Unsaturated downdraft in Alaro-1

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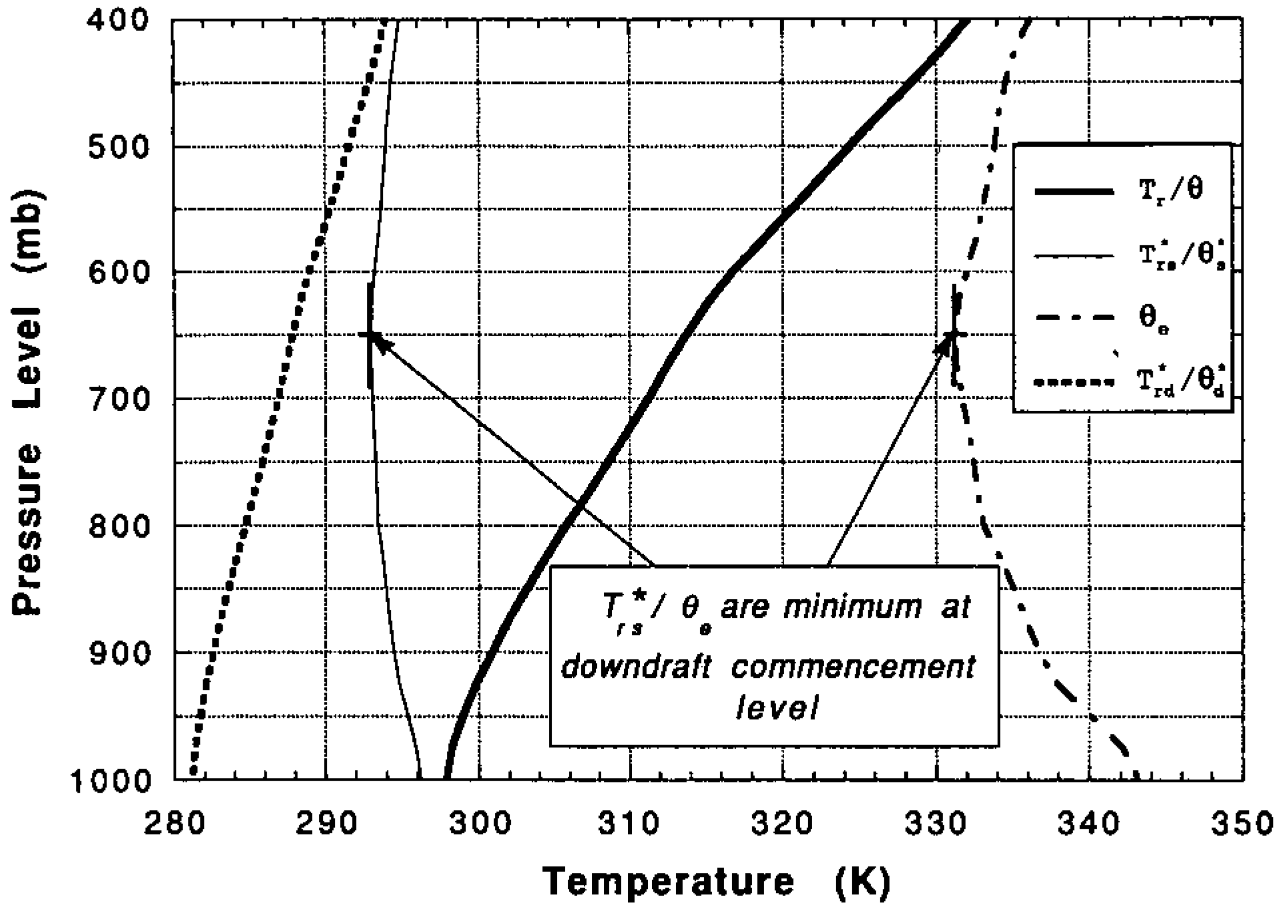
13 June 2012

Which downdraft

Knupp & Cotton 1985:

- Penetrative downdraft (non precipitating convection, width $<$1km, depth $\sim$ 500m to 5km, w$\sim$ 1-15 m/s)
- Cloud-edge downdraft (width $<$ 5km, depth $\sim$ 1-5 km, w$<$5m/s)
- Overshooting downdraft (cloud top, width $\sim$ 500m to 5km, depth $\sim$ 1 to 3km, w $\sim$ 1-40 m/s))
- Precipitation-driven downdraft (Low level, width $\sim$ 1 to 10 km, depth $\sim$ 1-5 km , w$<$15 to 20 m/s).

From where and how much ?



(GATE, time and space mean)

$$T_r = \frac{s}{c_p} = T + \frac{\phi - \phi_{\rm surf}}{c_p}$$

$$T^*_{rd} = T_{wd} + \frac{\phi - \phi_{\rm surf}}{c_p}$$

(assuming dry air)

$$T^*_{rs} = T_w + \frac{\phi - \phi_{\rm surf}}{c_p}$$

Sud and Walker 1993:
level of minimum θ_e close to 650hPa.

