Updraught and downdraught handling

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Topics

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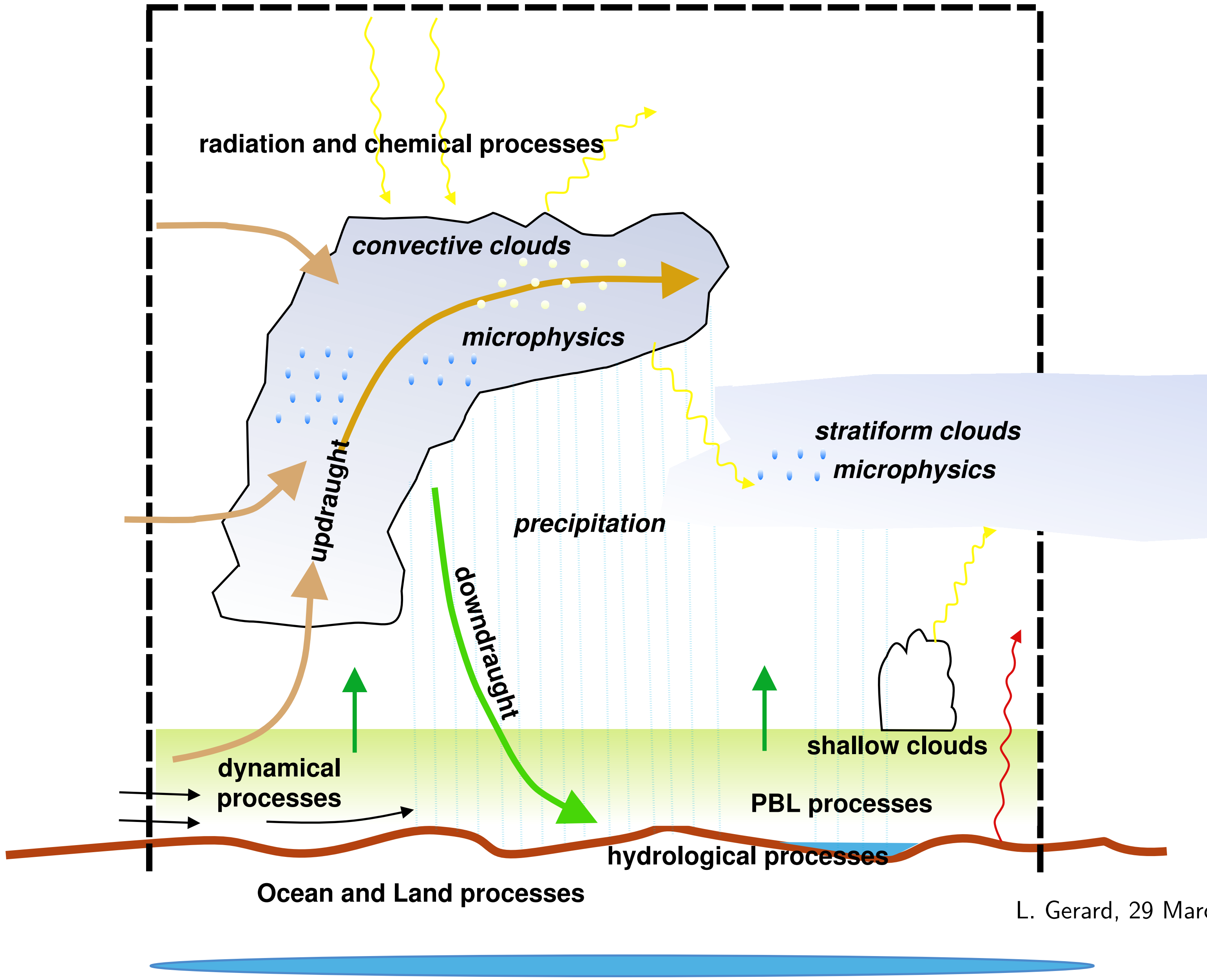
1. Physical context
2. Main choices :
   Mass-flux schemes – Condensation / evaporation / ud detrainment – MT coupling

