Reconnecting cloud representations in Alaro-1

Luc Gerard

Royal Meteorological Institute of Belgium

17 April 2018

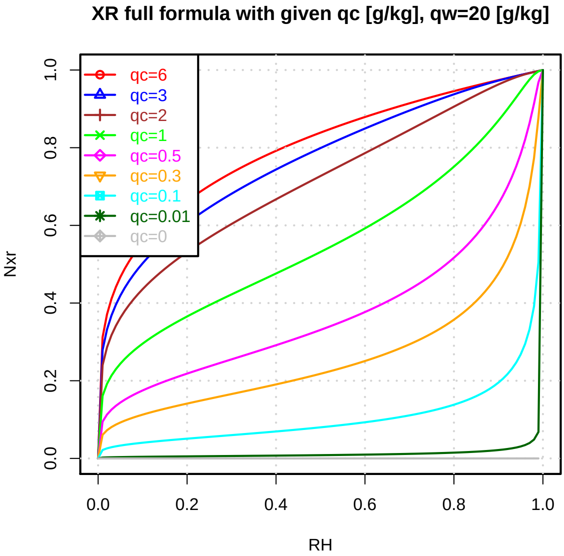
Xu-Randall's 1996 cloud fraction

$$\boxed{N = (RH)^r \left[1 - \exp\{ - \frac{\alpha \, \overline{q_c}}{\left(\overline{q_s}(1 - RH)\right)^{\delta}} \} \right]}$$

$$\alpha \sim 100; \; r \sim 0.25; \; \delta \sim 0.49$$

- mean $\overline{q_c}$ etc. over large grid boxes (64km)
- $RH = \frac{\overline{q_v}}{\overline{q_s}}$, saturation moisture $\overline{q_s}(\overline{T}, p)$
- $N \to 0$ for $\overline{q_c} \to 0$ (or $= 0$ for $RH = 1$)

Xu-Randall's 1996 cloud fraction



$$\frac{\alpha\,\overline{q_c}}{1-RH\big)\big)^{\delta}}\Big\}\Bigg]$$

0.49

Xu-Randall's 1996 cloud fraction

STEADY STATE DIAGNOSTIC

$$\boxed{N = (RH)^r \left[1 - \exp\left\{-\frac{\alpha\,\overline{q_c}}{\left(\overline{q_s}(1 - RH)\right)^{\delta}}\right\}\right]}$$

$$\alpha \sim 100;\ r \sim 0.25;\ \delta \sim 0.49$$

- mean $\overline{q_c}$ etc. over large grid boxes (64km)
- $RH = \frac{\overline{q_v}}{\overline{q_s}}$, saturation moisture $\overline{q_s}(\overline{T}, p)$
- $N \to 0$ for $\overline{q_c} \to 0$ (or $= 0$ for $RH = 1$)

Xu-Randall's 1996 cloud fraction

Joining target state ?

$$N = (RH)^r \left[1 - \exp\left\{ - \frac{\alpha\, \overline{q_c}}{\left(\overline{q_s}(1 - RH) \right)^{\delta}} \right\} \right]$$

$\alpha \sim 100$; $r \sim 0.25$; $\delta \sim 0.49$

- $\overline{q_c} \leq \overline{q_t} - RH \cdot \overline{q_w}$, $\overline{q_t} = \overline{q_{v0}} + \overline{q_{c0}}$

Xu-Randall's 1996 cloud fraction

Joining target state ?

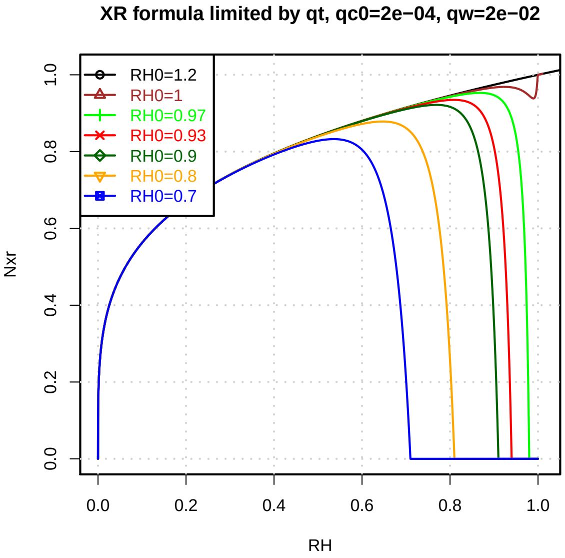
$$N = (RH)^r \left[1 - \exp\{-\frac{\alpha\ \overline{q_c}}{\left(\overline{q_s}(1-RH)\right)^{\delta}}\}\right]$$

