Combining a TKE scheme with a dual massflux scheme

(build from an older version Roel's scheme)

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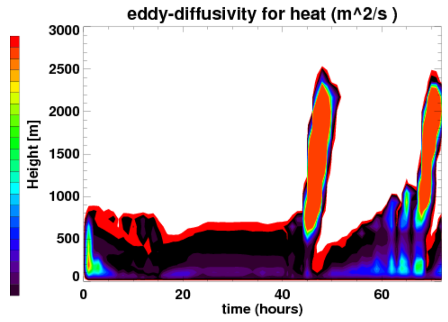
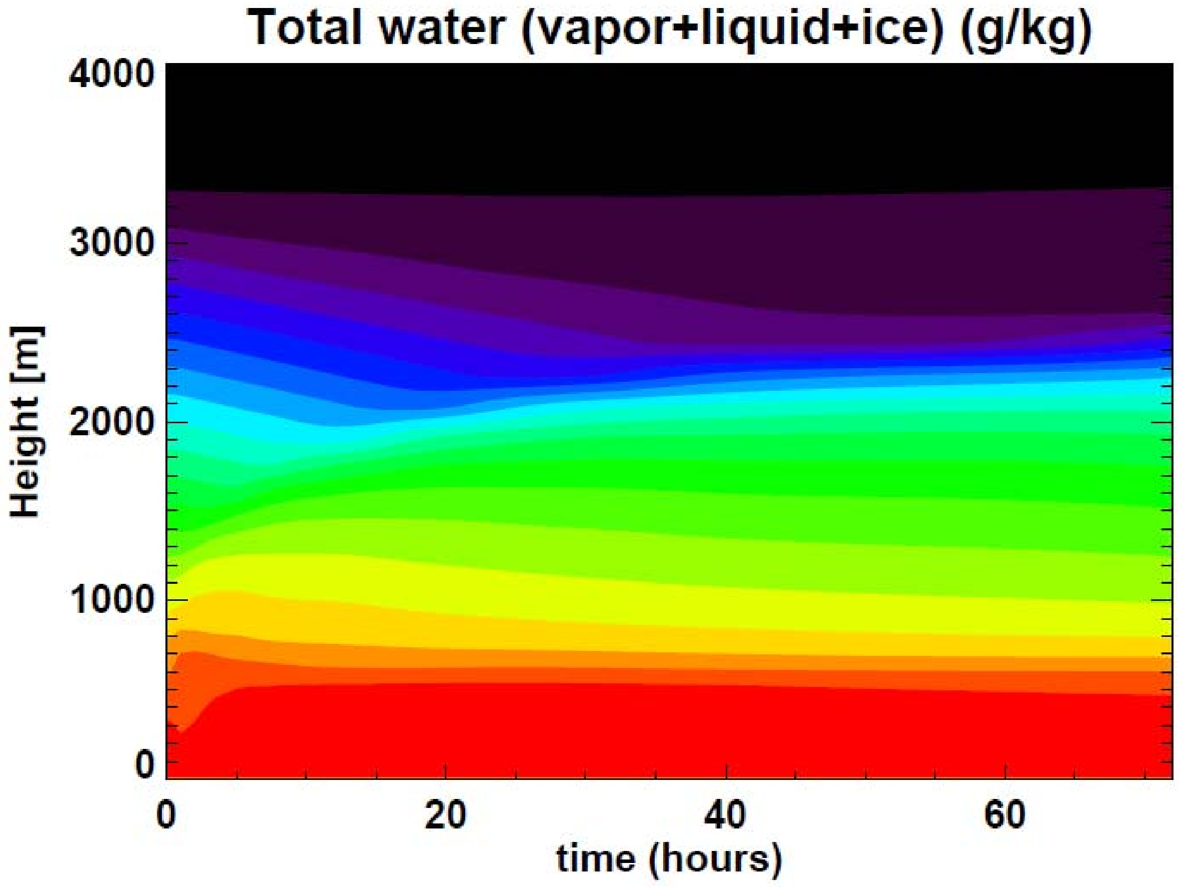
(thanks to Stephan de Roode, Pier Siebesma, en Wim de Rooy)

KNMI



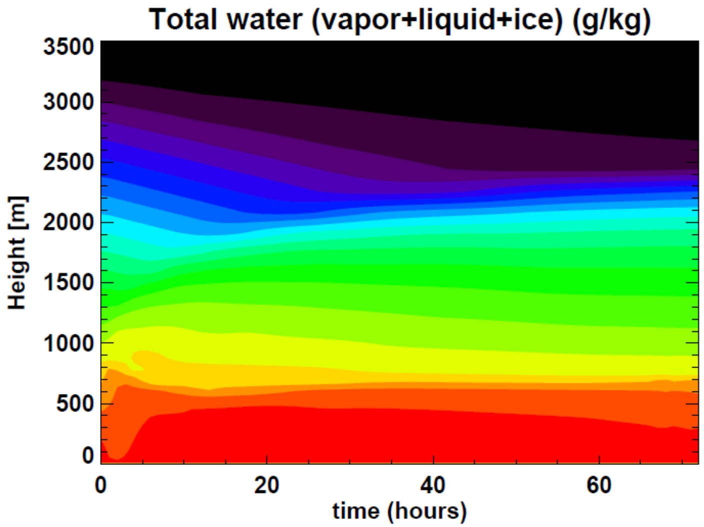
What I like ....

