Interactive mixing length and modifications of the exchange coefficient for the stable case

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1. Introduction

The GABLS experiment (GEWEX Atmospheric Boundary Layer Study) provides a clear framework for 1d and large-eddy simulations (LES) inter-comparisons on a stable boundary layer (SBL) situation (Holtslag, 2003). It is based on an Artic case studied by Kosovic and Curry (2000), the single-column model is driven by an imposed geostrophic wind, with a given surface cooling rate. The roughness length is specified, the radiation scheme is switched off, therefore only vertical diffusion is active. The ARPEGE/ALADIN model is not able to reproduce correctly the Ekman spiral and the low-level jet does not exist due to the excess mixing in the SBL on wind (Fig. 1) and temperature. The PBL parametrization, based on Louis et al (1981), computes the exchange coefficients for momentum and heat ($K_{m/h}$) as functions of the corresponding mixing lengths ($l_{m/h}$), the vertical wind-shear and the Richardson number (Ri) :

$$K_m = l_m l_m \left|\frac{\partial V}{\partial z}\right| F_m(Ri')$$
$$K_h = l_m l_h \left|\frac{\partial V}{\partial z}\right| F_h(Ri')$$

The mixing-length profiles (l_m, l_h) are constant in time and in space. Ri' is a Richardson number function of l_h, z. and a critical Richardson number, Ri_c.

2. The modifications

Firstly, a new coefficient k (EDK in NAMPHY0) has been introduced in the formulation of $F_{m/h}$ to reduce mixing in stable conditions (Fig. 1) :

	Oper, $b = d = 5\ (k \equiv 1)$	Dbl, $b = d = k = 5$
$1\ /F_m$	$1 + 2bRi/\sqrt{1+dRi}$	$1 + 2bRi/\sqrt{1+\frac{d}{k}Ri}$
$1\ /F_h$	$1 + 3bRi\ \sqrt{1+dRi}$	$1 + 3bRi\ \sqrt{1+dk\ Ri}$

Secondly, the PBL height ($PBLH$) is now computed following the Troen and Mahrt (1986) proposal and used to compute the mixing lengths. For temperature and humidity, the mixing length is a cubic function verifying :

$$\frac{d\,l_h}{dz} = k \text{ as } z \to 0\,, \quad l_h(z) = \lambda_h\,\beta_h \text{ for } z \geq PBLH$$

For the momentum part the operational function is used but, now, the parameter H_m (previously 1/UHDIFV) depends on the PBL height :

$$l_m = \left(\frac{kz}{1+kz/\lambda_m}\right)\left(\beta_m + \frac{1-\beta_m}{1+(z/H_m)^2}\right)$$

with : $\lambda_h = \frac{3}{2}\,d\,\lambda_m$, $\beta_h = \beta_m/\sqrt{3}$, $H_m = PBLH \cdot \mathrm{XKLM}$, hence $l_m(z) \approx \lambda_m\,\beta_m$ as $z \to \infty$. The new mixing lengths are shown in Figure 2 for two PBL heights, 1000 m and 4000 m (dotted and dashed lines respectively, the full line is the operational version).

The modified version, on the GABLS case, improves the vertical profile of wind speed with a maximum near the SBL top as seen in LES (Fig. 1). The friction velocity (u*), the Monin-Obukhov length (L_{MO}) and the surface angle for the wind direction are improved. However, it is not yet perfect for the Ekman spiral and the PBL height. The Prandl number is also overestimated by a factor 2 or 3 compared to the value provided by LES.

