# TOUCANS: pre-operational choices

**Ivan Bašták Ďurán***
Jean-François Geleyn**
Filip Váňa***

* ČHMÚ ONPP Prague, ivanbastak@gmail.com
** CNRM Météo-France Toulouse
***ECMWF Reading

1. Turbulent scheme
2. Length scale
3. Moisture influence
4. Prognostic computations
5. TOMs parametrisation

# TOUCANS

T - Third

O - Order moments (TOMs)

U - Unified

C - Condensation

A - Accounting and

N - N-dependent

S - Solver (for turbulence and diffusion)

# Turbulent scheme

$$\frac{D\overline{u}}{\partial t} = S_u \boxed{-\frac{\partial \overline{u'w'}}{\partial z}}, \quad \frac{D\overline{v}}{\partial t} = S_v \boxed{-\frac{\partial \overline{v'w'}}{\partial z}},$$

$$\frac{D\overline{s_{sL}}}{\partial t} = S_{s_{sL}} \boxed{-\frac{\partial \overline{s'_{sL}w'}}{\partial z}}, \quad \frac{D\overline{q_t}}{\partial t} = S_{q_t} \boxed{-\frac{\partial \overline{q'_t w'}}{\partial z}}$$

$u$, $v$, $w$ -wind components, $s_{sL} = c_{pd}\left(1 + \left[\frac{c_{pv}}{c_{pd}} - 1\right] q_t\right) T + g\,z - (L_v\,q_l + L_s\,q_i)$ a diffused moist conservative variable, $g$ gravitational acceleration, $z$ height, $c_{pd}$ and $c_{pv}$ specific heat values for dry air and water vapour, $L_v$ and $L_s$ latent heats of vaporisation and sublimation, $T$ temperature, $q_t$ total specific water content, $q_l$ and $q_i$ specific contents for liquid and solid water, $S_\psi$ - external source terms, $t$ - time, $\frac{D()}{\partial t} = \frac{\partial()}{\partial t} + \overline{u}\frac{\partial()}{\partial x} + \overline{v}\frac{\partial()}{\partial y}$, $\overline{()}$ - average, $()'$ - fluctuation

## Exchange coefficients

$$K_M = \frac{\nu^4}{C_\epsilon}\chi_3(Ri_f)\sqrt{e}L_K, \quad K_H = C_3\frac{\nu^4}{C_\epsilon}\phi_3(Ri_f)\sqrt{e}L_K$$

| free parameters / stab. functions | TKE | length scale |
|---|---|---|
| given by turbulence scheme | prognostic meassue of intensity | quasi-independent, may depend on TKE and BVF |

$\chi_3(Ri_f)$,$\phi_3(Ri_f)$ - stability functions, $\nu$ - free parameter, $C_3$ - inverse Prantl number at neutrality, $L_K$ - length scale, $Ri_f = Ri\frac{K_H}{K_M}$ - flux Richardson number

## Stability dependency functions $\chi_3$, $\phi_3$ and free parameters

- derived from Louis stability functions + RMC01 (pTKE)
- based on (Bašták Ďurán, Geleyn, and Váňa, 2014 -BGV14) (TOUCANS)
  - analytical framework given by four free parameters: $C_\epsilon$, $\nu$, $C_3$, $O_\lambda$ (+ two possible functional dependencies)
  - enables emulation of various schemes: EFB, QNSE, RMC01,..

# Stability dependency functions $\chi_3$, $\phi_3$

$$\phi_3\left(Ri_f\right) = \frac{1 - \frac{Ri_f}{P}}{1 - Ri_f},$$

$$\chi_3\left(Ri_f\right) = \frac{1 - \frac{Ri_f}{R}}{1 - Ri_f},$$

$$\frac{Ri}{Ri_f} = \frac{P(R - Ri_f)}{C_3\, R\left(P - Ri_f\right)}.$$

$R$ - variable describing the effect of the flow's anisotropy on the turbulent momentum exchange, $P$ - variable describing the joint effect of flow's anisotropy and TPE conversion on the turbulent heat exchange with : $\lim_{Ri \to \infty} P = Ri_{fc}$, $Ri_{fc} = \lim_{Ri \to \infty} Ri_f$ - critical flux-Richardson number