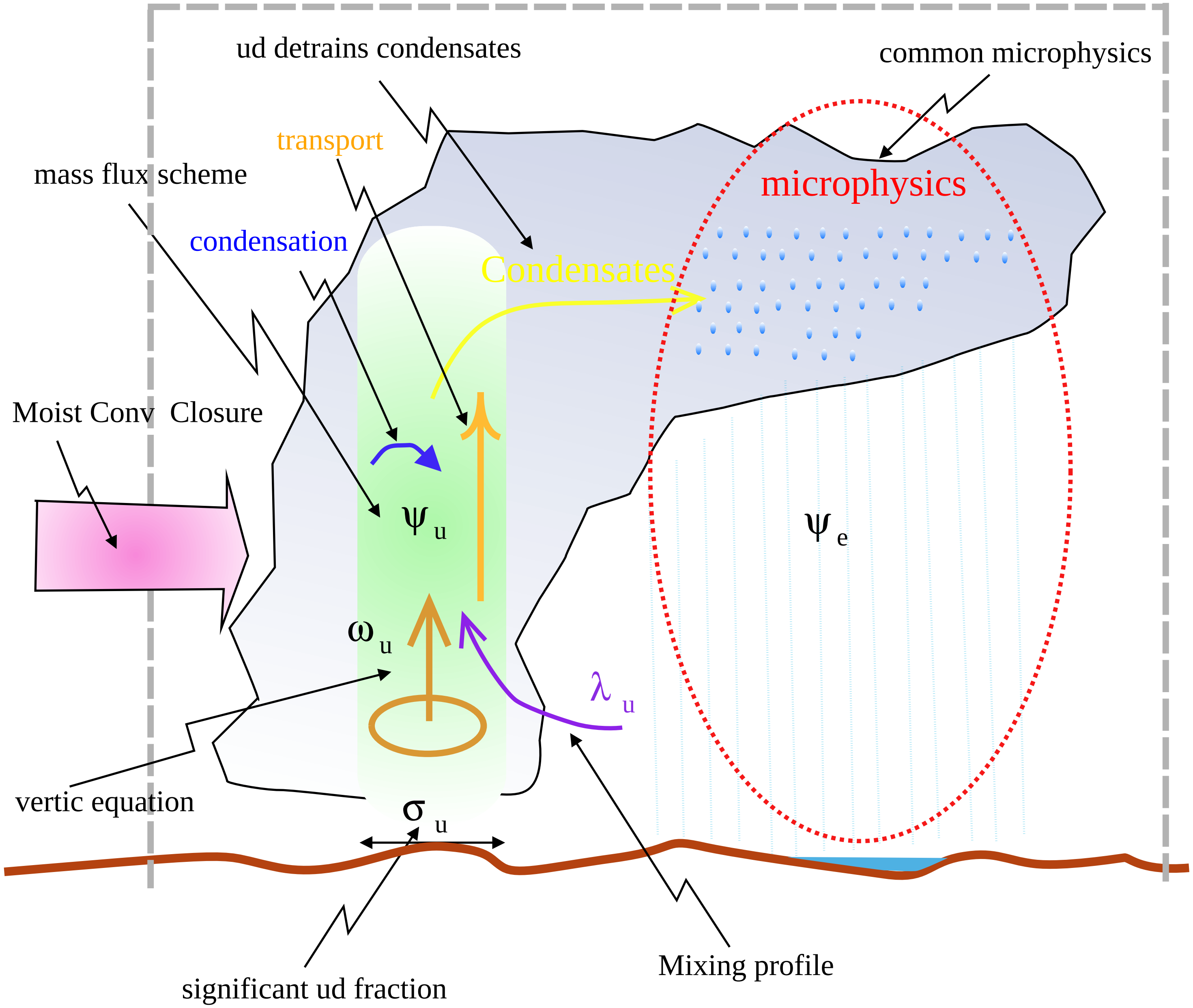
3. The updraught
   1. Cloud profile
      - Mixing – diagnostic – cloud ensemble – prognostic
      - Ascent – Condensates – detrained fraction
      - Vertical prognostic equation
   2. Closure and mesh fraction
   3. Momentum handling
   4. Outputs : fluxes – Other outputs

4. The downdraught
   1. Principles – environment
   2. Evaporating descent
      Mixing – Moist adiabat – Available condensate – Prognostic velocity
   3. How to close the downdraught
   4. Outputs - DD evaporation fluxes - DD transport fluxes
   5. Transport of precipitation by downdraught
   6. Implications on Sedimentation

Physical context



Main Choices



Convective updraught : ACCVUD

Structure :

