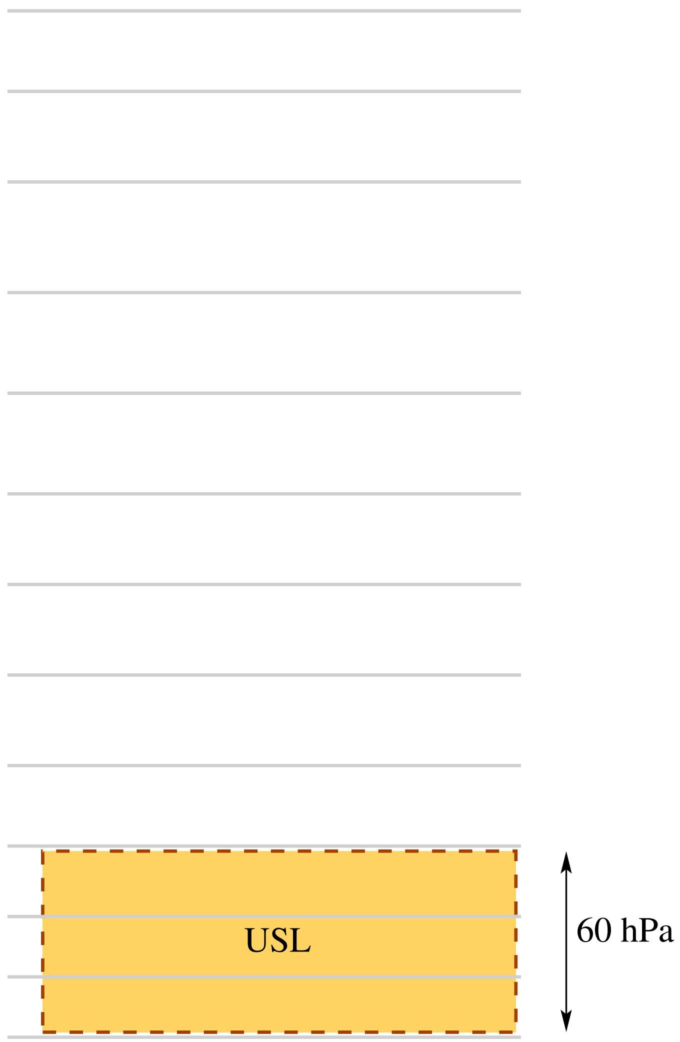

USL Ascent:

- more physical;
- independent of vertical discretization;
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  buoyancy kick ($\overline{w}$, TKE, dd history...);
- iterative → more expensive.

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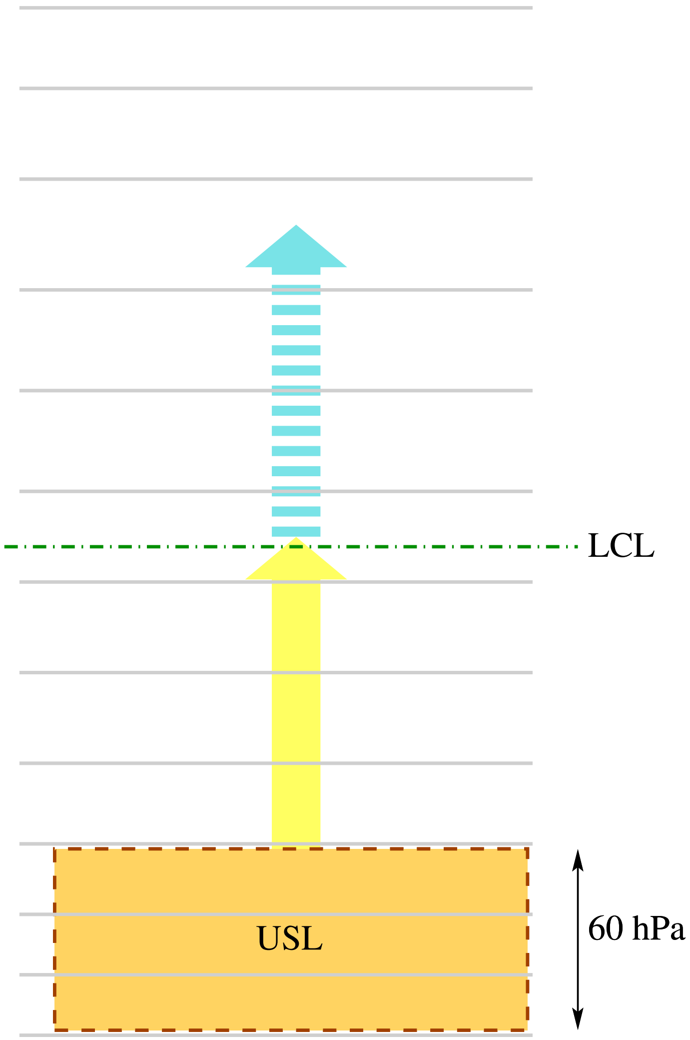

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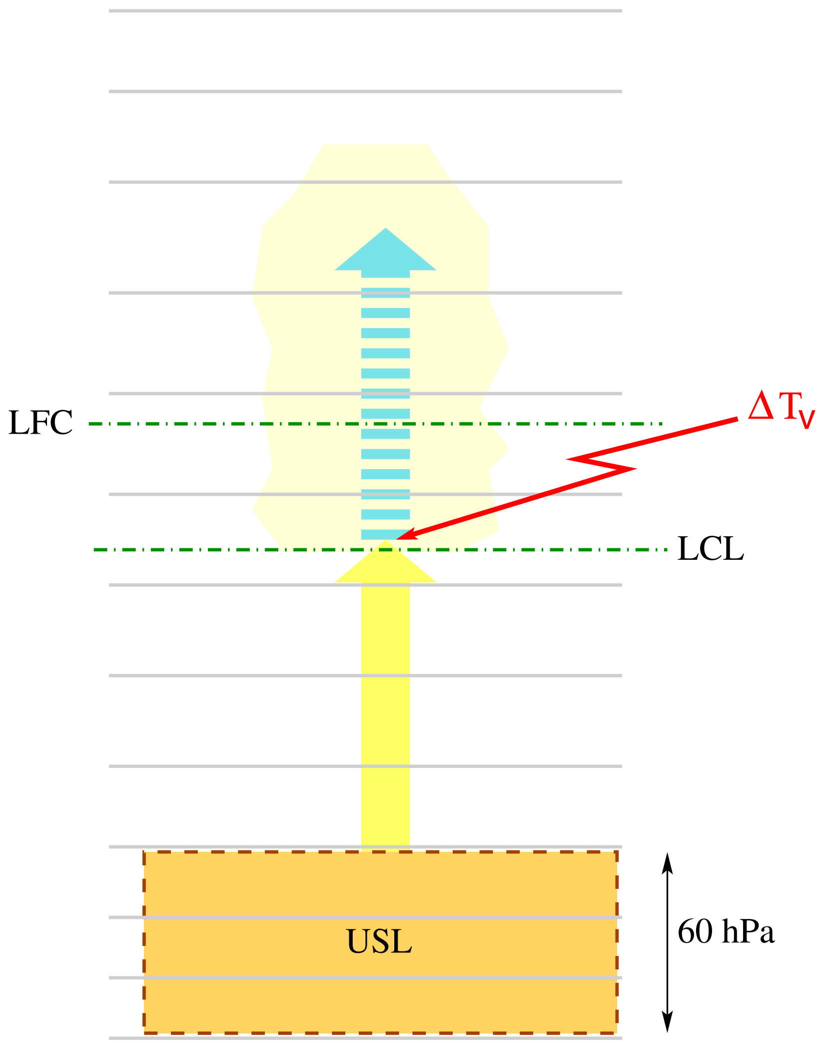

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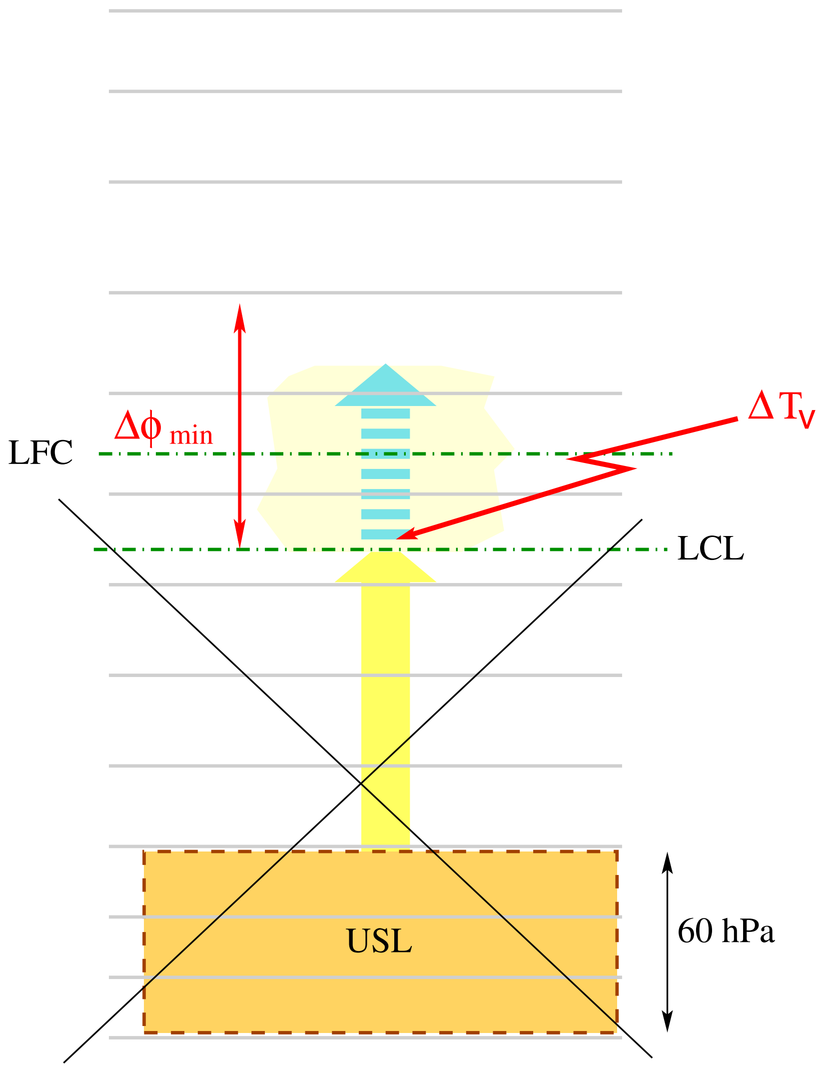

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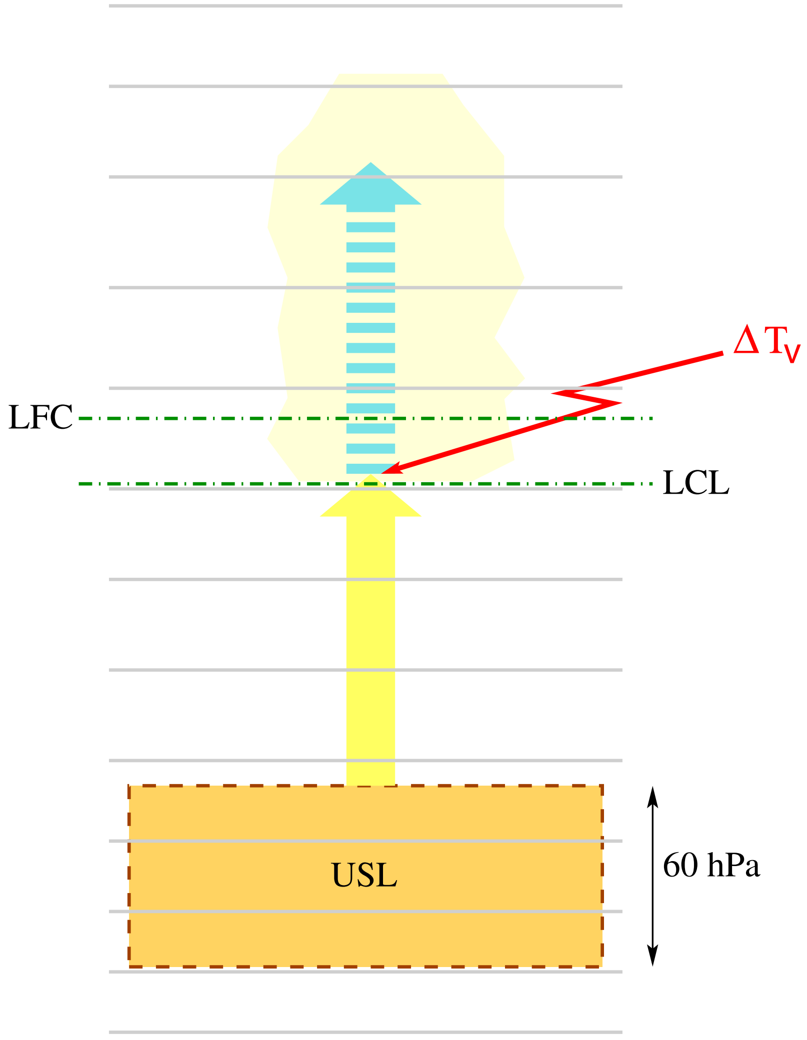

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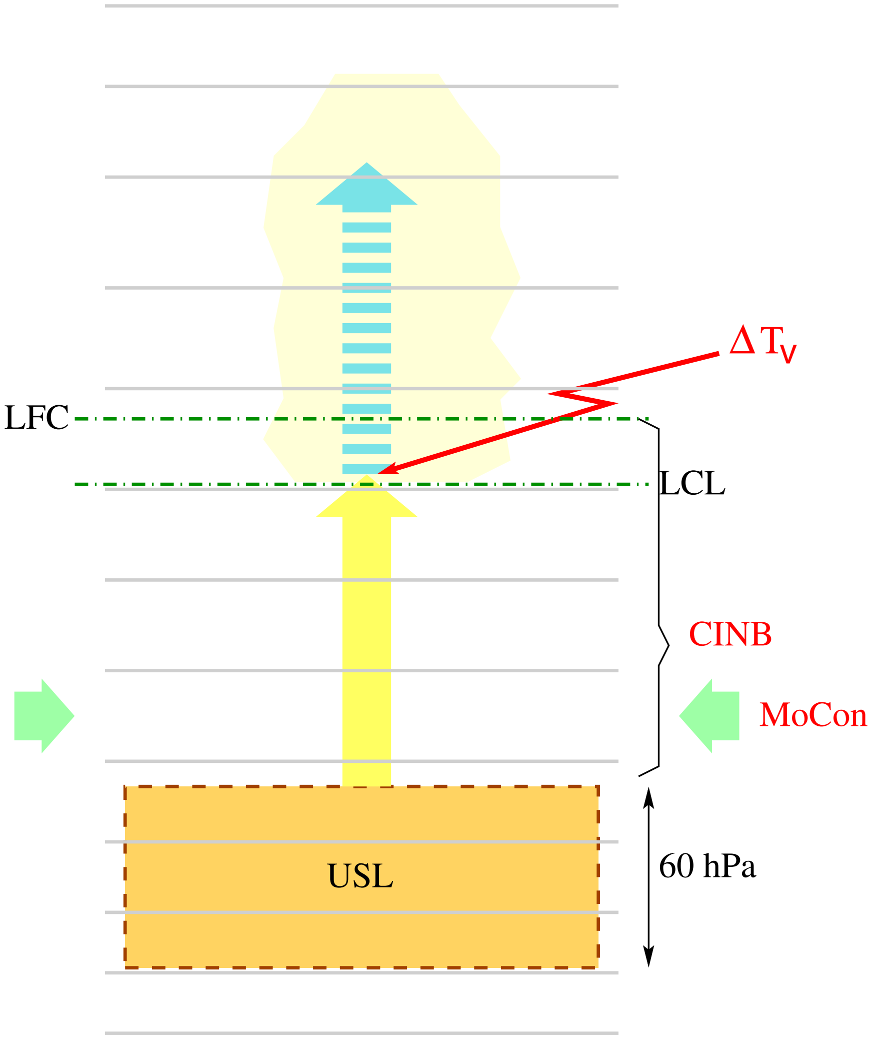

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Triggering criterion

- Kain-Fritsch (2004):

$$\triangle T_{v,KF} = \left[\gamma(\overline{w}_{LCL} - w_0 \min(1, \frac{z_{LCL}}{z_0})\right]^{1/3}, \quad \frac{1}{\gamma} \sim 0.01 \mathrm{m\,s^{-1}K^{-3}}, \quad z_0 = 2\mathrm{km},$$

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workaround: limit the kick to the one necessary to pass the CIN.

