TOUCANS
– internal architecture of turbulence part

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Introduction

Vertical turbulent flux:

$$\overline{w'\psi'} = -K_\psi \frac{\partial \overline{\psi}}{\partial z} \Rightarrow \frac{\partial \psi}{\partial t} = \frac{\partial}{\partial z}\left(K_\psi \frac{\partial \psi}{\partial z}\right)$$

$$z \longrightarrow 0 \; : \; \overline{w'\psi'} = C_\psi . \sqrt{\overline{u}^2 + \overline{v}^2}\,(\psi(z) - \psi_s)$$

K_ψ - exchange coefficient for ψ

C_ψ - drag coefficient for ψ, ψ_s - ψ at surface

Introduction

Exchange coefficients $K_{m/h}$ and drag coefficients $C_{M/H}$ in Louis scheme:

$$K_{m/h} = l_{m/h} l_m \left[\left(\frac{\partial \bar{u}}{\partial z} \right)^2 + \left(\frac{\partial \bar{v}}{\partial z} \right)^2 \right]^{\frac{1}{2}} F_{m/h}(Ri)$$

$$C_{M/H} = C^N_{M/H}(z, z_0, \kappa).F_{m/h}(Ri)$$

$l_{m/h}$ - Prandtl mixing length for momentum and pot. temperature
$F_{m/h}(Ri)$ - stability functions, Ri - Richardson gradient number
u, v , w - wind components , z - height, z_0 - roughness
$C^N_{M/H}$ - drag coefficient at neutrality($Ri = 0$)
κ - von Karman constant

Introduction

Louis stability functions F_m and F_h:

stable case:

$$F_m(Ri) = \frac{1}{1+\frac{2bRi}{\sqrt{1+\frac{d}{k}Ri}}}$$

$$F_h(Ri) = \frac{1}{1+3bRi\sqrt{1+dkRi}}$$

unstable case:

$$F_m(Ri) = 1 - \frac{2bRi}{1+3bc\sqrt{\frac{|Ri|}{27}}\left(\frac{l_m}{z+z_0}\right)^2}$$

$$F_h(Ri) = 1 - \frac{3bRi}{1+3bc\sqrt{\frac{|Ri|}{27}}\left(\frac{l_h}{z+z_{0h}}\right)\left(\frac{l_m}{z+z_0}\right)}$$

b, c, d, k - constants, z_0, z_{0H} - roughness

Introduction

TKE equation:

$$\frac{dE}{dt} = \underbrace{-\overline{u' \cdot w'}\frac{\partial \bar{u}}{\partial z} - \overline{v' \cdot w'}\frac{\partial \bar{v}}{\partial z}}_{\text{shear (I)}} + \underbrace{\frac{g}{\bar{\theta}}(\overline{w' \cdot \theta'})}_{\text{buoyancy(II)}}$$

$$\underbrace{-\frac{\partial(\overline{w' \cdot E})}{\partial z}}_{\text{turb. trans. of TKE}} \quad \underbrace{-\frac{1}{\bar{\rho}}\frac{\partial(\overline{w' \cdot p'})}{\partial z}}_{\text{pressure cor.}} \quad \underbrace{-C_\epsilon \frac{(E)^{\frac{3}{2}}}{L_\epsilon}}_{\text{dissipation}(\epsilon)}$$

$E = \frac{1}{2}(\overline{u' \cdot u' + v' \cdot v' + w' \cdot w'})$ - TKE (Turbulence Kinetic Energy)
L_ϵ - mixing length, C_ϵ - closure constant
θ - potential temperature, ρ -density, p -atm. pressure

Introduction

extended CBR scheme:

$$
\begin{aligned}
I = -\overline{u'w'}\frac{\partial \overline{u}}{\partial z} - \overline{v'w'}\frac{\partial \overline{v}}{z} &= L_K C_K \sqrt{E}\left[\left(\frac{\partial \overline{u}}{\partial z}\right)^2 + \left(\frac{\partial \overline{v}}{\partial z}\right)^2\right]\chi_3(Ri) \\
II = \frac{g}{\theta}\overline{\theta' w'} &= -\frac{g}{\theta} L_K C_K C_3 \sqrt{E}\frac{\partial \overline{\theta}}{\partial z}\phi_3(Ri) \\
III = -\epsilon &= -C_\epsilon \frac{(E)^{\frac{3}{2}}}{L_\epsilon} \\
\Rightarrow \qquad K_m &= L_K C_K \sqrt{E}\chi_3(Ri) \\
K_h &= L_K C_K C_3 \sqrt{E}\phi_3(Ri)
\end{aligned}
$$

$\chi_3(Ri)$, $\phi_3(Ri)$ - stability functions, L_K - mixing length

C_K - closure constant, C_3 - inverse Prandtl number at neutrality ($Ri = 0$)

Introduction

The full TKE equation:

$$\frac{dE}{dt} = -\frac{\partial}{\partial z}\left(\overline{E'w'} + \frac{\overline{p'w'}}{\rho}\right) + I + II + III$$

TKE eqation in pTKE:

$$\frac{dE}{dt} = -\frac{\partial}{\partial z}\left(\overline{-K_E\frac{\partial E}{\partial z}}\right) + \frac{1}{\tau_\epsilon}\left(\tilde{E} - E\right)$$

$\tilde{E}$ - TKE at stationary equilibrium
$\tau_\epsilon = \frac{E}{\epsilon}$ - dissipation time scale
$K_E = -\frac{\overline{E'w'} + \frac{\overline{p'w'}}{\rho}}{\frac{\partial E}{\partial z}}$ - auto-diffusion vertical coefficient for the TKE

Introduction

pTKE scheme:

$$\widetilde{E} = \left(\frac{K^*}{\nu l_m}\right)^2$$

$$\tau_\epsilon = \frac{\nu^3\sqrt{E}}{l_m} = \frac{l_m^2}{\nu^2 K^*}$$

$$K_E = \frac{l_m\sqrt{E}}{\nu} = \underbrace{\frac{K^*}{\nu^2}}_{\text{first time step}}$$

$$\nu = (C_K C_\epsilon)^{\frac{1}{4}}, K^* = \sqrt{K_m K_N}$$

K_N - K_m for neutral statification ($Ri = 0$)

Introduction

pTKE scheme - draft:

