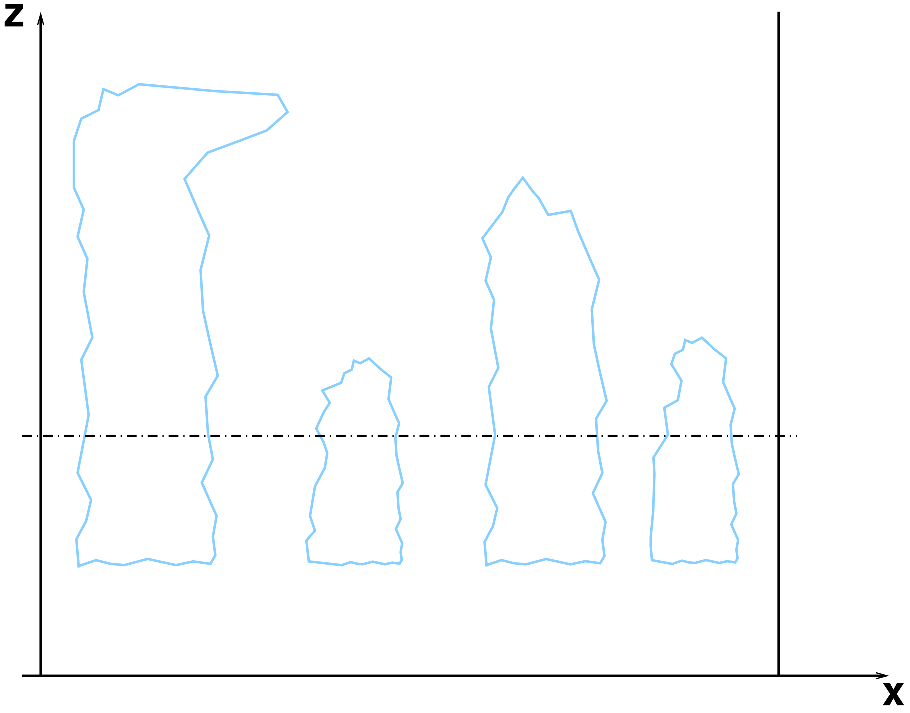
RMI

Geometrical aspects of sub-grid convective condensation and precipitation

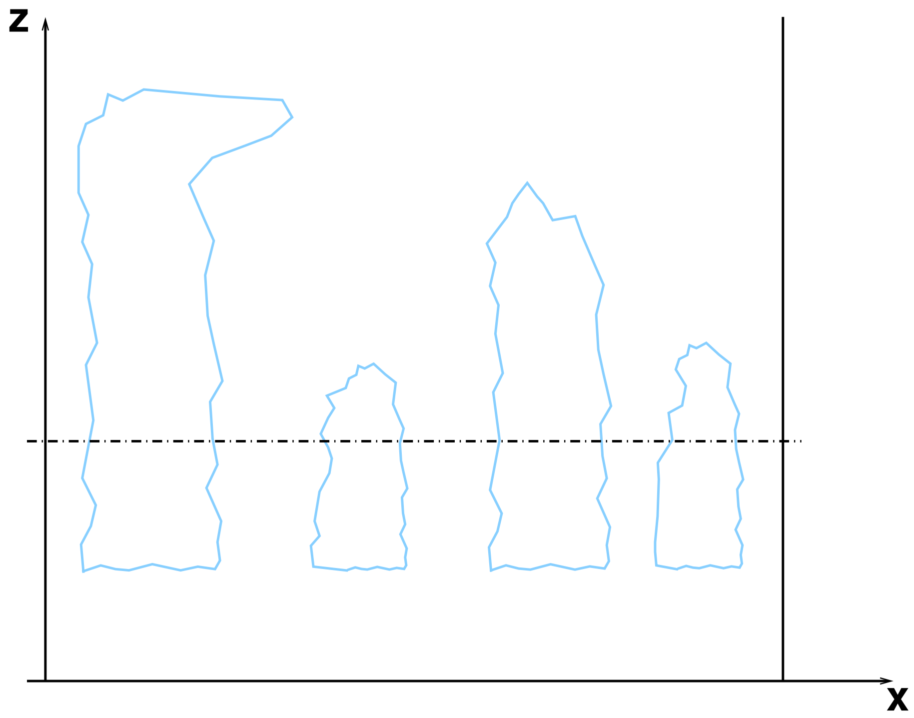
Luc Gerard

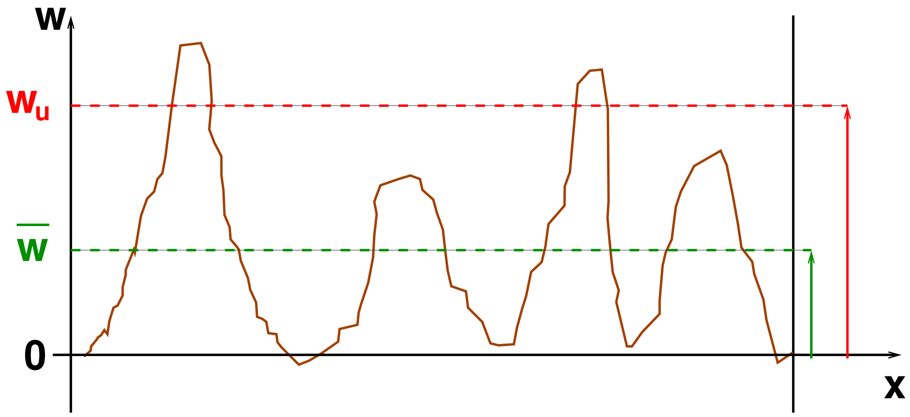
14 June 2012

Subgrid variability

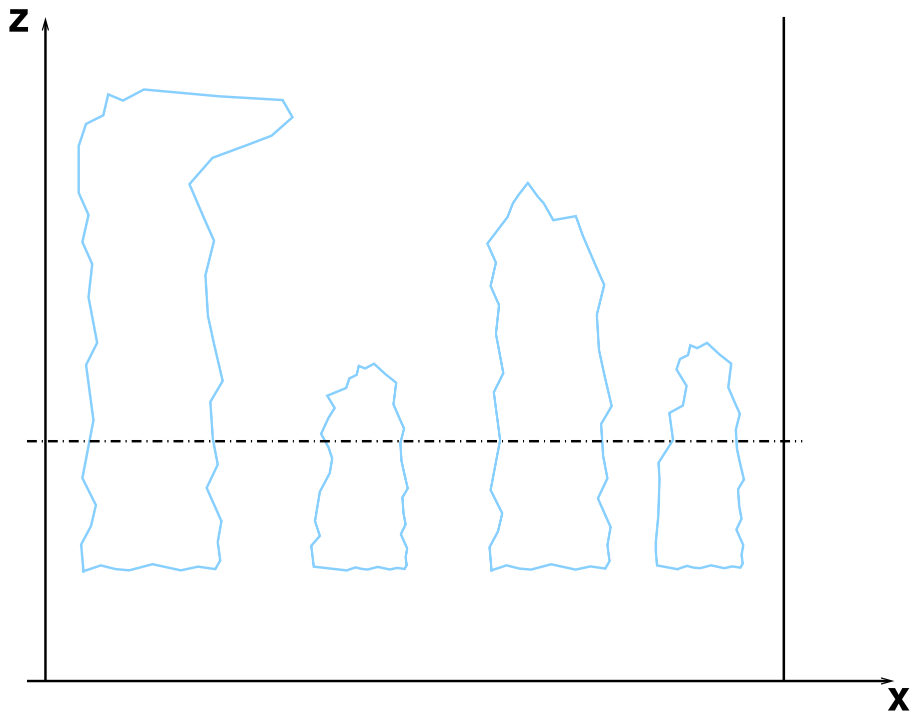


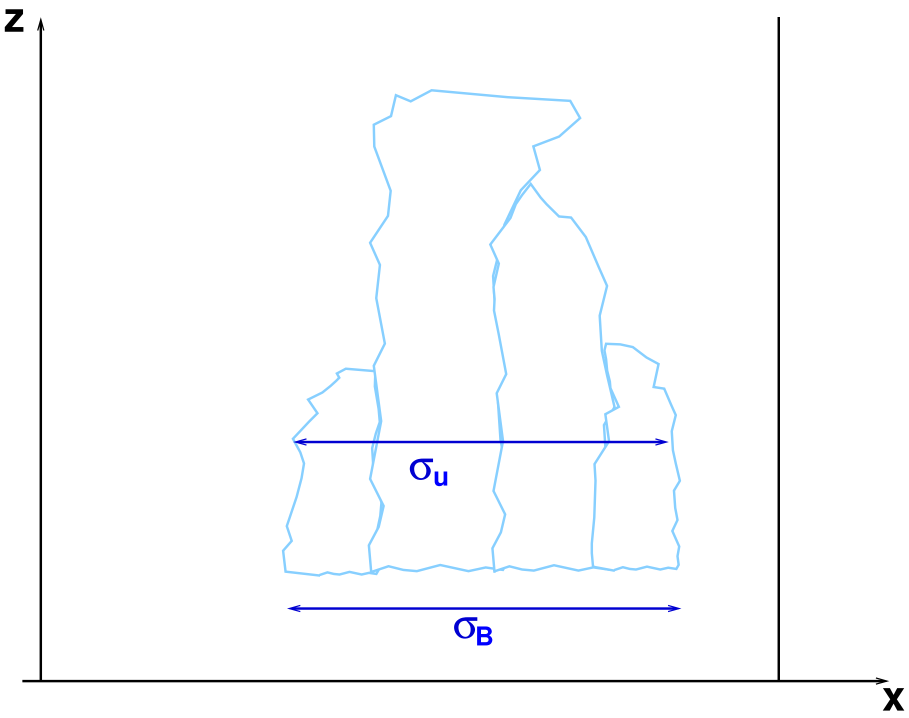
Subgrid variability

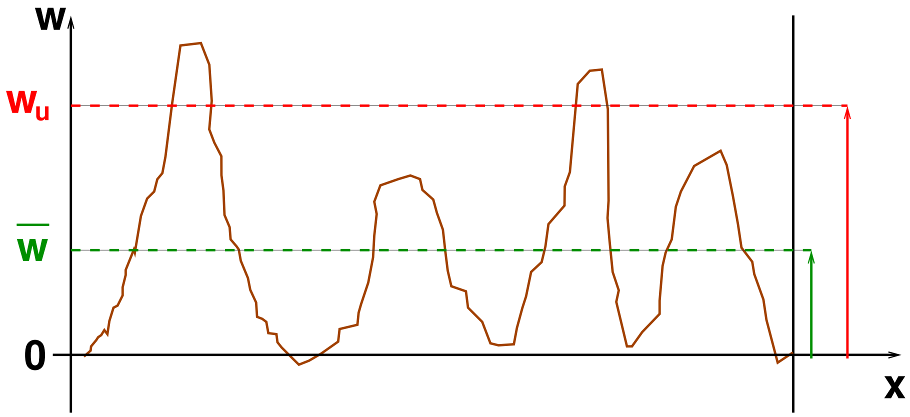




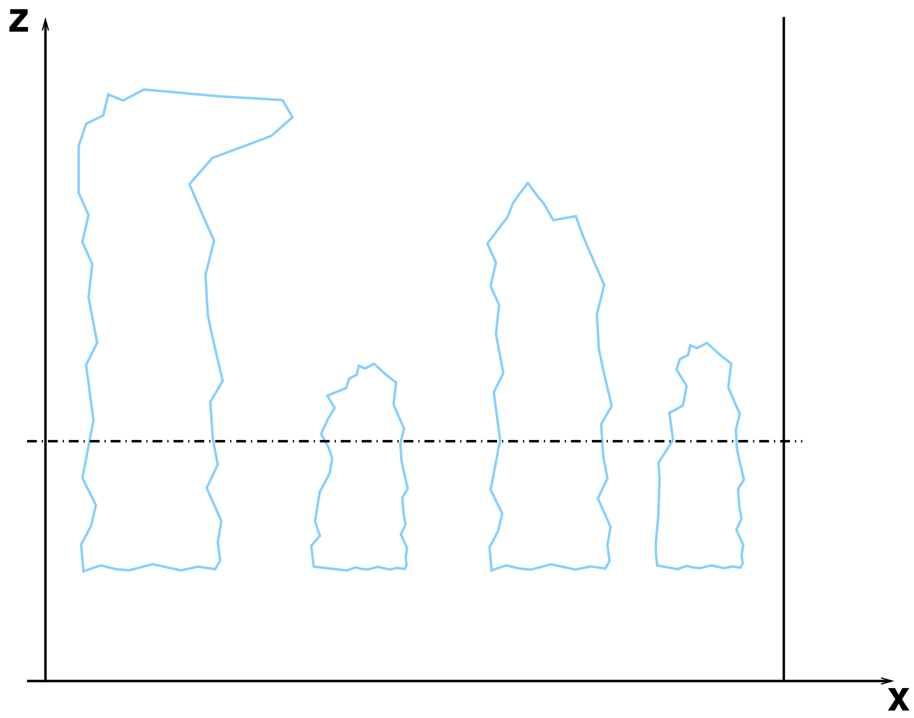
Subgrid variability

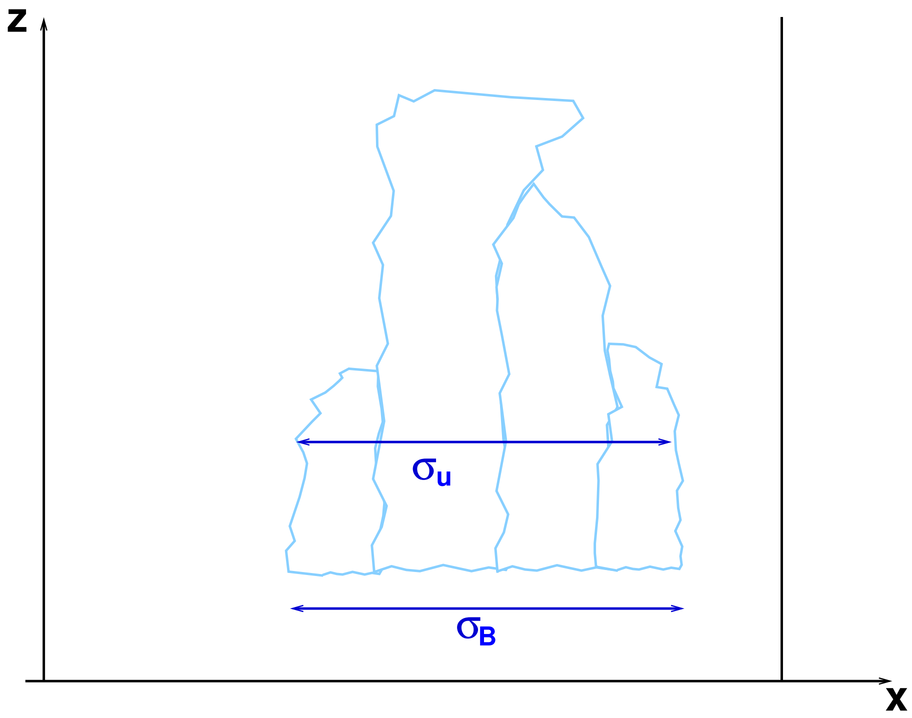


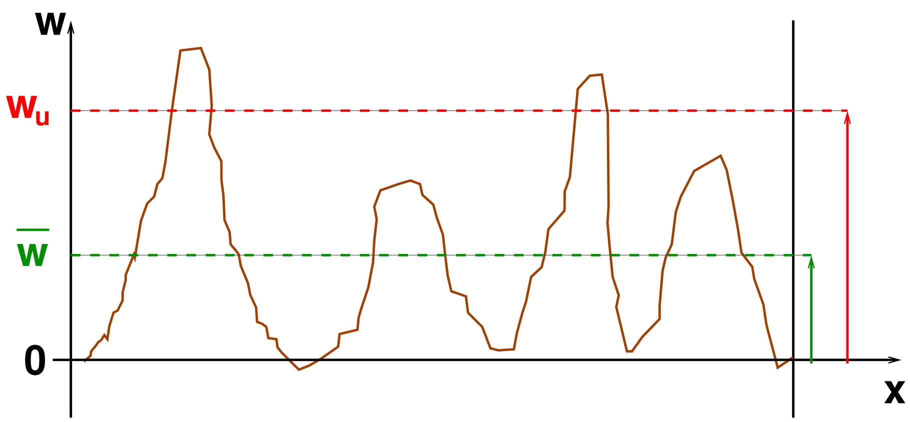




Subgrid variability

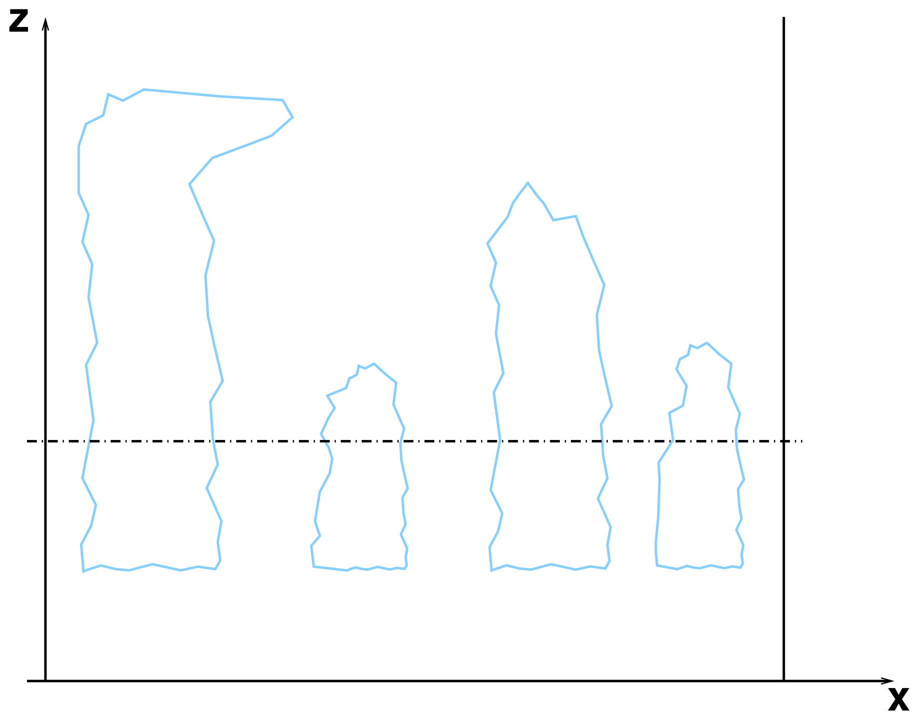


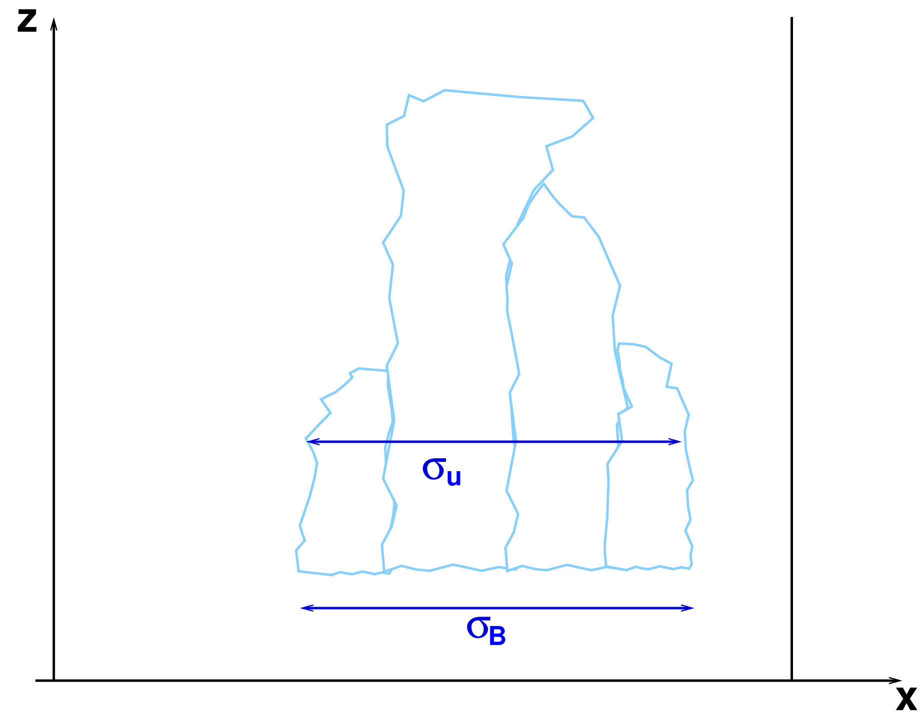


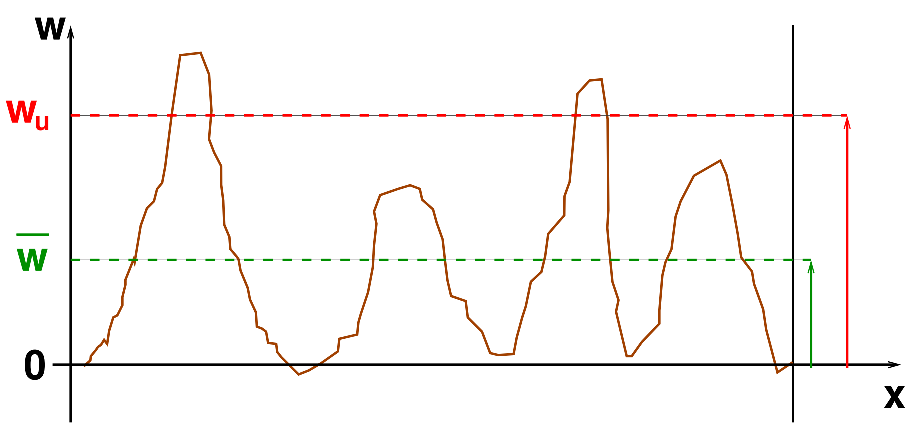


$$\overline{\psi} = \sum_u \sigma_i \psi_i + \sum_e \sigma_j \psi_j$$
$$= \sigma_u \psi_u + (1 - \sigma_u)\psi_e$$

Subgrid variability







$$\overline{\psi} = \sum_u \sigma_i \psi_i + \sum_e \sigma_j \psi_j$$

$$= \sigma_u \psi_u + (1 - \sigma_u)\psi_e$$

$$\psi_u^\diamond = \psi_u - \overline{\psi}, \quad \psi_e^\diamond = \psi_e - \overline{\psi},$$

$$\Rightarrow \quad \sigma_u \psi_u^\diamond + \sigma_e \psi_e^\diamond = 0$$

Complementary Subgrid Updraft

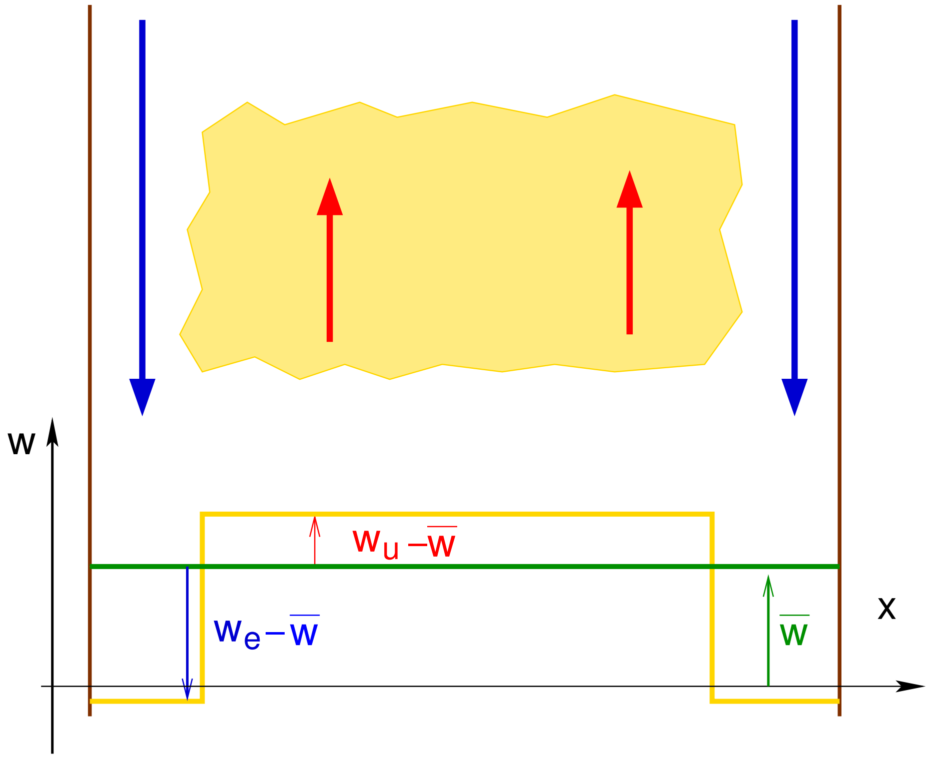
Provide complementary contribution to the resolved updraft

- Sequential physics (3MT cascade)

Complementary Subgrid Updraft

Provide complementary contribution to the resolved updraft

- Sequential physics (3MT cascade)
- Confinement in grid column:



Complementary Subgrid Updraft

Provide complementary contribution to the resolved updraft

- Sequential physics (3MT cascade)
- Confinement in grid column
- Closure relations: environmental CAPE/PEC

Complementary Subgrid Updraft

Provide complementary contribution to the resolved updraft

- Sequential physics (3MT cascade)
- Confinement in grid column
- Closure relations: environmental CAPE/PEC
- Evolution in time: geometrical and inertial

Complementary Subgrid Updraft

Provide complementary contribution to the resolved updraft

- Sequential physics (3MT cascade)
- Confinement in grid column
- Closure relations: environmental CAPE/PEC
- Evolution in time: geometrical and inertial
- Triggering of subgrid scheme $\neq$ triggering of convective updraft