\+ require min cloud condensate present in a layer above base

- CSD perturbation approach (LCVFIRST=F): use Cloud-scheme condensation

$$\triangle T_{v,RC} = \min(T_1, \left[\gamma(F_{cs} - F_{cs0})\right]^{1/3}), \qquad \frac{1}{\gamma} \sim 0.005\,\mathrm{kg\,m^{-1}s^{-1}K^{-3}}$$

F_{cs0} resolution-dependent threshold
\+ limitation by CIN
\+ require min condensation within given height above base

Real case tests

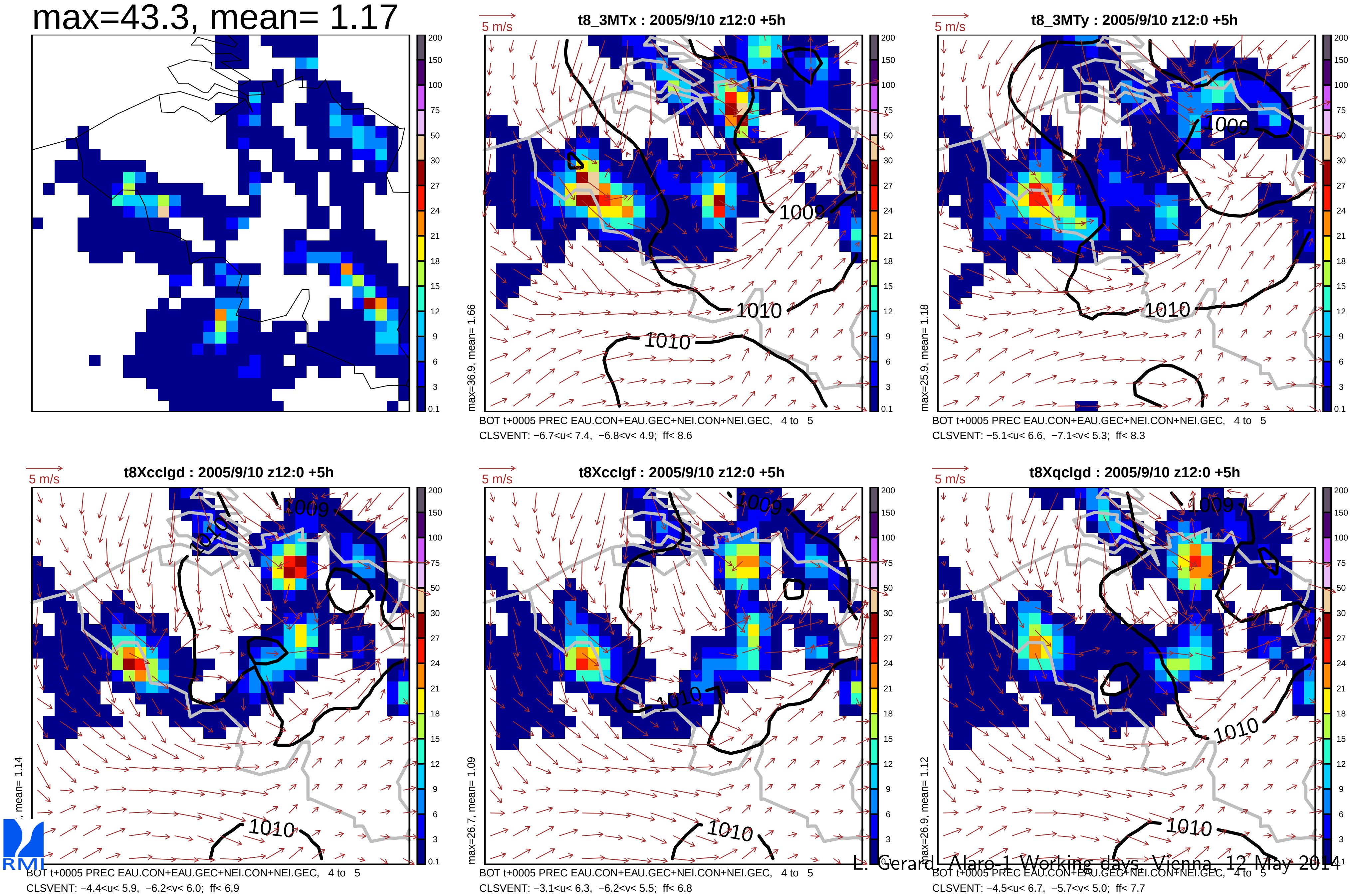
BB:

- Small domain at 8, 4, 2 and 1km. 8 and 4km are HS, 2 and 1km are NH.
- 41 levels, 60 levels at 1km.
- 12h run from cold start at 12pm, 2006-09-10.
- comparison with 1km run nocp and Wideumont radar (reprojected to the four grids).

Example of 1-h precipitation fields (BB)

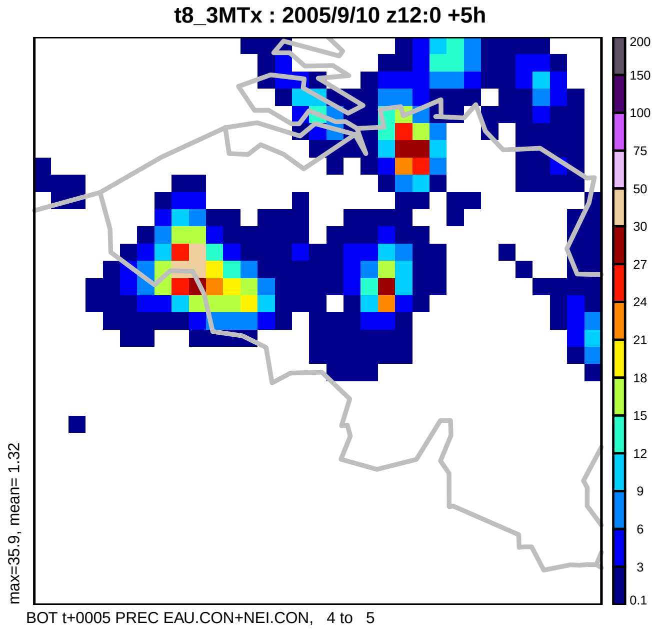
8km, total

max=43.3, mean= 1.17



Example of 1-h precipitation fields (BB)

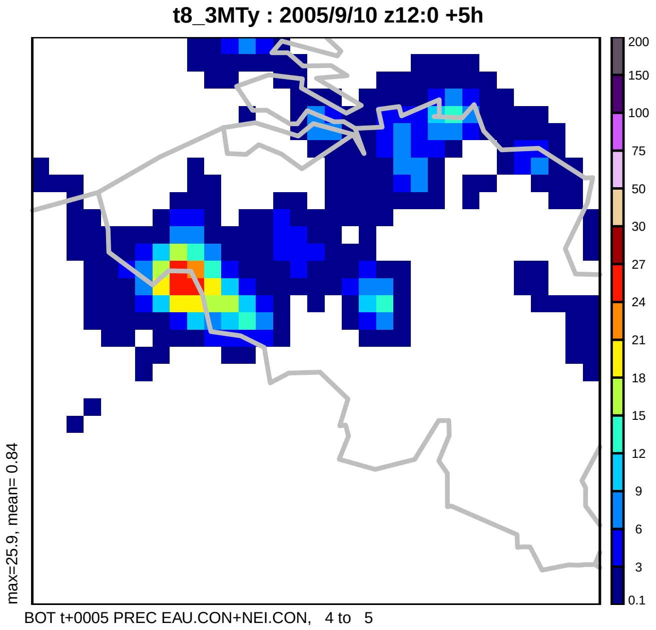
8km, subgrid/convective



t8_3MTx : 2005/9/10 z12:0 +5h

max=35.9, mean= 1.32

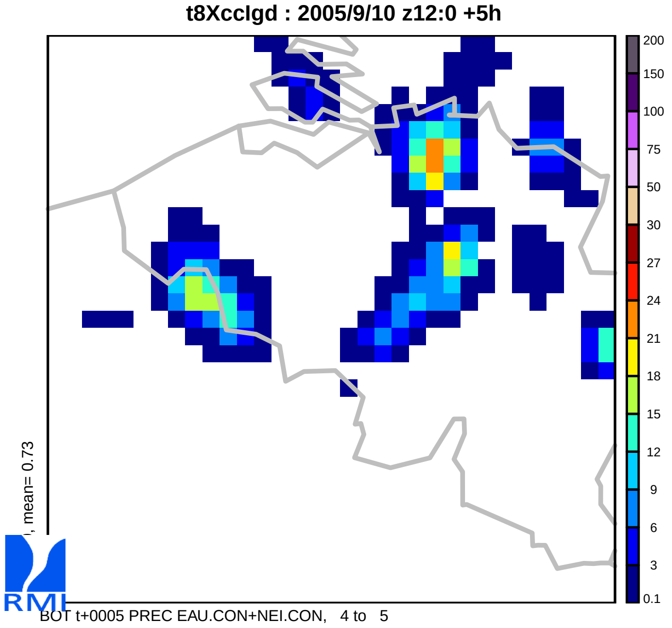
BOT t+0005 PREC EAU.CON+NEI.CON,   4 to   5



t8_3MTy : 2005/9/10 z12:0 +5h

max=25.9, mean= 0.84

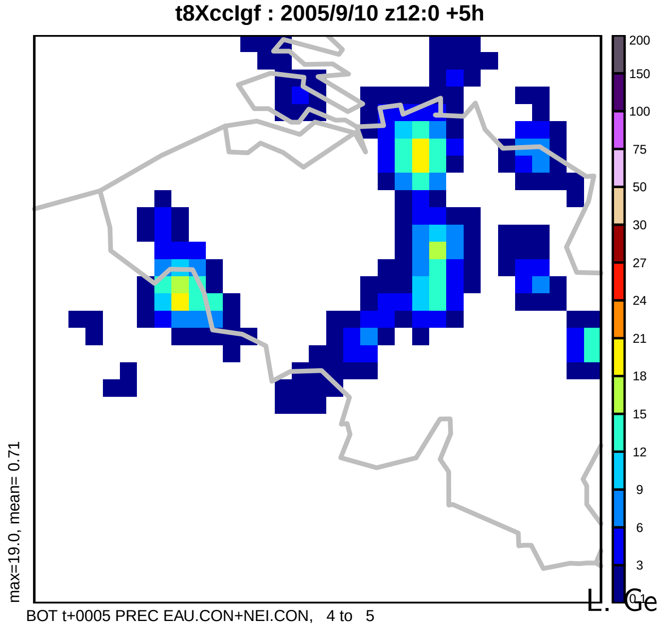
BOT t+0005 PREC EAU.CON+NEI.CON,   4 to   5



t8Xcclgd : 2005/9/10 z12:0 +5h

, mean= 0.73

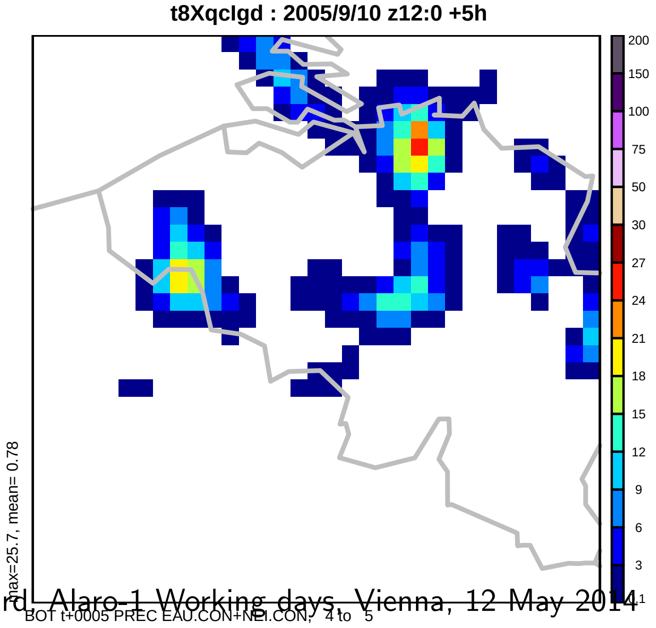
BOT t+0005 PREC EAU.CON+NEI.CON,   4 to   5



