windsim

When the terrain gets rough

Inclusion of temperature equation (simplified terrain)

Cathérine Meissner

User Meeting

Tønsberg, June16th 2008

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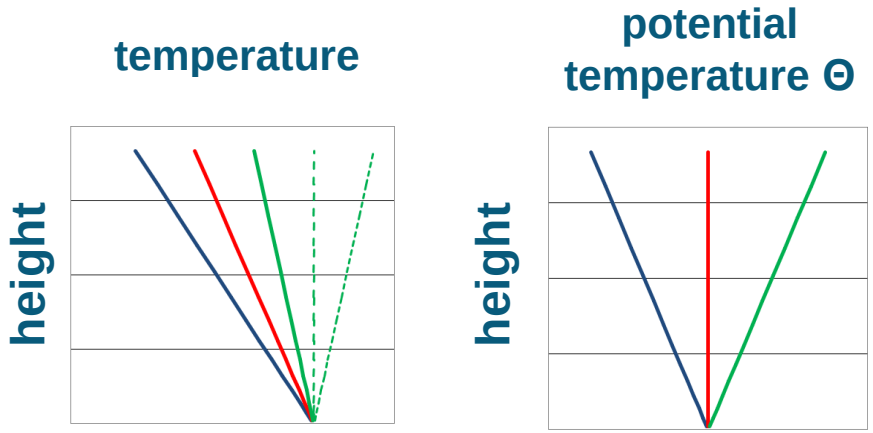
Stratification of the atmosphere

Dependent on the vertical temperature distribution 3 different atmospheric stratifications can be classified:

1) stable
2) neutral (adiabatic)
3) unstable

The temperature distribution can be described by the “normal” temperature T or by the potential temperature Θ

$$\Theta = T\left(\frac{p_0}{p}\right)^{\kappa}$$



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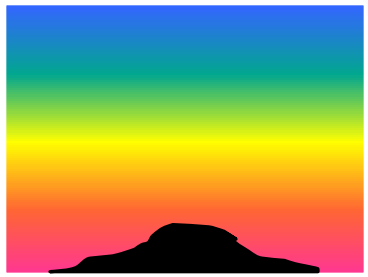
Stratification of the atmosphere

potential temperature

stable

neutral

unstable



The wind field is influenced by the stratification when the stratification is non-neutral

WindSim uses neutral stratification as default value

First influence of temperature on the wind field: change of the wind speed profile

Neutral case

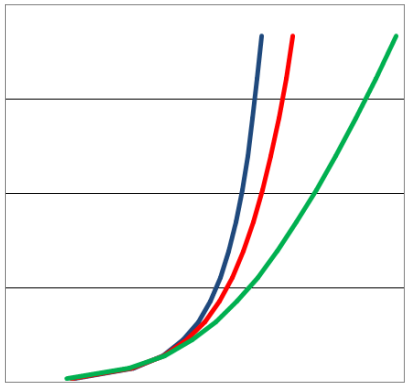
$$\bar{u}(z) = \frac{u_*}{\kappa} \, ln\left(\frac{z}{z_0}\right)$$

Non-neutral case

$$\bar{u}(z) = \frac{u_*}{\kappa}\left[ln\left(\frac{z}{z_0}\right) - \Psi_m\left(\frac{z}{L}\right)\right]$$

wind speed

height



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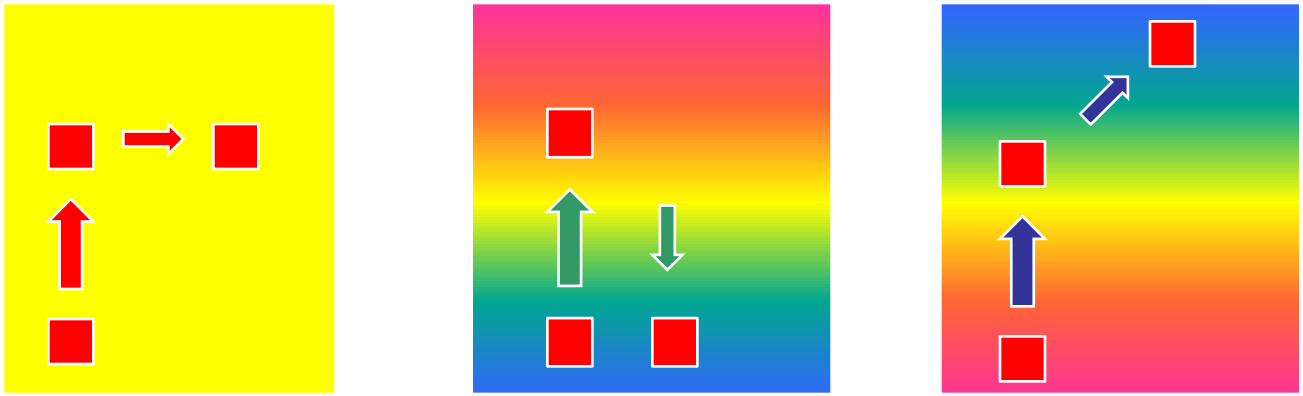
Second influence of temperature on the wind field: buoyancy force