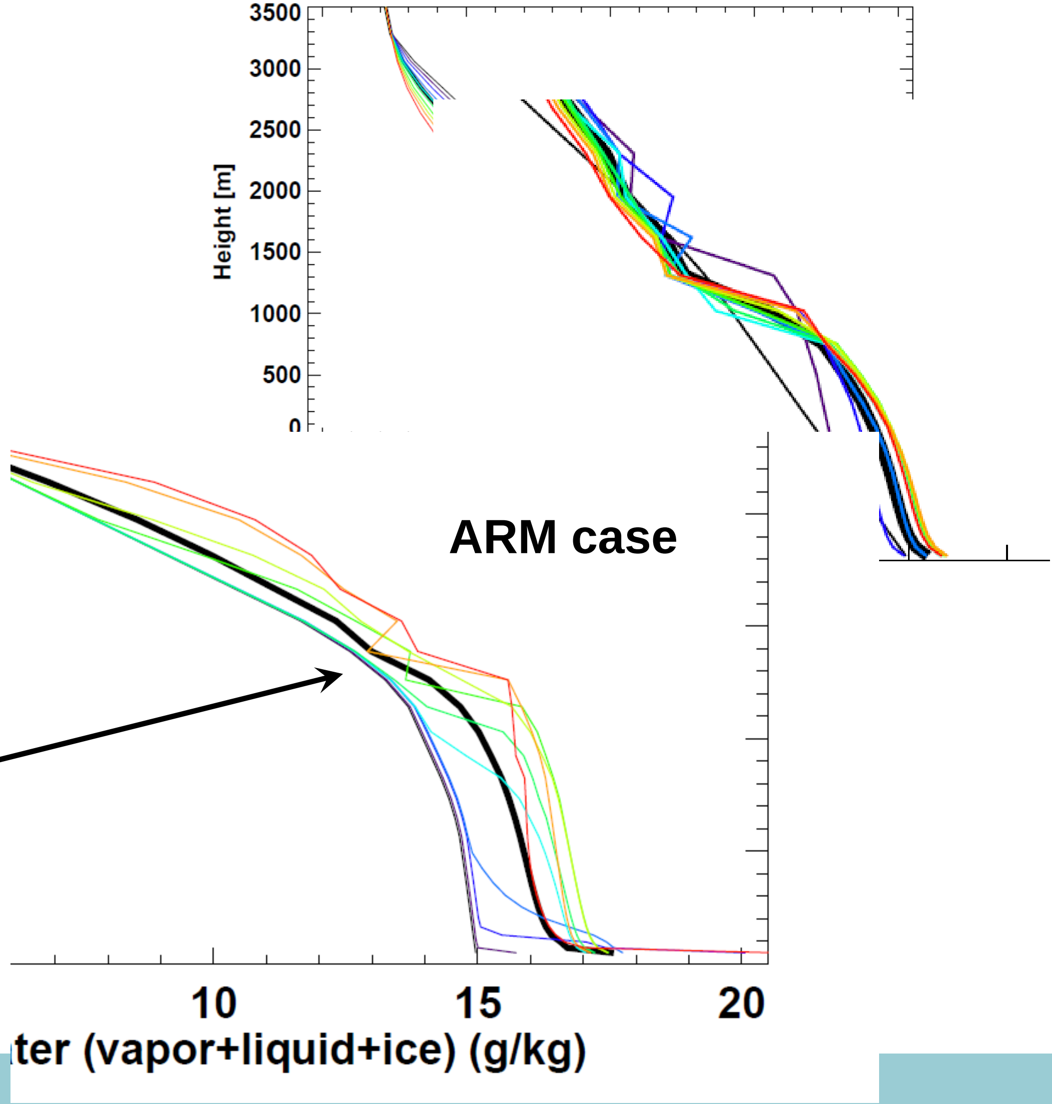
RICO
Cu case



What I hate ....

RICO case





instability

The usual TKE scheme

An equation for turbulent kinetic energy *E*

$$\frac{\partial E}{\partial t} = -\left(\overline{u'w'}\frac{\partial \overline{u}}{\partial z} + \overline{v'w'}\frac{\partial \overline{v}}{\partial z}\right) + \frac{g}{\theta_v}\overline{w'\theta_v'} - \frac{\partial}{\partial z}\left(\overline{w'E} + \overline{w'p'}/\rho\right) - \varepsilon$$

