Microphysics and convection in the "grey zone"

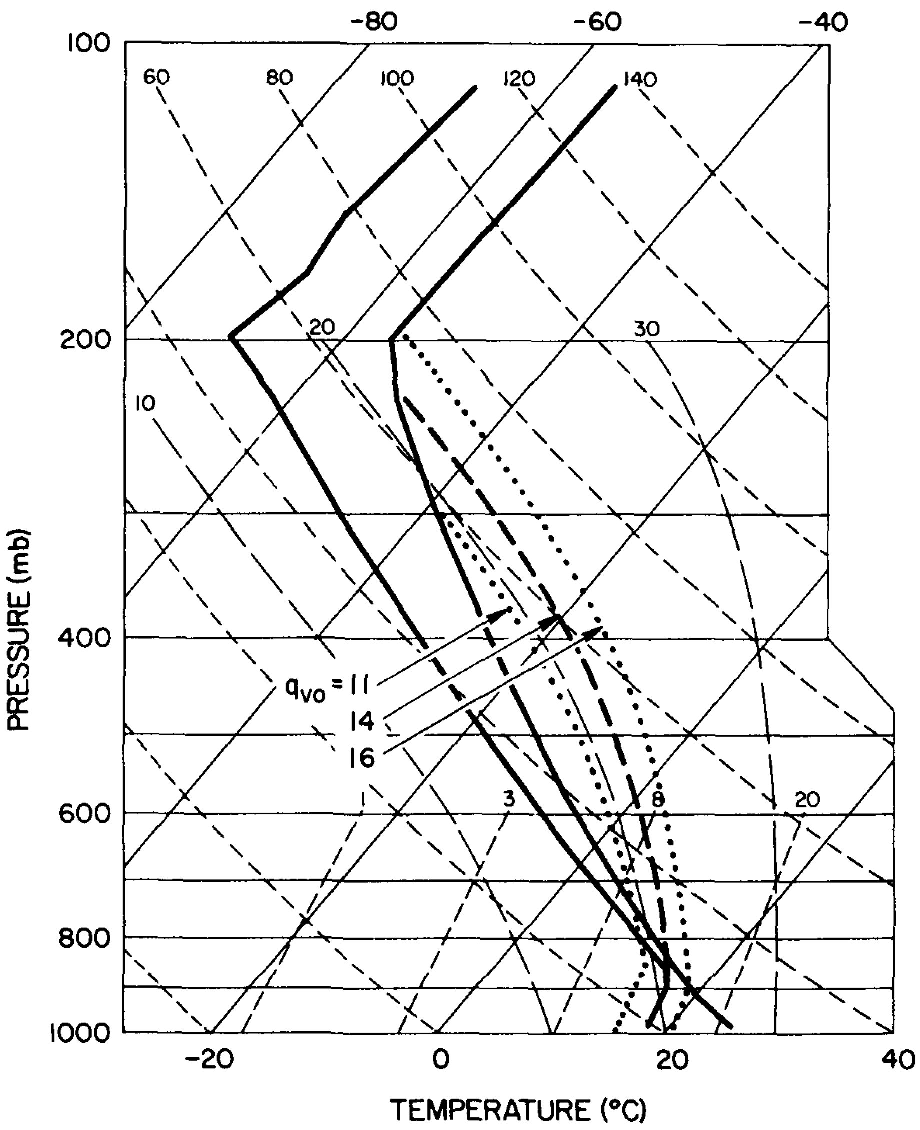
Luc Gerard

6 November 2012

(How) do we need to parameterize deep convection at resolutions of a few km ?

- Academic Study
  - No deep convection parametrization
  - Classical diagnostic scheme behaviour
  - A dedicated prognostic scheme: 3MT
    Model behaviour
  - Issues not addressed by 3MT
  - A complete scheme: CSU
    The triggering problem – Model behaviour
- Real case multi-resolution behaviour
  no conv param – diagnostic param – 3MT – CSU – Domain statistics –
- final remarks

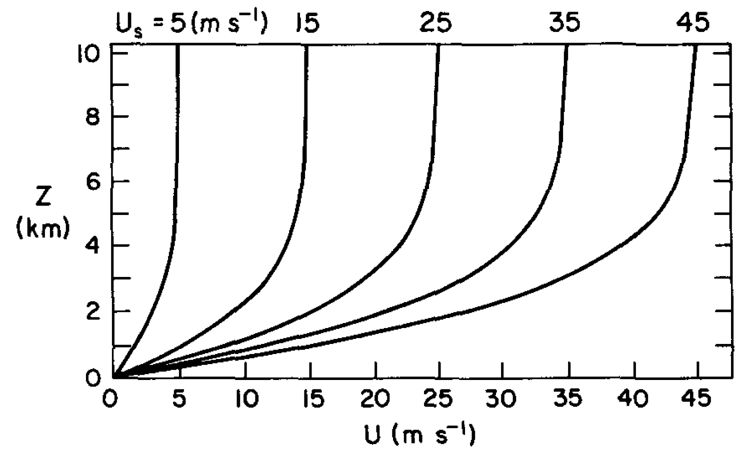
Academic test bench



Weisman & Klemp 1982: single profile with CAPE

Imposed pbl moisture

Zonal wind with vertical shear



Ellipsoïdal bubble of θ perturbation

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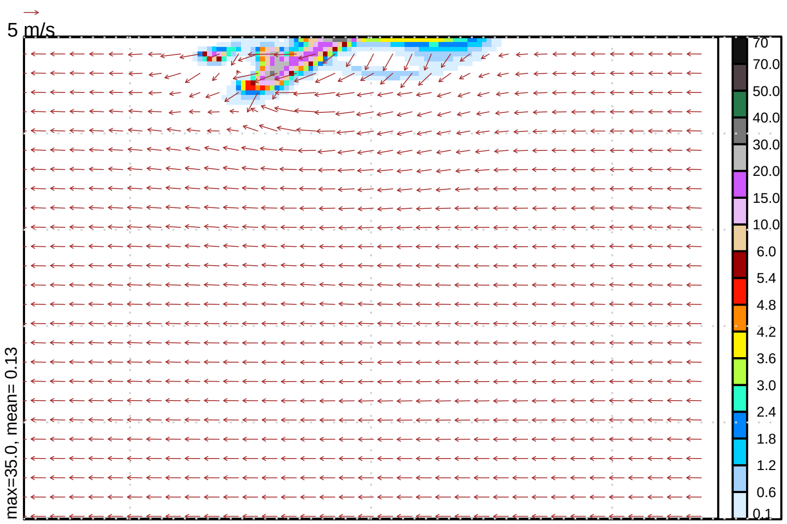
CAPE present over whole domain: very sensitive to perturbations inducing triggering

noCP: 2-h accumulated precipitation

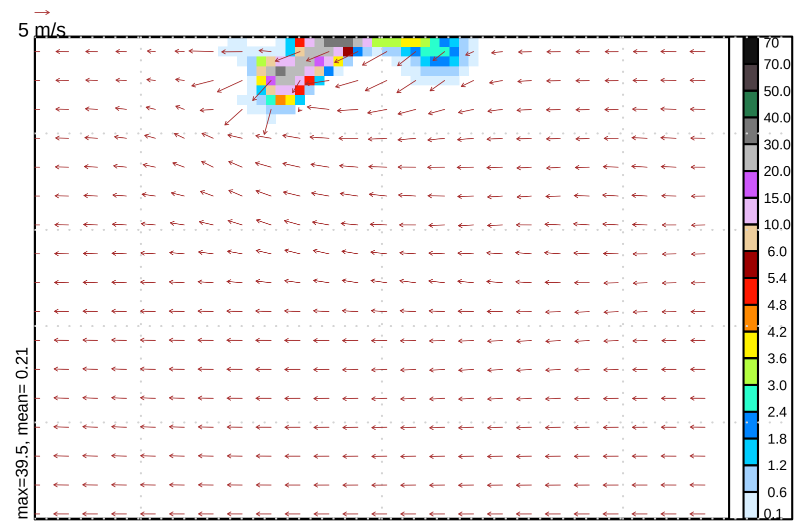
$\Delta x = 1km$

m10Y0C_noc : 2010/1/1 z0:0 +2h



BOT t+0240 PREC EAU.CON+EAU.GEC+NEI.CON+NEI.GEC
S074WIND: −10.8<u<−0.0, −7.5<v< 2.4; ff<10.9

m20Y0C_noc : 2010/1/1 z0:0 +2h



BOT t+0120 PREC EAU.CON+EAU.GEC+NEI.CON+NEI.GEC
S074WIND: −9.2<u< 2.0, −9.9<v< 2.1; ff<10.9

$\Delta x = 2km$

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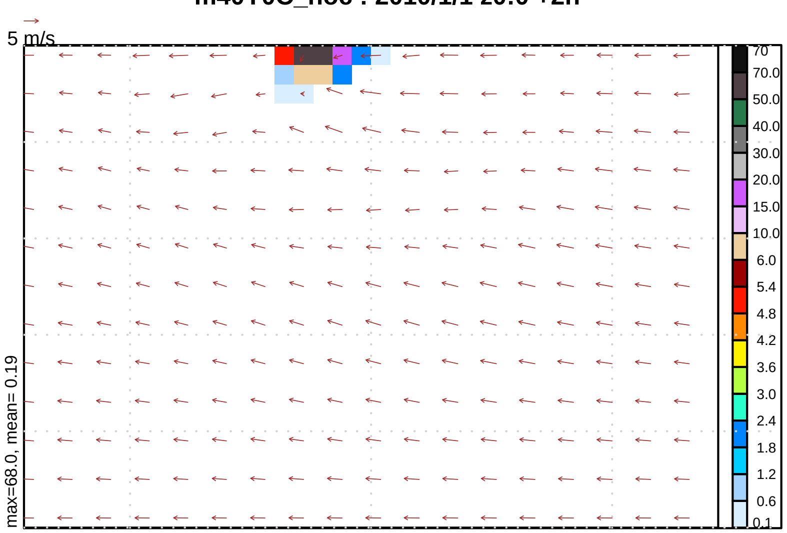
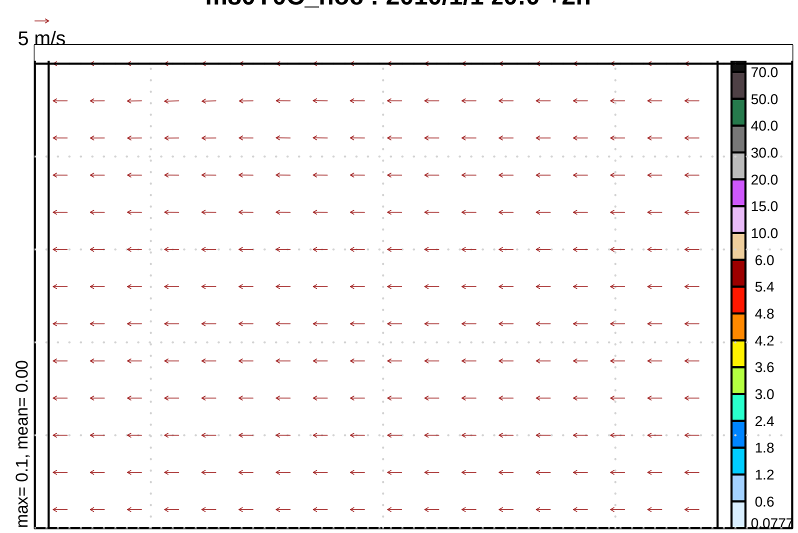
m40Y0C_noc : 2010/1/1 z0:0 +2h



BOT t+0060 PREC EAU.CON+EAU.GEC+NEI.CON+NEI.GEC
S074WIND: −7.2<u< 0.3, −2.8<v< 2.5; ff< 7.2

m80Y0C_noc : 2010/1/1 z0:0 +2h



BOT t+0030 PREC EAU.CON+EAU.GEC+NEI.CON+NEI.GEC
S074WIND: −5.2<u<−4.9, −0.2<v< 0.1; ff< 5.2

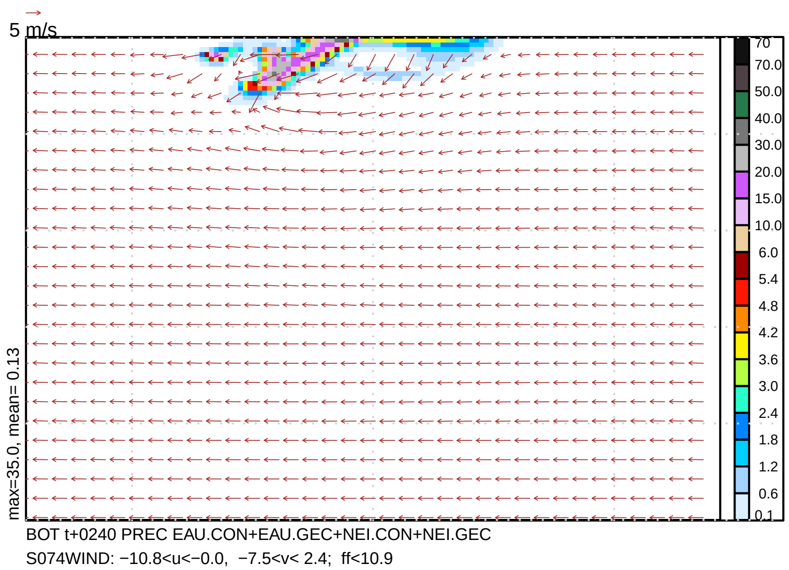
$\Delta x = 8km$

Diagn param: 2-h accumulated precipitation

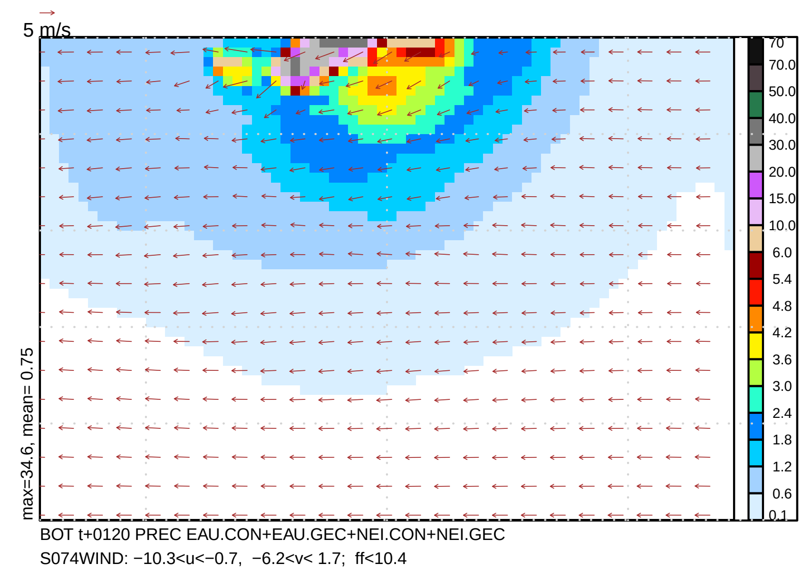
total

reference

m10Y0C_noc : 2010/1/1 z0:0 +2h



m20Y0C_LSP : 2010/1/1 z0:0 +2h



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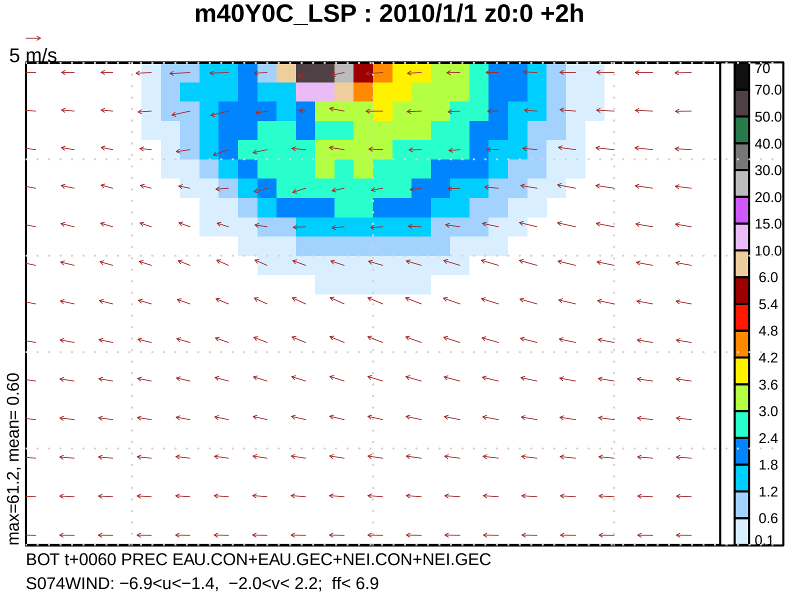
m40Y0C_LSP : 2010/1/1 z0:0 +2h



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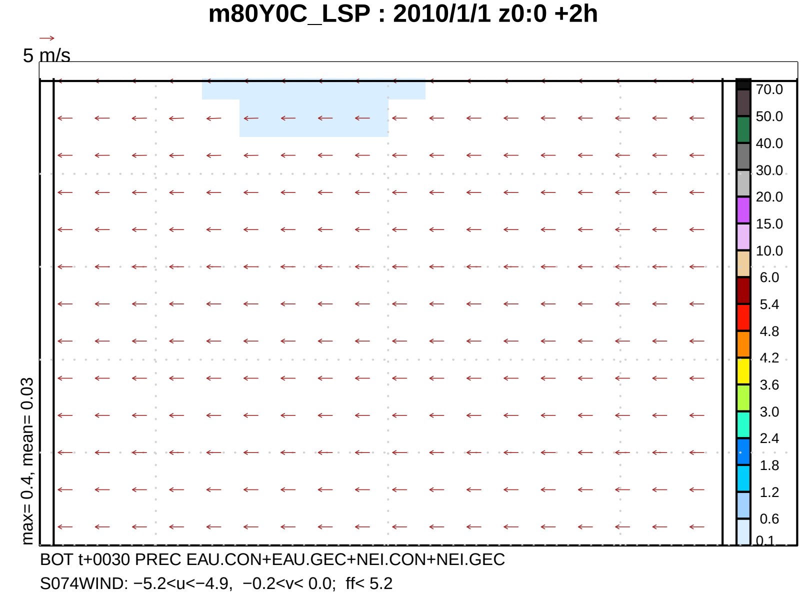

