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Contents

Abstract

The last version of turbulent scheme TOUCANS has been implemented in to local cycle CY38t1. Several machine specific bugs were eliminated in the code in this process.

Sensitivity of the model to TOUCANS modifications was tested in case study with stable stratification, where model produces large temperature bias. Tests with TOUCANS scheme indicate that the temperature bias is not caused by problem in turbulence parametrisation.

New TKE based mixing length computation was tested in TOUCANS scheme. Test show underestimation of mixing for TKE based mixing length. A solution for this problem was proposed.

1 TOUCANS

TOUCANS (Third Order moments (TOMs) Unified Condensation Accounting and N-dependent Solver (for turbulence and diffusion)) is a compact turbulence parametrisation. TOUCANS integrates several ideas in turbulence parametrization: no existence of critical Richardson number Ri_{cr}, anisotropy of turbulence, prognostic treatment of Turbulence Kinetic Energy (TKE),Turbulence Total Energy (TTE) and mixing length - L, Third Order Moments (TOMs) parametrisation, and parametrisation of shallow convection.

No existence of Ri_{cr} and anisotropy of turbulence are ensured by the shape of stability functions ϕ_3, χ_3. These are chosen among modified CCH02 turbulent scheme [4], emulation-extension of Quasi-Normal Scale Elimination (QNSE) scheme [12], emulation-extension of Energy and Flux Budget (EFB) scheme [15], and emulation of RMC01 [13] scheme. All acording to [1].

Prognostic treatment of TKE is adapted from pTKE [6] turbulent parametrisation. Prognostic computation of TTE and L use technically the same solver as the one for TKE.

Usage of TKE as prognostic variable enables computation of TKE dependent mixing lengths L. In TOUCANS are available six different settings for mixing length computation.

2 TOUCANS implementation

TOUCANS has been implemented in to cycle CY38t1. The technical details of TOUCANS scheme are presented in this subsection.

2.1 Turbulence scheme

The schemes with prognostic TKE (pseudo-TKE and TOUCANS) are turned on with LPTKE=.TRUE., otherwise the Louis scheme is used. TOUCANS is turned on by LCOEFKTKE=.TRUE. .

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

2.2 Prognostic TTE

The prognostic treatment of Total Turbulent Energy(TTE) is turned on by LCOEFK_PTTE=.TRUE.

2.3 Flux based computation of source terms

The source terms in energy TKE equation can be computed from gradients only (LCOEFK_FLX=.FALSE.) or can be influenced by fluxes computed in previous time step (LCOEFK_FLX=.TRUE.). In case of LCOEFK_PTTE=.TRUE. only the flux compuation is possible (LCOEFK_FLX=.TRUE.).

2.4 TOUCANS emulation

We have 5 possibilities, which are controlled by the string CGTURS:

Emulation	CGTURS
model I	MD1
model II	MD2
RMC01	RMC
QNSE	QNSE
EFB	EFB

The choice of turbulence scheme is connected with values of four free parameters: C_3, O_λ, ν, and C_ϵ.

In case of RMC, QNSE and EFB the degrees of freedom should correspond to original setting of emulated schemes:

Parameter	Parameter name	RMC	QNSE	EFB
C_3	C3TKEFREE	2.38	1.39	1.25
O_λ	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_ϵ	C_EPSILON	0.845	0.798	0.889

In case of MD1 and MD2 the free parameters can be adjusted. We reccommend these possible settings:

Parameter	Parameter name	MD1	MD2	MD2
C_3	C3TKEFREE	1.183	1.183	1.183
O_λ	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_ϵ	C_EPSILON	0.871	0.871	0.871

2.4.1 pseudo-TKE

pseudo-TKE is controled by one degree of freedom ν (NUPTKE). The default value is 0.52.

