Developement of eddy diffusivity method based on LES simulations in convective conditions

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Overview

- Review of work done/published/implemented on K(z) parameterisation in stable conditions

- Extension to convective conditions: theory&application

- LES simulations turbulence resolving modelling

  - Crucial tool in developing of constructive theory of PBL sensitivity to the imposed stability
  - Kh, Km, Pr…
  - Large-scale, semi –organized eddies driven by buoyancy forces
  - CBL-shear free, mean V<Vh_in large eddies

- Future work

Review: K(z) from LES stable cond.

- Methodology

  - LES data (DATABASE 64, e.g. Esau and Zilitinkevich, 2006)

Class	$w\theta_o$	N	Number	R_B	H_{LES}
Conventionally neutral	0	> 0	39	0.005 – 3.59	128 – 1652
Nocturnal	< 0	0	31	0.05 – 3.38	46 – 1875
Long-lived	< 0	> 0	15	0.35 – 7.6	16 - 507

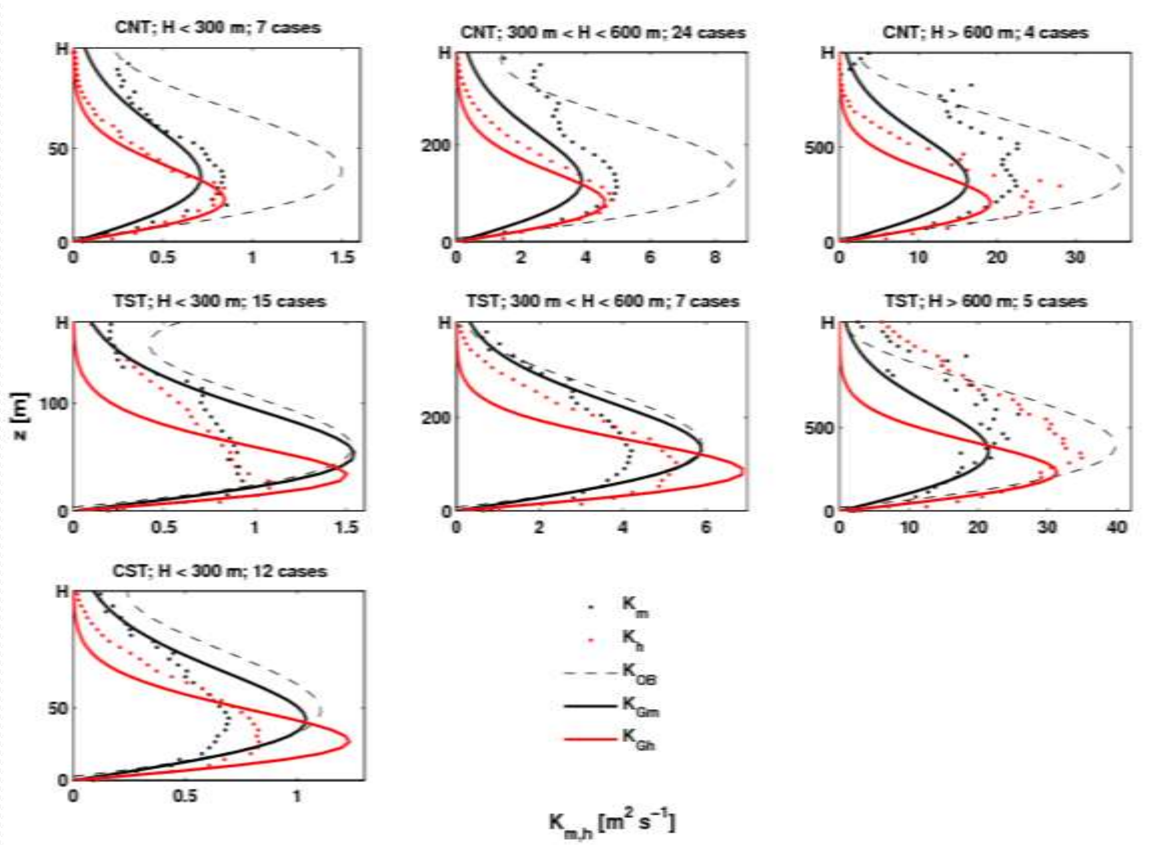
  - Each simulation was run for 15 hours to achieve a quasy steady state