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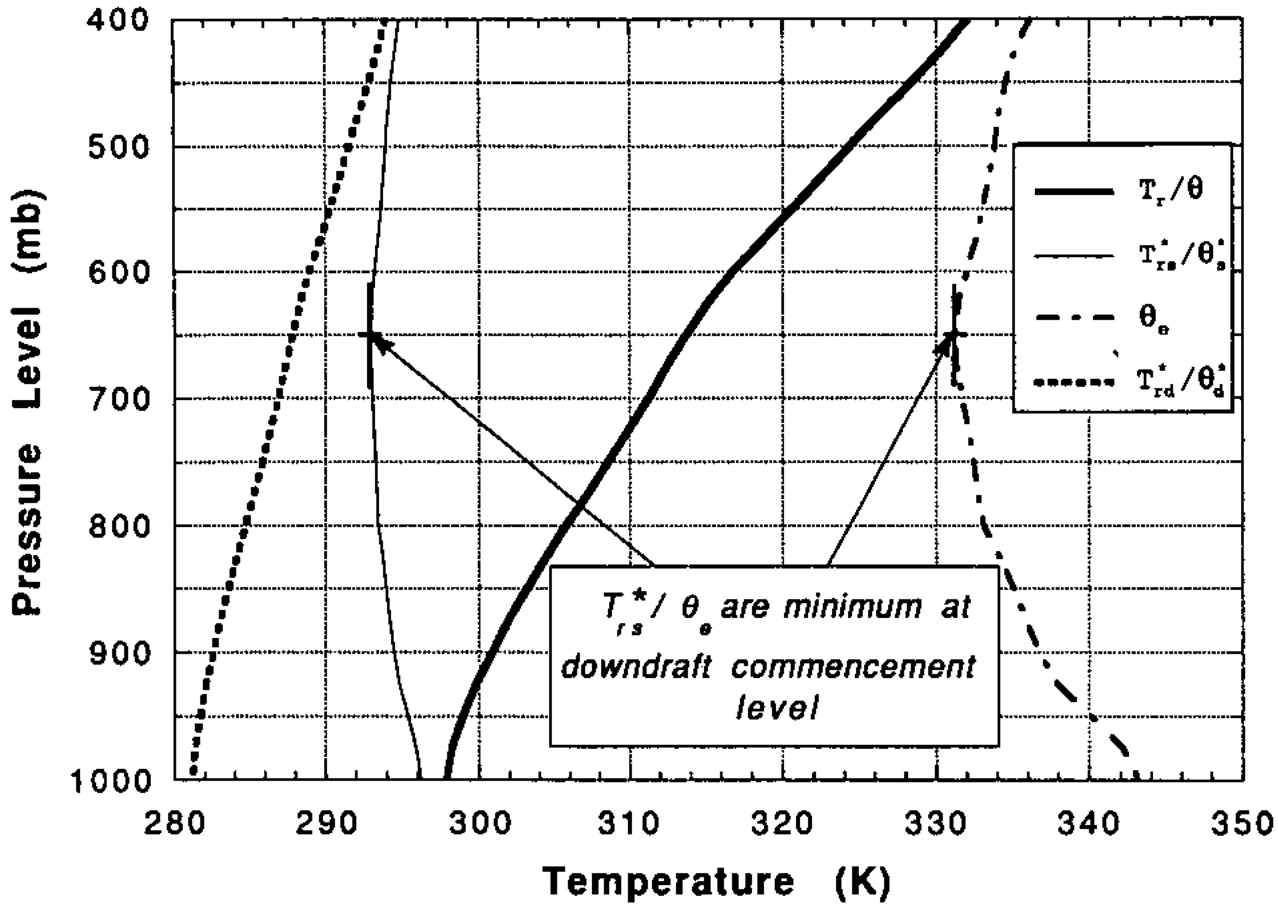

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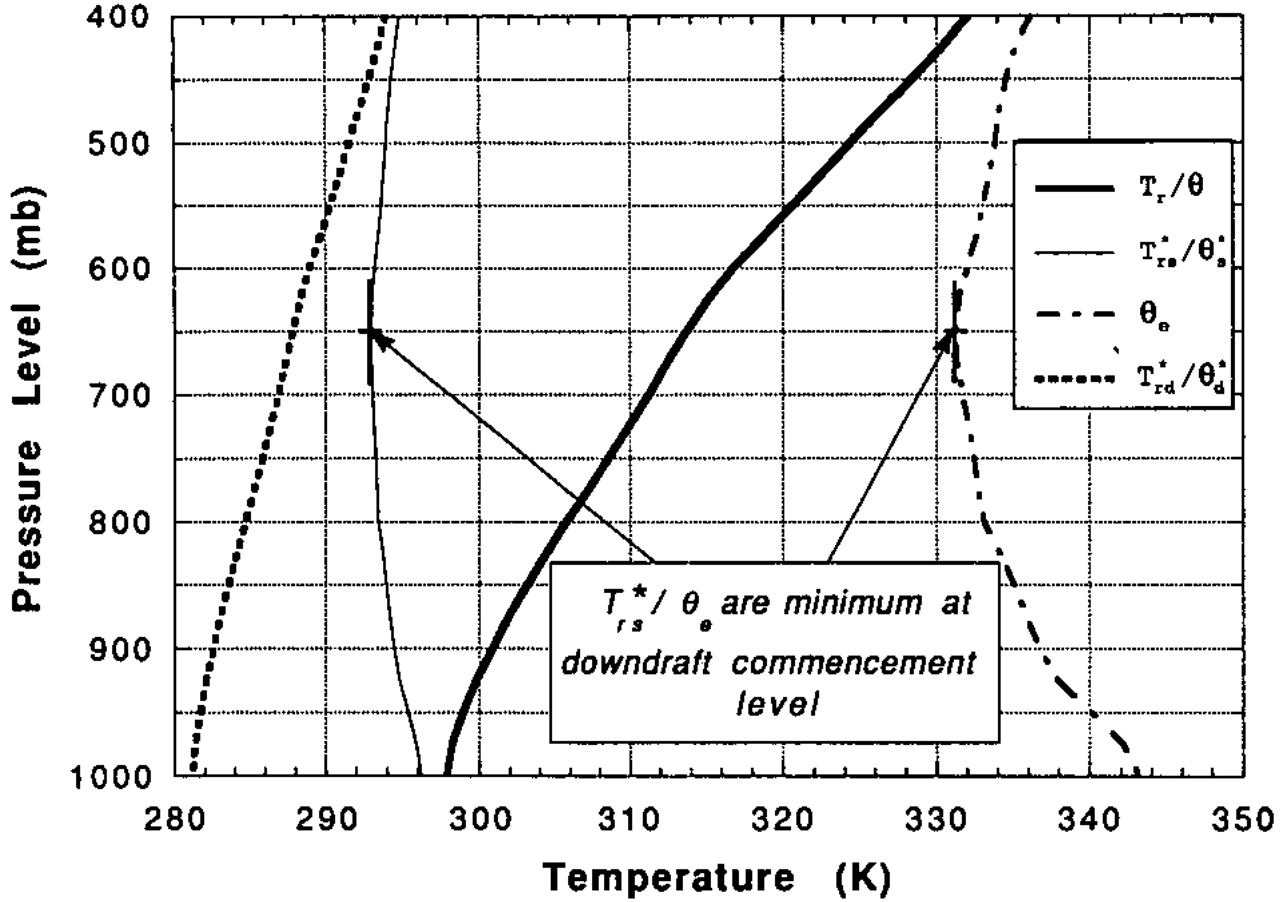

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- no dd in dry stable envt
- higher moisture below helps to produce negative buoyancy in dd

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Subsaturation

Downdraft are usually appreciably subsaturated:

1. transport of condensate to be entrained and evaporated by the downdraft $\rightarrow$ dependency to number/size of droplets or drops (especially in penetrative downdrafts)