St Sh B/B T D

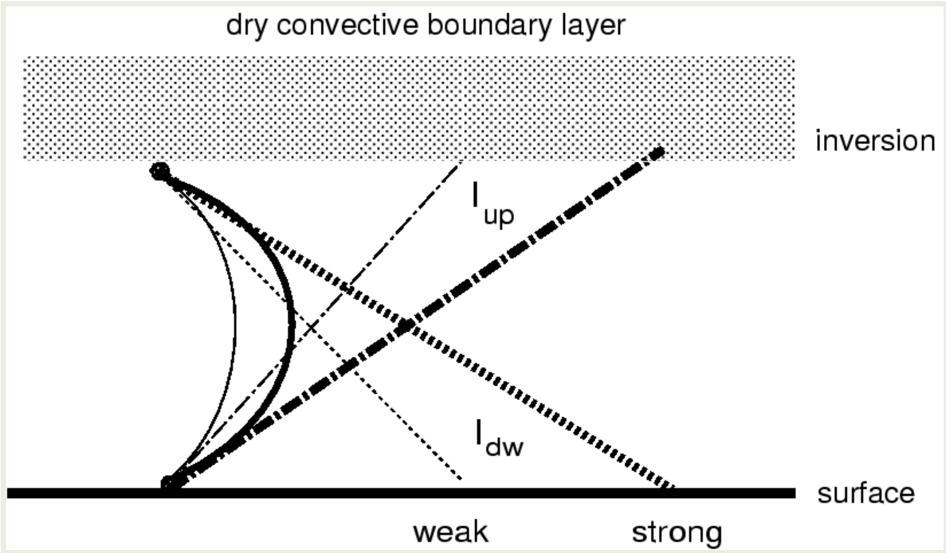
Mixing in boundary layer according to:

X: source

Y: sink

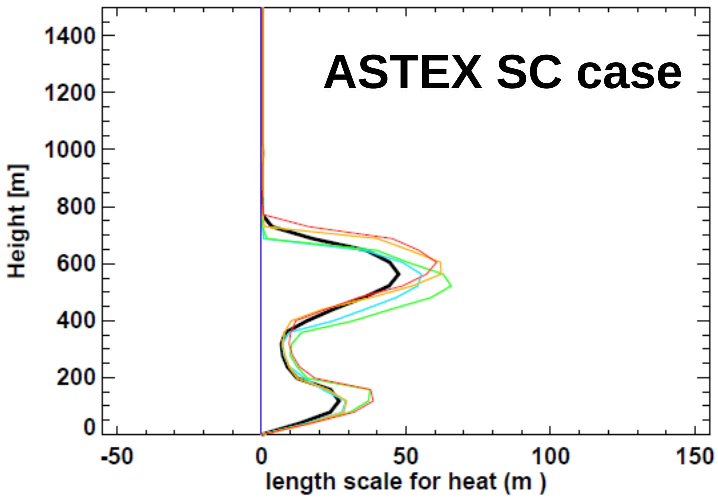
$$\text{Flux} = -K_\psi \frac{\partial \Psi}{\partial z} \quad \text{with} \quad K_\psi = l_\psi \sqrt{E}$$

Integral length scale formulation



$$l_{up} = \int_0^z f(Ri)dz$$

$$l_{dw} = \int_z^h f(Ri)dz$$



Lenderink & Holtslag, QJRMS, 2004

Dual mass flux scheme

Dry updraft

initialization : $\varphi^{up} = \varphi_s + \sim \sigma_\varphi$

updraft fraction : $a_d = 0.10 - a_m$

massflux : $M = a_d w_u$

entrainment : $\varepsilon \sim \frac{1}{z} + \frac{1}{h-z}$

Moist updraft

initialization : $\varphi^{up} = \varphi_s + \sim \sigma_\varphi$

updraft fraction : $a_m = 0.03$ (always Cu and Sc!)

massflux : $M = M_{base} f(z, \chi_{crit})$

$M_{base} = a_m w^*, \chi_{crit}$ (De Rooy & Siebesma, 2008)

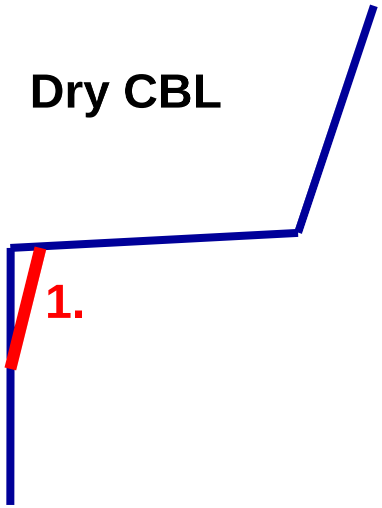
entrainment : $\varepsilon \sim \frac{1}{z} + \frac{1}{h-z}$ (subcloud)

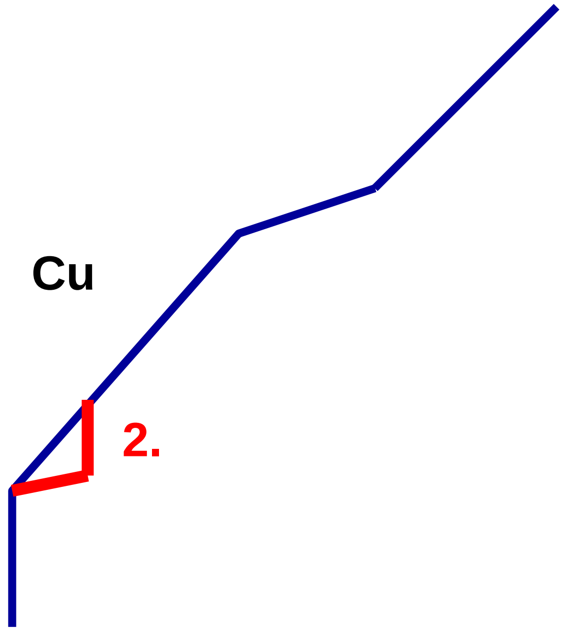
$\varepsilon \sim \frac{1}{z}$ (cloud) (or $\frac{1}{\mathrm{w}_{\mathrm{up}} \tau}$)

(no explicit formulation δ!)

