A Comparison between Two-Equation Turbulence Models for Simulating Flow over Complex Terrain

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Abstract

A comparison of three two-equation turbulence models namely the standard k-ε model, Renormalized Group Theory (RNG) k-ε model and the k-ω model of Wilcox for flow over two complex topographies is presented: (i) Bolund Hill and (ii) Askervein Hill. The numerical results clearly show the superiority of the k-ω model of Wilcox over the standard k-ε model and the RNG k-ε model for ABL flows. Although the velocity profiles obtained using all three models are alike, there exists a significant variation in the turbulent kinetic energy profiles for the cases considered in this investigation.

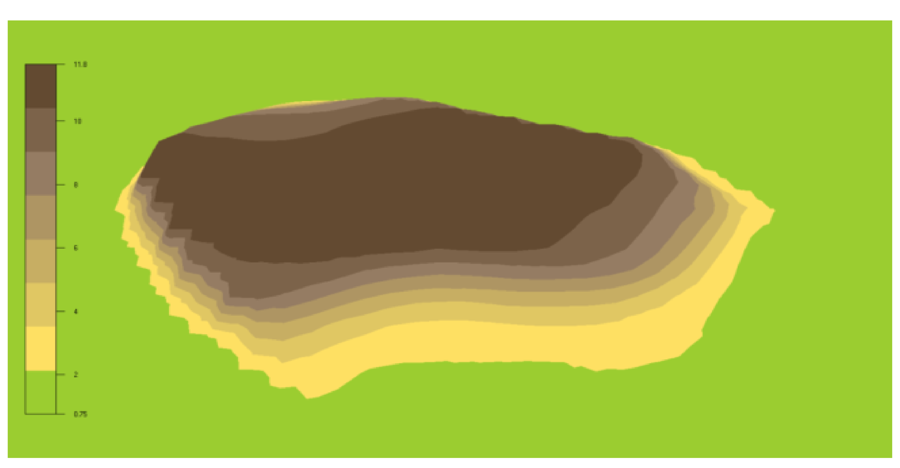
Introduction

The Reynolds averaged Navier-Stokes equations are solved along with the turbulence closure using WindSim 5.1.0 (a commercial wind farm design tool). The profiles of velocity and turbulent kinetic energy obtained using the various turbulence models are compared with available experimental data.

Results

Case-1 Bolund Hill

The Bolund experiment performed by the Risø laboratory of Denmark Technical University provides a dataset for validating models of flow over complex terrains. Bolund is a 12m high coastal hill located in Denmark. Fig.1 shows the contours of elevation and Fig.2 shows the orography and measurement points of the Bolund hill.



