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Dynamical Coupling of Meso- and Microscale Models With Nudging

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Abstract

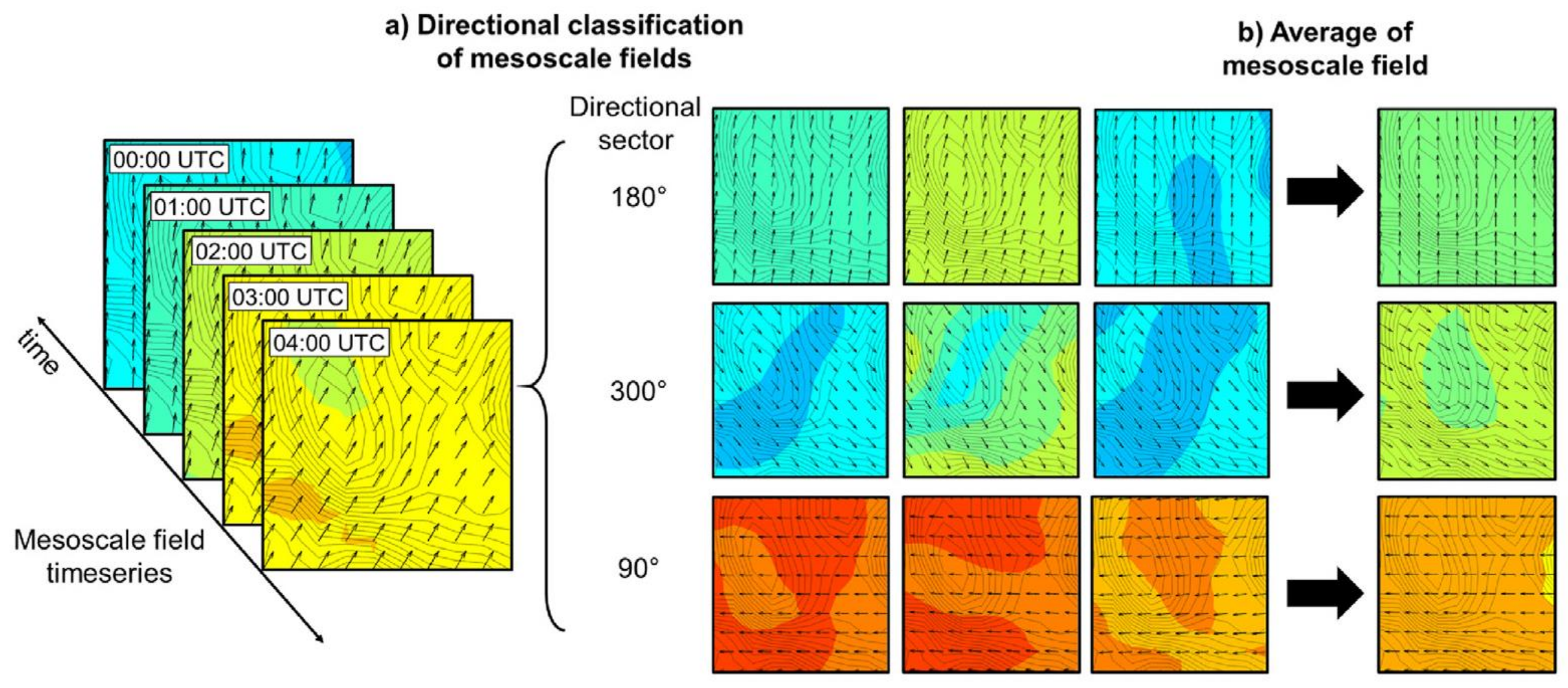
We couple steady-state WindSim microscale simulations to a mesoscale model by imposing a nudging term to the RANS equations. The purpose of the nudging scheme is to relax the microscale solutions closer to the mesoscale fields in an attempt to achieve a “best-of-the-both-worlds” approach to wind resource assessment. Because the errors in microscale models tend to grow larger as you approach the spatial scales dominated by mesoscale effects, we formulate the nudging coefficient in terms of length scale. Using a site with strong mesoscale forcing as a case study, we analyze the sensitivity of the coupled solution to this nudging length.

Objectives

We evaluate the effects of varying nudging strength on hub-height horizontal wind fields. To this end, we analyze a site with strong night-time katabatic winds, which tend to be very difficult to simulate in an uncoupled RANS model. Given our results and previous literature, we discuss the selection of an optimal nudging coefficient that balances the strengths and weaknesses of the meso- and microscale models.