$$\alpha \sim 100;\ r \sim 0.25;\ \delta \sim 0.49$$

- $\overline{q_c} \leq \overline{q_t} - RH \cdot \overline{q_w}$, $\overline{q_t} = \overline{q_{v0}} + \overline{q_{c0}}$

microphysics should precipitate excess $\widehat{q_c} - \widehat{\overline{q_{c\mathrm{susx}}}}$

Xu-Randall's 1996 cloud fraction



$$\alpha \, \overline{q_c} \qquad 1 - RH))^{\delta} \}]$$

0.49

precipitate excess $\widehat{q_c} - \widehat{q_{c\text{susx}}}$

Xu-Randall's 1996 cloud fraction

Joining target state ?

$$N = (RH)^r \left[1 - \exp\{-\frac{\alpha\, \overline{q_c}}{\left(\overline{q_s}(1 - RH)\right)^{\delta}}\}\right]$$

$\alpha \sim 100$; $r \sim 0.25$; $\delta \sim 0.49$

- $\overline{q_c} \leq \overline{q_t} - RH \cdot \overline{q_w}$, $\overline{q_t} = \overline{q_{v0}} + \overline{q_{c0}}$

microphysics should precipitate excess $\widehat{q_c} - \widehat{q_{c\mathrm{susx}}}$

Xu-Randall's 1996 cloud fraction

Joining target state ?

$$N = (RH)^r \left[1 - \exp\left\{ - \frac{\alpha \, \overline{q_c}}{\left(\overline{q_s}(1 - RH) \right)^{\delta}} \right\} \right]$$

$$\alpha \sim 100; \; r \sim 0.25; \; \delta \sim 0.49$$

- $\overline{q_c} \leq \overline{q_t} - RH \cdot \overline{q_w}$, $\overline{q_t} = \overline{q_{v0}} + \overline{q_{c0}}$

  microphysics should precipitate excess $\widehat{q_c} - \widehat{q_{c\mathrm{susx}}}$
- $RH = \frac{\overline{q_v}}{\overline{q_w}}$, mean grid-box wet bulb relative humidity

  (T_w, q_w) = attempt to avoid $q_s(T, p)$:
  - evaporate excess condensate, taking the heat from the air mass
  - bring oversaturated air mass to saturation, leaving the heat in the air

Xu-Randall's 1996 cloud fraction

Joining target state ?

$$N = (RH)^r \left[1 - \exp\left\{ - \frac{\alpha \, \overline{q_c}}{\left(\overline{q_s}(1 - RH) \right)^{\delta}} \right\} \right]$$

$$\alpha \sim 100;\ r \sim 0.25;\ \delta \sim 0.49$$

- $\overline{q_c} \leq \overline{q_t} - RH \cdot \overline{q_w}$, $\overline{q_t} = \overline{q_{v0}} + \overline{q_{c0}}$

  microphysics should precipitate excess $\widehat{q_c} - \widehat{q_{c\mathrm{susx}}}$

- $RH = \frac{\overline{q_v}}{\overline{q_w}}$, mean grid-box wet bulb relative humidity

  (T_w, q_w) = attempt to avoid $q_s(T, p)$:
  - evaporate excess condensate, taking the heat from the air mass
  - bring oversaturated air mass to saturation, leaving the heat in the air

but blowing new air continuously

Xu-Randall's 1996 cloud fraction

Joining target state ?

$$N = (RH)^r \left[1 - \exp\{ - \frac{\alpha\, \overline{q_c}}{\left(\overline{q_s}(1 - RH) \right)^{\delta}} \} \right]$$

$$\alpha \sim 100;\ r \sim 0.25;\ \delta \sim 0.49$$

- $\overline{q_c} \leq \overline{q_t} - RH \cdot \overline{q_w}$, $\overline{q_t} = \overline{q_{v0}} + \overline{q_{c0}}$
  microphysics should precipitate excess $\widehat{q_c} - \widehat{\overline{q_{c\mathrm{susx}}}}$
- $RH = \frac{\overline{q_v}}{\overline{q_w}}$, mean grid-box wet bulb relative humidity
  (T_w, q_w) = attempt to avoid $q_s(T, p)$:
  you cannot escape local diabatic effects:

$$L \cdot \delta q_v < \max(N, N_{xn}) \cdot c_p \left.\frac{\partial T}{\partial t}\right|_x \cdot \triangle t, \qquad \text{allow around } 10K/day$$