	PBLH	$\overline{w'\theta'}$	u^*	L_{MO}	surface angle
oper.	383 m	-0.013	0.34	204	23
modified	333 m	-0.014	0.31	142	29
LES	[160, 195]	[-0.01, -0.013]	[0.26, 0.30]	[120, 170]	[32, 38]

1D simulation with the prescribed vertical resolution δz = 6.25 m and δt = 30 s

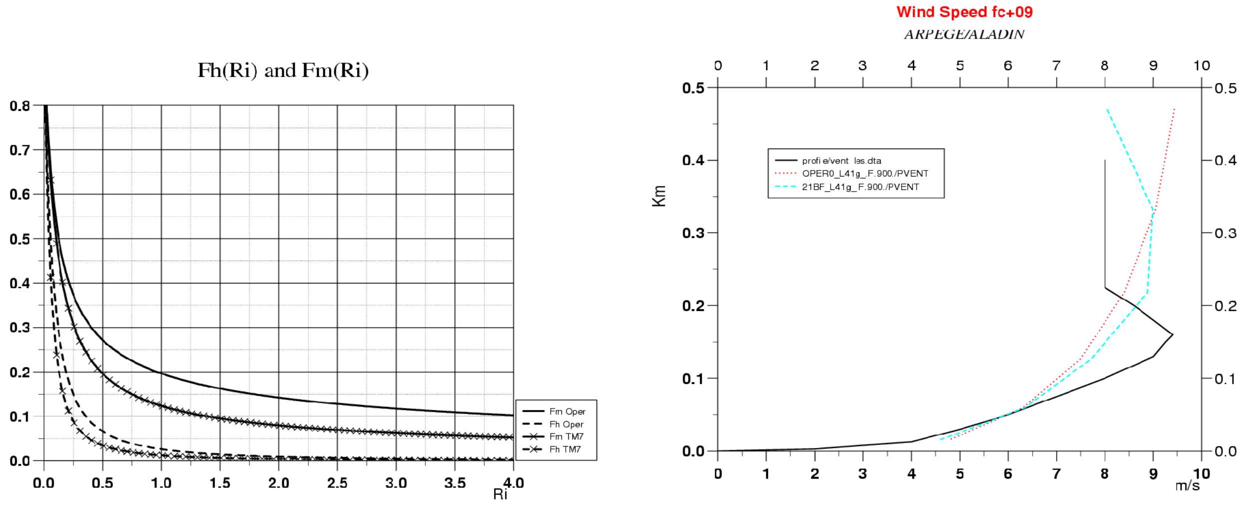

Figure 1 : Left : Functions $F_{m/h}$. Full line : F_m, dashed lines : F_h and lines with stars are for k=5. Right : Wind speed after a 9 h forecast with the 1D model on the GABLS case with the operational vertical level. Full line : LES mean profile. Dotted line : operational version. Dashed line : modified scheme

The main results of GABLS (Cuxart et al., 2004) are :

1. Operational schemes have a general tendency to mix more than the research models, with two important consequences :
   - the upper air inversion is not seen;
   - the surface friction velocity is overestimated.
2. Those using a Turbulence Kinetic Energy (TKE) scheme overestimate the mixing to a smaller extent, compared to the first order schemes.

3. The 3d impacts

Following the GABLS results, the impacts should be limited to the cold regions in stable conditions, but the interactive mixing-length should also modified the treatment of the dry PBL, in particular over Sahara, where the PBL height can reach 4000 m. The reduced mixing should improve the humidity profile with a moister PBL and consequently provide more lower clouds, as shown in Figure 3.

Since the 16th of December 2004, the modifications are tested in a parallel suite and should become operational in March. The scores are improved in the PBL over North America but also to a lower extent over the "North20" domain (Fig. 4). The wind direction is also improved, especially over the EWGLAM domain (Fig. 5).