ACHMT

$Ri \rightarrow F_m(Ri), F_h(Ri)$

↓

$F_m(Ri), F_h(Ri) \rightarrow C_M, C_H$

↓

ACCOEFK

$Ri \rightarrow F_m(Ri), F_h(Ri)$

↓

$F_m(Ri), F_h(Ri), l_m, l_h \rightarrow \widetilde{K_m}, \widetilde{K_h}, \widetilde{K_N}$

↓

ACPTKE

$\widetilde{K_m}, \widetilde{K_N} \rightarrow K_*$

↓

$K_*, E^0, l_m \rightarrow \widetilde{E}, K_E, \tau_\epsilon$

↓

$\widetilde{E}, K_E, \tau_\epsilon, E^0 \rightarrow E^+$

↓

$E^+, l_m, \widetilde{K_m}, \widetilde{K_h} \rightarrow K_m, K_h$

Stability functions F_m and F_h

Condition of equivalence with full TKE:

$$\tilde{E}\left(L_K\right) = \frac{E}{\epsilon\left(L_\epsilon\right)}\left[I\left(L_K\right) + II\left(L_K\right)\right]$$

Mixing lengths relation:

$$\begin{aligned} L_K C_K &= \nu l_m \frac{f(Ri)^{\frac{1}{4}}}{\chi_3^{\frac{1}{2}}} \quad , \\ \frac{L_\epsilon}{C_\epsilon} &= \frac{l_m}{\nu^3} \frac{\chi_3^{\frac{3}{2}}}{f(Ri)^{\frac{3}{4}}} \quad , \\ f(Ri) &= \chi_3(Ri) - Ri C_3 \phi_3(Ri) \end{aligned}$$

Stability functions F_m and F_h

From definition of $F_m(Ri)$ and $F_h(Ri)$:

$$F_{m/h}(Ri) = \frac{\widetilde{K}_{m/h}}{l_m l_{m/h}\sqrt{\left[\left(\frac{\partial \overline{u}}{\partial z}\right)^2 + \left(\frac{\partial \overline{v}}{\partial z}\right)^2\right]}}$$

we get resulting :

$$\begin{aligned} F_m(Ri) &= \chi_3(Ri)\sqrt{f(Ri)} = \chi_3(Ri)\sqrt{\chi_3(Ri)(1 - Ri_f)} \\ F_h(Ri) &= \frac{\phi_3(Ri)}{\chi_3(Ri)} F_m(Ri) \end{aligned}$$

$Ri_f = Ri\frac{K_h}{K_m}$ - flux Richardson number

Stability functions χ_3 , ϕ_3

Modified CCH02 scheme (no critical *Ri*):

$$
\begin{aligned}
\chi_3(Ri) &= \frac{1-\frac{Ri_f}{R}}{1-Ri_f} = \\
&= \frac{f(Ri)}{f(Ri).R+1-R} \quad , \\
\phi_3(Ri) &= \frac{1-\frac{Ri_f}{Ri_{fc}}}{1-Ri_f} = \\
&= \left(1-\frac{1-Q}{f(Ri).R+1-R}\right)\frac{f(Ri)}{f(Ri).Q+3\lambda_0 Ri} \quad , \\
Ri_f &= \frac{C_3 Ri\phi_3(Ri)}{\chi_3(Ri)}, \quad Ri_{fc} = \lim_{Ri\to\infty} Ri_f
\end{aligned}
$$

R, Q, λ_0 - constants

Stability functions χ_3 , ϕ_3

Fitted QNSE scheme:

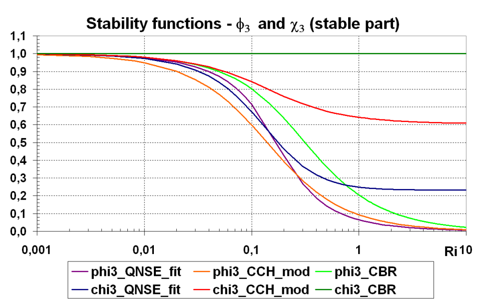
$$\begin{aligned} \text{for } Ri \geq 0 \quad \chi_3(Ri) &= \frac{1 + 0.75 Ri(1 + a.Ri)}{1 + 3.23 Ri(1 + a.Ri)} \quad , \\ \text{for } Ri < 0 \quad \chi_3(Ri) &= \frac{1 - b.Ri}{1 - (b - 2.48).Ri} \quad , \end{aligned}$$

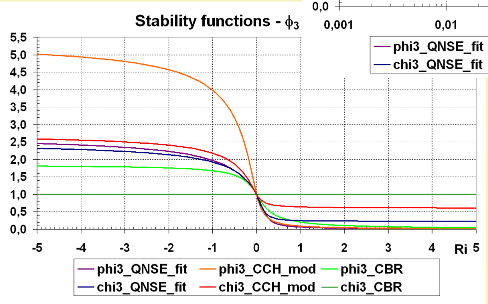
$a = 13.0$, $b = 4.16$ - tuning constants

Stability function $\phi_3(Ri)$ is computed from quadratic equation derived in modified CCH02:

$$C_3 Ri \phi_3(Ri)^2 - \left[\chi_3(Ri) + \frac{C_3 Ri}{Ri_{fc}}\right] \phi_3(Ri) + \chi_3(Ri) = 0$$

Stability functions χ_3 , ϕ_3





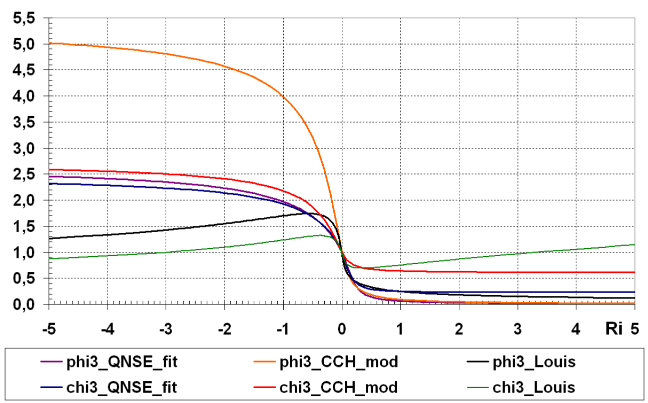
Modification in K_E, τ_ϵ

pTKE scheme:

-simplified assumptions

-derived for CBR scheme($\chi_3 = 1$)

-from Louis $F_{m/h}$:

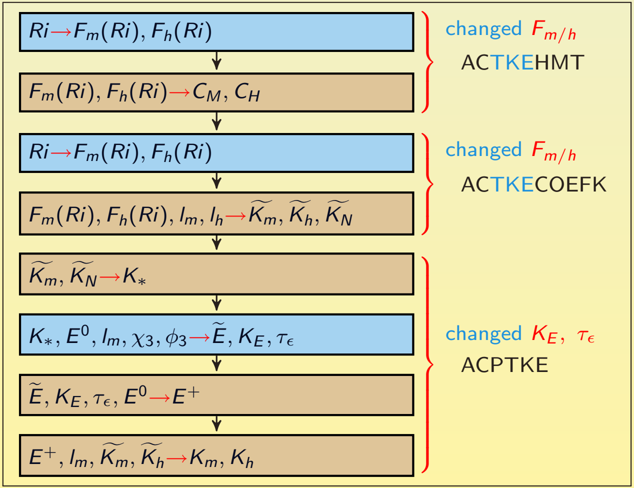


Modification in K_E, τ_ϵ

Relation for K_E, τ_ϵ in eTKE:

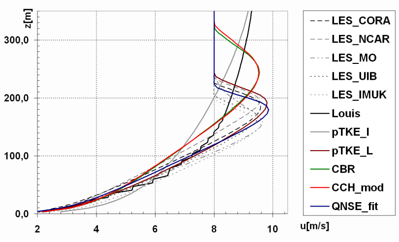
$$
\begin{aligned}
\tau_\epsilon &= \frac{l_m}{\nu^3 \sqrt{E}} \frac{\chi_3(Ri)^{\frac{3}{2}}}{f(Ri)^{\frac{3}{4}}} \\
K_E &= \frac{l_m \sqrt{E}}{\nu} \frac{f(Ri)^{\frac{3}{4}}}{\chi_3(Ri)^{\frac{3}{2}}}
\end{aligned}
$$

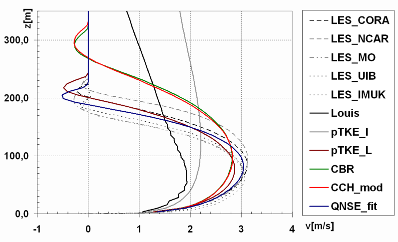
eTKE scheme - draft:



1D test: project GABLS

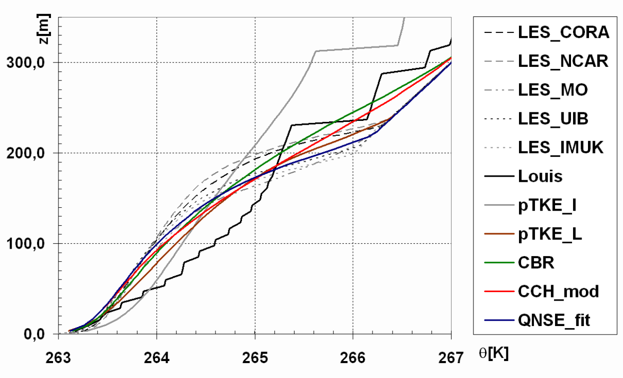
wind components:





1D test: project GABLS

potential temperature:



- inversion layer under top of PBL

'Dry' AF scheme

Antifibrillation scheme

-to avoid nonlinear instabilities in diffusion equation

Decentered diffusion equation:

$$\frac{\partial \psi}{\partial t} = \frac{\psi^{+} - \psi^{0}}{\Delta t} = \frac{\partial \left[(1-\beta) K_{\psi} \frac{\partial \psi^{0}}{\partial z} + \beta K_{\psi} \frac{\partial \psi^{+}}{\partial z} \right]}{\partial z}$$

β - decentering factor

Δt - timestep, t - time

'Dry' AF scheme

β is function of $\widetilde{K}_{m/h}$, α_u and α_θ:

$$\begin{aligned} \alpha_u &= \frac{Ri}{F_m(Ri)}\left(\frac{dF_m(Ri)}{dRi}\right) \\ \alpha_\theta &= \frac{Ri}{F_h(Ri)}\left(\frac{dF_h(Ri)}{dRi}\right) \end{aligned}$$

We modified computation of α_u and α_θ

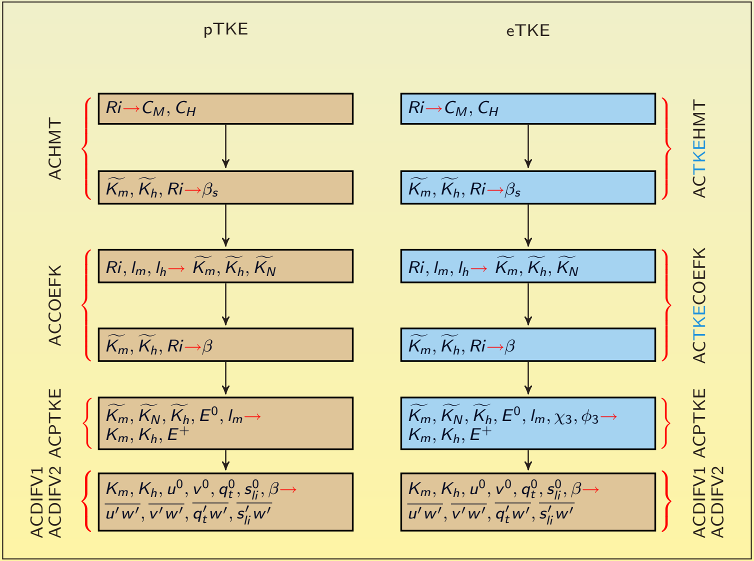
according to the 'new' $F_{m/h}$

'Dry' AF scheme

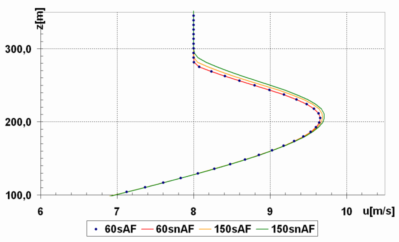
Conditions for use of 'dry' AF scheme are not fullfilled for all *Ri*:

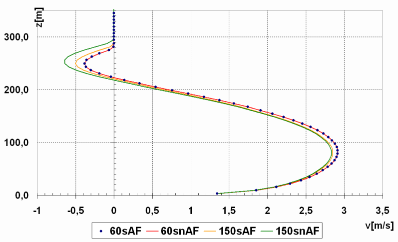
$$K_m \geq \frac{K_h}{3} \qquad \text{or} \qquad \alpha_\theta > -1 \qquad (\text{for} \quad Ri > 0)$$

$$\begin{array}{ccc} -2 < & (\alpha_u, \alpha_\theta) & < 1 \\ 2 & < & 3 - 2.\alpha_u + \alpha_\theta \\ 0 & < & 2 - 3.\alpha_u + 2.\alpha_\theta \leq 2 \end{array}$$


pTKE
eTKE
$Ri \rightarrow C_M, C_H$
$\widetilde{K_m}, \widetilde{K_h}, Ri \rightarrow \beta_s$
$Ri, l_m, l_h \rightarrow \widetilde{K_m}, \widetilde{K_h}, \widetilde{K_N}$
$\widetilde{K_m}, \widetilde{K_h}, Ri \rightarrow \beta$
$\widetilde{K_m}, \widetilde{K_N}, \widetilde{K_h}, E^0, l_m \rightarrow K_m, K_h, E^+$
$\widetilde{K_m}, \widetilde{K_N}, \widetilde{K_h}, E^0, l_m, \chi_3, \phi_3 \rightarrow K_m, K_h, E^+$
$K_m, K_h, u^0, v^0, q_t^0, s_{li}^0, \beta \rightarrow \overline{u'w'}, \overline{v'w'}, \overline{q_t'w'}, \overline{s_{li}'w'}$
ACHMT
ACCOEFK
ACPTKE
ACDIFV1
ACDIFV2
ACTKEHMT
ACTKECOEFK
ACPTKE
ACDIFV1
ACDIFV2

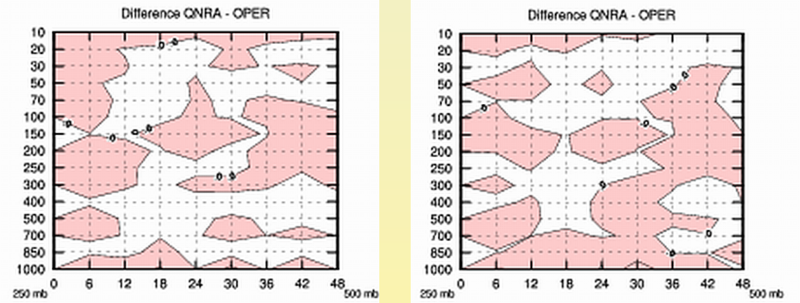
Influence of AF scheme:





CCH_mod: $C_3 = 1.83$, $\nu = 0.477$, $R = 0.367, Ri_{fc} = 0.186$, $\alpha_{TKE} = 3.9$

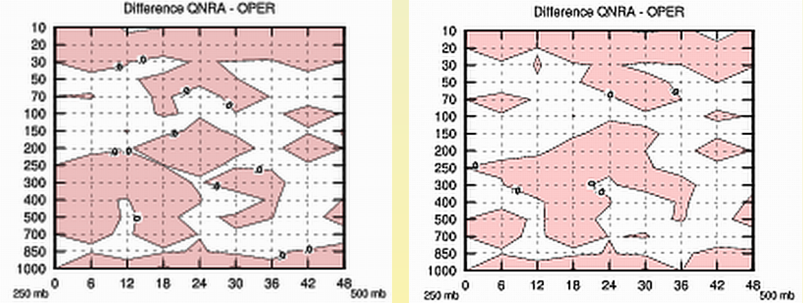
3D test: eTKE(QNSE) vs pTKE - temperature: 01.01.2009-24.01.2009, 00:00 UTC



RMSE STDEV

-red - better score for eTKE

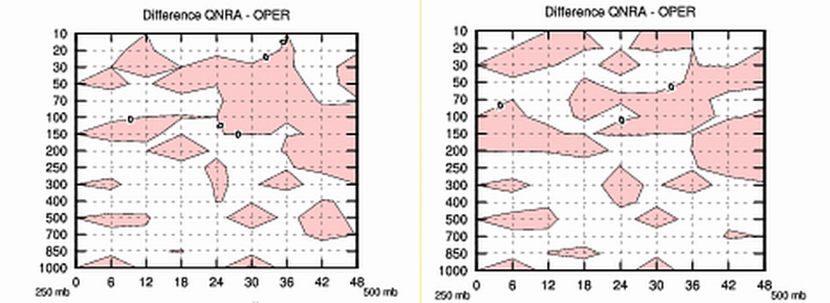
3D test: eTKE(QNSE) vs pTKE - wind speed:



RMSE STDEV

-red - better score for eTKE

3D test: eTKE(QNSE) vs pTKE - relative humidity:



RMSE STDEV

-red - better score for eTKE

Mixing lengths

Prandtl-type mixing lengths
(CGMIXLEN='AY', in ALARO0='CG'):

$$l^{AY}_{m/h} = \frac{\kappa z}{1 + \frac{\kappa z}{\lambda_{m/h}} \left[\frac{1+\exp\left(-a_{m/h}\sqrt{\frac{z}{H_{PBL}}}+b_{m/h}\right)}{\beta_{m/h}+\exp\left(-a_{m/h}\sqrt{\frac{z}{H_{PBL}}}+b_{m/h}\right)} \right]}$$

κ - Von Kármán constant, H_{PBL} - PBL height
$a_{m/h}$, $b_{m/h}, \lambda_{m/h}$ - tuning constants

Mixing lengths

TKE mixing lengths:

$$L^{BL}(E') = \left(\frac{L_{up}^{-\frac{4}{5}} + L_{down}^{-\frac{4}{5}}}{2}\right)^{-\frac{5}{4}},$$

$$L^{N}(E') = \sqrt{\frac{2E'}{N^2}},$$

$$E' = \alpha_{TKE} E.$$

$L_{up/down}$- represents the distance that a parcel originating from the given level, and having initial kinetic energy equal to the scaled mean TKE of the layer, can travel upward(downward) before being stopped by buoyancy effects

N - Brunt–Väisälä frequency

α_{TKE}-tunable degree of freedom

Mixing lengths

In the code we use l_m.
Conversion is made by $L_K(l_m)$:

$$L \equiv \sqrt{L_K L_\epsilon} = \frac{\nu}{C_K} l_m \frac{\chi_3(Ri)^{\frac{1}{2}}}{f(Ri)^{\frac{1}{4}}}$$

$\rightarrow$ l_m becomes function of Ri.