K(z) –stable case (Jeričević & Večenaj 2009 BLM; Jeričević et al. 2012. ACP)

$$K_h = -\frac{\overline{w'\theta'}}{d\theta/dz} \quad (1)$$

$$K_m = k u_* z \quad (2)\ \text{SL}$$

$$K_m = -\frac{\overline{u'w'}}{dU/dz} \quad (3)\ \text{OL}$$



$$K(z) = (K_{\max} e^{1/2} / z_{\max}) z \exp\left[-0.5(z/z_{\max})^2\right]$$

$$K_{\max} = C(K) H u_* \qquad z_{\max} = C(z_{\max}) H \quad (4)$$

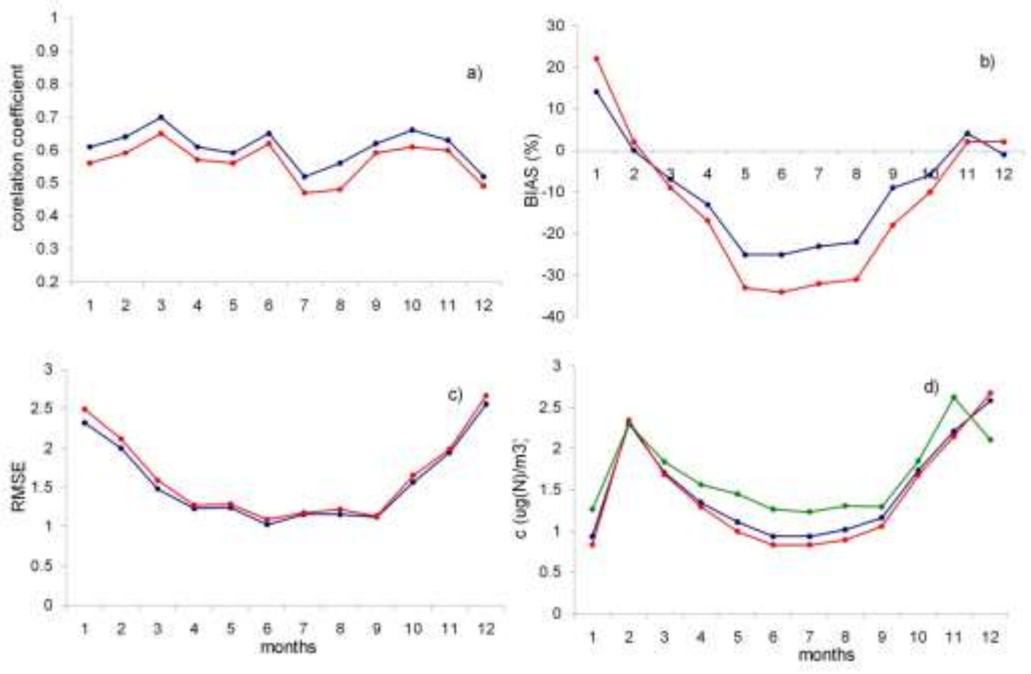
New lin-exp. function for stable conditions

		$C(K)\pm\sigma$	$C(z_{max})\pm\sigma$
Stable	K_m (m^2s^{-1})	0.04 ± 0.02	0.32 ± 0.16
	K_h (m^2s^{-1})	0.05 ± 0.02	0.21 ± 0.08

$$K(z) = C_s u_* z \exp\left(-0.5\left(z/0.21H\right)^2\right)$$

Cs =0.39

Implemented in the operational EMEP model, (Simpson et al. 2013. ACP)



Convective LES database

- General experiment conditions
  - LESNIC v231, latitude 45N, roughness 0.1m
  - Domain size 6x6x3 km
  - Mesh 128x128x128
  - Free atmospheric stability 0.065 Km^{-1}
  - Run duration 5h-18000 s

Wind speed	F_θ **Kms^{-1} 0.40**	F_θ **Kms^{-1} 0.25**	F_θ **Kms^{-1} 0.07**	F_θ **Kms^{-1} 0.02**
[0.5 0.0]	**A** run1	**A** run2	**A** run3	**A** run4
[1.5 0.0]	**B** run 5	**B** run 6	**C** run 7	**C** run 8
[2.5 0.0]	**B** run 9	**C** run 10		
[4.0 0.0]	C run 12	C run 13		
[6.0 0.0]	C run 14	**D** run 15		
[8.0 0.0]		**D** run 16		
[-8.0 0.]	**D** run 17	**D** run 18		