NOTE: all fluxes at interfaces (e.g. top entrainment) are done implicitely by the schemes

Challanges: combining TKE with a massflux (MF) scheme; MF -> TKE





1. **MF creates (slightly) stable layer above 0.6h (*wanted*) -> TKE mixing ceases (*unwanted*)**

2. MF creates jumps of qt and θl at cloud base (*unwanted*)

Modification 1.
adjusting Ri in length scale formulation (only dry updraft)

$$-K_h\left[\frac{\partial\theta_v}{\partial z}\right]_{\text{no mf}} = -K_h\left[\frac{\partial\theta_v}{\partial z}\right]_{\text{mf}} + M(\theta_v^{up} - \theta_v)$$

simplifications

$$K = 0.1hw^* \quad \text{and} \quad M = 0.1w_u \text{ and}$$

$$(\theta_v^{up} - \theta_v) = (\theta_v^{up} - \theta_v)_{surface}$$

Thus :

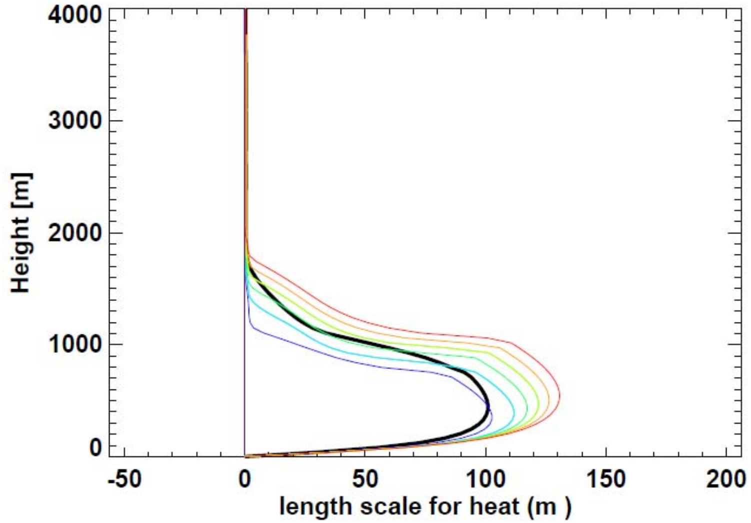
$$\text{Ri}_* = \frac{\text{N}_*^2}{\text{S}^2}$$

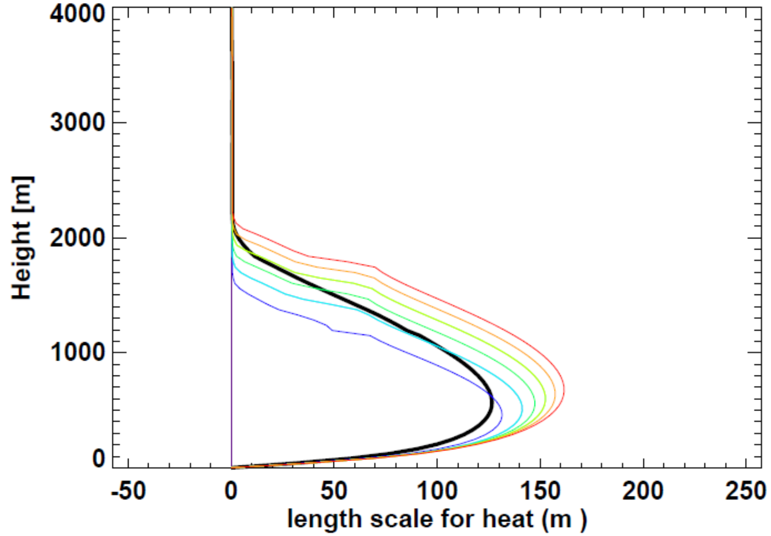
$$\text{N}_*^2 = \text{N}^2 - \frac{\text{g}}{\theta_v}\frac{w_u}{hw^*}(\theta_v^{up} - \theta_v)_{surface}$$

Note: only used in lengthscale formulation, not in buoyancy production in TKE equation !

Modification 1.
adjusting Ri in length scale formulation

Length scale in dry convective boundary layer





Without modification

With modification

Modification 2.
energy cascade term into TKE scheme

Dissipation term updraft equation added as a source term into TKE equation

$$\left[\frac{\partial E}{\partial t}\right]_{MF} = \varepsilon_1 w^2_{u,1} M_1 + \varepsilon_2 w^2_{u,2} M_2$$