– Initialisations

– Main vertical loop :

mixing coefficient λ_u

moist adiabatic segments alternating with isobaric mixing,

including Newton loop,.. $\rightarrow T_u, q_{vu}, q_{cu}, s_u, T_{vu}$

Activity diagnostic $\delta_{\rm act}$

prognostic vertical equation $\rightarrow \omega_u$

– Closure : prognostic equation $\rightarrow \sigma_u$

– Momentum profile $\rightarrow (u_u, v_u)$

– Output fluxes : condensation and transport

$\rightarrow F^u_{vi}, F^u_{v\ell}$, $J^u_v, J^u_i, J^u_\ell, J^u_s, J_{\mathbf{V}^u}$

Mixing

$$\frac{\partial \psi_u}{\partial \phi} = \lambda_u \left(\psi_e - \psi_u\right) = \frac{\lambda_u}{1 - \sigma_u} \left(\psi^* - \psi_u\right) \qquad \frac{\triangle M}{M} = \lambda_u \triangle \phi$$

$$\lambda_u^l = f(\phi, E_n, E_x, \alpha I_b)$$

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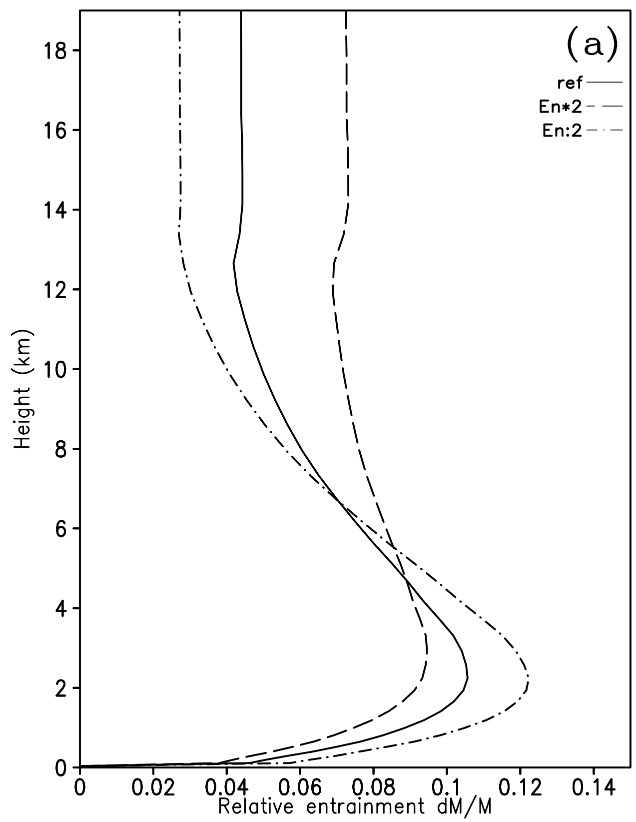

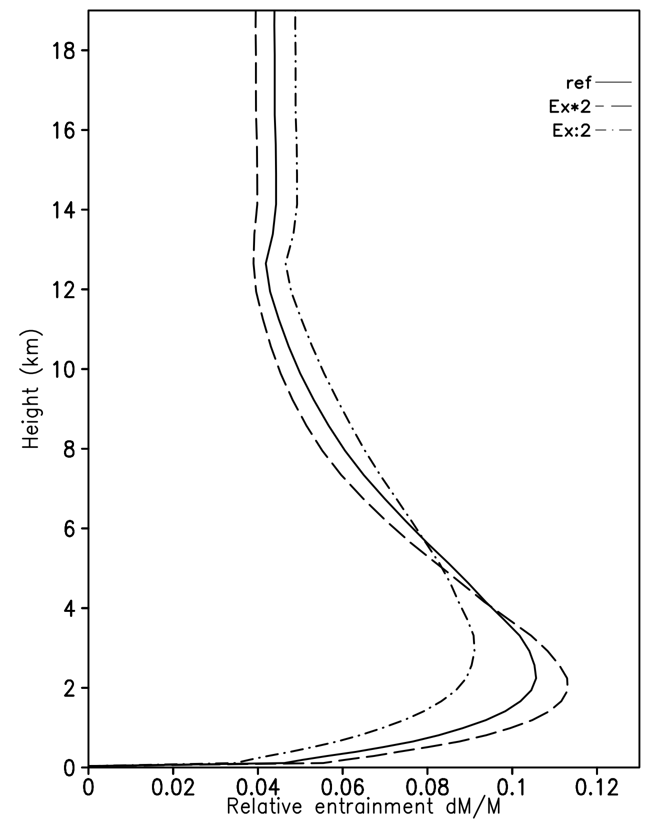

RMI

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$$I_b = \int_{\phi_L}^{\phi_1} (h_{ad} - h)\, d\phi$$

