Including thermal effects in CFD simulations

Catherine Meissner, **Arne Reidar Gravdahl**, Birthe Steensen

windsim

Summary of the work

The calculation of the wind field for resource assessment is done by using **CFD RANS simulations**, performed with the commercial software **WindSim**. A new interface has been created to use mesoscale simulation data from a meteorological model as driving data for the CFD simulations. This method makes it necessary to **take into account thermal effect**s on the wind field to exploit the full potential of this method.

The procedure to consider thermal effects in CFD wind field simulations and the improvements of simulations results due to the usage of this procedure are presented.

Equations

Temperature equation

$$\overline{u}_j \frac{\partial\overline{\Theta}}{\partial x_j} = \frac{\partial}{\partial x_j}\left(\alpha\left(\frac{\partial\overline{\Theta}}{\partial x_j}\right) - \left(\overline{u_j'\Theta'}\right)\right)$$

$$\left(\overline{u_j'\Theta'}\right) = -\frac{\upsilon_t}{\sigma_\Theta}\frac{\partial\overline{\Theta}}{\partial x_j}$$

Influence of temperature on the momentum equation

$$\overline{u}_j\frac{\partial\overline{u}_3}{\partial x_j} = \boxed{\frac{\Theta^*}{\Theta_0}g} - \frac{1}{\rho}\frac{\partial\overline{p}}{\partial x_3} + \frac{\partial}{\partial x_j}\left(\upsilon\left(\frac{\partial\overline{u}_3}{\partial x_j}+\frac{\partial\overline{u}_j}{\partial x_3}\right) - \left(\overline{u_3'u_j'}\right)\right)$$

Influence of temperature on TKE and dissipation

$$\frac{\partial\overline{u_j}k}{\partial x_j} = \frac{\partial}{\partial x_j}\left(\frac{\upsilon_T}{\sigma_k}\frac{\partial k}{\partial x_j}\right) + P_k + \boxed{P_b} - \varepsilon$$

$$\frac{\partial\overline{u_j}\varepsilon}{\partial x_j} = \frac{\partial}{\partial x_j}\left(\frac{\upsilon_T}{\sigma_\varepsilon}\frac{\partial\varepsilon}{\partial x_j}\right) + \frac{\varepsilon}{k}\left[c_{\varepsilon1}P_k + \boxed{c_{\varepsilon3}P_b}\right] - c_{\varepsilon2}\frac{\varepsilon^2}{k}$$

$$P_b = -\frac{g}{\overline{\overline{\Theta}}}\frac{\upsilon_T}{\sigma_\Theta}\frac{\partial\overline{\Theta}}{\partial x_3}$$

Simulation for artificial topography

In stable atmospheric conditions the wind flow is blocked by the mountains more than in neutral atmospheric conditions. The flow goes mainly around the mountain and not over it (Fig.1). Therefore, the wind speed on the hill top is reduced. In WindSim simulations for a cosine hill taking into account stability effects by the described procedure the expected decrease in speed-up over the hill top can be seen clearly for stable conditions (Fig. 2).

