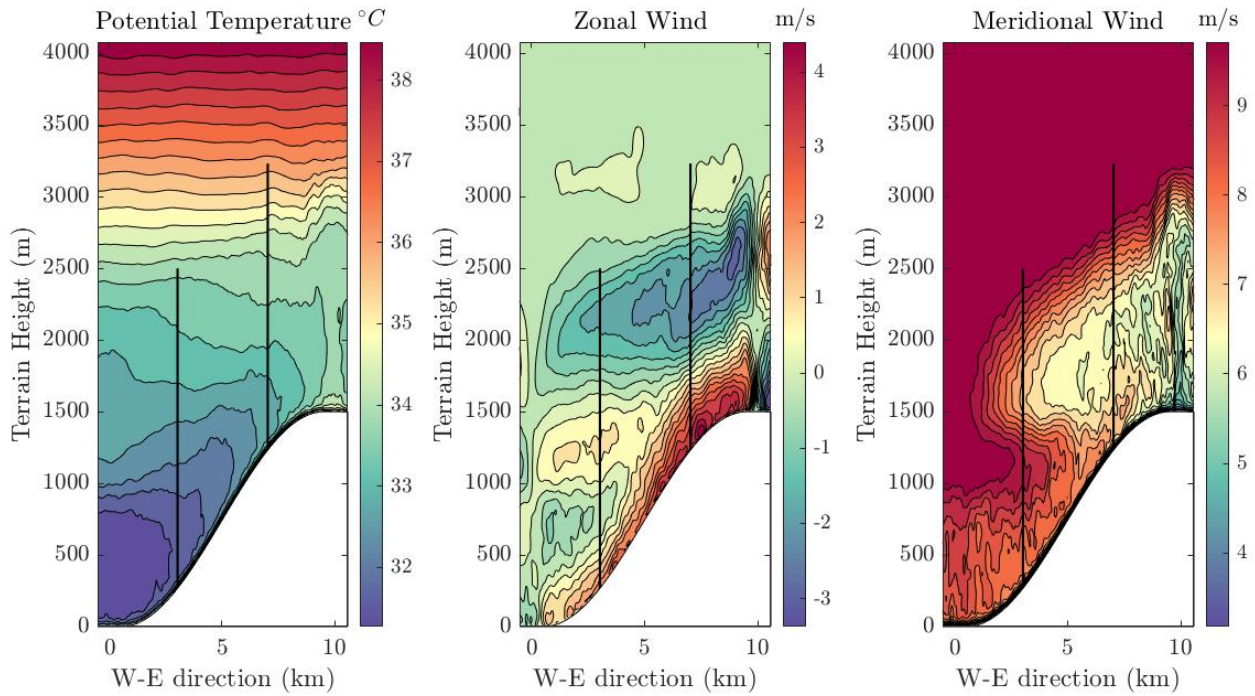
A new $K - \varepsilon$ turbulence parameterization for mesoscale meteorological models

A. Zonato, A. Martilli, P. A. Jimenez, J. Dudhia, D. Zardi & L. Giovannini



May 25, 2022

$K-\varepsilon$ turbulence closure - Objectives

Improve the **reproduction** of boundary layer dynamics at the **mesoscale**, through **novel turbulence closures**

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Idea!

Employing a $\boldsymbol{K-\varepsilon}$ closure in order to avoid to define a mixing length scale

The $K-\varepsilon$ turbulence closure (1.5 order)

Mixing coefficient

~~$\nu_\chi \sim \ell_\chi \sqrt{\mathbf{K}}$~~

$$\nu_\chi = \mathbf{c}_\mu \frac{\mathbf{K^2}}{\varepsilon}$$

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☺ PROGNOSTIC Turbulent Kinetic Energy (K) equation

$$\frac{\partial K}{\partial t} = \underbrace{-\frac{\partial \overline{wk}}{\partial z}}_{\text{v. diffusion}} \underbrace{-\overline{uw}\frac{\partial U}{\partial z} - \overline{vw}\frac{\partial V}{\partial z}}_{\text{shear prod.}} + \underbrace{\frac{g}{\Theta_0}\overline{w\theta}}_{\text{buoy. prod./destr.}} - \underbrace{\varepsilon}_{\text{dissipation}}$$