2. cooling rate (evap $+$ melting) $<$ adiabatic warming rate.
   Balance:
   - negative buoyancy increases downwards velocity
   - greater velocity
     - reduces residence time
     - increases the adiabatic warming rate

Precipitation-driven downdraft parametrization

Betts and Silva Dias 1979

ψ_d follows a path of constant θ_e while remaining unsaturated.

$$\frac{dq_d}{dp} = \frac{q_w - q_d}{\Pi_E} + \frac{q_e - q_d}{\mathcal{L}_e}, \qquad \Pi_e = \frac{\rho g w_d}{4\pi DF}, \qquad \frac{1}{\mathcal{L}_e} = \frac{1}{M_d}\frac{dM_d}{dp}\Big|_e = \frac{\lambda_d d\phi}{dp}$$

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Diffusion coefficient $D(T_w, p) \approx 2.E - 5m^2 s^{-1}$

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

$$C_v(r) = 1 + cr^{3/4} \qquad \text{(ventilation coefficient)}$$

$\mathcal{P}$=rainfall rate, r=droplet radius, μ(conv|strat) taken ~ 0

$$F(\mathcal{P}) \approx a_1 \mathcal{P}^{e_1} + a_2 \mathcal{P}^{e_2}, \qquad \underset{[l-1 \to l]}{2\Pi_E} \approx \frac{\alpha}{\mathcal{P}^{3/4} \triangle p} \widetilde{\omega_d} \triangle p = k^{\overline{l-1}} \widetilde{\omega}^{\overline{l-1}} \triangle p^{\overline{l-1}}$$

Downdraft properties

$$q_d^l = \frac{q_d^{l-1} + (q_w^{l-1} - q_d^{l-1} + q_w^l)\frac{\triangle p^{\overline{l-1}}}{2\Pi_E} + (q_e^{l-1} - q_d^{l-1} + q_e^l)\frac{\xi^{\overline{l-1}}}{2}}{1 + \frac{\triangle p^{\overline{l-1}}}{2\Pi_E} + \frac{\xi^{\overline{l-1}}}{2}} = \frac{m\,\widetilde{\omega_d} + n}{c'\,\widetilde{\omega_d} + 1}$$

$$T_d^l = \ldots = \frac{a'\,\widetilde{\omega_d} + b'}{c'\,\widetilde{\omega_d} + 1}$$

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$$\frac{1}{T_{vd}} \approx \frac{1}{T_d(1+\nu q_d)} \approx \frac{(c'\,\widetilde{\omega_d} + 1)}{(a'\,\widetilde{\omega_d} + b')} \cdot \left\{ \frac{(c'\,\widetilde{\omega_{d0}} + 1)}{[(c' + \nu m)\,\widetilde{\omega_{d0}} + (1 + \nu n)]} \right\}$$

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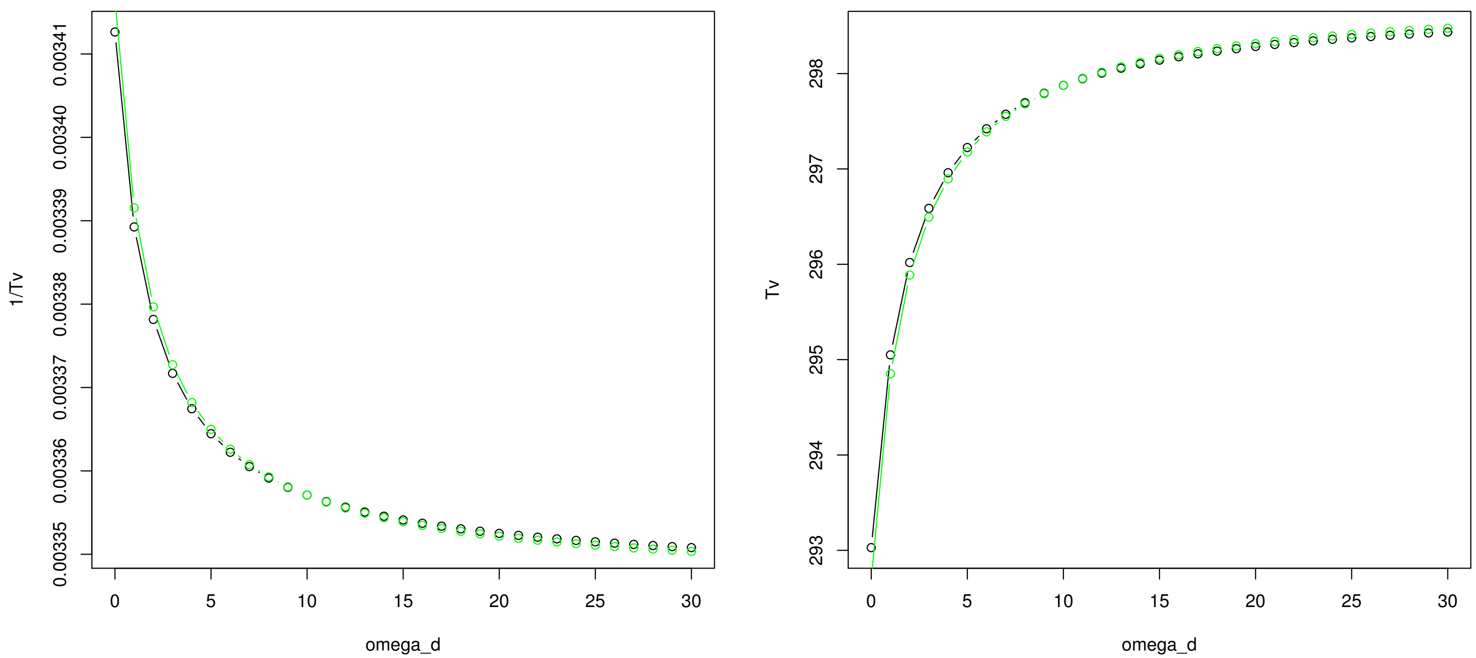