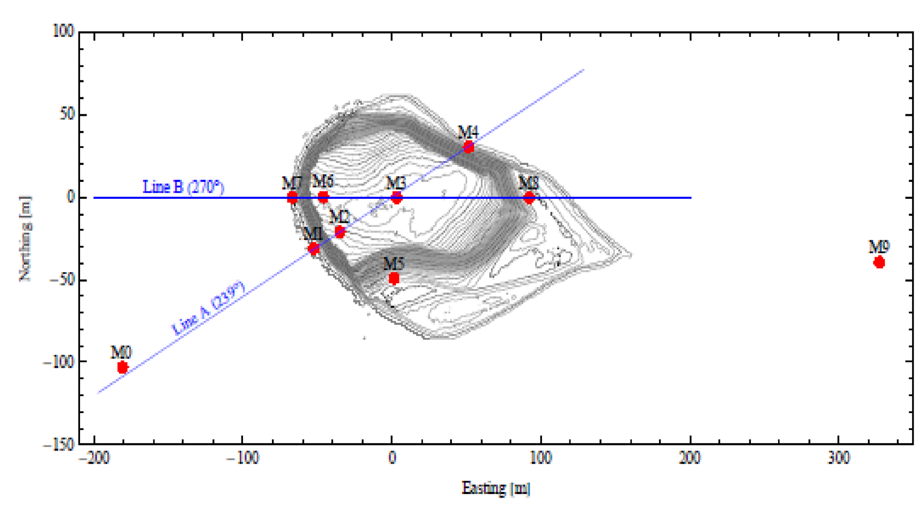


Fig. 1 Contours of elevation   Fig.2 Orography for the Bolund hill

The grid generated for the terrain is a body fitted coordinate grid. The grid is refined in the areas closer to the hill to ensure that the flow features are properly captured. Two cases have been considered for the present investigation wherein the flow enters from the westerly (270°) and south-westerly (239°) directions. A comparison of the results using the present simulations with the experimental data are presented in Fig. 3-6.

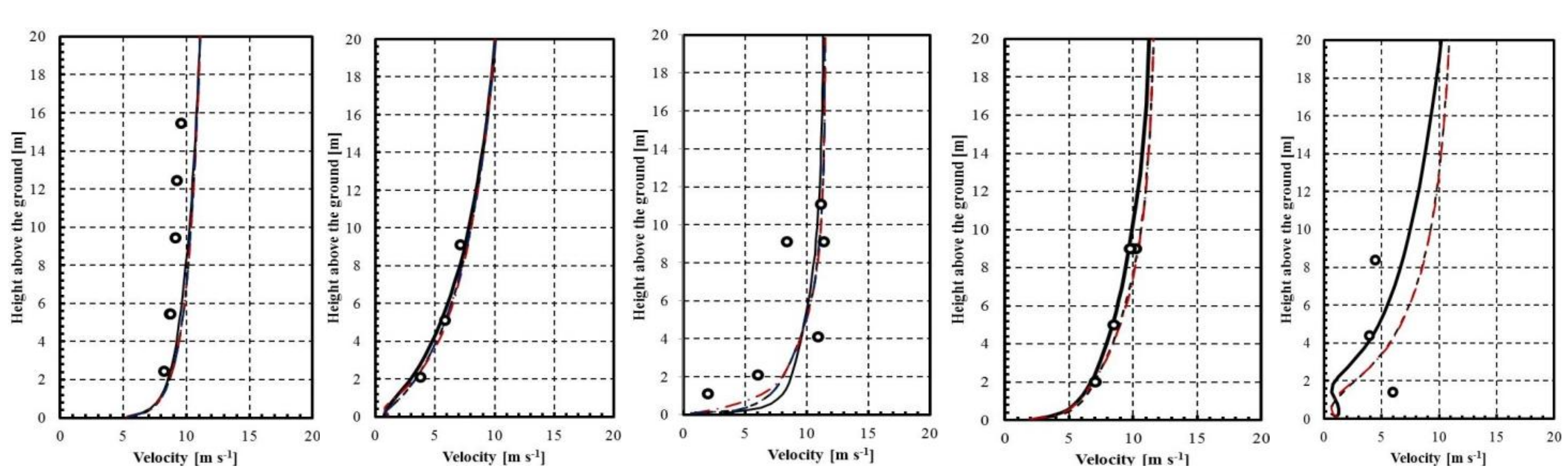


Fig.3 Comparison of velocity magnitude obtained using the present simulations with experiments for a wind direction of 239° (a) MAST-0; (b) MAST-1; (c) MAST-2;(d) MAST-3; (e) MAST-4