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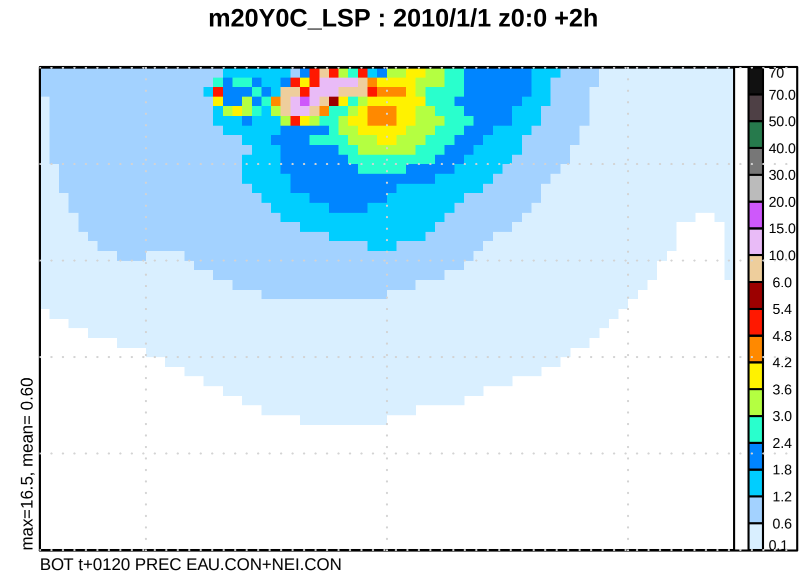
Diagn param: 2-h accumulated precipitation

subgrid part

reference



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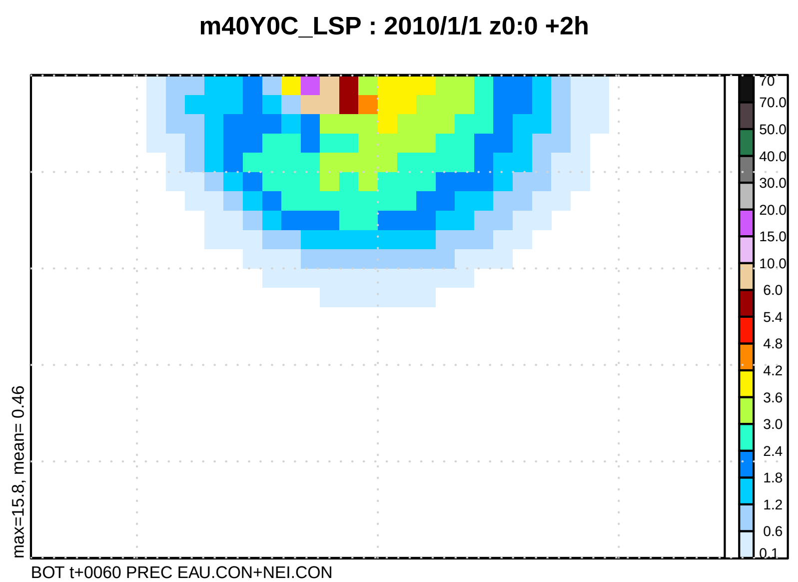
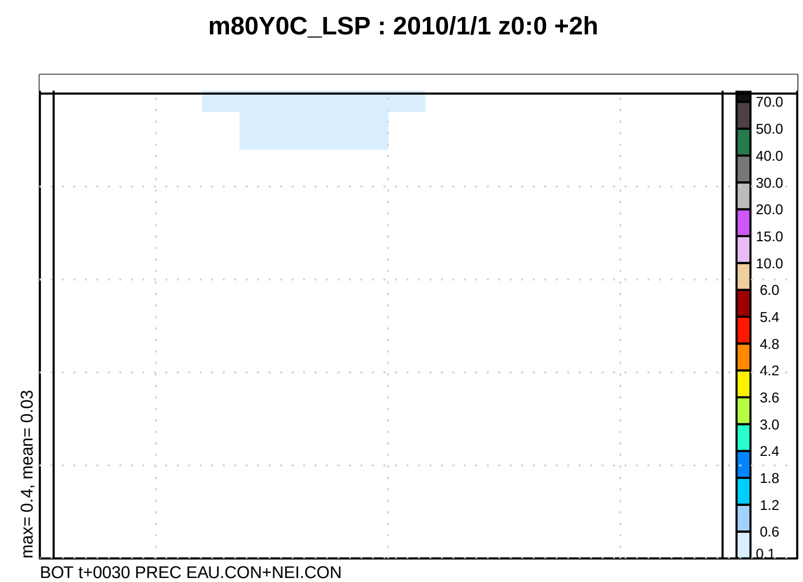




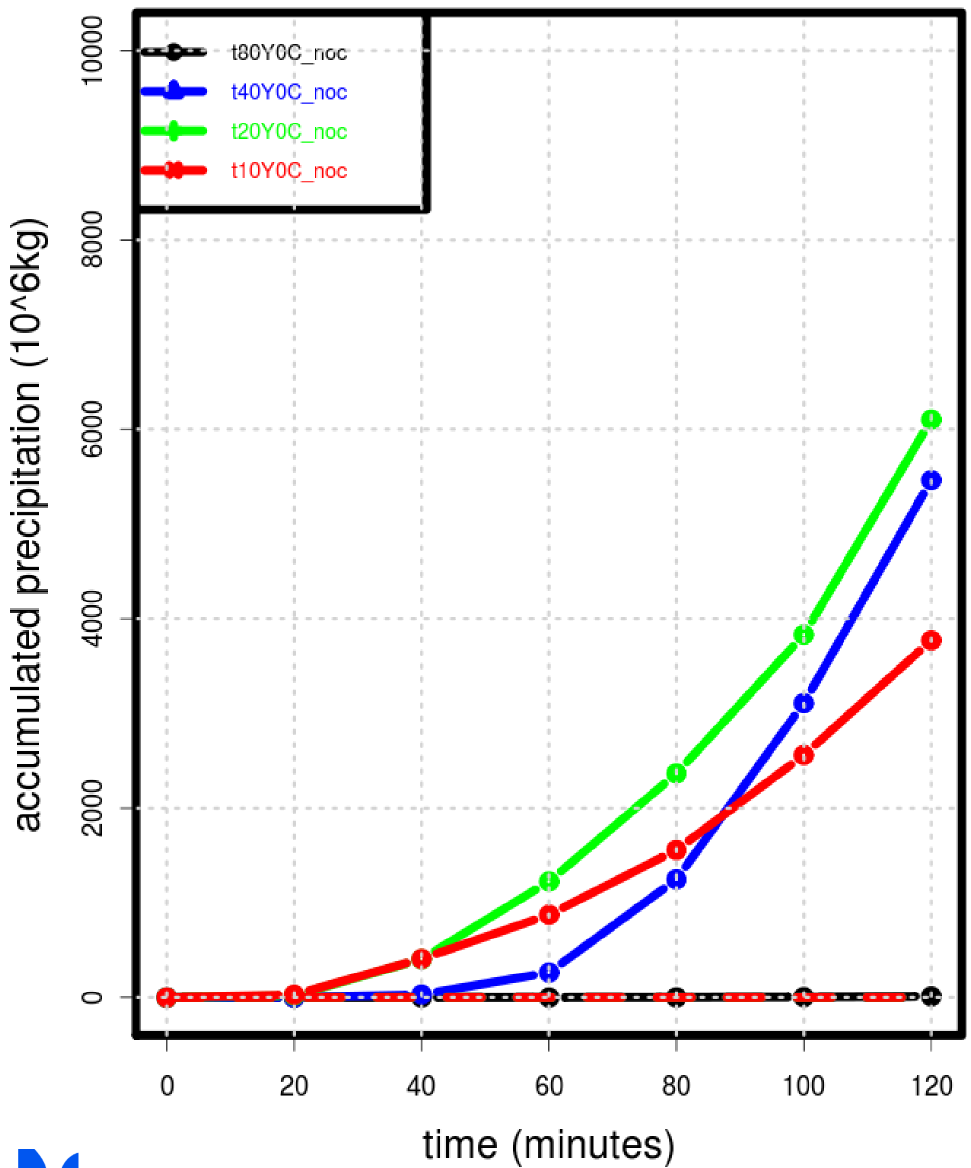
$\triangle x = 8km$

Statements

- NOCP:
  - no signal at 8km resolution
  - excessive maximum at 4km resolution
- Diagnostic parametrization:
  - Acceptable at 8km
  - Strong maximum at 4km
  - very wide extension at 4 and 2 km (also, no triggering criterion)
  - Subgrid contribution remains predominant
  - Not shown: structure and evolution in time.
  - Consequences on wind, circulation and further evolution.

Domain-total accumulated precipitation evolution

accumulated water $[10^6 kg]$ over domain 100x200km



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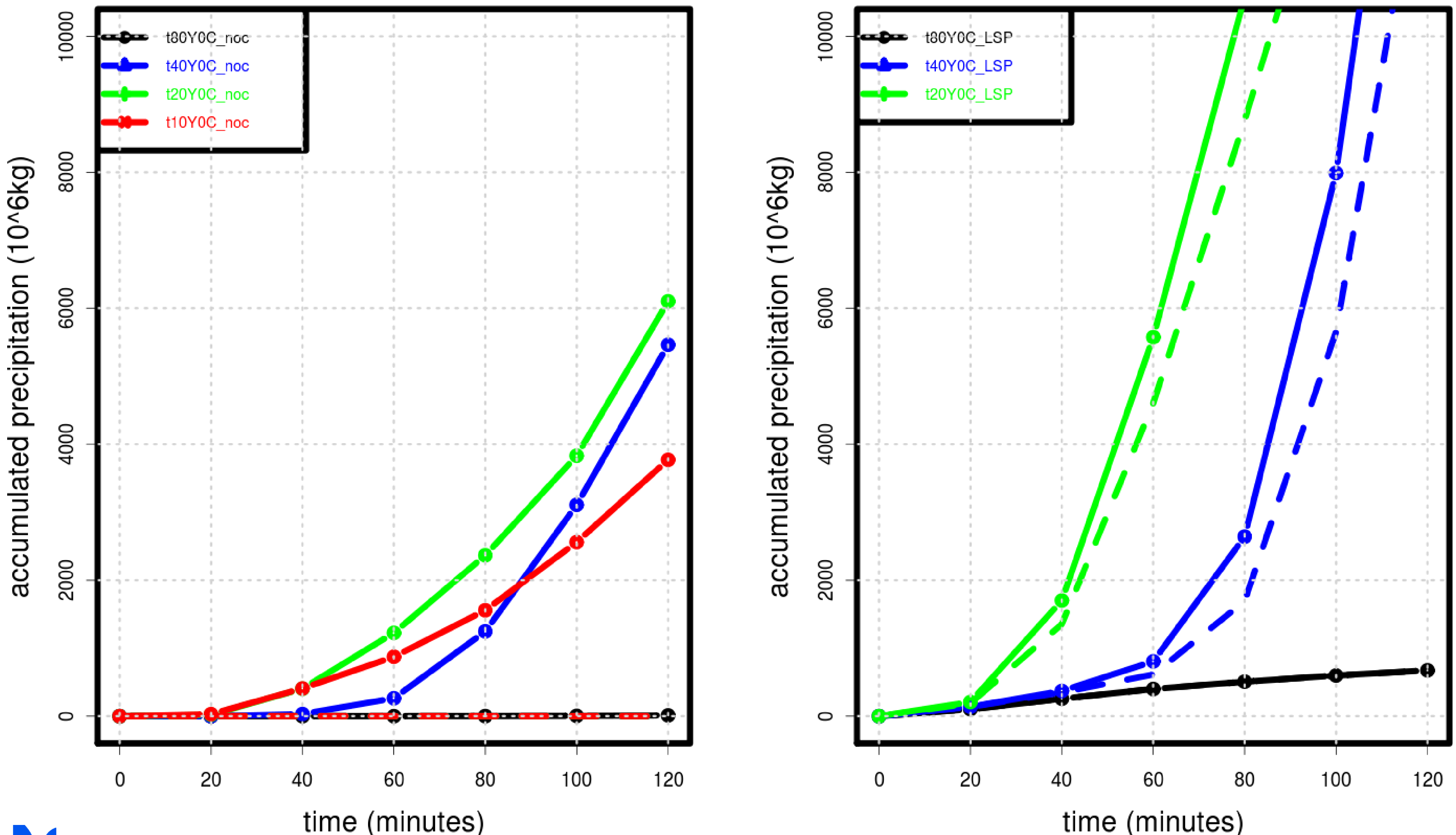

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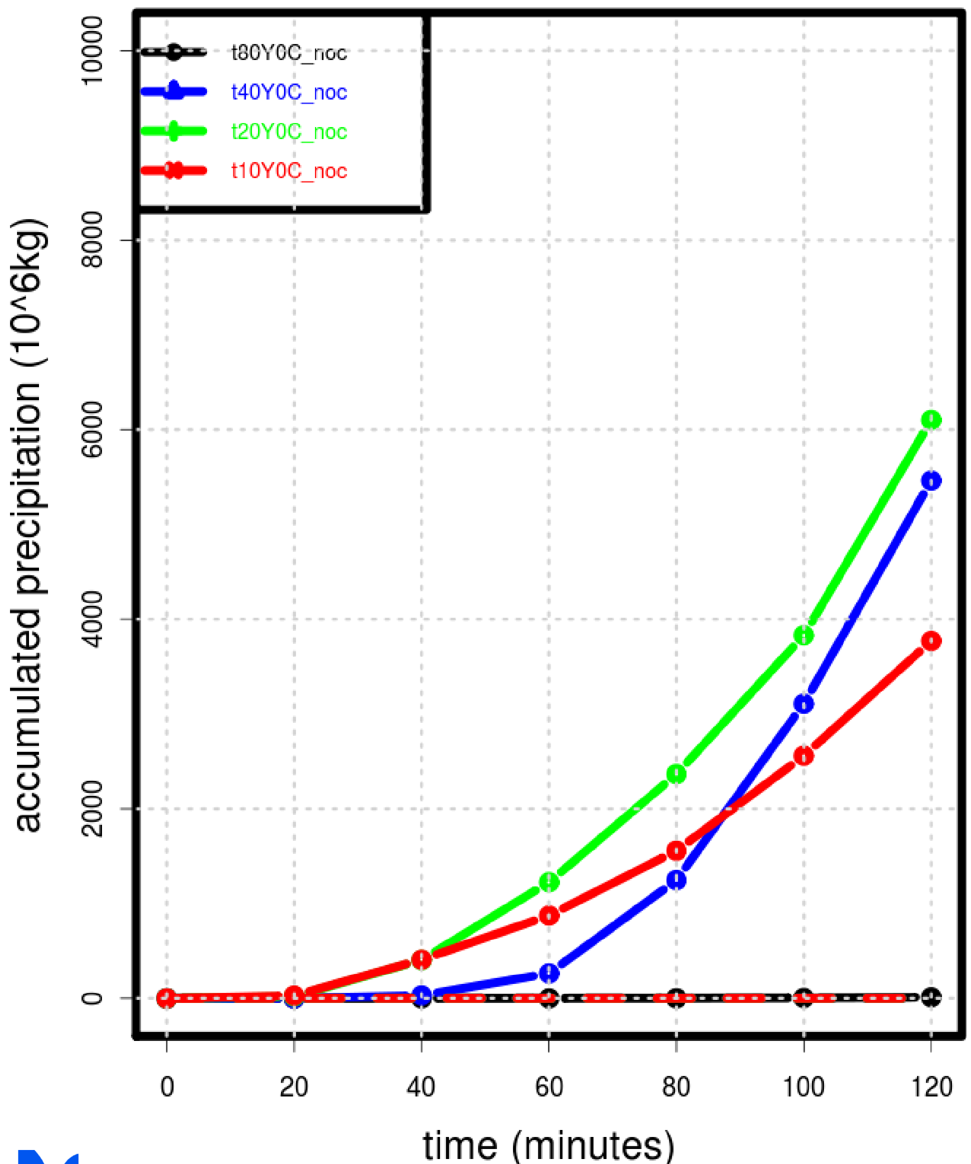
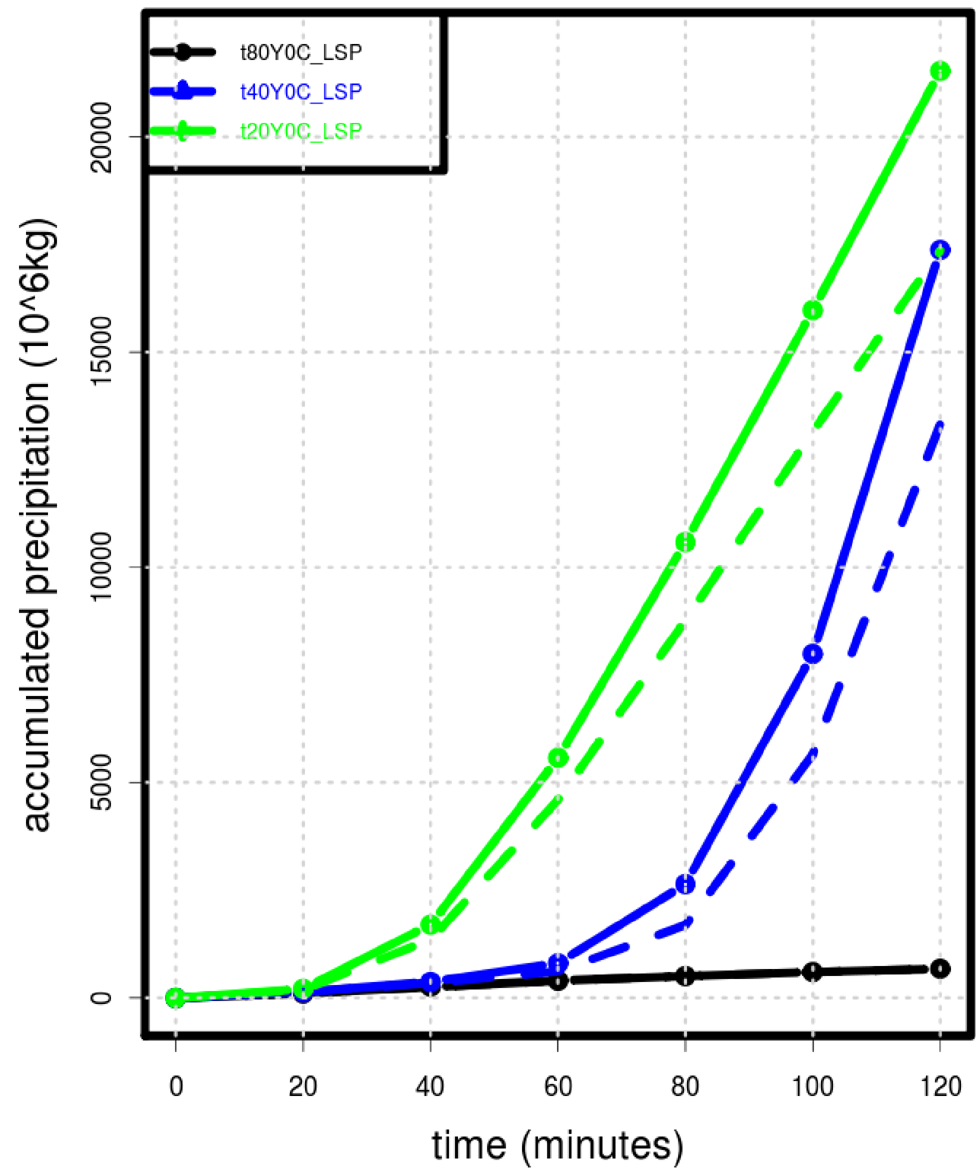




The 3MT approach, successes and limitations

Main features:

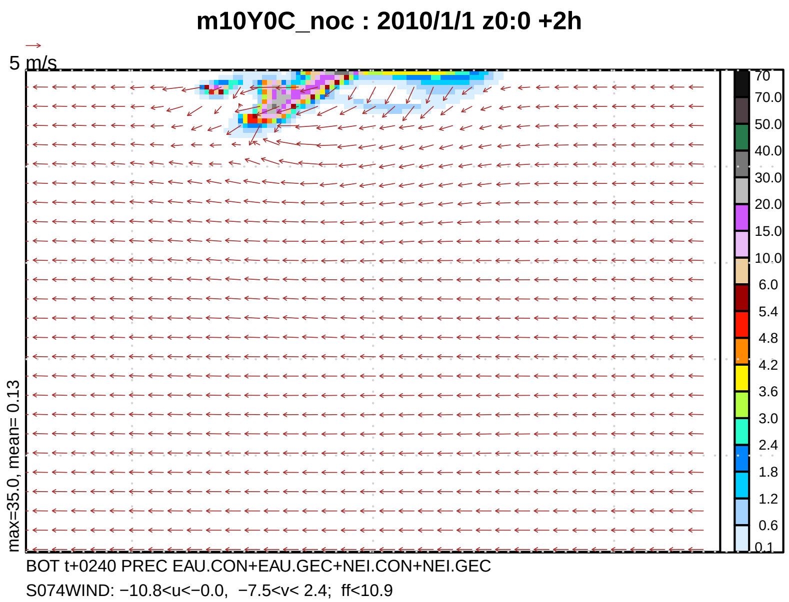
- Sequential organization, single microphysics.
- MT concept
- Prognostic variables for updraught: ω_u, σ_u.
- cloud geometry
- Interaction between parameterizations from one time-step to the next

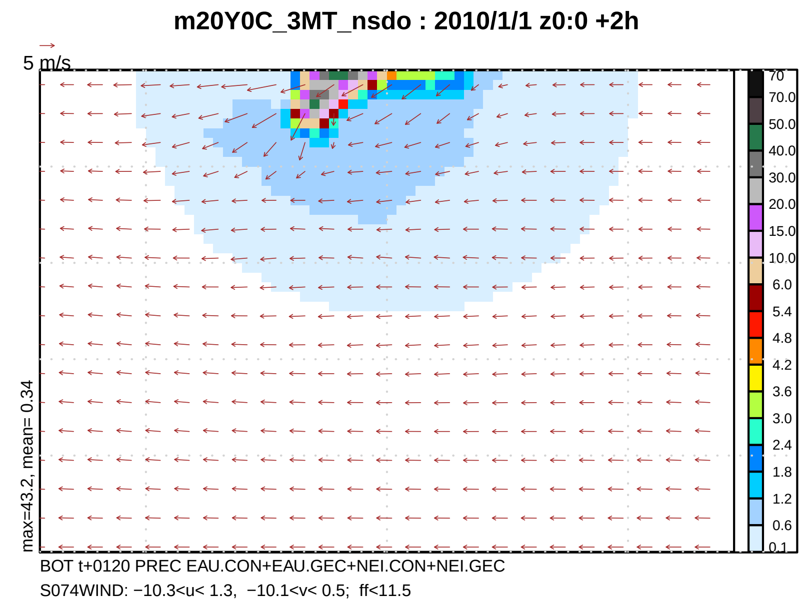
(Gerard *et al.* Mon. Wea. Rev. 2009.)
Benefits: significant model improvement, consistent forecasts at 4-km resolution.
But: while the total precipitation is kept realistic, no gradual extinction of the subgrid contribution when increasing resolution.

3MT: 2-h accumulated precipitation

total

reference





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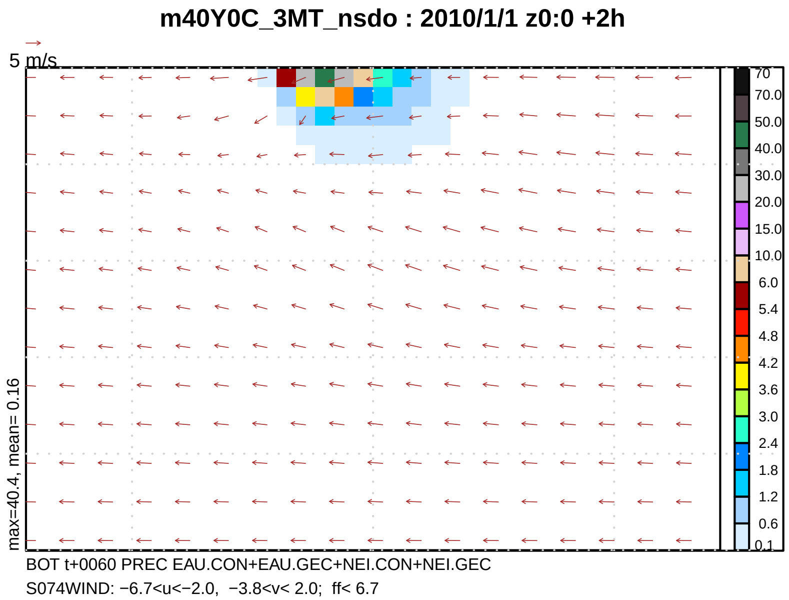

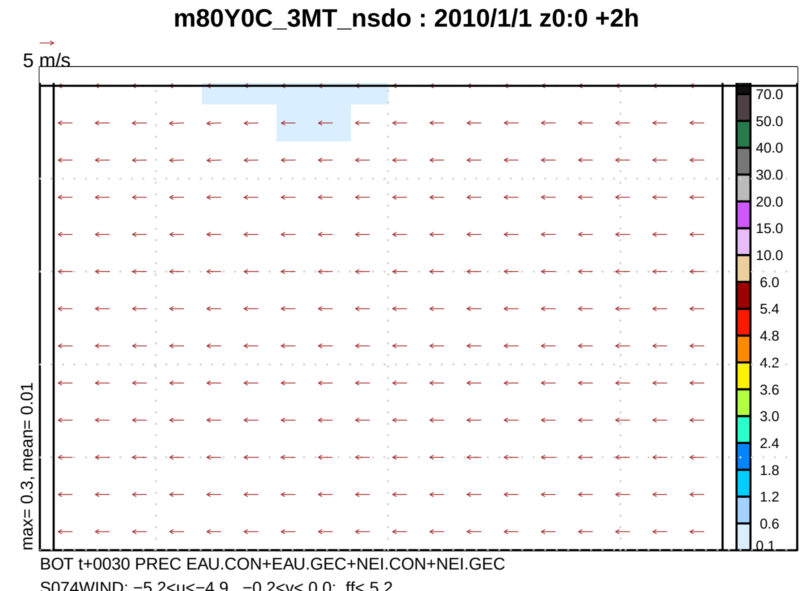

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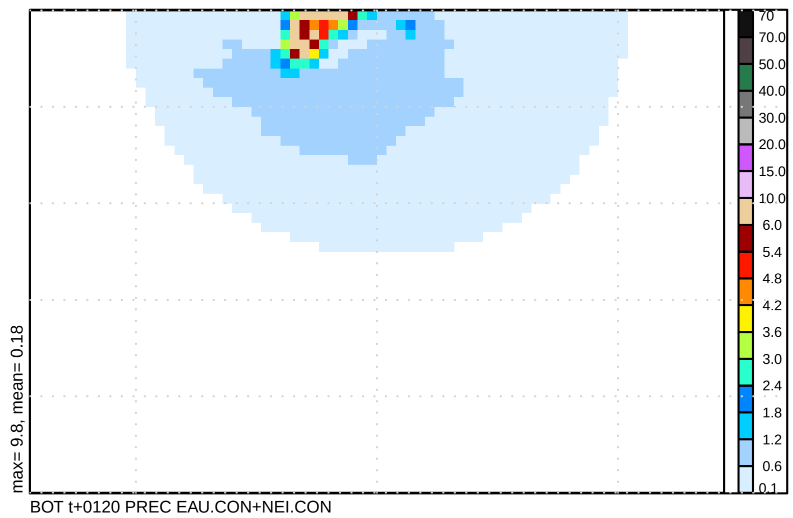
reference

m20Y0C_3MT_nsdo : 2010/1/1 z0:0 +2h



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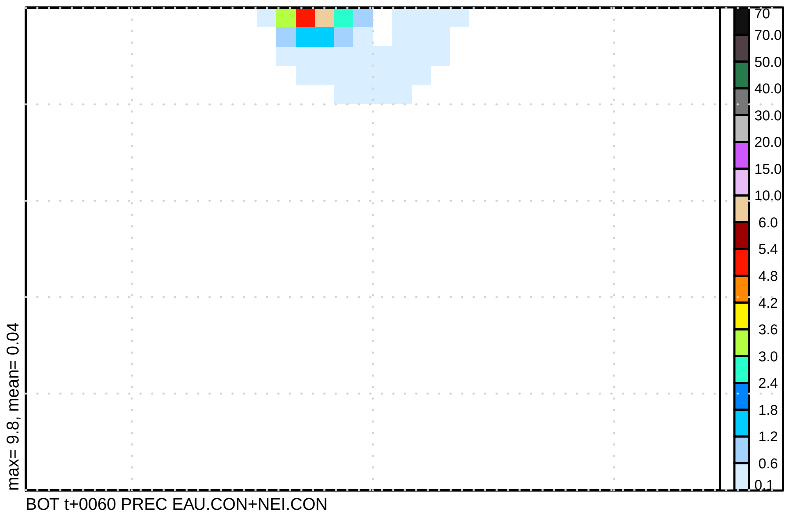

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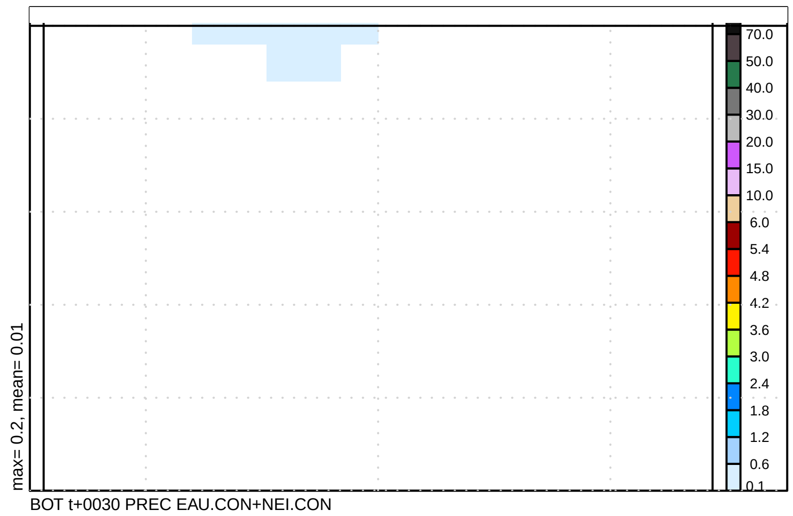

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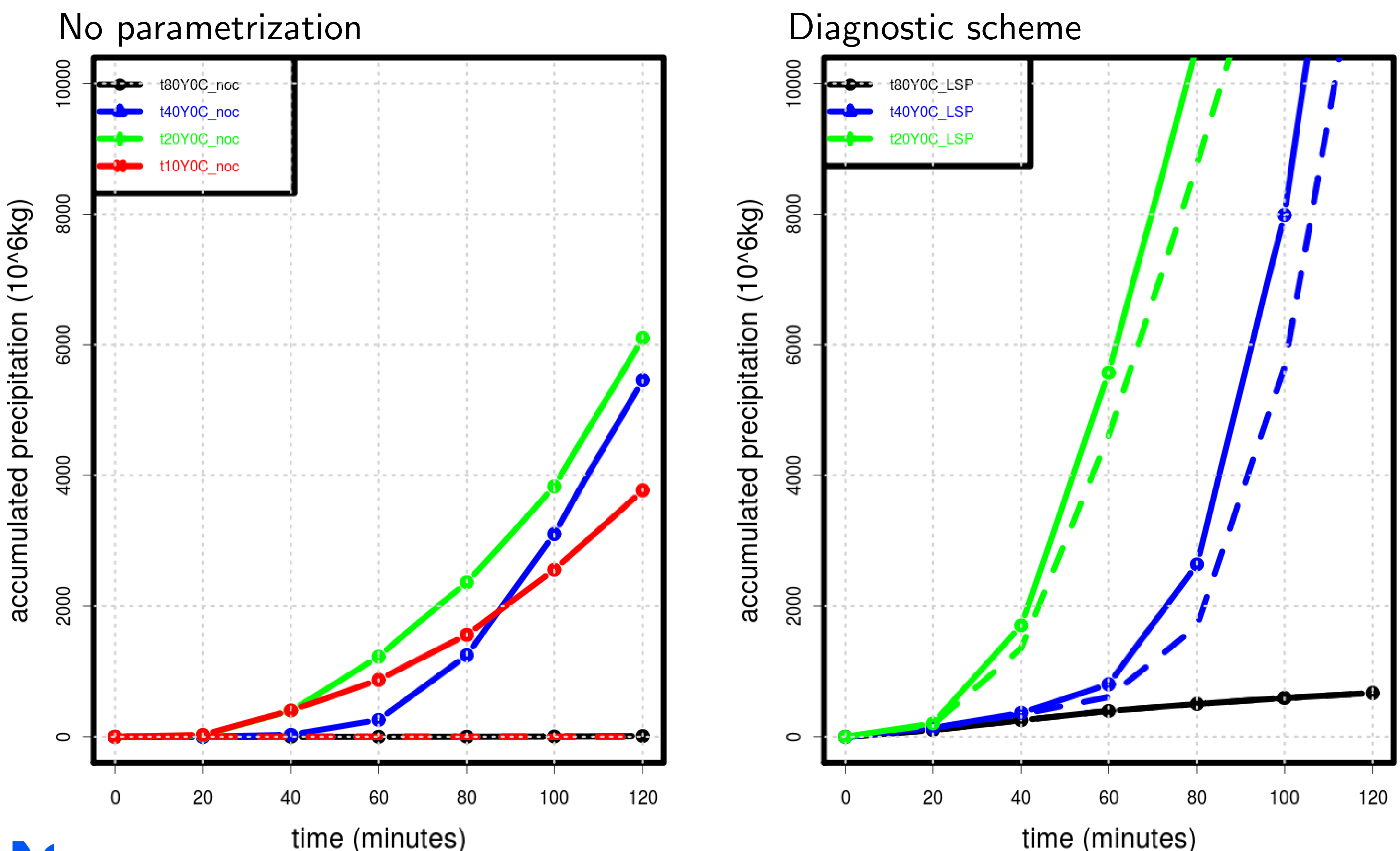

RMI

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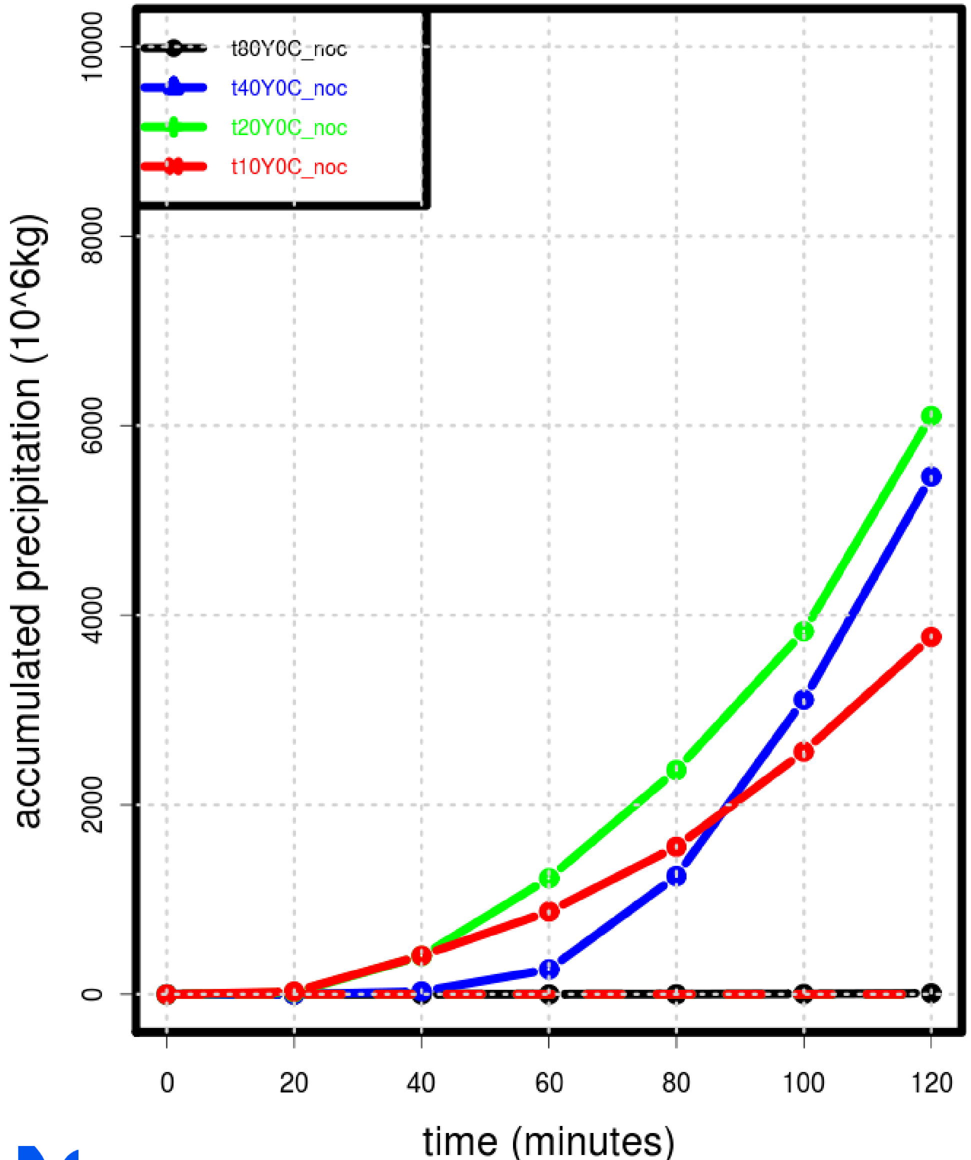
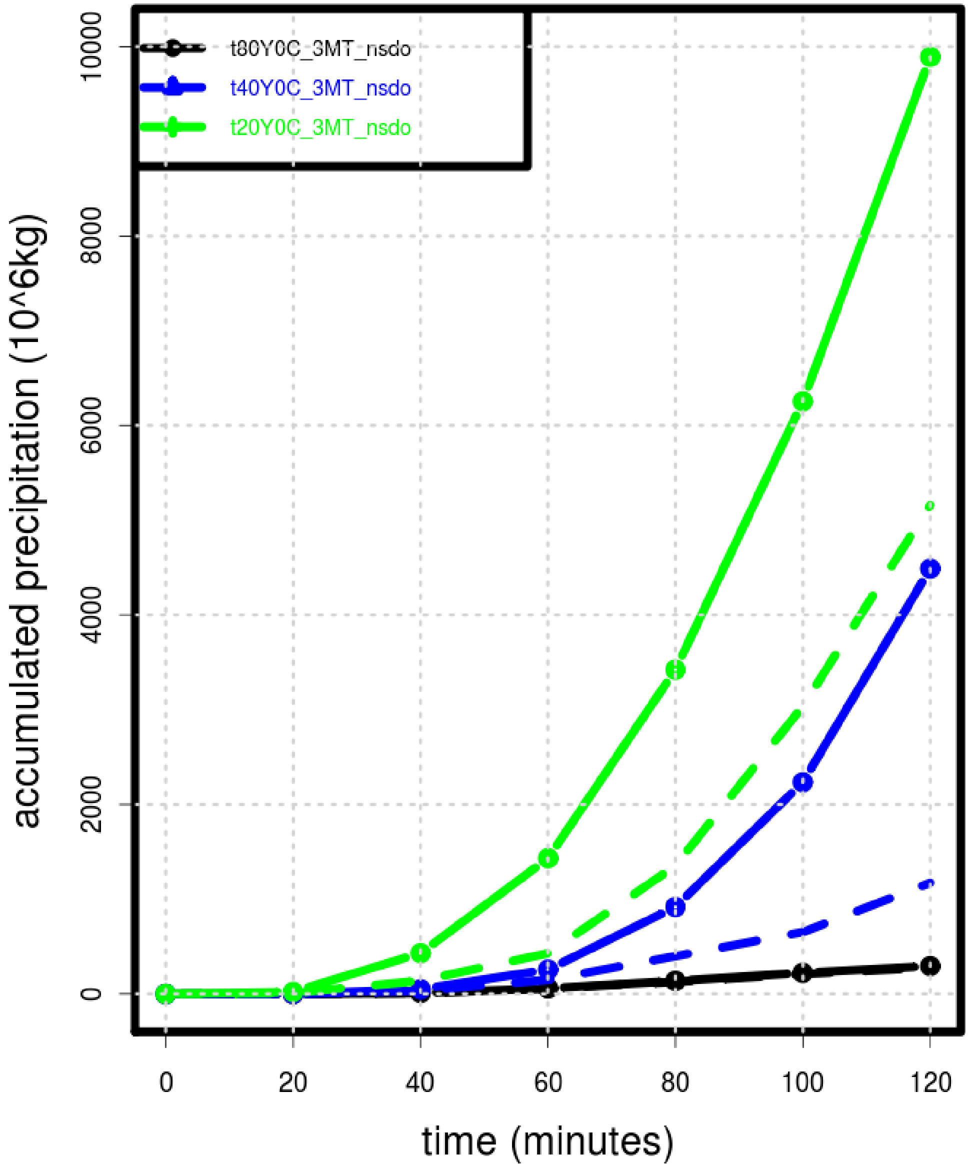
No parametrization