neutral **stable** **unstable**

- neutral : lifted air remains in the lifting level
- stable : lifted air sinks down to the original position
- unstable: lifted air raises further above the lifting level

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Second influence of temperature on the wind field: buoyancy force

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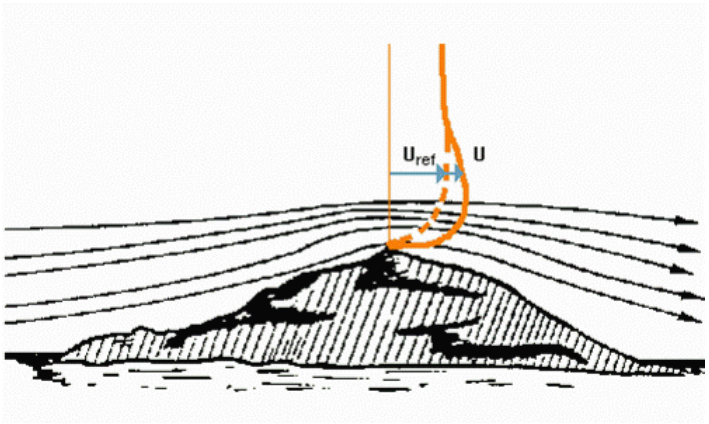
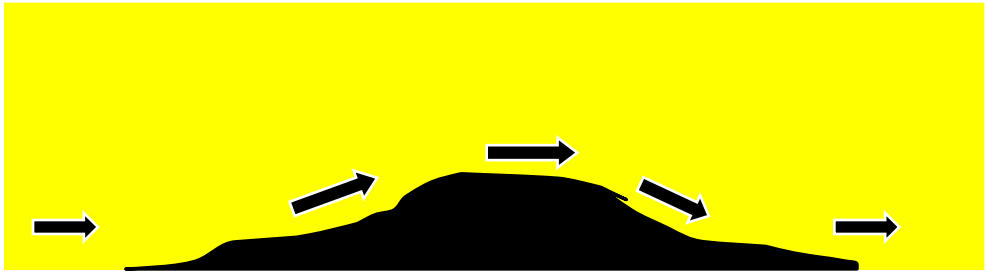
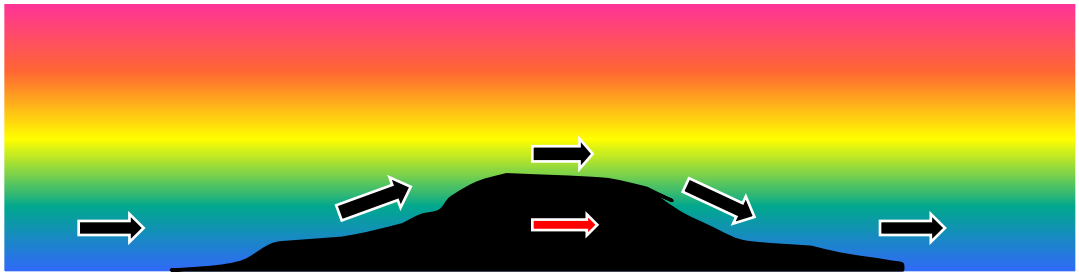
neutral



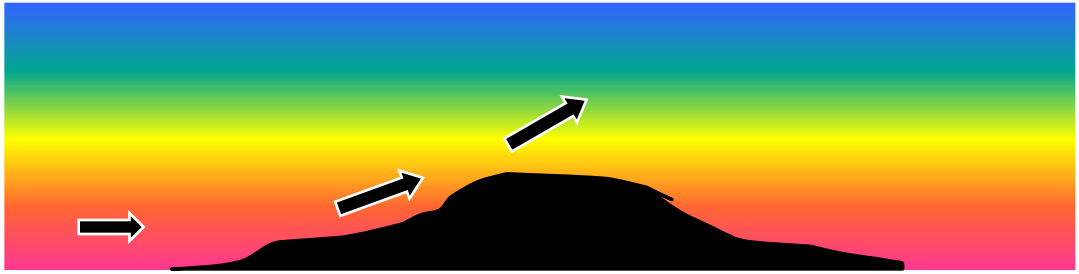


Second influence of temperature on the wind field: buoyancy force

stable



unstable



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Representation of stability in CFD codes