Playing with Xu-Randall's 1996 formula

$$N = (RH)^r \left[1 - \exp\{-\frac{\alpha\, \overline{q_c}}{\left(\overline{q_w}(1 - RH)\right)^{\delta}}\right] \qquad \text{re-defining } RH = \frac{\overline{q_v}}{\overline{q_w}}$$

$$\overline{q_c} = \min[\overline{q_{cx}}, q_t - RH \cdot \overline{q_w}], \qquad \overline{q_t} = \overline{q_w} \cdot RH_0 + q_{c0}$$

- known: RH_0, $\overline{q_w}$, $\overline{q_{c0}}$, hence $\overline{q_t}$
- 3 unknowns: N, RH, $\overline{q_c}$
- parameters: $\alpha \sim 100$, $r \sim 0.25$, $\delta \sim 0.49$
- q_{cx} to be parameterized, e.g. $\overline{q_{cx}} = \widehat{q_{cx0}}\, N^{\gamma} f(\overline{\omega})$

Playing with Xu-Randall's 1996 formula

$$N = (RH)^r \left[1 - \exp\{-\frac{\alpha\,\overline{q_c}}{\left(\overline{q_w}(1-RH)\right)^\delta}\right] \qquad \text{re-defining } RH = \frac{\overline{q_v}}{\overline{q_w}}$$

$$\overline{q_c} = \min[\overline{q_{cx}}, q_t - RH \cdot \overline{q_w}], \qquad \overline{q_t} = \overline{q_w} \cdot RH_0 + q_{c0}$$

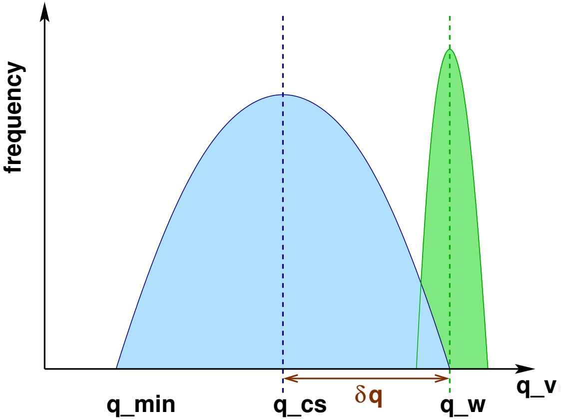
- known: RH_0, $\overline{q_w}$, $\overline{q_{c0}}$, hence $\overline{q_t}$
- 3 unknowns: N, RH, $\overline{q_c}$
- parameters: $\alpha \sim 100$, $r \sim 0.25$, $\delta \sim 0.49$
- q_{cx} to be parameterized, e.g. $\overline{q_{cx}} = \widehat{q_{cx0}}\, N^\gamma f(\overline{\omega})$

$\Rightarrow$ We need one more relation between N and RH to close, e.g.

$$RH = N + (1-N)RH_{cs}$$

i.e. $RH = 1$ in cloud and a mean RH_{cs} in clear sky.

Closure: subgrid variability assumption

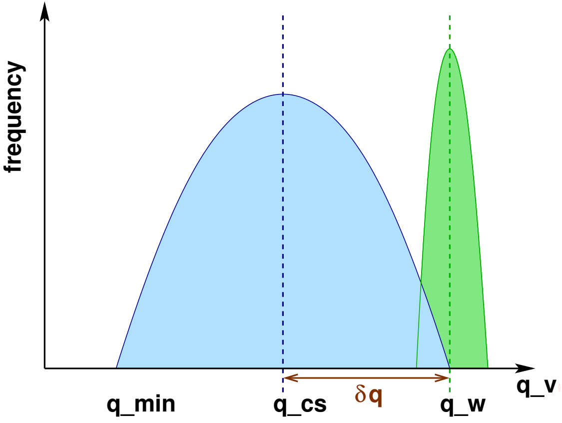


Closure: subgrid variability assumption

The range of RH in clear part $(1 - N)$ may vary with its area (granularity)

$$\delta q = \left[(1-N)\frac{A}{A_{\mathrm{ref}}}\right]^p \frac{\overline{q_w} - q_{\mathrm{min}}}{2} \equiv \overline{q_w}(1-N)^p(1-H_0)$$