2.5 Mixing lengths

The calculation of mixing length l_m is not restricted to 'classical' computation of z-dependent mixing length (parameter CGMIXELEN='AY', or default CGMIXLEN='Z'; difference is in PBL height computation):

$$l_{m/h} \quad = \quad \frac{\kappa z}{1 + \frac{\kappa z}{\lambda_{m/h}} \left[\frac{1+\exp\left(-a_{m/h}\sqrt{\frac{z}{H_{pbl}}}+b_{m/h}\right)}{\beta_{m/h}+\exp\left(-a_{m/h}\sqrt{\frac{z}{H_{pbl}}}+b_{m/h}\right)} \right]}. \tag{1}$$

(κ is Von Kármán constant, z is height, $a_{m/h}$, $b_{m/h}$ and $\lambda_{m/h}$ are tuning constants and H_{pbl} is PBL height)

, but we can also use mixing lengths dependent on TKE (e) L:

- modified Bougeault and Lacarrère (1989) approach:

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

  $L_{up}(e)$ ($L_{down}(e)$) - upward(downward) mixing distances
- $L_N = \sqrt{\frac{2.e}{N^2}}$ for stable regimes (N is Brunt-Väisälä Frequency)

One 'old' and five new appropriately combined mixing lengths are available in the code:

Parameter 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 (1) converted to TKE type mixing length.

The dependence of mixing length L on TKE can be tuned by the parameter TKEMULT (by default TKEMULT=1): $L(e) \rightarrow L(\text{TKEMULT}.e)$

2.5.1 Prognostic mixing length

The prognostic treatment of mixing length is turned on by LCOEFK_PL=.TRUE.
The intsity of vertical diffusion for mixing length can be modified via coefficient ETKE_TAUM. Default value is ETKE_TAUM=1.0.

2.6 Influence of moisture

2.6.1 Shallow convection parametrisation

Shallow convection can be parametrised with parametrisation after Geleyn 1987 (Ri^*) or with new shallow convection parametrisation based on Pascal Marquet's moist entropy potential temperature θ_{s1}: 1, Ri^{**} - similar to Ri^* approach (q_{sat} dependence):

LCOEFK_THS1	.TRUE.	.FALSE.
Ri:	Ri^{**}	Ri^*

The 'sharpness' of on and off switching of shallow convection parametrisation by Ri^{**} is controlled by ETKE_RIFC_MAF. The default value is ETKE_RIFC_MAF=0.5. Higher value makes the transition from $Ri < 0$ to $Ri > 0$ less steep.

Note that currently Ri^* or Ri^{**} are used as inputs for computation of Shallow Convection Cloudiness(SCC) - LCOEFK_RIS=.TRUE. Currently there is no other alternative, i.e LCOEFK_RIS=.FALSE. is not usable.

Moist AntiFibrillation (AF) scheme can be turned off by setting XDAMP=0.0. The default value is XDAMP=1.0.

In case of LCOEFK_PTTE=.TRUE. moist AF scheme is not required and is automatically turned off independent from XDAMP value.

2.6.2 Conservation(entropy) and conversion(energy) aspects

In hybrid mode - LCOEFK_RIH=.TRUE. a pair of stability parameters is used: Rif_{s1} (or Ri_{s1}) and Rif_m (or Ri_m) to separate the conservation and conversion aspect in the turbulent exchange coefficients.

[still under development]

2.6.3 Influence of skewness

If LCOEFK_SCQ=.TRUE. the Q (specifically horizontal part of the deviation form Gaussianity for the influence of the partial cloudiness on the buoyancy flux) is influenced by skewness equivalent parameter - C_n. Otherwise (If LCOEFK_SCQ=.FALSE.) Q=SCC.

2.6.4 Mixing length influenced by moisture

If LCOEFK_ML=.TRUE. then TKE based mixing lengths are computed from moist BVF.

2.7 Third Order Moments (TOMs)

TOMs parametrisation is turned on by LCOEFK_TOMS=.TRUE. .

It is possible to tune individual TOMs terms by multiplying factors (default values are 1.0):

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

If LCOEFK_TOMS_D=.TRUE. then heat and moisture non-local transport via TOMs is done separatly.

2.8 Security

The limitation for τ against too small values is set by ETKE_BETA_EPS : $\tau = \tau + \text{ETKE\_BETA\_EPS}\,\Delta t$. The default value is 0.02.