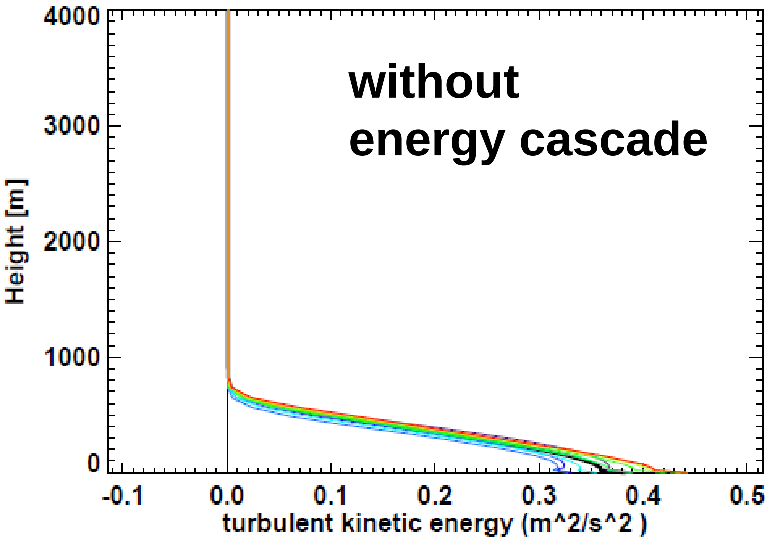
=> Simple formulation, used here

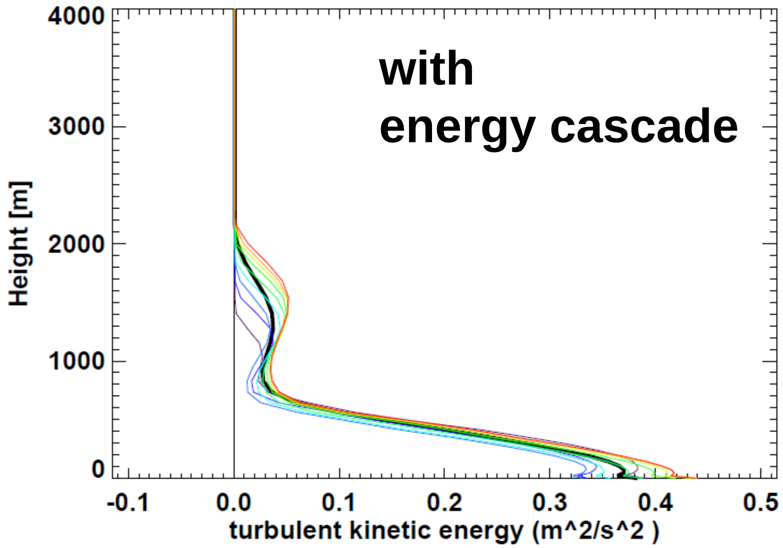
$$\left[\frac{\partial E}{\partial t}\right]_{MF} = \varepsilon_1 w^2_{u,1} M_1 + \varepsilon_2 w^2_{u,2} M_2 - \frac{\partial M_1}{\partial z} w^2_{u,1} - \frac{\partial M_2}{\partial z} w^2_{u,2}$$

(from Stephan de Roode)

Modification 2.
energy cascade term into TKE scheme

TKE in RICO Cu case





Modification 3.
additional diffusion in massflux (only wet parcel)

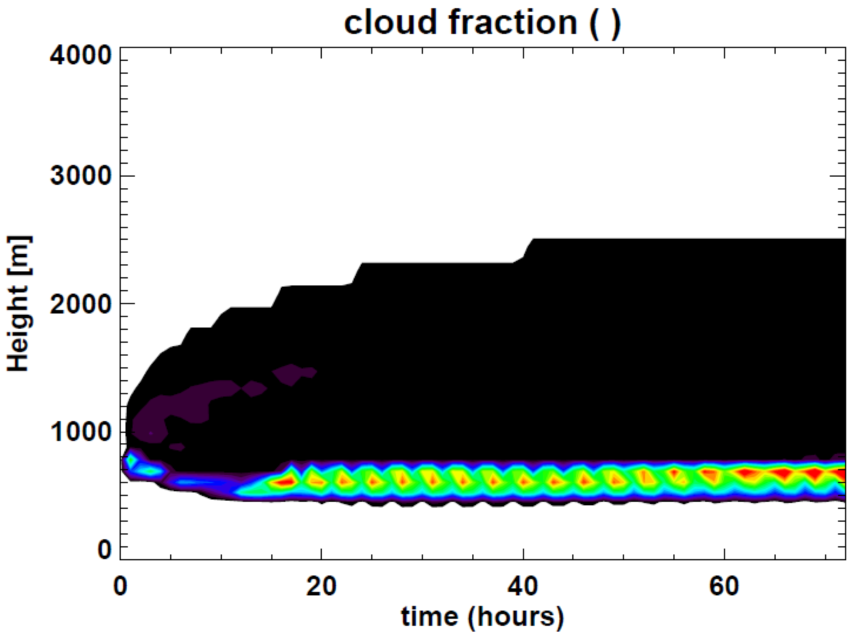
Add additional diffusion ..

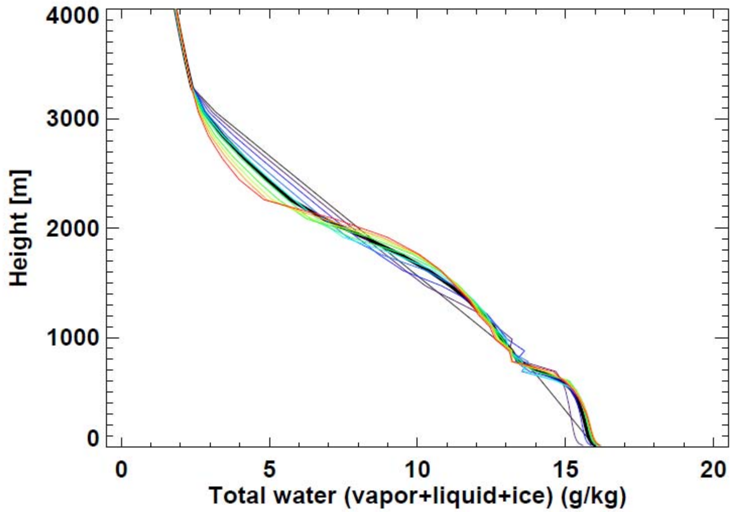
$$K_{mf} = 0.05 l_{cloud} M_2$$
$$\sim 1\text{ - }2\ \mathrm{m^2 s^{-1}}$$