Larger p when more homogeneity (large TKE)

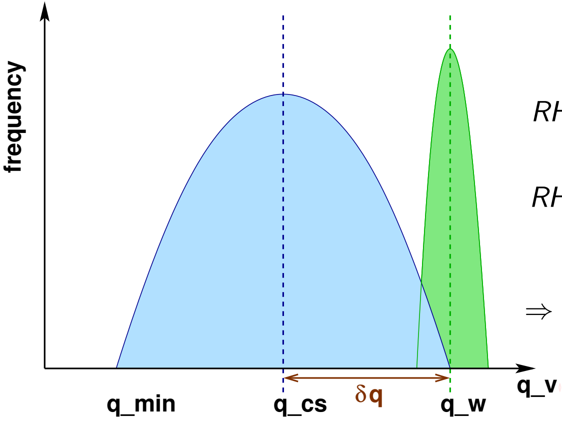


Closure: subgrid variability assumption

The range of RH in clear part $(1-N)$ may vary with its area (granularity)

$$\delta q = \left[(1-N)\frac{A}{A_{\mathrm{ref}}}\right]^p \frac{\overline{q_w} - q_{\mathrm{min}}}{2} \equiv \overline{q_w}(1-N)^p(1-H_0)$$

Larger p when more homogeneity (large TKE)



$$q_{cs} = \overline{q_w} - \delta q$$

$$RH_{cs} = 1 - (1-N)^p(1-H_0)$$

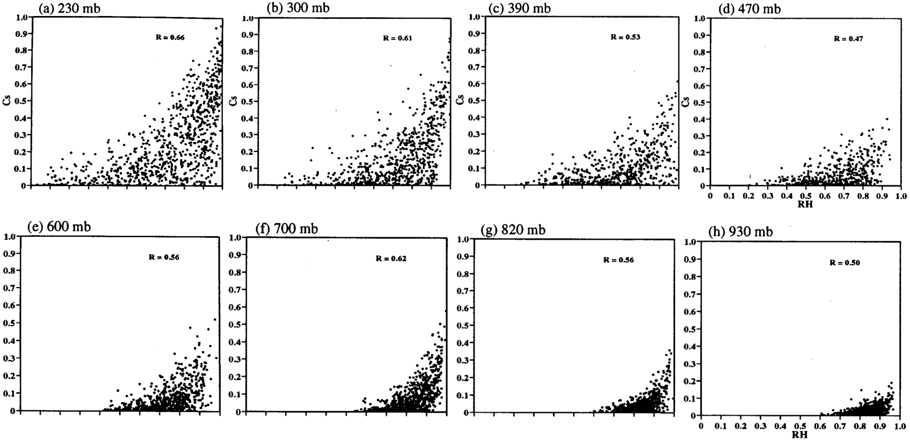
$$RH = N + (1-N) - RH_{cs}$$
$$= 1 - (1-N)^{p+1}(1-H_0)$$

$\Rightarrow H_0 =$ 'critical' RH $(N \to 0)$

Critical relative humidity ?

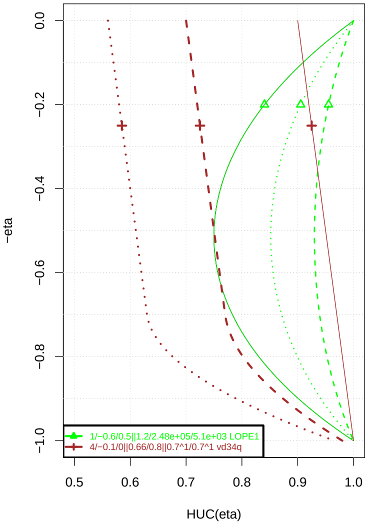
Xu-Randall 1997 Fig 5

Scatterplot: stratiform cloud amount vs large-scale RH (GATE 64km subdomain)