Anelastic equation

$$\rho_0 = \rho_0(z) \qquad \Longrightarrow \qquad \nabla \cdot \mathbf{u} = -w \frac{d \ln \rho_0}{dz}$$

Anelastic equation

$$\rho_0 = \rho_0(z) \qquad \Longrightarrow \qquad \nabla \cdot \mathbf{u} = -w\frac{d \ln \rho_0}{dz}$$

$$\frac{\partial \psi}{\partial t} + \nabla_h \cdot (\mathbf{V}\psi) + \frac{\partial w \psi}{\partial z} + \psi w \frac{d \ln \rho_0}{dz} = f_\psi$$

Anelastic equation

$$\rho_0 = \rho_0(z) \qquad \Longrightarrow \qquad \nabla \cdot \mathbf{u} = -w \frac{d \ln \rho_0}{dz}$$

$$\frac{\partial \psi}{\partial t} + \nabla_h \cdot (\mathbf{V}\psi) + \frac{\partial w \psi}{\partial z} + \psi w \frac{d \ln \rho_0}{dz} = f_\psi$$

Assumptions:

- neglect effects of updraft touching the mesh boundaries

Anelastic equation

$$\rho_0 = \rho_0(z) \qquad \Longrightarrow \qquad \nabla \cdot \mathbf{u} = -w\frac{d\ln\rho_0}{dz}$$

$$\frac{\partial\psi}{\partial t} + \nabla_h \cdot (\mathbf{V}\psi) + \frac{\partial w\psi}{\partial z} + \psi w\frac{d\ln\rho_0}{dz} = f_\psi$$

Assumptions:

- neglect effects of updraft touching the mesh boundaries
- updraft boundary b: $\overline{\psi' u'}^b = \eta|w_u - w_e|(\psi_u - \psi_e|$

Anelastic equation

$$\rho_0 = \rho_0(z) \qquad \Longrightarrow \qquad \nabla \cdot \mathbf{u} = -w\frac{d\ln\rho_0}{dz}$$

$$\frac{\partial \psi}{\partial t} + \nabla_h \cdot (\mathbf{V}\psi) + \frac{\partial w\psi}{\partial z} + \psi w \frac{d\ln\rho_0}{dz} = f_\psi$$

Assumptions:

- neglect effects of updraft touching the mesh boundaries
- updraft boundary b: $\overline{\psi' u'}^b = \eta|w_u - w_e|(\psi_u - \psi_e|$
- neglect $\frac{\partial \sigma_u}{\partial t}$

Anelastic equation

$$\rho_0 = \rho_0(z) \qquad \Longrightarrow \qquad \nabla \cdot \mathbf{u} = -w \frac{d \ln \rho_0}{dz}$$

$$\frac{\partial \psi}{\partial t} + \nabla_h \cdot (\mathbf{V}\psi) + \frac{\partial w \psi}{\partial z} + \psi w \frac{d \ln \rho_0}{dz} = f_\psi$$

Assumptions:

- neglect effects of updraft touching the mesh boundaries
- updraft boundary b: $\overline{\psi' u'}^b = \eta |w_u - w_e| (\psi_u - \psi_e|$
- neglect $\frac{\partial \sigma_u}{\partial t}$
- address subplume entrainment and vertical transport through bulk buoyancy reduction.