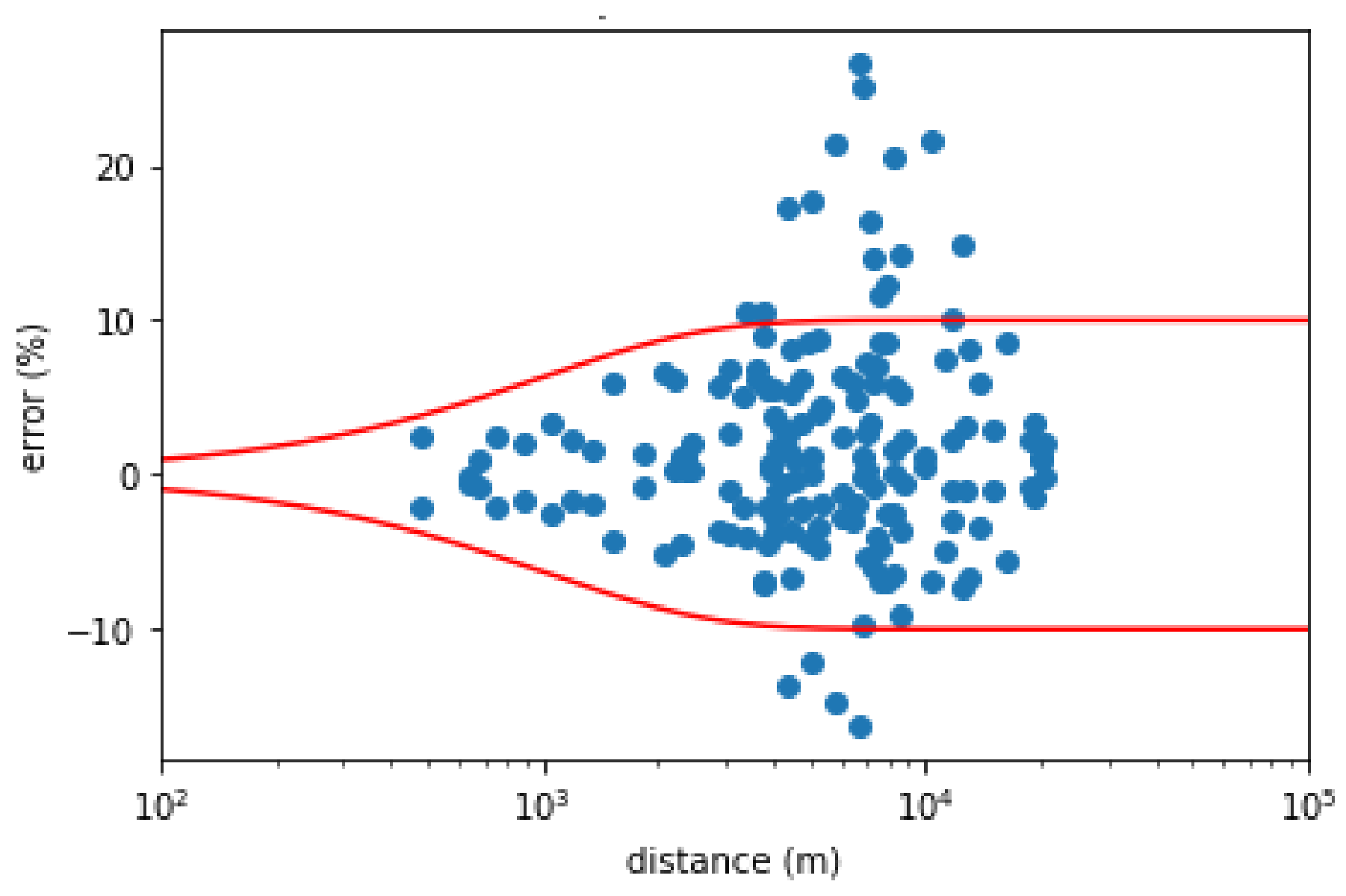
Methods

We start by averaging 1-km WRF data to sectors according to average wind direction (Duran et al., 2020)



These sector averages are used as boundary conditions and nudging fields in steady-state WindSim RANS simulations. Temperature equation and the Coriolis force are ignored.

Mesoscale coupling has the potential to improve WindSim results, because accuracy of the standalone microscale simulations tends to decrease with increasing spatial scale (see also Clerc et al., 2012).