Other CFD codes

Stability dependent vertical wind speed profile at the inlet

$$\bar{u}(z) = \frac{u_*}{\kappa}\left[ln\left(\frac{z}{z_0}\right) - \Psi_m\left(\frac{z}{L}\right)\right]$$

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Stability dependent vertical wind speed profile at the inlet

and

explicit calculation of temperature to include buoyancy effects inside the simulation area

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Temperature and momentum

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

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

Influence of temperature on velocity considered by the Boussinesq approximation

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

Θ_0 **reference temperature**

$\Theta^* = \overline{\Theta} - \Theta_0$ **deviation from the reference temperature**

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Turbulent kinetic energy and dissipation

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

$$\frac{\partial \overline{u_j} \varepsilon}{\partial x_j} = \frac{\partial}{\partial x_j}\left(\frac{\upsilon_T}{\sigma_\varepsilon}\frac{\partial \varepsilon}{\partial x_j}\right) + \frac{\varepsilon}{k}\left[c_{\varepsilon 1} P_k + c_{\varepsilon 3} P_b\right] - c_{\varepsilon 2}\frac{\varepsilon^2}{k}$$

Influence of temperature on turbulent kinetic energy and dissipation considered by additional term

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

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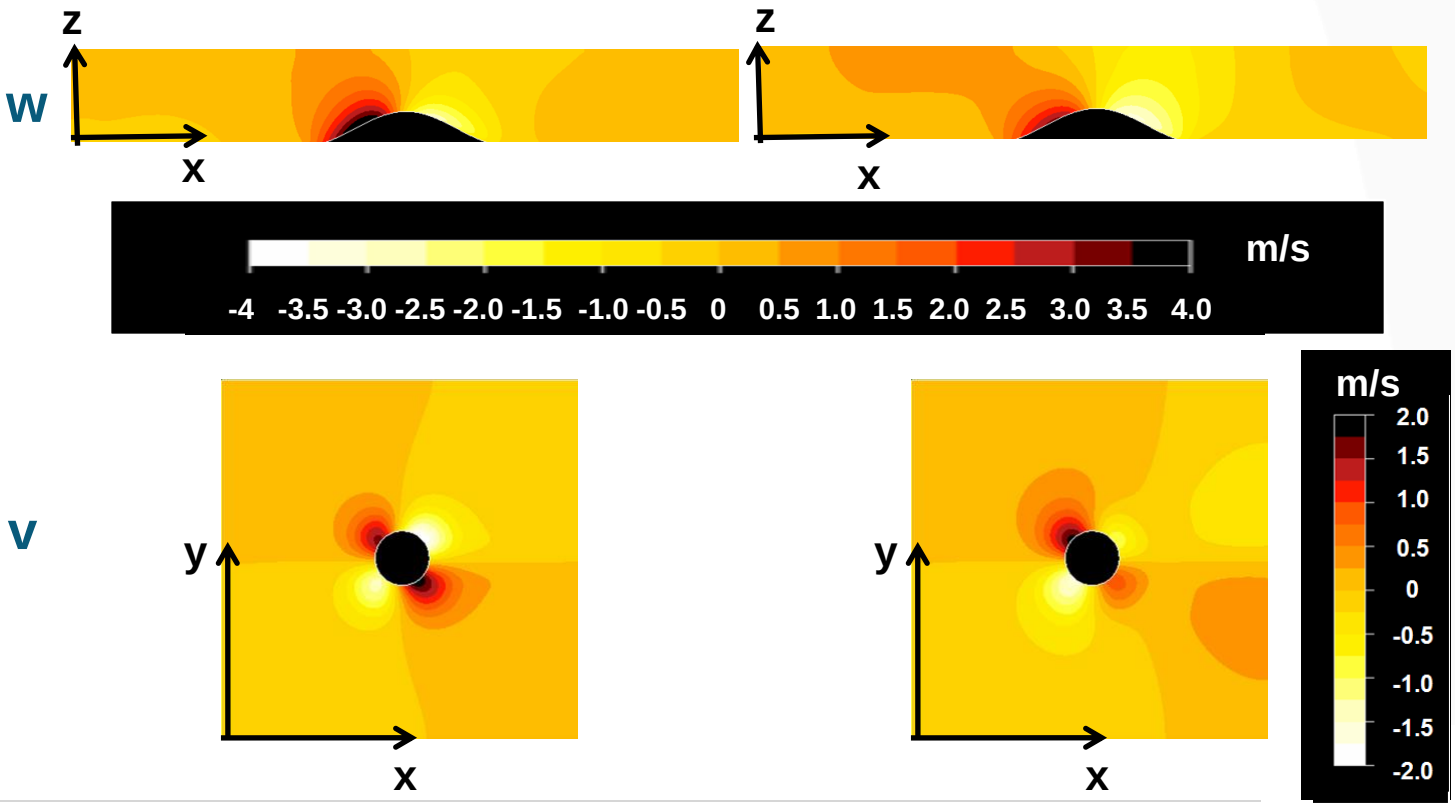
Simulation for cosine hill