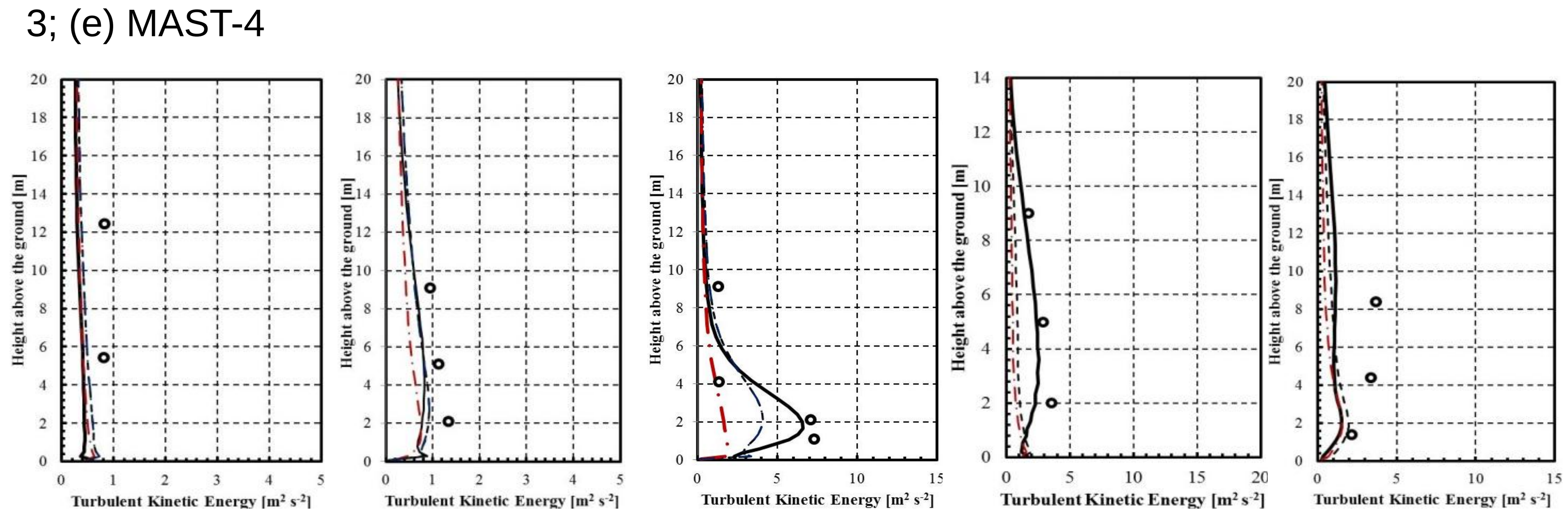
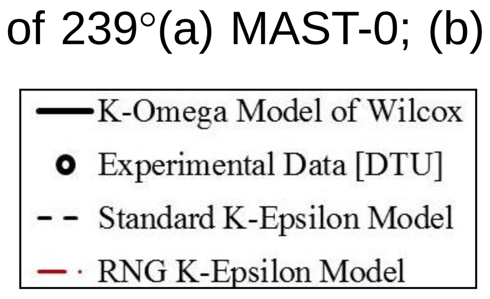


Fig.4 Comparison of turbulent kinetic energy obtained using the present simulations with experiments for a wind direction of 239°(a) MAST-0; (b) MAST-1; (c) MAST-2; (d) MAST-3; (e) MAST-4



