The non-saturated downdraught in Alaro-1

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RMI

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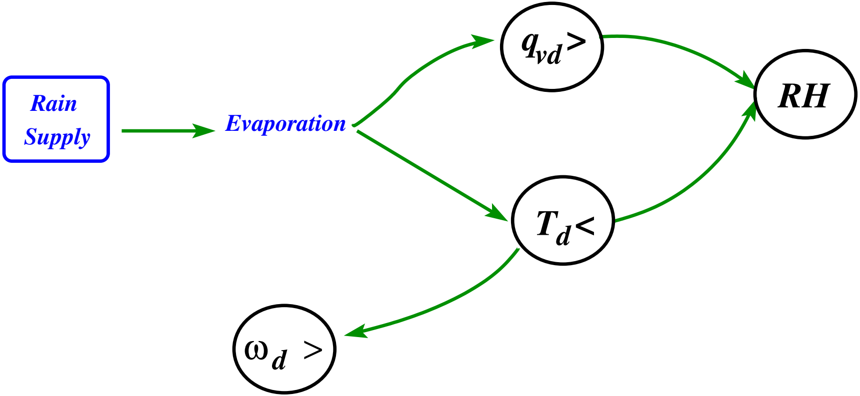
Why downdraught is subsaturated

Rain evaporation moistens and cools the downdraught parcel ⇒ negative buoyancy



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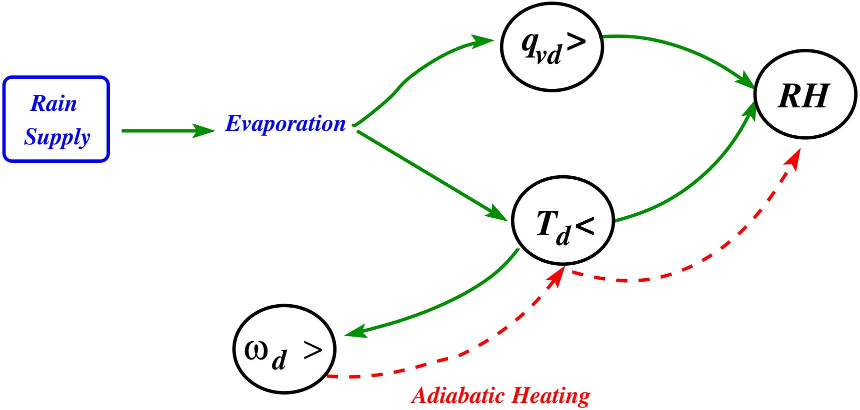

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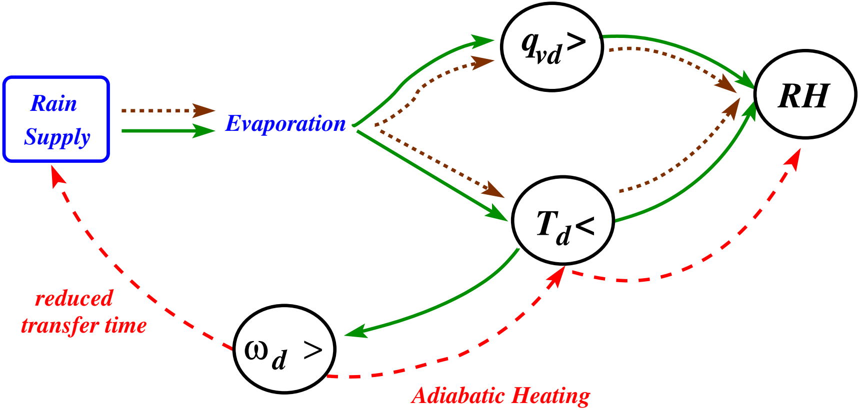

Starting point

- Süd and Walker (1993): around level of minimim θ_{eq} close to 650hPa, anyway below 500hPa: higher up, mostly driven by water loading, with $\Gamma_e \approx \Gamma_{\mathrm{adiab}}$.
- Start with saturated state $(\check{T}, \check{q}) = (\overline{T_w}, \overline{q_w})$ (environment blue point).