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☺ PROGNOSTIC Dissipation Rate (ε) equation

$$\frac{\partial \varepsilon}{\partial t} = \underbrace{-\frac{1}{\sigma_\varepsilon}\frac{\partial \overline{\varepsilon w}}{\partial z}}_{\text{v. diffusion}} \underbrace{-\left[c_1\left(\overline{uw}\frac{\partial U}{\partial z} + \overline{vw}\frac{\partial V}{\partial z}\right) - c_3\frac{g}{\Theta_0}\overline{w\theta}\right]}_{\text{shear+buoy. prod./destr.}} \underbrace{\frac{\varepsilon}{K}}_{1/\tau} - \underbrace{c_2\frac{\varepsilon^2}{K}}_{\text{dissipation}}$$

Tuning the standard $K-\varepsilon$ closure

a) Dissipation dependence on the eddy scale (Zeng et al., 2020)

$$\text{Buoy prod} = \text{Buoy prod} + c_4 \min\left(1, \sqrt{\frac{Ri}{c_5}}\right) N\varepsilon$$

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b) Counter-gradient term for the heat flux

1) $\overline{w\theta} = -\nu_H \left(\frac{\partial \Theta}{\partial z} - \gamma\right)$ $\qquad \gamma = C\frac{\overline{w\theta}_s}{w_\star h}$ $\qquad$ (NL)