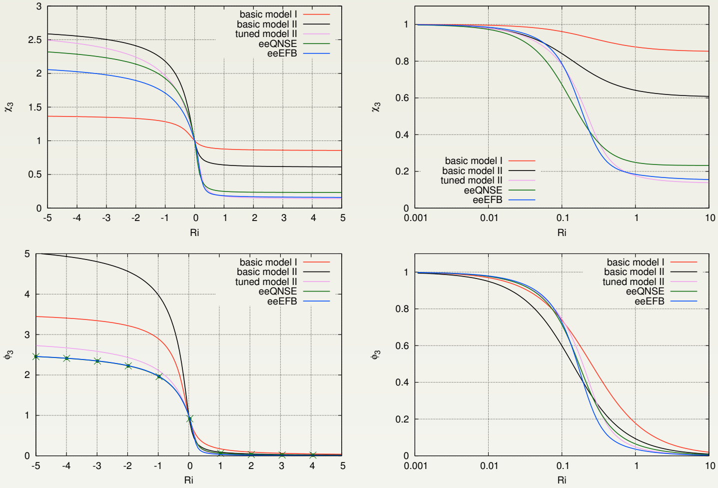
## Turbulent scheme - switches

| | | | |
|---|---|---|---|
| LPTKE | .TRUE. | | .FALSE. |
| LCOEFKTKE | .TRUE. | .FALSE. | - |
| Scheme: | TOUCANS | pseudo-TKE | Louis scheme |

TOUCANS ON:

| | |
|---|---|
| Emulation | CGTURS |
| model I | MD1 |
| model II | MD2 |
| eRMC01 | RMC |
| eeQNSE | QNSE |
| eeEFB | EFB |

# Stability dependency functions $\phi_3$ and $\chi_3$ -BGV14



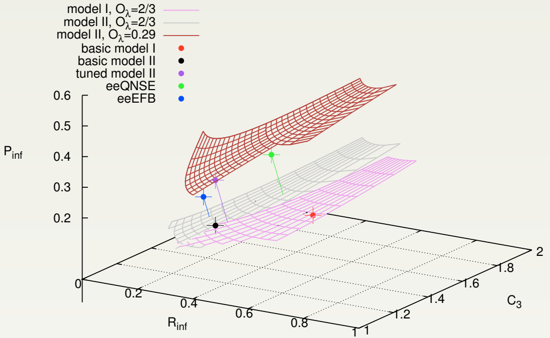
# Free parameters -BGV14

| Parameter | Parameter name | MD1 | MD2 | MD2 |
|---|---|---|---|---|
| $C_3$ | C3TKEFREE | 1.183 | 1.183 | 1.183 |
| $O_\lambda$ | ETKE_OLAM | 2.0/3.0 | 2.0/3.0 | 0.29 |
| $\nu \equiv (C_K C_\epsilon)^{\frac{1}{4}}$ | NUPTKE | 0.5265 | 0.5265 | 0.5265 |
| $C_\epsilon$ | C_EPSILON | 0.871 | 0.871 | 0.871 |

| Parameter | Parameter name | eRMC01 | eeQNSE | eeEFB |
|---|---|---|---|---|
| $C_3$ | C3TKEFREE | 2.38 | 1.39 | 1.25 |
| $O_\lambda$ | ETKE_OLAM | 2.0/3.0 | 0.324 | 0.113 |
| $\nu \equiv (C_K C_\epsilon)^{\frac{1}{4}}$ | NUPTKE | 0.5265 | 0.504 | 0.532 |
| $C_\epsilon$ | C_EPSILON | 0.845 | 0.798 | 0.889 |

# Free parameters - relation to shape of $\phi_3$ and $\chi_3$

- $R(C_3, \nu)$, $P(C_3, \nu, O_\lambda)$




$R_{\text{inf}} = \lim_{Ri \to \infty} R$, $P_{\text{inf}} = \lim_{Ri \to \infty} P$

# TKE based length scales $L$

- Bougeault a Lacarrère (1989) :

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

$L_{up}(E)$ ($L_{down}(E)$) - $L$ upward (downward)

- $L_N = \sqrt{\frac{2.E}{N^2}}$ for stable straification
- with possibility to use moist BVF (computed from $Ri^*$)
- prognostic treatment of $L$ (under development)

# Conversion between $L$ and $l_m$

- following RMC01:

$$L_K = \frac{C_\epsilon}{\nu^3} l_m \frac{f(Ri)^{\frac{1}{4}}}{\chi_3^{\frac{1}{2}}}, \quad L_\epsilon = \frac{C_\epsilon}{\nu^3} l_m \frac{\chi_3^{\frac{3}{2}}}{f(Ri)^{\frac{3}{4}}}$$

- assuming: $L \equiv \left(L_K^3 L_\epsilon\right)^{\frac{1}{4}}$ we get:

$$L = \frac{C_\epsilon}{\nu^3} l_m$$

# Length scale choice

| CGMIXELEN | $Ri > 0$ | $Ri \leq 0$ |
|---|---|---|
| EL0 | $L_{GC}$ | $L_{GC}$ |
| EL1 | $L_{BL}$ | $L_{BL}$ |
| EL2 | $L_{BL}$ | $\min\left(\sqrt{L_{BL}\,L_{GC}}, L_{BL}\right)$ |
| EL3 | $\min\left(L_N, L_{max}\right)$ | $L_{GC}$ |
| EL4 | $\frac{L_{GC}\,L_N}{\sqrt{L_{GC}^2+L_N^2}}$ | $L_{GC}$ |
| EL5 | $\min\left(L_{BL}, L_N\right)$ | $L_{BL}$ |

$L_{max}$ - upper limit for mixing length in stable stratification;

$L_{GC}$ is $l_m$ converted to TKE type mixing length.