The limitation for τ against too large values is set by ETKE_GAMMA_EPS : $\tau = \frac{\tau}{1+\text{ETKE\_GAMMA\_EPS}\,\frac{\tau}{\Delta t}}$. The default value is 0.03.

3 Reasonable setup

```
&NAMPHY
LPTKE=.T.,
LCOEFKTKE=.T.,
LCVPP=.T.,
LCOEFK_THS1=.F.,
LCOEFK_RIH=.F.,
LDIFCONS=.T.,
LCOEFK_TOMS=.T.,
LCOEFK_TOMS_D=.T.,
LCOEFK_PTTE=.T.,
LCOEFK_FLX=.T.,
LCOEFK_SCQ=.T.,
LCOEFK_PL=.F.,
LCOEFK_ML=.F.,
CGMIXLEN='EL0',
CGTURS='MD2',

&NAMPHY0
C3TKEFREE=1.183,
ETKE_OLAM=0.29,
NUPTKE=0.5265,
C_EPSILON=0.871,
ETKE_CG01=1.0,
ETKE_CG02=1.0,
ETKE_CG03=1.0,
ETKE_TAUM=1.0,
ETKE_RIFC_MAF=0.5,
ETKE_BETA_EPS=0.05,
ETKE_GAMMA_EPS =0.03,
TKEMULT=5.0,
XDAMP=1.0,
XMULAF=-1.85,
```

4 Case study 3. February 2014 - large temperature bias

In the ALADIN (operational setting of CY38 in SHMI, usage of pTKE scheme; 87 vertical levels) forecast for 3.2.2014 were detected large surface temperature biases in the easter part of Slovakia. The predicted temperature was significantly (ranging to 10°C) lower then the observed values (please see Figure 1). The stratification of the atmosphere was near neutral or stable, wind was calm and the surface was covered with snow (3-4 cm). We assumed that the model bias could be caused by inaccurate parametrisation of turbulence in stable stratification. To verify this hypotheses we used new turbulence parametrisation TOUCANS, which enables emulation of multiple stability schemes and usage of several TKE based mixing lengths. 5 emulations of turbulent schemes (RMC01, MD1, MD2, QNSE, EFB; please see 2.1) and 5 TKE based mixing lengths (EL1-EL5; please see 2.5) were tested in model 12 hour forecasts starting on 3.February 2014 at 00:00 a.m.

In general (for all tested settings; only one setting is presented) the tests with TOUCANS scheme give lower surface temperature than the forecast done with operational settings (please see Figure 2). This increases the negative temperature bias of the model. The magnitude of the temperature change is around 2°C, so the modifications in turbulence parametrisation can not explain the large temperature bias in operational run for the region of east Slovakia.

Nevertheless an overestimation of mixing near the surface was detected in TOUCANS after this stay. So the above results are influenced by this behavior. This was corrected in the latest TOUCANS code by modifying stability functions (F_M, F_H) near surface.