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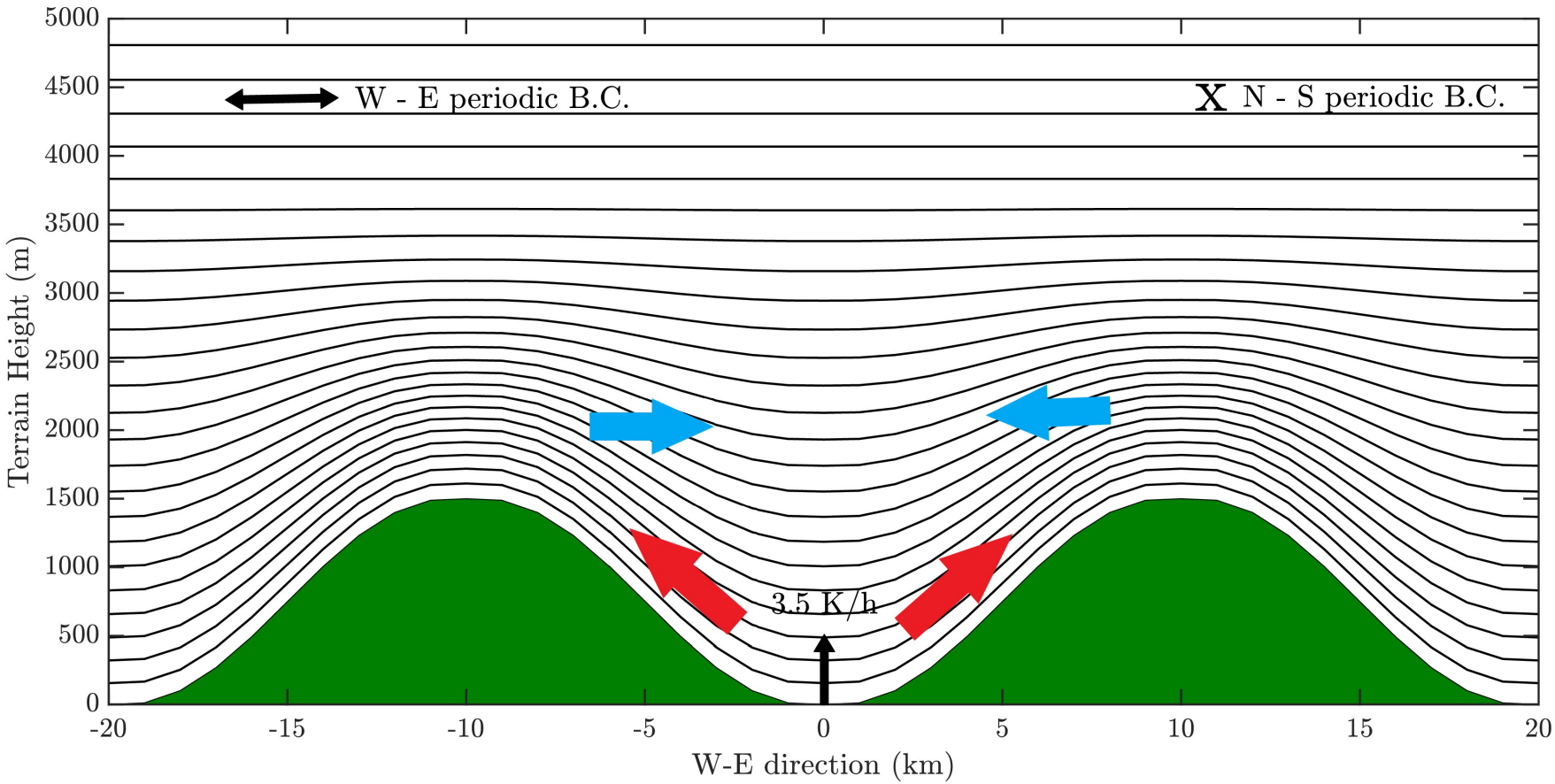
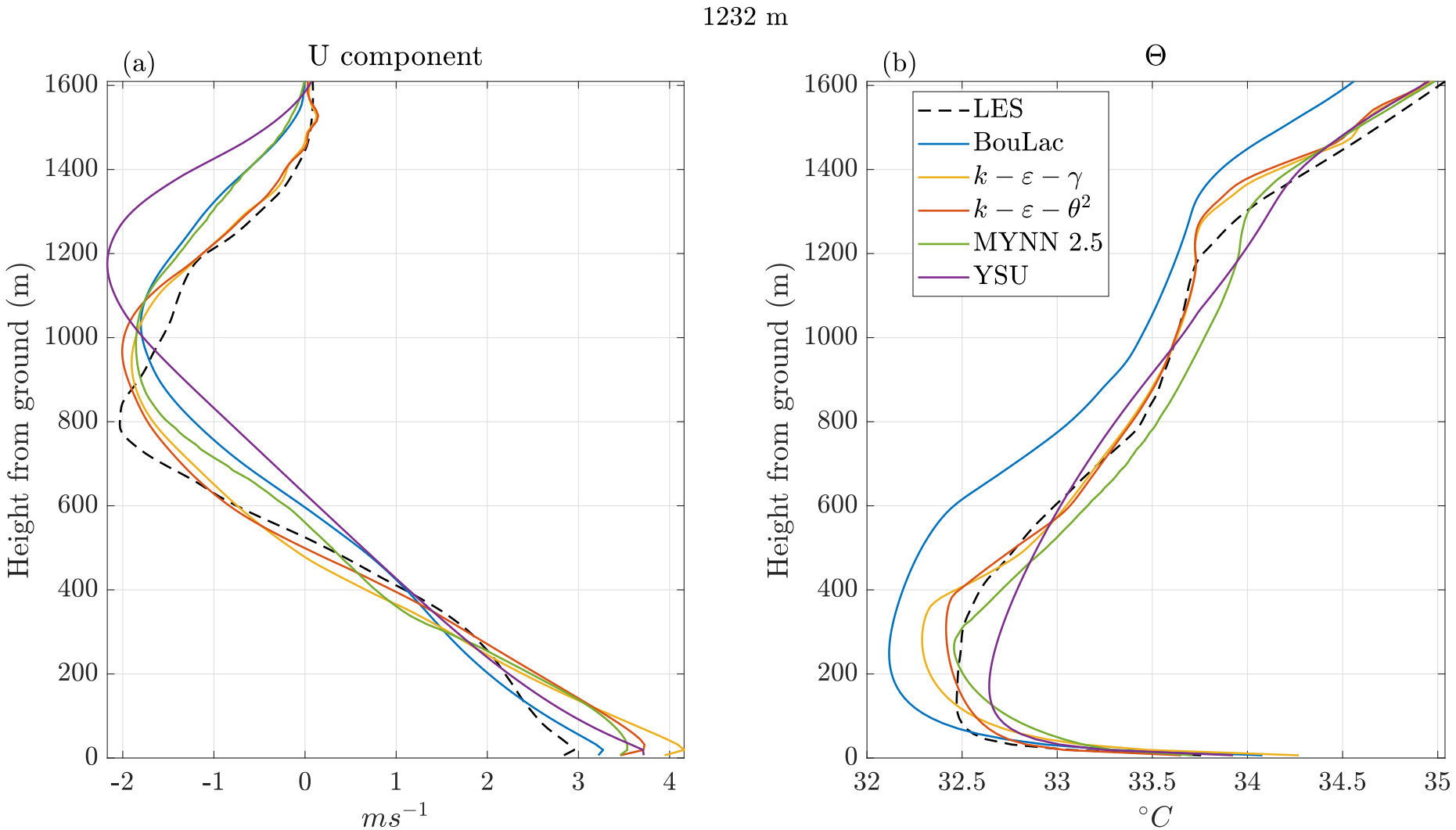
2) $\overline{w\theta} = -\nu_H \frac{\partial \Theta}{\partial z} + \Phi_{cg}(K_\theta)$ $\qquad \frac{\partial K_\theta}{\partial t} = -\frac{\partial \overline{wK_\theta}}{\partial z} - \overline{w\theta}\frac{\partial \Theta}{\partial z} - \varepsilon_\theta$ $\qquad$ (L)