Horizontal cross-prediction errors for standalone (uncoupled) WindSim simulations as a function of distance between measurement masts.

Nudging is only applied to the horizontal momentum equations (i = 1,2)

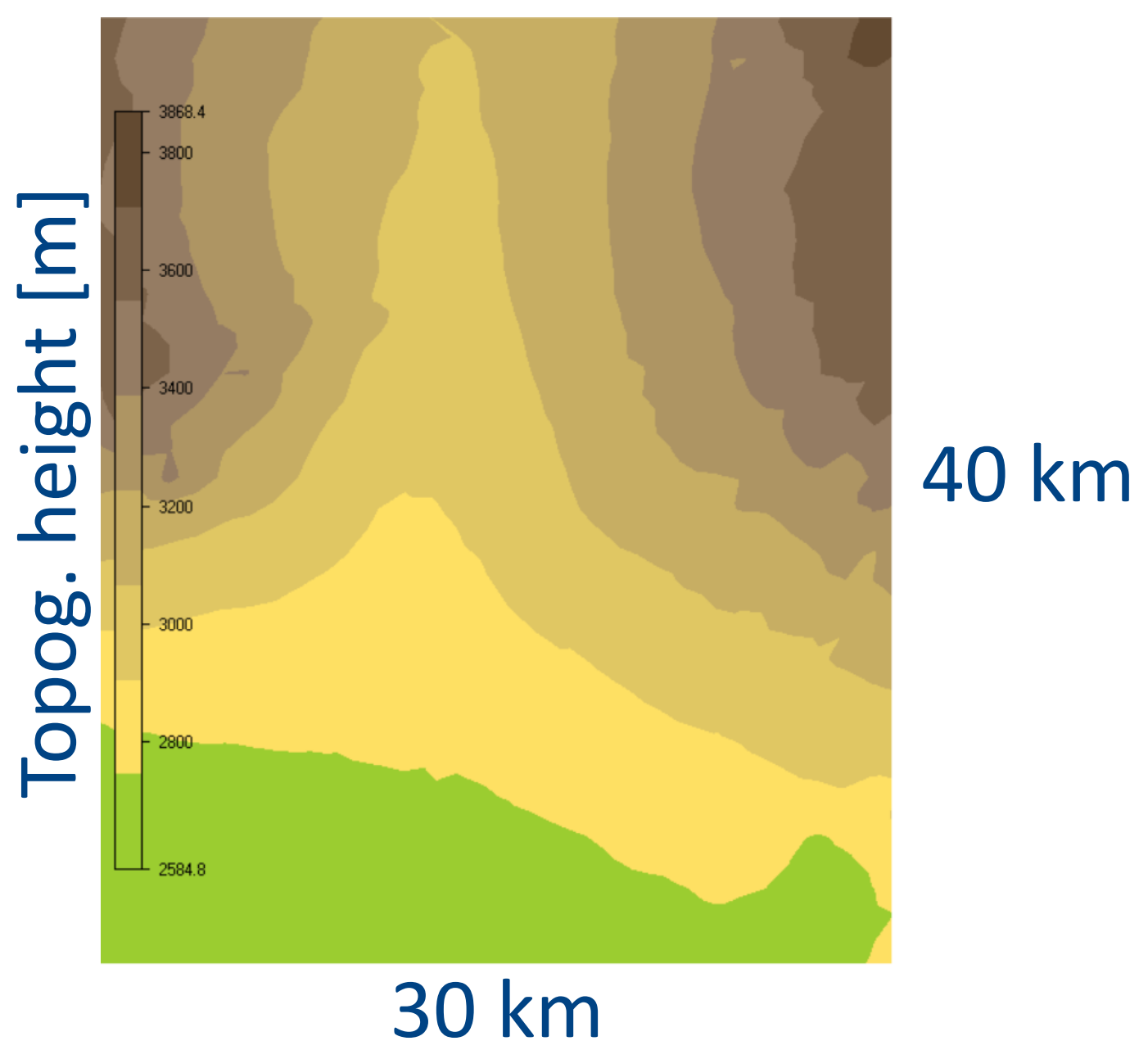
$$u_j \frac{\partial u_i}{\partial x_j} = -\frac{1}{\rho}\frac{\partial p}{\partial x_i} - \frac{\partial \overline{u_i u_j}}{\partial x_j} - r\left(u_i - u_{i,meso}\right)$$