Anelastic equation

$$\rho_0 = \rho_0(z) \quad \Longrightarrow \quad \nabla \cdot \mathbf{u} = -w\frac{d\ln\rho_0}{dz}$$

$$\frac{\partial\psi}{\partial t} + \nabla_h \cdot (\mathbf{V}\psi) + \frac{\partial w\psi}{\partial z} + \psi w\frac{d\ln\rho_0}{dz} = f_\psi$$

Assumptions:

- neglect effects of updraft touching the mesh boundaries
- updraft boundary b: $\overline{\psi' u'}^b = \eta|w_u - w_e|(\psi_u - \psi_e|$
- neglect $\frac{\partial\sigma_u}{\partial t}$
- address subplume entrainment and vertical transport through bulk buoyancy reduction.

$$\underbrace{\frac{\partial(\sigma_u\psi_u)}{\partial t}}_{\text{tendency}} \underbrace{+\frac{\mathcal{L}_b}{\rho_0 g A}\eta|\omega_u - \omega_e|(\psi_u - \psi_e)}_{\text{turb. mixing}} \underbrace{+\frac{\partial\sigma_u\omega_u}{\partial p}(\psi_u - \psi_b)}_{\text{organized entrainment}} \underbrace{+\sigma_u\omega_u\frac{\partial\psi_u}{\partial p}}_{\text{vertical transport}}$$

$$\underbrace{-\psi_b\frac{\partial\sigma_u}{\partial t}}_{\text{creation } \psi_b} \underbrace{-\overline{\omega'\psi'}^b\frac{\partial\sigma_u}{\partial p}}_{\text{subplume entrainment}} \underbrace{+\frac{\partial\sigma_u\overline{\omega'\psi'}^u}{\partial p}}_{\text{subplume vertic transport}} = \underbrace{\sigma_u\overline{f_\psi}^u}_{\text{forcing}}$$

RMI

Derivation of CSU equations

updraft: $$\sigma_u \frac{\partial \psi_u}{\partial t} = \sigma_u \frac{\lambda_u}{\rho_0}(\omega_u - \omega_e) + \frac{\partial \sigma_u \omega_u}{\partial p}(\psi_u - \psi_b) + \sigma_u \omega_u \frac{\partial \psi_u}{\partial p} = \sigma_u \overline{f_\psi}^u$$

Derivation of CSU equations

updraft: $$\sigma_u \frac{\partial \psi_u}{\partial t} = \sigma_u \frac{\lambda_u}{\rho_0}(\omega_u - \omega_e) + \frac{\partial \sigma_u \omega_u}{\partial p}(\psi_u - \psi_b) + \sigma_u \omega_u \frac{\partial \psi_u}{\partial p} = \sigma_u \overline{f_\psi}^u$$

resolved: $$\frac{\partial \overline{\psi}}{\partial t} = -\overline{(\mathbf{V} \cdot \nabla)\psi} - \overline{\omega}\frac{\partial \overline{\psi}}{\partial p} - \frac{\partial \overline{\omega' \psi'}}{\partial p} + \overline{f_\psi}$$

$$\approx -\overline{\omega}\frac{\partial \overline{\psi}}{\partial p} - \frac{\partial \sigma_u (1 - \sigma_u)(\omega_u - \omega_e)(\psi_u - \psi_e)}{\partial p} + \overline{f_\psi}$$

Derivation of CSU equations

updraft: $$\sigma_u \frac{\partial \psi_u}{\partial t} = \sigma_u \frac{\lambda_u}{\rho_0}(\omega_u - \omega_e) + \frac{\partial \sigma_u \omega_u}{\partial p}(\psi_u - \psi_b) + \sigma_u \omega_u \frac{\partial \psi_u}{\partial p} = \sigma_u \overline{f_\psi}^u$$

resolved: $$\frac{\partial \overline{\psi}}{\partial t} = -\overline{(\mathbf{V} \cdot \nabla)\psi} - \overline{\omega} \frac{\partial \overline{\psi}}{\partial p} - \frac{\partial \overline{\omega' \psi'}}{\partial p} + \overline{f_\psi}$$

$$\approx -\overline{\omega} \frac{\partial \overline{\psi}}{\partial p} - \frac{\partial \sigma_u (1 - \sigma_u)(\omega_u - \omega_e)(\psi_u - \psi_e)}{\partial p} + \overline{f_\psi}$$

Gathering and transforming yields

$$\frac{\partial \psi_u^\diamond}{\partial t} - \Lambda \frac{\omega_u^\diamond \psi_u^\diamond}{1 - \sigma_u} + (\omega_u^\diamond + \omega_e) \frac{\partial \psi_u^\diamond}{\partial p} + \omega_u^\diamond \frac{\partial \overline{\psi}}{\partial p} = (1 - \sigma_u)[\overline{f_{\psi sm}}^u - \overline{f_{\psi sm}}^e]$$

Derivation of CSU equations

updraft: $$\sigma_u \frac{\partial \psi_u}{\partial t} = \sigma_u \frac{\lambda_u}{\rho_0}(\omega_u - \omega_e) + \frac{\partial \sigma_u \omega_u}{\partial p}(\psi_u - \psi_b) + \sigma_u \omega_u \frac{\partial \psi_u}{\partial p} = \sigma_u \overline{f_\psi}^u$$

resolved: $$\frac{\partial \overline{\psi}}{\partial t} = -\overline{(\mathbf{V}\cdot\nabla)\psi} - \overline{\omega}\frac{\partial \overline{\psi}}{\partial p} - \frac{\partial \overline{\omega'\psi'}}{\partial p} + \overline{f_\psi}$$

$$\approx -\overline{\omega}\frac{\partial \overline{\psi}}{\partial p} - \frac{\partial \sigma_u(1-\sigma_u)(\omega_u - \omega_e)(\psi_u - \psi_e)}{\partial p} + \overline{f_\psi}$$

Gathering and transforming yields

$$\frac{\partial \psi_u^\diamond}{\partial t} - \Lambda \frac{\omega_u^\diamond \psi_u^\diamond}{1-\sigma_u} + (\omega_u^\diamond + \omega_e)\frac{\partial \psi_u^\diamond}{\partial p} + \omega_u^\diamond \frac{\partial \overline{\psi}}{\partial p} = (1-\sigma_u)[\overline{f_{\psi sm}}^u - \overline{f_{\psi sm}}^e]$$

$$\Lambda_w \approx \frac{\lambda_u + \mathcal{K}_{du}}{\rho_0(1-\sigma_u)} + \underbrace{(\sigma_u - \frac{\delta_{oe}}{k})\frac{1}{M_u^*}\frac{\partial M_u^*}{\partial p}}_{\Lambda_{\mathrm{dyn}}}, \qquad k = \frac{\omega_u^\diamond}{\omega_u} \quad \sim (1-\sigma_u) \text{ if } \omega_e \sim 0$$

Derivation of CSU equations

updraft: $$\sigma_u \frac{\partial \psi_u}{\partial t} = \sigma_u \frac{\lambda_u}{\rho_0}(\omega_u - \omega_e) + \frac{\partial \sigma_u \omega_u}{\partial p}(\psi_u - \psi_b) + \sigma_u \omega_u \frac{\partial \psi_u}{\partial p} = \sigma_u \overline{f_\psi}^u$$

resolved: $$\frac{\partial \overline{\psi}}{\partial t} = -\overline{(\mathbf{V} \cdot \nabla)\psi} - \overline{\omega}\frac{\partial \overline{\psi}}{\partial p} - \frac{\partial \overline{\omega' \psi'}}{\partial p} + \overline{f_\psi}$$

$$\approx -\overline{\omega}\frac{\partial \overline{\psi}}{\partial p} - \frac{\partial \sigma_u (1-\sigma_u)(\omega_u - \omega_e)(\psi_u - \psi_e)}{\partial p} + \overline{f_\psi}$$

Gathering and transforming yields

$$\frac{\partial \psi_u^\diamond}{\partial t} - \Lambda \frac{\omega_u^\diamond \psi_u^\diamond}{1-\sigma_u} + (\omega_u^\diamond + \omega_e)\frac{\partial \psi_u^\diamond}{\partial p} + \omega_u^\diamond \frac{\partial \overline{\psi}}{\partial p} = (1-\sigma_u)[\overline{f_{\psi sm}}^u - \overline{f_{\psi sm}}^e]$$

$$\Lambda_w \approx \frac{\lambda_u + \mathcal{K}_{du}}{\rho_0(1-\sigma_u)} + \underbrace{(\sigma_u - \frac{\delta_{oe}}{k})\frac{1}{M_u^*}\frac{\partial M_u^*}{\partial p}}_{\Lambda_{\mathrm{dyn}}}, \qquad k = \frac{\omega_u^\diamond}{\omega_u} \quad \sim (1-\sigma_u) \text{ if } \omega_e \sim 0$$

$\mathcal{K}_{du}$ = TUDFR used for momentum only

Further considerations

- Source

$$\overline{f_\psi} = \sigma_u \overline{f_\psi}^u + \sigma_e \overline{f_\psi}^e = \sigma_u \overline{f_{\psi sm}}^u + \sigma_e \overline{f_{\psi sm}}^e + f_{\psi rm}$$

Further considerations

- Source

$$\overline{f_\psi} = \sigma_u \overline{f_\psi}^u + \sigma_e \overline{f_\psi}^e = \sigma_u \overline{f_{\psi sm}}^u + \sigma_e \overline{f_{\psi sm}}^e + f_{\psi rm}$$

- Formulate in term of $\psi^\diamond = \psi_u - \overline{\psi}$

Further considerations

- Source

$$\overline{f_\psi} = \sigma_u \overline{f_\psi}^u + \sigma_e \overline{f_\psi}^e = \sigma_u \overline{f_{\psi sm}}^u + \sigma_e \overline{f_{\psi sm}}^e + f_{\psi rm}$$

- Formulate in term of $\psi^\diamond = \psi_u - \overline{\psi}$
- Two-stages calculation: resolved advection vs physical parametrization.

Further considerations

- Source

$$\overline{f_\psi} = \sigma_u \overline{f_\psi}^u + \sigma_e \overline{f_\psi}^e = \sigma_u \overline{f_{\psi sm}}^u + \sigma_e \overline{f_{\psi sm}}^e + f_{\psi rm}$$

- Formulate in term of $\psi^\diamond = \psi_u - \overline{\psi}$
- Two-stages calculation: resolved advection vs physical parametrization.

- σ_u vertical variation: ensembling effect,
  entrainment-detrainment budget (effect of moisture...)
  see below.