t8Xcclgf : 2005/9/10 z12:0 +5h

max=19.0, mean= 0.71

BOT t+0005 PREC EAU.CON+NEI.CON,   4 to   5



t8Xqclgd : 2005/9/10 z12:0 +5h

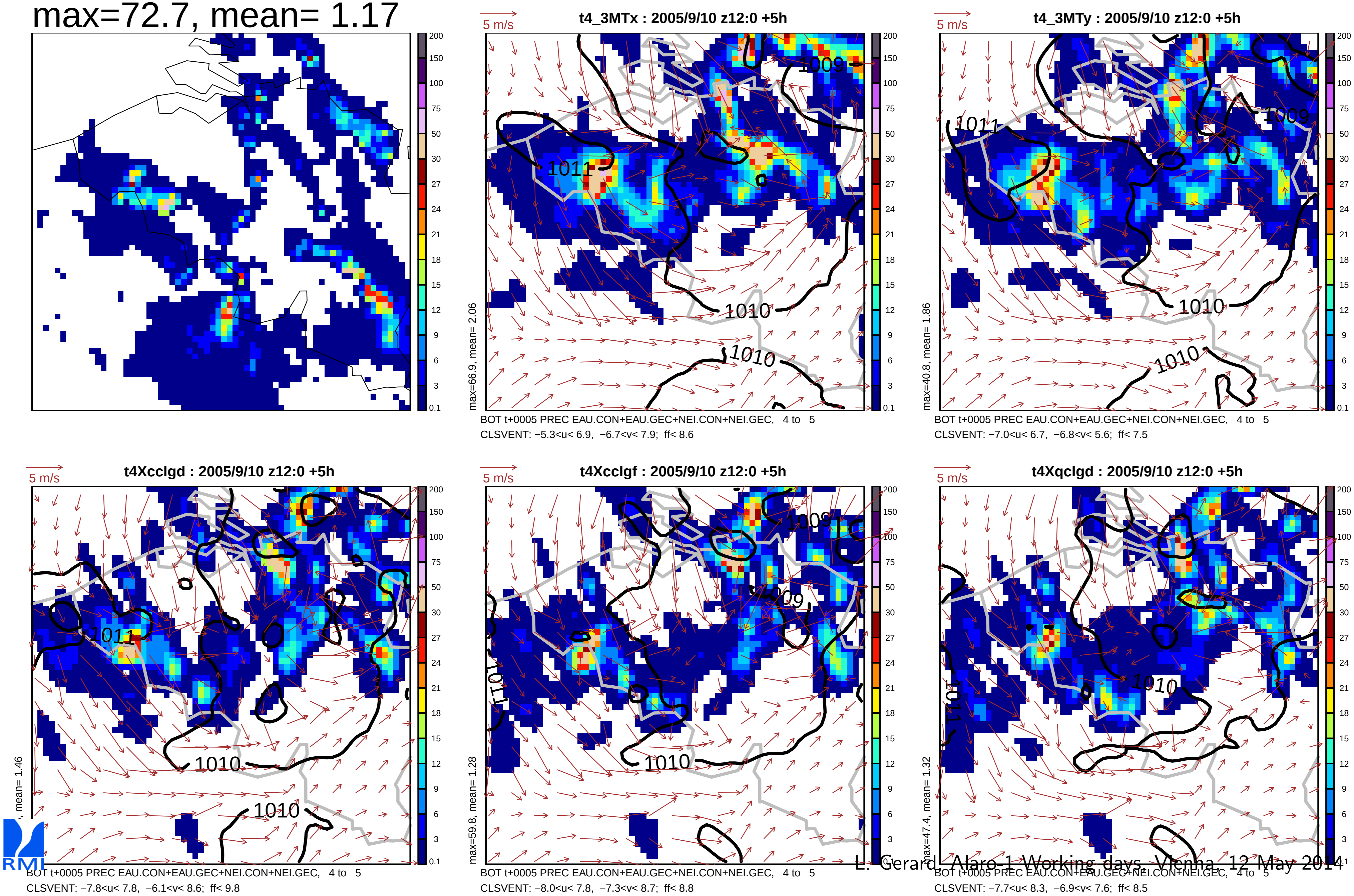
max=25.7, mean= 0.78

BOT t+0005 PREC EAU.CON+NEI.CON,   4 to   5

Example of 1-h precipitation fields (BB)

4km, total

max=72.7, mean= 1.17



t4_3MTx : 2005/9/10 z12:0 +5h

BOT t+0005 PREC EAU.CON+EAU.GEC+NEI.CON+NEI.GEC, 4 to 5
CLSVENT: −5.3<u< 6.9, −6.7<v< 7.9; ff< 8.6

t4_3MTy : 2005/9/10 z12:0 +5h

BOT t+0005 PREC EAU.CON+EAU.GEC+NEI.CON+NEI.GEC, 4 to 5
CLSVENT: −7.0<u< 6.7, −6.8<v< 5.6; ff< 7.5

t4Xcclgd : 2005/9/10 z12:0 +5h

BOT t+0005 PREC EAU.CON+EAU.GEC+NEI.CON+NEI.GEC, 4 to 5
CLSVENT: −7.8<u< 7.8, −6.1<v< 8.6; ff< 9.8

t4Xcclgf : 2005/9/10 z12:0 +5h

BOT t+0005 PREC EAU.CON+EAU.GEC+NEI.CON+NEI.GEC, 4 to 5
CLSVENT: −8.0<u< 7.8, −7.3<v< 8.7; ff< 8.8

t4Xqclgd : 2005/9/10 z12:0 +5h

BOT t+0005 PREC EAU.CON+EAU.GEC+NEI.CON+NEI.GEC, 4 to 5
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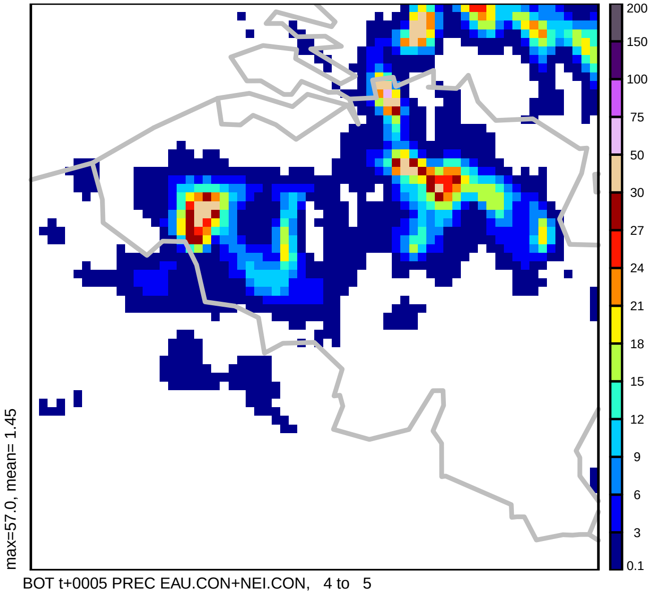
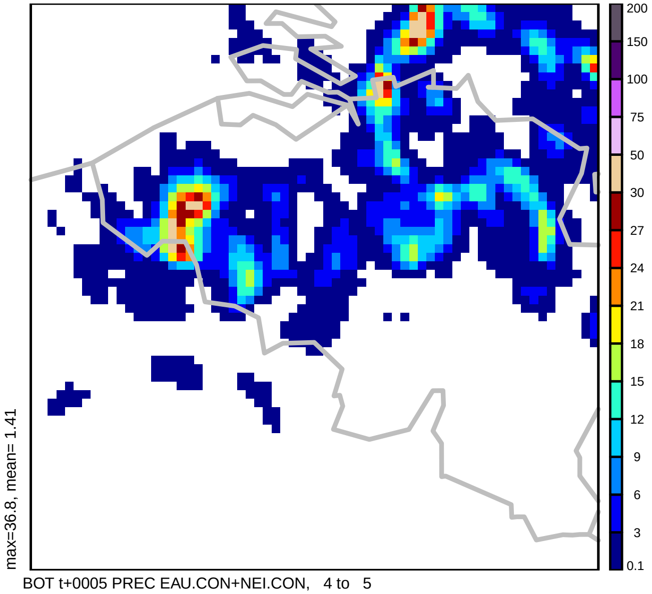
Example of 1-h precipitation fields (BB)

4km, subgrid/convective

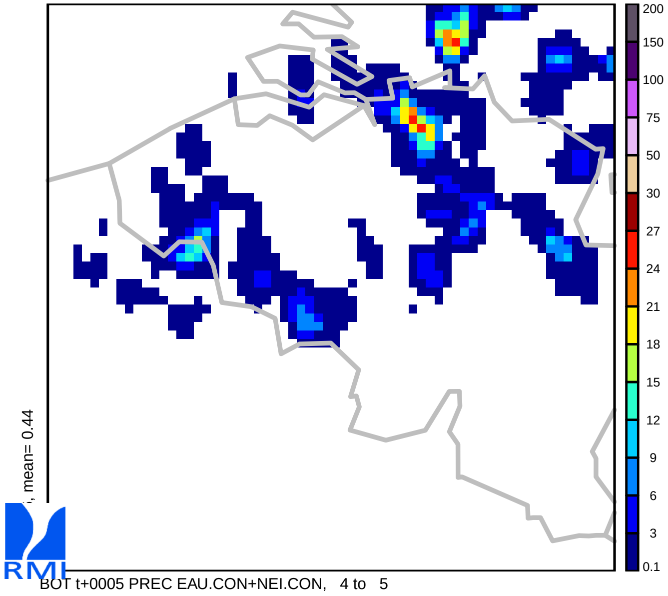
t4_3MTx : 2005/9/10 z12:0 +5h



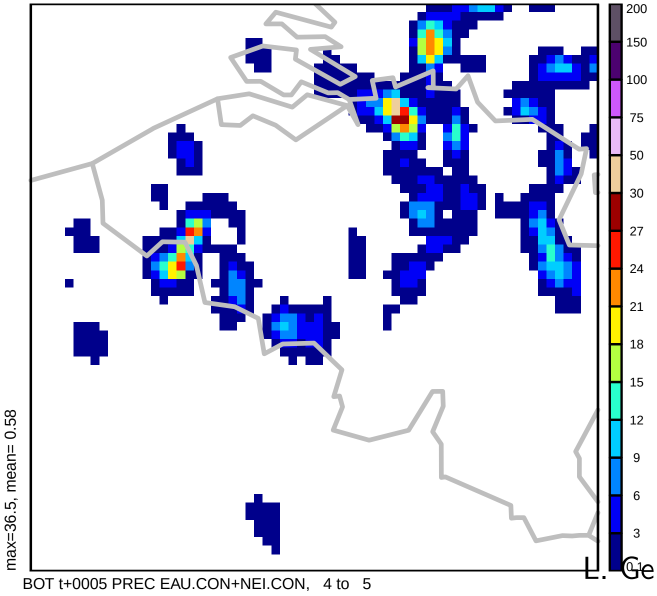
t4_3MTy : 2005/9/10 z12:0 +5h



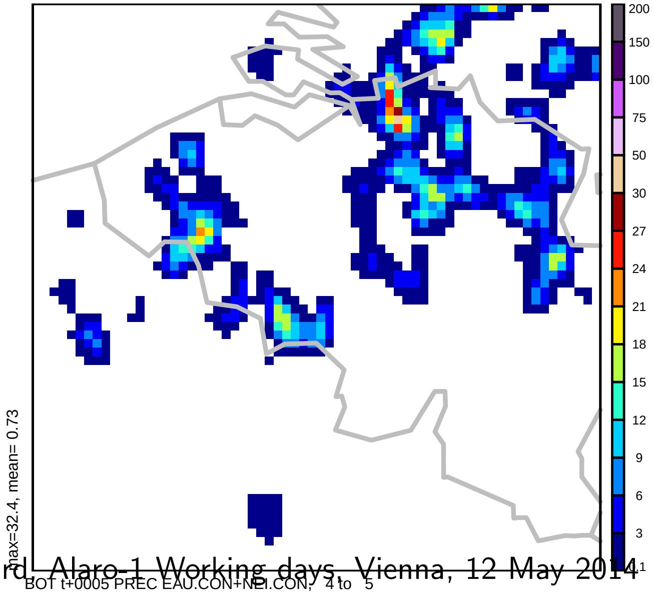
t4Xcclgd : 2005/9/10 z12:0 +5h



t4Xcclgf : 2005/9/10 z12:0 +5h



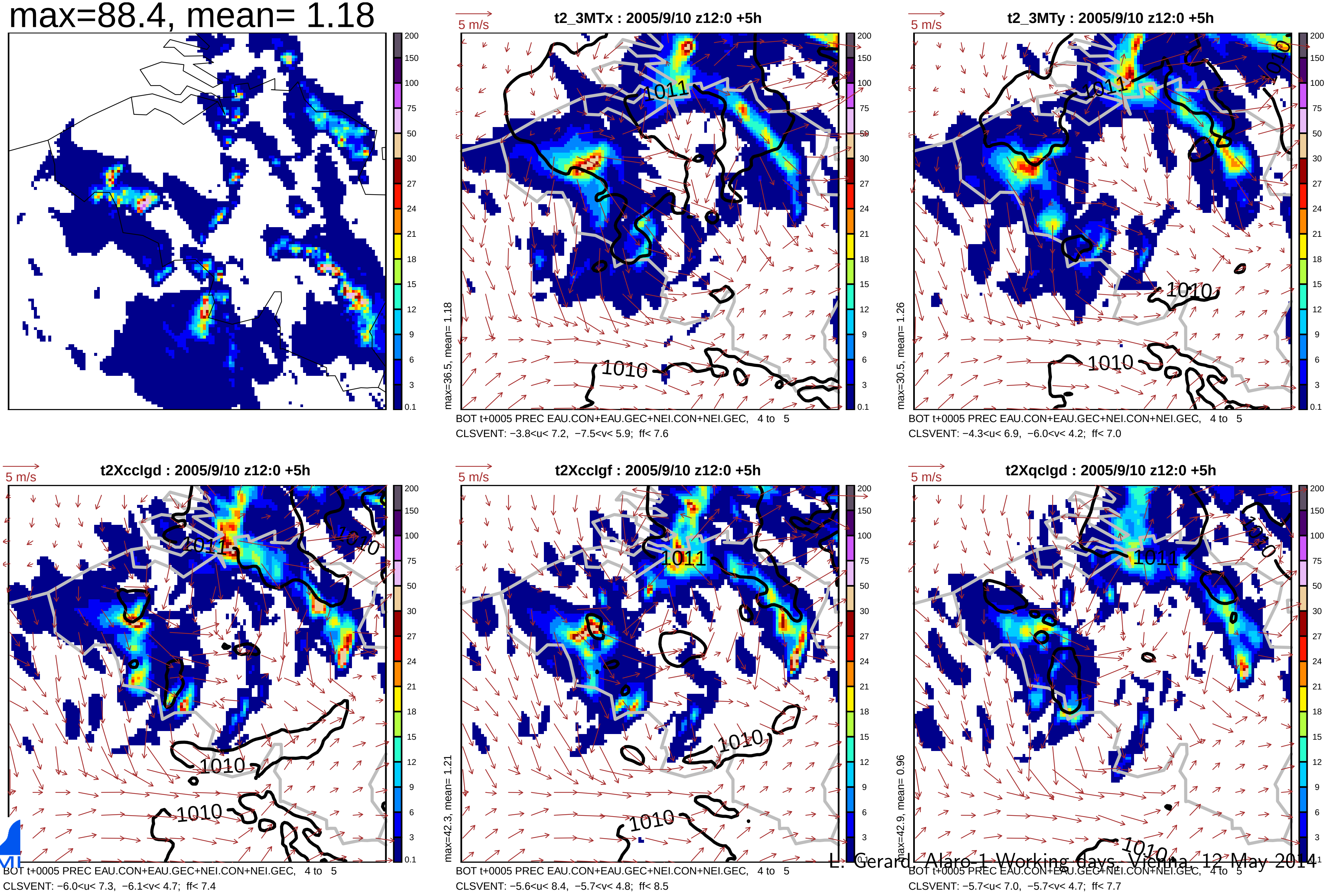
t4Xqclgd : 2005/9/10 z12:0 +5h



Example of 1-h precipitation fields (BB)