LES and RANS simulation Set-Up



Complex terrain - LES (50 m) vs RANS (1 km)



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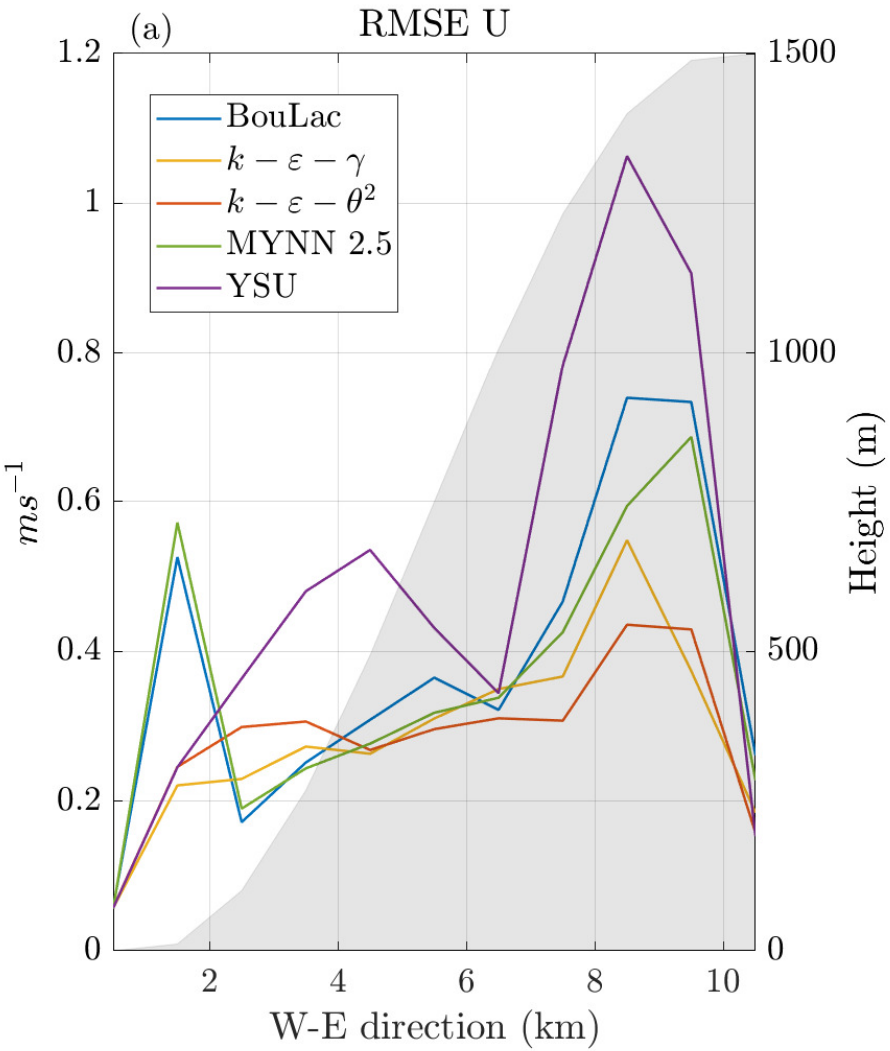
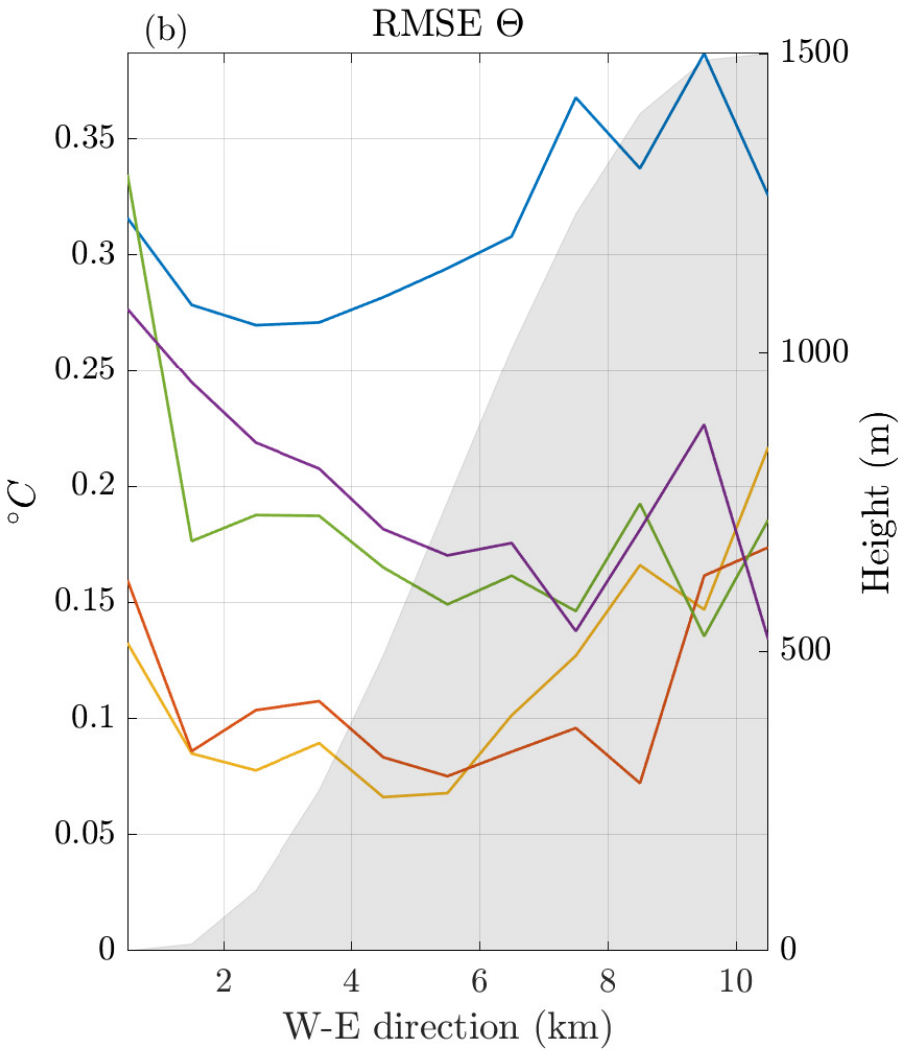