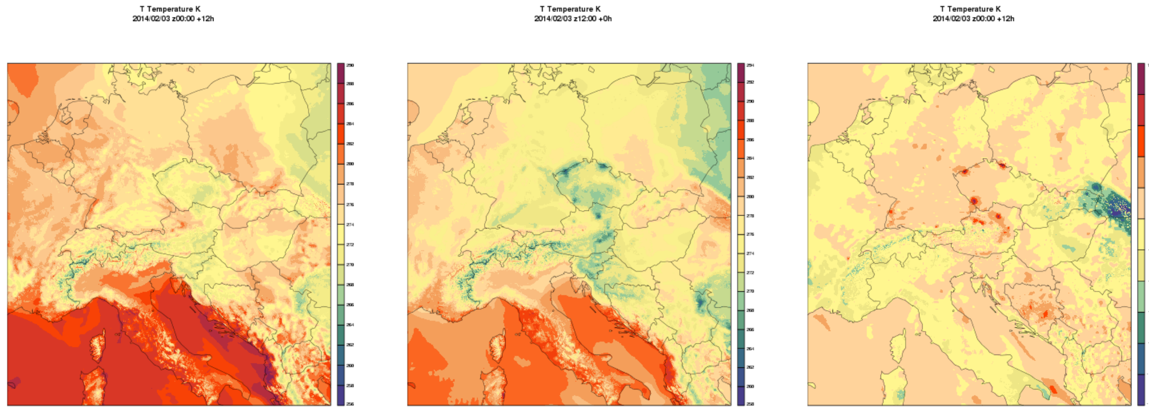

Figure 1: Surface temperature on 3.February 2014 at 12:00 a.m. Left - model forecas, middle - output from INCA system, right difference between value from model and INCA system.

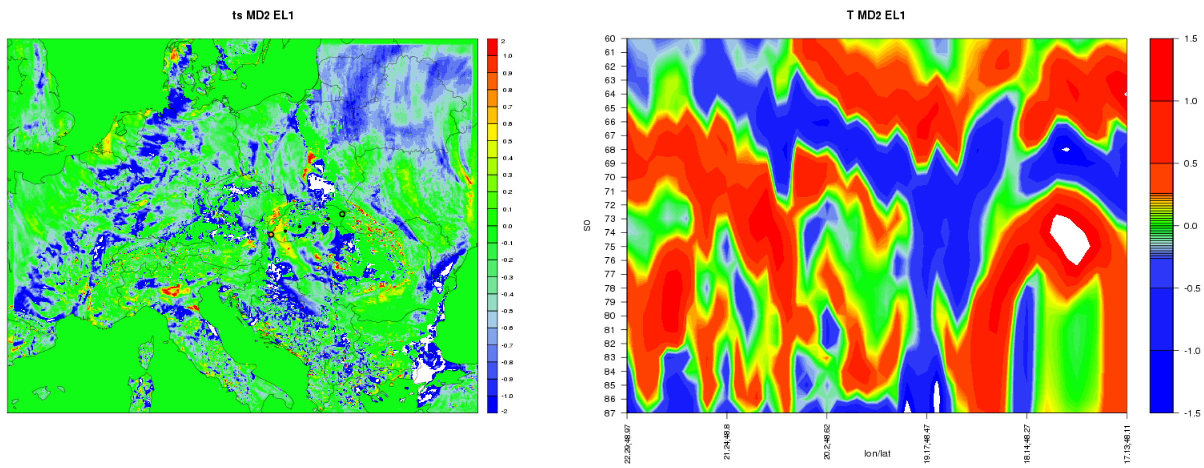

Figure 2: Difference in temperature on 3.February 2014 at 12:00 a.m. between runs (12 h integration) with TOUCANS (mixing length and MD2 turbulent scheme) and pTKE scheme. Left - surface temperature difference. Right - vertical cross section along the line starting in 'green point' and ending in 'red point' displayed on the left picture.

5 TKE based mixing length

TOUCANS turbulent scheme enables usage of TKE based mixing lengths. Their advantage is their direct relation with TKE, which is a measure of turbulence mixing intensity. The 'classical' mixing length AY relies on the diagnostics of PBL height and offers only specific smooth vertical profile (please see Figure 3, black line).

We made a comparison of 'classical' mixing length AY (in TOUCANS named as EL0) and the 5 possible TKE based mixing lengths in TOUCANS in 3D integration of the model (5 step integration starting at 3.3.2011 6:00 a.m.; 87 vertical levels). We can see on the 6 selected (chosen as representatives for various situations) that the TKE based mixing lengths tends to underestimate mixing. This behavior can be modified by increasing tuning parameter TKEMULT (please see 2.5).

According to our tuning we recommend usage of TKEMULT=5. As you can see on Figure 4 the profiles of EL1-EL5 are closer to the profile of EL0 with TKEMULT=5.0 . Larger value of TKEMULT would lead to overestimation of mixing length mainly in higher levels of the model.