$$K_{mf} \frac{\partial q_t}{\partial z} = 0.05 l_{cloud} M_2 \frac{\partial q_t}{\partial z}$$
$$\sim 0.05 l_{cloud} M_2 \frac{q_t^{up} - q_t}{l_{cloud}} = 0.05 M_2 (q_t^{up} - q_t)$$

Without modification 2 & 3 Cu clouds get unstable

$$\left[\frac{\partial E}{\partial t}\right]_{MF} \qquad K_{mf} = 0.05 l_{cloud} M_2$$





Challanges: combining TKE with a massflux (MF) scheme; moist TKE feedback

Buoyancy producton in TKE scheme

$$\left[\frac{\partial \theta_v}{\partial z}\right]^* = [c a_c + (1-c) a_d] \frac{\partial \theta_l}{\partial z} + [c b_c + (1-c) b_d] \frac{\partial q_t}{\partial z}$$

$c = \text{cloud fraction}$

a_c, a_d, b_c, b_d "constants"

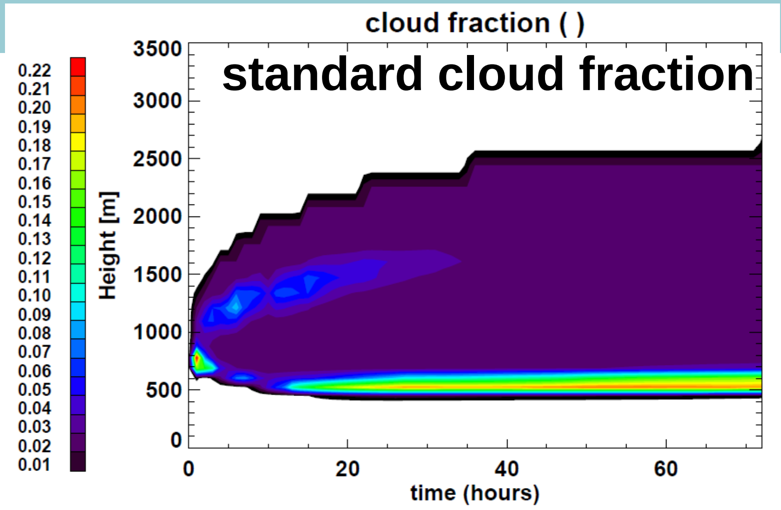
Typically Cu profiles are unstable compared to moist mixing (cloud fraction = 1) and stable compared to “dry” mixing (cloud fraction = 0)

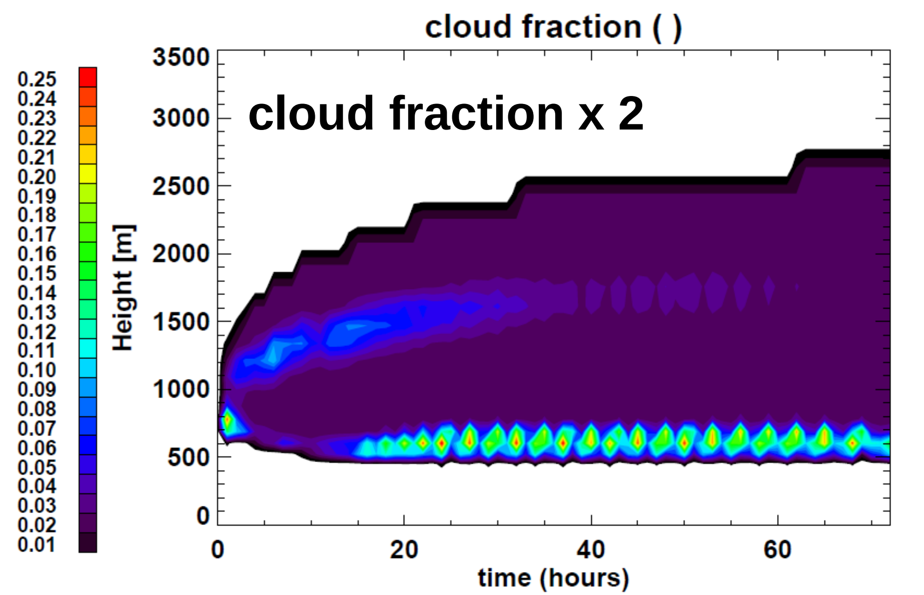
Positive feedback for cloud fraction sufficiently high (typically 40 %)
mixing -> more bouyancy prod. -> more TKE -> more mixing.