Final equations

$$\left.\frac{\partial \omega_u^\diamond}{\partial t}\right|_{sm} - \left(\frac{\Lambda_w}{1-\sigma_u} + \frac{1}{k}\frac{d\ln\rho_0}{dp}\right){\omega_u^\diamond}^2 + \frac{\omega_u^\diamond}{k}\frac{\partial \omega_u^\diamond}{\partial p} = -\alpha_b \rho_0 g^2 \frac{T_{vu} - \overline{T_v}}{\overline{T_v}}$$

Final equations

$$\frac{\partial \omega_u^\diamond}{\partial t}\Big|_{sm} - \left(\frac{\Lambda_w}{1-\sigma_u} + \frac{1}{k}\frac{d\ln\rho_0}{dp}\right){\omega_u^\diamond}^2 + \frac{\omega_u^\diamond}{k}\frac{\partial \omega_u^\diamond}{\partial p} = -\alpha_b \rho_0 g^2 \frac{T_{vu} - \overline{T_v}}{\overline{T_v}}$$

$$\frac{\partial q_u^\diamond}{\partial p} = \frac{\Lambda}{1-\sigma_u} q_u^\diamond + \frac{1}{\triangle p}\Big[-(1-\sigma_u)\delta q_{ca} - \triangle \overline{q}\Big]$$

Final equations

$$\frac{\partial \omega_u^\diamond}{\partial t}\Big|_{sm} - (\frac{\Lambda_w}{1-\sigma_u} + \frac{1}{k}\frac{d\ln\rho_0}{dp})\omega_u^{\diamond 2} + \frac{\omega_u^\diamond}{k}\frac{\partial \omega_u^\diamond}{\partial p} = -\alpha_b \rho_0 g^2 \frac{T_{vu} - \overline{T_v}}{\overline{T_v}}$$

$$\frac{\partial q_u^\diamond}{\partial p} = \frac{\Lambda}{1-\sigma_u} q_u^\diamond + \frac{1}{\triangle p}\Big[-(1-\sigma_u)\delta q_{ca} - \triangle \overline{q}\Big]$$

$$\frac{\partial \theta_u^\diamond}{\partial p} = \frac{\Lambda}{1-\sigma_u} \theta_u^\diamond + \frac{1}{\triangle p}\Big[(1-\sigma_u)\frac{L}{c_p}\delta q_{ca}(\frac{p_{00}}{p})^{R_a/c_{pa}} - \triangle \overline{\theta}\Big]$$

Final equations

$$\frac{\partial \omega_u^\diamond}{\partial t}\Big|_{sm} - (\frac{\Lambda_w}{1-\sigma_u} + \frac{1}{k}\frac{d\ln\rho_0}{dp})\omega_u^{\diamond 2} + \frac{\omega_u^\diamond}{k}\frac{\partial \omega_u^\diamond}{\partial p} = -\alpha_b \rho_0 g^2 \frac{T_{vu} - \overline{T_v}}{\overline{T_v}}$$

$$\frac{\partial q_u^\diamond}{\partial p} = \frac{\Lambda}{1-\sigma_u} q_u^\diamond + \frac{1}{\triangle p}\Big[-(1-\sigma_u)\delta q_{ca} - \triangle \overline{q}\Big]$$

$$\frac{\partial \theta_u^\diamond}{\partial p} = \frac{\Lambda}{1-\sigma_u}\theta_u^\diamond + \frac{1}{\triangle p}\Big[(1-\sigma_u)\frac{L}{c_p}\delta q_{ca}(\frac{p_{00}}{p})^{R_a/c_{pa}} - \triangle\overline{\theta}\Big]$$

$$\Longrightarrow \quad \psi_u^\diamond = \psi_b^\diamond e^{\left(\frac{\Lambda\triangle p}{1-\sigma_u}\right)} - \frac{(1-\sigma_u)}{\Lambda\triangle p}\Big[(1-\sigma_u)(\psi_h - \psi_b) - (\overline{\psi}^l - \overline{\psi}^{l+1})\Big](1 - e^{\left(\frac{\Lambda\triangle p}{1-\sigma_u}\right)})$$

$$\frac{\partial q}{\partial p}\Big|_{\mathrm{cond}} = -\frac{\triangle q_{ca}}{\triangle p} \text{ such that } q_u = q_{\mathrm{sat}}(p, T_u) \quad :$$

RMI

Final equations

$$\frac{\partial \omega_u^\diamond}{\partial t}\Big|_{sm} - (\frac{\Lambda_w}{1-\sigma_u} + \frac{1}{k}\frac{d\ln\rho_0}{dp})\omega_u^{\diamond 2} + \frac{\omega_u^\diamond}{k}\frac{\partial \omega_u^\diamond}{\partial p} = -\alpha_b \rho_0 g^2 \frac{T_{vu} - \overline{T_v}}{\overline{T_v}}$$

$$\frac{\partial q_u^\diamond}{\partial p} = \frac{\Lambda}{1-\sigma_u} q_u^\diamond + \frac{1}{\triangle p}\Big[-(1-\sigma_u)\delta q_{ca} - \triangle \overline{q}\Big]$$

$$\frac{\partial \theta_u^\diamond}{\partial p} = \frac{\Lambda}{1-\sigma_u} \theta_u^\diamond + \frac{1}{\triangle p}\Big[(1-\sigma_u)\frac{L}{c_p}\delta q_{ca}(\frac{p_{00}}{p})^{R_a/c_{pa}} - \triangle \overline{\theta}\Big]$$

$$\Longrightarrow \quad \psi_u^\diamond = \psi_b^\diamond e^{\left(\frac{\Lambda \triangle p}{1-\sigma_u}\right)} - \frac{(1-\sigma_u)}{\Lambda \triangle p}\Big[(1-\sigma_u)(\psi_h - \psi_b) - (\overline{\psi}^l - \overline{\psi}^{l+1})\Big](1 - e^{\left(\frac{\Lambda \triangle p}{1-\sigma_u}\right)})$$

$$\frac{\partial q}{\partial p}\Big|_{\text{cond}} = -\frac{\triangle q_{ca}}{\triangle p} \text{ such that } q_u = q_{\text{sat}}(p, T_u) \quad :$$

for this,

- first guess from moist adiabatic ascent $\rightarrow \{T_u^0, q_u^0, \delta q_{ca}^0\}$;
- interpolate linearly $\rightarrow \{T_u^+, q_u^+ = q_{\text{sat}}(p, T_u^+), \delta q_{ca}^+\}$

RMI

Steady-state ascent calculation

- Updraft base:
  - LCL from triggering routine
  - Top dry ascent velocity

$$\omega^{\diamond}_{u\text{top dry}} \sim \omega^{\diamond}_{u\text{free}} \exp[-\frac{p^{b+1} - p^{b}}{\triangle p_{bx}}], \qquad \frac{1}{\triangle p_{bx}} = \text{gidpbas}$$

Steady-state ascent calculation

- Updraft base:
  - LCL from triggering routine
  - Top dry ascent velocity

$$\omega^{\diamond}_{u\text{top dry}} \sim \omega^{\diamond}_{u\text{free}} \exp[-\frac{p^{b+1} - p^{b}}{\triangle p_{bx}}], \qquad \frac{1}{\triangle p_{bx}} = \text{gidpbas}$$

- start with k and $\sigma^{\bullet}_{B}$ guessed from $\overline{\omega}, \sigma^{-}_{u}, \omega^{\diamond -}_{u}$:

$$\sigma^{*}_{B} = \min\left[\text{gcvalmx}, \max[\text{zepsaln}, < \sigma^{-}_{u} >, \text{sigig}\frac{\sum \frac{\overline{\omega}}{\omega^{\diamond -}_{u} + \overline{\omega}} \triangle p}{\sum \triangle p} + (1 - \text{sigig}) < \sigma^{-}_{u} >]\right]$$

Steady-state ascent calculation

- Updraft base:
  - LCL from triggering routine
  - Top dry ascent velocity

$$\omega^{\diamond}_{u\text{top dry}} \sim \omega^{\diamond}_{u\text{free}} \exp[-\frac{p^{b+1}-p^{b}}{\triangle p_{bx}}], \qquad \frac{1}{\triangle p_{bx}} = \text{gidpbas}$$

- start with k and $\sigma_B^{\bullet}$ guessed from $\overline{\omega}, \sigma_u^-, \omega_u^{\diamond -}$:

$$\sigma_B^* = \min\left[\text{gcvalmx}, \max[\text{zepsaln}, <\sigma_u^- >, \text{sigig}\frac{\sum \frac{\overline{\omega}}{\omega_u^{\diamond -}+\overline{\omega}}\triangle p}{\sum \triangle p} + (1-\text{sigig}) < \sigma_u^- >]\right]$$

- σ_u vertical variation: ensembling effect,
  entrainment-detrainment budget (effect of moisture...)

$$(1-\sigma_u) = \mu(1-\sigma_B), \qquad \mu = f(x, \mu^{\text{TOP}}),$$

$$x = \frac{p^{LCL}-p}{p^{\text{LCL}}-p^{\text{TOP}}}, \qquad \mu^{\text{TOP}} \rightarrow 1 \text{ if } \sigma_B^{\bullet} \rightarrow 1$$

p^{TOP} estimated for the non-diluted ascent.

Steady-state ascent calculation (continued)

- stationnarized $\omega_u^\diamond$ equation
  $\Rightarrow$ Organized entr/detr (restrained to $\pm$gcvendymax $\cdot \triangle\phi$),

$$\Lambda_{\rm dyn} \triangle p = (\sigma_u^\bullet - \frac{\delta_{oe}}{k}) \frac{\triangle M_u^*}{M_u^*}, \qquad M_u^* = \frac{\sigma_u^\bullet \omega_u^\diamond}{1 - \sigma_u^\bullet}$$

Steady-state ascent calculation (continued)

- stationnarized $\omega_u^\diamond$ equation
  $\Rightarrow$ Organized entr/detr (restrained to $\pm$gcvendymax $\cdot \triangle\phi$),

$$\Lambda_{\rm dyn}\triangle p = (\sigma_u^\bullet - \frac{\delta_{oe}}{k})\frac{\triangle M_u^*}{M_u^*}, \qquad M_u^* = \frac{\sigma_u^\bullet \omega_u^\diamond}{1-\sigma_u^\bullet}$$

$\Rightarrow$ Guess at next level.

$$(\Lambda_{\rm dyn}\triangle p)^{l*} = (\Lambda_{\rm dyn}\triangle p)^{l+1} \overset{-}{\underset{+}{}} \delta_{\rm asc}^{l+1} \cdot \text{gcvendy1} \cdot \triangle\phi^{\bar{l}} \cdot e^{-\max(0,\text{gcvendy2}(\phi^{l+1}-\phi_b))} \quad \text{if } \overset{>}{\underset{<}{}} 0$$

Steady-state ascent calculation (continued)

- stationnarized $\omega_u^\diamond$ equation
  $\Rightarrow$ Organized entr/detr (restrained to $\pm$gcvendymax $\cdot \triangle\phi$),

$$\Lambda_{\rm dyn}\triangle p = (\sigma_u^\bullet - \frac{\delta_{oe}}{k})\frac{\triangle M_u^*}{M_u^*}, \qquad M_u^* = \frac{\sigma_u^\bullet \omega_u^\diamond}{1-\sigma_u^\bullet}$$

  $\Rightarrow$ Guess at next level.

$$(\Lambda_{\rm dyn}\triangle p)^{l*} = (\Lambda_{\rm dyn}\triangle p)^{l+1} \mp \delta_{\rm asc}^{l+1} \cdot \text{gcvendy1} \cdot \triangle\phi^{\bar{l}} \cdot e^{-\max(0,\text{gcvendy2}(\phi^{l+1}-\phi_b))} \quad \text{if} \gtrless 0$$

  $\Rightarrow$ Mixing

$$\Lambda\triangle p = \frac{\lambda_u \triangle\phi}{1-\sigma_u^\bullet} + \Lambda_{\rm dyn}\triangle p$$

RMI

Steady-state ascent calculation (continued)

- stationnarized $\omega_u^\diamond$ equation
  $\Rightarrow$ Organized entr/detr (restrained to $\pm$gcvendymax $\cdot \triangle\phi$),

$$\Lambda_{\rm dyn}\triangle p = (\sigma_u^\bullet - \frac{\delta_{oe}}{k})\frac{\triangle M_u^*}{M_u^*}, \qquad M_u^* = \frac{\sigma_u^\bullet \omega_u^\diamond}{1-\sigma_u^\bullet}$$

  $\Rightarrow$ Guess at next level.

$$(\Lambda_{\rm dyn}\triangle p)^{l*} = (\Lambda_{\rm dyn}\triangle p)^{l+1} \mp \delta_{\rm asc}^{l+1} \cdot \text{gcvendy1} \cdot \triangle\phi^{\bar{l}} \cdot e^{-\max(0,\text{gcvendy2}(\phi^{l+1}-\phi_b))} \quad \text{if} \gtrless 0$$

  $\Rightarrow$ Mixing

$$\Lambda\triangle p = \frac{\lambda_u \triangle\phi}{1-\sigma_u^\bullet} + \Lambda_{\rm dyn}\triangle p$$

- Steady-state for $q_u^\diamond$ and $\theta_u^\diamond$.

Steady-state closure in the CSU context

* Potential Energy Convertibility (Yano et al. 2005) (LPEC=T):

$$\mathrm{PEC} = \int_b^t m \frac{\theta_{vu} - \overline{\theta_v}}{\overline{\theta_v}} d\phi = -R_a \int_b^t m (T_{vu} - \overline{T_v}) \frac{dp}{p}, \qquad m = \frac{\omega}{\omega^*} \text{ (or 1 for CAPE)}$$

Steady-state closure in the CSU context

* Potential Energy Convertibility (Yano et al. 2005) (LPEC=T):

$$\text{PEC} = \int_b^t m \frac{\theta_{vu} - \overline{\theta_v}}{\overline{\theta_v}} d\phi = -R_a \int_b^t m(T_{vu} - \overline{T_v}) \frac{dp}{p}, \qquad m = \frac{\omega}{\omega^*} \text{ (or 1 for CAPE)}$$

* Characteristic time τ (= RTCAPE) for CAPE consumption

$$\frac{\partial \text{CAPE}}{\partial t} \sim -\frac{\text{CAPE}}{\tau}$$

Steady-state closure in the CSU context

* Potential Energy Convertibility (Yano et al. 2005) (LPEC=T):

$$\text{PEC} = \int_b^t m \frac{\theta_{vu} - \overline{\theta_v}}{\overline{\theta_v}} d\phi = -R_a \int_b^t m (T_{vu} - \overline{T_v}) \frac{dp}{p}, \qquad m = \frac{\omega}{\omega^*} \text{ (or 1 for CAPE)}$$

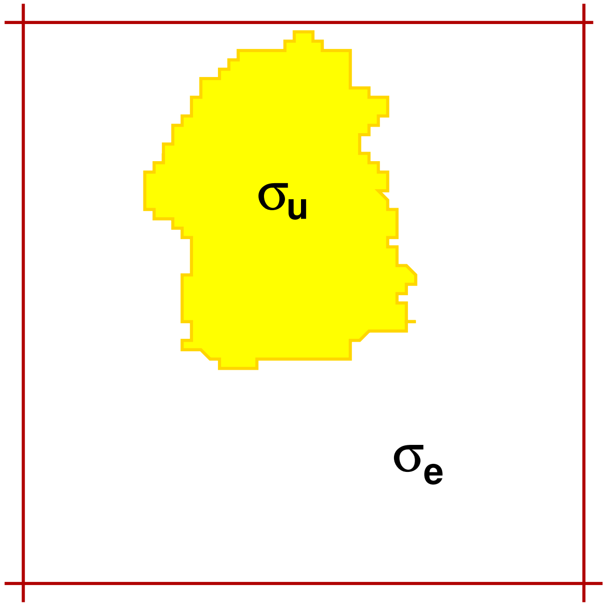
* Characteristic time τ (= RTCAPE) for CAPE consumption

$$\frac{\partial \text{CAPE}}{\partial t} \sim -\frac{\text{CAPE}}{\tau}$$

...by the *real-world* deep convective process if it was *alone*.