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– Ensemblist effects : *the highest clouds are the less entraining ones*
$\Rightarrow$ reduce the upward decrease of h_u, more if $(h_{ad} - h_u)$ greater.
For this use $\triangle \phi_u < \overline{\triangle \phi}$ above.

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Real prognostic approach,

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$$\frac{\partial\zeta}{\partial t} = \alpha_E \sigma_d - \frac{\zeta}{\tau_E}$$

- Turbulent contribution
- Acceleration with assumed constant mesh fraction induces additional mixing
- Downdraught activity reduces the mixing

RMI

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– Handle the produced condensate δq_{ca} :

$$\frac{\partial (q_{vu} + q_{cu})}{\partial \phi} = -\frac{q_{cu}}{\phi_0} \;\Rightarrow\; q_{cu} = q_{cb} e^{-\frac{\triangle \phi_u}{\phi_0}} + \delta q_{ca} \frac{\phi_0}{\triangle \phi_u} \left(1 - e^{-\frac{\triangle \phi_u}{\phi_0}}\right)$$

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– Activity declared if $T_{vu} > T_{ve}$ and moisture convergence.

Prognostic vertical equation

Prognostic model variable : $\omega_u^* = \omega_u - \omega_e$ (assuming $|\omega_u| \gg |\omega_e|$)

$$\frac{\partial \omega_u^*}{\partial t} + (\mathbf{V} \cdot \nabla)_\eta \omega_u^* + \dot{\eta}_u \frac{\partial p}{\partial \eta} \frac{\partial \omega_u^*}{\partial p} = \mathsf{source}(\omega_u^*)$$

RMI

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$$\left.\frac{\partial \omega_u^*}{\partial t}\right|_\Phi = -\frac{g^2}{1+\gamma'} \frac{p}{R_a} \frac{T_{vu} - \overline{T_v}}{\overline{T_v} T_{vu}} \qquad \text{buoyancy}$$

$$+ \frac{{\omega_u^*}^2}{p} \{(1-\sigma_u) + R_a T_{vu}(\lambda_u + \mathcal{K}_{du}/g)\} \qquad \text{"drag"}$$

$$- \frac{(1-\sigma_u)}{2} \frac{\partial {\omega_u^*}^2}{\partial p} \qquad \text{auto-advection}$$

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$$= A{\omega_u^*}^2 - \sigma_e \omega_u^* \frac{\partial \omega_u^*}{\partial p} - B'$$

Updraught closure by Moisture Convergence

Driving forces : from larger/slower scale *and* local scale

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buoyancy : generates the motion

supply of water vapour : generates the buoyancy by condensing.

$\Longrightarrow$ assumed to be the limiting factor.

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Driving forces : buoyancy, water vapour supply.

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$$h = s + Lq_v = c_p T + \phi + Lq_v$$

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condensation $\Rightarrow q_u \searrow$ but $T_u \nearrow$
$\Rightarrow$ moisture supply drives $\sigma_u(h_u - h_e)$

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Moisture transport :

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- Resolved convergence of water vapour towards the grid box
- Local convergence of water vapour from vertical turbulent diffusion
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$$\int_{p_t}^{p_b} \left[\frac{\partial \sigma_u}{\partial t}(h_u - h_e) \right] \frac{dp}{g} = L \int_{p_t}^{p_b} \left[CVGQ - \sigma_u(\omega_u - \omega_e) \frac{\partial \overline{q}}{\partial p} \right] \frac{dp}{g}$$

RMI

Momentum treatment

$$\frac{\partial M_u \mathbf{V}_u}{\partial p} = E\overline{\mathbf{V}} - D\mathbf{V}_u + \frac{\sigma_u}{g}\nabla\overline{\phi}$$

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cloud base : $\mathbf{V}_u^b = \overline{\mathbf{V}}^b$