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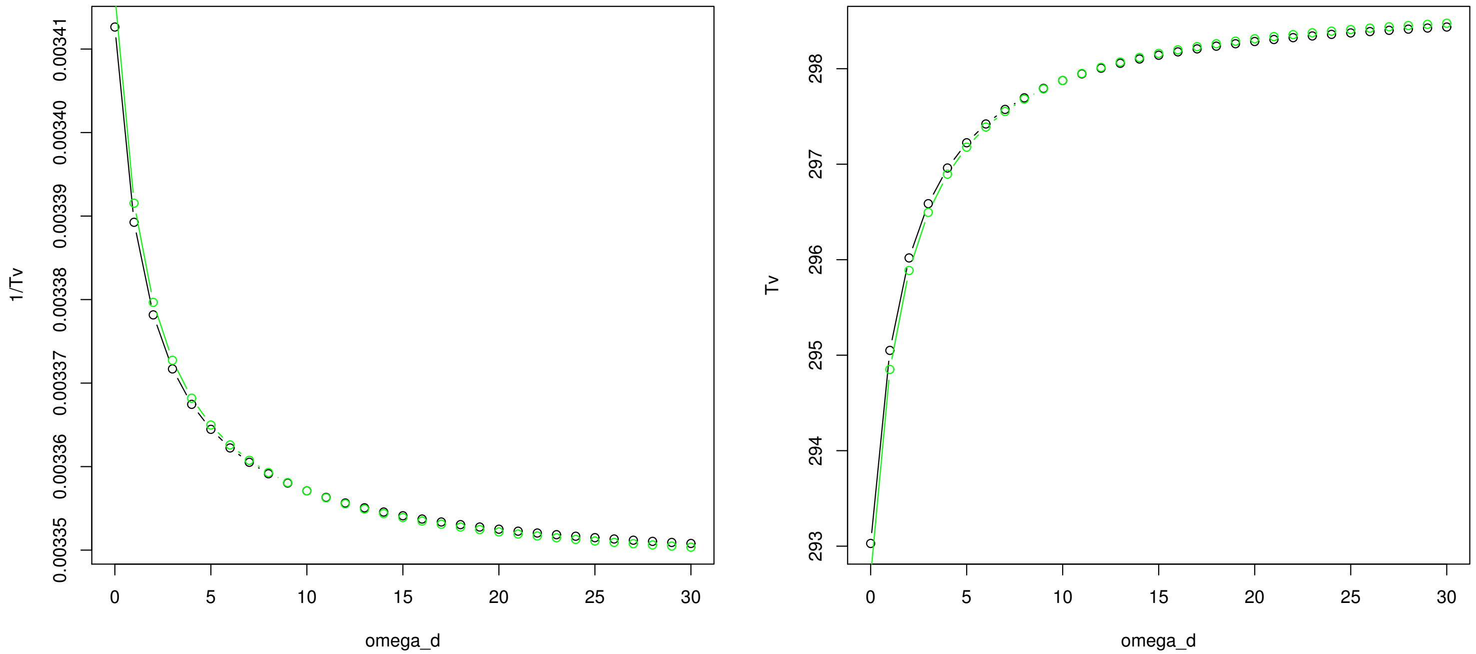

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$$\approx \frac{(c\,\widetilde{\omega_d}+d)}{(a\,\widetilde{\omega_d}+b)}$$

Vertical velocity equation

$$\frac{\partial \omega_d^\diamond}{\partial t} = -D{\omega_d^\diamond}^2 - \omega_d^\diamond\Big(\frac{\partial \omega_d^\diamond}{\partial p} + \frac{\partial \overline{\omega}}{\partial p}\Big) + \frac{g^2 p}{2R_a}\Big[\frac{(c\omega_d^\diamond + d)}{(a\omega_d^\diamond + b)} - \frac{1}{\overline{\overline{T_v}}}\Big]$$

D: drag, $\ni$ entrainment, friction, surface ∇p

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$$\alpha(F_{n+1}^{\overline{l-1}})^3 + \beta(F_{n+1}^{\overline{l-1}})^2 + \gamma(F_{n+1}^{\overline{l-1}}) + \delta = 0, \qquad F_n^{\bar{l}} = \frac{\omega_d^{\diamond l} + \omega_d^{\diamond l+1}}{2} \text{ at time n}$$

Up to 3 analytical solutions (Tartaglia-Cardano)

$\Rightarrow$ retain the smallest non negative one.

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$$D^l = \frac{1}{2(1-\sigma_d^l)^2}\left[\frac{R_a T_{vd}^l}{p^l}\Big(\underbrace{\lambda_d^l}_{\text{TENTRD}} + \underbrace{\frac{1}{g}}_{\text{TDDFR}}\mathcal{K}_{dd}\Big) + \frac{\text{GDDDP}}{(p^{\overline{L}} - p^l)^{\text{GDDBETA}}}\right]$$

Descent computation

- Saturated entraining moist adiabat: mixed $\psi_b \to \psi_n$

$$T_b^{l-1} = \psi_n^{l-1} + \xi^{\overline{l-1}}(\overline{T_w}^{l-1} - T_n^{l-1})$$

- parallel computation of

$$\alpha\widetilde{\omega_d}^3 + \beta\widetilde{\omega_d}^2 + \gamma\widetilde{\omega_d} + \delta = 0, \qquad q_d^l = \frac{m\,\widetilde{\omega_d} + n}{c'\,\widetilde{\omega_d} + 1}, \qquad T_d^l = \frac{a'\,\widetilde{\omega_d} + b'}{c'\,\widetilde{\omega_d} + 1}$$

- Control arrival level:
- not saturated
- remaining precipitation
- $k\widetilde{\omega_d} > 1.E - 12$

$$\delta q_{ev}^{\overline{l-1}} = \frac{q_w - q_d}{\Pi_e} \triangle p^{\overline{l-1}}$$

Closure: mesh fraction

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- rain evaporation efficiency η depends on mean mass M, N_0 (number), residence time $\triangle t = \triangle z/w$;
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α_i	0.52	0.34	0.09	0.04	0.01
I_d	0	0.40	2.6	11.25	18
%	0	23.6	23.4	45	18