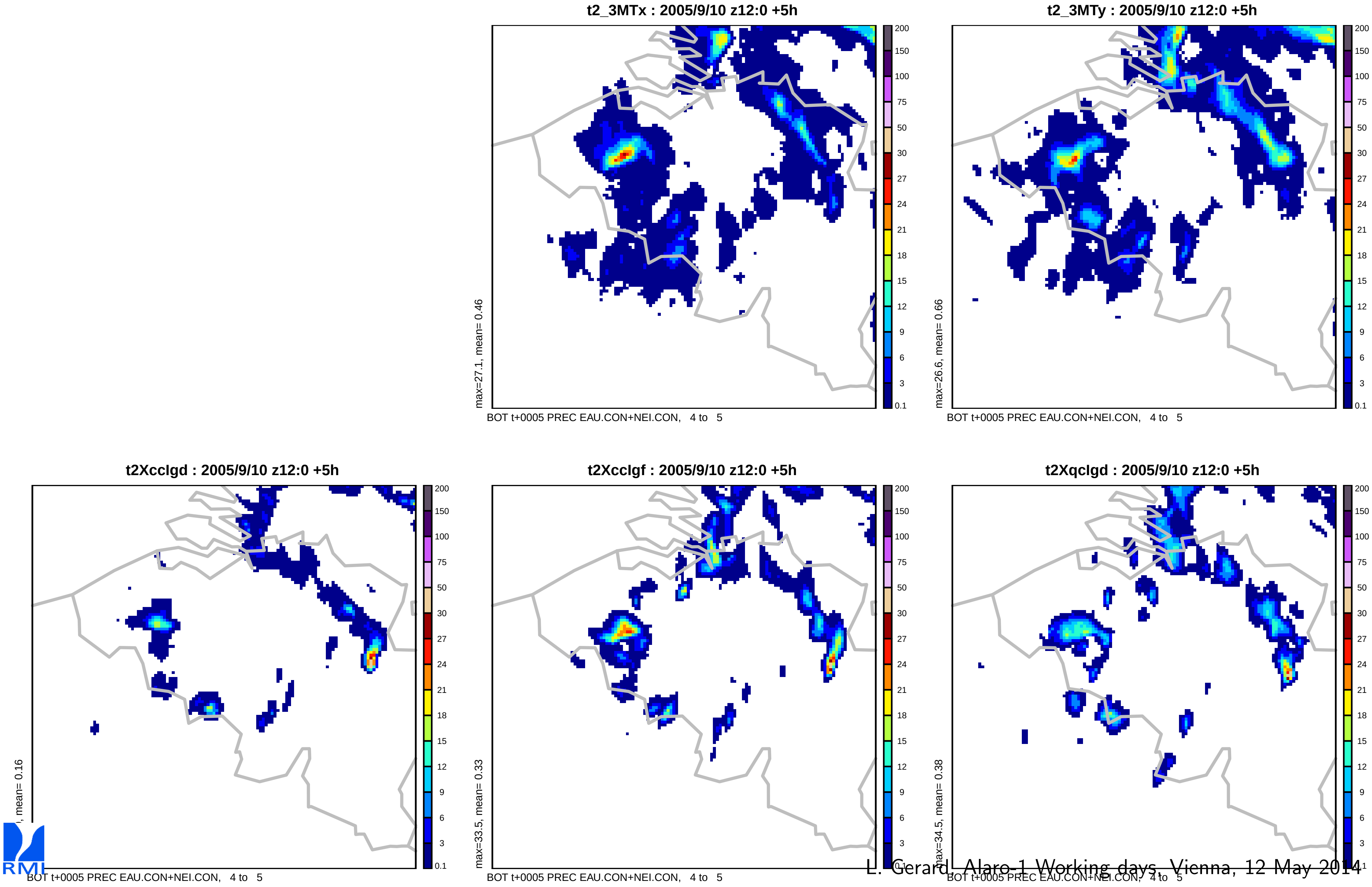
2km, total

max=88.4, mean= 1.18



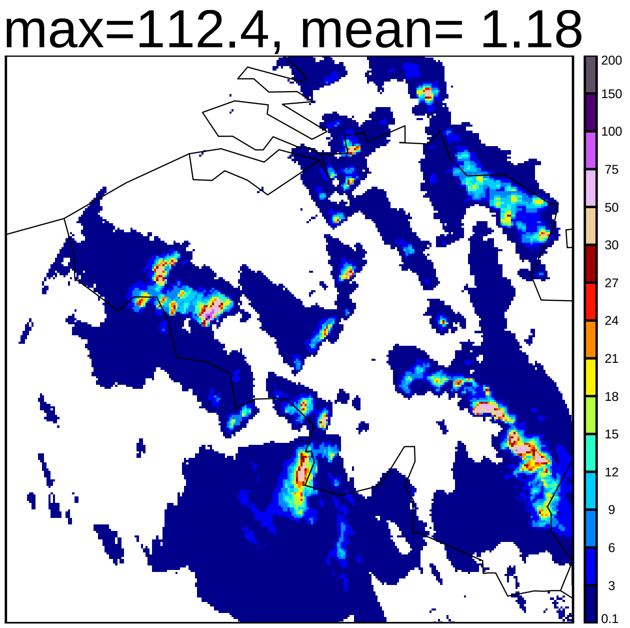
Example of 1-h precipitation fields (BB)

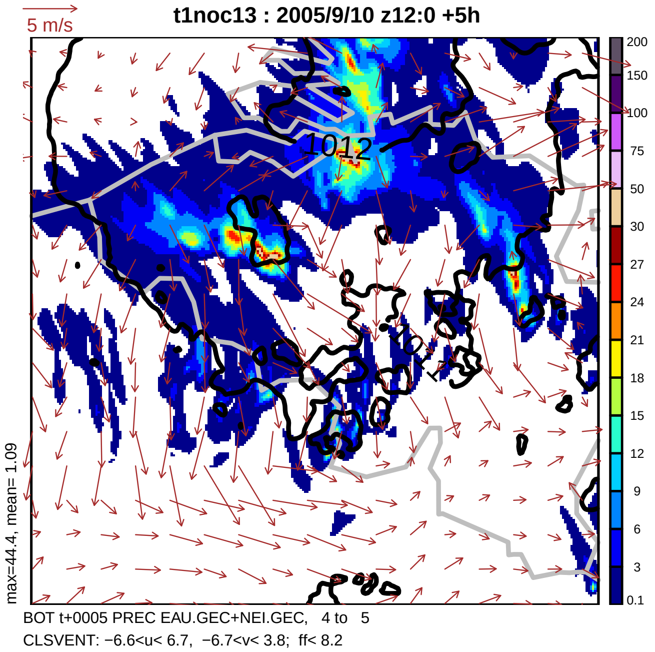
2km, subgrid/convective



Example of 1-h precipitation fields (BB)

1km, ‘reference’



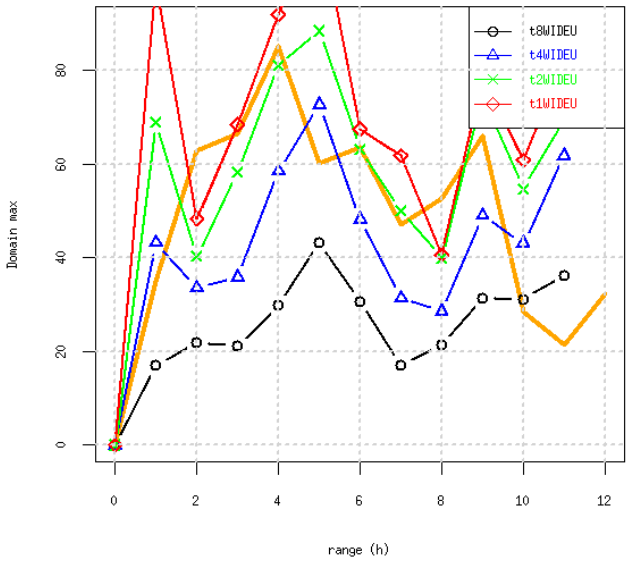


Real case tests BB

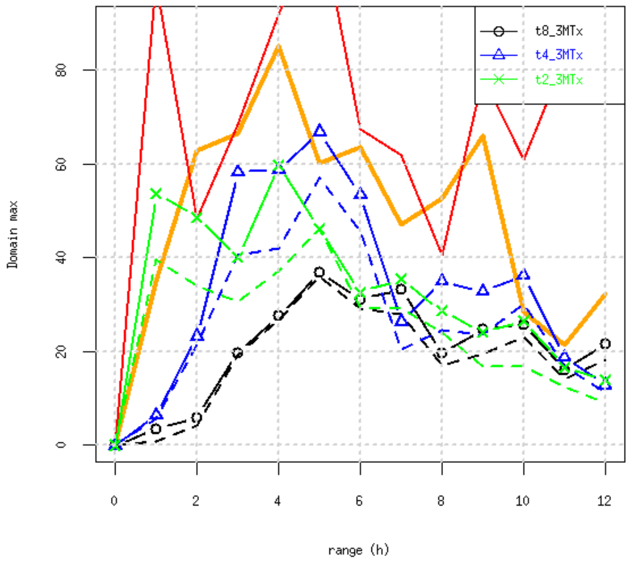
Peak 1-hour total/convective precipitation evolution

reference : nocp 1km run

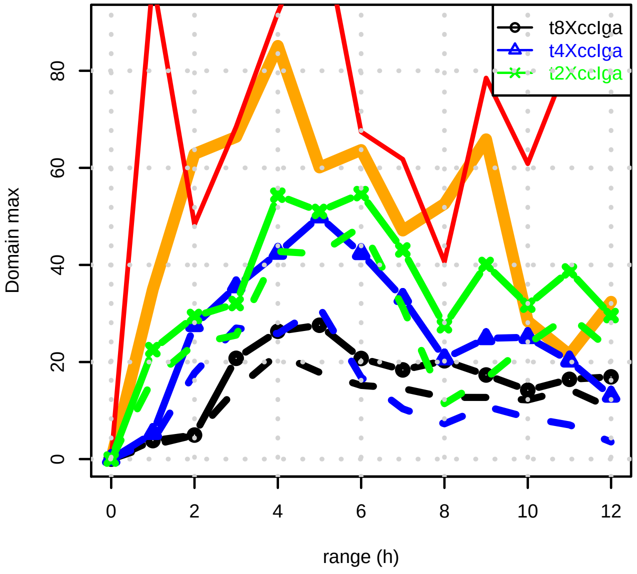
Wideumont radar



3MT+nsdd

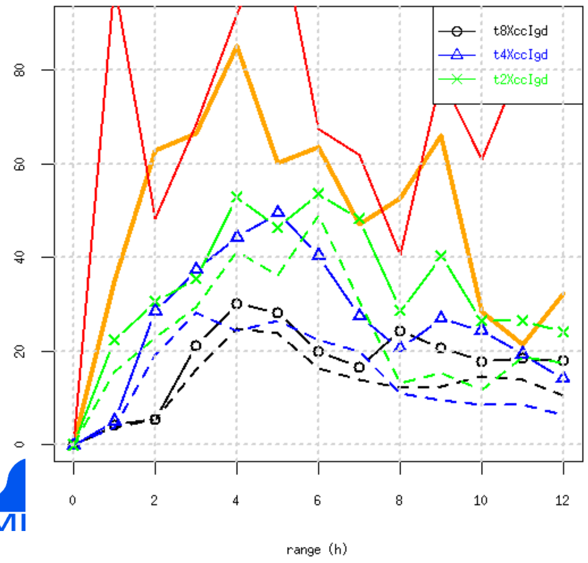


nfsig=0, LRITO=F, CAPE

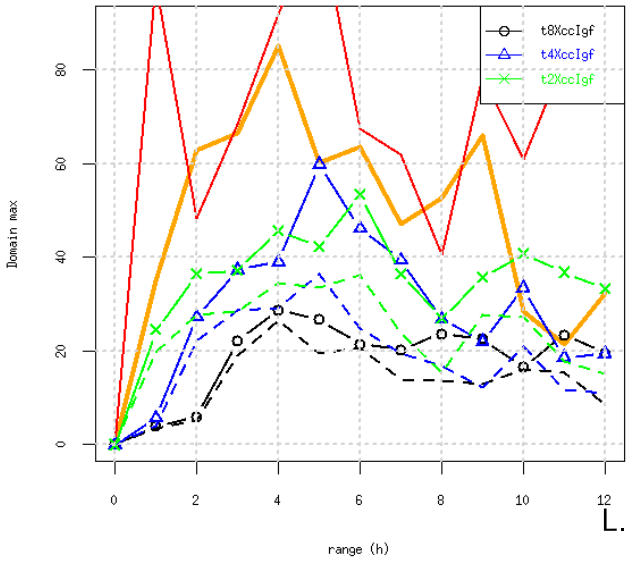


CSD

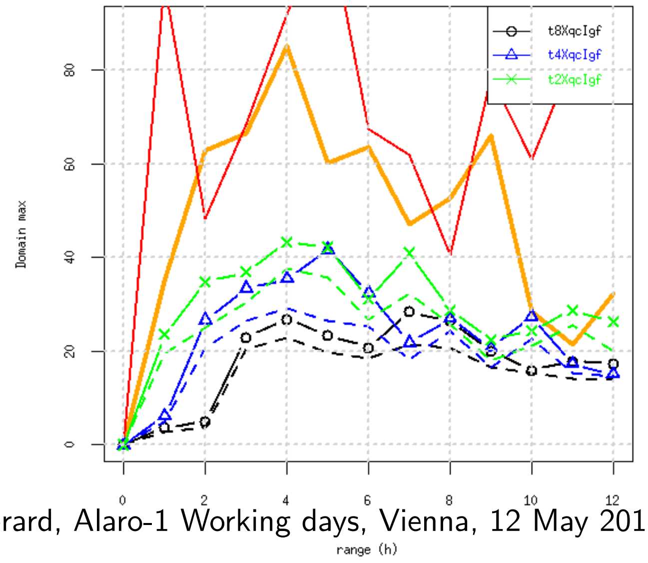
CAPE



CAPE + secondary closure



MoCON

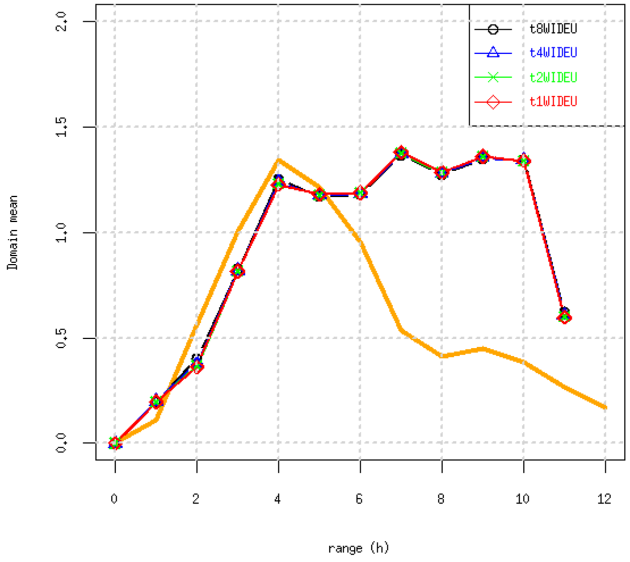


Real case tests BB

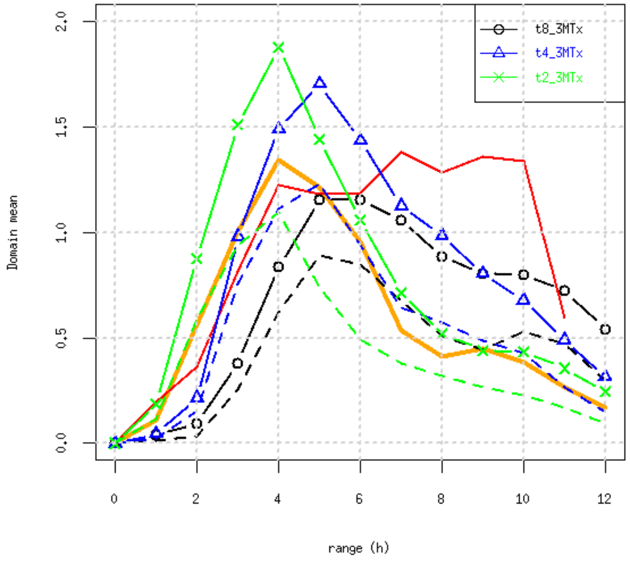
Domain mean 1-hour precipitation evolution