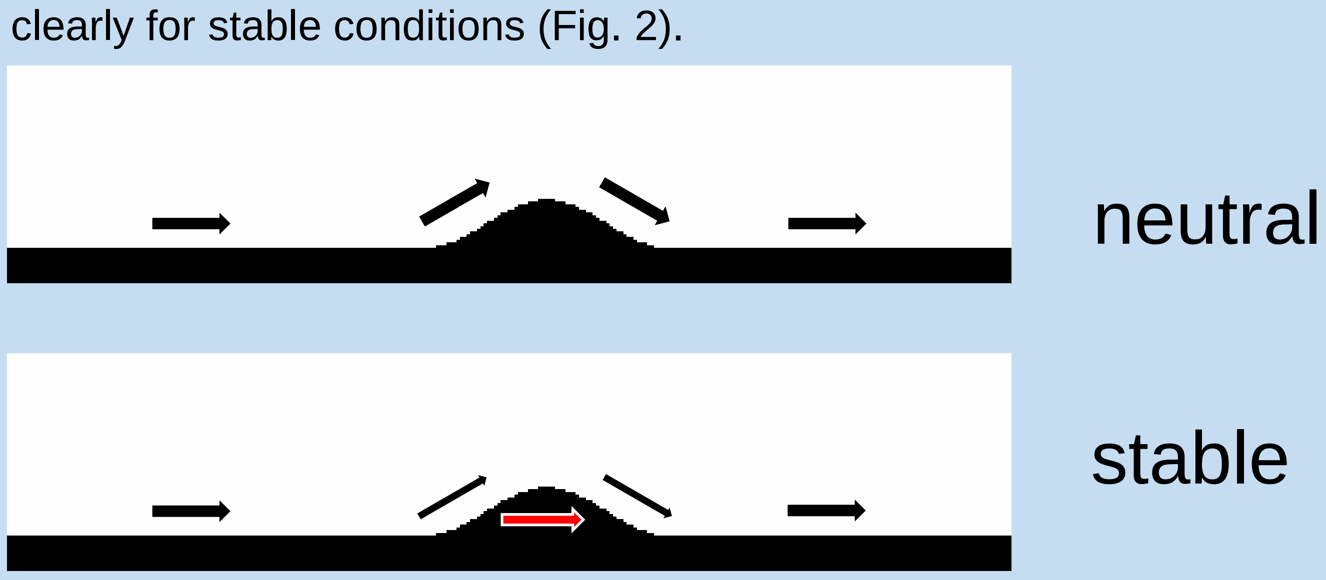


Fig.1 *: Sketch of the wind flow for neutral (top) and stable conditions (bottom).*

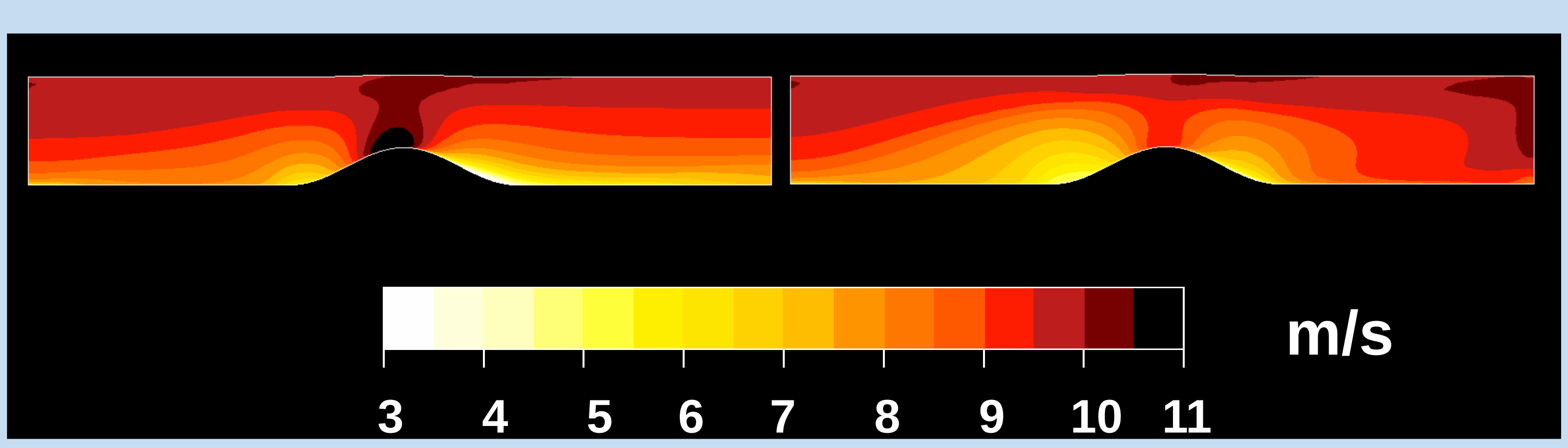


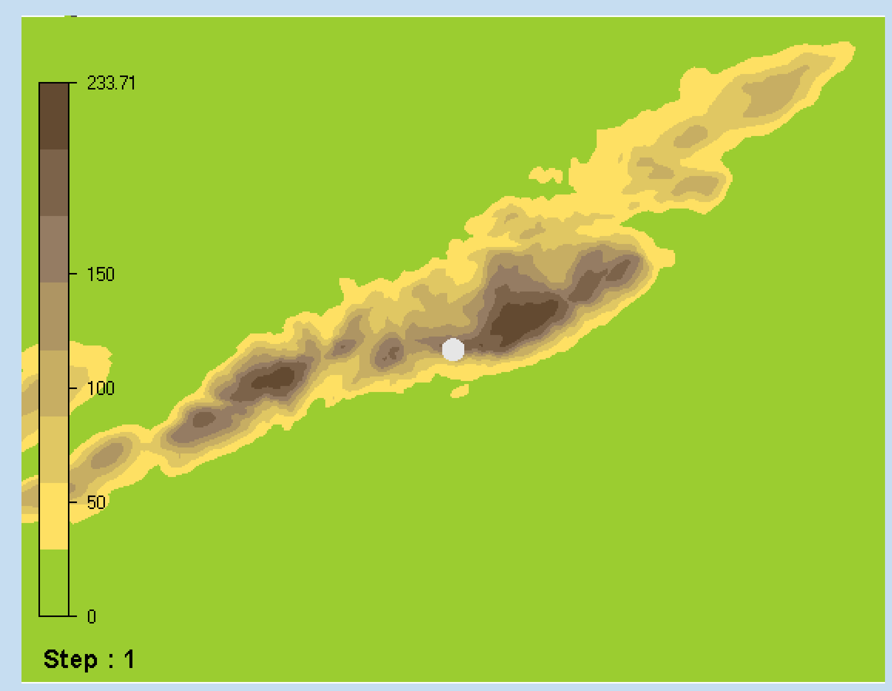
Fig.2 *: 3D WindSim simulation of horizontal wind speed for neutral (left) and stable (right) conditions.*