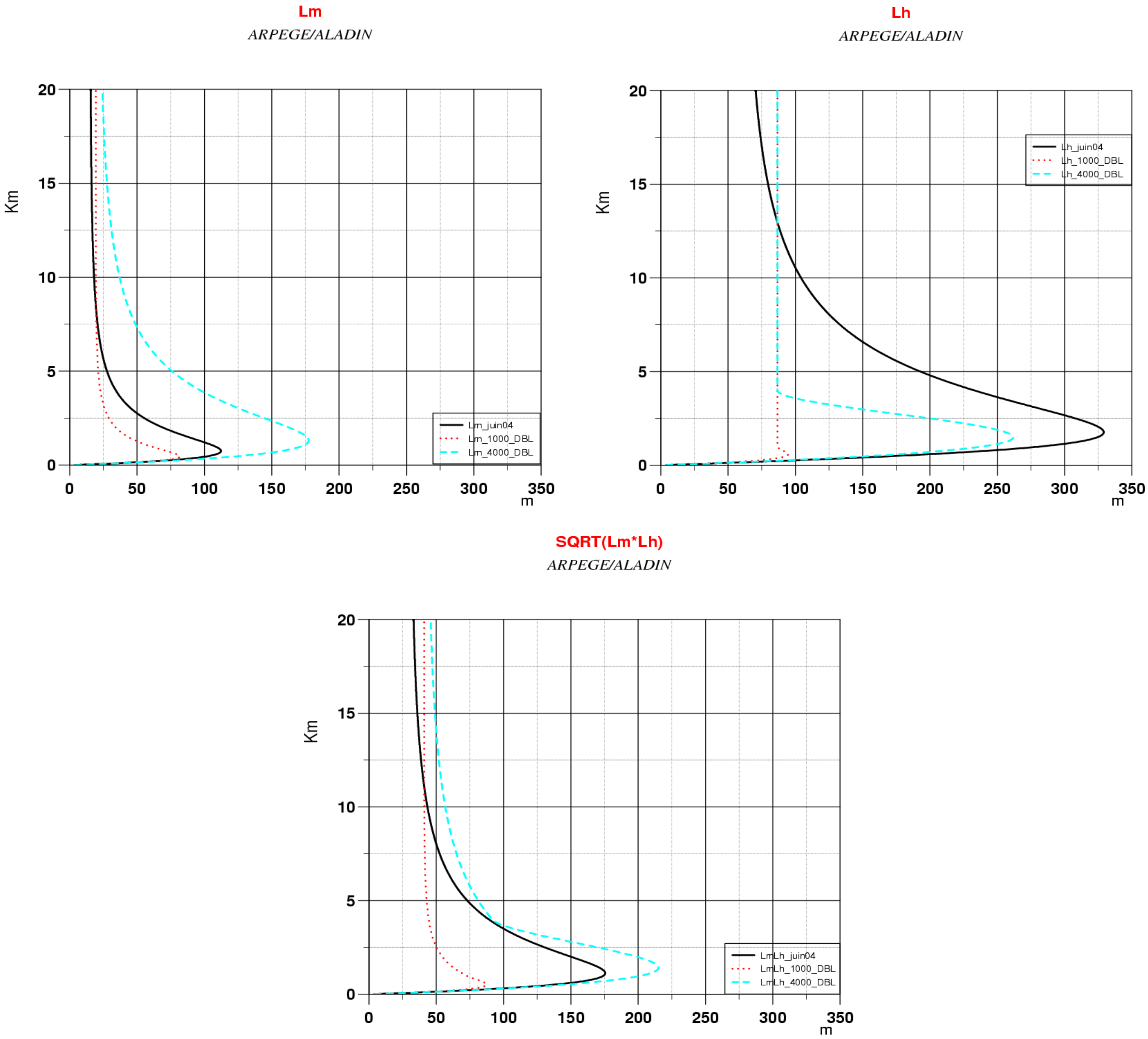

Figure 2 : l_m, l_h, $\sqrt{l_m l_h}$ for two PBL heights : 1000 m (dotted line) and 4000 m (dashed line); operational mixing length : full line.