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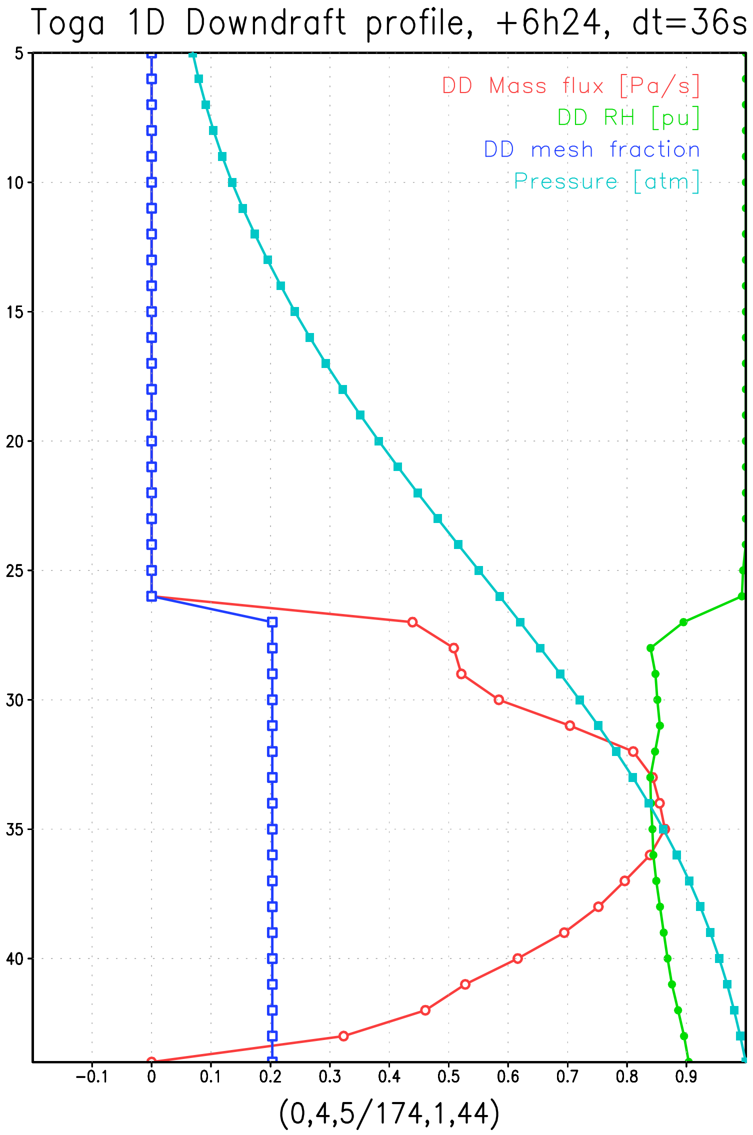
maybe $\sigma_{\mathcal{P}}$ presently quite crudely estimated

1-D model profiles



Downdraft effect on updraft closure

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CAPE is affected by

- resolved and subgrid convergence
- resolved and subgrid precipitation
- radiative transfers
- deep convective updraft
- boundary layer transfers
- downdraft
- ...

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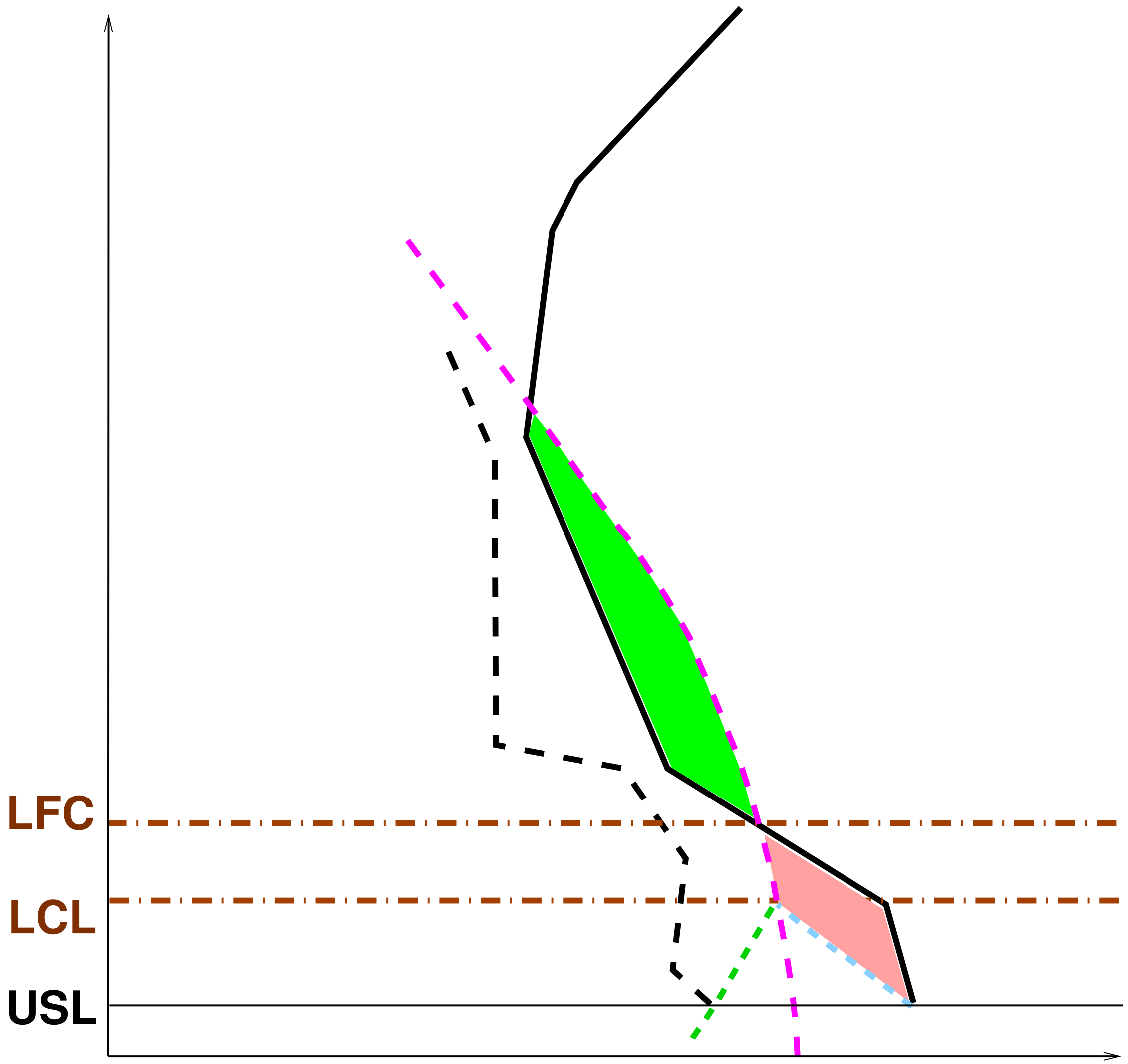
$\Rightarrow$ it could be seen as a *subjective choice* to include or not the effect of downdraft on CAPE in the updraft parameterization itself.

