Mixing length computation in TOUCANS

Mario Hrastinski

hrastinski@cirus.dhz.hr

Croatian Meteorological and Hydrological Service

ALARO-1 WORKING DAYS

Brussels, Belgium, 12-14th September 2016

Outline:

- **Introduction**
  - Computation of turbulent fluxes in TOUCANS
  - Basic schemes and emulations
  - Mixing length options
- **Validation of mixing length experiments**
  - $L \rightarrow l$ conversion coefficient
  - Different formulations of Bougeault-Lacarèrre length scale
  - Profiles of turbulent diffusion terms
- **Conclusion and plan for further work**

Computation of turbulent fluxes in TOUCANS:

- TOUCANS – **T**hird **O**rder moments (TOMs) **U**nified **C**ondensation **A**ccounting and **N**-dependent **S**olver (for turbulence and diffusion)

- Upper-air vertical turbulent fluxes:

$$\overline{u'w'} = -K_M \frac{\partial u}{\partial z} + TOMs \quad (1)$$

$$\overline{v'w'} = -K_M \frac{\partial v}{\partial z} + TOMs \quad (2)$$

$$\overline{w'\theta'} = -K_H \frac{\partial \theta}{\partial z} + K_H \frac{1}{A_z} \frac{O_\lambda}{C_4} \left(\frac{g}{\theta} \overline{\theta'^2} \right) + TOMs \quad (3)$$

$$K_M = \frac{\nu^4}{C_\epsilon} \sqrt{\chi_3 \sqrt{f(Ri)} L \sqrt{e_k}} \quad (4)$$

$$K_H = C_3 \frac{\nu^4}{C_\epsilon} \frac{\phi_Q}{\chi_3} \sqrt{\chi_3 \sqrt{f(Ri)} L \sqrt{e_k}} \quad (5)$$

→ $f(Ri) = \chi_3(Ri) - Ri \cdot C_3 \cdot \phi_3(Ri)$

Computation of turbulent fluxes in TOUCANS:

- Prognostic TKE-equation:

$$\frac{de_k}{dt} = -g\frac{\partial}{\partial p}\left(\rho K_{ek}\frac{\partial e_k}{\partial z}\right) + I + II - \frac{C_\epsilon e_k^{3/2}}{L} \quad (6)$$

$$I = -\overline{u'w'}\frac{\partial u}{\partial z} - \overline{v'w'}\frac{\partial v}{\partial z} = K_M S^2$$

$$II = \frac{g}{\theta}\overline{w'\theta'} = K_M N^2$$

- Surface layer vertical turbulent fluxes:

$$\overline{u'w'} = \chi_3(Ri)\cdot f(Ri)\cdot\left(\frac{\kappa}{ln\left(1+\frac{z}{z_0}\right)}\right)^2\cdot\sqrt{u^2+v^2}\cdot u \quad (7)$$

$$\overline{v'w'} = \chi_3(Ri)\cdot f(Ri)\cdot\left(\frac{\kappa}{ln\left(1+\frac{z}{z_0}\right)}\right)^2\cdot\sqrt{u^2+v^2}\cdot v \quad (8)$$

$$\overline{w'\theta'} = C_3\cdot\chi_3(Ri)\cdot f(Ri)\cdot\left(\frac{\kappa}{ln\left(1+\frac{z}{z_0}\right)\cdot ln\left(1+\frac{z}{z_{0h}}\right)}\right)^2\cdot\sqrt{u^2+v^2}\cdot\Delta\theta \quad (9)$$

Basic schemes and emulations:

- Turbulence scheme depends on:
  - 4 free parameters ($C_3, C_\epsilon, \upsilon$ and O_λ) – basic properties
  - 3 functional dependencies (P, Q and R) – shape of stability functions
- Scheme realisations:

	Model I	Model II	eeQNSE	eeEFB
C_3	1.18	1.18	1.39	1.25
C_ϵ	0.871	0.871	0.798	0.889
υ	0.526	0.526	0.464	0.532
O_λ	2/3	0.29	0.324	0.113
P	const.	const.	const.	F(Ri)
Q	const.	const.	F(Ri)	F(Ri)
R	const.	F(Ri)	F(Ri)	F(Ri)

Mixing length options:

- Geleyn-Cedilnik (GC):

$$l_m^{GC} = \frac{\kappa z}{1+\frac{\kappa z}{\lambda_m}\left[\frac{1+\exp(-a_m\sqrt{\frac{z}{H_{PBL}}}+b_m)}{\beta_m+\exp(-a_m\sqrt{\frac{z}{H_{PBL}}}+b_m)}\right]} \quad (10)$$

- Bougeault-Lacarrère (BL89):

$$\int_z^{z+l_{up}} N_v^2(z'-z)\,dz' = e(z) \quad (11)$$

$$\int_{z-l_{down}}^{z} N_v^2(z-z')\,dz' = e(z) \quad (12)$$

$$L_{BL} = min(l_{up}, l_{down}) \quad (13)$$

$$L_{BL-TC} = \left(\frac{l_{up}^{-\frac{4}{5}} + l_{down}^{-\frac{4}{5}}}{2}\right)^{-\frac{5}{4}} \quad (14)$$

$$L_{BL-SC} = \sqrt{l_{up}\cdot l_{down}} \quad (15)$$

$$L_{BL-MX} = max(l_{up}, l_{down}) \quad (16)$$

Mixing length options:

$$l_m = \frac{v^3}{C_\epsilon} \cdot L = \alpha \cdot L \qquad (*)$$

- Deardorff (DE80):