height: 200 m
length: 800 m

neutral atmosphere

stable atmosphere



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Simulation for cosine hill

neutral atmosphere

stable atmosphere

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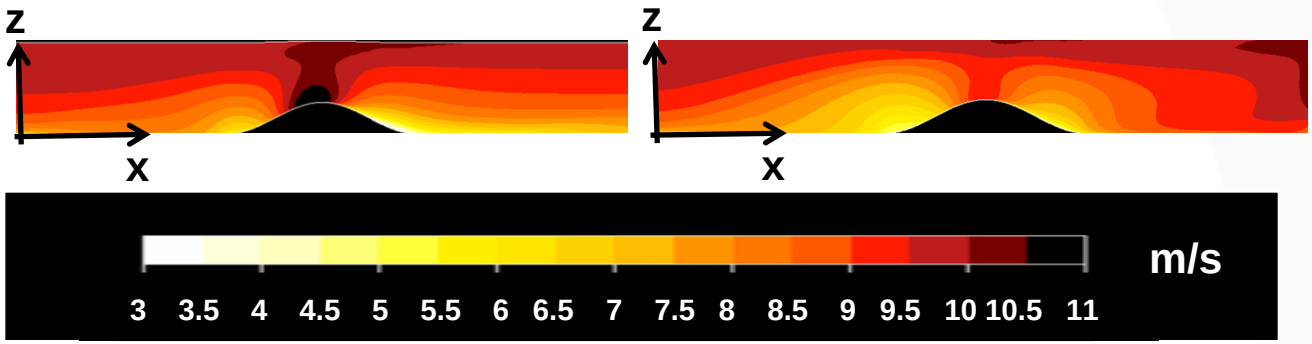
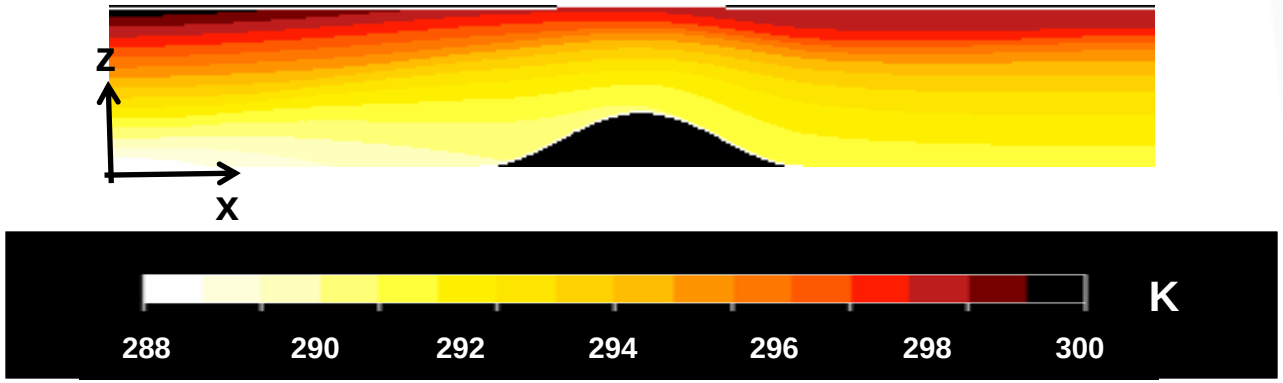


stable atmosphere

Θ



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Activation of the temperature equation

The temperature equation is not yet activated in the official version but can be activated in the Q1 file

Two additional parameters have to be set:

- potential temperature at the sea level
- potential temperature gradient

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Summary

- WindSim is able to take into account the stratification of the atmosphere by:
  - Altering the vertical wind speed profile at the inlet
  - Solving the temperature equation to introduce buoyancy effects
- Validation of model results against observations and literature cases will follow soon

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