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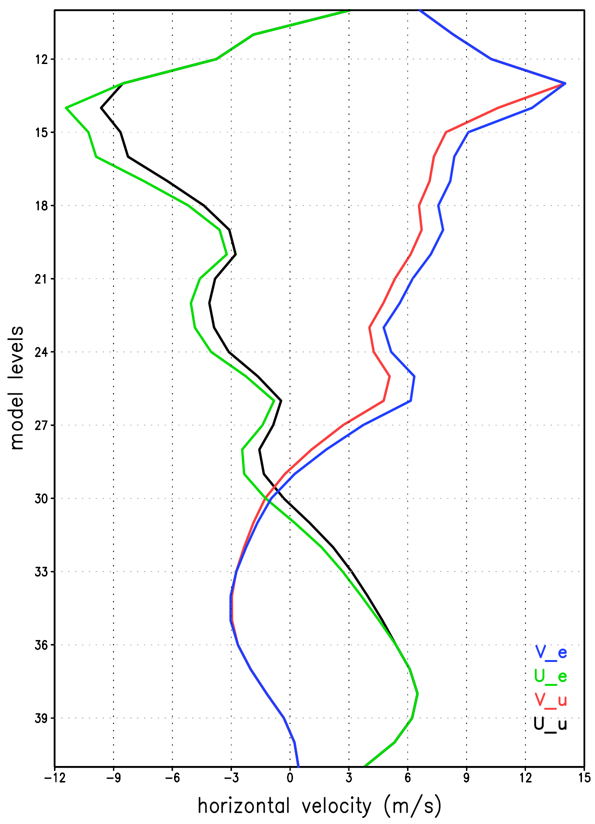

u_u, v_u, $\overline{u}$, $\overline{v}$

Output fluxes

Condensation in the ascent $\delta q_{ca} \Rightarrow$ condensation fluxes :

$$F_{cci}^{\bar{l}} = F_{cci}^{\overline{l-1}} + \alpha_i \delta q_{ca} \frac{(M_u)}{g}$$

$$F_{cc\ell}^{\bar{l}} = F_{cc\ell}^{\overline{l-1}} + (1-\alpha_i) \delta q_{ca} \frac{(M_u)}{g}$$

Mass-flux transport :

$$\frac{\partial \psi}{\partial t} = -\frac{\partial}{\partial p}\big(M_u(\overline{\psi} - \psi_u)\big) = -g \frac{\partial J_\psi^{cu}}{\partial p}$$

– applied, using an implicit discretization, to s, q_v, q_i, q_ℓ, u, v.

– no transport of q_r, q_s presently.

RMI

Other outputs

– Detrained condensate : local budget.

$$\underbrace{q_{cD}\delta\sigma_D\frac{\triangle p}{g} + q_{cu}\delta\sigma_u\frac{\triangle p}{g}}_{\text{storages}} = \underbrace{\delta q_{ca}\frac{M_u}{g}}_{\text{source}} - \underbrace{\frac{\triangle\left(M_u q_{cu}\right)}{g}}_{\text{ud transport}} - \underbrace{\frac{\lambda_u \triangle\phi M_u \overline{q_c}}{g}}_{\text{entrained}}$$

Assuming $q_{cD} = q_{cu} \Rightarrow \sigma'_D$
Then $\sigma_D = \min(\sigma'_D, 1 - \sigma_u) \Rightarrow q_{cD} \geq q_{cu}$

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– Updraught properties ⇒ updraught environment

$$\overline{\psi} = \sigma_u\psi_u + (1 - \sigma_u)\psi_e \qquad \Rightarrow \psi_e = \frac{\overline{\psi} - \sigma_u\psi_u}{1 - \sigma_u}$$

– Vertical velocity in updraught environment :

$$\omega_u^* \equiv \omega_u - \omega_e \qquad \Rightarrow \omega_e = \overline{\omega} - \sigma_u\omega_u^*$$

Moist downdraught : ACMODO

Driving process : cooling associated to precipitation flux :

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Driving process : cooling associated to precipitation flux :

– Taking the local temperature (but requires adapted c_p)
– Evaporating
– Melting
$\Rightarrow$ use *a part of* div $F_{h\mathcal{P}}$, (div precipitation flux latent heat).

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In which environment ?