$$L_N = \sqrt{\frac{2e}{N^2}} \qquad (17)$$

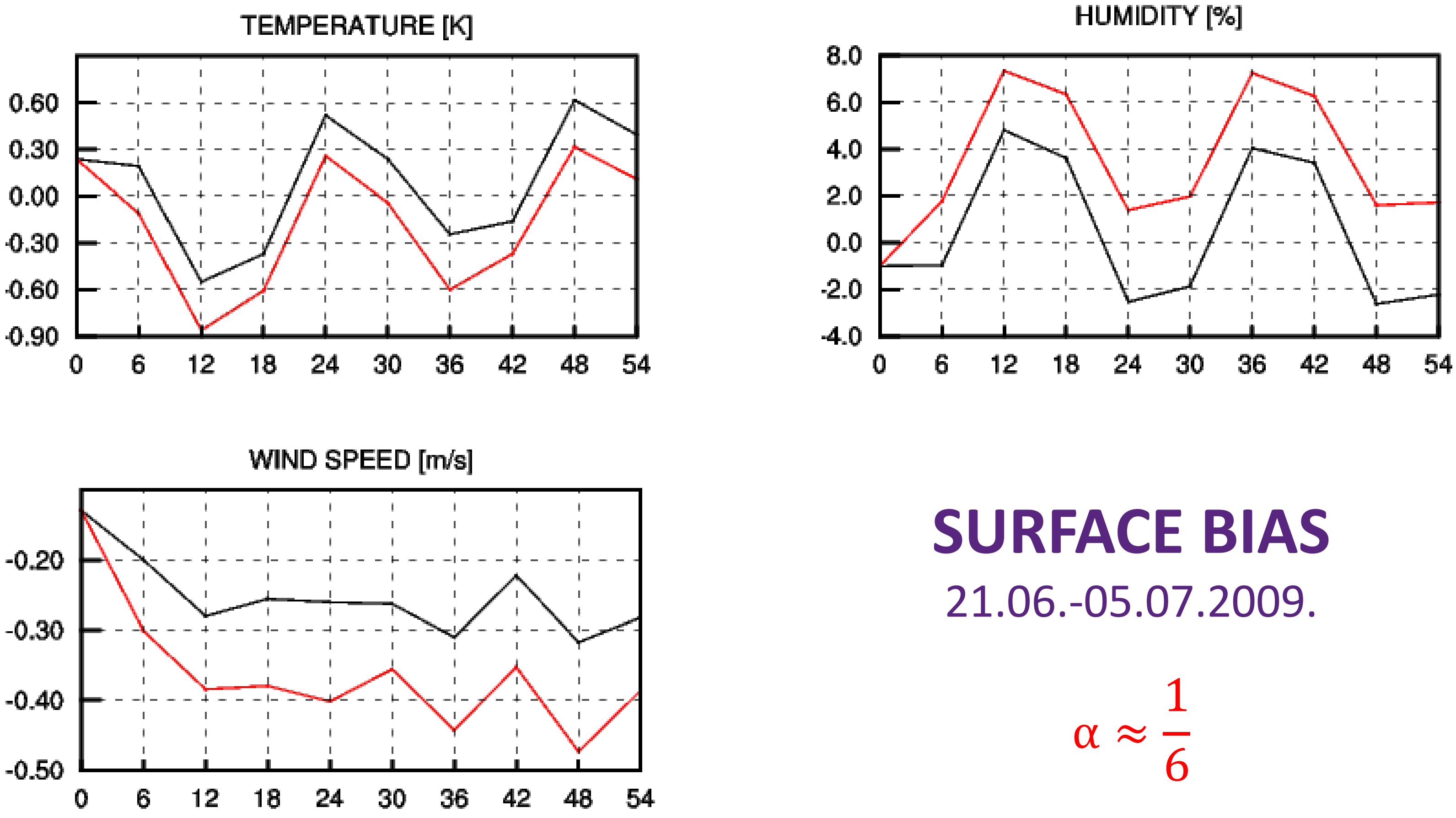
- Coded combinations:

CGMIXELEN	Ri > 0	Ri ≤ 0
EL0	L_{GC}	L_{GC}
EL1	L_{BL-TO}	L_{BL-TO}
EL2	L_{BL-TO}	$min\left(\sqrt{L_{BL-TO} \cdot L_{GC}}, L_{BL-TO}\right)$
EL3	$min(L_N, L_{max})$	L_{GC}
EL4	$\frac{L_{GC} \cdot L_N}{\sqrt{L_{GC}^2 + L_N^2}}$	L_{GC}
EL5	$min(L_{BL-TO}, L_N)$	L_{BL-TO}
EL6	L_{BL}, L_{BL-SC} or L_{BL-MX}	L_{BL}, L_{BL-SC} or L_{BL-MX}

$L \rightarrow l$ conversion coefficient:

- using the model II values from Table2. and (*):