- **A**: **very unstable** case characterized by low wind speed ~0.5m/s and gradually decreasing heat flux from run 1 →run 4
- **B**: **unstable**: run 5 and 6 have higher heat flux and wind ~1.5m/s
- **C: slightly unstable:** run 7 and 8-low heat flux wind ~1.5m/s, run 10-13 higher heat flux but with gradually increasing wind speeds
- **D: neutral:** heat flux ~0.4 and 0.25 and windy conditions > 6m/s

K(z) profiles - convective LES

Troen & Mahrt, 1986

$$K_h = -\frac{\overline{w'\theta'}}{(d\theta/dz - \gamma_h)} \qquad \gamma_h = C\frac{\left(\overline{w'\theta'}\right)_0}{w_s H} \quad 5$$

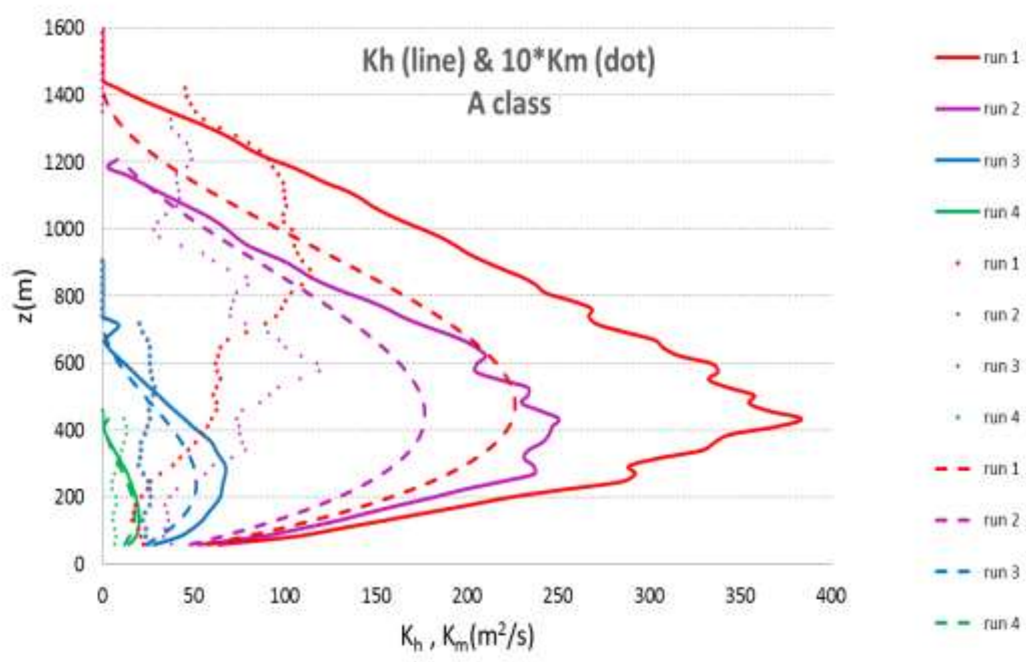
Noh et al., 2002.

$$K_m = -\frac{\overline{w'u'}}{(du/dz - \gamma_m)} \quad 6$$

$$\gamma_m = \frac{1}{H - z_s}\int_{z_s}^{H} \frac{-\overline{u'w'} - K_m \,\partial u/\partial z}{K_m} dz$$