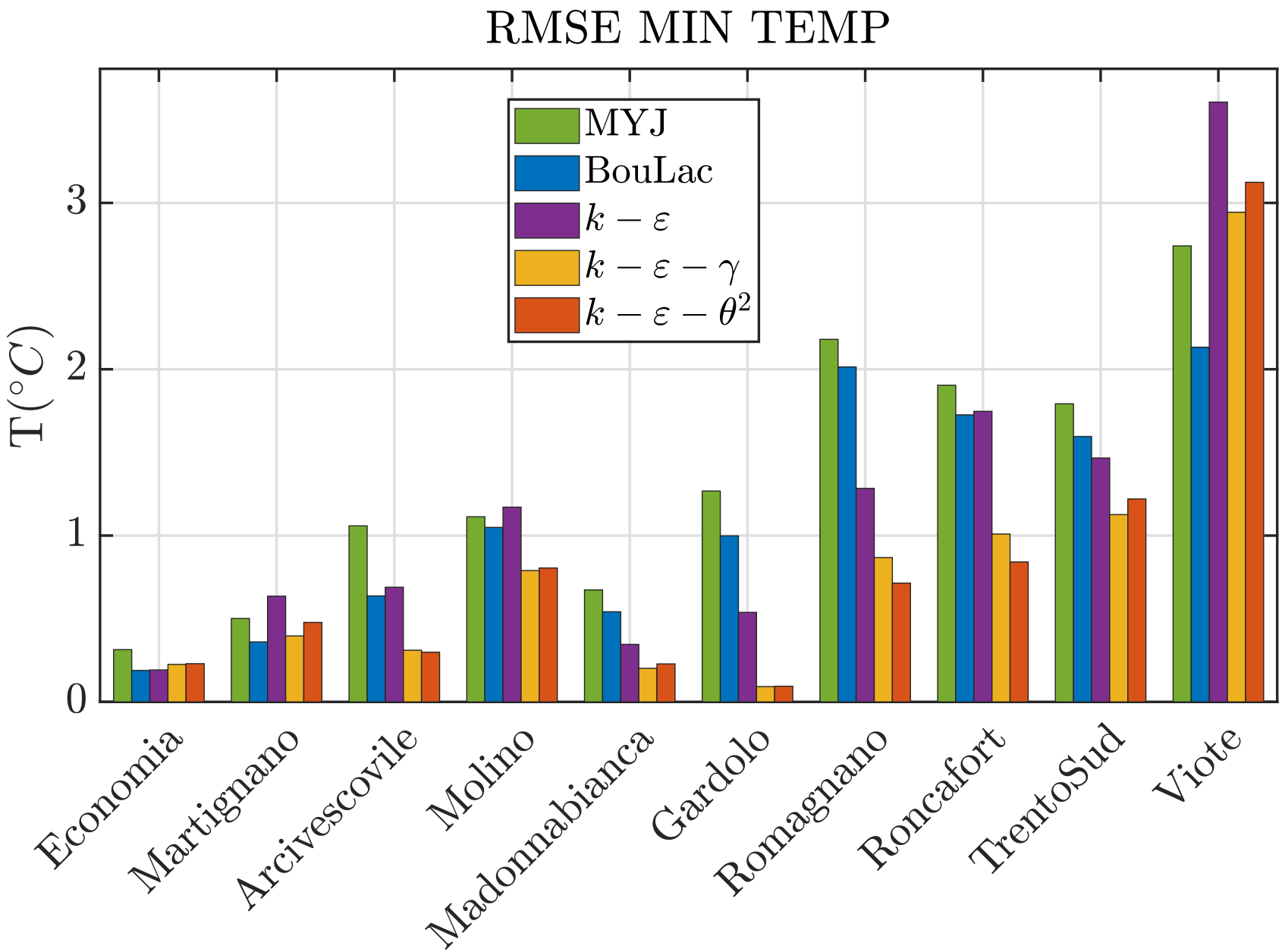
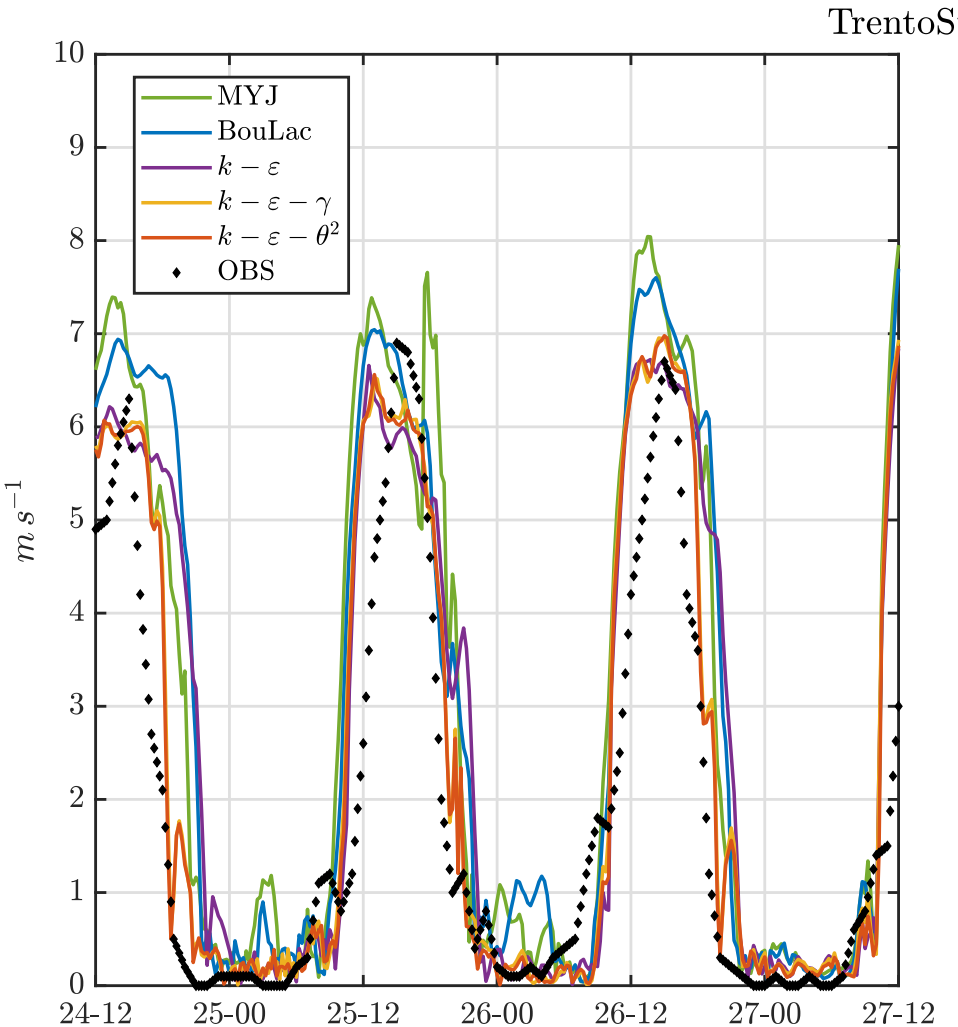