reference : nocp 1km run

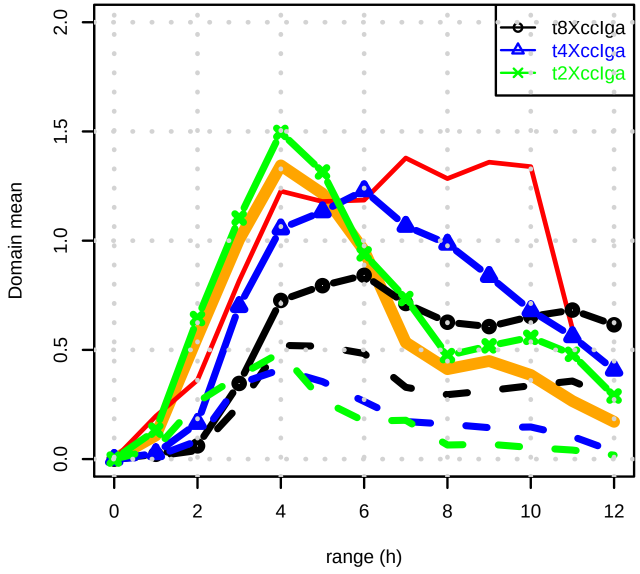
Wideumont radar



3MT+nsdd

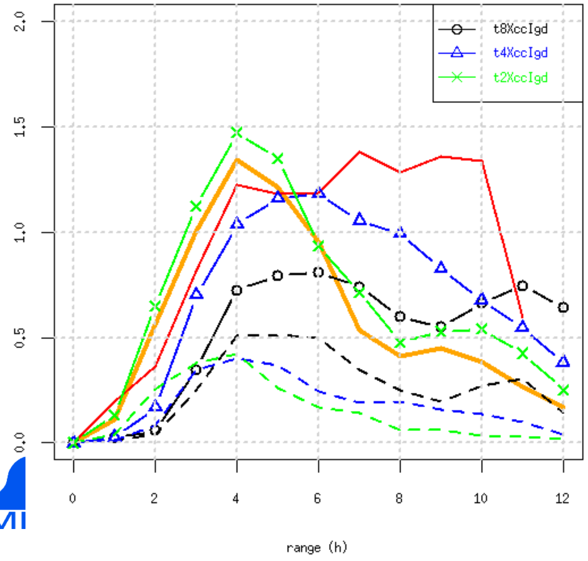


nfsig=0, LRITO=F, CAPE

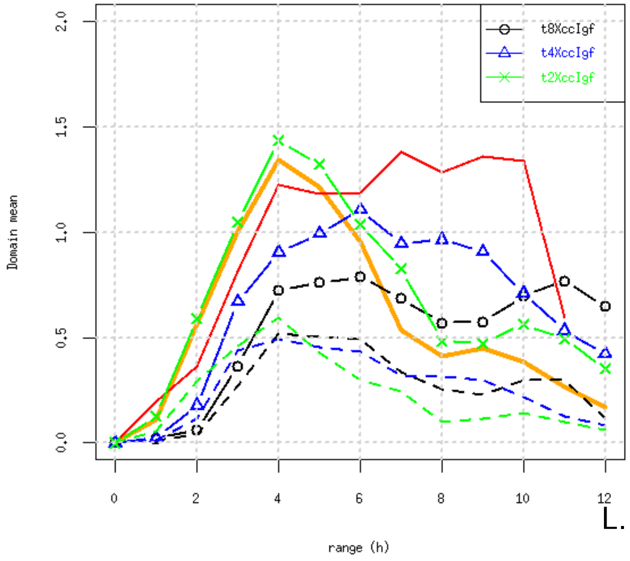


CAPE

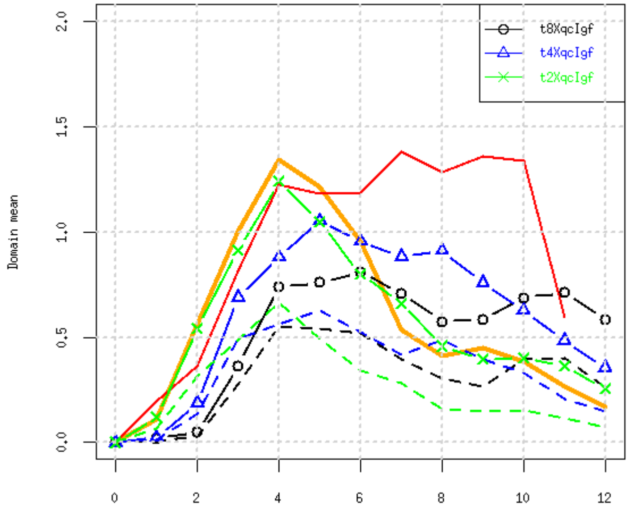
CSD



CAPE + secondary closure



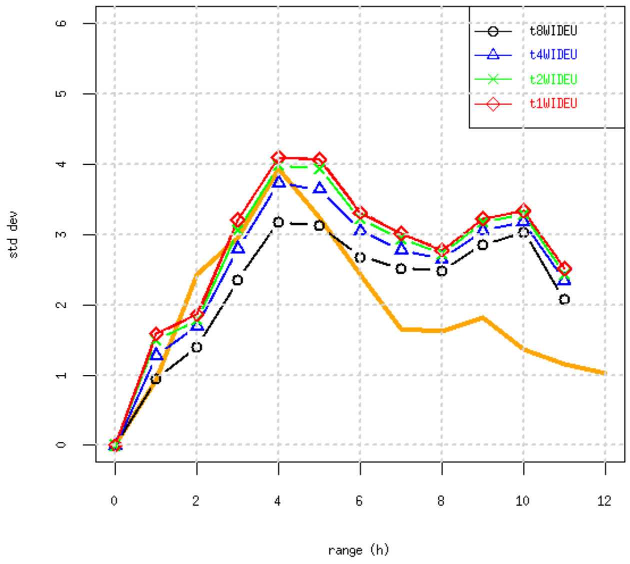
MoCON



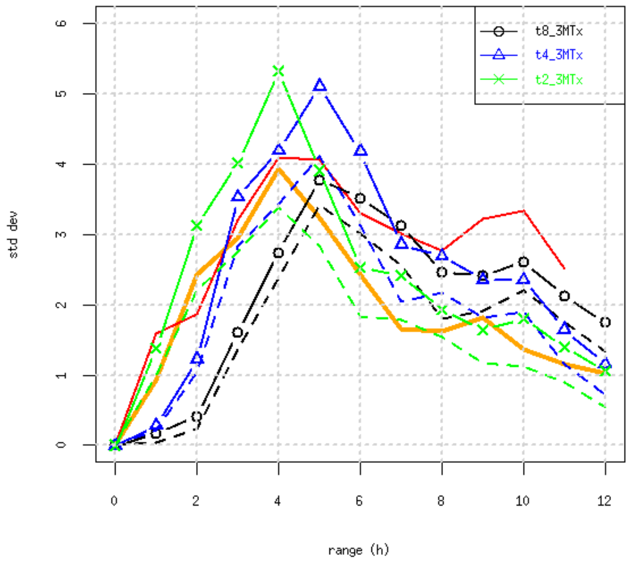
Real case tests BB

Domain standard deviation 1-hour precipitation evolution   reference : nocp 1km run

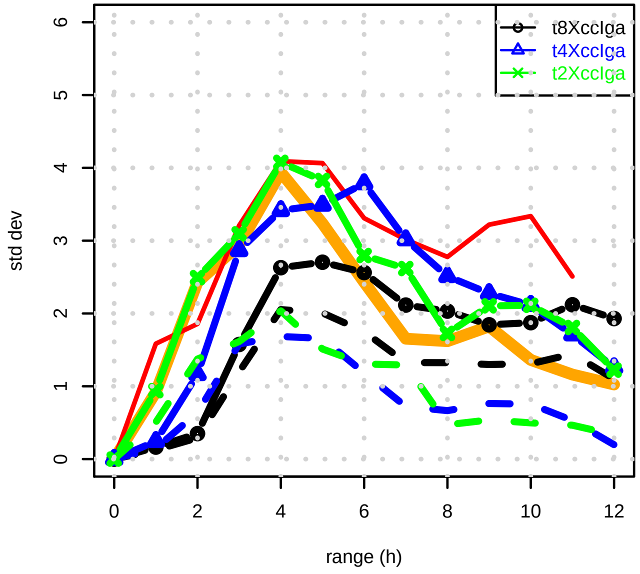
Wideumont radar



3MT+nsdd

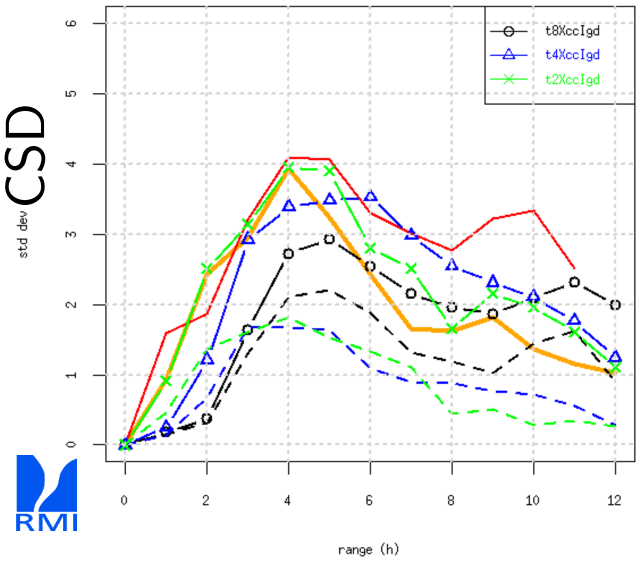


nfsig=0, LRITO=F, CAPE

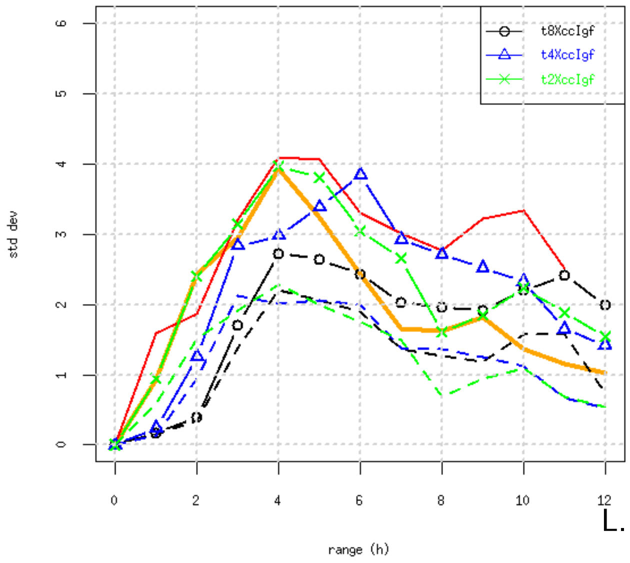


CAPE

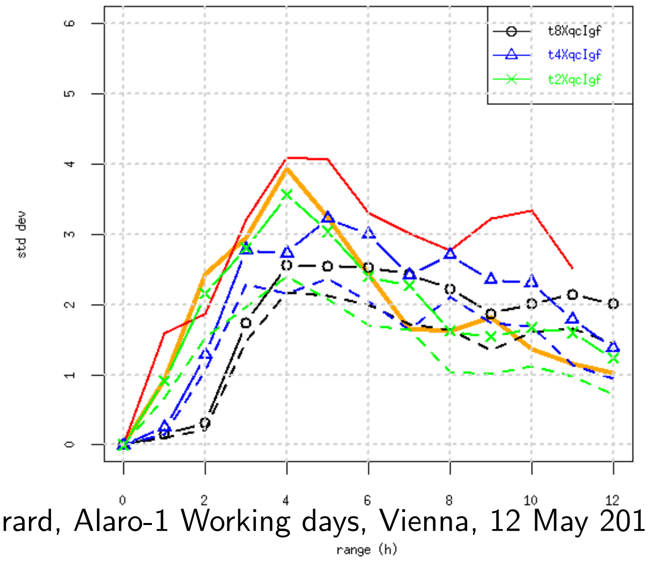
CSD



CAPE + secondary closure



MoCON



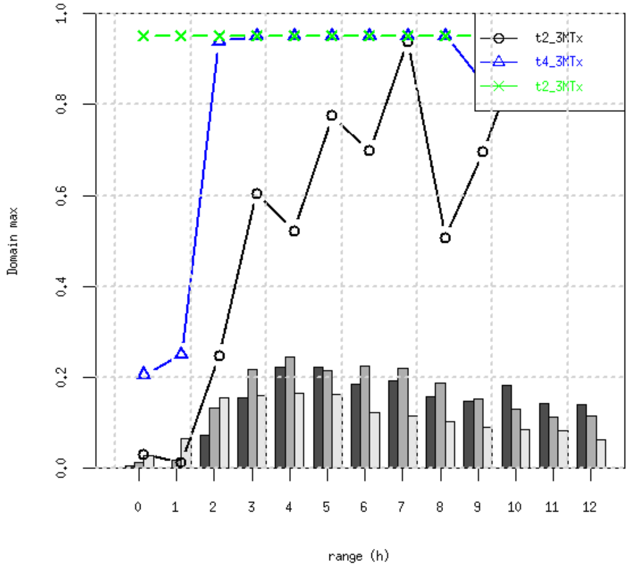
Real case tests BB: updraught mesh fraction