no unique RH_c but higher threshold and less scatter downwards

Profiles for subgrid variability

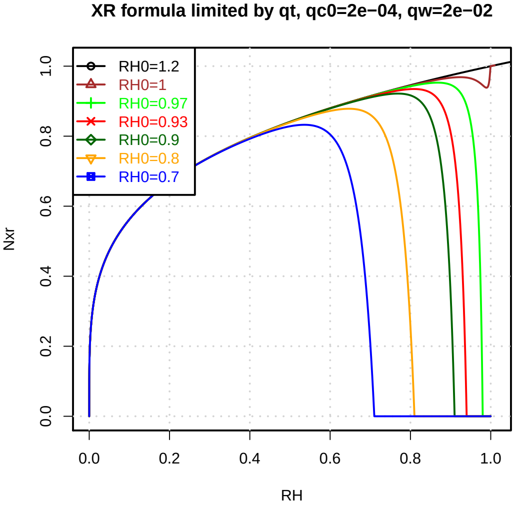


'Critical' relative humidity

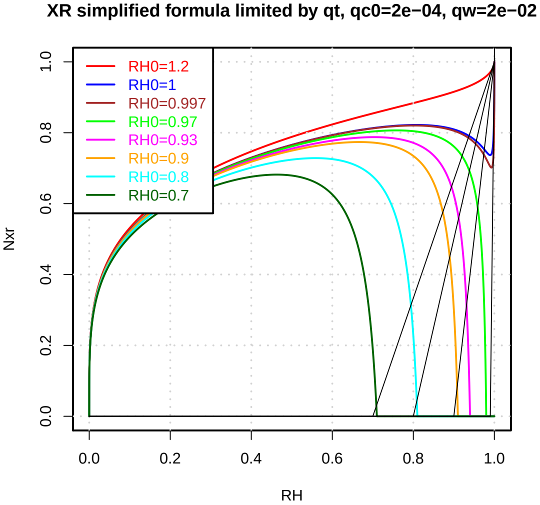
- phase dependent
- increasing downwards
- was found necessary to return close to 1 at the surface

p exponent: increase towards surface

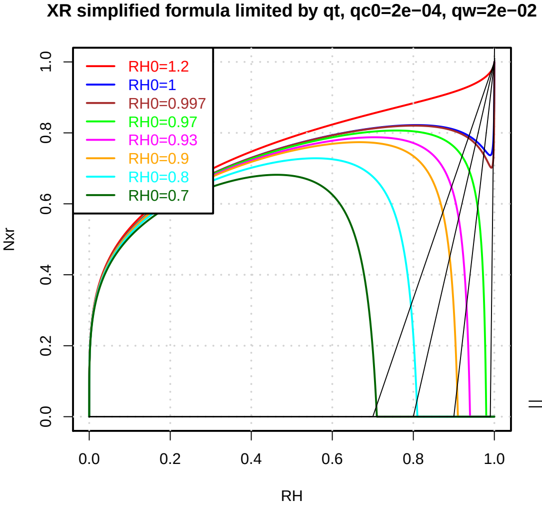
Problems of initial (Alaro-0) implementation



Problems of initial (Alaro-0) implementation



Problems of initial (Alaro-0) implementation



- simplified XR formula

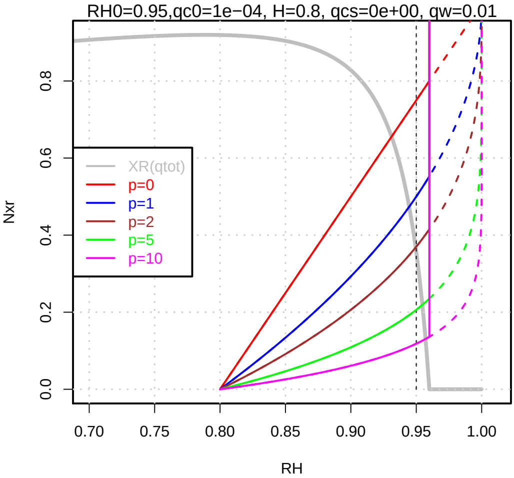
$$N \approx RH^{\frac{1}{4}} \frac{\alpha \overline{q_c}}{\alpha \overline{q_c} + \sqrt{q_w(1-RH)}}$$

- $\overline{q_c} = \overline{q_t} - RH \cdot \overline{q_w}$
- $p = 0 \;\Rightarrow\; RH = N + (1-N)H_0$
- H_0 set very high to limit condensation

$\Rightarrow$ imprecise N, binary.