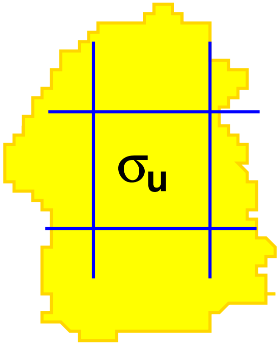
How to get to real CAPE ?

How to get to real CAPE ?



CSU: $\overline{\psi} \neq \psi_e$:
model-column CAPE < 'environmental CAPE'

How to get to real CAPE ?

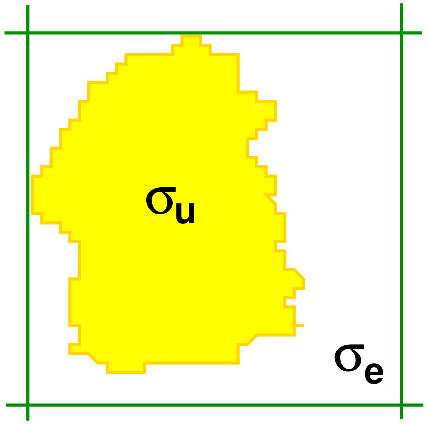


CSU: $\overline{\psi} \neq \psi_e$:

model-column CAPE $<$ 'environmental CAPE'

In any updraft CAPE ≈ 0:

How to get to real CAPE ?



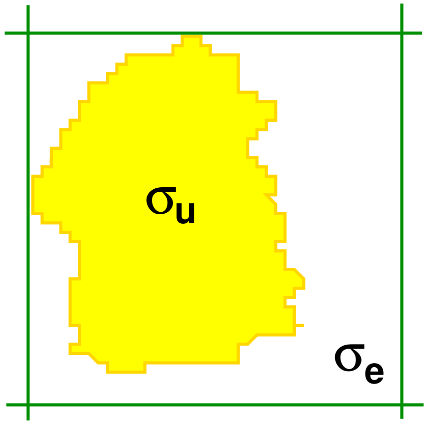
CSU: $\overline{\psi} \neq \psi_e$:

model-column CAPE $<$ 'environmental CAPE'

In any updraft CAPE ≈ 0:

If $\sigma_u < 1$ rather consider the environment at rest

How to get to real CAPE ?



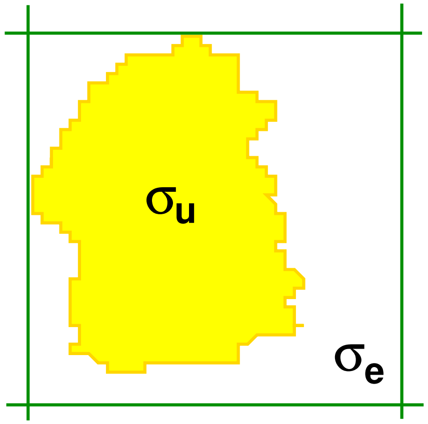
CSU: $\overline{\psi} \neq \psi_e$:
model-column CAPE $<$ 'environmental CAPE'

In any updraft CAPE ≈ 0:

If $\sigma_u < 1$ rather consider the environment at rest

the available energy for the updraft is the theoretical CAPE comparing a rising parcel property to an environment at rest

How to get to real CAPE ?



CSU: $\overline{\psi} \neq \psi_e$:

model-column CAPE $<$ 'environmental CAPE'

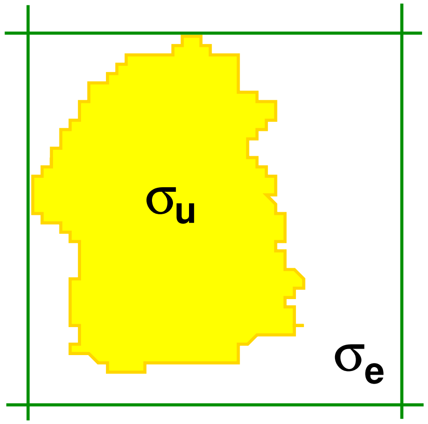
In any updraft CAPE ≈ 0:

If $\sigma_u < 1$ rather consider the environment at rest

the available energy for the updraft is the theoretical CAPE comparing a rising parcel property to an environment at rest

$\Rightarrow$ consider $(T_{vu} - T_{ve}) = \frac{T_{vu} - \overline{Tv}}{1 - \sigma_u}$

How to get to real CAPE ?



CSU: $\overline{\psi} \neq \psi_e$:

model-column CAPE < 'environmental CAPE'

In any updraft CAPE ≈ 0:

If $\sigma_u < 1$ rather consider the environment at rest

the available energy for the updraft is the theoretical CAPE comparing a rising parcel property to an environment at rest

$\Rightarrow$ consider $(T_{vu} - T_{ve}) = \frac{T_{vu} - \overline{Tv}}{1 - \sigma_u}$

The mean grid-box state $\overline{\psi}$ input to the updraft routine

- is already affected by resolved vertical motion $\overline{\omega}$
- has been updated after the resolved condensation (3MT cascade)

$$\overline{s}_1 = \overline{s_0} + gL \frac{\partial F_{cs}}{\partial p} \triangle t, \qquad \overline{q}_1 = \overline{q_0} - g \frac{\partial F_{cs}}{\partial p} \triangle t$$

Environmental CAPE / PEC

$$\text{eCAPE} = -R_a \int_b^t m(T_{vu} - T_{ve0}) \frac{dp}{p} \approx -R_a \int_b^t m \frac{T_{vu}^{\diamond} - \frac{L}{c_p} \frac{\partial F_{cs}}{\partial p} \triangle t}{(1 - \sigma_u)} \frac{dp}{p}$$

Environmental CAPE / PEC

$$\text{eCAPE} = -R_a \int_b^t m(T_{vu} - T_{ve0})\frac{dp}{p} \approx -R_a \int_b^t m \frac{T_{vu}^{\diamond} - \frac{L}{c_p}\frac{\partial F_{cs}}{\partial p}\triangle t}{(1-\sigma_u)}\frac{dp}{p}$$

$$\frac{\partial \text{eCAPE}}{\partial t} \approx -R_a \int_b^t \frac{m}{(1-\sigma_u)}\frac{\partial (T_{vu} - \overline{T_v})}{\partial t}\frac{dp}{p}$$

Environmental CAPE / PEC

$$\text{eCAPE} = -R_a \int_b^t m(T_{vu} - T_{ve0})\frac{dp}{p} \approx -R_a \int_b^t m \frac{T_{vu}^{\diamond} - \frac{L}{c_p}\frac{\partial F_{cs}}{\partial p}\triangle t}{(1-\sigma_u)}\frac{dp}{p}$$

$$\frac{\partial \text{eCAPE}}{\partial t} \approx -R_a \int_b^t \frac{m}{(1-\sigma_u)}\frac{\partial (T_{vu} - \overline{T_v})}{\partial t}\frac{dp}{p}$$

Still needs $\left.\frac{\partial T_{vu}^{\diamond}}{\partial t}\right|_{ud} \approx \frac{\partial T_u^{\diamond}}{\partial t}(1+\kappa q_u) + \frac{\partial q_u^{\diamond}}{\partial p}\kappa T_u$

Environmental CAPE / PEC

$$\text{eCAPE} = -R_a \int_b^t m(T_{vu} - T_{ve0})\frac{dp}{p} \approx -R_a \int_b^t m\frac{T_{vu}^{\diamond} - \frac{L}{c_p}\frac{\partial F_{cs}}{\partial p}\triangle t}{(1-\sigma_u)}\frac{dp}{p}$$

$$\frac{\partial \text{eCAPE}}{\partial t} \approx -R_a \int_b^t \frac{m}{(1-\sigma_u)}\frac{\partial (T_{vu} - \overline{T_v})}{\partial t}\frac{dp}{p}$$

Still needs $\left.\frac{\partial T_{vu}^{\diamond}}{\partial t}\right|_{ud} \approx \frac{\partial T_u^{\diamond}}{\partial t}(1+\kappa q_u) + \frac{\partial q_u^{\diamond}}{\partial p}\kappa T_u$ with $\frac{\partial \theta_u^{\diamond}}{\partial t}$ and $\frac{\partial q_u^{\diamond}}{\partial t}$ from CSU equations.

Environmental CAPE / PEC

$$\text{eCAPE} = -R_a \int_b^t m(T_{vu} - T_{ve0})\frac{dp}{p} \approx -R_a \int_b^t m \frac{T_{vu}^{\diamond} - \frac{L}{c_p}\frac{\partial F_{cs}}{\partial p}\triangle t}{(1-\sigma_u)}\frac{dp}{p}$$

$$\frac{\partial \text{eCAPE}}{\partial t} \approx -R_a \int_b^t \frac{m}{(1-\sigma_u)}\frac{\partial (T_{vu} - \overline{T_v})}{\partial t}\frac{dp}{p}$$

Still needs $\left.\frac{\partial T_{vu}^{\diamond}}{\partial t}\right|_{ud} \approx \frac{\partial T_u^{\diamond}}{\partial t}(1+\kappa q_u) + \frac{\partial q_u^{\diamond}}{\partial p}\kappa T_u$ with $\frac{\partial \theta_u^{\diamond}}{\partial t}$ and $\frac{\partial q_u^{\diamond}}{\partial t}$ from CSU equations.

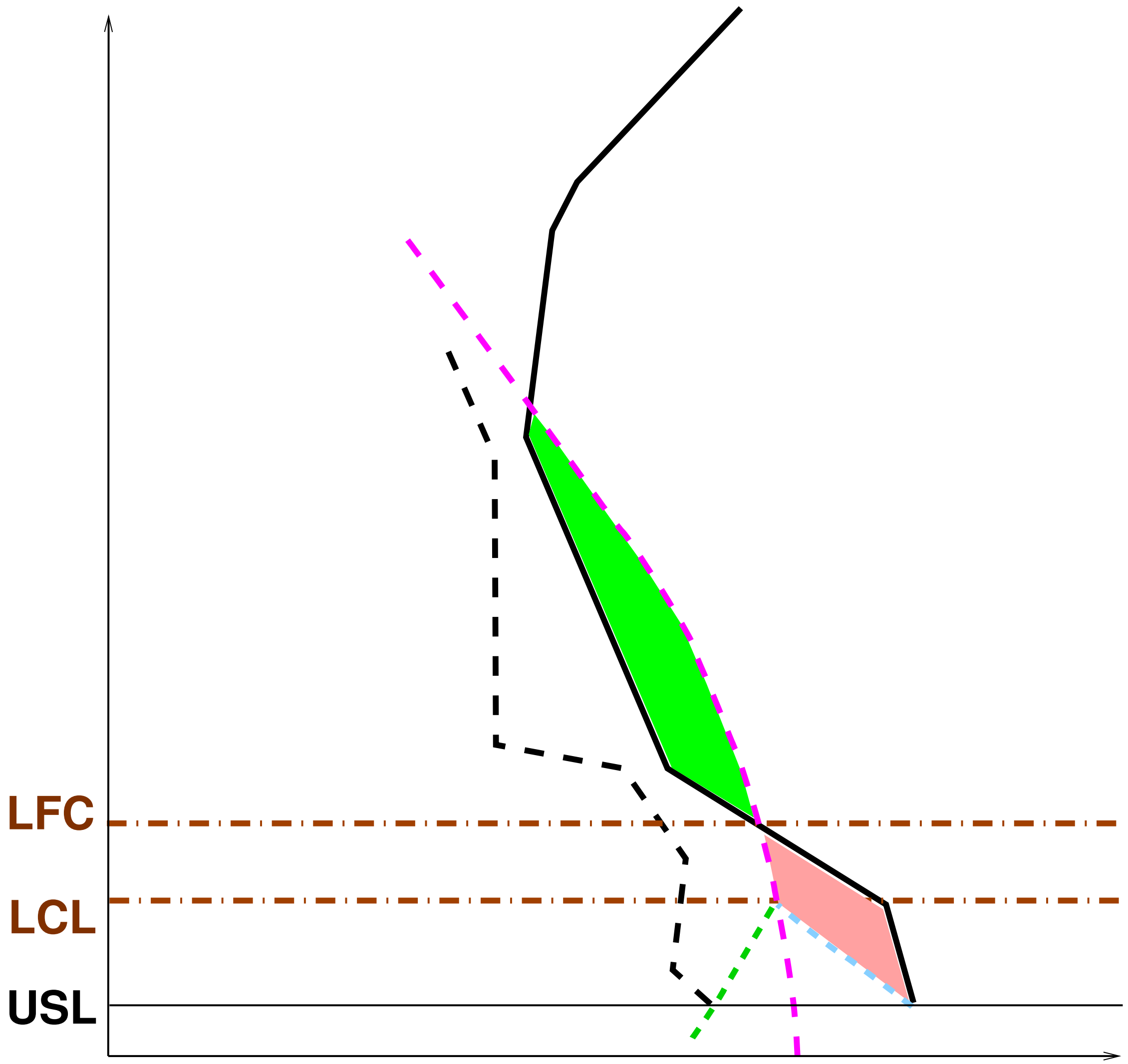
Then

$$\frac{\partial \text{eCAPE}}{\partial t} = -\frac{\text{eCAPE}}{\tau}$$

will lead $(1-\sigma_B)$ if the profile $\mu = \frac{(1-\sigma_u)}{(1-\sigma_B)}$ is given.