3MT scheme

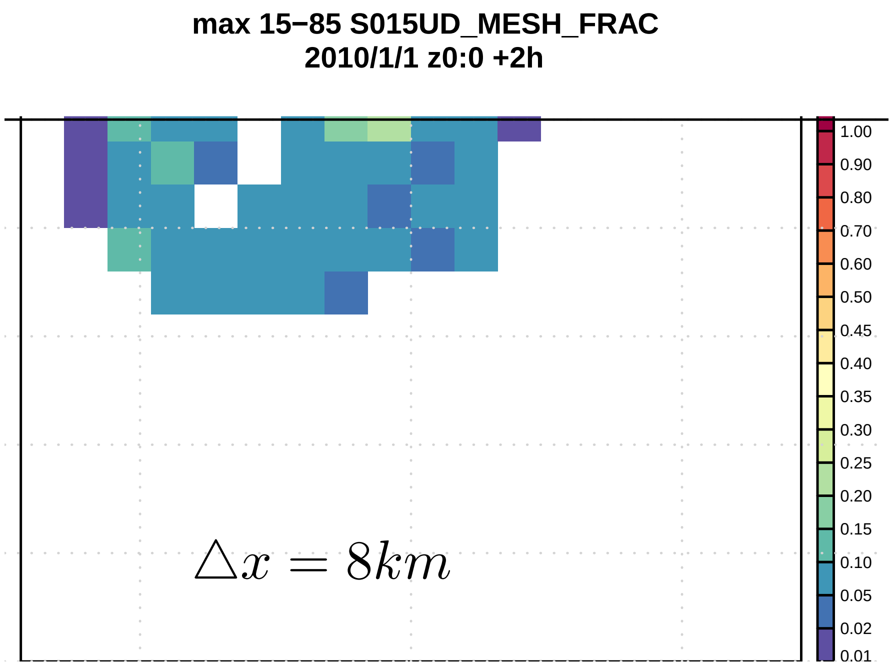


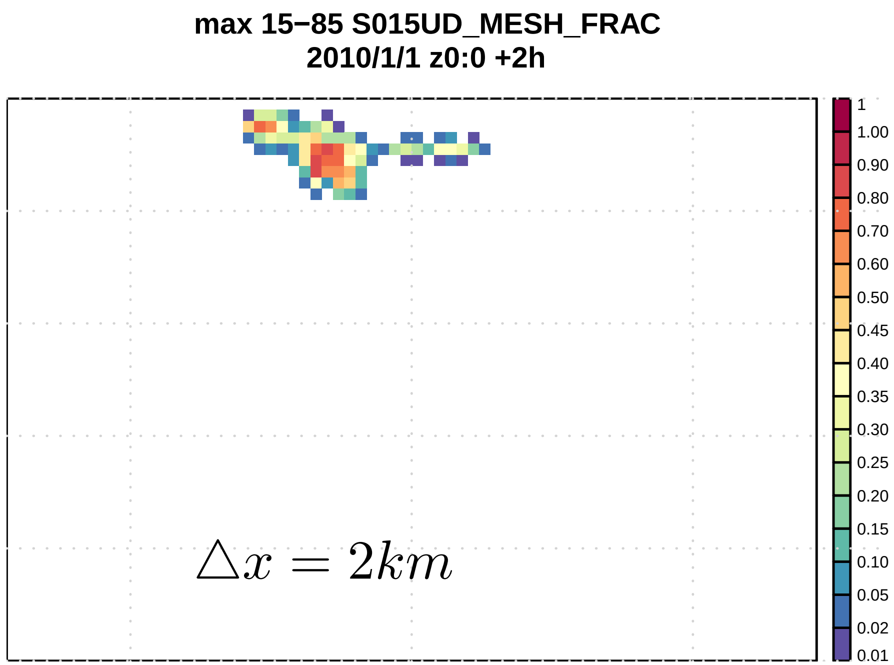
How to smoothly glide towards 100% resolved ?

Statements:

when increasing resolution, e.g. from 10km to 1km, on a region with convective activity:

- The fraction σ_u of the mesh covered by subgrid updraughts increases, depending on the granularity. It should finally tend to 1 in some of the grid boxes, when $\triangle x$ small enough.





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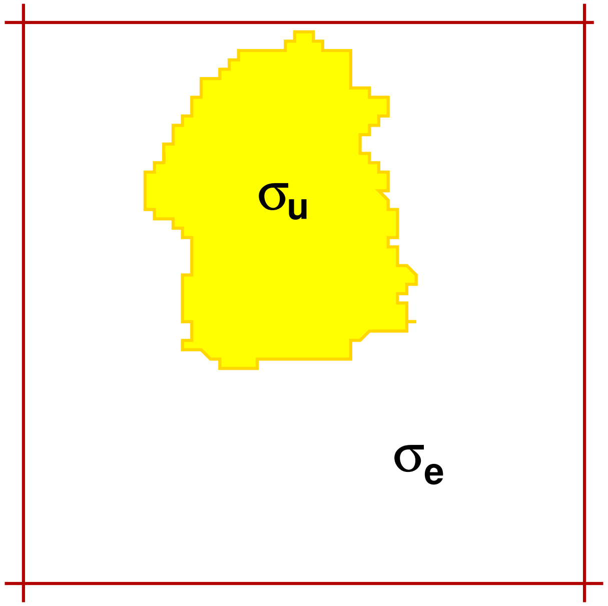

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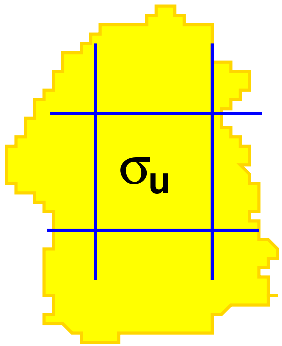

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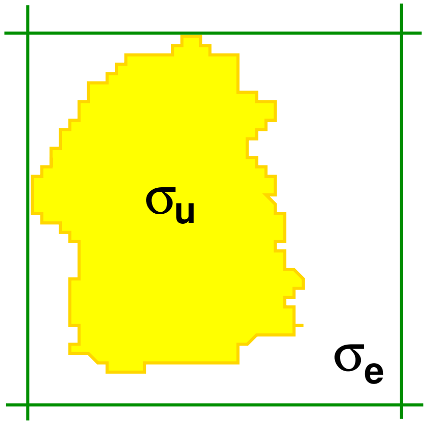

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- Triggering criteria are often badly affected: e.g. buoyancy kick increasing with resolved $\overline{w}$.

Complementary Subgrid Updraught

Perturbation approach: provide a complementary contribution to the part of the updraught resolved by the mean grid-box: $\psi' = (\psi_u - \overline{\psi})$

- 3MT sequential organization.

- Ascent properties obtained from the anelastic equations. The CSU contribution is confined in the grid column: effects of mesh fraction, of the resolved profile.

- Updraught evolution: prognostic perturbation velocity, evoluting mesh fraction, gradually rising top.

- Closure referring to steady state and estimation of 'real world' CAPE.

- CSU triggering: threshold of resolved condensation (together with updraught viability). Threshold $\propto (\triangle x)^{-2}$.

Triggering at 'grey zone' resolutions

- 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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  - $w_0 \sim 0.02m/s$: threshold resolved w
    between positive and negative kick

    $\Rightarrow$ resolution dependent ?... ...how ?

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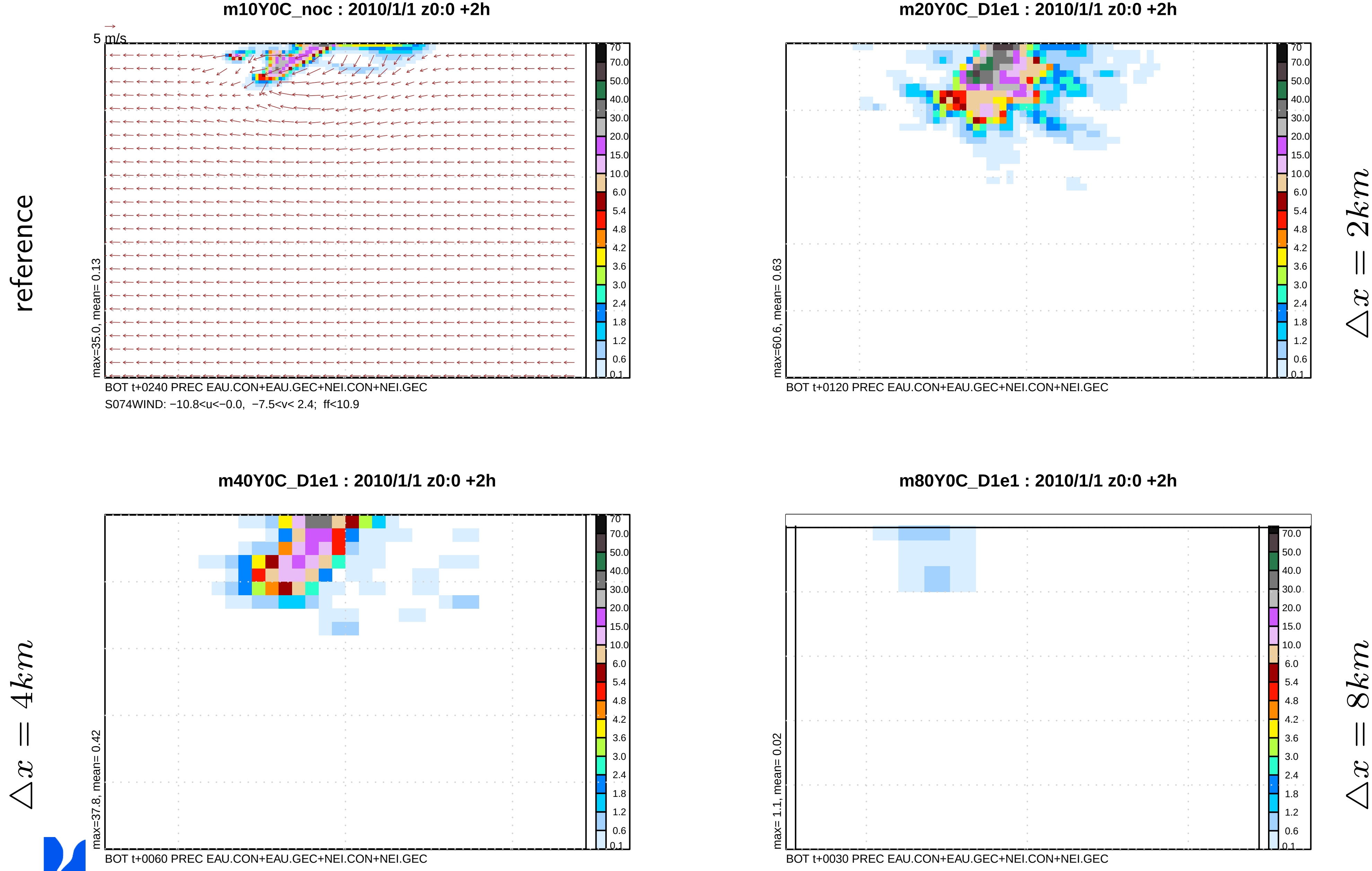
Fixed KF Trigger: 2-h accumulated precipitation

total



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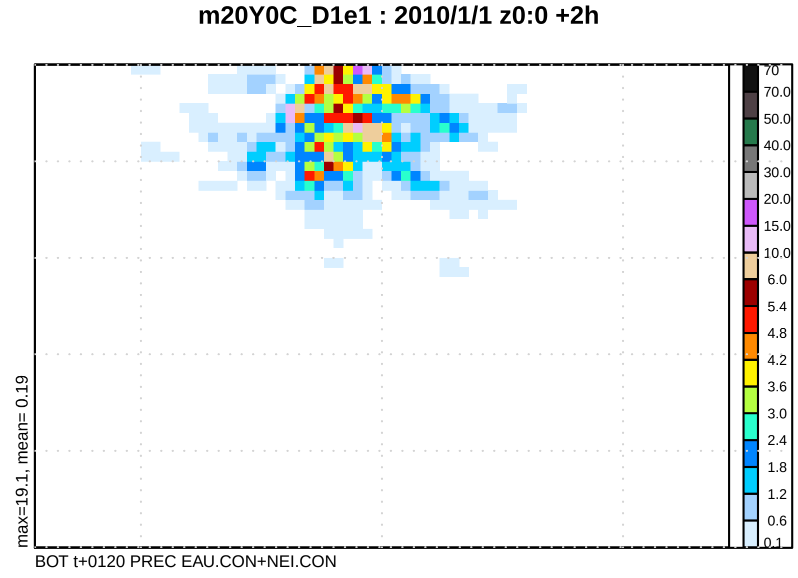

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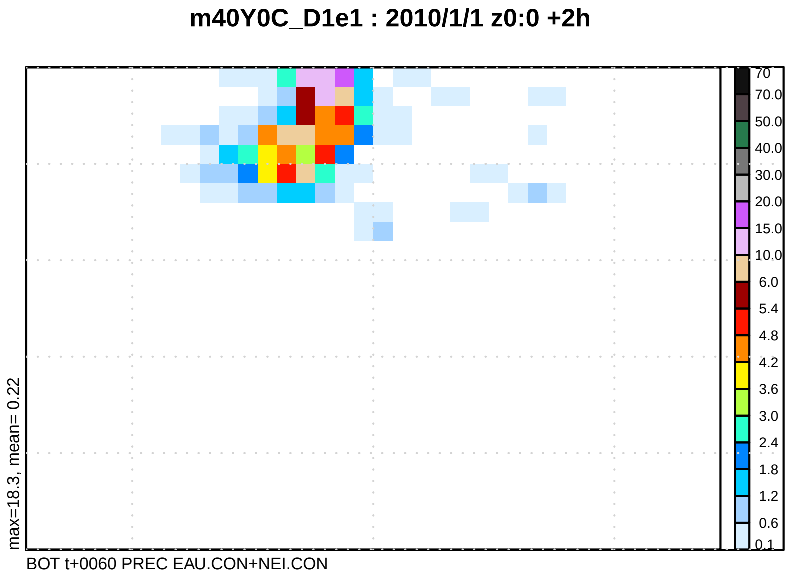

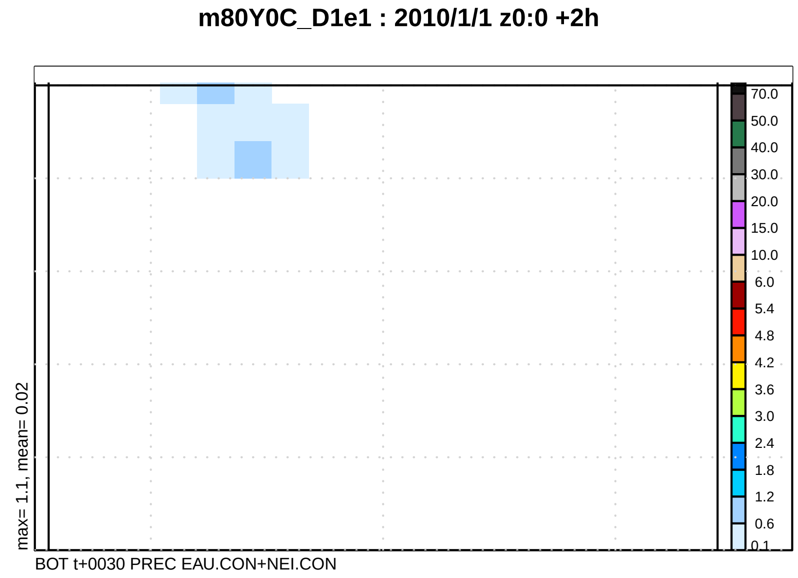

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total

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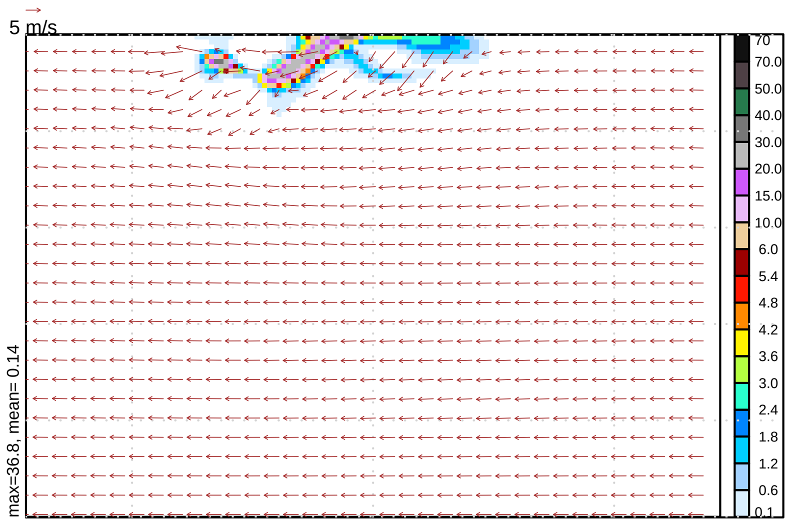
m10Y0C_D6e1 : 2010/1/1 z0:0 +2h