→ Out of the updraught, *hence over* $\sigma_e = 1 - \sigma_u$

$$\omega_e = \overline{\omega} - \sigma_u \omega_u^*, \qquad \psi_e = \frac{\overline{\psi} - \sigma_u \psi_u}{1 - \sigma_u}$$

→ In the precipitation area.

→ The input profile not updated for what enters the closure.

→ Downdraught properties ψ_d, mesh fraction σ_d and output fluxes will be referred to σ_e.

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Phase partition for evaporation : determined by the phase of the precipitation α_{snow}, instead of $\alpha_i(T)$

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- Estimate cumulative evaporation flux to adapt $\mathcal{P}_{\rm av}$

$$F_{evP}{}^{*\overline{l-1}} = \sum_{k=1}^{k=l-1} \frac{1}{g\triangle t} \delta q_{ev}{}^{k} \sigma_d^k \omega_d^k \qquad \Rightarrow \mathcal{P}_{\rm av} \approx \mathcal{P} - F_{evP}{}^{*}$$

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$$F_{evP}{}^{*\overline{l-1}} = \sum_{k=1}^{k=l-1} \frac{1}{g\triangle t} \delta q_{ev}{}^k \sigma_d^k \omega_d^k \qquad \Rightarrow \mathcal{P}_{\mathrm{av}} \approx \mathcal{P} - F_{evP}{}^*$$

– Activity diagnostic : $\delta_{\mathrm{av}} = 1$ and
$T_{vd} < T_{ve}$ or $\omega_d > \omega_e$ at current or above level.

RMI

Prognostic downdraught velocity

– Use absolute velocity ω_d (not correlated with ω_e).

$$\frac{\partial \omega_d}{\partial t} + (\mathbf{V}\cdot\nabla)_\eta \omega_d + \dot{\eta}_d \frac{\partial p}{\partial \eta}\frac{\partial \omega_d}{\partial p} = \text{source}(\omega_d)$$

$$\left.\frac{\partial \omega_d}{\partial t}\right|_\Phi + (\omega_d - \overline{\omega})\left(\frac{\partial \omega_d}{\partial p} - \frac{\omega_d}{p} + \omega_d \frac{\partial \ln T_v}{\partial p}\right) = -\rho g \cdot \text{source}(w_d)$$

$$= -\frac{g^2}{1+\gamma'}\frac{\pi}{R_a}\frac{T_{vd}-T_{ve}}{T_{ve}T_{vd}} \qquad \text{buoyancy}$$

$$-\,\delta_{d\mathcal{P}}\left\{(\lambda_d + \mathcal{K}_{dd}/g)\frac{R_a T_{vd}}{\pi}\right\}(\omega_d - \omega_{\mathcal{P}})^2 \qquad \text{drag}$$

$$-\,\frac{a\omega_d^2}{(p_{\text{surf}} - p)^\beta} \qquad \text{surface braking (if } \omega_d > 0)$$

Downdraught closure

Downdraught does not depend on a larger scale forcing : driving forces coming
– from the same grid box
– with comparable time scale

Downdraught closure

– Driving force : cooling associated to precipitation flux

$$\varepsilon \cdot \int_{p_t}^{p_b} -g \frac{\partial F_{h\mathcal{P}}}{\partial p} \frac{dp}{g} \qquad [W m^{-2}] \qquad (\varepsilon \sim \frac{\sigma_d}{\sigma_{\mathcal{P}}})$$

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Evaporation in the descent $\delta q_{ev} \Rightarrow$ evaporation fluxes :

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Mass-flux transport :

$$\frac{\partial \psi}{\partial t} = -\frac{\partial}{\partial p}\Big(M_d(\psi_d - \overline{\psi})\Big) = -g \frac{\partial J_{\psi}^{dd}}{\partial p}$$

- applied, using an implicit discretization, to s, q_v, q_i, q_ℓ (with $q_{id} = 0 = q_{\ell d}$), u, v.
- no transport of q_r, q_s presently.

RMI

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$$\Rightarrow \sigma_P \text{ reduced downwards ?}$$

$$\omega_P \text{ increased by dd}$$

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Finite velocity sedimentation $\Rightarrow \delta\mathcal{P}$ occurs later than δF_{evP}.

Transient is missed !

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* Do not modify q_r, q_s at this time step
but dd activity intervenes in microphysics at next time step :
– to estimate the sedimentation velocity
– to reinforce evaporation