Applying the limitations

$$N = (RH)^r \left[1 - \exp\{ - \frac{\alpha\, \overline{q_c}}{\left(\overline{q_w}(1 - RH) \right)^{\delta}} \} \right]$$

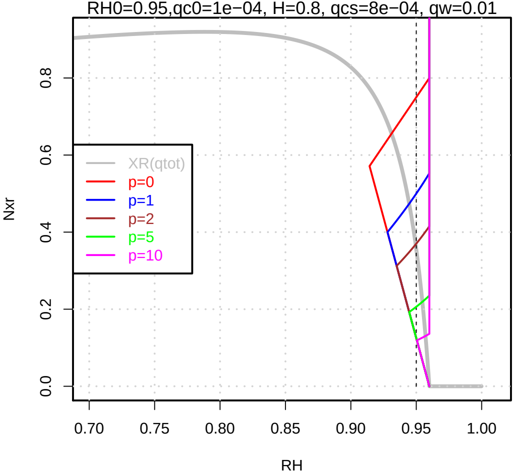


$$\overline{q_c} = \overline{q_t} - RH\overline{q_w}$$

$$RH = N + (1 - N)^{p+1}(1 - H_0)$$

Applying the limitations

$$N = (RH)^r \left[1 - \exp\{-\frac{\alpha\,\overline{q_c}}{\left(\overline{q_w}(1-RH)\right)^{\delta}}\}\right]$$

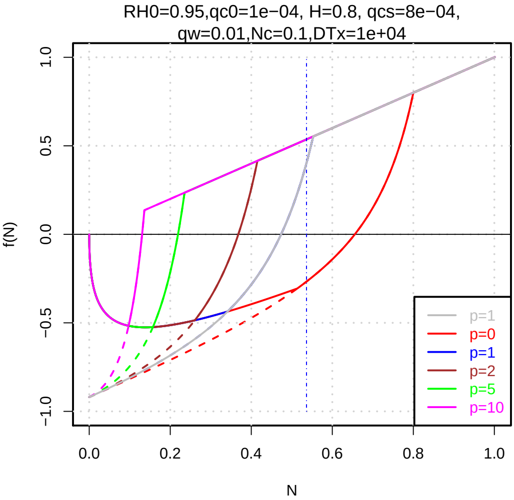


$$\overline{q_c} = \max[\overline{q_{cx}}, \overline{q_t} - RH\overline{q_w}]$$

$$RH = N + (1-N)^{p+1}(1-H_0)$$

Applying the limitations

$$f(N) = N - (RH)^r \left[1 - \exp\{-\frac{\alpha\,\overline{q_c}}{\left(\overline{q_w}(1-RH)\right)^{\delta}}\}\right]$$



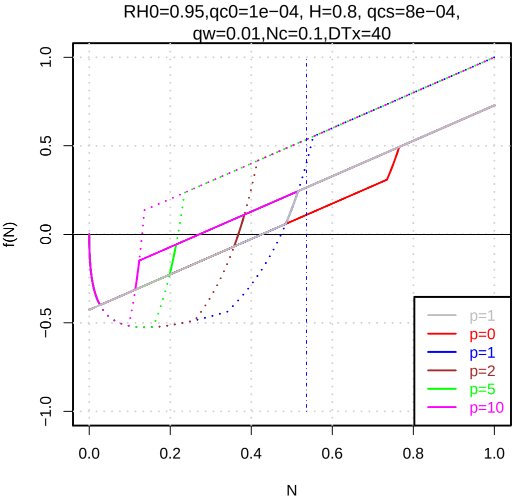
linear part: $\overline{q_t}$ limitation

dashed: no $\widehat{q_{csus}}$ limitation

solid: $\widehat{q_{csus}}$=0.8g/kg

Applying the limitations

$$f(N) = N - (RH)^r \left[1 - \exp\{-\frac{\alpha\,\overline{q_c}}{\left(\overline{q_w}(1-RH)\right)^{\delta}}\}\right]$$



protect convective condensate

$$RH < \frac{\overline{q_{t0}} - \overline{q_{cc}}}{\overline{q_w}}$$

limit cooling:

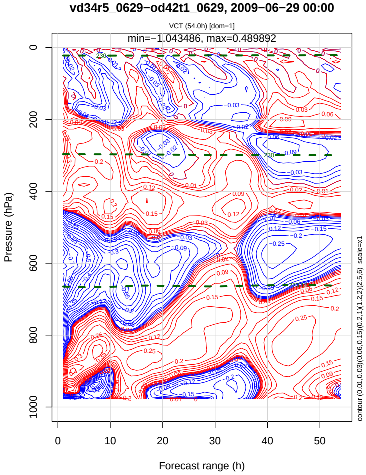
$$RH < RH_0 + \frac{c_p \triangle T_x}{L\overline{q_w}} g(N)$$