Comparison with observations

Data from a measurement mast at Hundhammerfjellet wind farm (Norway) is used to evaluate WindSim simulations with and without consideration of stability effects (Fig. 3). In this area the atmosphere is often stable stratified.

Wind speed measurements for 30, 73 and 83 m height, and temperature measurements for 50 and 83 m are available for the period from April 2006 to January 2007.

From this data the atmospheric stability was calculated for the wind sectors (Tab.1).



Sector (°)	Stability
0	s
30	s
60	s
90	s
120	s
150	s
180	s
210	n
240	n
270	n
300	n
330	s

Fig. 3*: left: Hundhammerfjellet area. The met mast is marked by a grey dot . Right: wind sectors with neutral (n) and stable (s) stratification.*

Default WindSim simulations without consideration of thermal effects show good results for the sectors with neutral stratification but fail to predict the shape of the wind profile for sectors with stable stratification (Fig. 4).

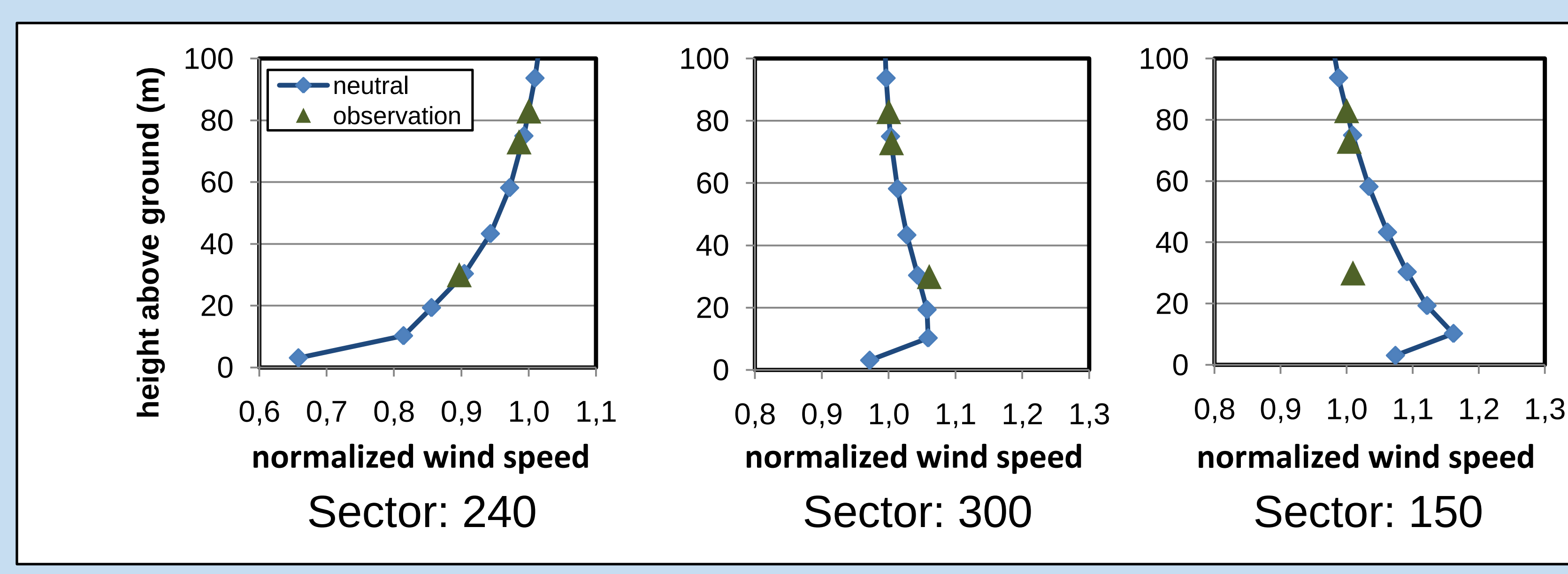


Fig. 4*: Simulations without consideration of thermal effects (blue) and measurements (green) for sectors with neutral (left, middle) and stable (right) stratification.*

WindSim simulations taking into account stability by the described procedure show good agreement with the observations for the sectors with stable stratification (Fig.5).