Downdraft effect on updraft closure

Main effect of downdraft is cooling and moistening USL



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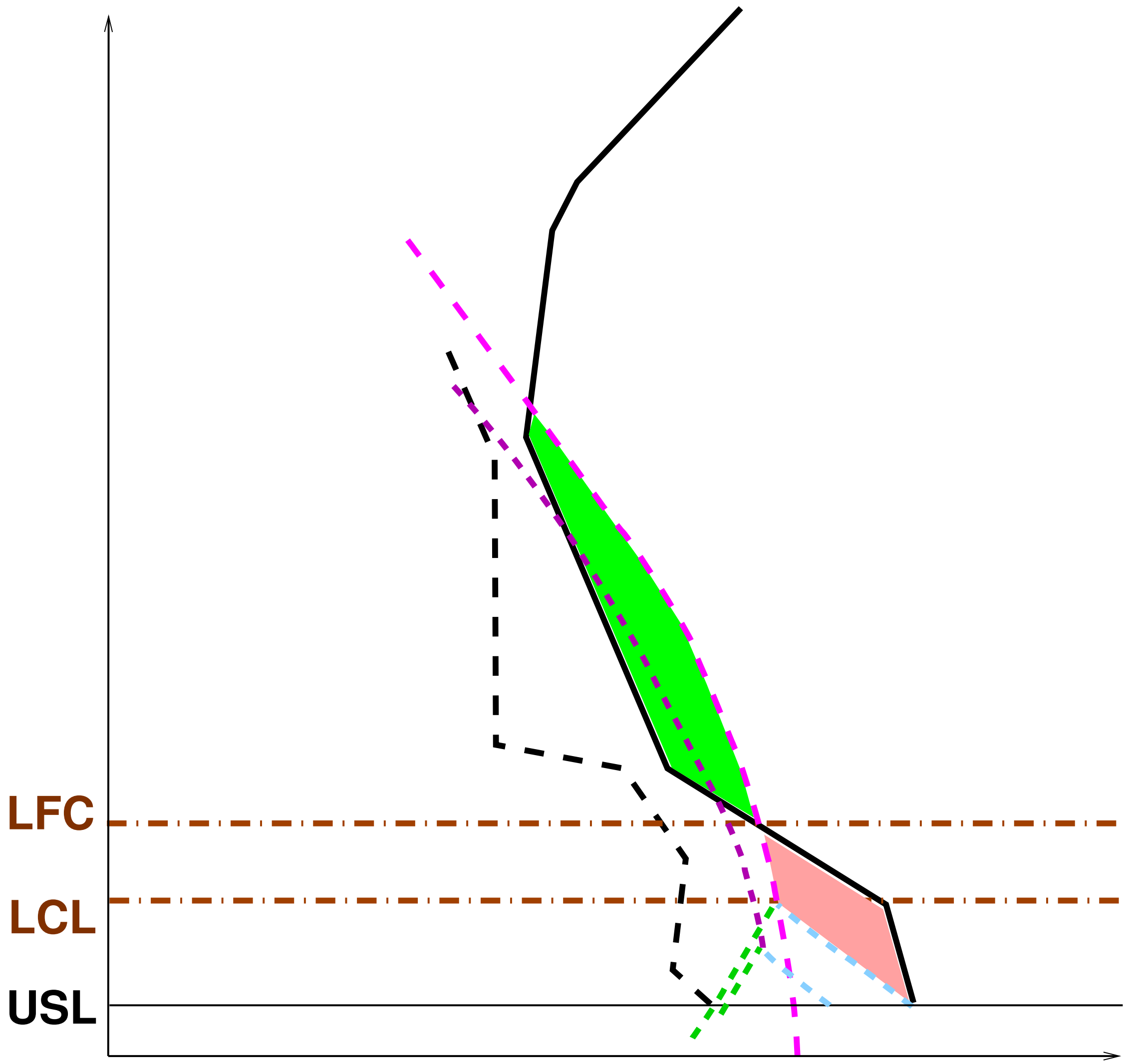

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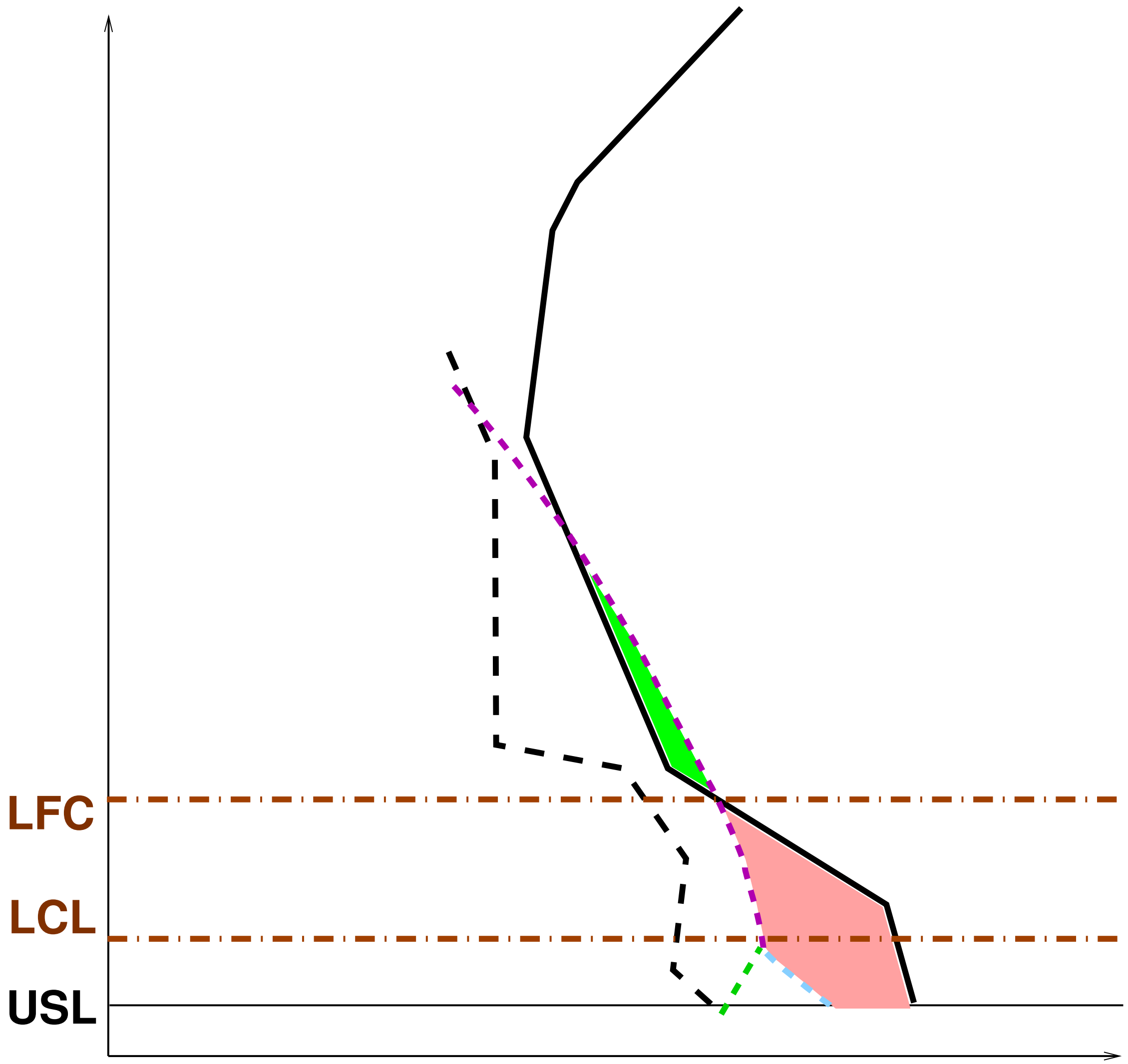