Mixing lengths

Combinations of mixing lengths CGMIXLEN=:

'EL1' $l_m = l_m^{BL}$

'EL2' $Ri > 0 : l_m = \min(l_m^{BL}, l_m^{N}); Ri < 0 : l_m = \sqrt{l_m^{BL} l_m^{AY}}$

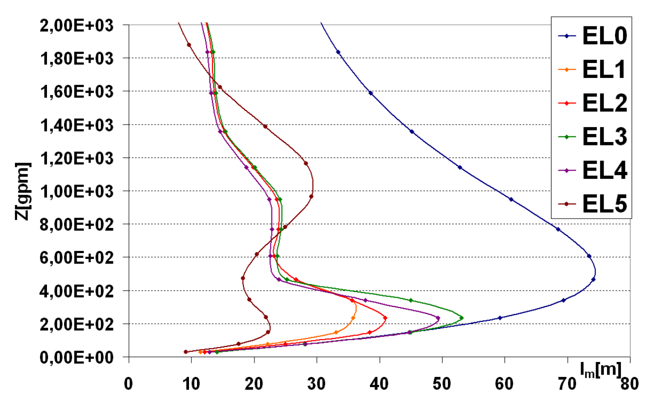
'EL3' $Ri > 0 : l_m = \min(l_m^{N}, l_m^{max}); Ri < 0 : l_m = l_m^{AY}$

'EL4' $Ri > 0 : l_m = \left(\frac{1}{(l_m^{AY})^2} + \frac{1}{(l_m^{N})^2}\right)^{-2}; Ri < 0 : l_m = l_m^{AY}$

'EL5' $Ri > 0 : l_m = \min(l_m^{BL}, l_m^{N}); Ri < 0 : l_m = l_m^{BL}$

l_m^{max} - limitation for mixing length

Mixing lengths



CCH_mod:

$C_3 = 1.83$, $\nu = 0.477$, $R = 0.367$, $Ri_{fc} = 0.186$,

$\alpha_{TKE} = 3.9$, $\delta_t = 360s$, $t = 360s$

19.04.2009 00:00 UTC

Vertical profile of Prandtl number at neutrality

Trubulent Prandtl number:

$$Prt = \frac{K_m}{K_h}$$

In the code:

$$Prt(Ri = 0) \equiv Prt_0 = \frac{l_m}{l_h}$$

Conditions:

$$\text{free atmosphere:} \quad Prt_0 = \frac{1}{C_3}$$

$$\text{surface:} \quad Prt_0 = 1$$

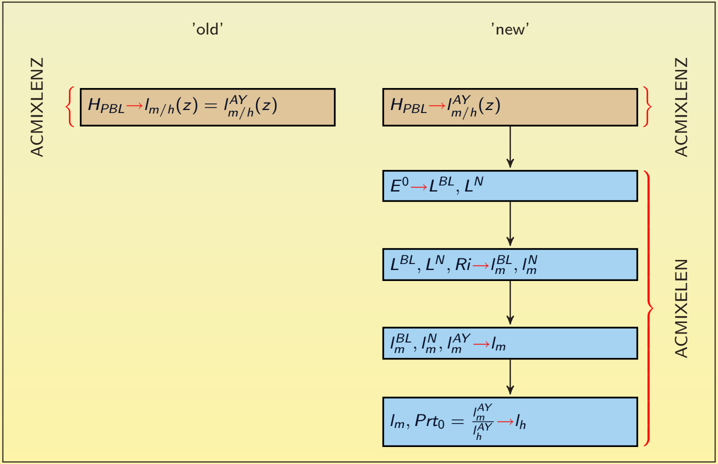
Vertical profile of Prandtl number at neutrality

Solution with use of $l_{m/h}^{AY}$:

$$\frac{\lambda_m}{\lambda_h} = \frac{1}{C_3}$$
$$\frac{\beta_m}{\beta_h} = 1$$

Usage:

$$l_h = \frac{l_h^{AY}}{l_m^{AY}} l_m$$


'old'
'new'
ACMIXLENZ
$H_{PBL} \rightarrow l_{m/h}(z) = l^{AY}_{m/h}(z)$
$H_{PBL} \rightarrow l^{AY}_{m/h}(z)$
ACMIXLENZ
$E^0 \rightarrow L^{BL}, L^N$
$L^{BL}, L^N, Ri \rightarrow l^{BL}_m, l^N_m$
$l^{BL}_m, l^N_m, l^{AY}_m \rightarrow l_m$
$l_m, Prt_0 = \frac{l^{AY}_m}{l^{AY}_h} \rightarrow l_h$
ACMIXELEN

We need to modify the code so, that there are no modification of exchange coefficients $K_{m/h}$ after their calculation from stability functions $F_{m/h}$.

Currently there are two modifications:

- 'moist' AF scheme
- parametrisation of moist gustiness

'Moist' antifibrillation scheme

Shallow convection parametrisation:

$$Ri^* = Ri_d + \frac{g}{c_p T} \frac{L_v.min\left[0, \frac{\partial(q-q_s)}{\partial z}\right]}{\left[\frac{\partial u}{\partial z}\right]^2 + \left[\frac{\partial v}{\partial z}\right]^2}$$

q - specific moisture, q_s - specific moisture for saturated air
L_v - latent heat of vaporization, c_p - specific heat capacity
Ri_d - 'dry' (without shallow convection parametrisation) Ri

'Moist' antifibrillation scheme

'Moist' antifibrillation scheme:

$$K'_{m/h}(Ri_d, Ri^*) = K_{m/h}(Ri_d) + \frac{K_{m/h}(Ri^*) - K_{m/h}(Ri_d)}{1 + (\beta_m - 1)(K_{m/h}(Ri^*) - K_{m/h}(Ri_d))\Delta t}$$

$$\beta_m = \frac{\frac{\partial(q_s^+)}{\partial z}}{\frac{\partial(q - q_s)}{\partial z}} \frac{1}{XDAMP}$$

q_s^+ - specific moisture for saturated air after mixing
$XDAMP$ - damping factor
β_m - decentering factor,obtained independently by considering the ratio of the vertical gradients before and after mixing

'Moist' antifibrillation scheme

We shifted 'moist' AF into computation of Ri

Modification in stability functions $F_{m/h}$ instead of $K_{m/h}$:

$$F_{m/h}(Ri') = F'_{m/h}(Ri, Ri^*) = F_{m/h}(Ri_d) + \\ + \frac{F_{m/h}(Ri^*) - F_{m/h}(Ri_d)}{1 + (\beta_m - 1)(F_{m/h}(Ri^*) - F_{m/h}(Ri_d)) l_m l_h \sqrt{\left(\frac{\partial \overline{u}}{\partial z}\right)^2 + \left(\frac{\partial \overline{v}}{\partial z}\right)^2} \Delta t}$$