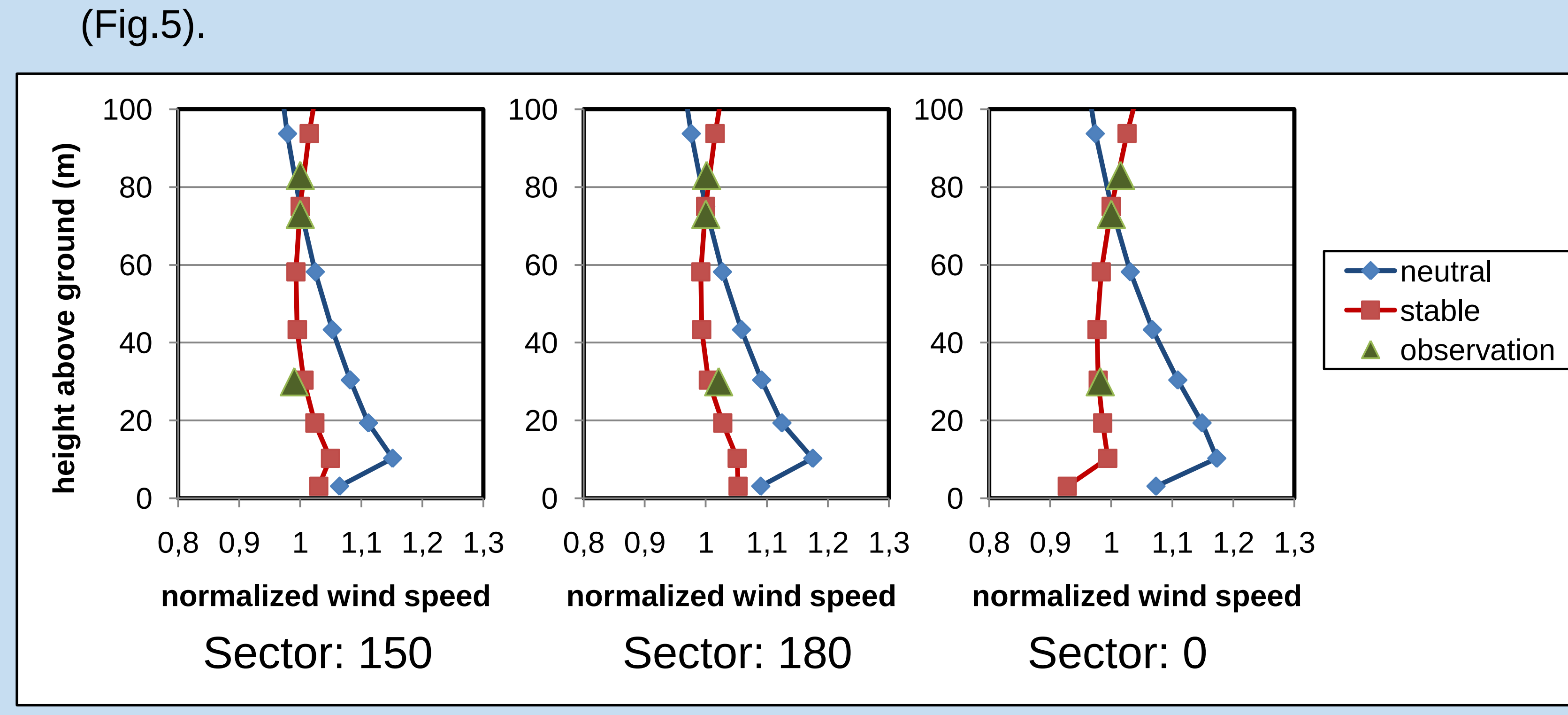


Fig. 5*: Simulations with (red) and without (blue) consideration of thermal effects and observations (green) for sectors with stable stratification.*

Conclusions

- WindSim is able to simulate the influence of thermal stratification on the wind flow explicitly by solving the temperature equation
- Comparisons with observations show an improvement in simulation results for stable stratified atmospheres with the new method

European Wind Energy Conference and Exhibition 2009, Marseille, France