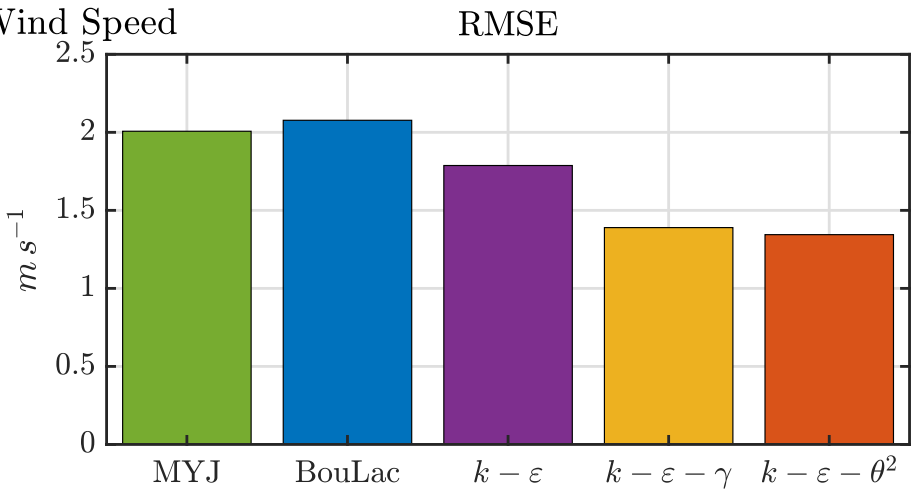


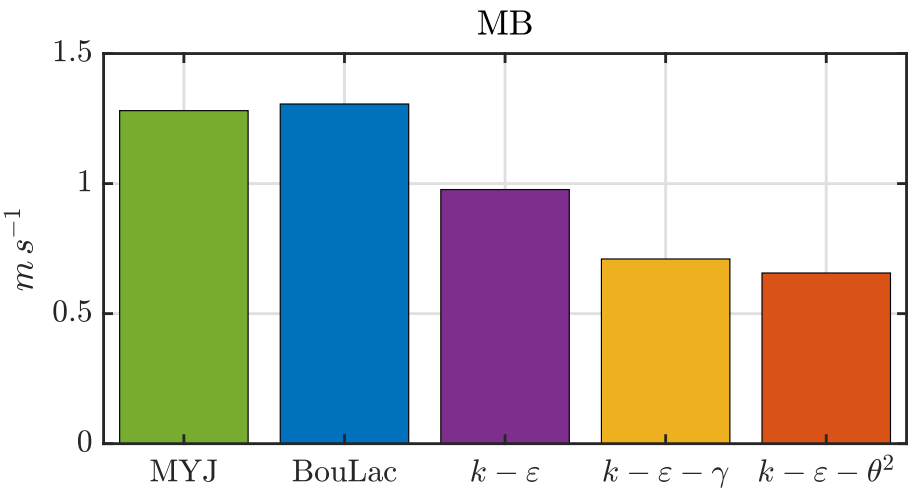
SIM vs OBS - RMSE - 2-m min air temperature



SIM vs OBS - 10-m wind speed







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Idealized simulations

✓ The new $k-\varepsilon$ **outperforms PBL models** in complex terrain. The best results are shown by the scheme with **temperature variance prognostic equation**. We can deduce that:

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