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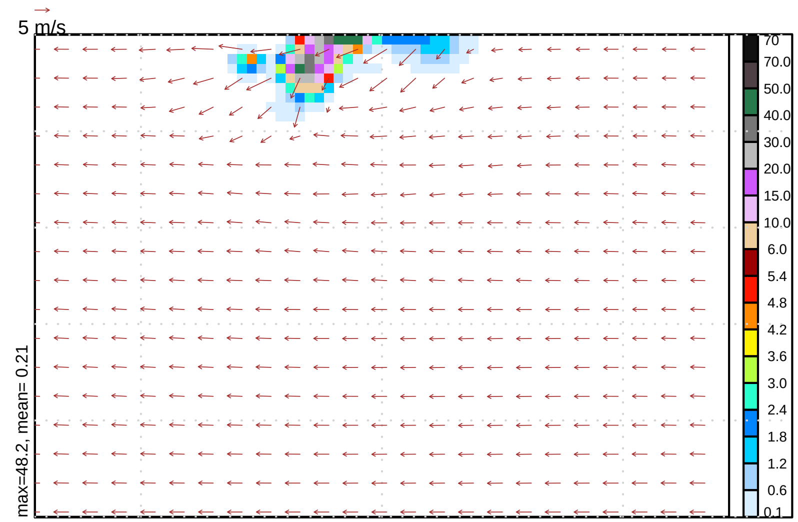
$\triangle x = 2km$

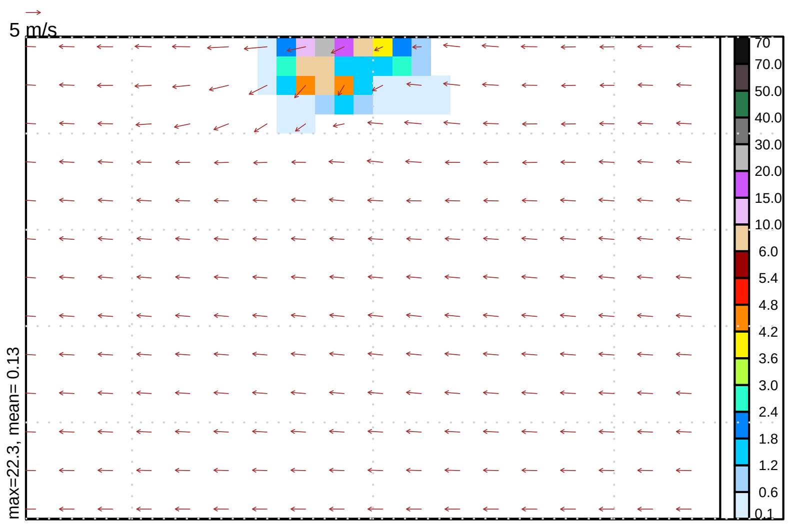
m20Y0C_D6e1 : 2010/1/1 z0:0 +2h



BOT t+0120 PREC EAU.CON+EAU.GEC+NEI.CON+NEI.GEC
S074WIND: −9.5<u< 0.8, −9.4<v< 1.6; ff<10.5

$\triangle x = 4km$

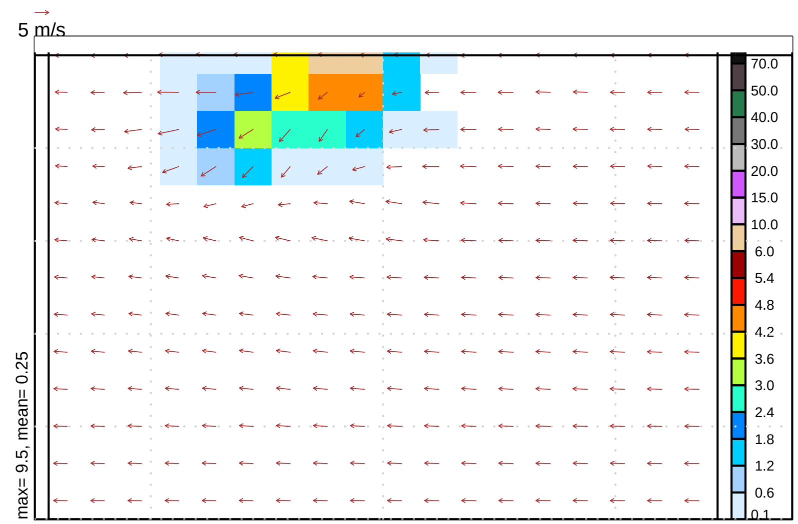
m40Y0C_D6e1 : 2010/1/1 z0:0 +2h



BOT t+0060 PREC EAU.CON+EAU.GEC+NEI.CON+NEI.GEC
S074WIND: −7.9<u<−2.0, −4.3<v< 0.8; ff< 7.9

$\triangle x = 8km$

m80Y0C_D6e1 : 2010/1/1 z0:0 +2h

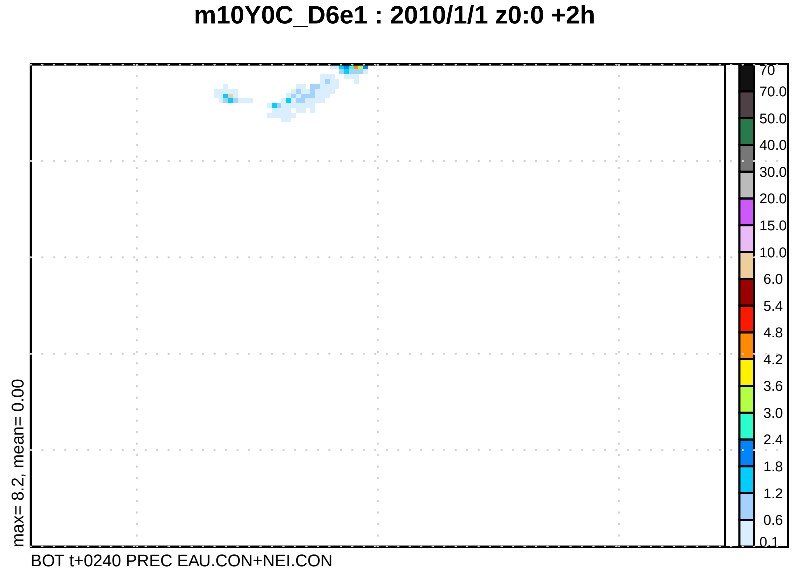


BOT t+0030 PREC EAU.CON+EAU.GEC+NEI.CON+NEI.GEC
S074WIND: −7.6<u<−1.6, −4.4<v< 1.3; ff< 7.6

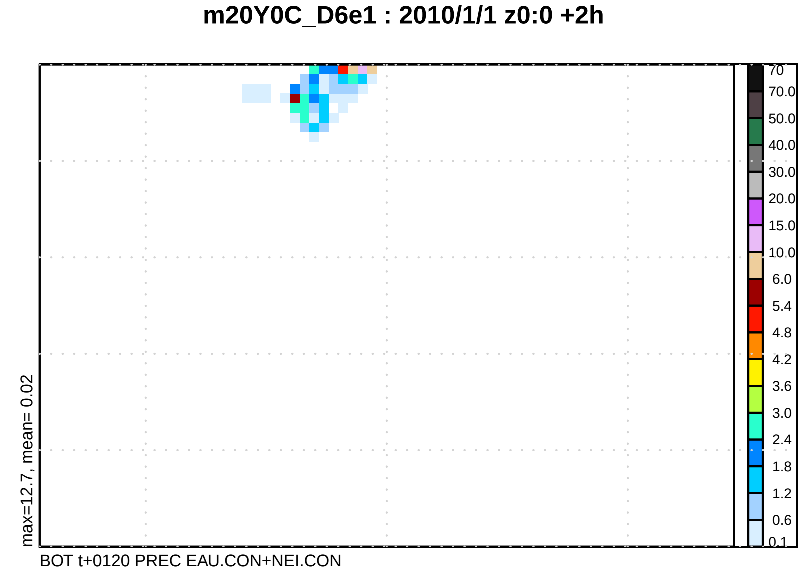
CSU: 2-h accumulated precipitation

subgrid part

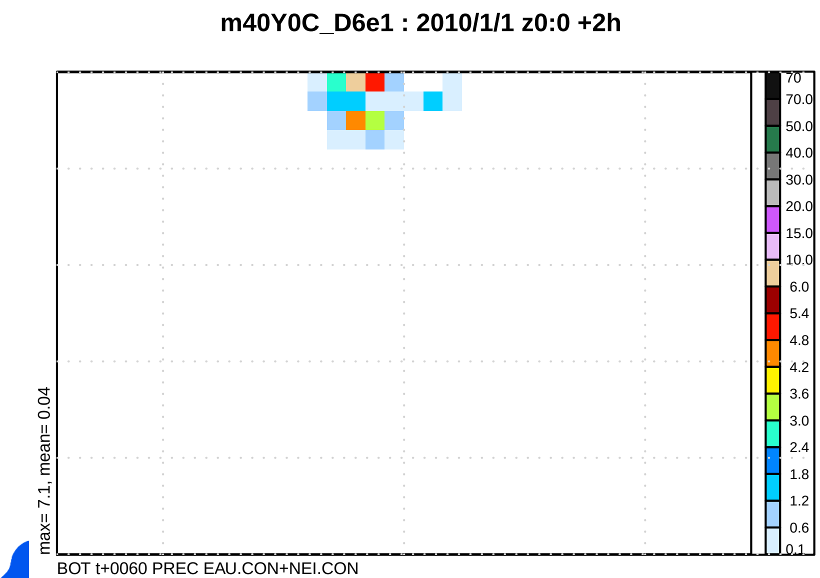
$\triangle x = 1km$



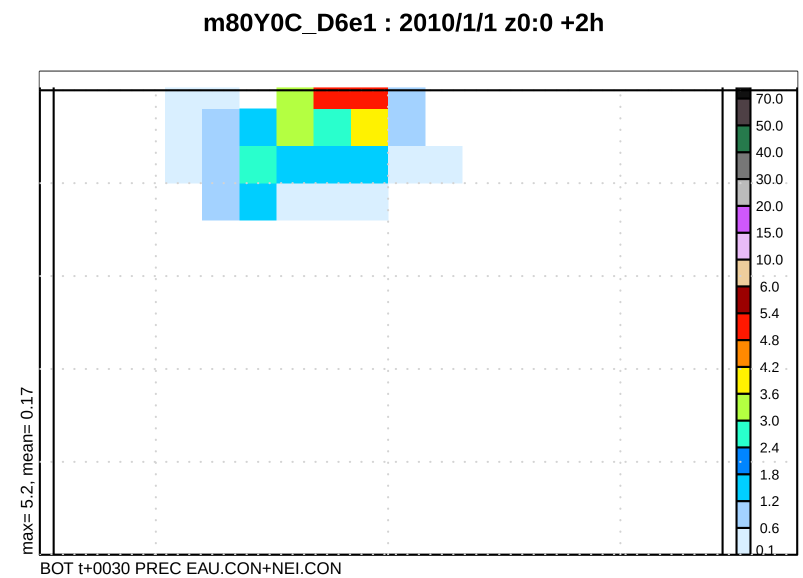
$\triangle x = 2km$



$\triangle x = 4km$

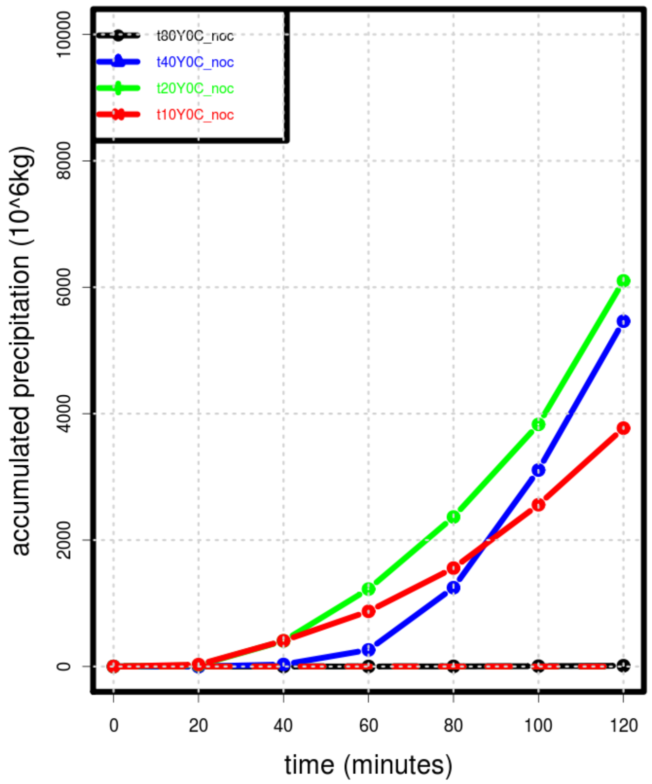


$\triangle x = 8km$



Domain-total accumulated precipitation evolution

accumulated water $[10^6 kg]$ over domain 100x200km

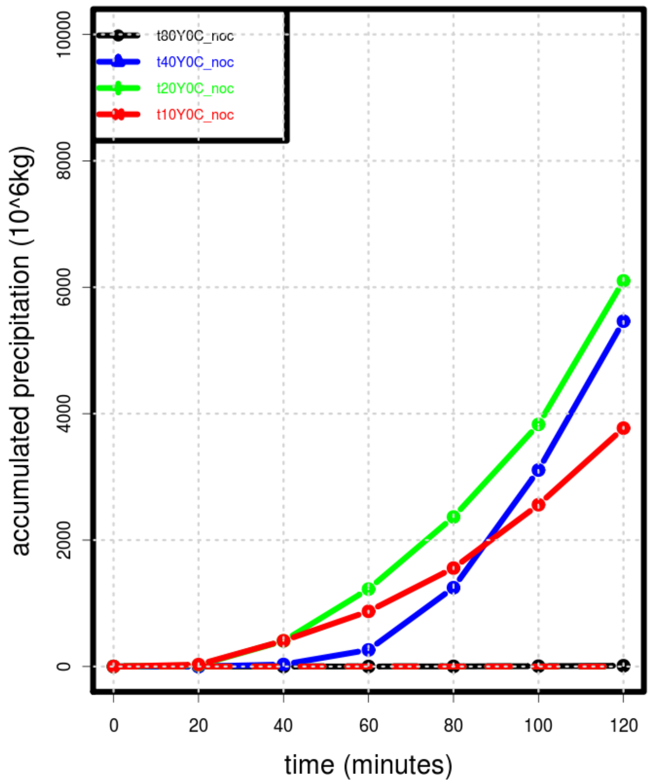


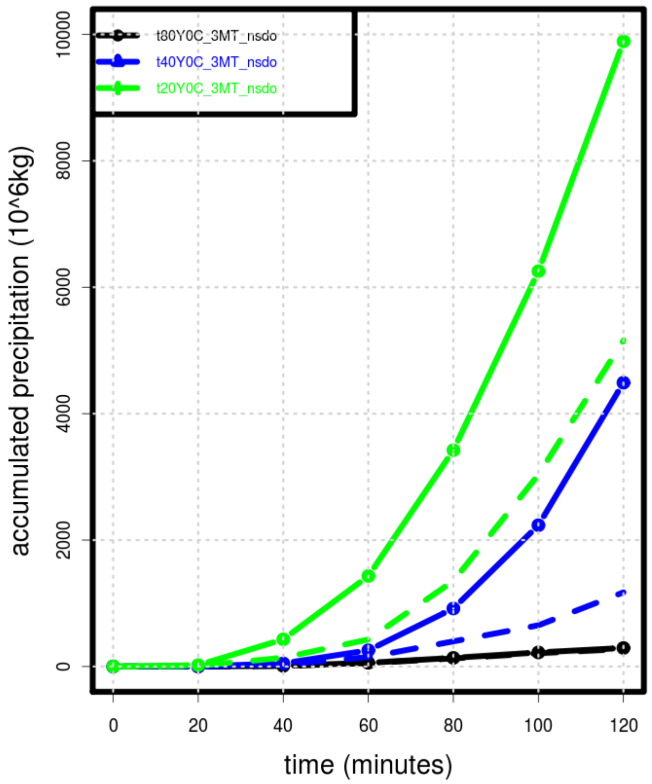
no conv param.

1km, 2km, 4km, 8km.

Domain-total accumulated precipitation evolution

accumulated water $[10^6 kg]$ over domain 100x200km



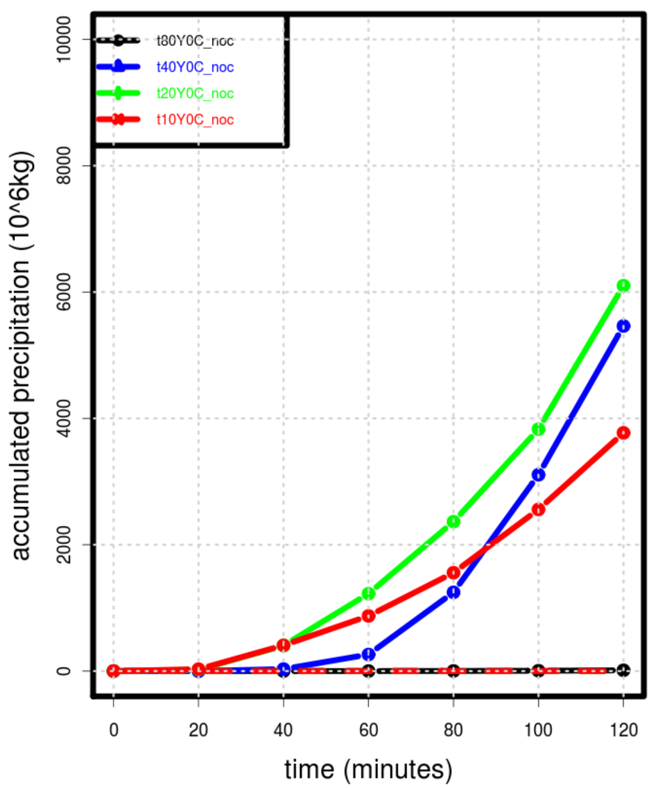


no conv param. 3MT

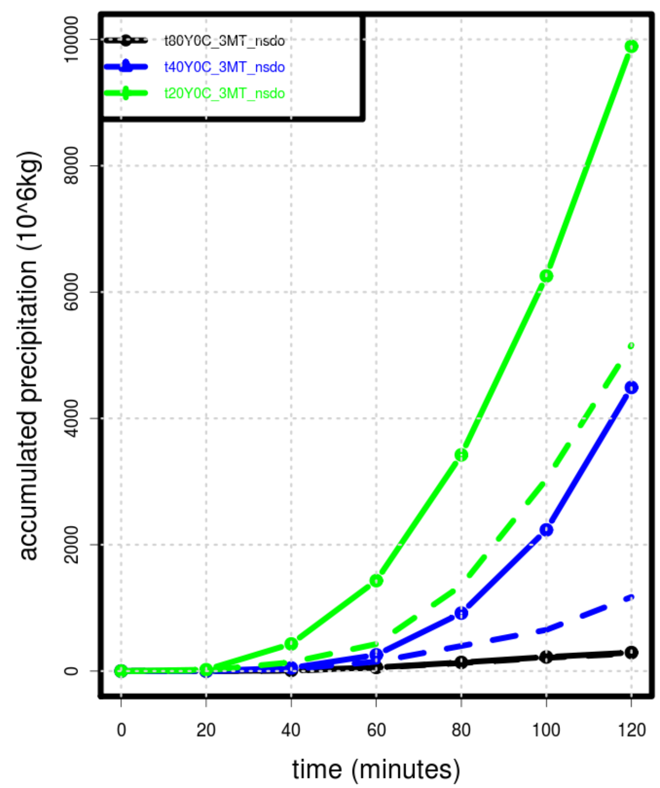
1km, 2km, 4km, 8km.