Downdraft effect on updraft closure

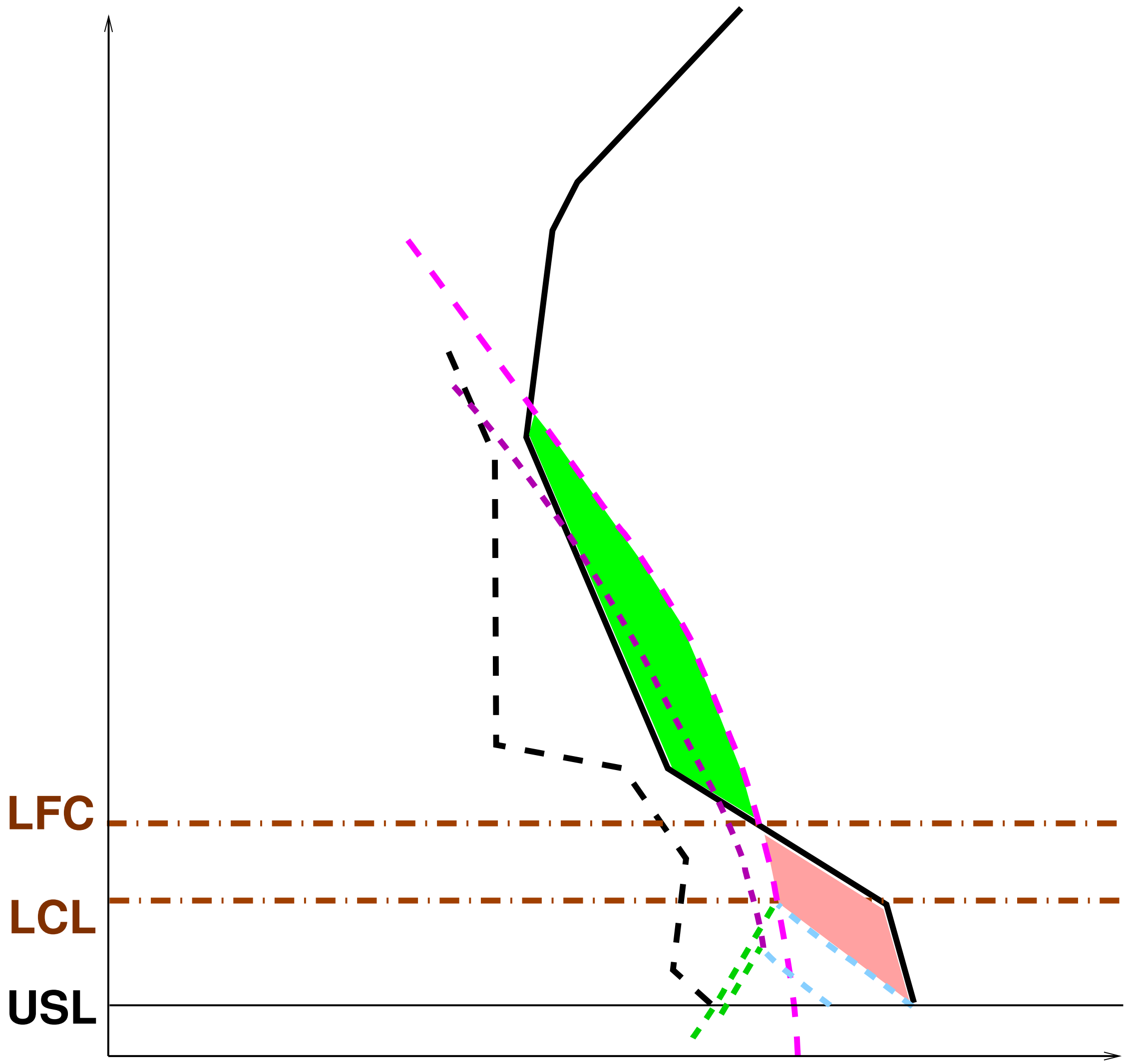
Main effect of downdraft is cooling and moistening USL



RMI

Downdraft effect on updraft closure

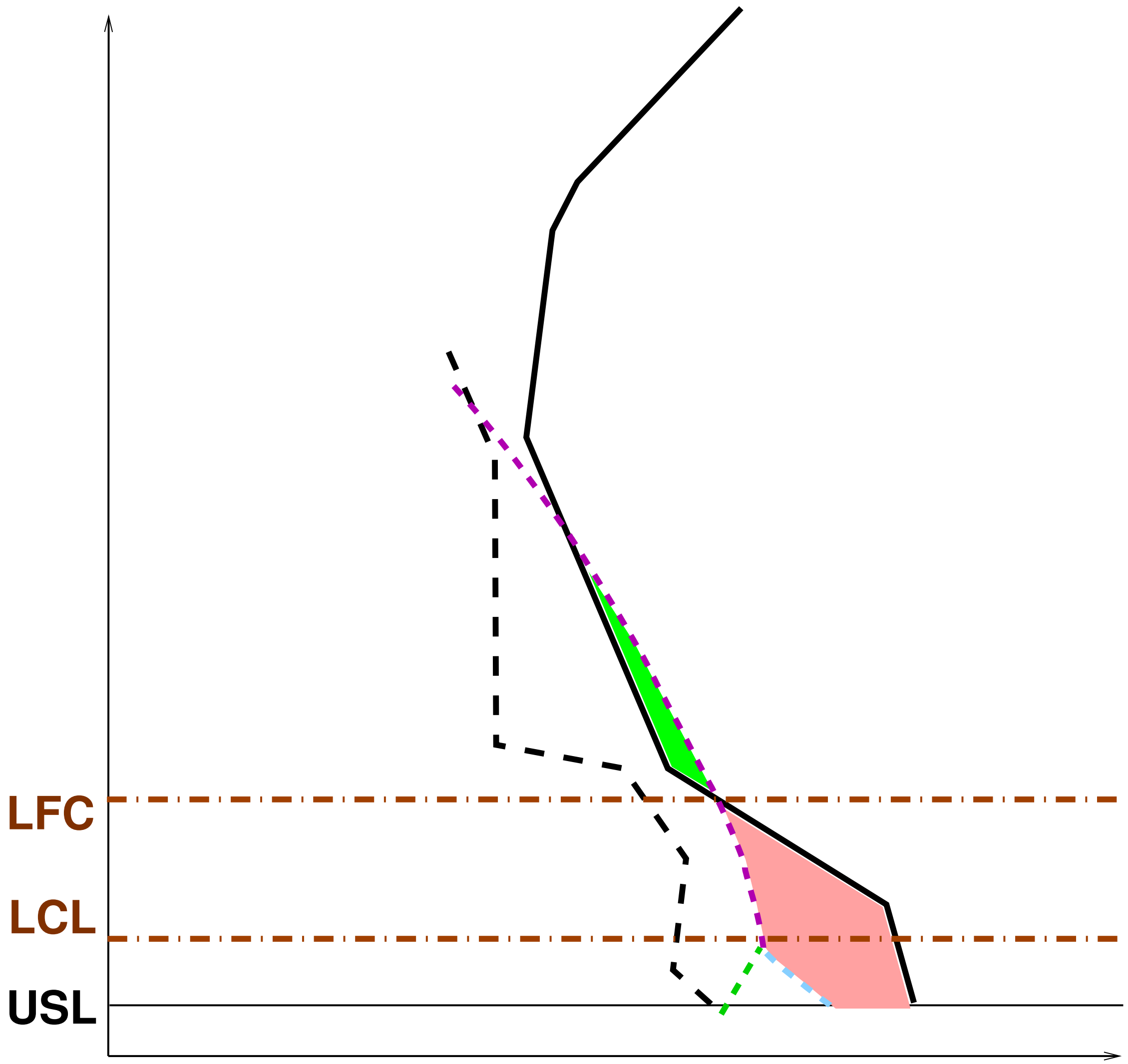
Main effect of downdraft is cooling and moistening USL



- Change LCL temperature and pressure level

Downdraft effect on updraft closure

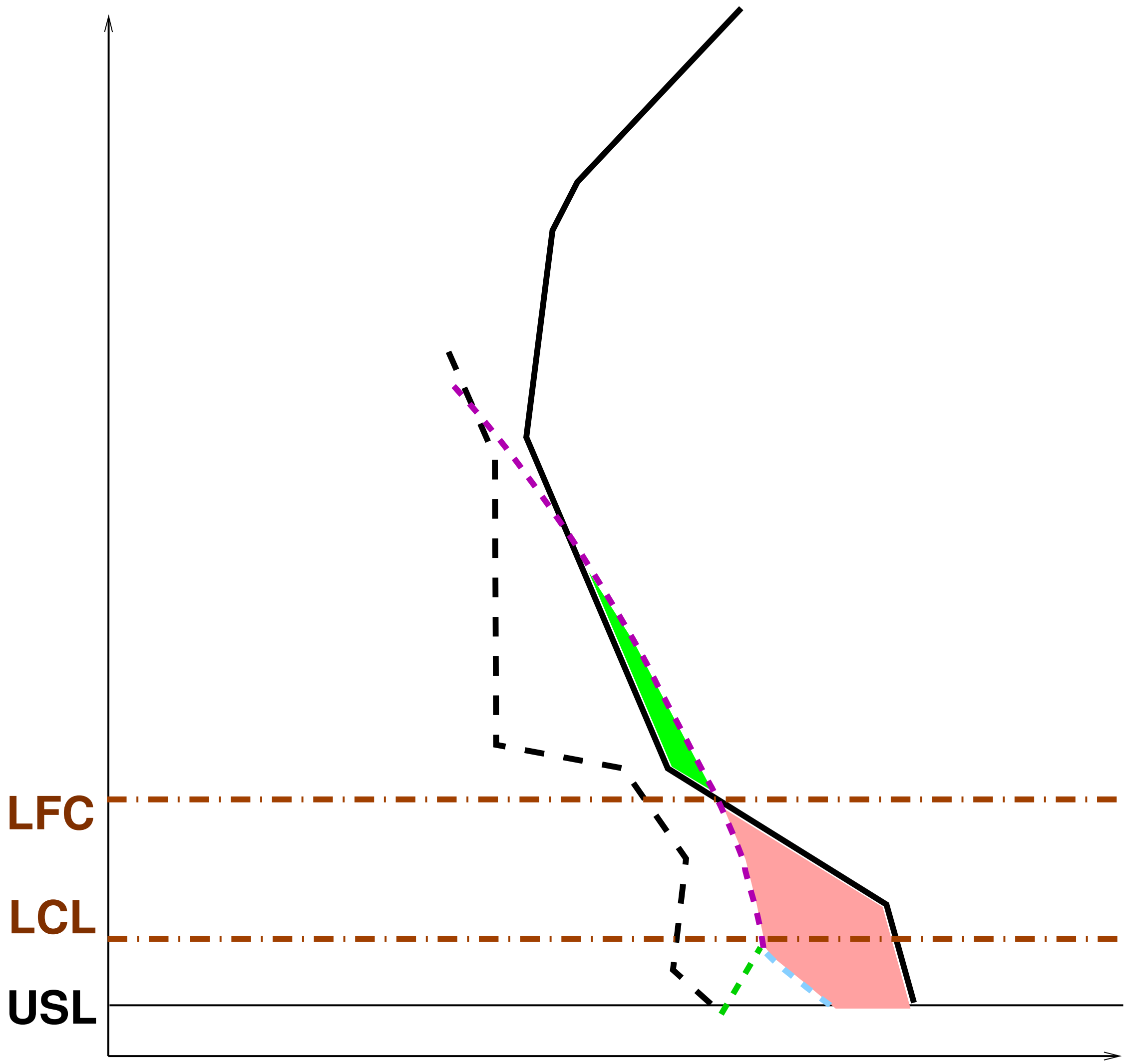
Main effect of downdraft is cooling and moistening USL



- Change LCL temperature and pressure level
- Change LFC ⇒ increased CIN
- Decreased CAPE

Downdraft effect on updraft closure

Main effect of downdraft is cooling and moistening USL



- Change LCL temperature and pressure level
- Change LFC $\Rightarrow$ increased CIN
- Decreased CAPE

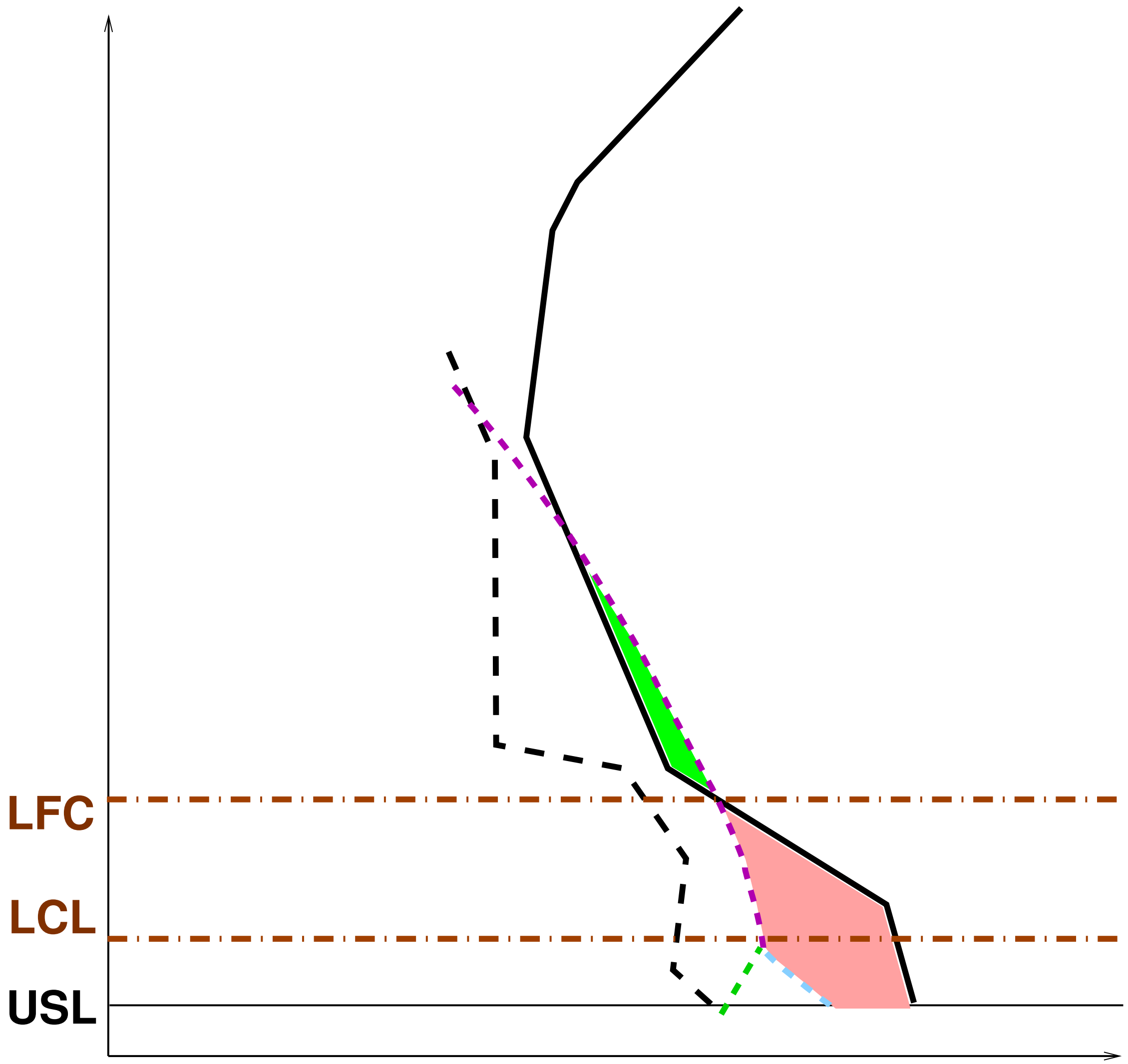
$$\int_b^t \frac{\theta_{vu} - \overline{\theta_v}}{\overline{\theta_v}} d\phi = -R_a \int_b^t (T_{vu} - \overline{T_v}) \frac{dp}{p}$$