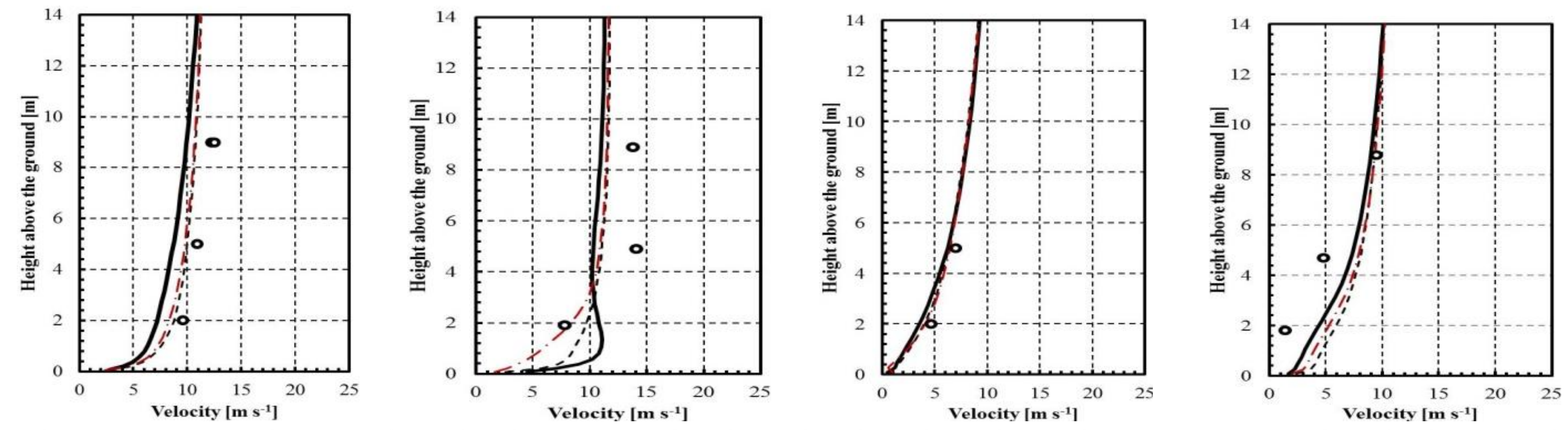


Fig.5 Comparison of velocity magnitude obtained using the present simulations with experiments for a wind direction of 270° (a) MAST-3; (b) MAST-6; (c) MAST-7 and (d) MAST-8

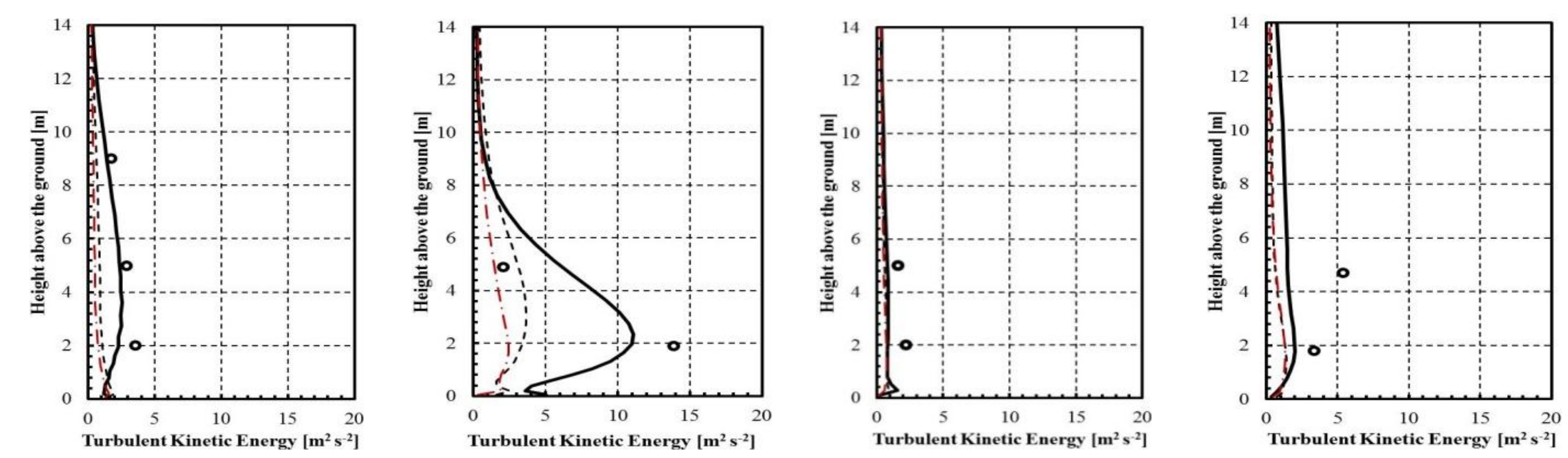


Fig. 6 Comparison of turbulent kinetic energy obtained using the present simulations with experiments for a wind direction of 270°(a) MAST-3; (b) MAST-6; (c) MAST-7 and (d) MAST-8