Domain-total accumulated precipitation evolution

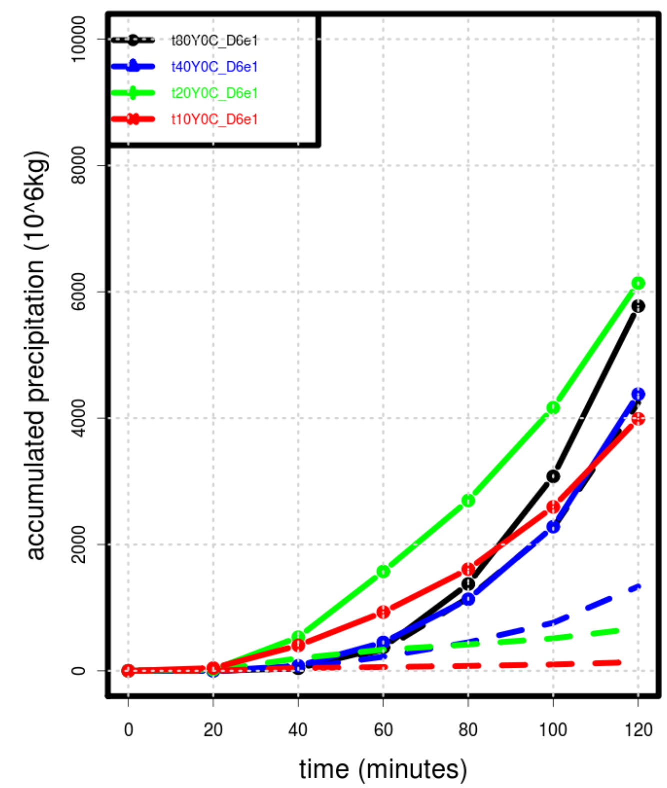
accumulated water $[10^6 kg]$ over domain 100x200km



no conv param.



3MT



CSU

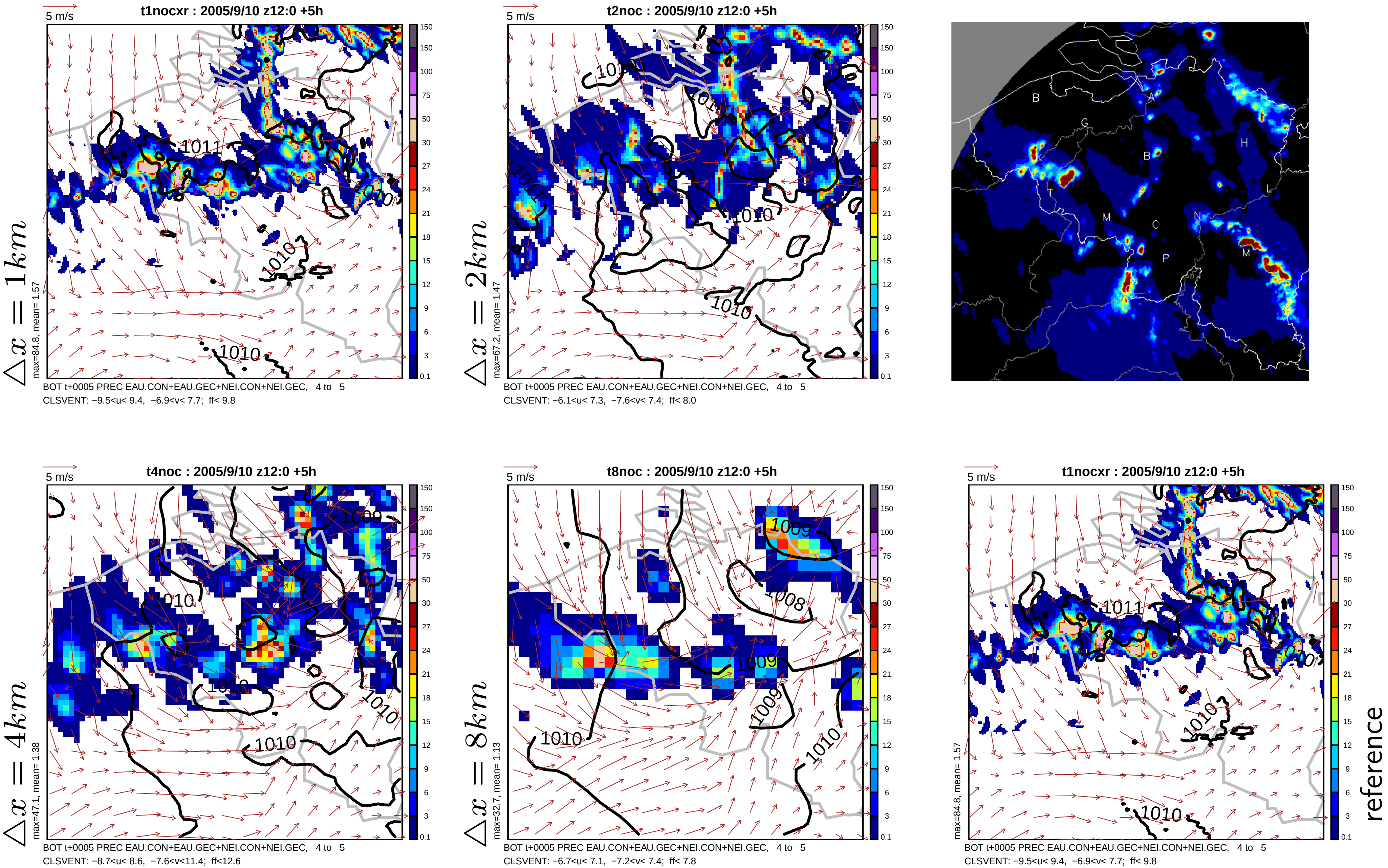
1km, 2km, 4km, 8km.

Real case

thunderstorms over Belgium on 10 September 2005
Hydrostatic model at 8km and 4km, non-hydrostatic at 2 and 1km
41 vertical hybrid levels

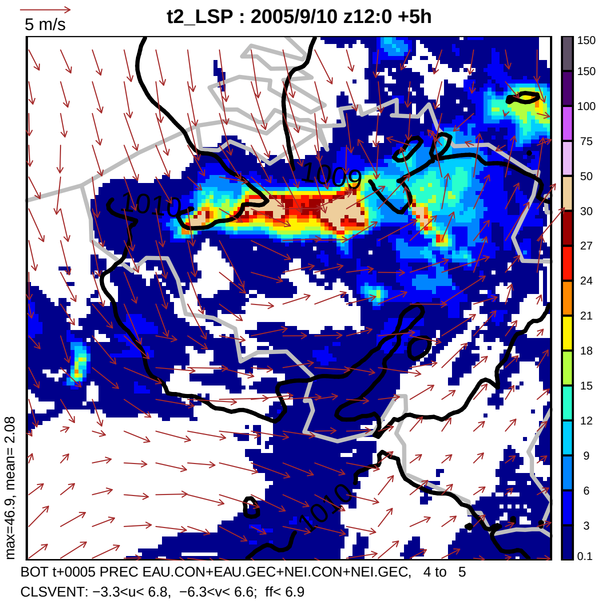
Remark: Belgian territory is quite flat.

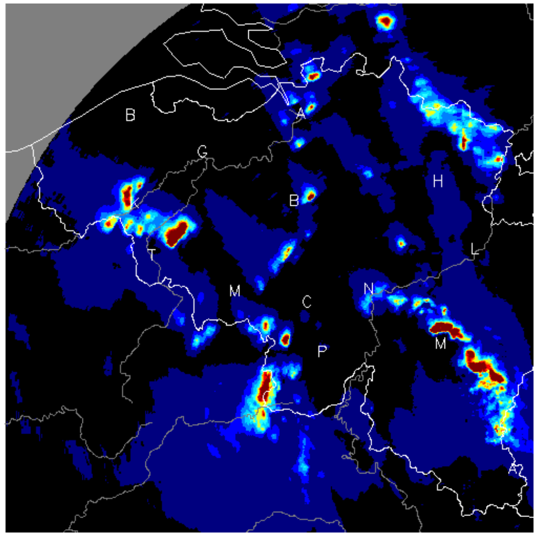
No cp: 1h-accumulated precipitation



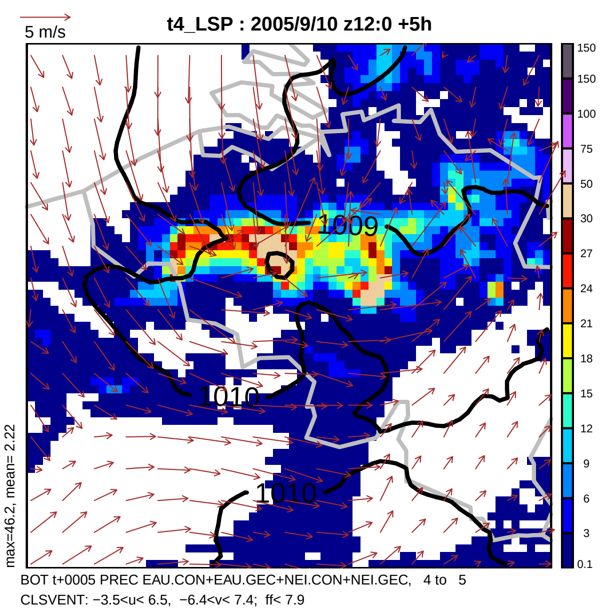
Diag param: 1h-accumulated precipitation

$\triangle x = 2km$

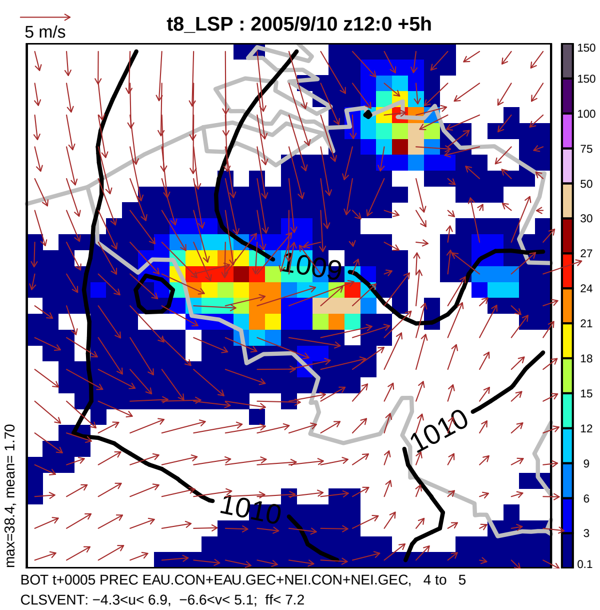


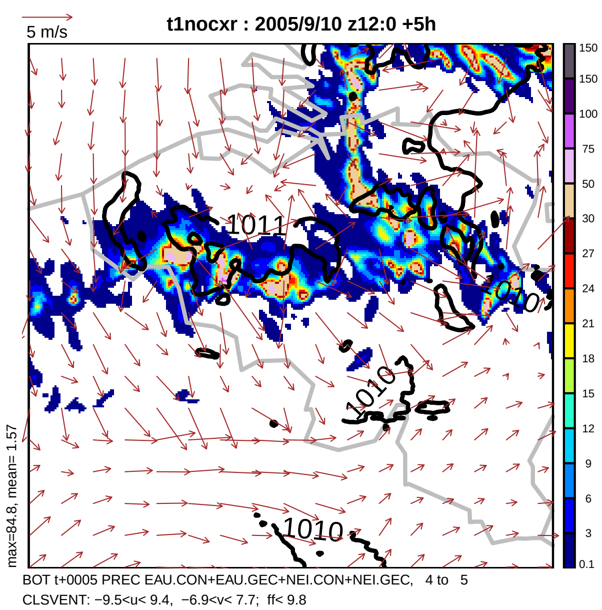


$\triangle x = 4km$



$\triangle x = 8km$

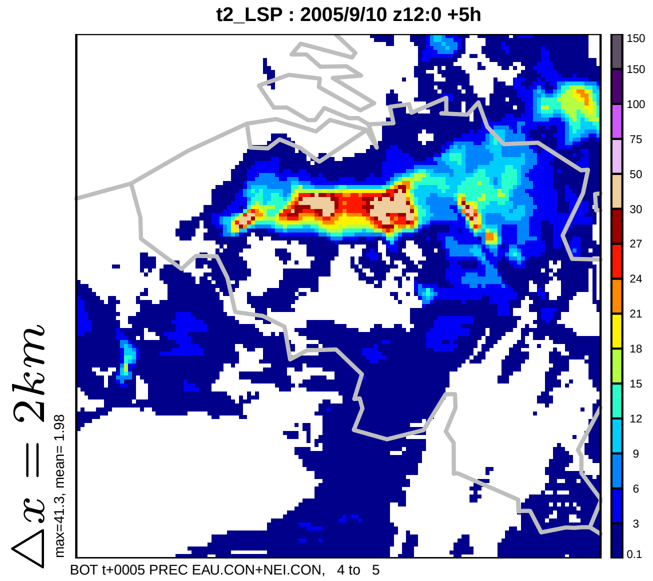


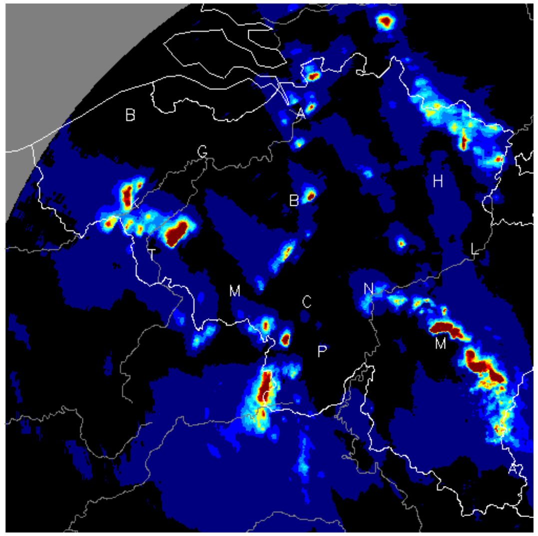


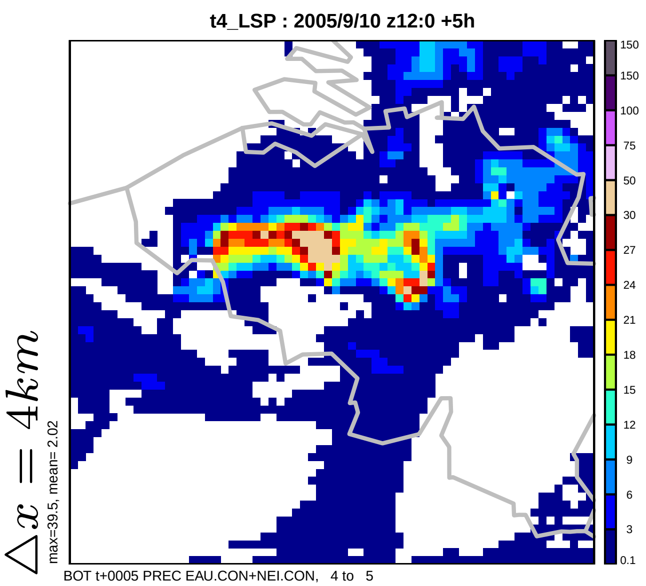
reference

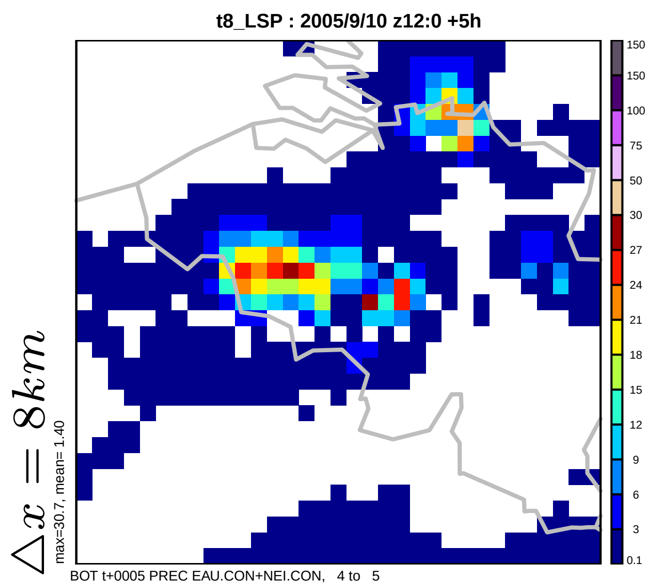
total

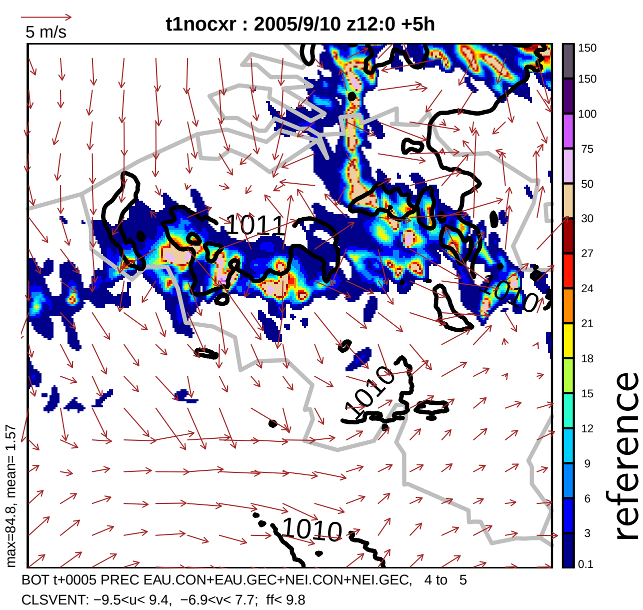
Diag param: 1h-accumulated precipitation