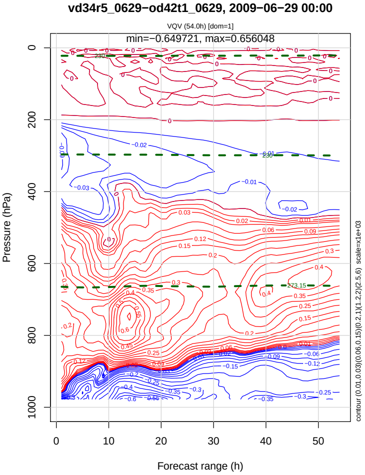
and heating:

$$RH > RH_0 - \frac{c_p \triangle T_x}{L\overline{q_w}} g(N)$$

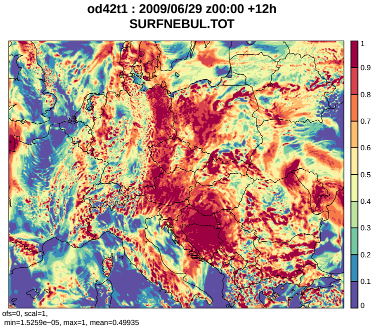
(shown $\triangle Tx = 40K/d$, $g(N) \equiv 1$)

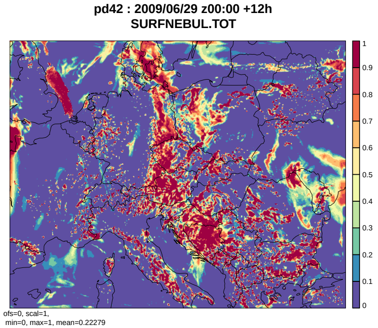
Progress ? DDH tendencies not yet close enough...





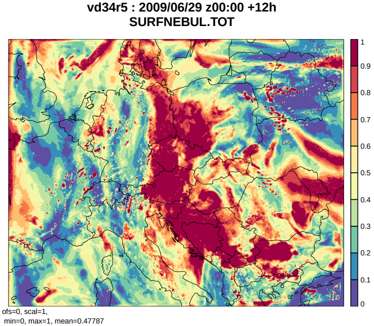
small $\triangle T_x \Rightarrow$ long spinup starting from null condensates
but larger $\triangle T_x$ may lead to excessive condensation, precipitation and evaporation.