$$l_m = \alpha \cdot L \approx \frac{1}{6} \cdot L \qquad (**)$$



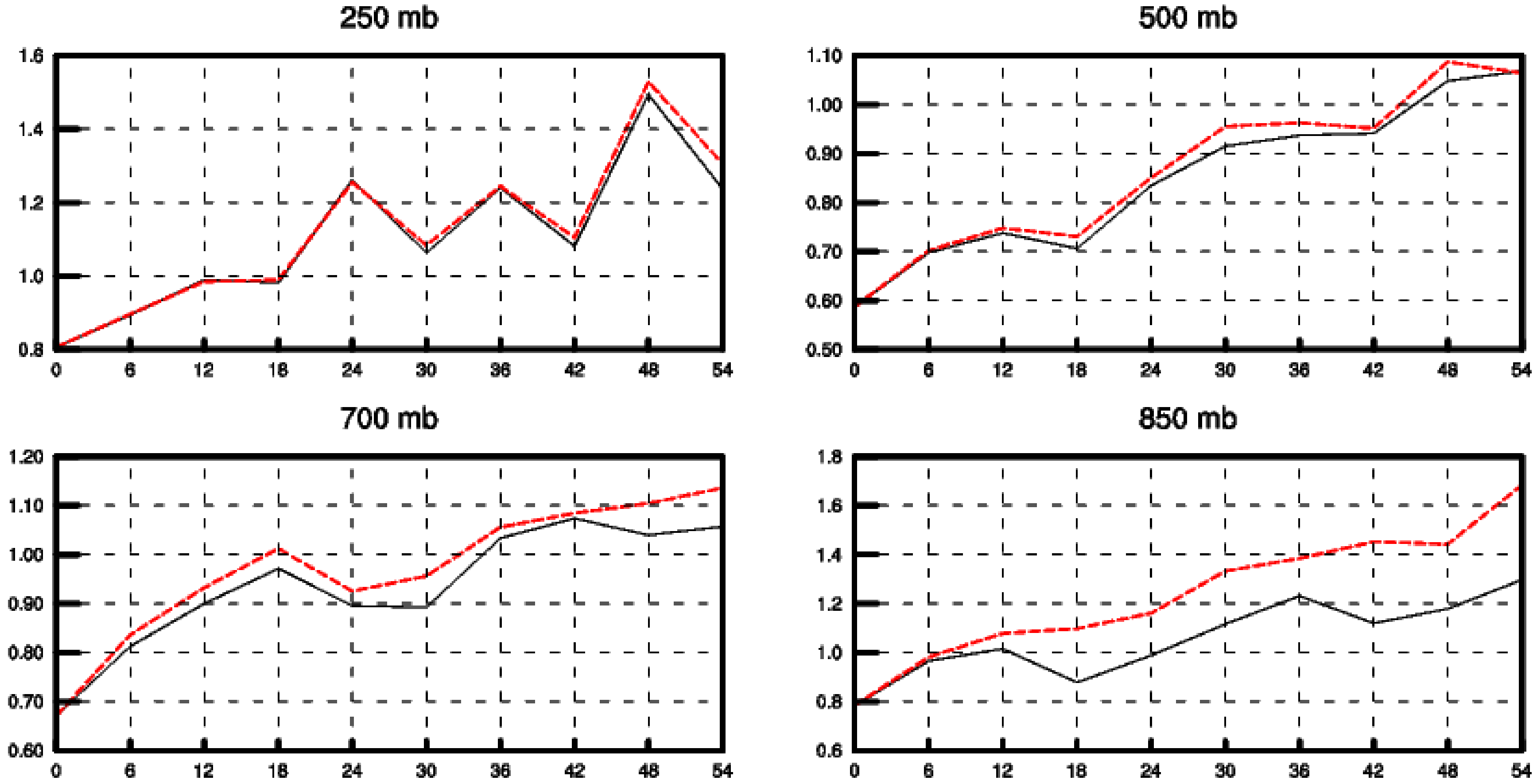
SURFACE BIAS

21.06.-05.07.2009.

$$\alpha \approx \frac{1}{6}$$

$L \to l$ conversion coefficient:

Temperature

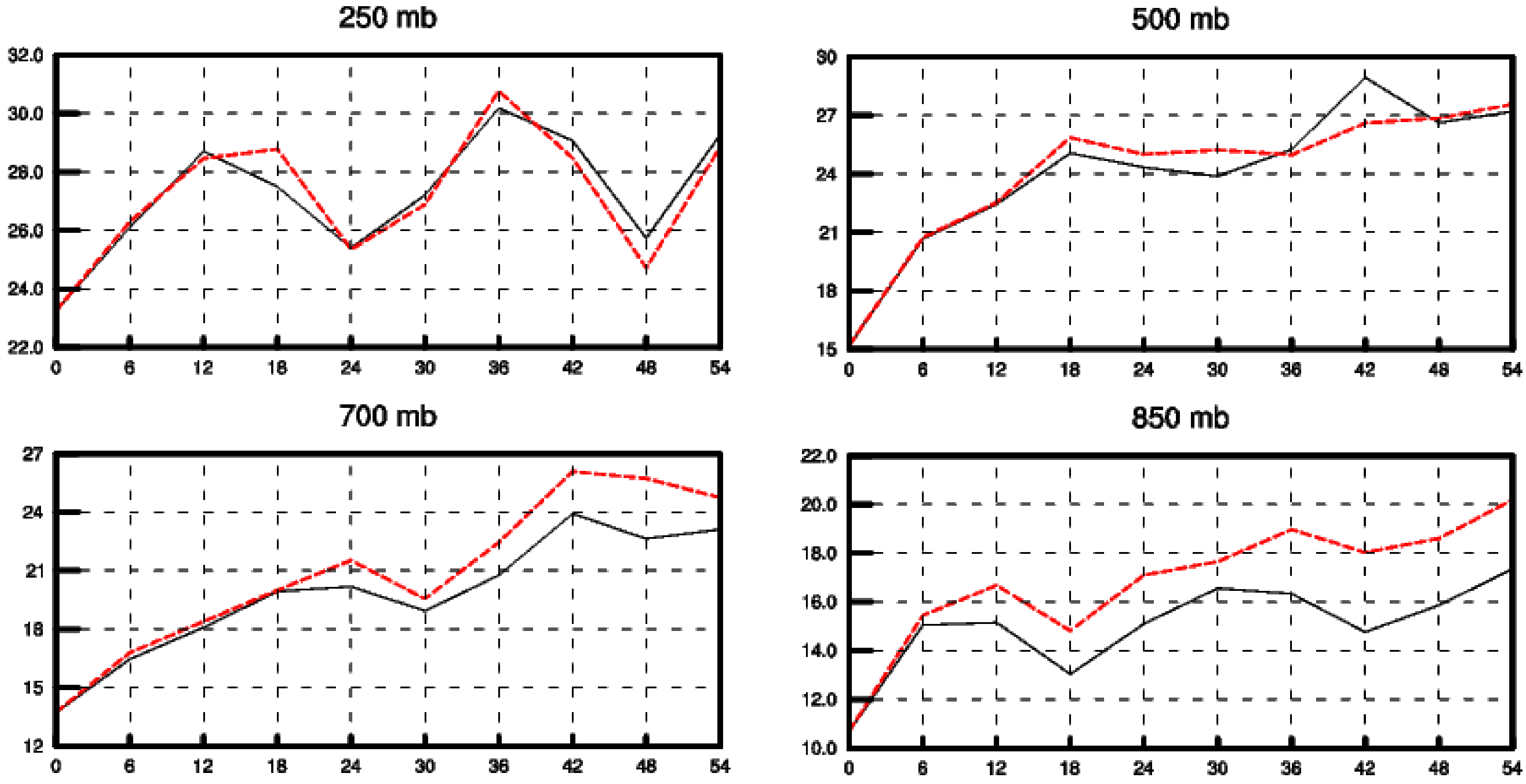


RMSE PROFILE

21.06.-05.07.2009.

$L \rightarrow l$ conversion coefficient:

Relative humidity

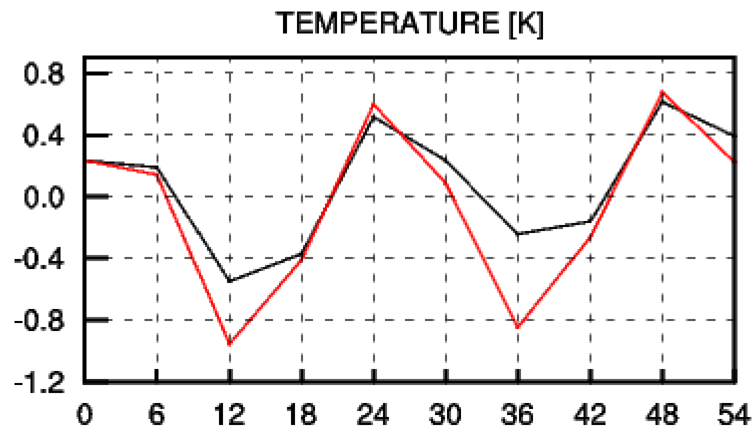


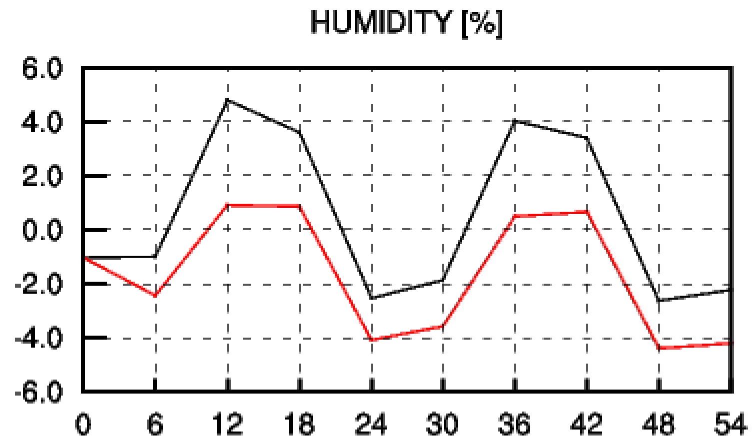
RMSE PROFILE

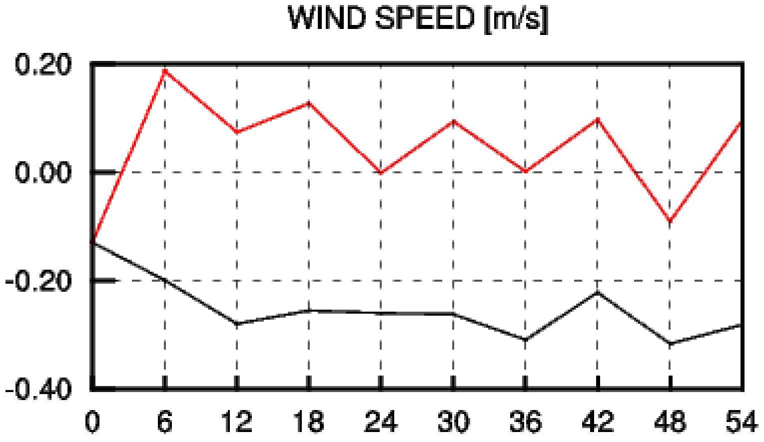
21.06.-05.07.2009.

$L \rightarrow l$ conversion coefficient:

- This α seems to be to small. What happens if we increase it?







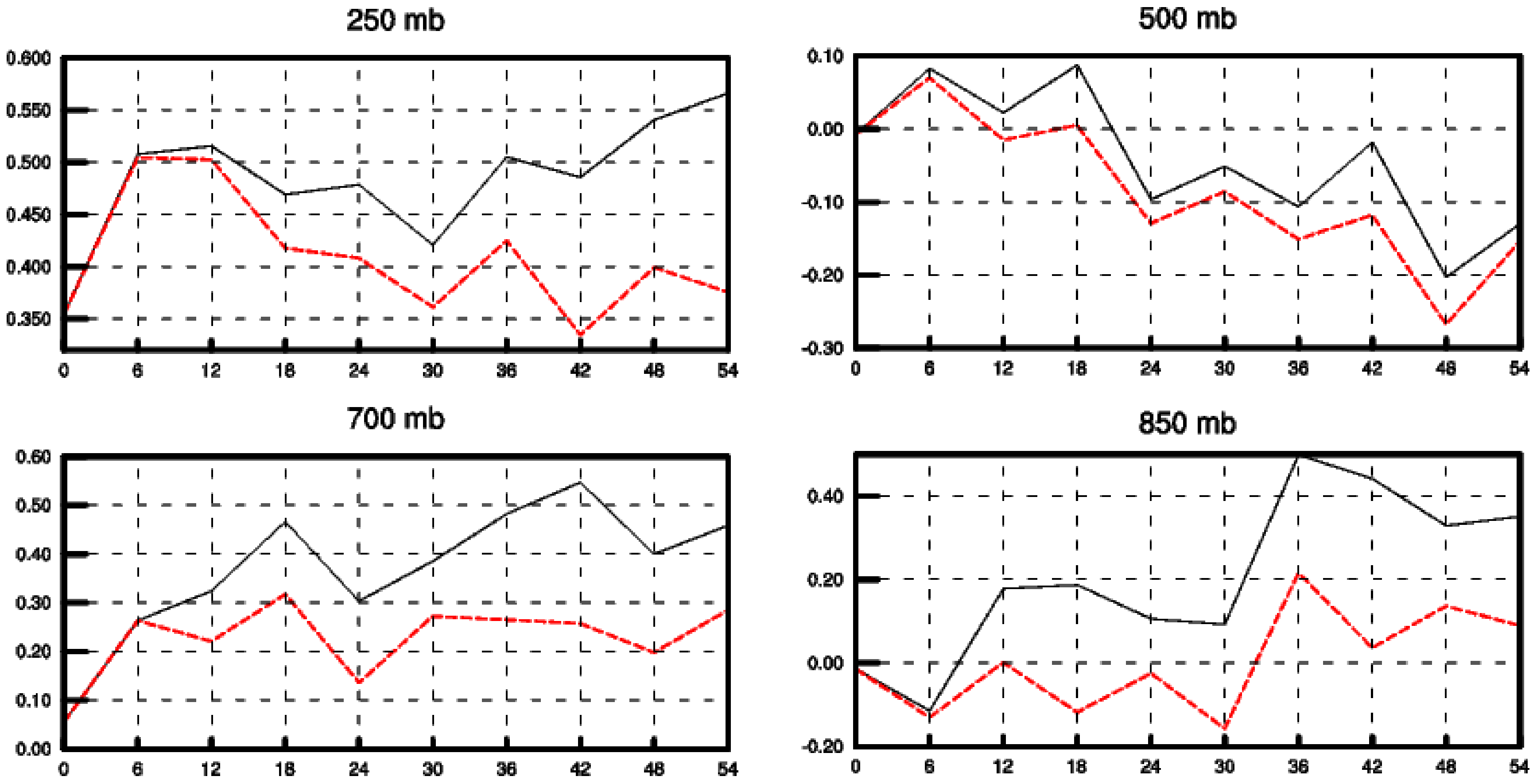
SURFACE BIAS

21.06.-05.07.2009.