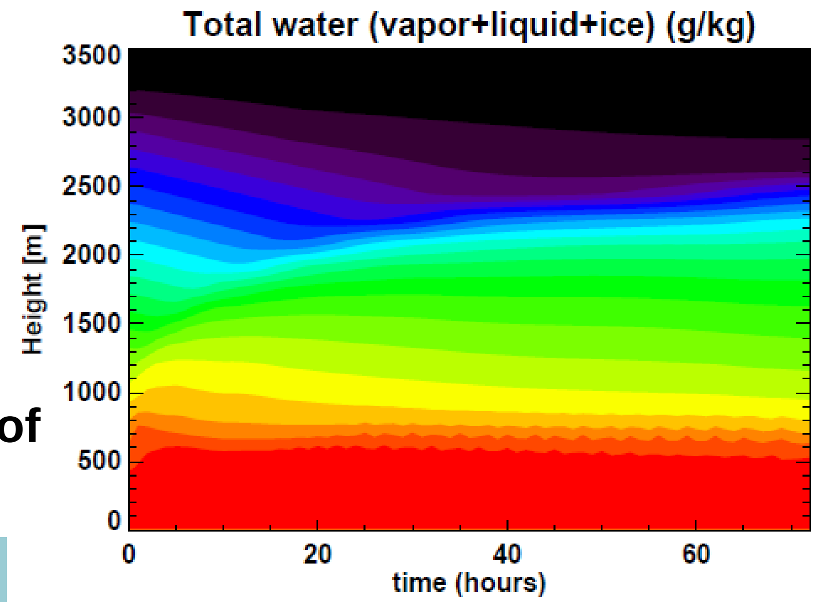
Often scheme adjust its cloud fraction to avoid this feedback

In our scheme, simple formulation of cloud fraction based on qt and variance qt is used.

Moist TKE feedback: RICO case



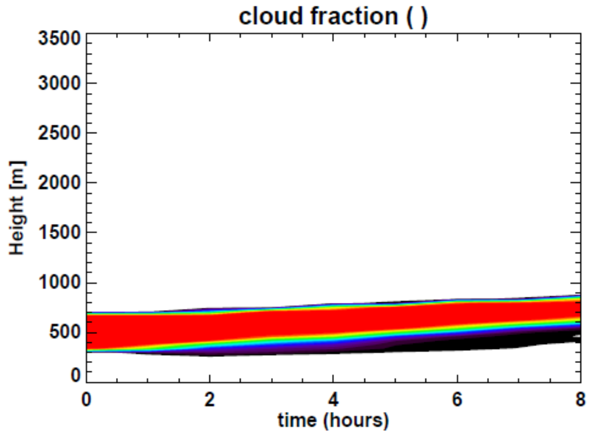


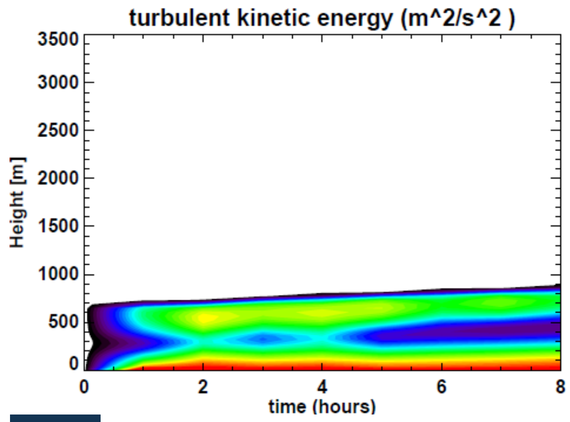


Oscillations, but no sign of instability (yet)

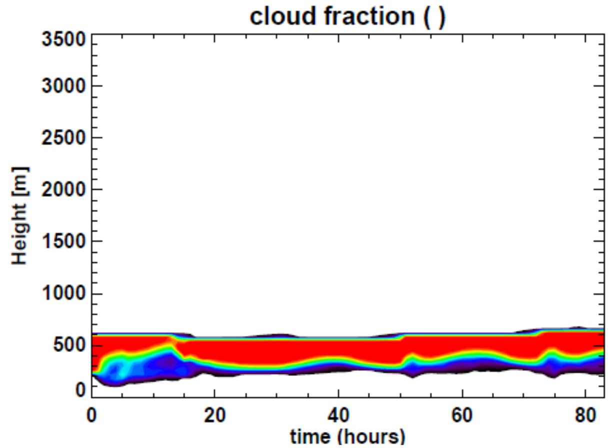
Simple physics, “same” for Cu and Sc, yet the scheme can do many Cu and Sc cases