Unsaturated descent segments

- Betts and Silva Dias (1979): curve of constant θ_{eq} but unsaturated.
  $\Rightarrow$ const $\check{h}_* = \check{s}_* + L\check{q}_*$, $s = c_p T + \phi$ *(h^* not affected by de-saturation)*

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$$\Pi_e = \frac{\check{\omega}}{4\pi DF} = \frac{\check{\omega}}{\mathcal{F}(\mathcal{P})}, \qquad \mathcal{L}_e = \left[\frac{1}{\check{M}}\frac{d\check{M}}{dp}\right]^{-1}$$

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- prognostic velocity $\check{\omega}$: inertia $\leftrightarrow$ drag $\leftrightarrow$ buoyancy $\propto (\frac{1}{\check{T}_v} - \frac{1}{\overline{T_v}})$,

$$\check{T}_v = \check{T}(1 - q_r - q_s - \nu\check{q}), \qquad \overline{T_v} = \overline{T}(1 - \overline{q_c} - \nu\overline{q})$$

$$\boxed{\frac{1}{\check{T}_v} \approx \frac{(c\check{\omega} + d)}{(a\check{\omega} + b)},} \qquad a, b, c, d > 0$$

Water transport to the downdraft

$$\Pi_e = \frac{\breve{\omega}}{4\pi DF} = \frac{\breve{\omega}}{\mathcal{F}(\mathcal{P})}$$

Diffusion coefficient $D \approx 2 \cdot 10^{-5} m^2 s^{-1}$

$$F = \int_0^\infty n(r) C_v(r) r dr, \qquad n(r) = n_0 (2r)^\mu \exp(-2b\mathcal{P}^{-\beta} r),$$

$$C_v(r) = 1 + 0.22\sqrt{\mathcal{R}e}, \qquad \mathcal{R}e = \frac{2\rho r V}{\eta}, \qquad V \approx \sqrt{v_T^2(r) + u^2}$$

Increased ventilation in detrainment part: $u \sim -\frac{r_d}{2}\frac{\triangle\omega_d}{\triangle p}$

Fitting a curve, gddfp[1:3]=(k_{F1}, β_F, k_{F2}):

$$\mathcal{F}(\mathcal{P}) = k_F \mathcal{P}^{\beta_F}, \qquad k_F = k_{F0}\left(1 + k_{F1}\sqrt{-\frac{\triangle\omega_d}{\triangle p}}\right)$$

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  + account for precipitation inhomogeneity: gddinhom
  cooling by evaporation and melting computed in microphysics is larger at downdraught location than in the rest of $\sigma_{\mathcal{P}}$

$$\delta T_d = G \delta T_e = \frac{G}{1+\sigma_d(G-1)} \left[-\frac{g \triangle t}{c_p} \frac{\triangle F_{h\mathcal{P}}}{\triangle p} \right], \qquad G = G_0(1-\sigma_d)+1$$

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- Prognostic vertical velocity ω_d computed together with the descent (3rd degree equation) (tentrd, tddfr, gddalbu).
  Braking towards surface (gddbeta, gdddp).

$$\frac{\partial \check{\omega}}{\partial t} = -k(\Lambda_w + k\frac{\text{gdddp}}{(p_s - p^l)^{\beta}})\check{\omega}^2 - (\check{\omega} - \overline{\omega})\frac{\partial \check{\omega}}{\partial p} - \frac{\alpha_b g^2}{R_a} p(\frac{1}{\overline{\overline{T_v}}} - \frac{(c\check{\omega} + d)}{(a\check{\omega} + b)})$$

$$k \sim 1 - \frac{\overline{\omega}}{\check{\omega}}, \qquad \Lambda_w = \frac{1}{\triangle p}\Big[\frac{-\triangle \phi}{k}(\lambda_d + \frac{\mathcal{K}_{dd}}{g}) + \delta_{oe}(\frac{\triangle \check{\omega}}{\check{\omega}} + \frac{\triangle k}{k})\Big]$$

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- Compatibility with CSD approach when $\overline{\omega} > 0$ (lcddcsd=T): $k < 1$.