'Moist' antifibrillation scheme

Special form of χ_3 , ϕ_3 in modified CCH02 derived by Daan Degrauwe:

$$
\begin{aligned}
\phi_3 &= \frac{S-1}{Ri_{fc}.S-1} \\
\chi_3 &= \frac{\frac{S}{\sigma}-1}{Ri_{fc}.S-1} \\
S &= \frac{Ri_f}{Ri_{fc}} = \frac{1}{2}\left[\sigma(1+\rho) - \sqrt{(1+\rho)^2\sigma^2 - 4\rho\sigma}\right] \\
\sigma &= \frac{R}{Ri_{fc}} \quad , \quad \rho = \frac{C_3 Ri}{Ri_{fc}}
\end{aligned}
$$

'Moist' antifibrillation scheme

$$F_h = \phi_3\sqrt{\chi_3(1-Ri_f)} = \frac{S-1}{Ri_{fc}.S-1}\sqrt{\frac{S}{\sigma}-1}$$

Inversion of F_h in modified CCH02:

$$\begin{aligned} 0 &= S^3 + \left(\left({F_h}^2\,{Ri_{fc}}^2-1\right)\,\sigma-2\right)\,S^2 + \\ &\quad + \left(\left(2-2\,{F_h}^2\,Ri_{fc}\right)\,\sigma+1\right)\,S + \left({F_h}^2-1\right)\,\sigma \\ Ri' &= \frac{Ri_{fc}}{C_3}\,\frac{S}{\sigma}\,\frac{S-\sigma}{S-1} \end{aligned}$$

'Moist' antifibrillation scheme

QNSE:

- unable to invert F_h analytically
- we fitted QNSE functions χ_3 , ϕ_3
  in modified CCH02 :
  R, C_3 - functions of Ri, $Ri_{fc} = 0.377$, $\nu = 0.464$

Moist gustiness modification

Gustiness:

$$\overline{w'\psi'} \sim \overline{\left[\left(\frac{\partial u}{\partial z}\right)^2 + \left(\frac{\partial v}{\partial z}\right)^2\right]^{\frac{1}{2}}}$$

$$\underbrace{\left[\left(\frac{\partial \overline{u}}{\partial z}\right)^2 + \left(\frac{\partial \overline{v}}{\partial z}\right)^2\right]^{\frac{1}{2}}}_{NWP\ model} < \overline{\left[\left(\frac{\partial u}{\partial z}\right)^2 + \left(\frac{\partial v}{\partial z}\right)^2\right]^{\frac{1}{2}}}$$

Moist gustiness modification

Moist gustiness
-induced by moist convection:

$$K^{PRC}_{m/h} = \gamma^{PRC} K_{m/h} \quad , \quad C^{PRC}_{M/H} = \gamma^{PRC} C_{M/H}$$

$$\gamma^{PRC} = \sqrt{1 + \left(\left(\frac{J_{Pr}}{J_{Pr} + J^0_{Pr}}\right)^{\gamma} \widetilde{U}\right)^2 \frac{\rho}{J_m}}$$

J_{Pr} - precipitation flux, J^0_{Pr} - typical steadily strong precipitation flux
J_m - momentum flux:
above surface $= \rho . K_m . \sqrt{\left(\frac{\partial \overline{u}}{\partial z}\right)^2 + \left(\frac{\partial \overline{v}}{\partial z}\right)^2}$, surface $= \rho . C_M . \left(\overline{u}^2 + \overline{v}^2\right)$

$\widetilde{U}$ - typical surface friction velocity, $\gamma = 0.8$ - tuning constant

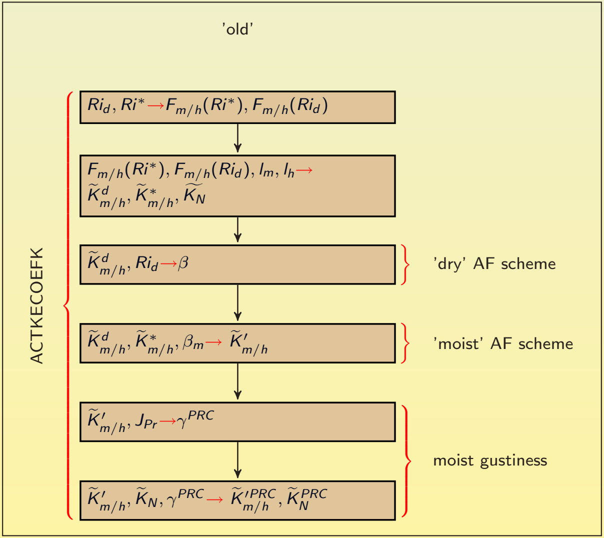
Moist gustiness modification

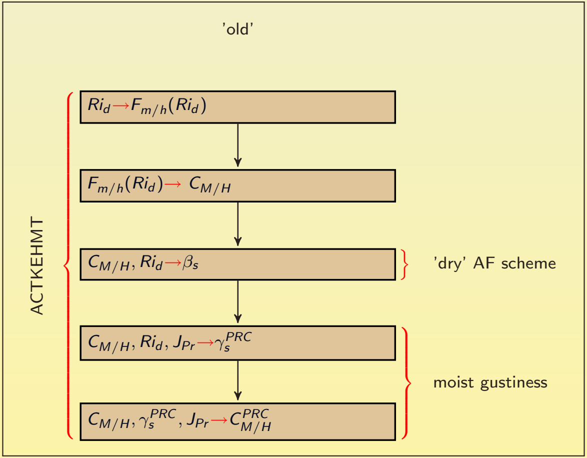
We shifted moist gustiness
in to the computation of $l_{m/h}$:

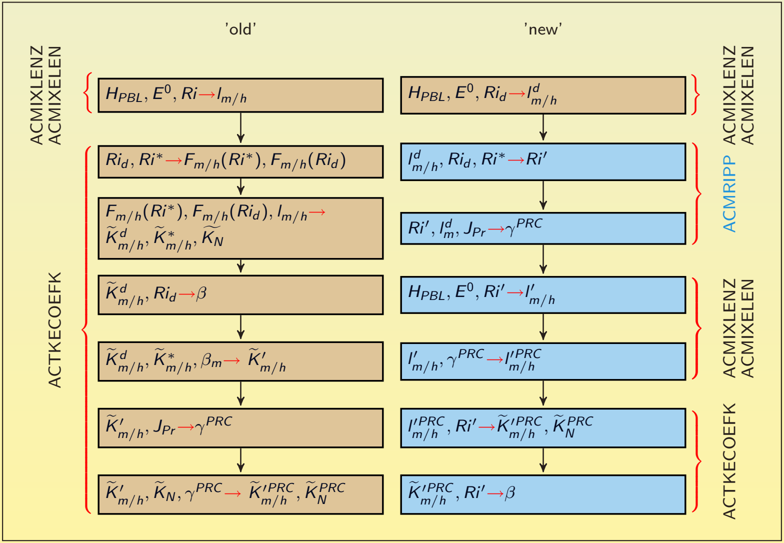
$$
\begin{aligned}
l_{m/h}^{PRC} &= \sqrt{\gamma^{PRC}} l_{m/h} \\
K_{m/h} &\sim l_{m/h} l_m
\end{aligned}
$$

Mixing lengths

New 'moist' AF scheme (with Ri') and moist gustiness par. influence mixing lengths $l_{m/h}$, but $l_{m/h}$ are also inputs for them.
To avoid iterative methods we simply use l_m^d (without 'moist' AF scheme and 'moist' gustiness) in both schemes.


'old'
ACTKECOEFK
$Ri_d, Ri^* \rightarrow F_{m/h}(Ri^*), F_{m/h}(Ri_d)$
$F_{m/h}(Ri^*), F_{m/h}(Ri_d), l_m, l_h \rightarrow \widetilde{K}^d_{m/h}, \widetilde{K}^*_{m/h}, \widetilde{K_N}$
$\widetilde{K}^d_{m/h}, Ri_d \rightarrow \beta$
'dry' AF scheme
$\widetilde{K}^d_{m/h}, \widetilde{K}^*_{m/h}, \beta_m \rightarrow \widetilde{K}'_{m/h}$
'moist' AF scheme
$\widetilde{K}'_{m/h}, J_{Pr} \rightarrow \gamma^{PRC}$
$\widetilde{K}'_{m/h}, \widetilde{K}_N, \gamma^{PRC} \rightarrow \widetilde{K}'^{PRC}_{m/h}, \widetilde{K}^{PRC}_N$
moist gustiness


'old'
ACTKEHMT
$Ri_d \rightarrow F_{m/h}(Ri_d)$
$F_{m/h}(Ri_d) \rightarrow C_{M/H}$
$C_{M/H}, Ri_d \rightarrow \beta_s$
'dry' AF scheme
$C_{M/H}, Ri_d, J_{Pr} \rightarrow \gamma_s^{PRC}$
$C_{M/H}, \gamma_s^{PRC}, J_{Pr} \rightarrow C_{M/H}^{PRC}$
moist gustiness


'old'
'new'
ACMIXLENZ
ACMIXELEN
$H_{PBL}, E^0, Ri \to l_{m/h}$
$Ri_d, Ri^* \to F_{m/h}(Ri^*), F_{m/h}(Ri_d)$
$F_{m/h}(Ri^*), F_{m/h}(Ri_d), l_{m/h} \to \widetilde{K}^d_{m/h}, \widetilde{K}^*_{m/h}, \widetilde{K}_N$
$\widetilde{K}^d_{m/h}, Ri_d \to \beta$
$\widetilde{K}^d_{m/h}, \widetilde{K}^*_{m/h}, \beta_m \to \widetilde{K}'_{m/h}$
$\widetilde{K}'_{m/h}, J_{Pr} \to \gamma^{PRC}$
$\widetilde{K}'_{m/h}, \widetilde{K}_N, \gamma^{PRC} \to \widetilde{K}'^{PRC}_{m/h}, \widetilde{K}^{PRC}_N$
ACTKECOEFK
$H_{PBL}, E^0, Ri_d \to l^d_{m/h}$
ACMIXLENZ
ACMIXELEN
$l^d_{m/h}, Ri_d, Ri^* \to Ri'$
$Ri', l^d_m, J_{Pr} \to \gamma^{PRC}$
ACMRIPP
$H_{PBL}, E^0, Ri' \to l'_{m/h}$
$l'_{m/h}, \gamma^{PRC} \to l'^{PRC}_{m/h}$
ACMIXLENZ
ACMIXELEN
$l'^{PRC}_{m/h}, Ri' \to \widetilde{K}'^{PRC}_{m/h}, \widetilde{K}^{PRC}_N$
$\widetilde{K}'^{PRC}_{m/h}, Ri' \to \beta$
ACTKECOEFK

Shallow convection cloudiness

Ri' should be limited by:

Ri_d (no clouds in grid box) and

Ri_m (Richardson number for saturated air - 100 % cloudiness in grid box):

$$Ri_m = g \frac{1 + \frac{L_v.q_w}{R.T}}{1 + \left(\frac{\frac{R_d}{R_v}.L_v^2.q_w}{c_p.R.T^2} \right)} \left(\frac{d \ln \theta}{dz} + \frac{L_v}{c_p.T} \frac{dq_w}{dz} \right) \frac{1}{\left(\frac{\partial \overline{u}}{\partial z}\right)^2 + \left(\frac{\partial \overline{v}}{\partial z}\right)^2}$$

q_w - specific moisture corresponding to wet bulb temperature

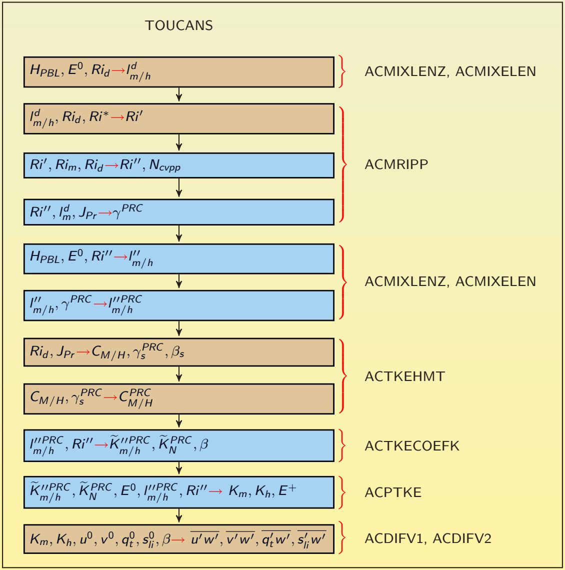
R_d - gas constant for dry air, R_v - gas constant for water vapor