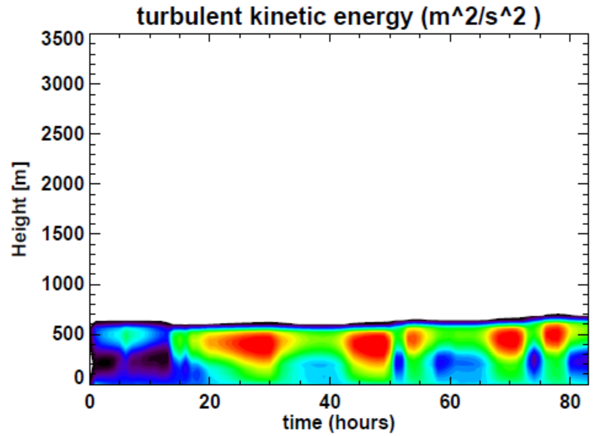
ASTEX SC



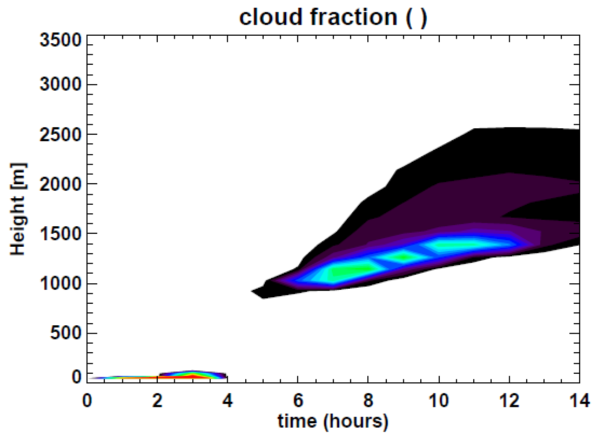


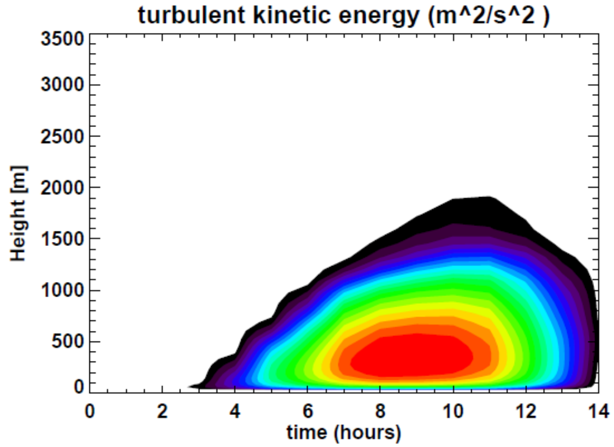
FIRE SC





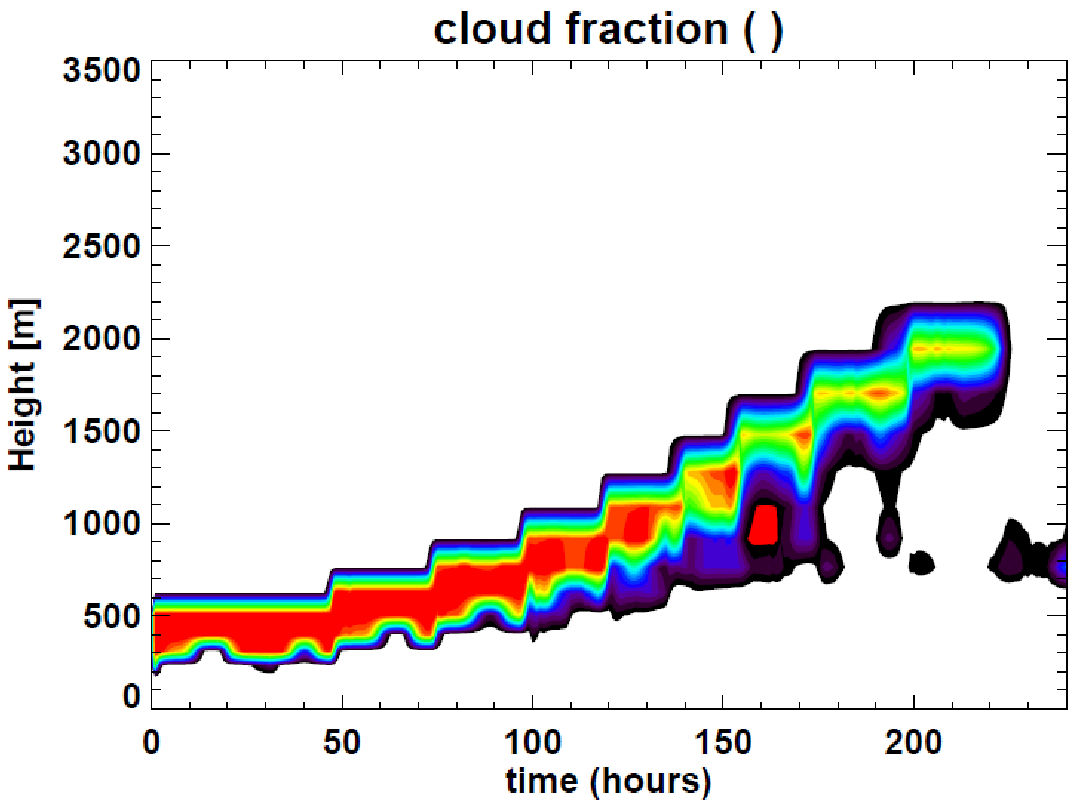
ARM Cu





Can it do a transition...?

Note: updraft fraction = 0.03 for both Sc and Cu



Concluding remarks:

Combining TKE with a mass flux scheme

- the mass flux scheme may reduce activity of the TKE scheme close to the LCL or in the top of a dry CBL
- this may lead to (numerical) instabilities
- to prevent this we i) modified the lengthscale formulation, ii) added an energy cascade term, and iii) added a small additional diffusion

General remarks (my own opinion)

- Keep things simple.
- Only add complexity if you are sure you need it; simple schemes can do complex things !
- consider the numerical stability of your scheme

Mind: TKE needs high vertical resolution & relatively small timesteps