α=1

$L \rightarrow l$ conversion coefficient:

Temperature

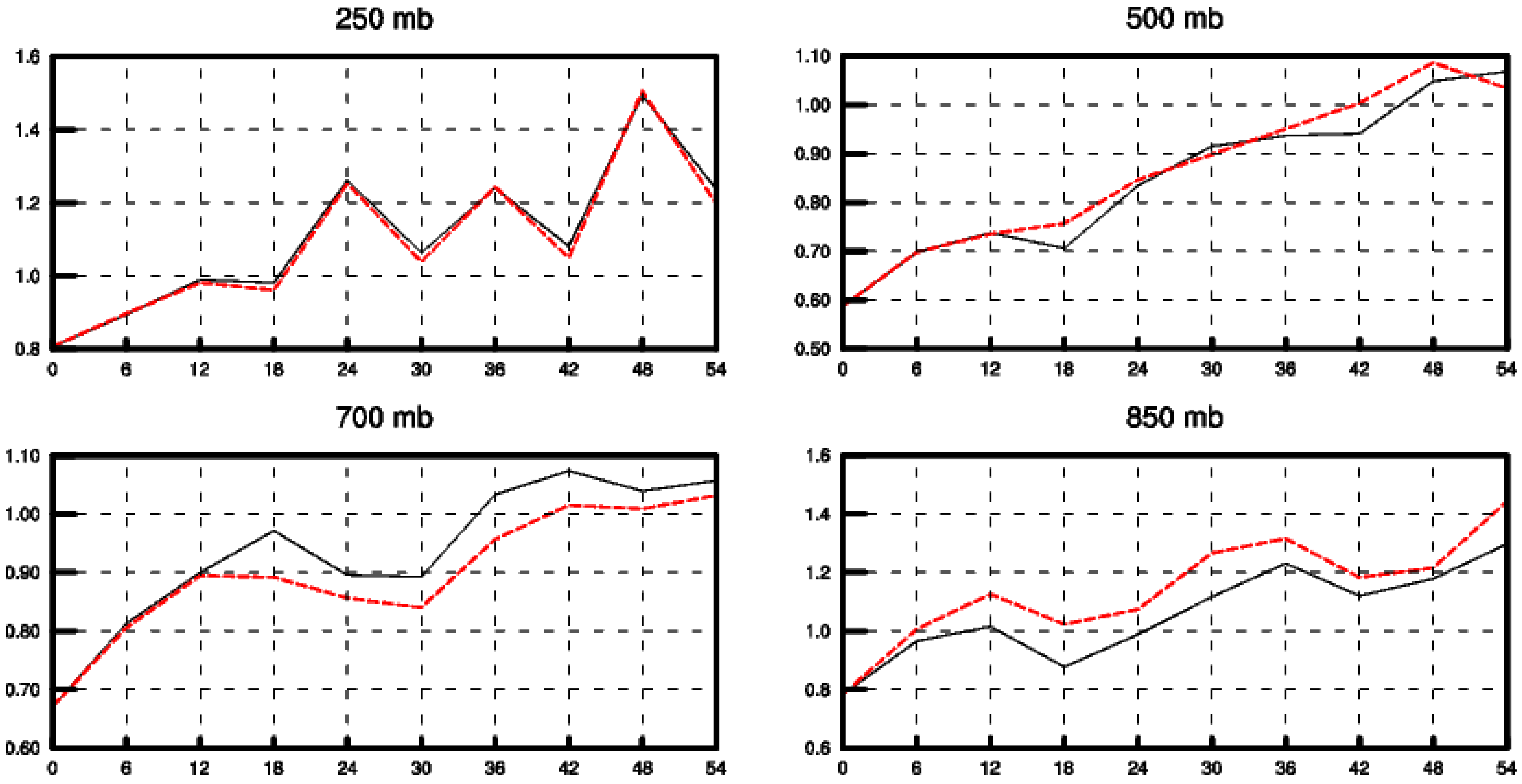


BIAS PROFILE

21.06.-05.07.2009.

$L \rightarrow l$ conversion coefficient:

Temperature

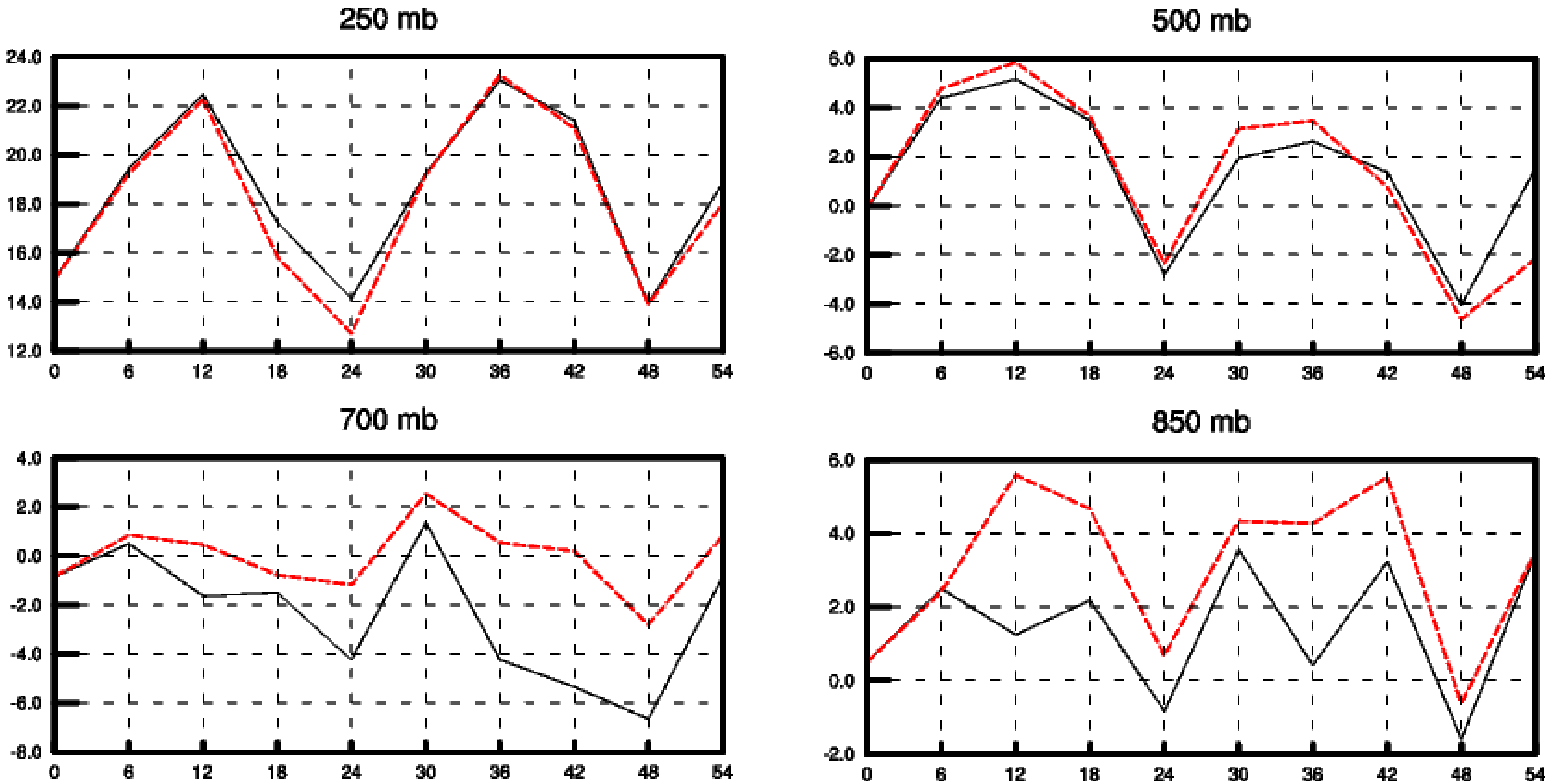


RMSE PROFILE

21.06.-05.07.2009.

$L \rightarrow l$ conversion coefficient:

Relative humidity

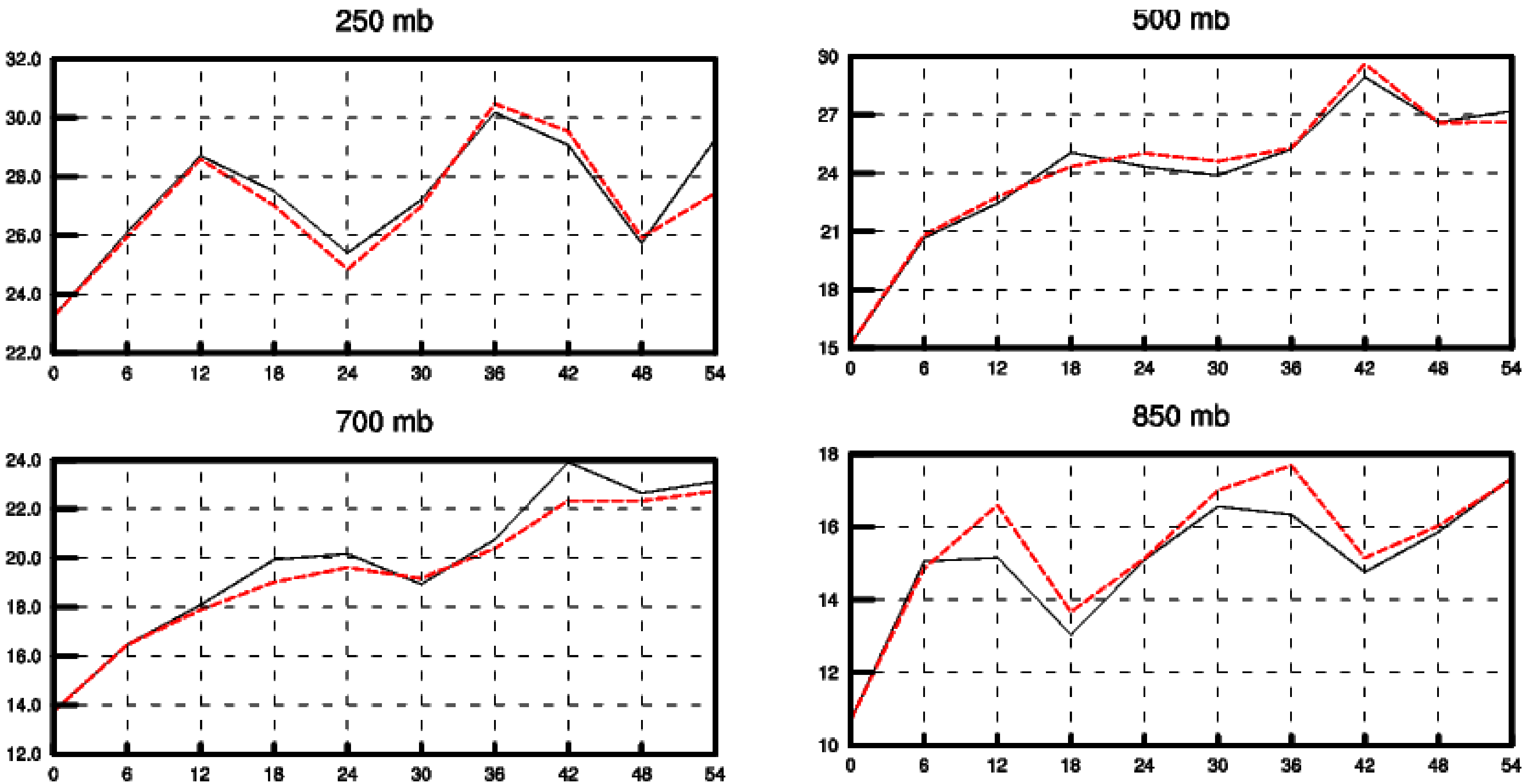


BIAS PROFILE

21.06.-05.07.2009.

$L \rightarrow l$ conversion coefficient:

Relative humidity

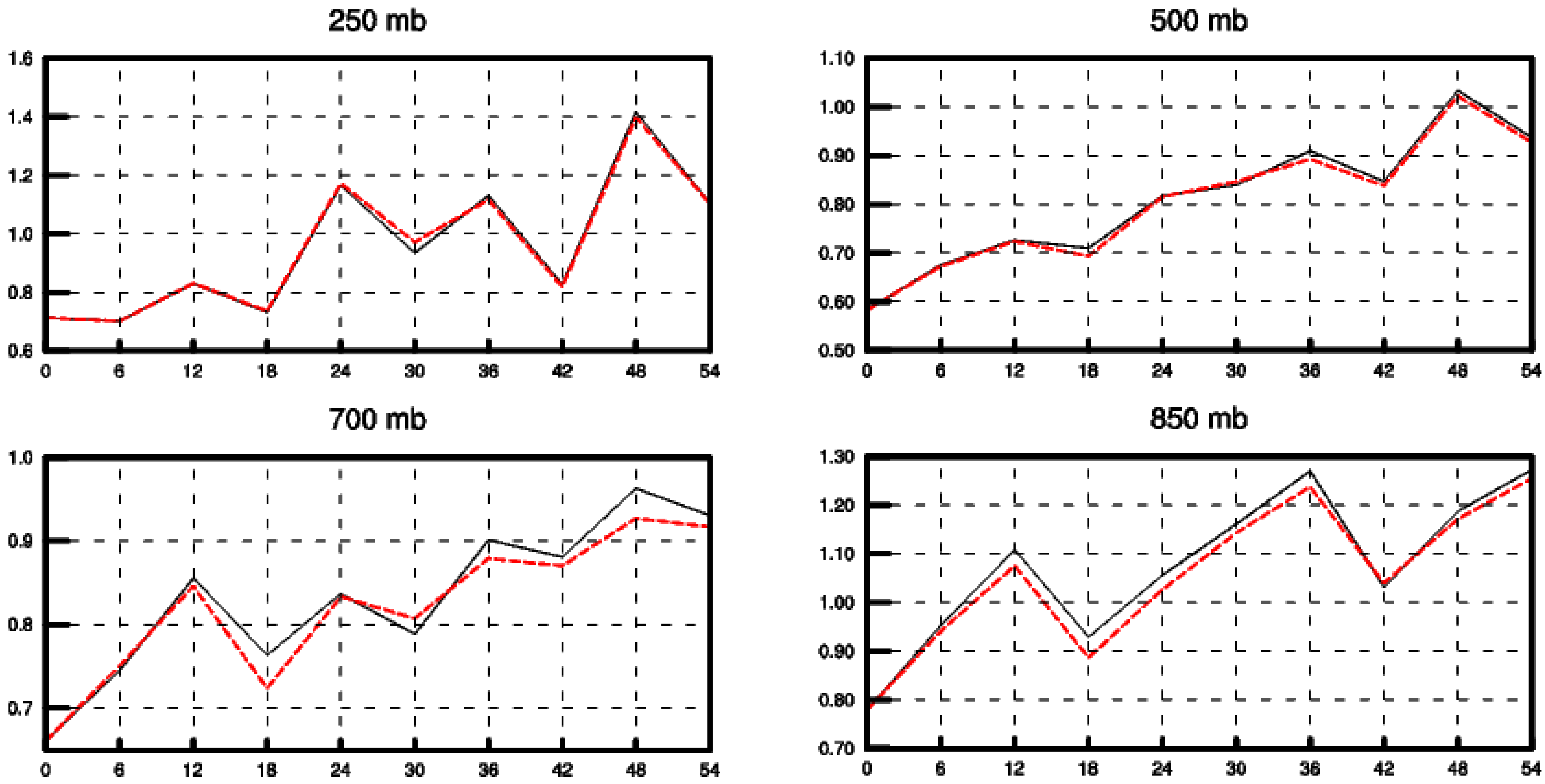


RMSE PROFILE

21.06.-05.07.2009.

Different formulations of BL89 length scale:

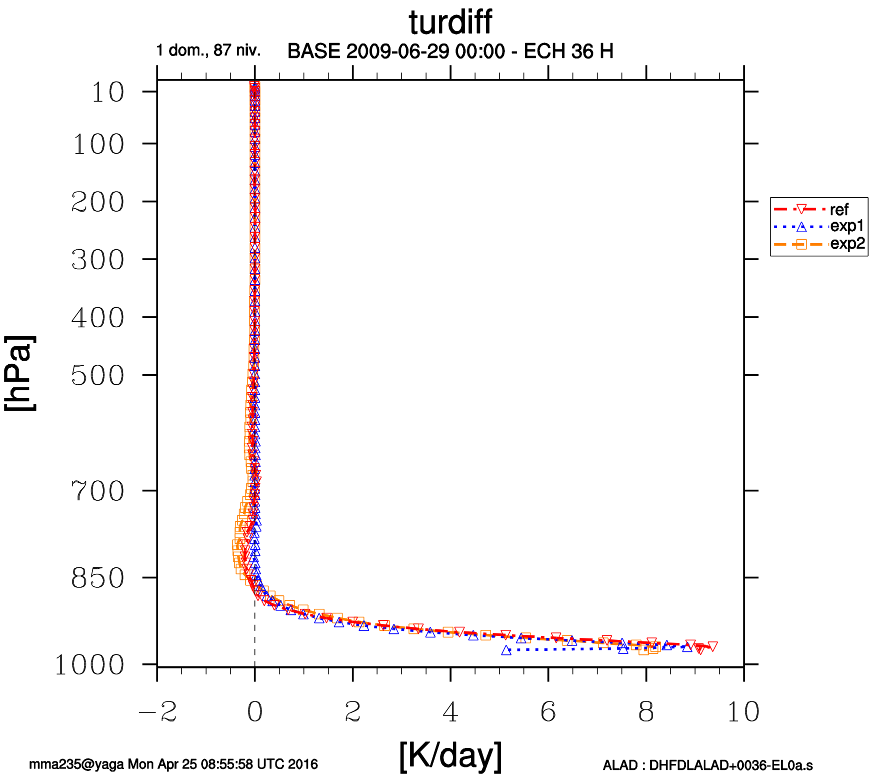
Temperature

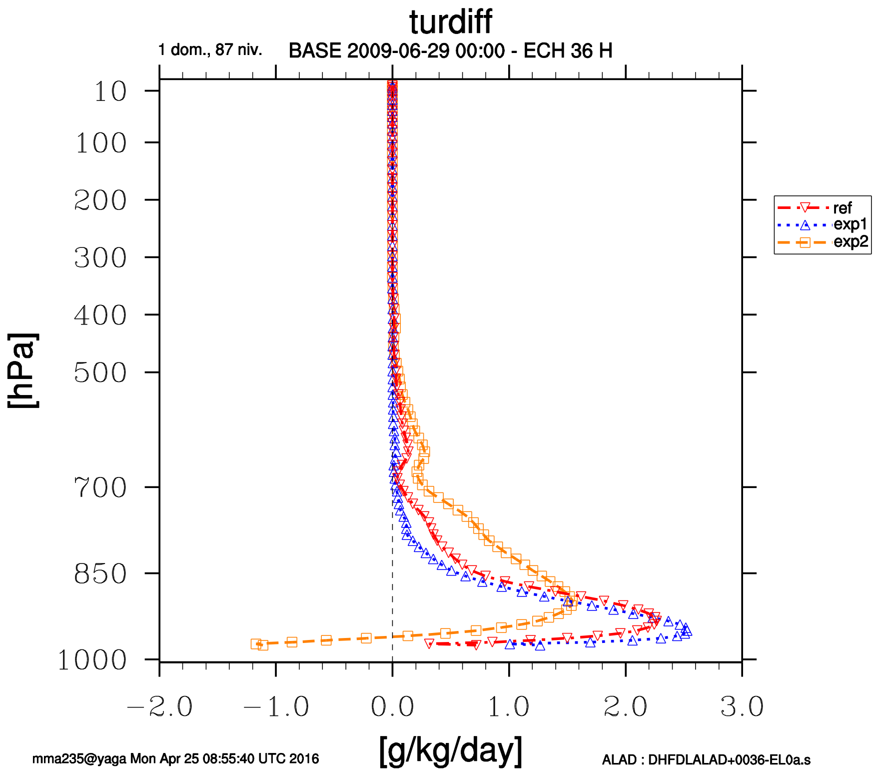


STDE PROFILE

21.06.-05.07.2009.

Profiles of turbulent diffusion terms:

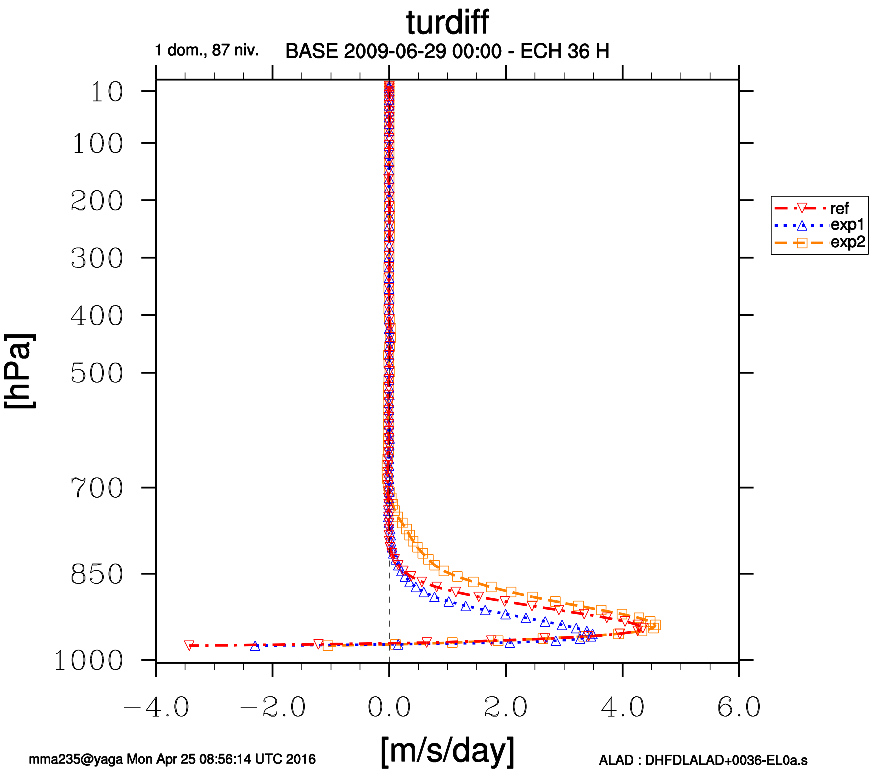




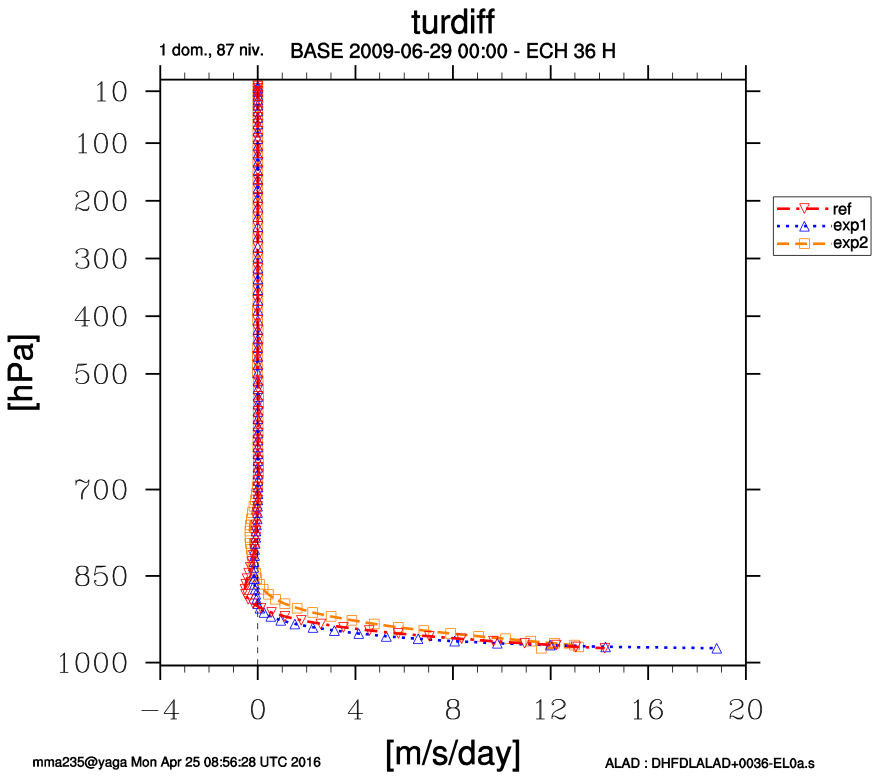
Temperature

Specific humidity

Profiles of turbulent diffusion terms:



U-wind



V-wind

Conclusion and plan for further work:

- Setting $L \rightarrow l$ conversion factor for BL89 length scale to α=1 leads to significant decrease of BIAS over L_{GC}, but high STDEV deteriorates RMSE.

- Implementation of original BL89 length scale formulation leads to decrease of STDEV and RMSE for temperature (compared to L_{BL-TO}).

- Further work:

  - Check the rest of TOUCANS code

  - Limit the value of L to the height of the computation level

  - Verification of prognostic TKE using available tower measurements like Cabauw or few Croatian towers

  - Implementation of TKE and TTE budget equations into DDH and verification of corresponding terms using tower data

Thank you for your attention!

Any questions?
Suggestions?