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  $\kappa =$ gddfrac ~ 0.02
- Along the descent, estimate maximum viable fraction σ_{dx}^l for evaporating
  - less than $\frac{1}{3}$ of remaining precipitation flux when in the higher part,
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- maintain $\sigma_{d0}^l \leq \sigma_{dx}^l \Rightarrow (\sigma_{d0}, \sigma_{dx})$ at bottom
  - precipitation never exhausted
  - single downdraught along the vertical, no restart
  - final σ_{d0}, σ_{dx} obtained at bottom

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- maintain $\sigma_{d0}^l \leq \sigma_{dx}^l \Rightarrow (\sigma_{d0}, \sigma_{dx})$ at bottom
- Evolution by relaxation: $\sigma_{d1} = \sigma_{d0} e^{\frac{-\triangle t}{\tau_d}} + \sigma_{dx}(1 - e^{\frac{-\triangle t}{\tau_d}})$

$$\tau_d = \begin{cases} \text{gddtausig} & \\ |\text{gddtausig}| \cdot (1 - \sigma_{d9}) & \text{if gddtausig} < 0 \\ |\text{gddtausig}| \cdot [1 - \min(0.99, \frac{\mathcal{P}_{\text{surf}}}{|\text{gddwpf}|})] & \text{if gddwpf} < 0 \end{cases}$$

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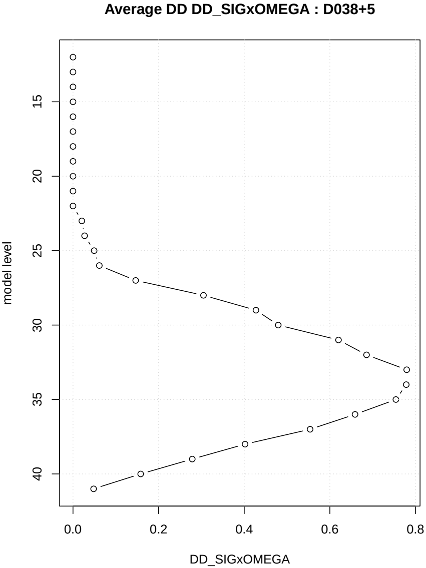
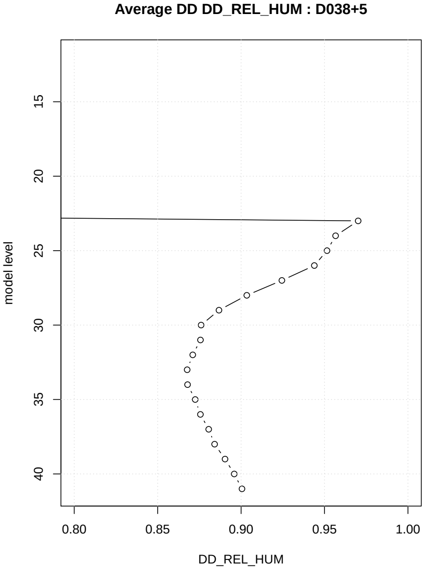
- σ_{d1} copied at all active levels for advection by model wind