Case-2 Askervein Hill

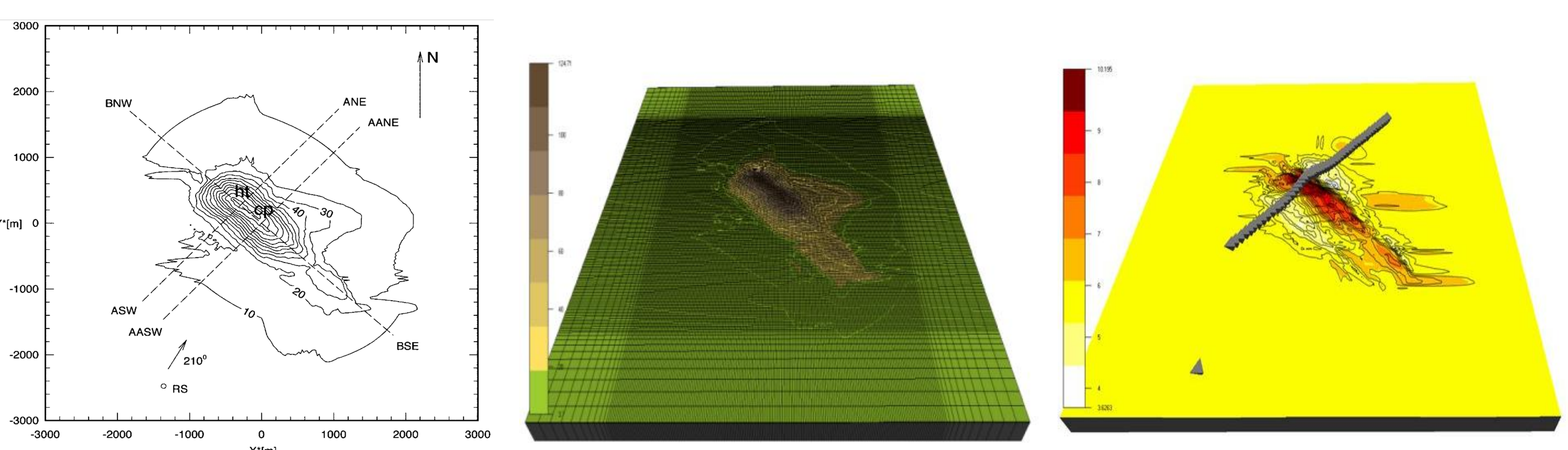


Fig.7(a) Orography for the Askervein hill (b) Grid generated for Askervein hill © Contours of Velocity magnitude

The grid generated for the present investigation along with the elevation map is shown in Fig.7. The BFC grid is refined close to the terrain to capture flow behavior in the vicinity of the hill. The grid spacing along the x and y direction ranges from 25 m to 150 m. The aspect ratio along the vertical direction is kept as 0.1 to generate a grid that is sufficiently fine close to the ground.