The difference between 'classical' EL0 and new EL1 can be seen also on the scatter plot (using points from whole domain from levels bellow level 60) on Figure 5. The off-diagonal area with high density of points in the lower part of the plots is caused by non-zero value of EL0 in the levels above the PBL height. In this region is TKE almost zero so the TKE based mixing lengths are nearly zero. However this syndrome does not create a large difference between runs with EL0 and EL1 since the computed exchange coefficients K_M and K_H are decreased by almost zero TKE and low values of stability functions $\chi_3(Ri)$ and $\phi_3(Ri)$ in stable stratification:

$$K_M = C_K \, L \, \chi_3(Ri).\sqrt{e}, \tag{2}$$
$$K_H = C_3 \, C_K \, L \, \phi_3(Ri).\sqrt{e}. \tag{3}$$

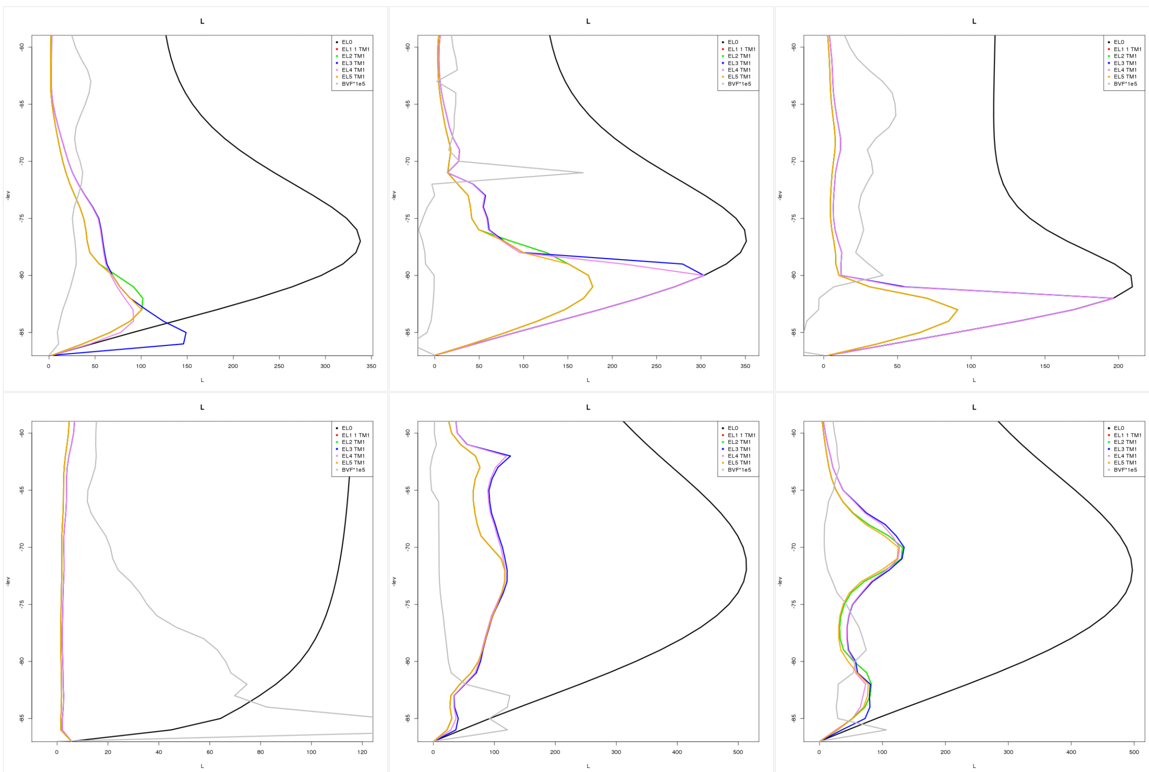

Figure 3: 6 chosen vertical profiles of mixing lengths EL0-EL5 with TKEMULT parameter equal to 1.0. Gray profile is BVF·1e5.