Peak 500hPa $\sigma_u > 0.01$ evolution

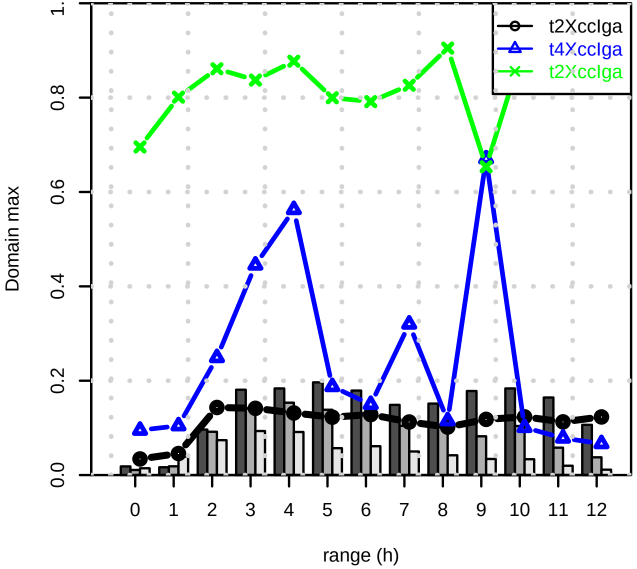
8km, 4km, 2km

bars: fraction of domain points included

3MT+nsdd

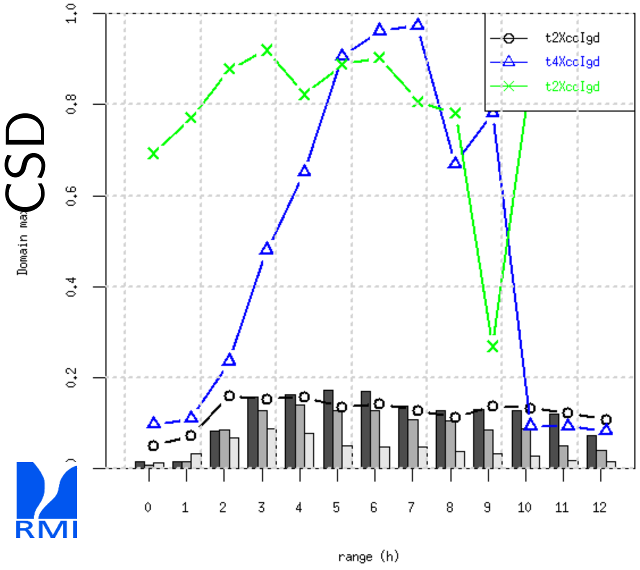


nfsig=0, LRITO=F, CAPE

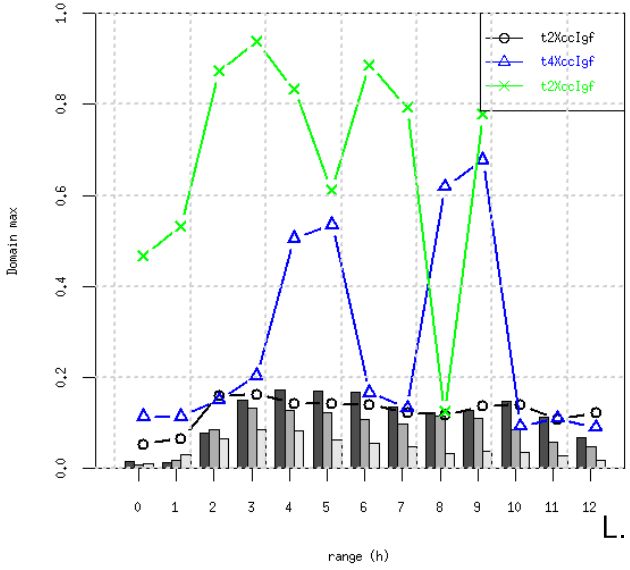


CSD

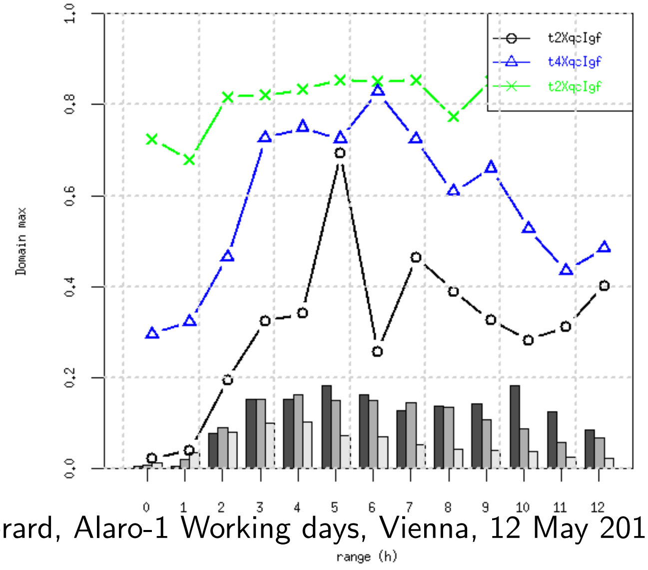
CAPE



CAPE + secondary closure



MoCON



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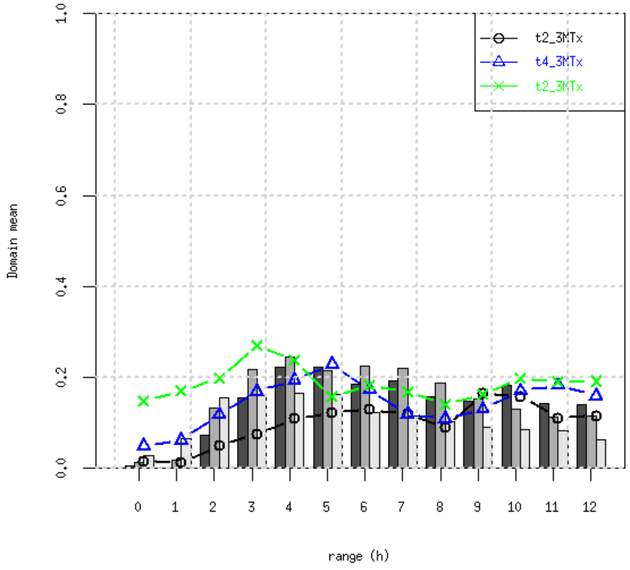
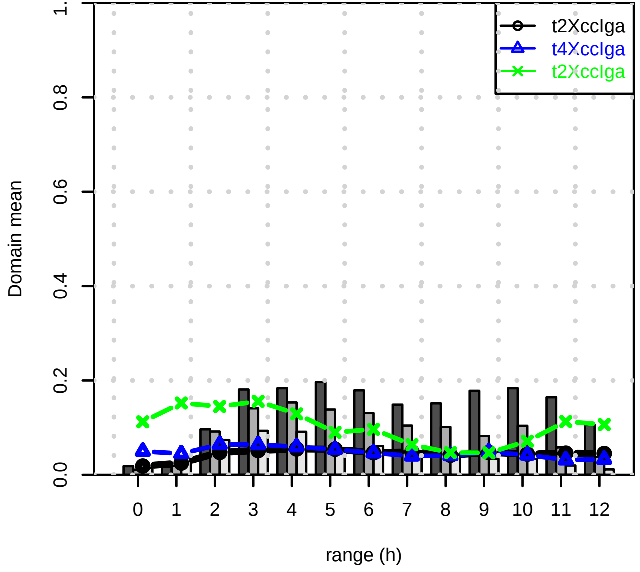
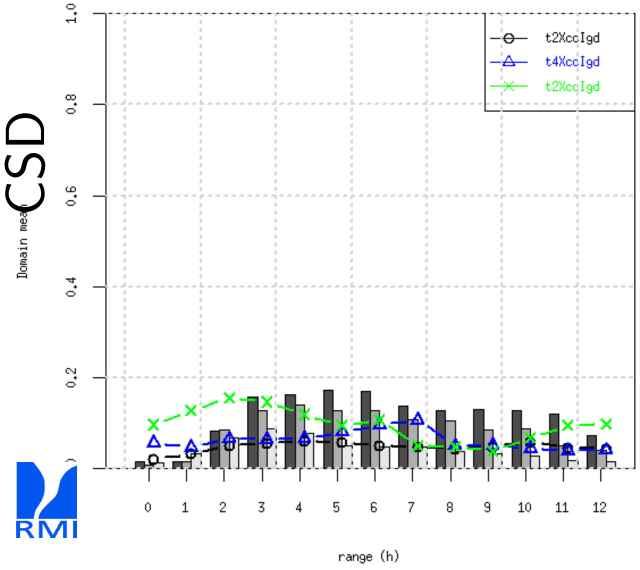


nfsig=0, LRITO=F, CAPE

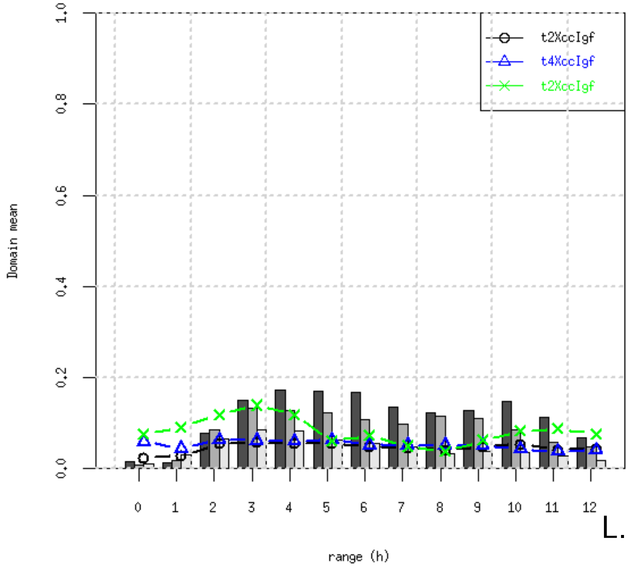


CSD

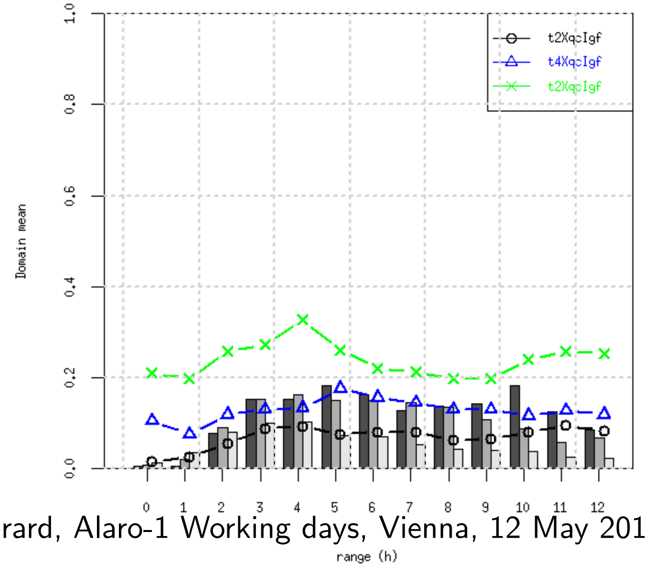
CAPE



CAPE + secondary closure



MoCON



Real case tests BB: updraught mesh fraction

Standard Deviation 500hPa $\sigma_u > 0.01$ evolution

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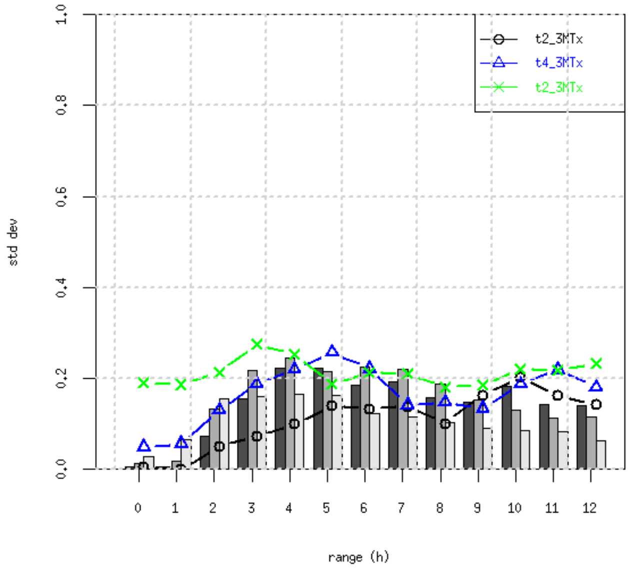
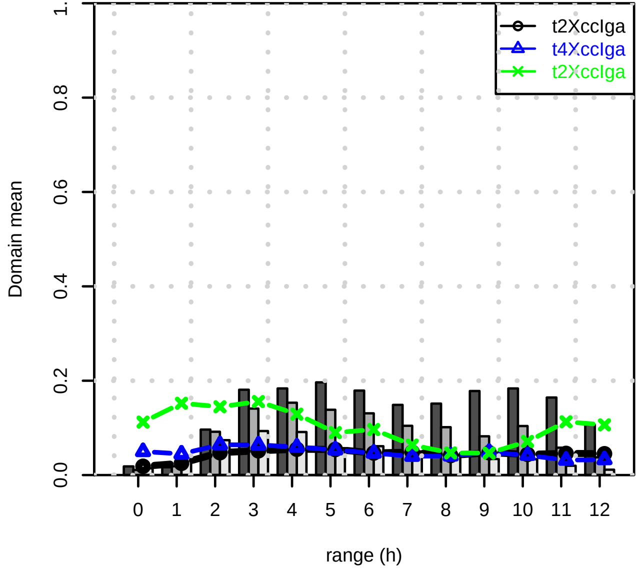
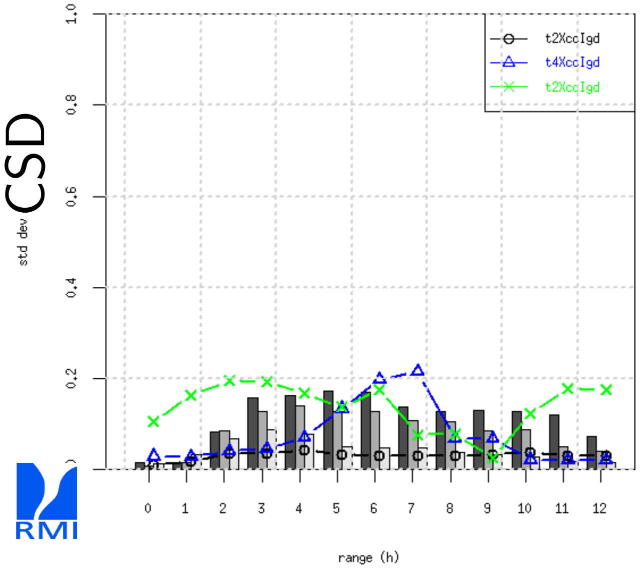