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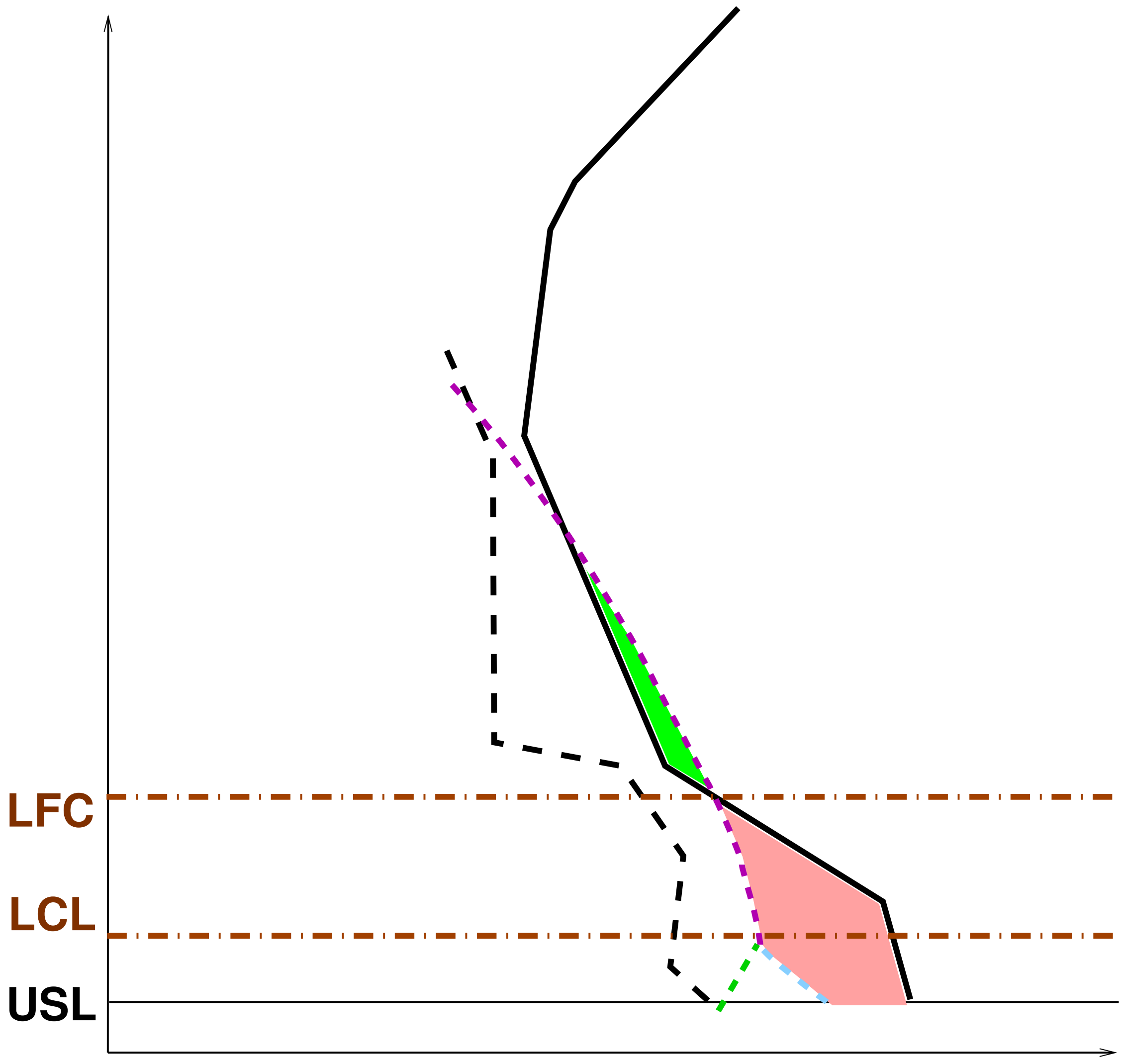