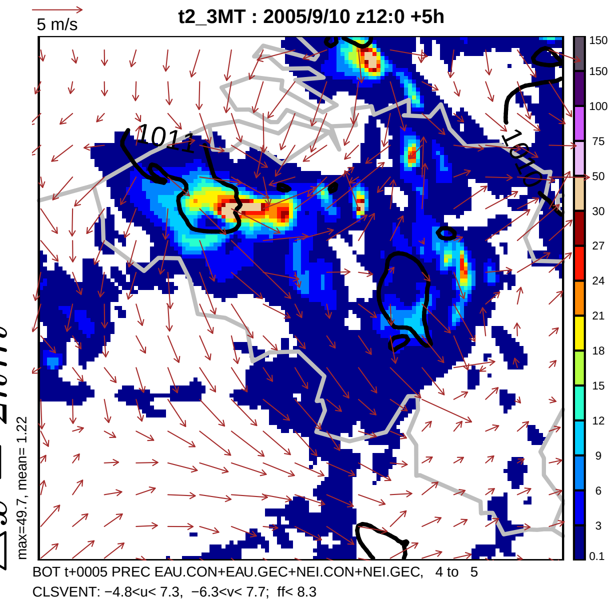


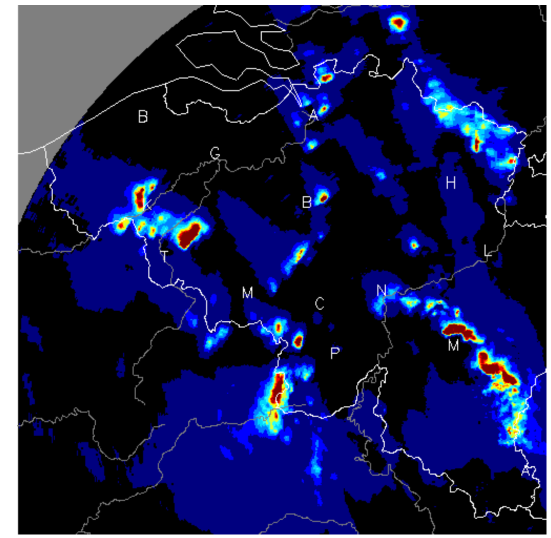


subgrid

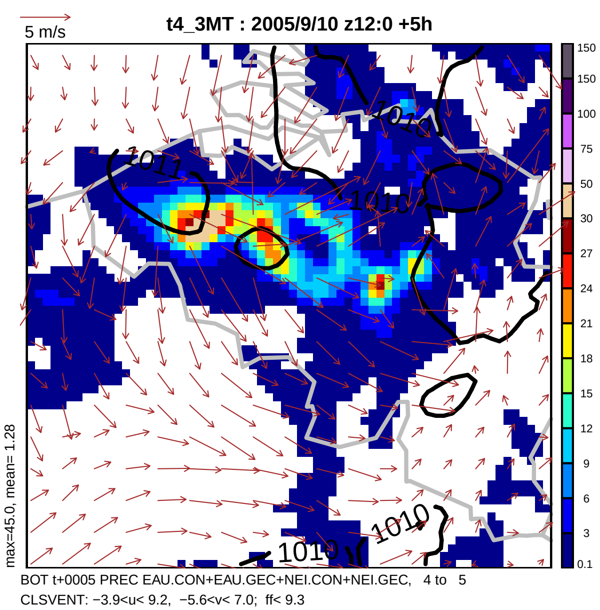
3MT: 1h-accumulated precipitation

$\triangle x = 2km$

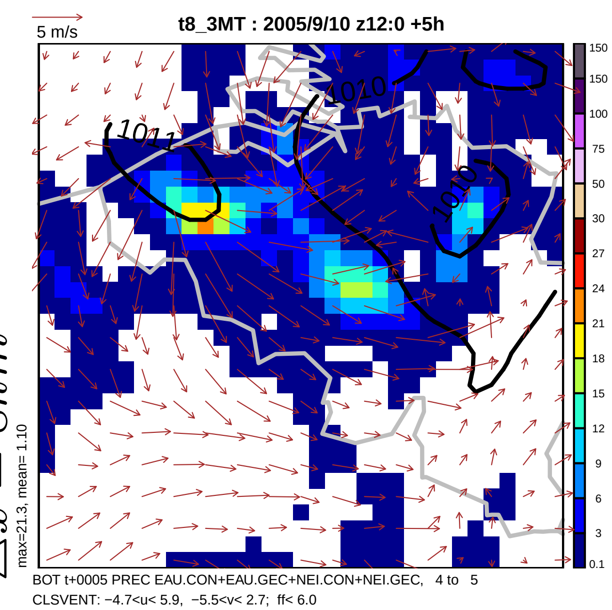




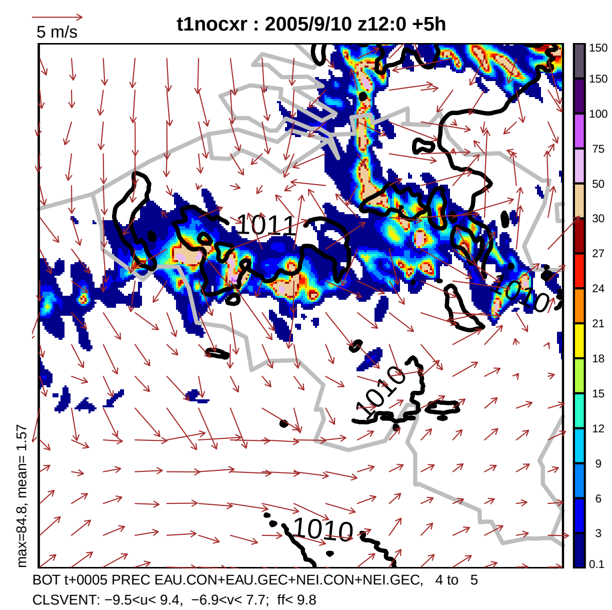
$\triangle x = 4km$



$\triangle x = 8km$

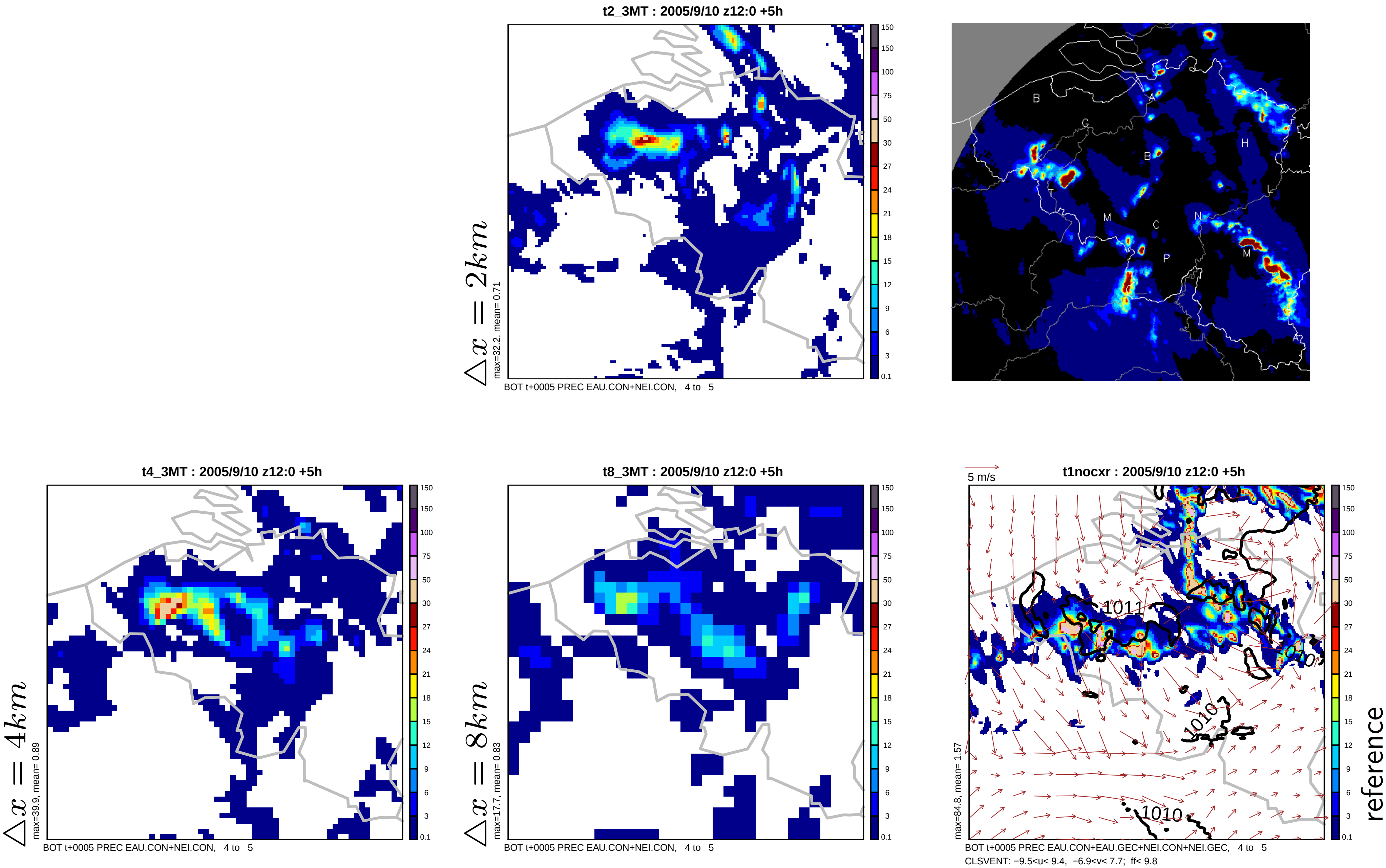


total



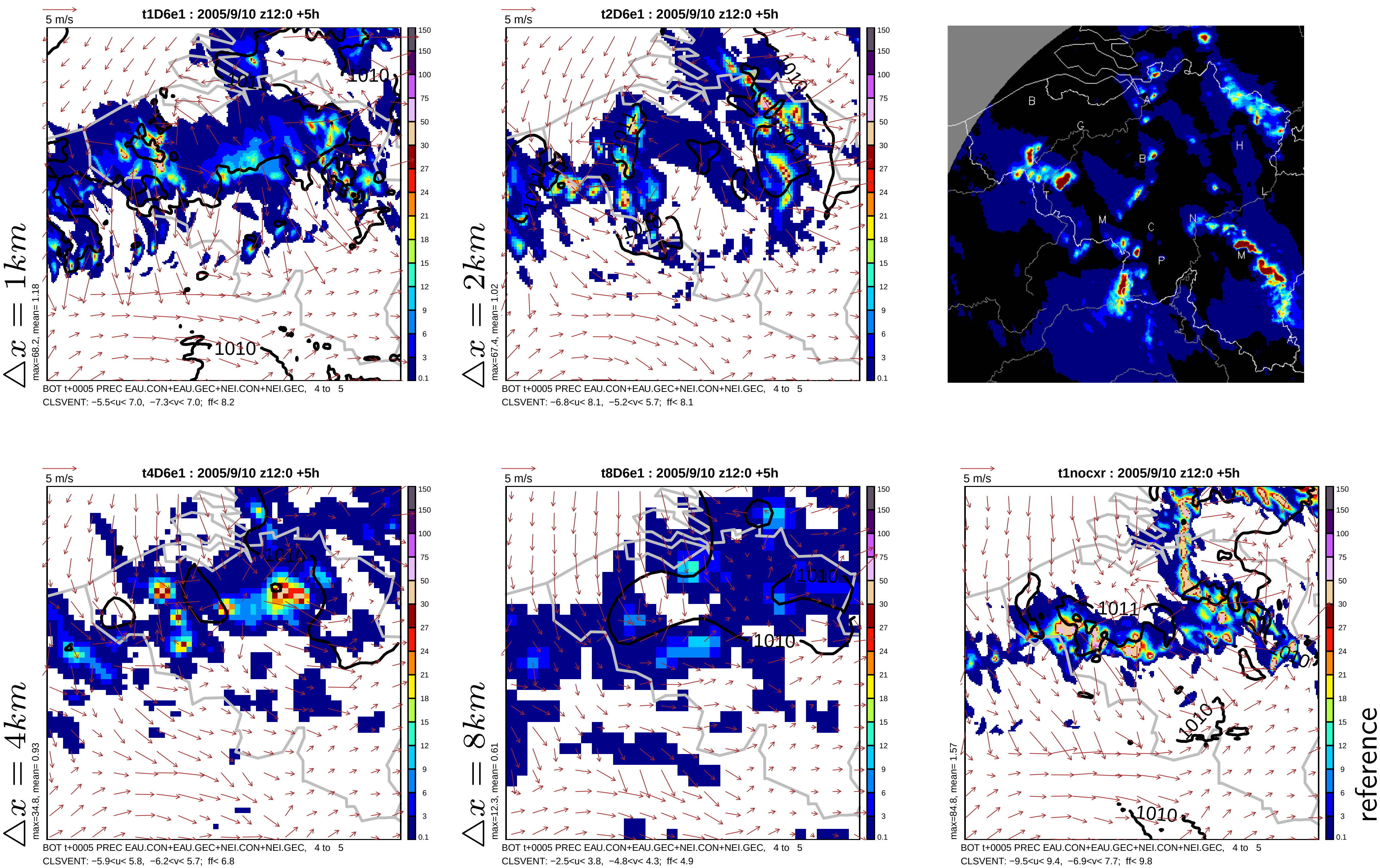
reference

3MT: 1h-accumulated precipitation



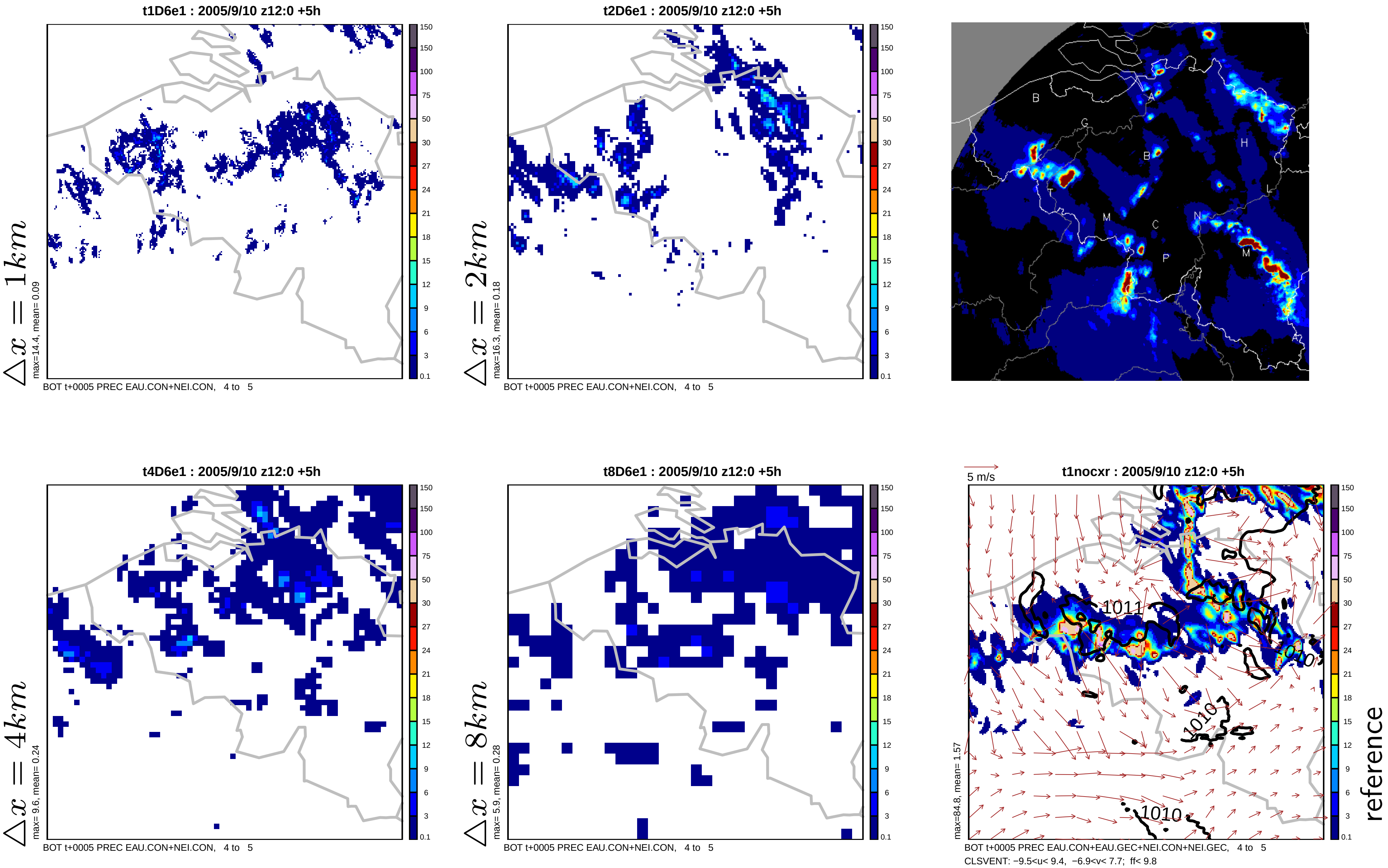
subgrid

CSU: 1h-accumulated precipitation



total

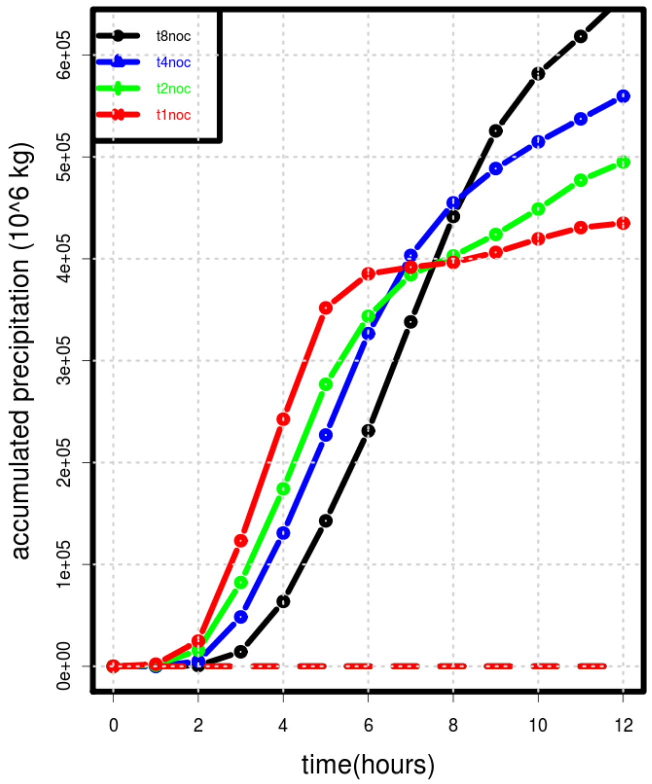
CSU: 1h-accumulated precipitation



subgrid

Domain-total accumulated precipitation evolution

accumulated water $[10^6 kg]$ over domain 264x264 km

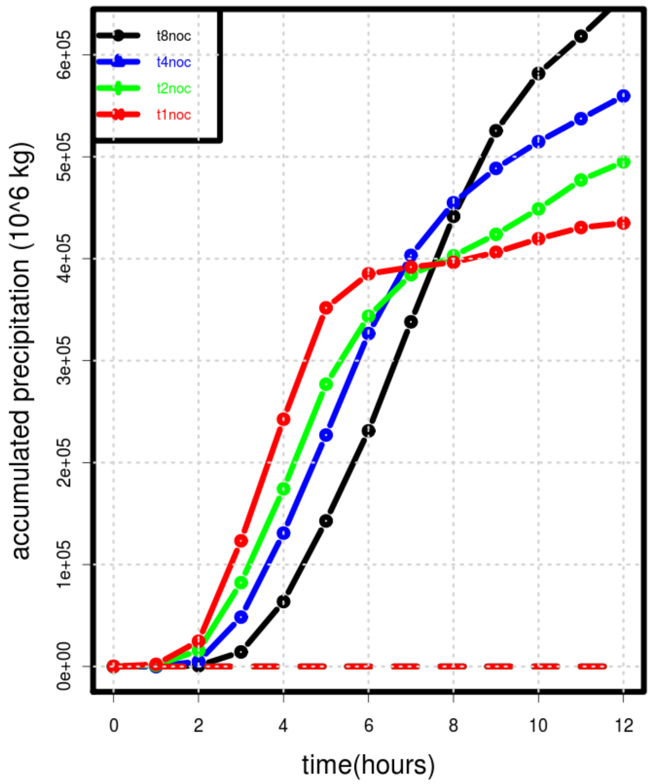


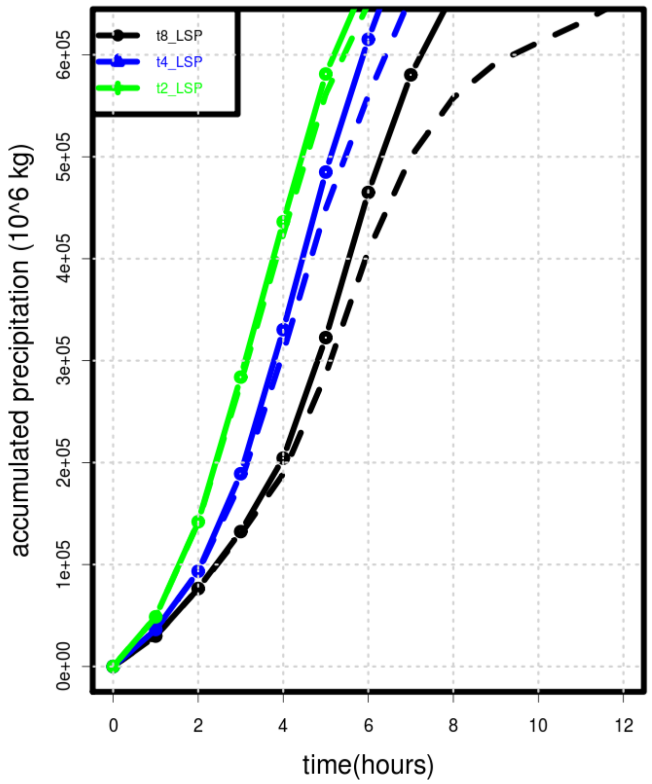
no conv param.

1km, 2km, 4km, 8km.

Domain-total accumulated precipitation evolution

accumulated water $[10^6 kg]$ over domain 264x264 km



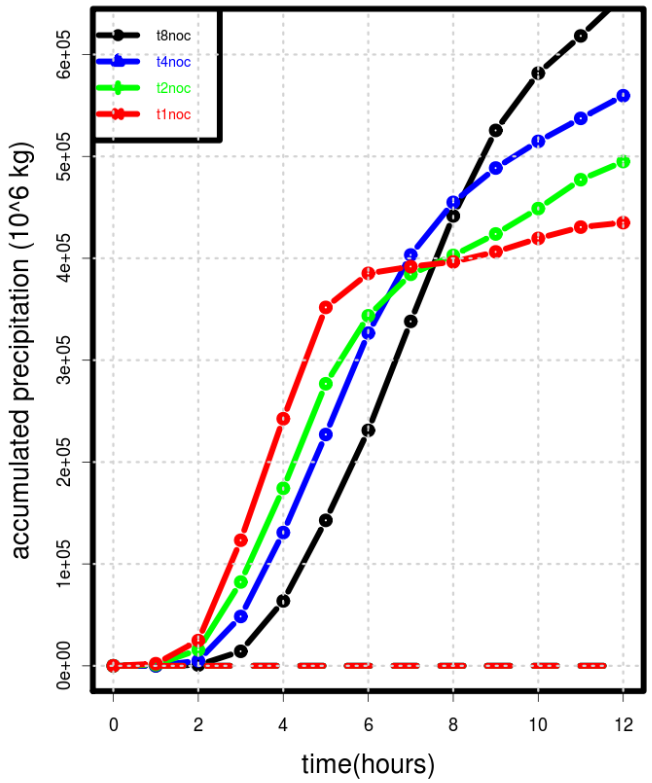


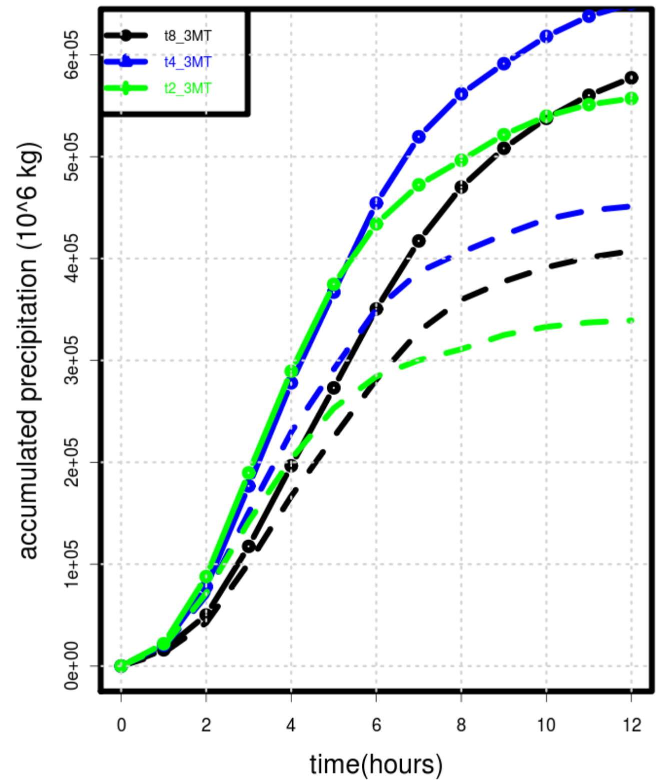
no conv param. Diagn. param

1km, 2km, 4km, 8km.