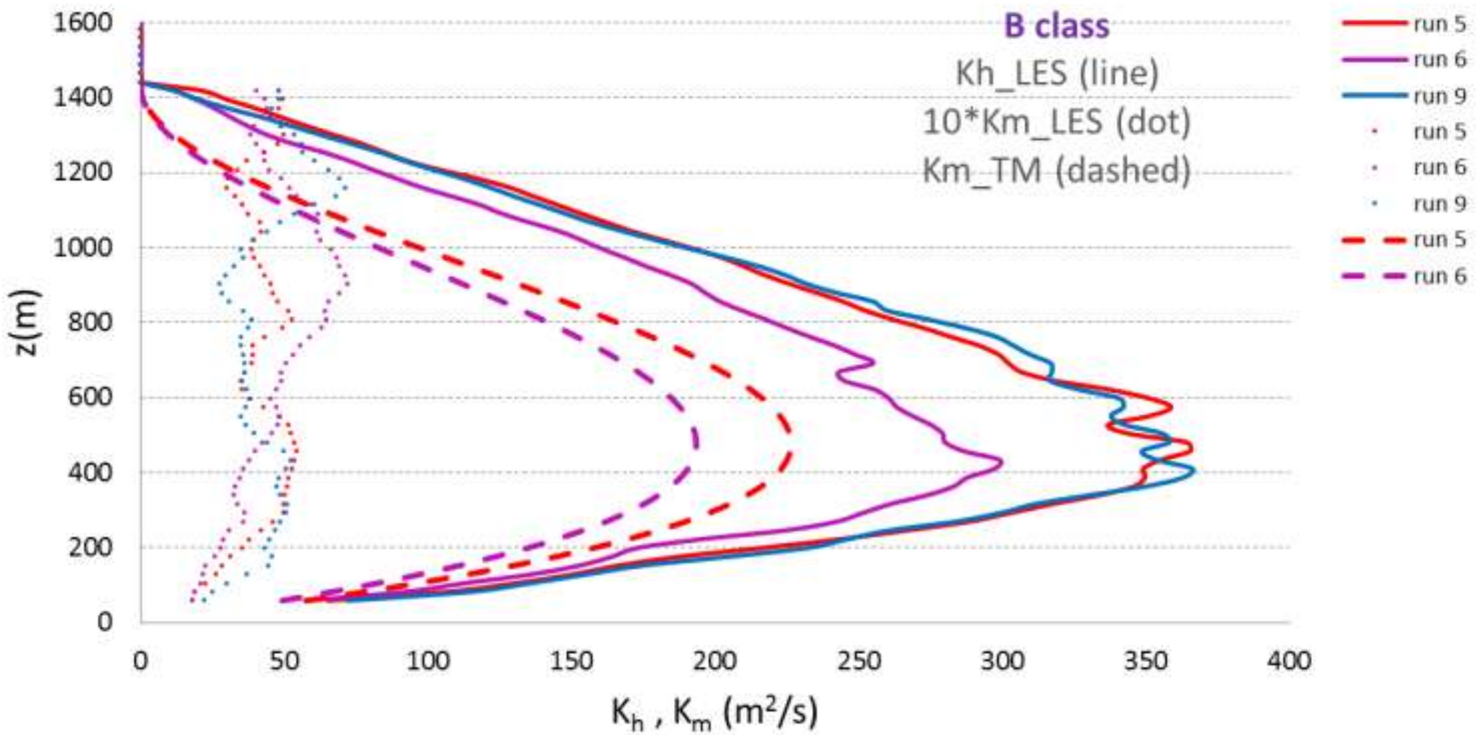
TM, Holtslag et al. 1990; Holtslag and Boville, 1992