Example mean vertical profiles

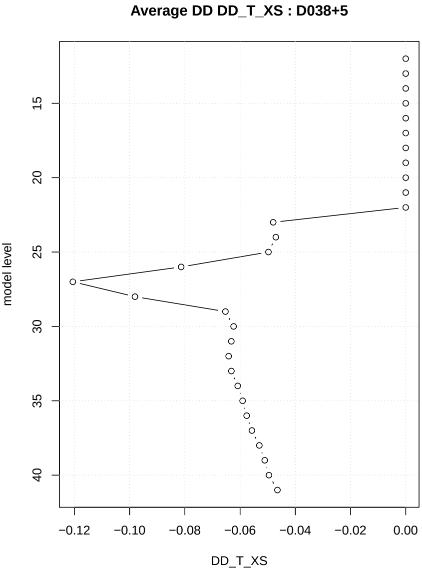
Mass flux and relative humidity

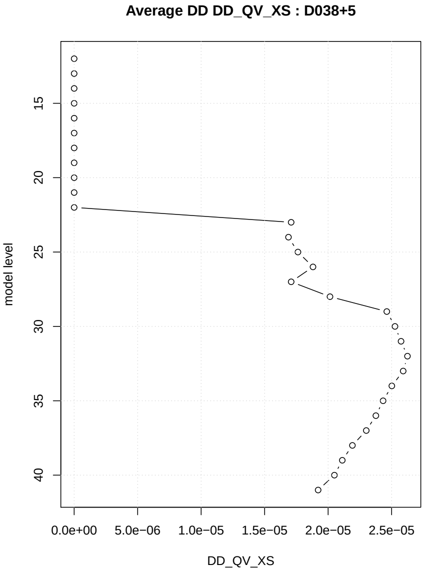




Example mean vertical profiles

Additional cooling/moistening by inhomogeneity

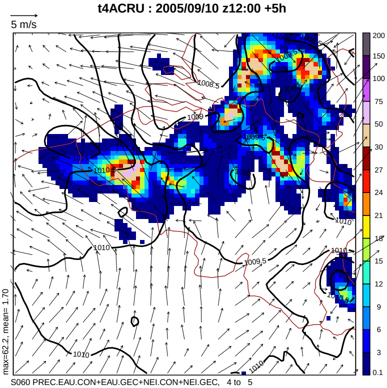


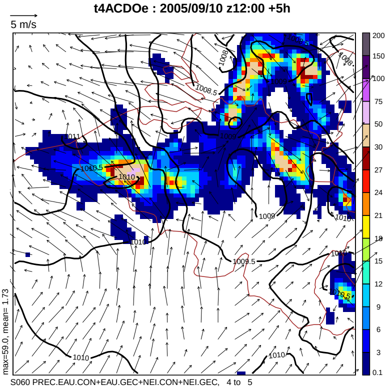


Comparison with Saturated downdraught

The downdraught activity is now localized at places with precipitation;
it yields a smaller domain-averaged evaporation

...but not only that (see further).





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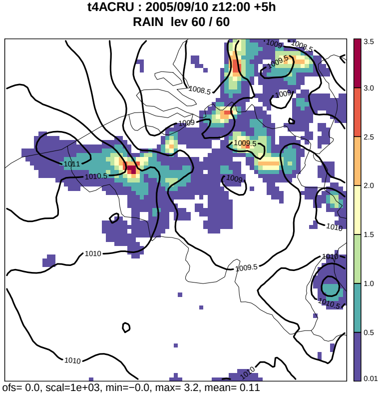

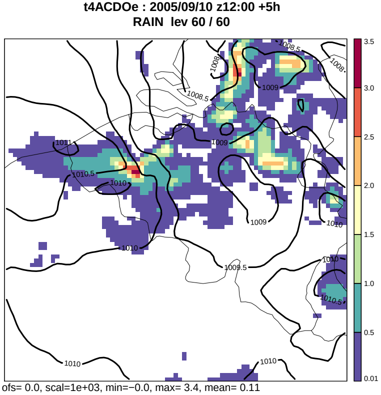

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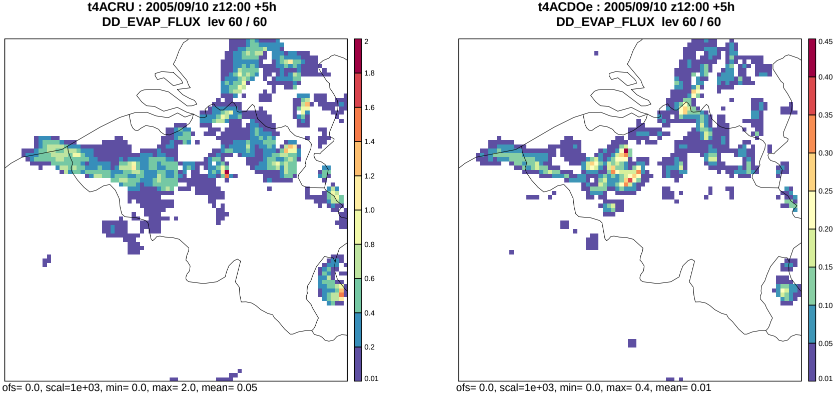
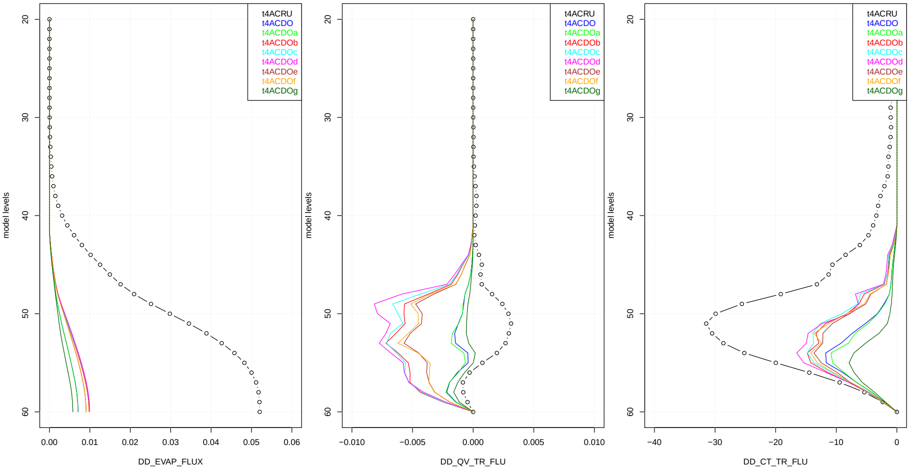