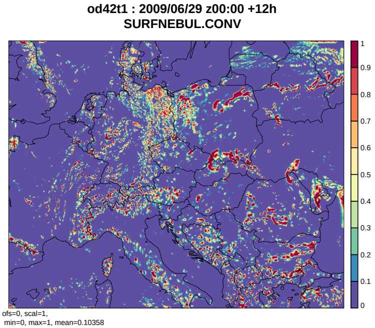


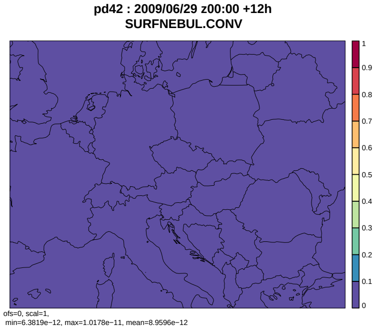
3MT Diag cloud

3MT μphys. cloud



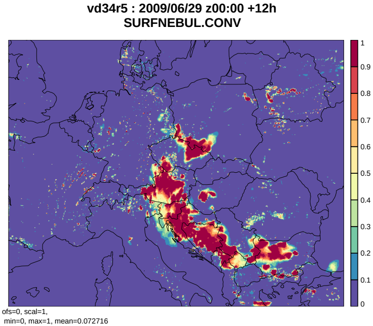
CSD+ unified cloud



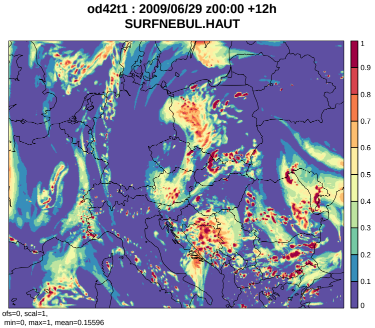


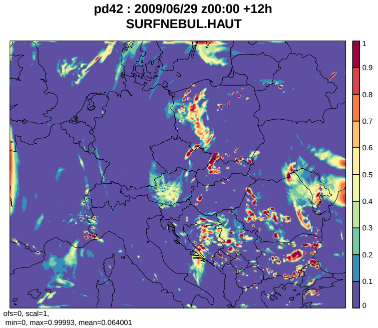
3MT Diag cloud

3MT μphys. cloud



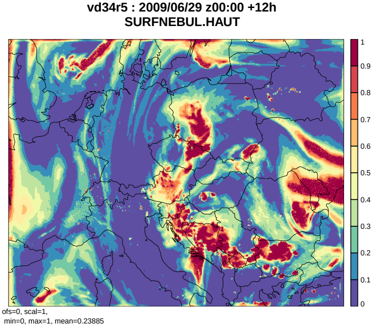
CSD+ unified cloud



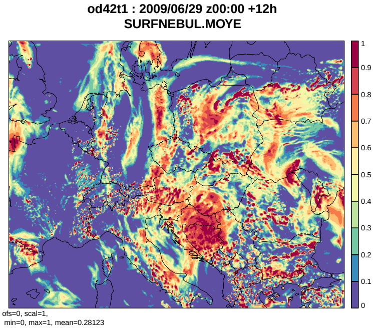


3MT Diag cloud

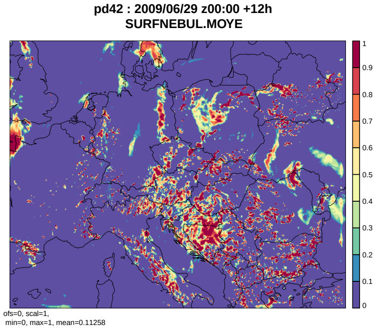
3MT μphys. cloud



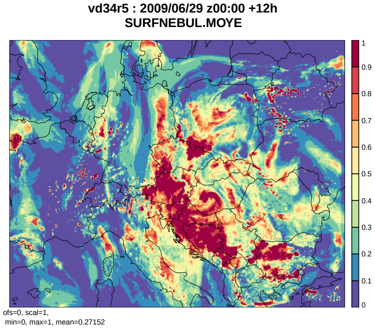
CSD+ unified cloud



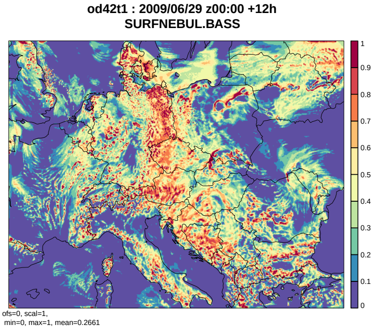
3MT Diag cloud

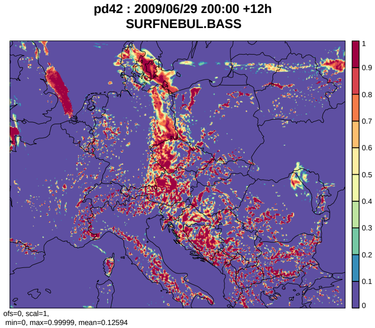


3MT μphys. cloud



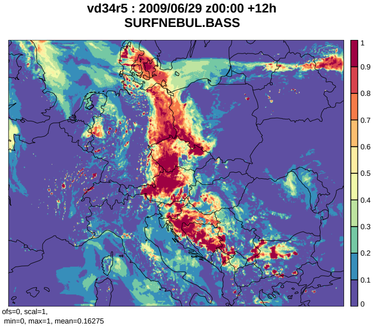
CSD+ unified cloud





3MT Diag cloud

3MT μphys. cloud



CSD+ unified cloud

And further on...

- Spinup problem, starting from zero condensates
- Tuning using CSD convection scheme (using initial 3MT as reference): means different split of condensation between convective and cloud cheme – test with 3MT planned.
- Tuning in parallel on winter and summer events.
- Control DDH components (T, q_v, q_c, q_r) and cloud aspect
- Multiple and complex feedbacks : e.g. more condensation $\Rightarrow$ heating but also increased rr $\Rightarrow$ more evaporative cooling and more downdraught activity, e.g. substantial surface cooling by subgrid transport.
- Most sensitive tunings are $\triangle Tx$, H_0 profile, parameters of autoconversion.