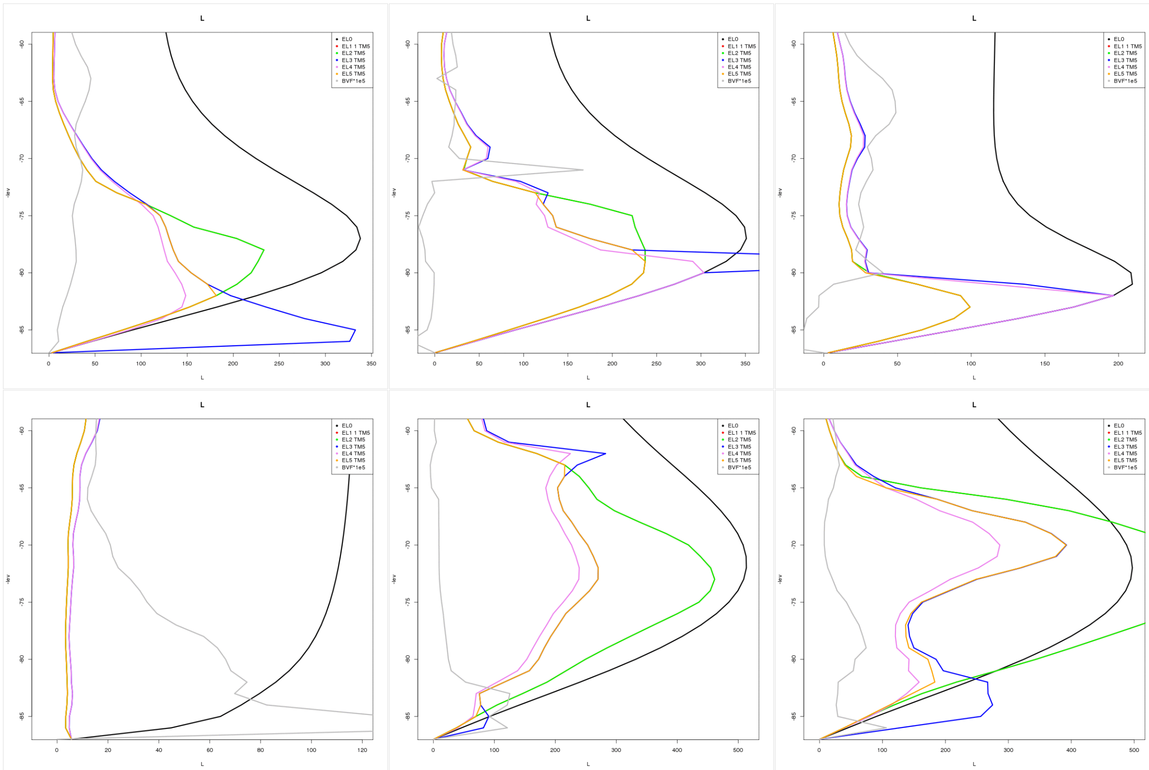

Figure 4: 6 chosen vertical profiles of mixing lengths EL0-EL5 with TKEMULT parameter equal to 5.0. Gray profile is BVF·1e5.

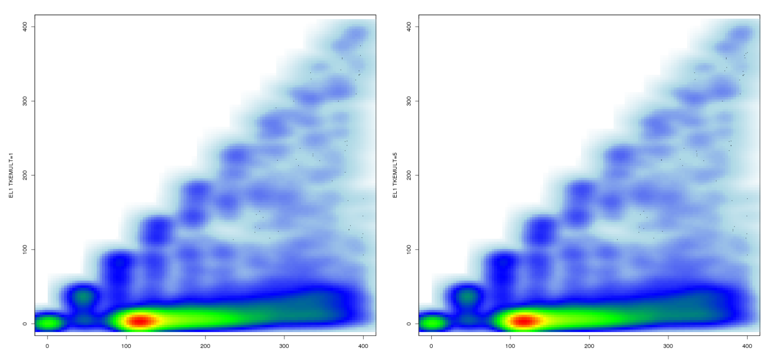

Figure 5: Scatterplot of EL0 mixing length versus EL1 mixing length. Left EL1 with TKEMULT=1.0, right EL1 with TKEMULT=5.0.

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