- TKEMULT - controls influence of TKE on $L$:
  $L(e_k) \rightarrow L(\mathrm{TKEMULT}.e_k)$

# Moisture influence

- expansion and latent heat release influences BVF - $N^2 (\rightarrow Ri, Ri_f, ..)$ (Marquet and Geleyn, 2013):

  $$N^2 = E_{s_{sL}} (SCC, Q) \frac{\partial s_{sL}}{\partial z} + E_{q_t, s_{sL}, Q} (SCC, Q) \frac{\partial q_t}{\partial z}$$

  $SCC$ - Shallow Convection Cloudiness
  $Q(SCC)$ (or $\widehat{R^*}$) - represents the effects of non-Gaussian distributions (influence of skewness) of fluctuations

| LCOEFK_SCQ | .TRUE. | .FALSE. |
|---|---|---|
| | $Q(SCC) = SCC$ | $Q(SCC) = SCC^{F(C_n)}$ |

$$F(C_n) = 0.5 \left[ \sqrt{(6.25\, C_n)^2 + 4} - 6.25\, C_n \right]$$

$C_n$ a skewness-linked parameter.

## Moist Anti-fibrillation scheme

- (currently) required due to *SCC* compuation from $Ri^*$
- controlled by XDAMP
- turned off by XDAMP=0
- automatically turned off in case of prognostic TTE computation

# Hybrid computation

- in dry case is $Ri(\theta)$ single stability parameter for indication of well mixed state (entropic considerations) and also for intensity of turbulent mixing (buoyancy considerations)
- moist case - two stability parameters required:
  - $Ri_{f\,m} = -\frac{II}{I}$ (buoyancy considerations)
  - $Ri_{f\,s1} = -\frac{\frac{g\,M(SCC)}{\theta_{s(1)}}\overline{w'\theta'_{s(1)}}}{I}$ (entropic considerations)

  $\theta_{s(1)}$ - moist entropy potential temperature $\theta_{s(1)}$ derived by (Marquet, 2011)

$I$ - shear source term, $II$ - buoyancy source term

# Hybrid computation

$$\overline{w' s'_{sL}} = -K'_H\left(Ri_{f\,s1}\right)\frac{\partial s_{sL}}{\partial z} - K'_H\left(Ri_{f\,m}\right)\frac{O_\lambda\,\tau_k}{2\,C_3\,\overline{w'^2}}\left(\overline{w' s'_{sL}}\,N^2 + \frac{\partial s_{sL}}{\partial z}\,I\right.$$
$$+TOMs$$

$$\overline{w' q'_t} = -K'_H\left(Ri_{f\,s1}\right)\frac{\partial q_t}{\partial z} - K'_H\left(Ri_{f\,m}\right)\frac{O_\lambda\,\tau_k}{2\,C_3\,\overline{w'^2}}\left(\overline{w' q'_t}\,N^2 + \frac{\partial q_t}{\partial z}\,II\right)$$
$$+TOMs$$

$$\overline{w' u'} = -K_M\left(Ri_{f\,s1}\right)\frac{\partial u}{\partial z}$$

$$\overline{w' v'} = -K_M\left(Ri_{f\,s1}\right)\frac{\partial v}{\partial z}$$

- Hybrid computation activated by LCOEFK_RIH=.TRUE.

# Prognostic computations

- source terms $I$ and $II$ computation:
  - (LCOEFK_FLX=.F.) from gradients only in current time step with TKE correction due to TOMs contribution:
    $$I = K_M \left[ \left(\frac{\partial u}{\partial z}\right)^2 + \left(\frac{\partial v}{\partial z}\right)^2 \right],$$
    $$II = -E_{s_{sL}} K_H \frac{\partial s_{sL}}{\partial z} - E_{q_t,s_{sL}} K_H \frac{\partial q_t}{\partial z}$$
  - (LCOEFK_FLX=.T.) from fluxes and gradients from previous time step:
    $$I = -\overline{u'w'}\frac{\partial u}{\partial z} - \overline{v'w'}\frac{\partial v}{\partial z},$$
    $$II = E_{s_{sL}} \overline{w's'_{sL}} + E_{q_t,s_{sL}} \overline{w'q'_t}$$
- prognostic $L$ activated by LCOEFK_PL=.TRUE.
- prognostic TTE activated by LCOEFK_PTTE=.TRUE.

## TOMs parametrisation

- turned on by LCOEFK_TOMS=.TRUE.
- contributions from TOM terms can be controlled via coefficients:

| TOM term | Multiplying parameter |
|---|---|
| $\overline{w'^3}$ | ETKE_CG01 |
| $\overline{w'\theta'^2}$ | ETKE_CG02 |
| $\overline{w'^2\theta'}$ | ETKE_CG03 |

# Thank you for your attention!