Domain-total accumulated precipitation evolution

accumulated water $[10^6 kg]$ over domain 264x264 km





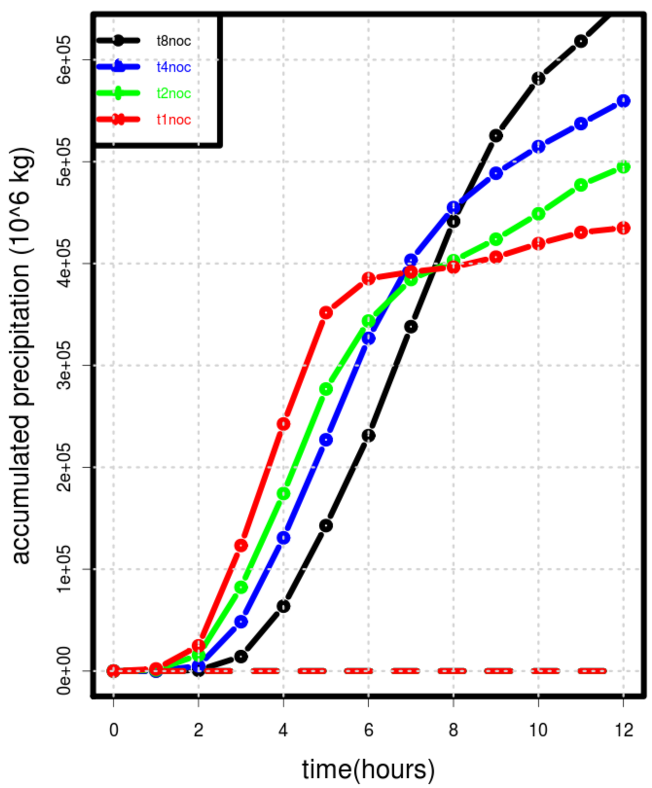
no conv param.

3MT

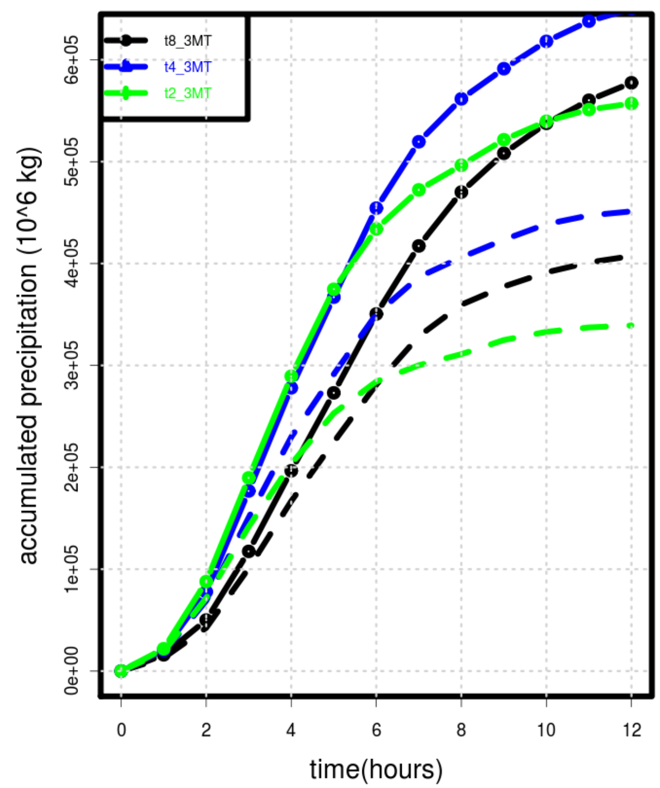
1km, 2km, 4km, 8km.

Domain-total accumulated precipitation evolution

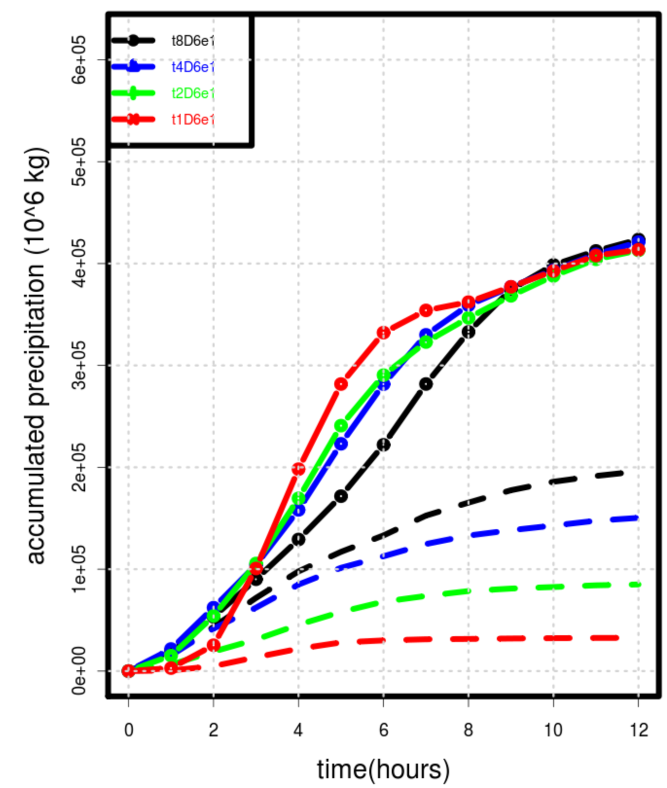
accumulated water $[10^6 kg]$ over domain 264x264 km



no conv param.



3MT

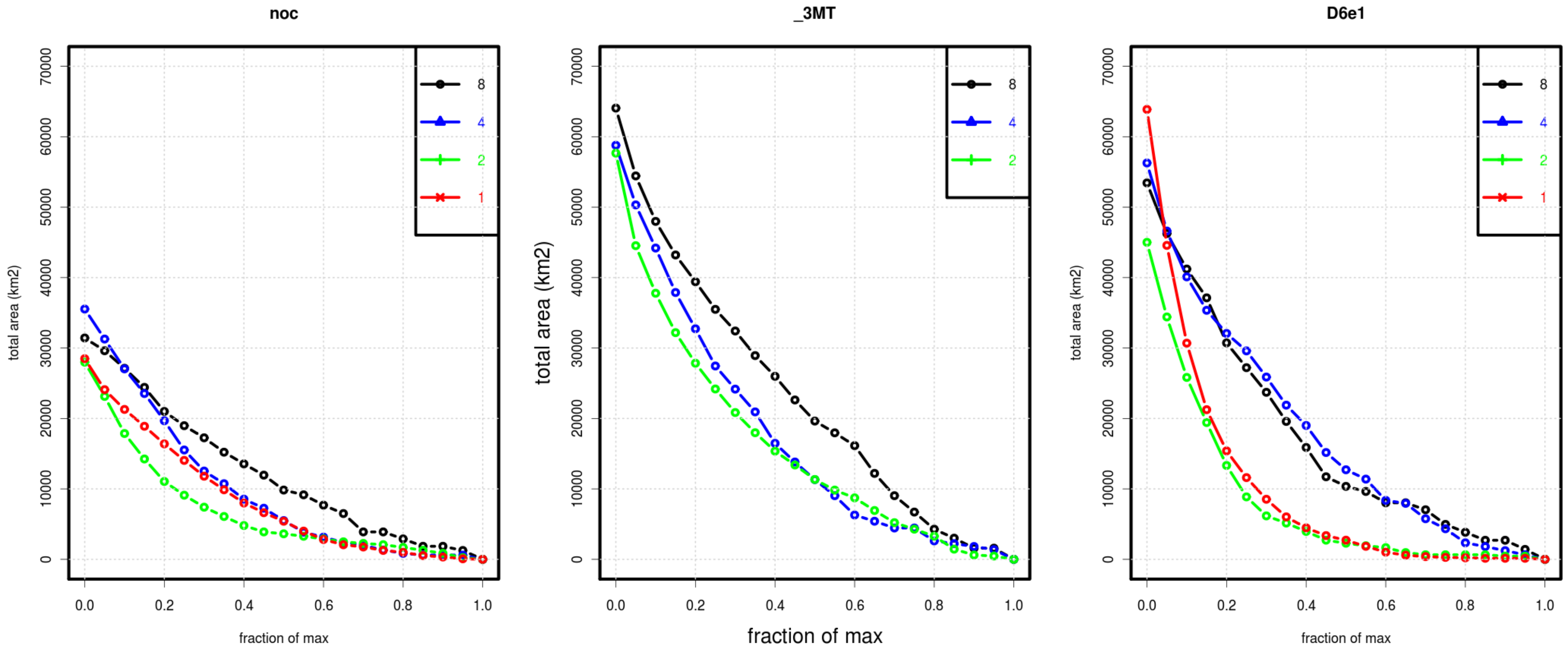


CSU

1km, 2km, 4km, 8km.

Precipitation area distribution

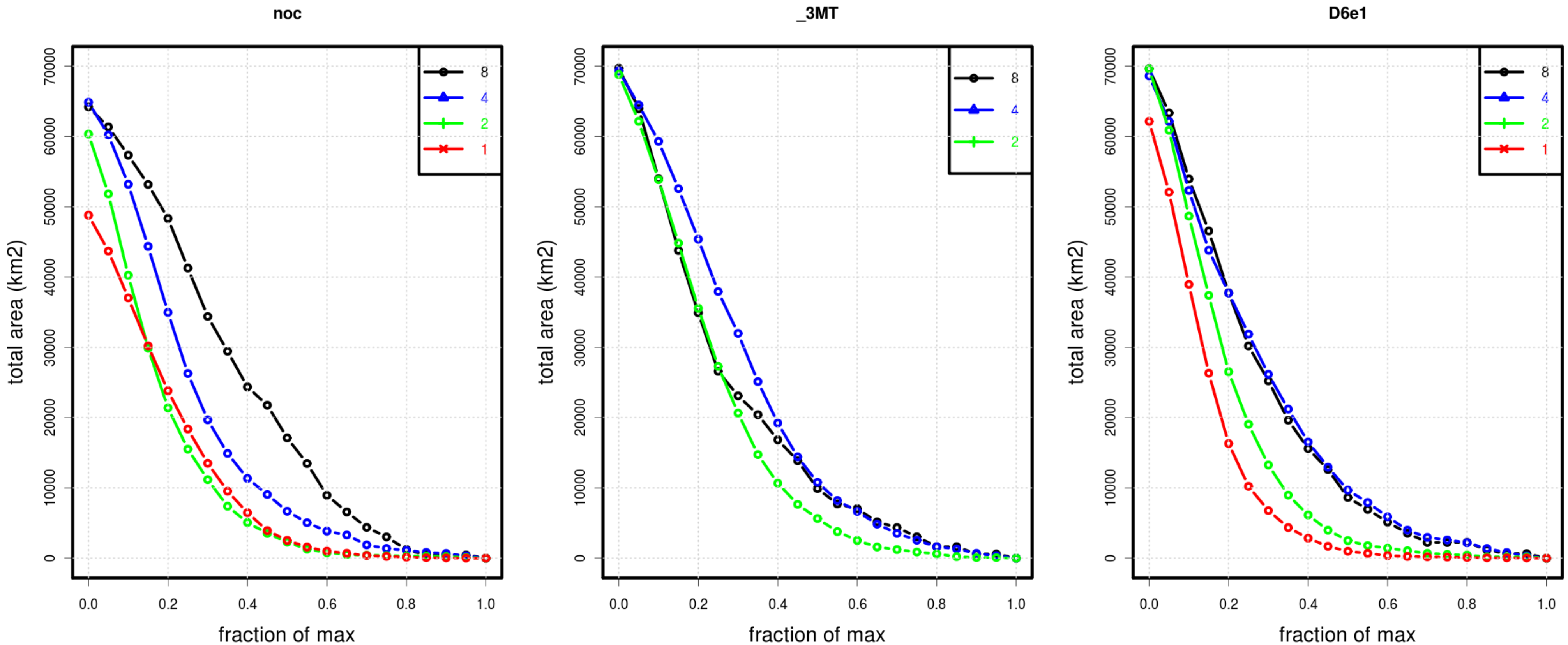
surface covered by precipitation > fraction of maximum



accumulation from +5h to +6h

Precipitation area distribution

surface covered by precipitation > fraction of maximum



accumulation from +0h to +12h

Final highlights

- The CSU approach allows to maintain the total accumulation at all resolutions: benefits for hydrology.
- Consistency of precipitation is a necessary condition to ensure consistency of evolution.
- Finer scale features and evolution are improved at higher resolutions, even down to 1km.
- Multiscale behaviour important for coupling or variable resolution.