Similar to spectral nudging (von Storch et al., 2000), the nudging coefficient is reformulated in terms of length scale L, which divides 3D WRF velocities to give r:

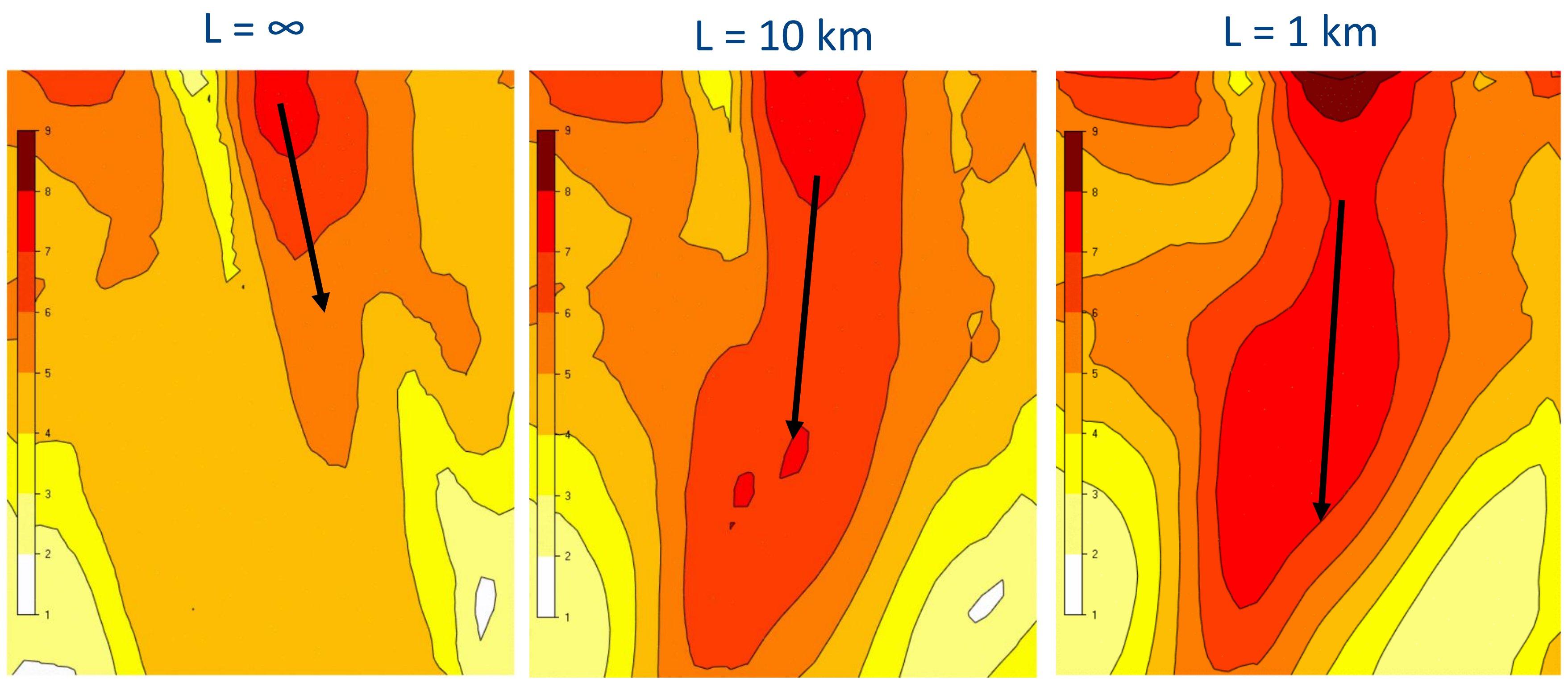
$$[r] = \frac{1}{s} = \frac{ms^{-1}}{m} \longrightarrow r = \frac{U}{L} = \frac{\|\mathbf{U_{WRF}}\|}{L}$$