nfsig=0, LRITO=F, CAPE

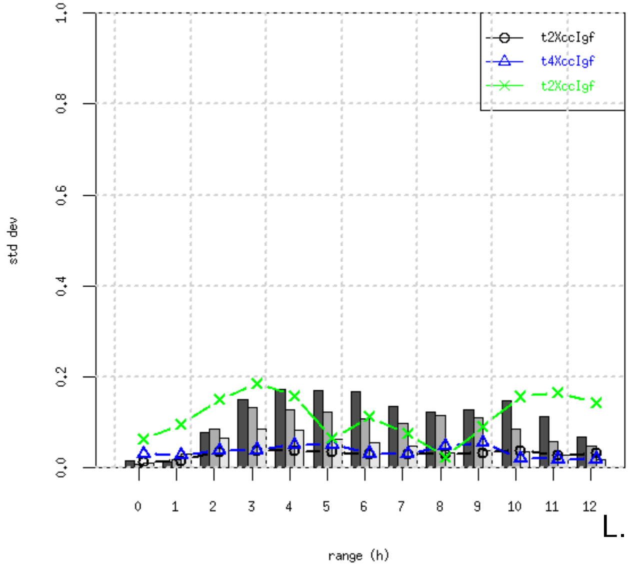


CSD

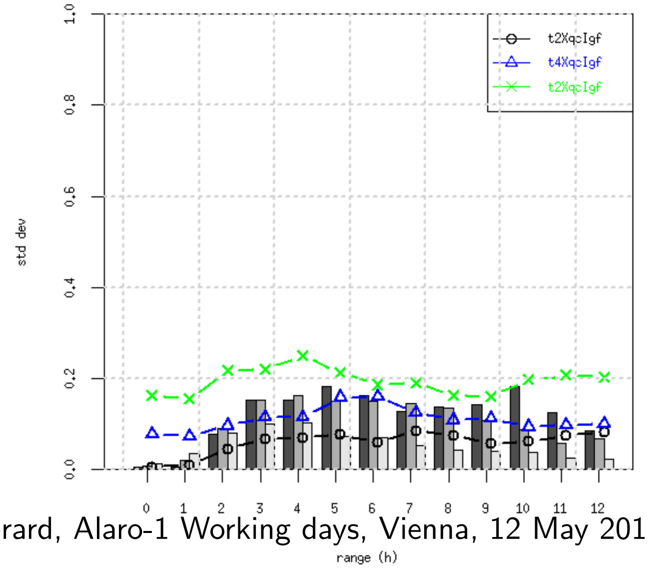
CAPE



CAPE + secondary closure

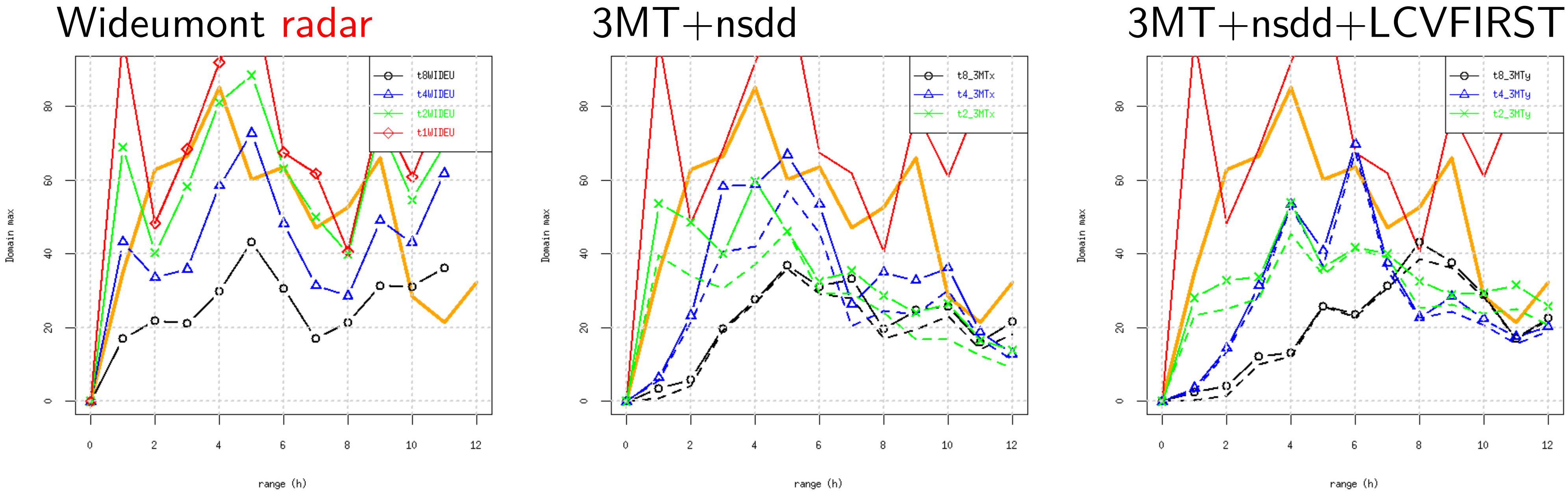


MoCON



Real case tests BB: LCVFIRST +3MT (accvud)

Domain peak 1-hour precipitation evolution


Wideumont radar

3MT+nsdd

3MT+nsdd+LCVFIRST

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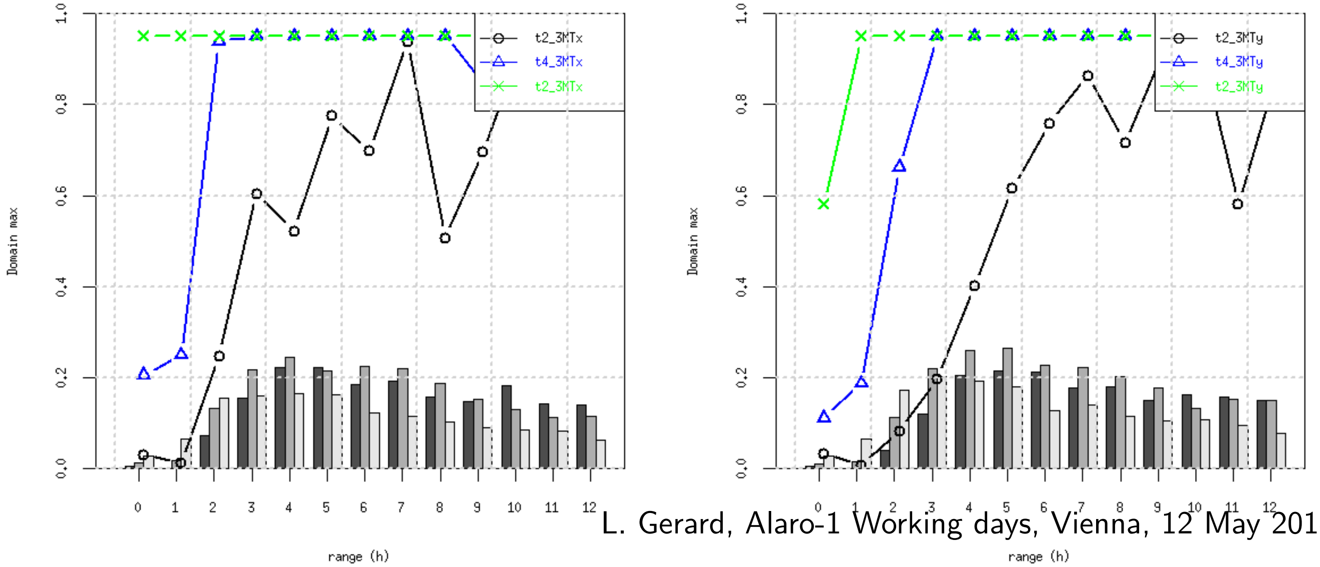
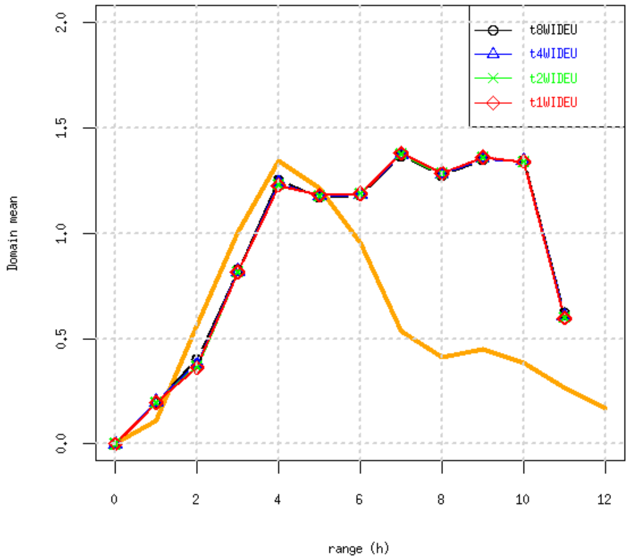


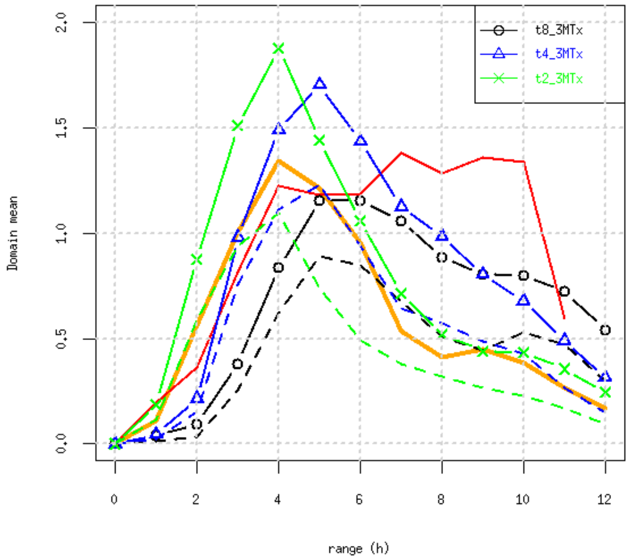
Real case tests BB: LCVFIRST +3MT (accvud)

Domain mean 1-hour precipitation evolution

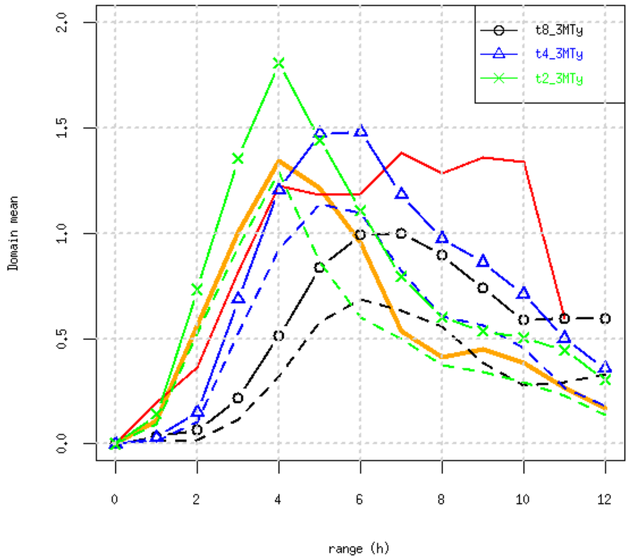
Wideumont radar



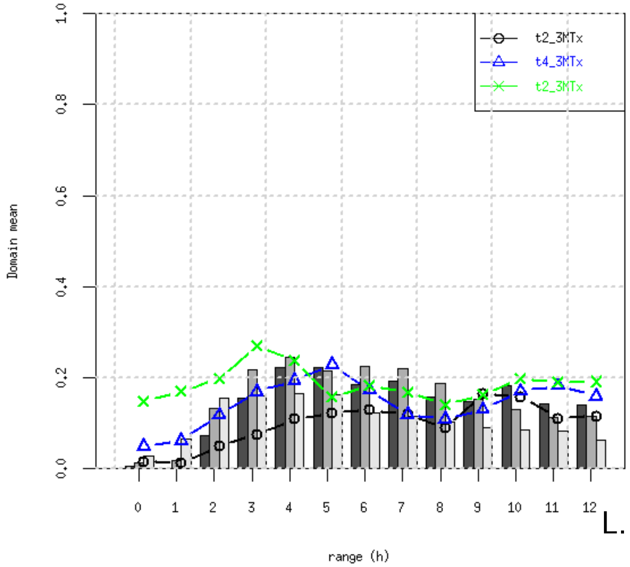
3MT+nsdd

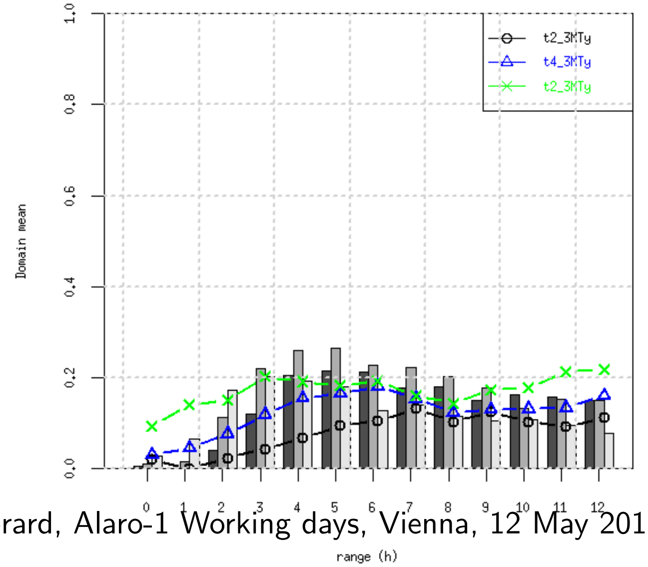


3MT+nsdd+LCVFIRST



Mean 500hPa $\sigma_u > 0.01$ evolution

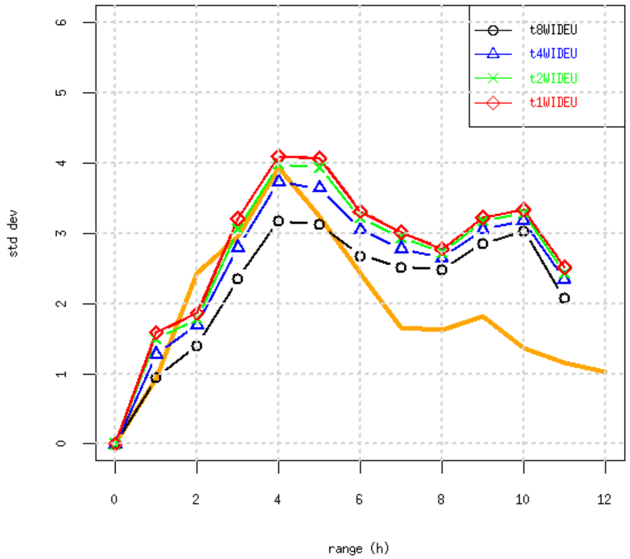




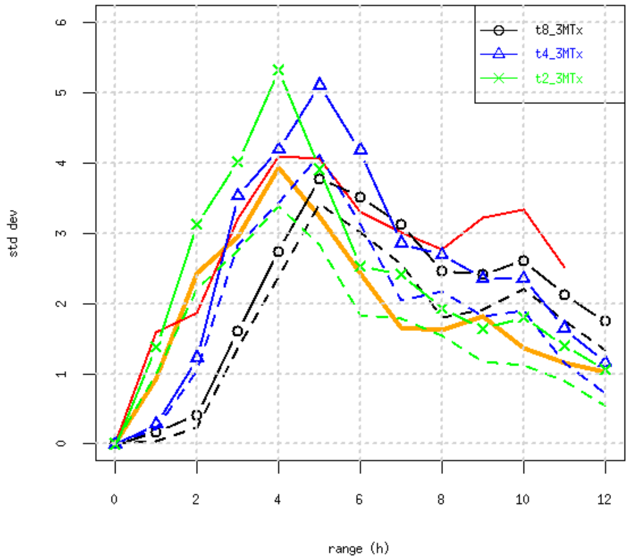
Real case tests BB: LCVFIRST +3MT (accvud)