Sensitivity tests

- turbulent mixing tentrd
- drag coefficient tddfr
- braking towards surface gddbeta$\sim$2, gddalbu$\sim 3E4$
- evolution/inertia of mesh fraction gddtausig: 1800s reduced down to 1% by intense precipitation

	tentrd	tddfr	saturated
ACRU	16E-5	12E-4	yes
ACDO	12E-5	16E-4	no
ACDOa	12E-5	24E-4	no
ACDOb	12E-6	16E-4	no
ACDOc	12E-6	12E-4	no
ACDOd	12E-6	4E-4	no
ACDOe	40E-6	4E-4	no
ACDOf	40E-6	2E-4	no
ACDOg	24E-5	24E-4	no

Domain-averaged profiles



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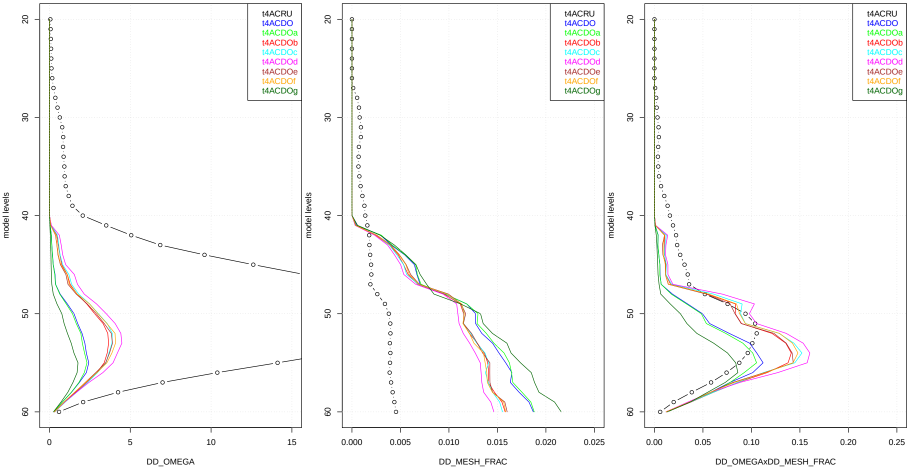

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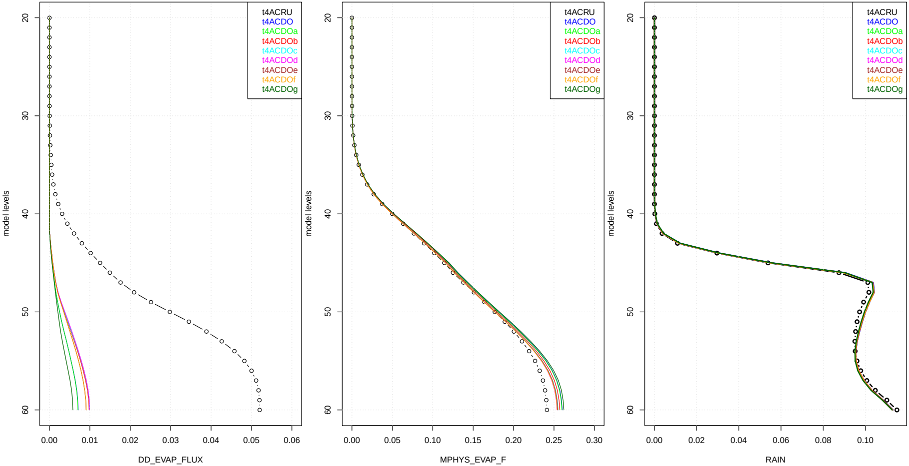
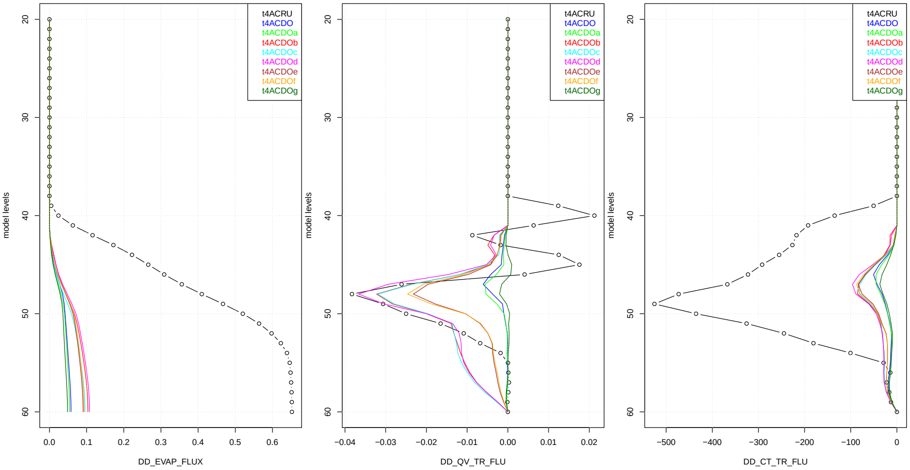