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RMI

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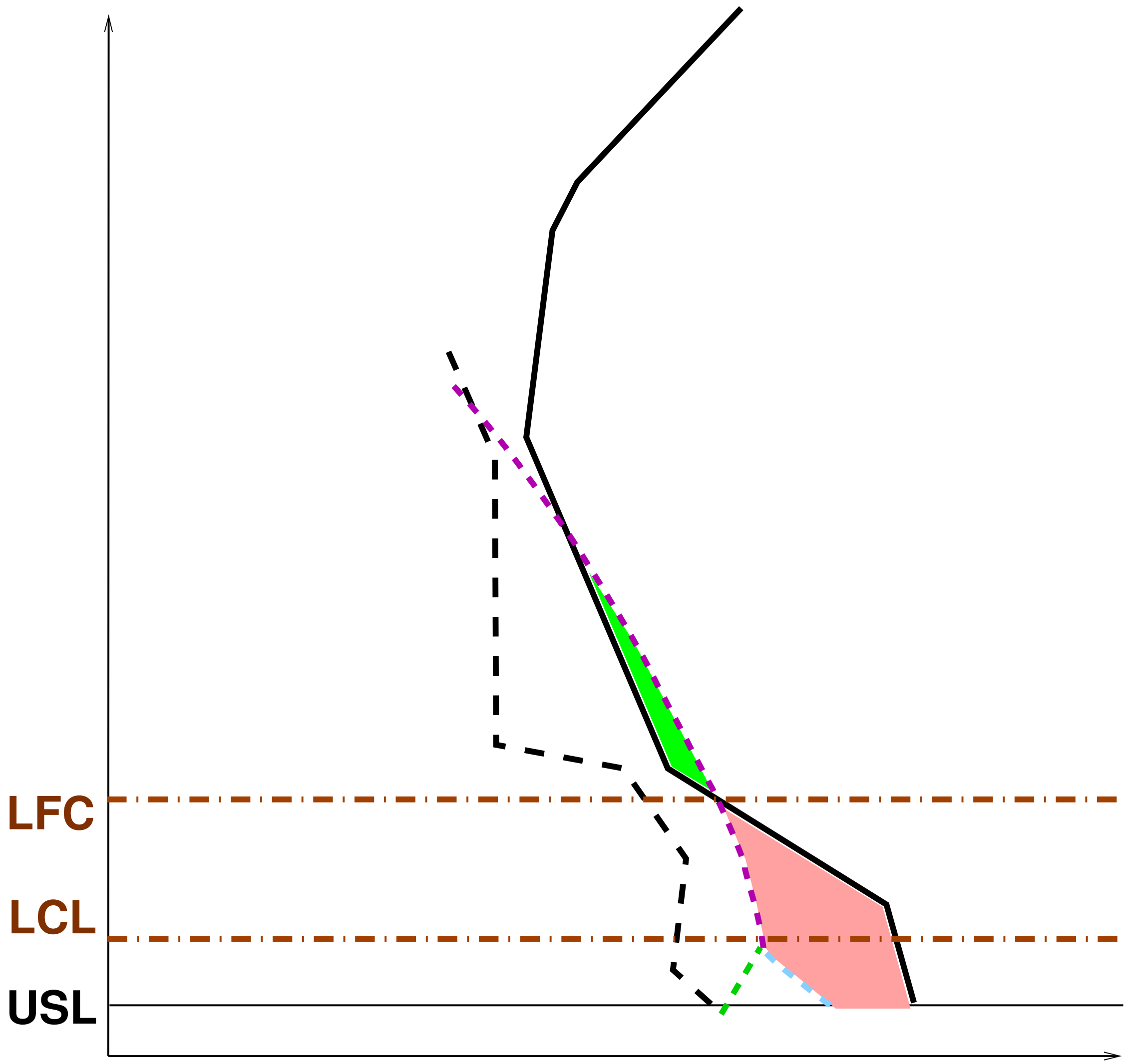

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$$\left.\frac{\partial \text{CAPE}}{\partial t}\right|_{dd} \approx -R_a \int_b^t \left.\frac{\partial (T_{vu} - \overline{T_v})}{\partial t}\right|_{dd} \frac{dp}{p}$$

Downdraft effect on updraft closure

M_d^* advected from previous time step

$$\left.\frac{\partial \overline{T}^{\mathrm{USL}}}{\partial t}\right|_{dd} \approx -\frac{\sum\limits_{uslb}^{uslt} M_d^* \frac{1}{cp} \frac{\partial \overline{s}}{\partial p} \triangle p}{\triangle p^{mix}}, \qquad \left.\frac{\partial \overline{q}^{\mathrm{USL}}}{\partial t}\right|_{dd} \approx -\frac{\sum\limits_{uslb}^{uslt} M_d^* \frac{\partial \overline{q}}{\partial p} \triangle p}{\triangle p^{mix}}, \qquad \left.\frac{\partial p^{USL}}{\partial t}\right|_{dd} \sim 0$$

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Bolton (1980)

$$T^{\mathrm{LCL}} = \frac{2840}{3.5\ln T^{\mathrm{USL}} - \ln\frac{e^{\mathrm{USL}}}{100} - 4.805} + 55., \qquad e^{\mathrm{USL}} = \frac{q^{\mathrm{USL}}}{q^{\mathrm{USL}} + \frac{R_a}{R_v}(1 - q^{\mathrm{USL}})} p^{\mathrm{USL}}$$

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Assume a constant $\triangle\theta_{vu}$ along the updraft

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Bolton (1980)

$$T^{\rm LCL} = \frac{2840}{3.5 \ln T^{\rm USL} - \ln \frac{e^{\rm USL}}{100} - 4.805} + 55., \qquad e^{\rm USL} = \frac{q^{\rm USL}}{q^{\rm USL} + \frac{R_a}{R_v}(1-q^{\rm USL})} p^{\rm USL}$$

$$\Rightarrow \frac{\partial T^{\rm LCL}}{\partial t} = -\frac{(T^{\rm LCL}-55)^2}{2840}\Big[\frac{3.5}{T^{\rm USL}}\frac{\partial T^{\rm USL}}{\partial t} - \frac{1}{q^{\rm USL}}\frac{\partial q^{\rm USL}}{\partial t}\frac{R_a}{R_a + q^{\rm USL}(R_v - R_a)}\Big] \quad < 0,$$

$$\frac{\partial q^{\rm LCL}}{\partial t} \approx \frac{\partial \overline{q}^{\rm USL}}{\partial t} \quad > 0, \qquad \frac{\partial p^{LCL}}{\partial t} = p^{\rm LCL}\frac{c_{pa}}{R_a}\Big(\frac{1}{T^{\rm LCL}}\frac{\partial T^{\rm LCL}}{\partial t} - \frac{1}{T^{\rm USL}}\frac{\partial T^{\rm USL}}{\partial t}\Big)$$

Assume a constant $\triangle\theta_{vu}$ along the updraft

$$\frac{\partial T_{vu} - \overline{T_v}}{\partial t}\Big|_{dd} = \frac{\partial T^{LCL}}{\partial t}\Big|_{dd}(1+\kappa q_u) + \frac{\partial q^{LCL}}{\partial t}\Big|_{dd}\kappa T_u - \frac{1}{c_p}M_d^*\frac{\partial \overline{s}}{\partial p}(1+\kappa q_u) + M_d^*\frac{\partial \overline{q}}{\partial p}\kappa T_u$$

RMI

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- Tuning parameters:
  - gddevf : $\sigma_d/\sigma_\mathcal{P}$ (0.33)
  - tentrd : entrainment rate (1.E-4), tddfr : drag (6.E-4, def)
  - gddbeta=5., gdddp =8.E15 : braking applied to ω_d towards the surface.
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- Profiles are realistic, further tuning should be based on model scores.

- Possible re-tuning of hard-coded constants.

- Further refinements: better estimation of $\sigma_\mathcal{P}$