Domain standard deviation 1-hour precipitation evolution

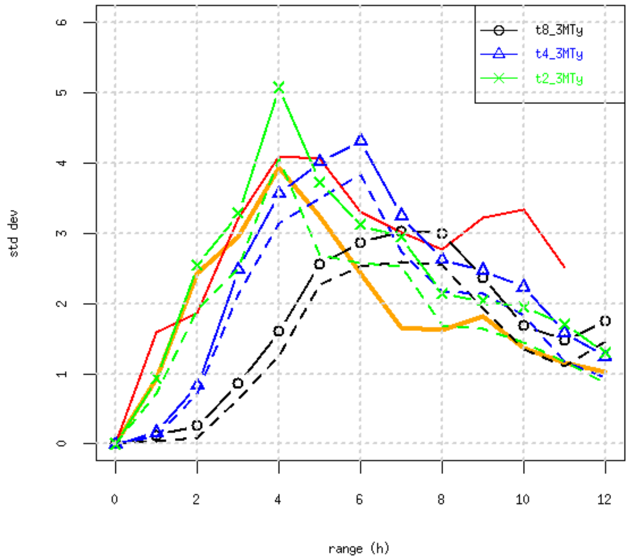
Wideumont radar



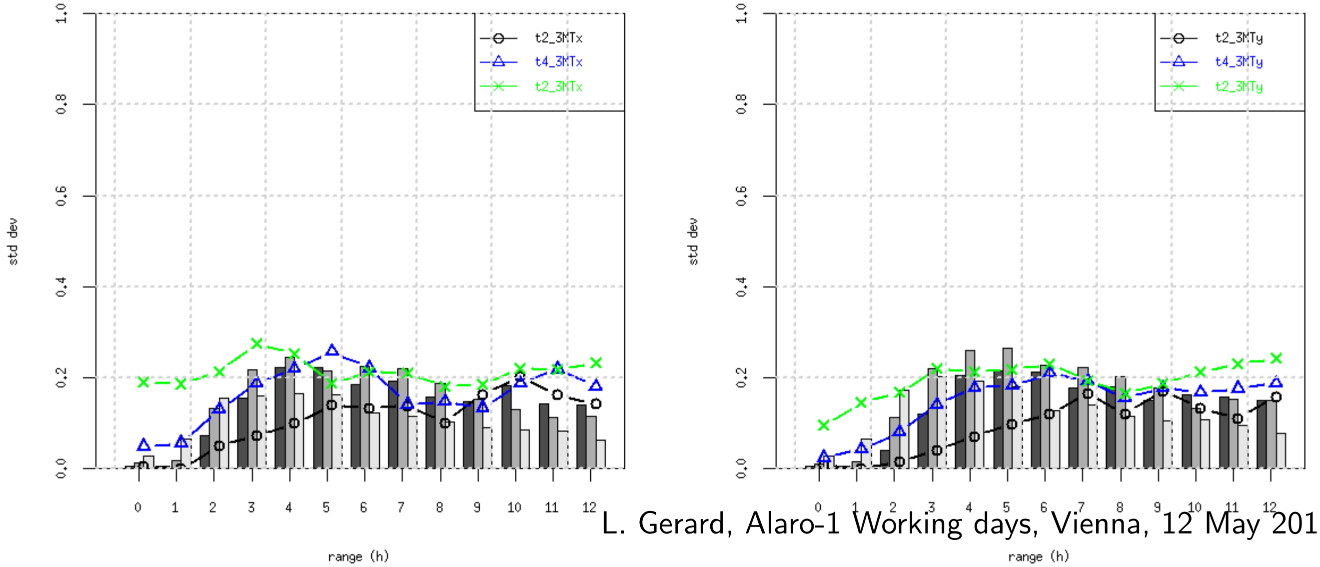
3MT+nsdd



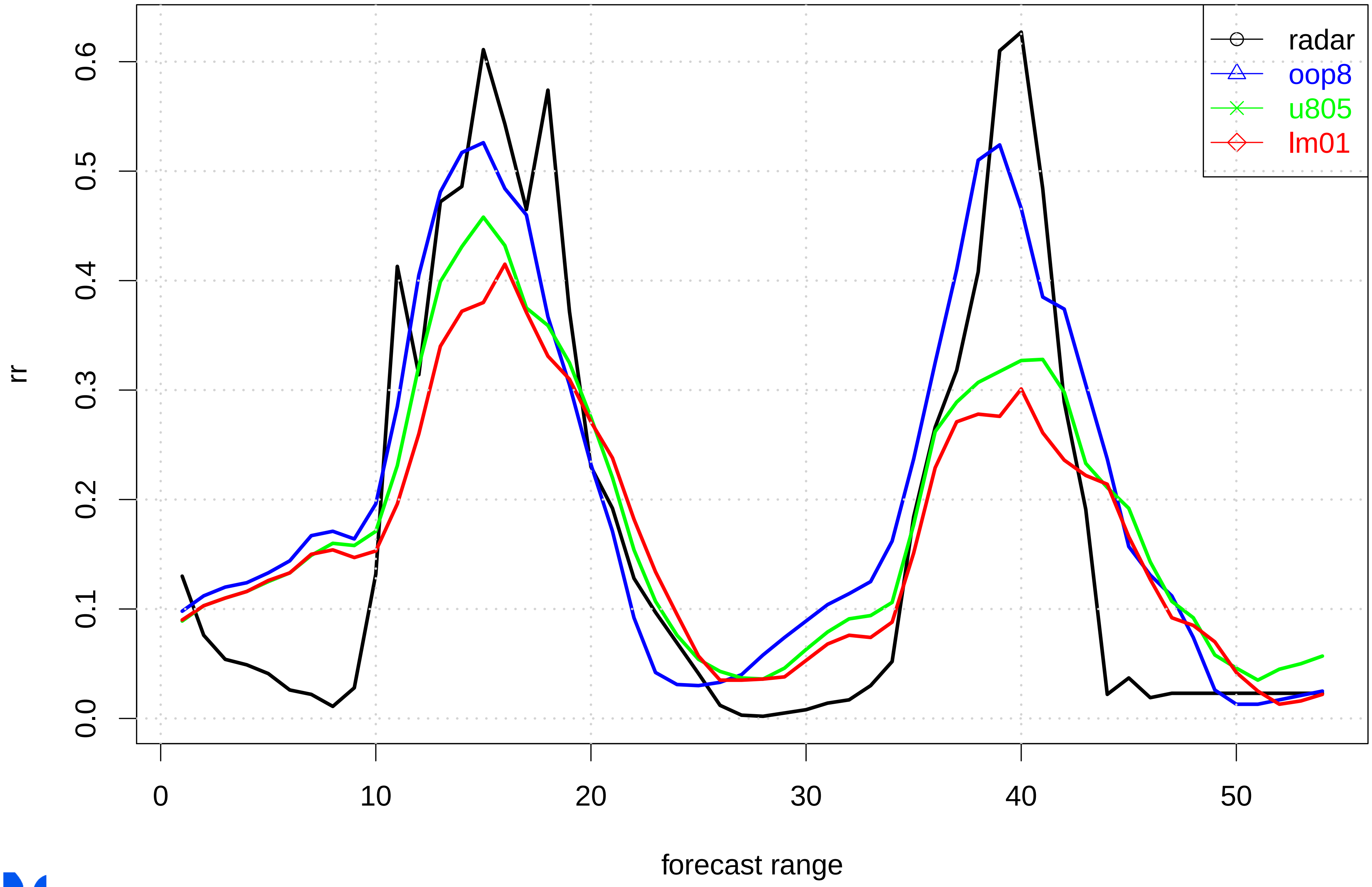
3MT+nsdd+LCVFIRST



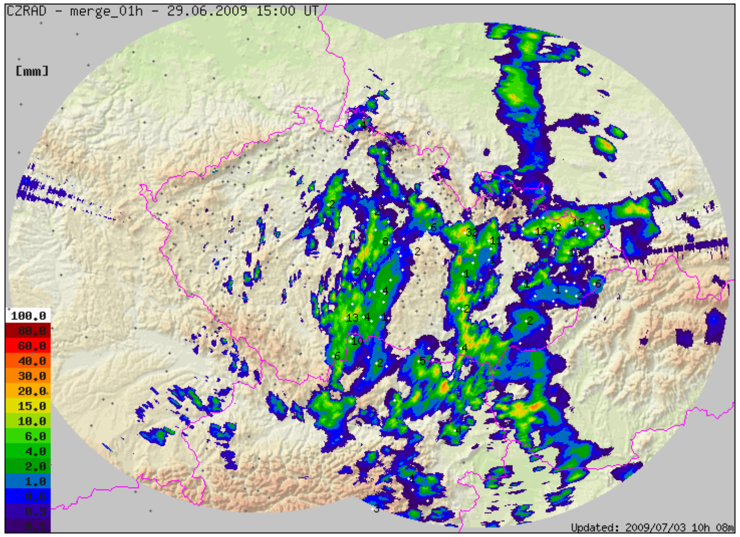
Standard Deviation 500hPa $\sigma_u > 0.01$ evolution

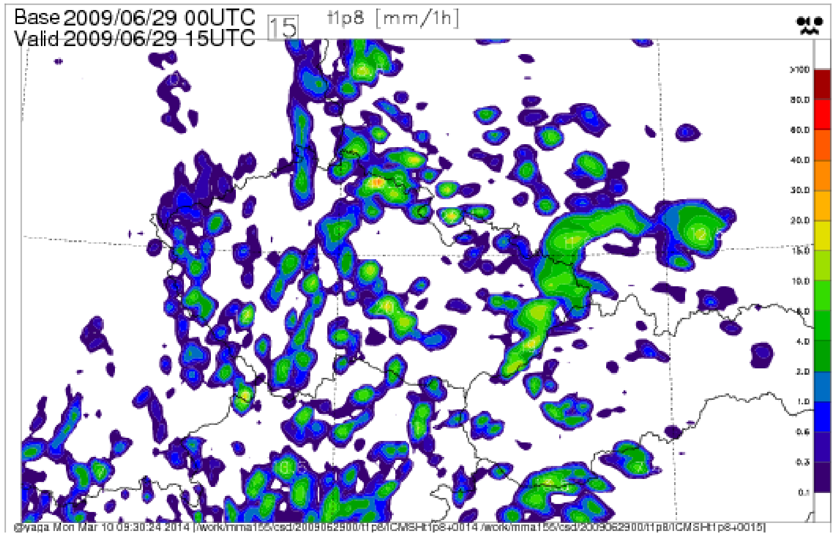


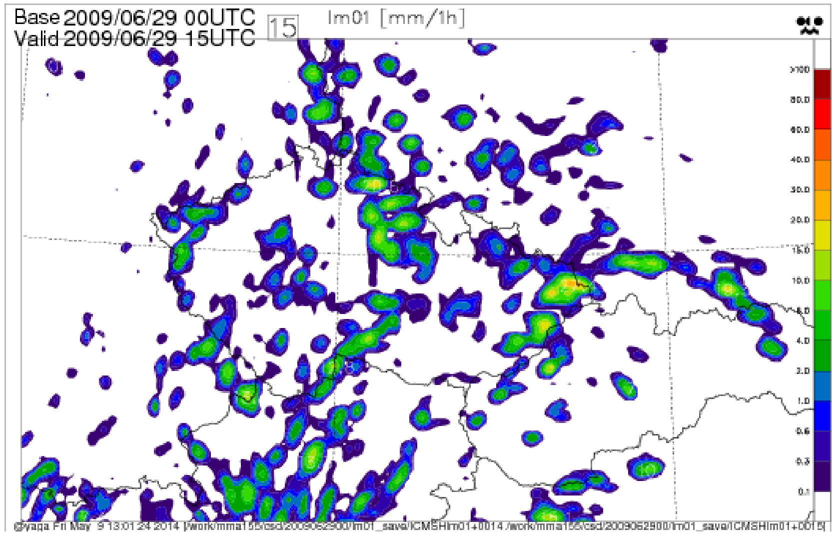
Diurnal cycle



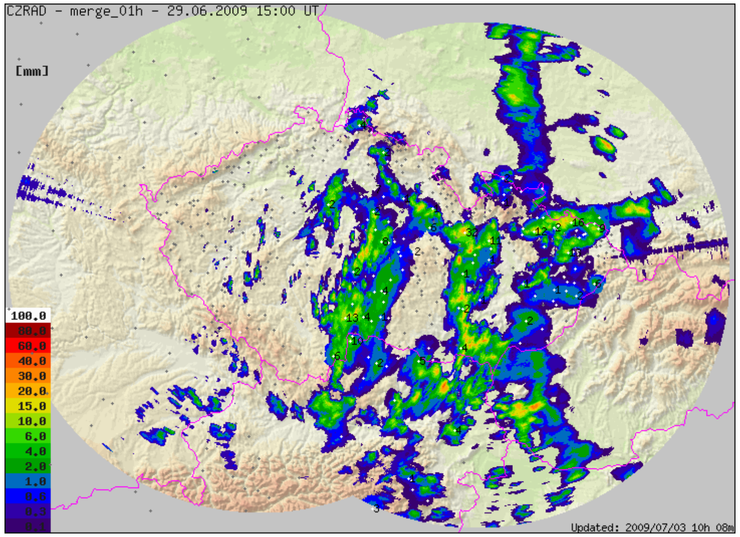
Travel pictures

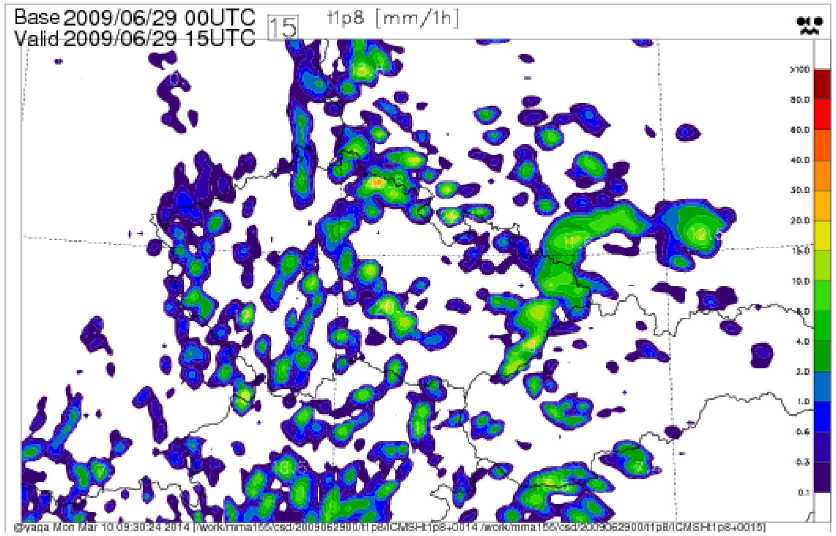




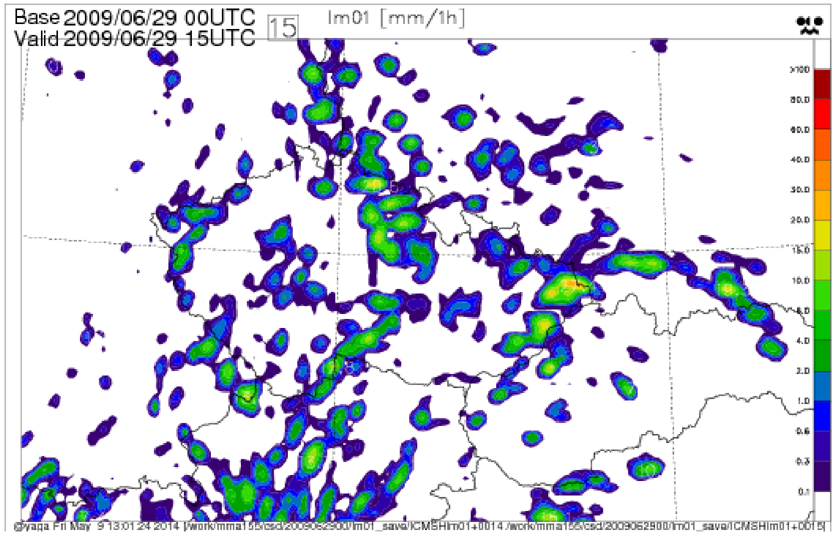


Travel pictures





Should the model reach the same amplitude as the radar while it misses some precipitation systems ?



A never ending story ?

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  - physical consistency or merely smooth and beautiful external behaviour ?

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  - triggering and its cost.
  - choice of prognostic variables: advecting discontinuous properties remains counter-intuitive.
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- *Is there a will to put energy in all this, and resources to help to it ?*