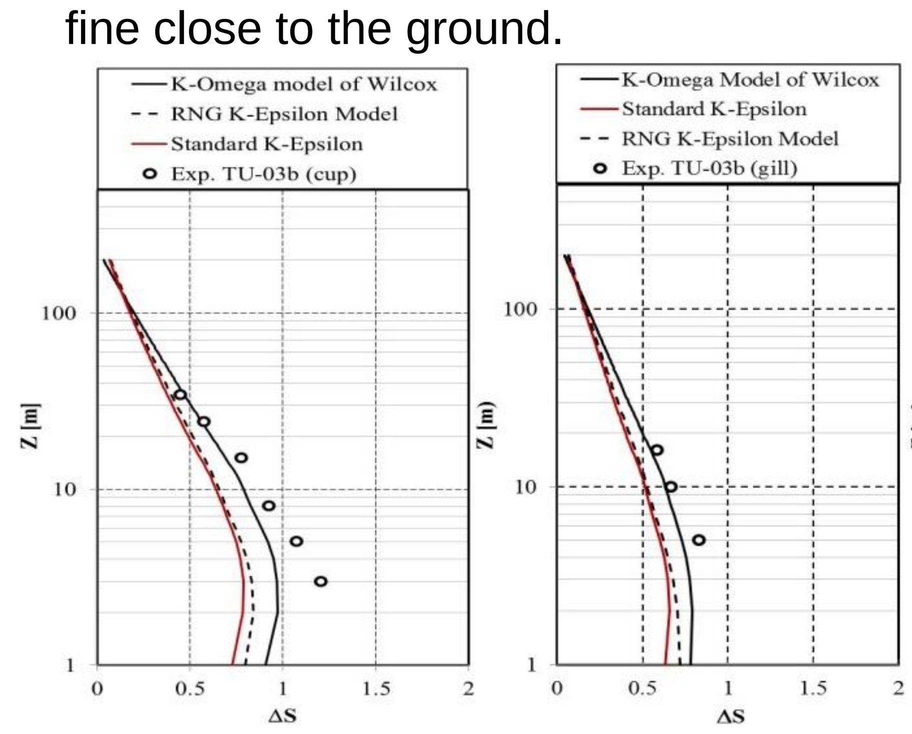


Fig.8 Vertical profile of ΔS at location (a) ht (b) Cp (refer Fig.7(a)

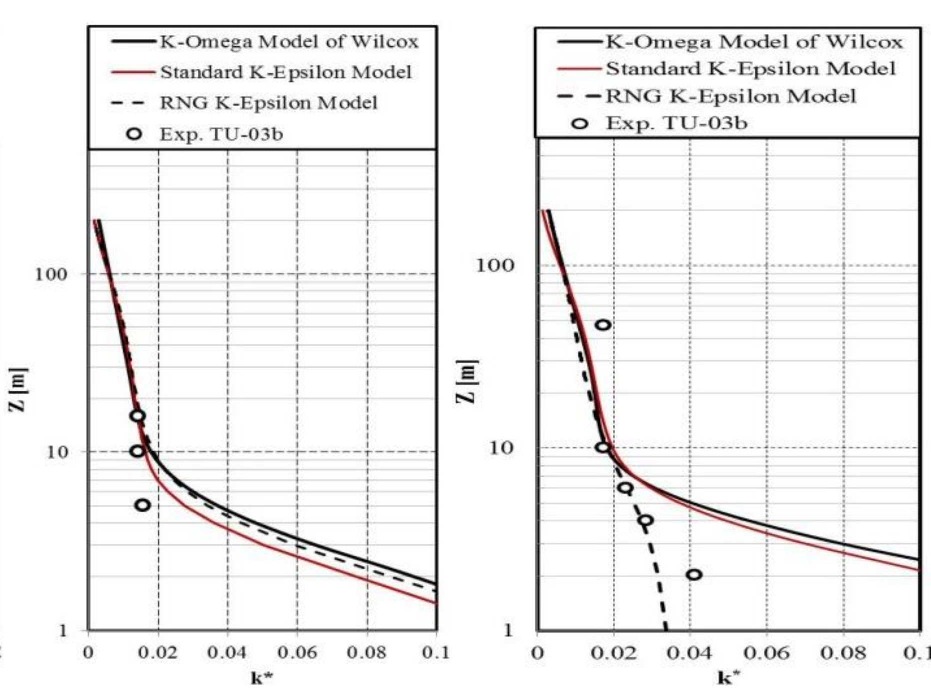


Fig.9 Vertical profile of k*($k^* = k/v_{ref}^2$) at location (a) ht (b) Cp

Conclusions

The standard k-ε model, RNG k-ε model and the k-ω model of Wilcox have been validated for flow over complex terrain by comparing the numerical results obtained from the software WindSim with the available experimental data.

- The k-ω model is able to predict the mean velocity and the turbulent kinetic energy that are closer to the measurements than the other models.
- In the case of the Bolund Hill, the Standard k-epsilon & RNG k-epsilon model predicts lower turbulent kinetic energy and therefore under predicts the turbulent intensity.
- The results obtained using the k-ω model of Wilcox are quite promising but more validation cases are required to confirm that the k-ω model is more suitable than the various variants of the k-ε model for atmospheric boundary layer flows.
- None of the two-equation models considered for the present investigation could predict the flow behavior on the leeward side of the hill where the elliptic effects are more pronounced.