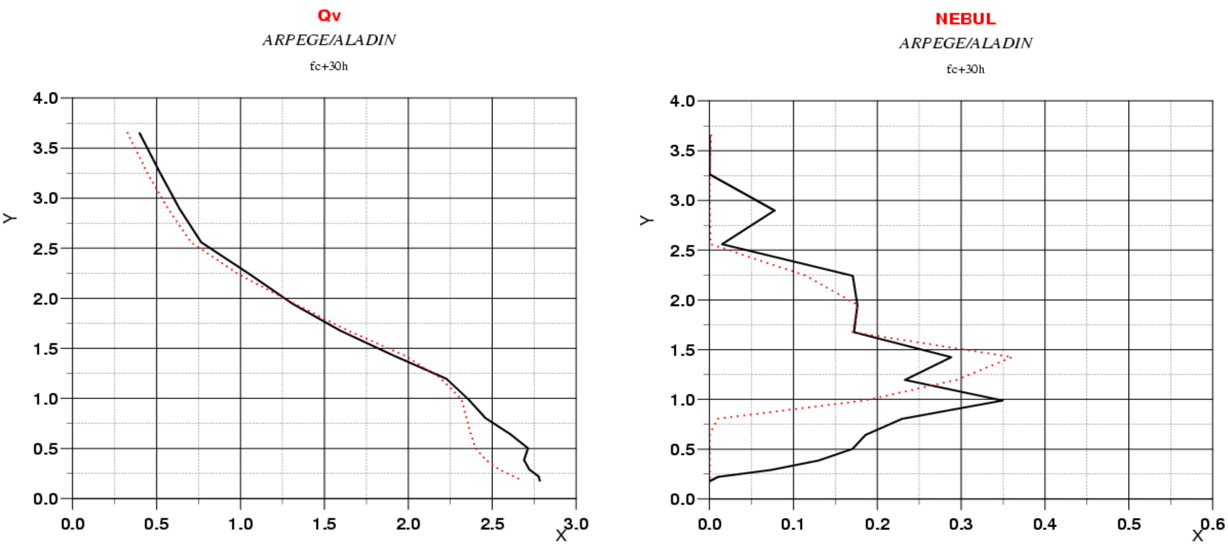

Figure 3 : Mean of five 30 h forecasts at Roissy Airport (24/02/2004-28/02/2004). Left : vertical profile for the specific humidity. Right : vertical profile for the cloud cover. Dotted line : operational version. Full line : modified one.

Figure 4 : Scores against radiosonde data for temperature (rmse, std, bias, period 15/12/2004-24/02/2005).
Full (green) lines : the test model is better. Dashed (red) lines : the opposite !

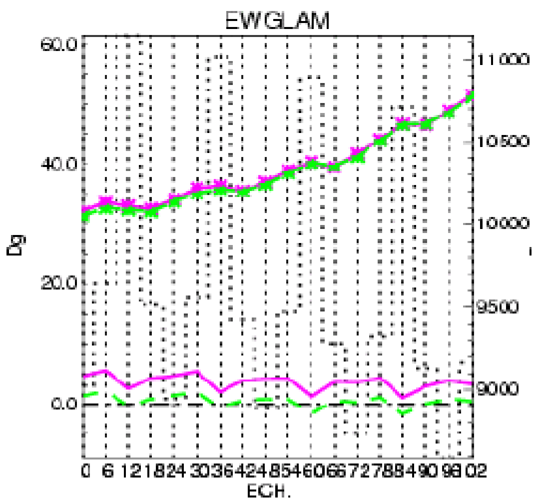

Figure 5 : Score against SYNOP data (EWGLAM stations) for wind direction (rmse and bias, 15/12/2004-24/02/2005).
Full (magenta) line : operational suite. Dashed(green) line: test suite

4. How to use it ?

The modifications are on the cycle *28t3_op1* and when compared to the ALADIN export version only a small modification in APLPAR is needed.

In NAMPHY :

- add CGMIXLEN='TM' (the default is CGMIXLEN='Z')

In NAMPHY0 :

- ALMAV=400. (operational scheme : ALMAV= 300.)
- XMINLM=500. : minimum PBL height for the computation of $l_{m/h}$
- XMAXLM=4000. : maximum PBL height for the computation of $l_{m/h}$
- RICRLM=0.5 : critical Richardson number Ri_c used to determine the PBL height (default)
- XBLM=8.5 : parameter to correct θ_s : $\theta_s = \theta_{vs} + \mathrm{XBLM}\,\overline{(w'\theta'_v)_s}/w_m$, w_m is a function of the friction velocity and the scale of the convective speed (the default is 6.5)
- EDK=5. : new parameter used in the computation of $F_{m/h}$ (operational scheme : EDK=1)
- XKLM=0.6 : parameter to use the interactive PBL height for momentum

5. References

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