$$\frac{\partial \text{CAPE}}{\partial t} \sim -\frac{\text{CAPE}}{\tau}$$

RMI

Downdraft effect on updraft closure

Main effect of downdraft is cooling and moistening USL



- Change LCL temperature and pressure level
- Change LFC ⇒ increased CIN
- Decreased CAPE

$$\int_b^t \frac{\theta_{vu} - \overline{\theta_v}}{\overline{\theta_v}} d\phi = -R_a \int_b^t (T_{vu} - \overline{T_v}) \frac{dp}{p}$$

$$\frac{\partial \text{CAPE}}{\partial t} \sim -\frac{\text{CAPE}}{\tau}$$

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

Downdraft effect on updraft closure

M_d^* advected from previous time step

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

RMI

Downdraft effect on updraft closure

M_d^* advected from previous time step

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

Bolton (1980)

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

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

Downdraft effect on updraft closure

M_d^* advected from previous time step

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

Bolton (1980)

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

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

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

RMI

Downdraft effect on updraft closure

M_d^* advected from previous time step

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

Bolton (1980)

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

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

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

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

RMI

Downdraft effect on updraft closure

M_d^* advected from previous time step

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

Bolton (1980)

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

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

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

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

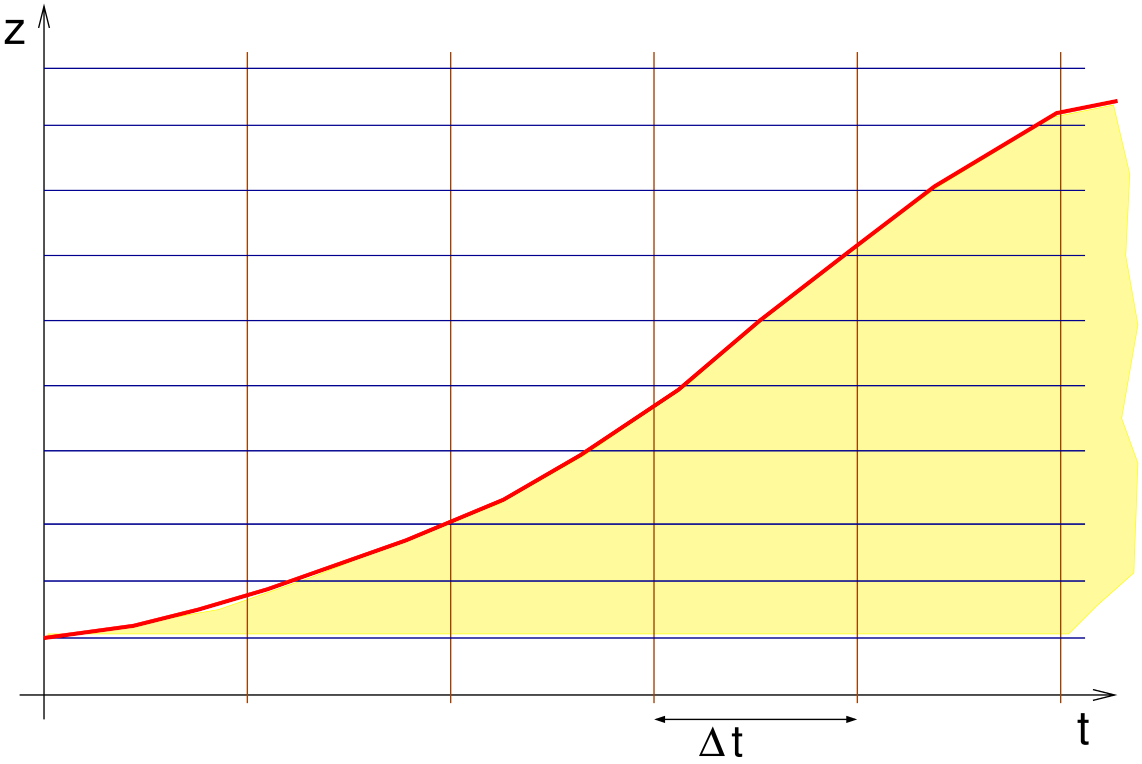
$$\frac{\partial T_{vu} - \overline{T_v}}{\partial t}\Big|_{dd} = \frac{\partial T^{LCL}}{\partial t}\Big|_{dd}(1 + \kappa q_u) + \frac{\partial q^{LCL}}{\partial t}\Big|_{dd}\kappa T_u - \frac{1}{c_p}M_d^*\frac{\partial \overline{s}}{\partial p}(1 + \kappa q_u) + M_d^*\frac{\partial \overline{q}}{\partial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

Updraft evolution

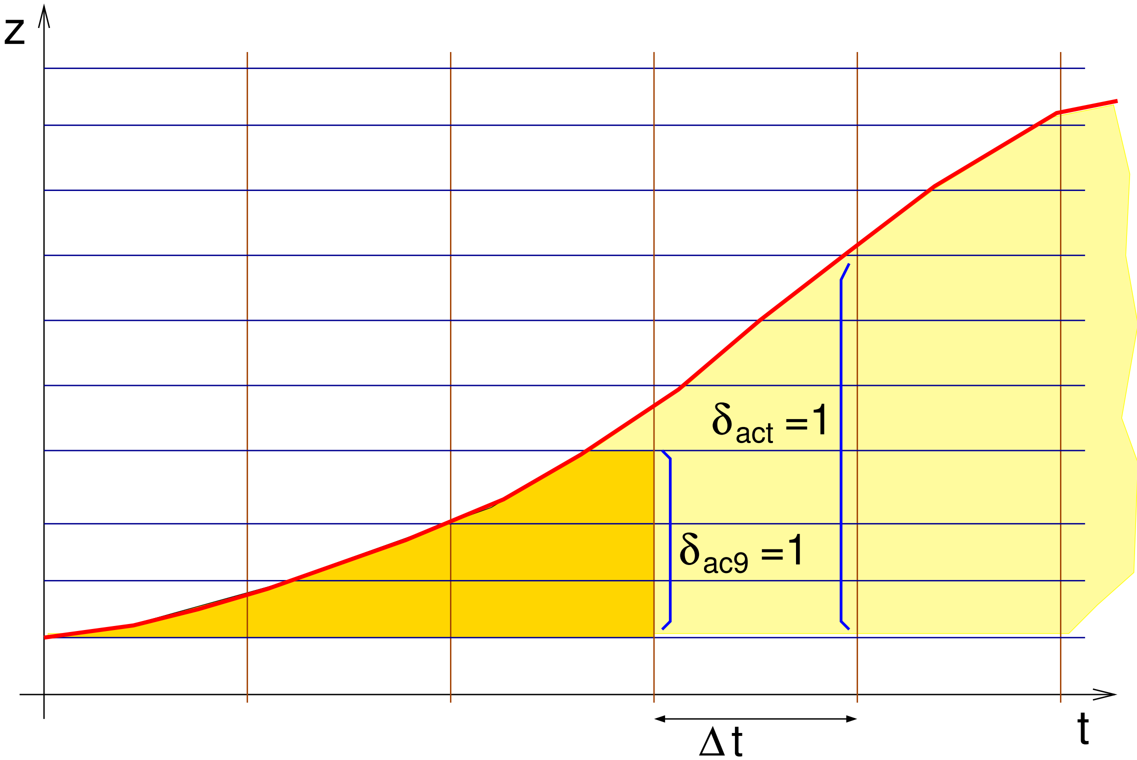
- Gradual elevation of the equivalent cloud top because:
  - The small grid box cannot contain a whole ensemble of clouds of different heights;
  - the time step is to short for the clouds to reach their full height in one time step.

Top evolution: activity index

Top evolution: activity index



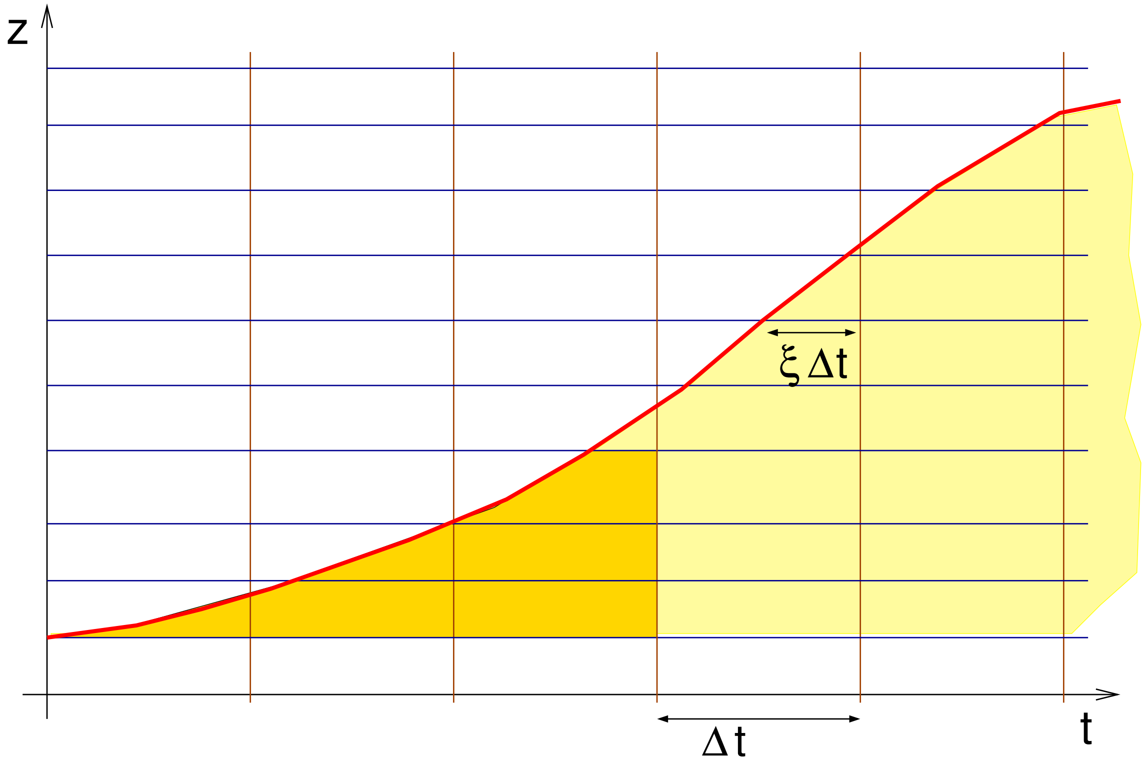
Top evolution: activity index



$\delta_{\mathrm{act}} = 1$ at levels reached by the ascent originating at the base

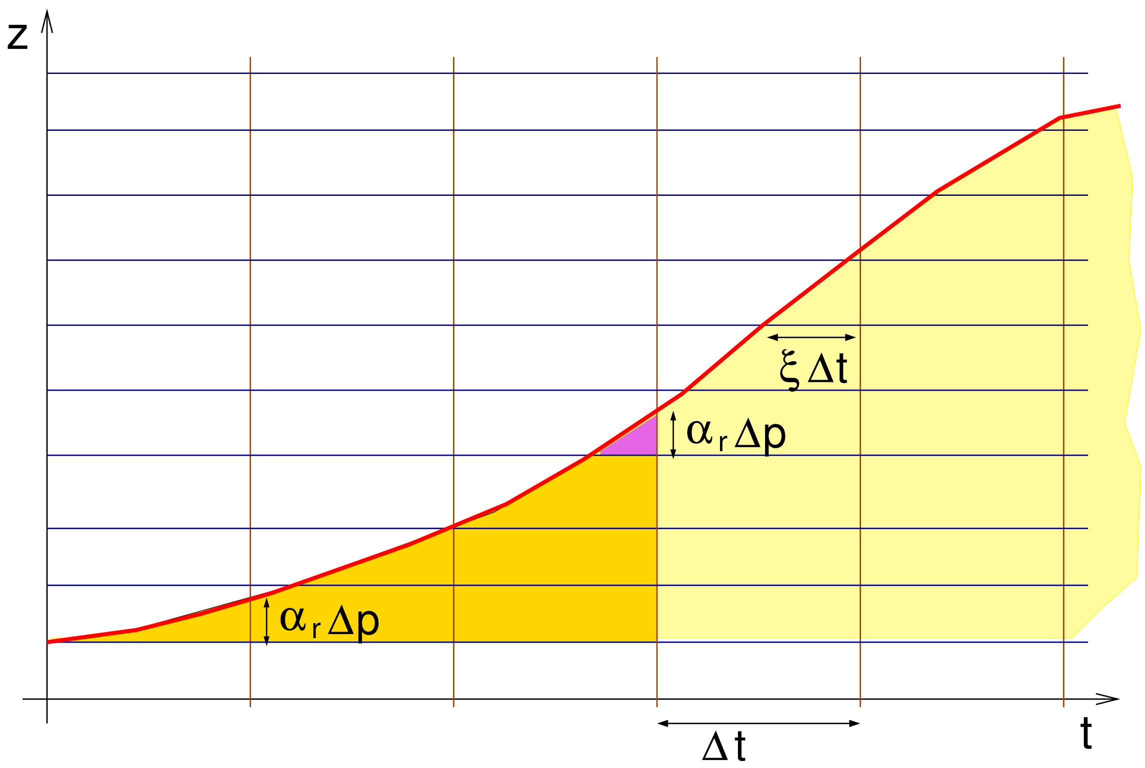
δ_{ac9} retrieved from profile of ω_u^- or σ_u^-