Shallow convection cloudiness

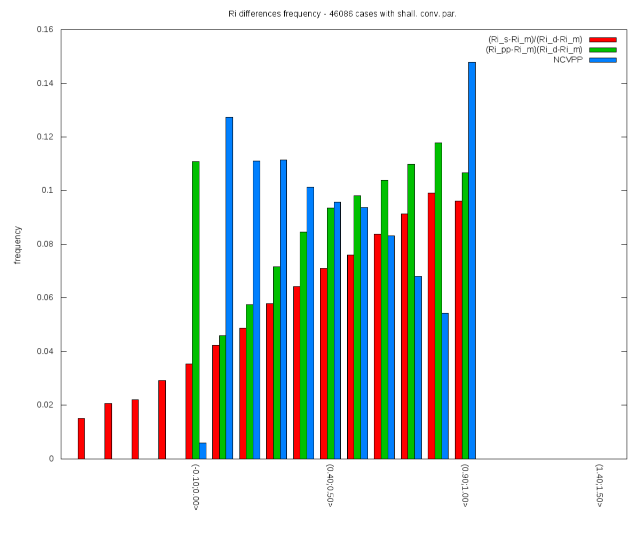
Shallow convection cloudiness N_{cvpp}:

$$N_{cvpp} = \frac{Ri'' - Ri_d}{Ri_m - Ri_d}$$

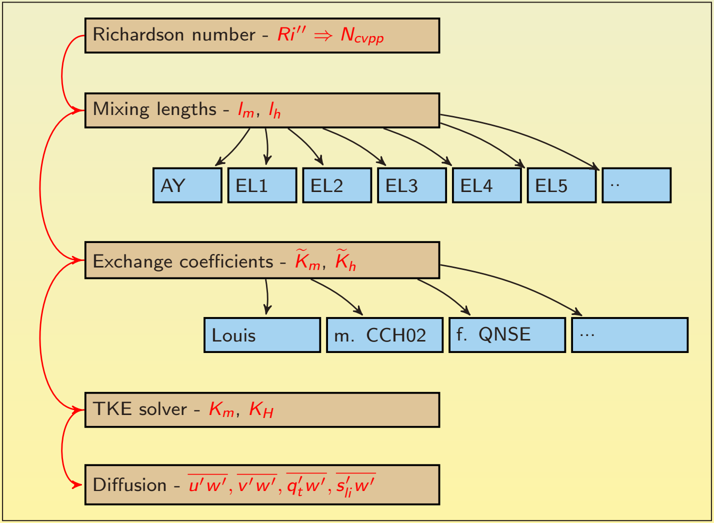
$$Ri'' = \min(\max(Ri_d, Ri'), Ri_m)$$


TOUCANS
$H_{PBL}, E^0, Ri_d \rightarrow l^d_{m/h}$
ACMIXLENZ, ACMIXELEN
$l^d_{m/h}, Ri_d, Ri^* \rightarrow Ri'$
$Ri', Ri_m, Ri_d \rightarrow Ri'', N_{cvpp}$
$Ri'', l^d_m, J_{Pr} \rightarrow \gamma^{PRC}$
ACMRIPP
$H_{PBL}, E^0, Ri'' \rightarrow l''_{m/h}$
$l''_{m/h}, \gamma^{PRC} \rightarrow l''^{PRC}_{m/h}$
ACMIXLENZ, ACMIXELEN
$Ri_d, J_{Pr} \rightarrow C_{M/H}, \gamma_s^{PRC}, \beta_s$
$C_{M/H}, \gamma_s^{PRC} \rightarrow C^{PRC}_{M/H}$
ACTKEHMT
$l''^{PRC}_{m/h}, Ri'' \rightarrow \widetilde{K}''^{PRC}_{m/h}, \widetilde{K}^{PRC}_N, \beta$
ACTKECOEFK
$\widetilde{K}''^{PRC}_{m/h}, \widetilde{K}^{PRC}_N, E^0, l''^{PRC}_{m/h}, Ri'' \rightarrow K_m, K_h, E^+$
ACPTKE
$K_m, K_h, u^0, v^0, q_t^0, s_{li}^0, \beta \rightarrow \overline{u'w'}, \overline{v'w'}, \overline{q_t'w'}, \overline{s_{li}'w'}$
ACDIFV1, ACDIFV2

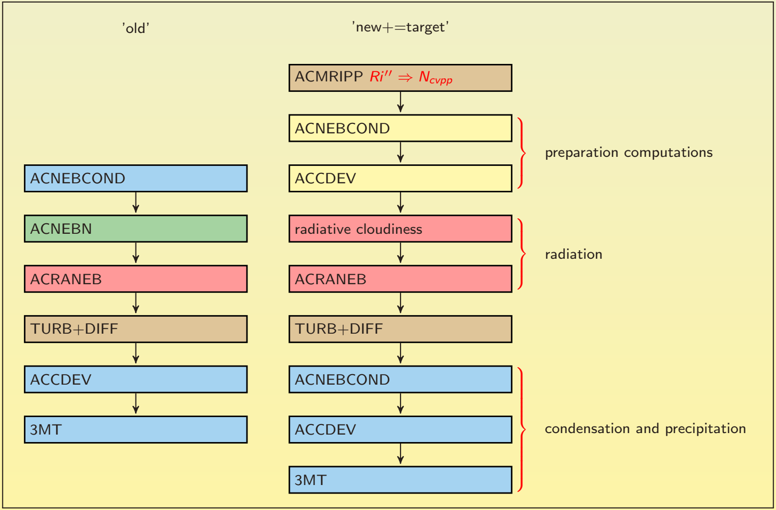
Shallow convection cloudiness distribution:



Internal modularity



External identification



Summary

- New turbulent scheme:
  - equivalence with full TKE scheme
  - easy implementation (new stability functions $F_{m/h}$)
  - modified TKE solver
  - modified 'dry' AF scheme
- Mixnig lengths from TKE
- Preparations for TOMs:
  - modification in 'moist' AF scheme
  - modification in moist gustiness par.
- Shallow convection cloudiness
  - computation
  - used in cloudiness computations

Thank you for your attention!