Results

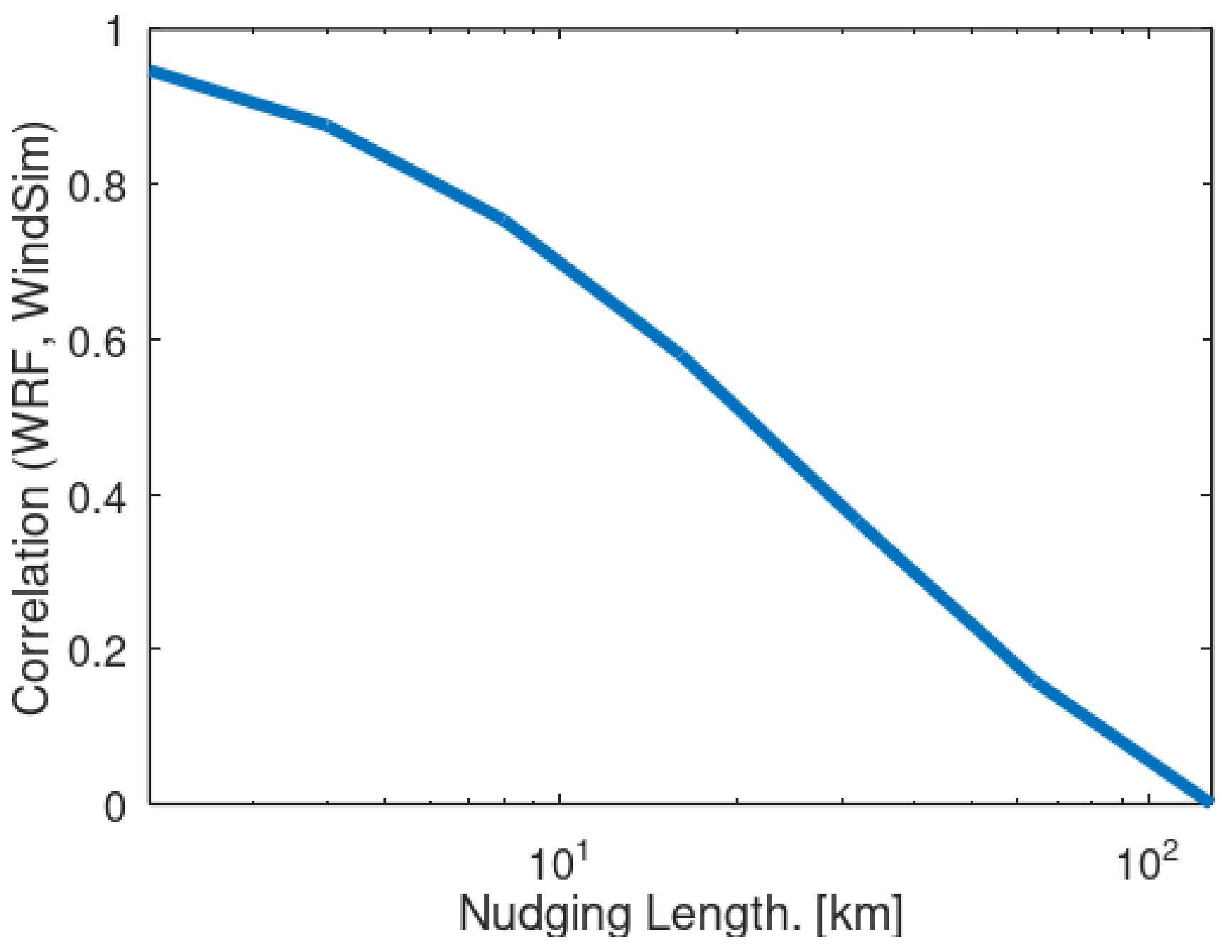
Site with strong night-time katabatic winds



Horizontal night-time (sector 1) 80-meter wind speed with different nudging scales:



At large scales, sector-averaged WRF and nudged WindSim should look similar:



Correlation of horizontal wind speed between WRF and WindSim at 80-meter height for sector 1

Conclusions

1. Specifying boundary conditions alone without nudging is not enough to capture mesoscale effects
   - Nudging required to correct for the large differences in model physics between WRF and WindSim
2. Nudging should be applied cautiously so as to not override the microscale physics
   - Nudging length scales of O(10 km) are likely to be optimal

References

Clerc, A., Anderson, M., Stuart, P., & Habenicht, G. (2012). A systematic method for quantifying wind flow modelling uncertainty in wind resource assessment. *Journal of Wind Engineering and Industrial Aerodynamics*, *111*, 85-94.

Durán, P., Meißner, C., & Casso, P. (2020). A new meso-microscale coupled modelling framework for wind resource assessment: A validation study. *Renewable energy*, *160*, 538-554.

von Storch, H., Langenberg, H., & Feser, F. (2000). A spectral nudging technique for dynamical downscaling purposes. *Monthly weather review*, *128*(10), 3664-3673.