Top evolution: activity index



Buoyancy accelerates the fluid during $\xi \triangle t$

Top evolution: activity index

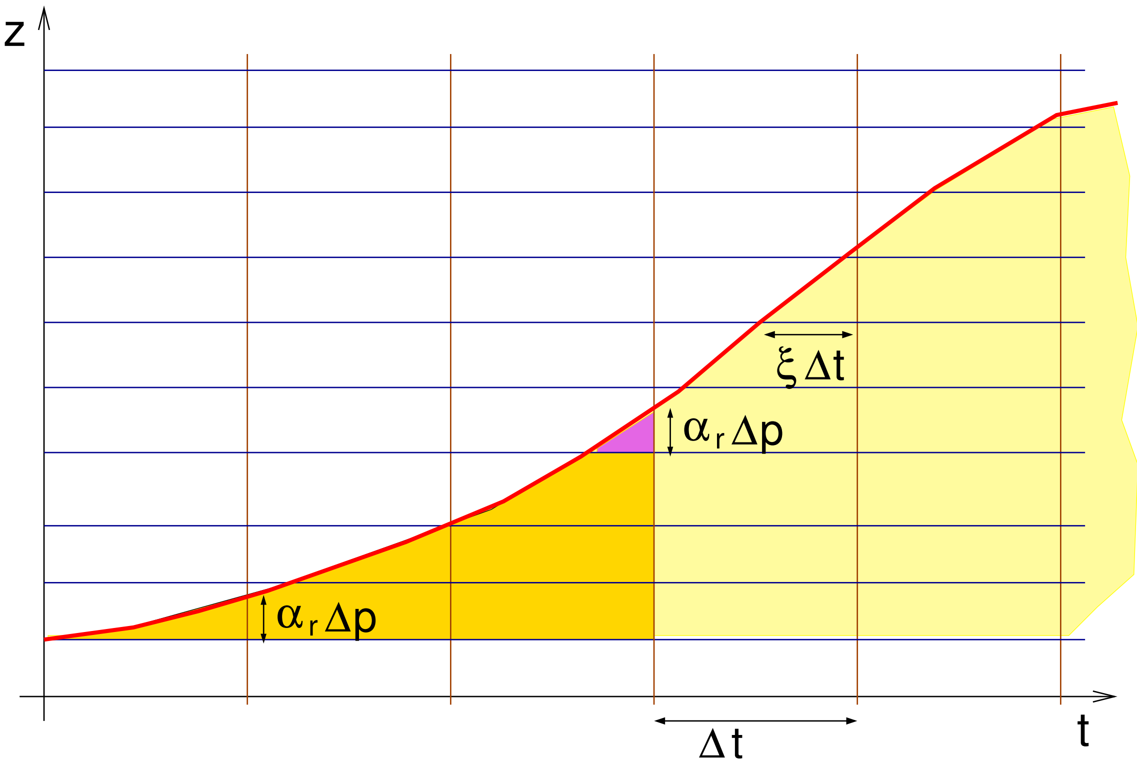


δ_{ac9}, δ_{act} record the discrete evolution of cloud vertical extension

ξ diagnosed for estimating time-averaged and final states

α_r records fractional path above upper last active level

Top evolution: activity index



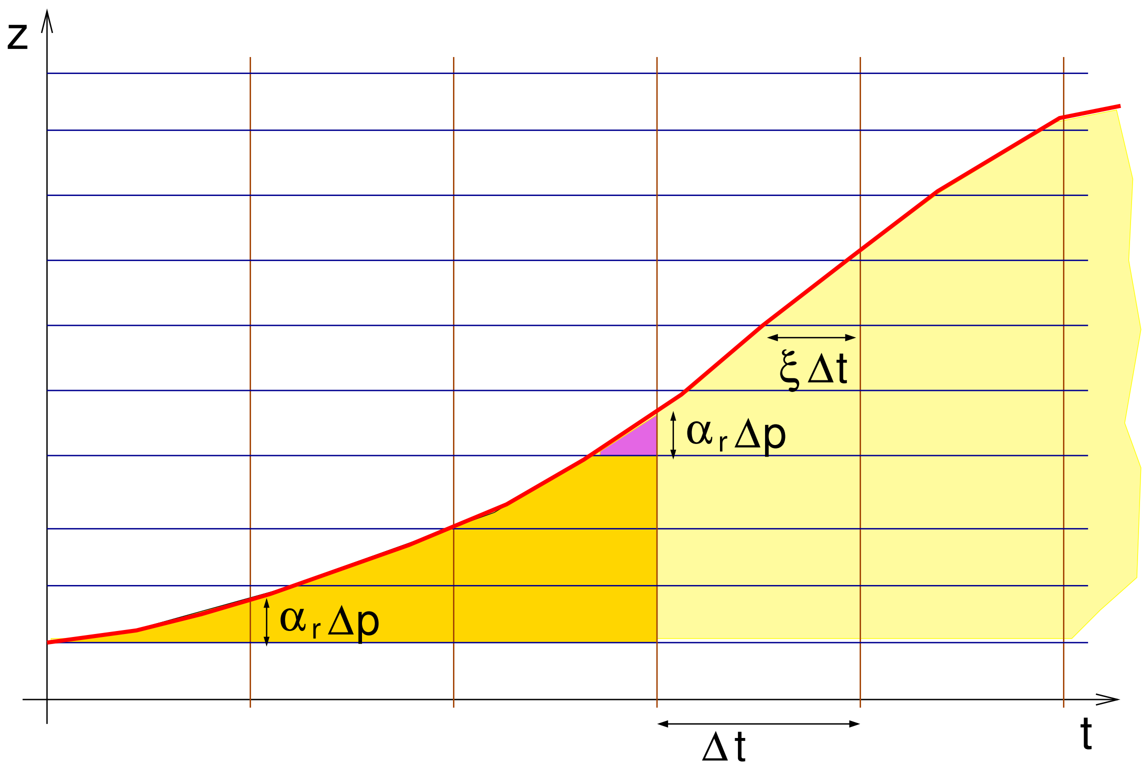
δ_{ac9}, δ_{act} record the discrete evolution of cloud vertical extension

ξ diagnosed for estimating time-averaged and final states

α_r records fractional path above upper last active level

- α_r is necessary for *initiating* an updraught with $|\omega_u|$ small;
- is necessary to compute ξ;
- is associated to a single cloud top:
  top level detected in advected variables (ω_u, σ_u), and can move its position following resolved advection.
- α_r cannot be interpolated between different columns.

Top evolution: activity index



δ_{ac9}, δ_{act} record the discrete evolution of cloud vertical extension

ξ diagnosed for estimating time-averaged and final states

α_r records fractional path above upper last active level

Idea: use a single α_r for the column, memorized in a local pseudo-historical variable:

- not advected, no interpolation;
- corresponding to the 'main' updraught segment.

Updraft evolution (continued)

- Gradual elevation of the equivalent cloud top because:
  - The small grid box cannot contain a whole ensemble of clouds of different heights;
  - the time step is to short for the clouds to reach their full height in one time step.

- Evolution of σ_u: relaxation towards $\sigma_u^{\parallel}$

$$\sigma_B^+ = \sigma_B^{\parallel}(1 - e^{-\triangle t/\tau}) + \sigma_B^- e^{-\triangle t/\tau} \qquad \tau = \text{gcvtausig} \sim 300\text{s}$$

Updraft evolution (continued)

- Gradual elevation of the equivalent cloud top because:
  - The small grid box cannot contain a whole ensemble of clouds of different heights;
  - the time step is to short for the clouds to reach their full height in one time step.

- Evolution of σ_u: relaxation towards $\sigma_u^{\|}$

$$\sigma_B^+ = \sigma_B^{\|}(1 - e^{-\triangle t/\tau}) + \sigma_B^- e^{-\triangle t/\tau} \qquad \tau = \text{gcvtausig} \sim 300\text{s}$$

  - allows to smooth the behaviour

Updraft evolution (continued)

- Gradual elevation of the equivalent cloud top because:
  - The small grid box cannot contain a whole ensemble of clouds of different heights;
  - the time step is to short for the clouds to reach their full height in one time step.

- Evolution of σ_u: relaxation towards $\sigma_u^{\|}$

$$\sigma_B^+ = \sigma_B^{\|}(1 - e^{-\triangle t/\tau}) + \sigma_B^- e^{-\triangle t/\tau} \qquad \tau = \text{gcvtausig} \sim 300\text{s}$$

  - allows to smooth the behaviour
  - appears better and simpler than a prognostic equation.

RMI

Updraft evolution (continued)

- Gradual elevation of the equivalent cloud top because:
  - The small grid box cannot contain a whole ensemble of clouds of different heights;
  - the time step is to short for the clouds to reach their full height in one time step.

- Evolution of σ_u: relaxation towards $\sigma_u^{\|}$

$$\sigma_B^+ = \sigma_B^{\|}(1 - e^{-\triangle t/\tau}) + \sigma_B^- e^{-\triangle t/\tau} \qquad \tau = \text{gcvtausig} \sim 300\text{s}$$

  - allows to smooth the behaviour
  - appears better and simpler than a prognostic equation.

- Evolution of $\omega_u^\diamond$: prognostic equation, using the final σ_u^+.

Limit $\dfrac{\omega_u^{\diamond +}}{\omega_u^\diamond} \leq \text{gmomuss} \sim 1.5$

Convective fluxes

MTCS: interaction with mean flow through transport and condensation.

- Production flux $M_u^\diamond = \sigma_u(\omega_u - \overline{\omega})$
- Transport flux $M_u^* = \sigma_u(\omega_u - \omega_e) = \frac{M_u^\diamond}{1-\sigma_u}$

Convective fluxes

MTCS: interaction with mean flow through transport and condensation.

- Production flux $M_u^\diamond = \sigma_u(\omega_u - \overline{\omega})$
- Transport flux $M_u^* = \sigma_u(\omega_u - \omega_e) = \frac{M_u^\diamond}{1-\sigma_u}$

Correction of the condensation: aplmini:
must apply to the effect of the absolute updraft
hence include an effect of the resolved condensation (ntypmel=1):

$$\triangle F_{cc} + 2\sqrt{\sigma_u(1-\sigma_u)}\triangle F_{cs}$$

Convective fluxes

MTCS: interaction with mean flow through transport and condensation.

- Production flux $M_u^\diamond = \sigma_u(\omega_u - \overline{\omega})$
- Transport flux $M_u^* = \sigma_u(\omega_u - \omega_e) = \frac{M_u^\diamond}{1-\sigma_u}$

Correction of the condensation: aplmini:
must apply to the effect of the absolute updraft
hence include an effect of the resolved condensation (ntypmel=1):

$$\triangle F_{cc} + 2\sqrt{\sigma_u(1-\sigma_u)}\triangle F_{cs}$$

Detrainment area σ_D: like in 3MT.

Convective fluxes

MTCS: interaction with mean flow through transport and condensation.

- Production flux $M_u^\diamond = \sigma_u(\omega_u - \overline{\omega})$
- Transport flux $M_u^* = \sigma_u(\omega_u - \omega_e) = \frac{M_u^\diamond}{1-\sigma_u}$

Correction of the condensation: aplmini:
must apply to the effect of the absolute updraft
hence include an effect of the resolved condensation (ntypmel=1):

$$\triangle F_{cc} + 2\sqrt{\sigma_u(1-\sigma_u)}\triangle F_{cs}$$

Detrainment area σ_D: like in 3MT.

Convective fraction $\sigma_u + \sigma_D$:
in the future, better to use a skewed distribution of moisture (Tompkins condensation scheme) and the same one to account for the intensive condensate estimation in the microphysics

Current status

- Equations appear complete — final re-read welcome.
  Related paper close to be finalized.

Current status

- Equations appear complete — final re-read welcome.
  Related paper close to be finalized.

- Final form of closure will be re-tested in coming weeks

Current status

- Equations appear complete — final re-read welcome.
  Related paper close to be finalized.

- Final form of closure will be re-tested in coming weeks

- Vertical variation of normalized mesh fraction μ: idem.

Current status

- Equations appear complete — final re-read welcome.
  Related paper close to be finalized.

- Final form of closure will be re-tested in coming weeks

- Vertical variation of normalized mesh fraction μ: idem.

- Possible dependency of entrainment on humidity, Lentch,... (later).

Current status

- Equations appear complete — final re-read welcome.
  Related paper close to be finalized.
- Final form of closure will be re-tested in coming weeks
- Vertical variation of normalized mesh fraction μ: idem.
- Possible dependency of entrainment on humidity, Lentch,... (later).
- accsu routine can be cleaned from various experimental options, final choice of relevant parameters.
- 1 additional scalar pseudo-historic field (updraft elevation between two levels).
- See triggering issues in next part.