Profile at location of maximum surface rain



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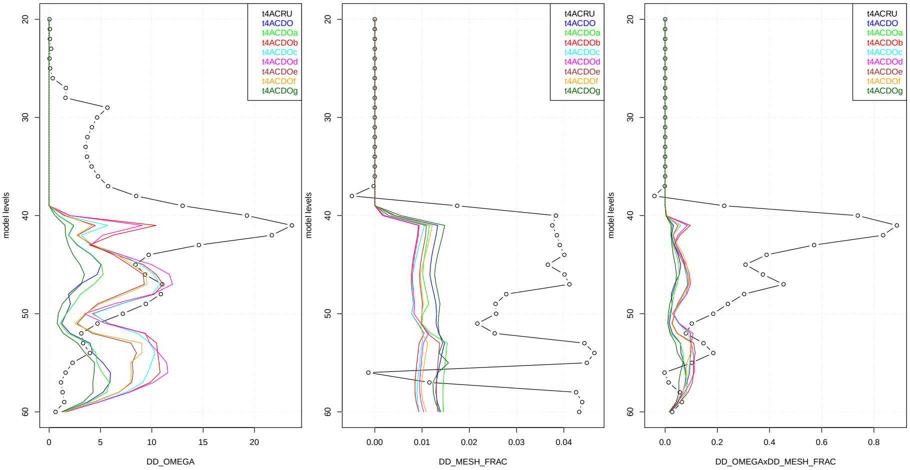

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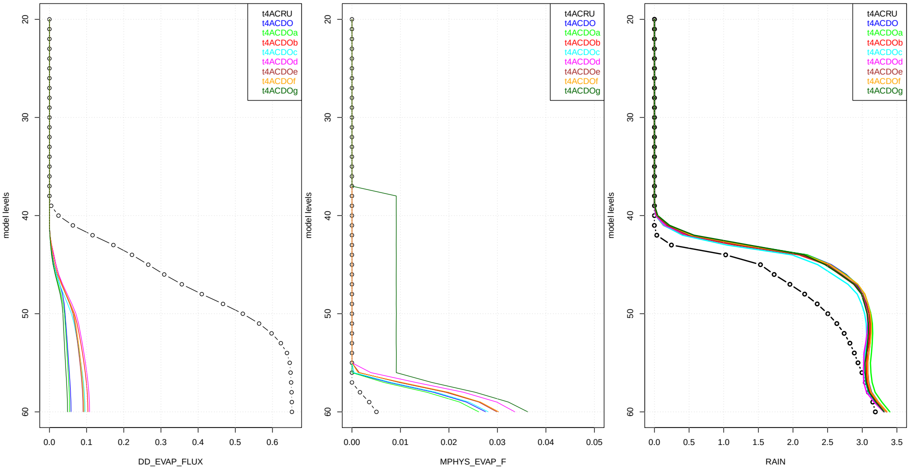

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  - due to more feedbacks tha in saturated version, not straightforward to foresee the effect on one tuning on the evaporation
  - Multiple feedbacks in Alaro-1, how to choose at which level a problem has to be addressed: cloud scheme (critical humidity profile), microphysics (auto-conversion), radiation (incl. radiative cloud and condensates), updraught, downdraught ?

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- Uncertainties:
  - formulation of water transfer: different values of the constants in the litterature (but small impact)
  - ignoring microphysical effects
  - no local radiative effects
  - 'inertia' (gddtausig) and the closure method:
    what does actually determine the downdraught area ?