$$K_m = k w_m z\left(1 - \frac{z}{H}\right)^2 \quad 7$$



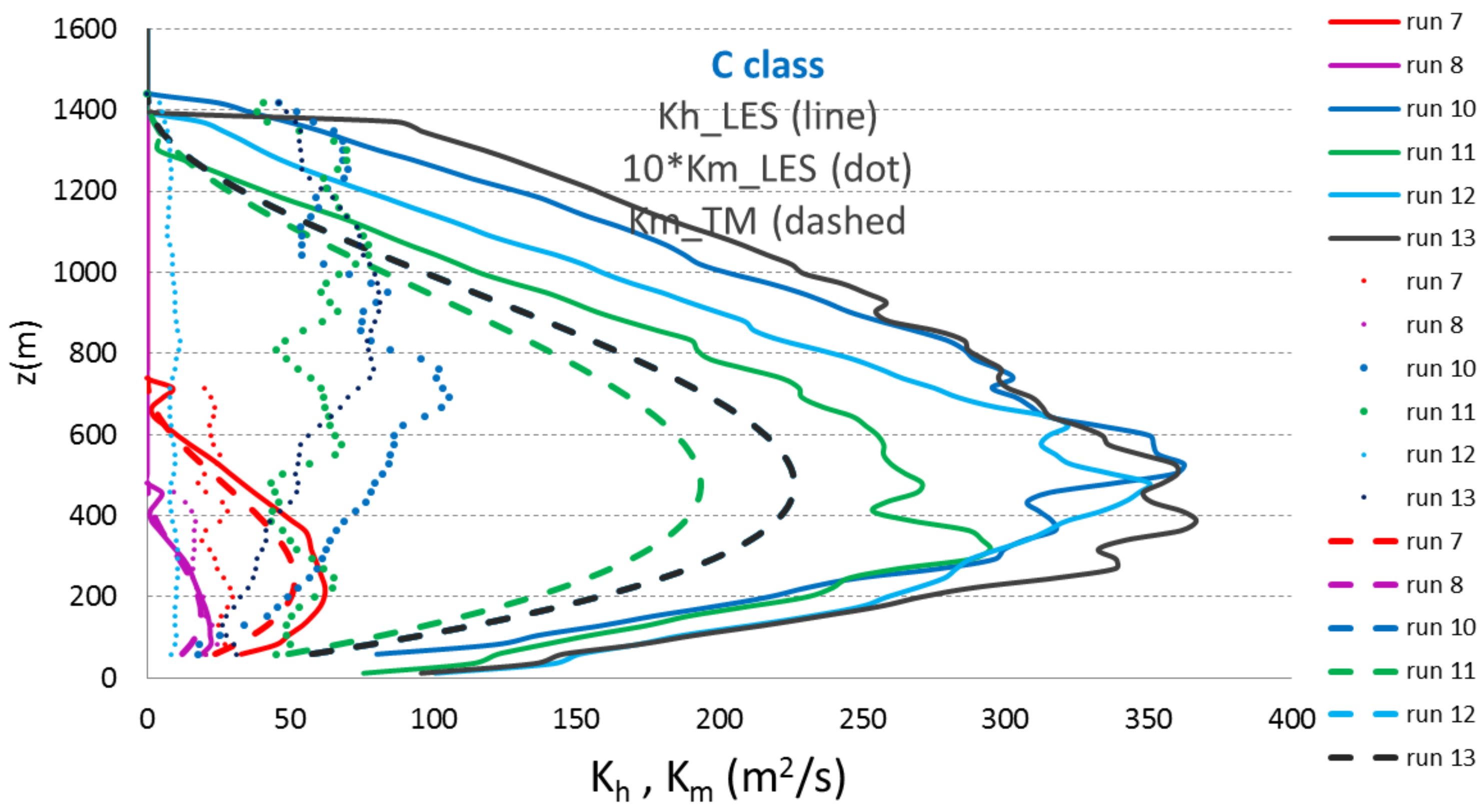
Class B

Wind speed	F_θ Kms^{-1} 0.40	F_θ Kms^{-1} 0.25	F_θ Kms^{-1} 0.07	F_θ Kms^{-1} 0.02
[0.5 0.0]	**A** run1	**A** run2	**A** run3	**A** run4
[1.5 0.0]	**B** run 5	**B** run 6	**C** run 7	**C** run 8
[2.5 0.0]	**B** run 9	**C** run 10		
[4.0 0.0]	**C** run 12	C run 13		
[6.0 0.0]	C run 14	**D** run 15		
[8.0 0.0]		**D** run 16		
[-8.0 0.]	**D** run 17	**D** run 18		



Class C

Wind speed	F_θ **Kms**$^{-1}$ **0.40**	F_θ **Kms**$^{-1}$ **0.25**	F_θ **Kms**$^{-1}$ **0.07**	F_θ **Kms**$^{-1}$ **0.02**
[0.5 0.0]	**A** run1	**A** run2	**A** run3	**A** run4
[1.5 0.0]	**B** run 5	**B** run 6	**C** run 7	**C** run 8
[2.5 0.0]	**B** run 9	**C** run 10		
[4.0 0.0]	**C** run 12	C run 13		
[6.0 0.0]	C run 14	**D** run 15		
[8.0 0.0]		**D** run 16		
[-8.0 0.]	**D** run 17	**D** run 18		



D class

Wind speed	F_θ Kms^{-1} 0.40	F_θ Kms^{-1} 0.25	F_θ Kms^{-1} 0.07	F_θ Kms^{-1} 0.02
[0.5 0.0]	**A** run1	**A** run2	**A** run3	**A** run4
[1.5 0.0]	**B** run 5	**B** run 6	**C** run 7	**C** run 8
[2.5 0.0]	**B** run 9	**C** run 10		
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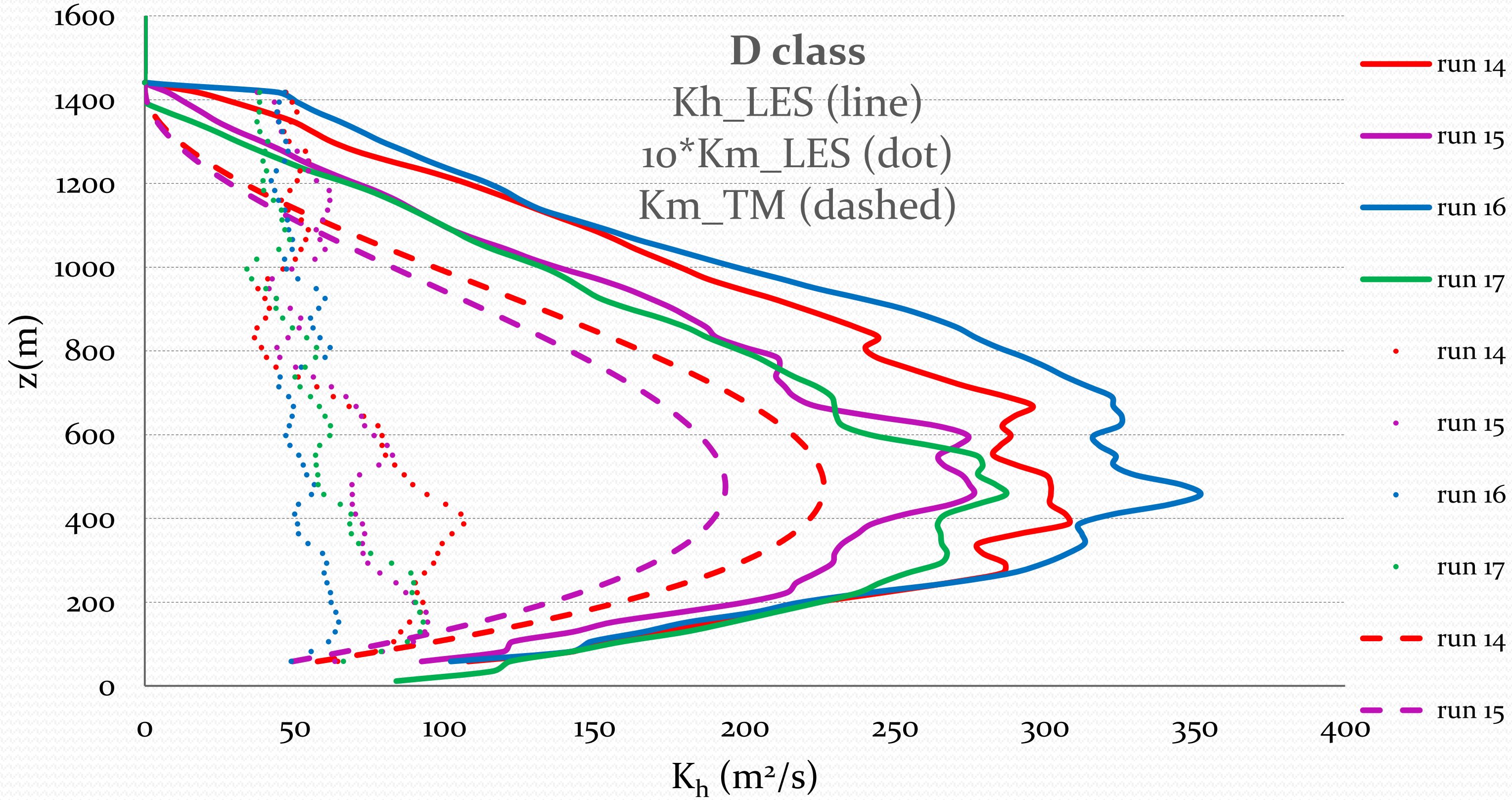

New K(z) formulation

$$K(z) = (K_{max} e^{1/2} / z_{max}) z \exp\left[-0.5(z/z_{max})^2\right]$$

$$z_{max} = C(z_{max})H$$

$$K_{max} = C(K)Hw_*$$

$$w_* = \left(\left(g/\theta_{v0}\right)\left(\overline{w'\theta_v'}\right)_0 H\right)^{1/3}$$ Convective velocity scale

$$K(z) = C_s u_* z \exp\left(-0.5\left(z/0.21H\right)^2\right)$$ stable conditions, Cs=0.39

$$K(z) = C_u w_* z \exp\left(-0.5\left(z/0.31H\right)^2\right)$$ unstable conditions, Cu=1.65~ $e^{1/2}$

Conclusions

- Km does not vary significantly with stability < $10 m^2/s$

- In stable conditions
  - Km described by exp. or polynomial,
  - similar to Kh
  - Pr>>1 with increasing stability

- In convective conditions,
  - with height but not significantly in almost constant & small range with height and with Pr=Km/Kh<<1 since Kh>>Km

- Applied Km based on TM, Holtslag significantly overestimates Km
  - Pr/Pr_TM= 0,131579 i.e. Pr is overestimated ~7,6 times by TM approach!

- Theory: Are some mechanism(s) is missing? Are the parameterisations wrong?

Conclusions-cont.

- Future work
  - implementation and verification
    - WRF, EMEP
  - Inclusion of entrainment layer in parametrisations