Technical University of Denmark

Wake effects of large offshore wind farms - a study of mesoscale atmosphere and ocean feedbacks

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Wake effects of large offshore wind farms - a study of mesoscale atmosphere and ocean feedbacks

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Overview

1) We planned to use the mesoscale model WRF for this study. At the moment I began (20111001) there was no wind farm desciption included in WRF.

→ A new parametrisation had to developed from scratch.

This month (hopefully) the introduction/validation of the parametrisation will be submitted.

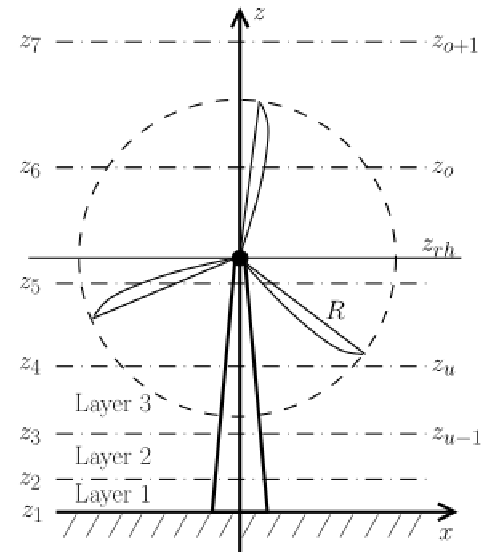
2) Study of the atmospheric impact and ocean feedbacks in the external stay.

1) Wind Farm parametrisation

From WRFV3.2.1 a wind farm parametrisation was included, which has been used from that point on the reference (U. Blahak, 2010):

$$T_k = \frac{C_t N_{ij}\, A_k\, V_{h,k}^2}{2\,(\Delta x)^2\,\Delta z_k}$$

- $C_t = \mathtt{min}(7C_p/4, 0.9)$
- N_{ij} the number of turbines in the grid
- A_k turbine blade intersecting with level k
- $V_{h,k}$ horizontal velocity



It adds turbulence proportional to the power extracted by the turbine:

$$\frac{\partial tke_k}{\partial t} = \frac{\partial tke_k}{\partial t} + C_{tke}\frac{N_{ij}\, A_k\, V_k^3}{(\Delta x)^2\,\Delta z_k}$$

- Where $tke = \overline{u_i'^2}/2, i \in 1, 2, 3$
- $C_{tke} = C_t - C_p$

1) Wind Farm parametrisation ("EWP" Wind Farm)

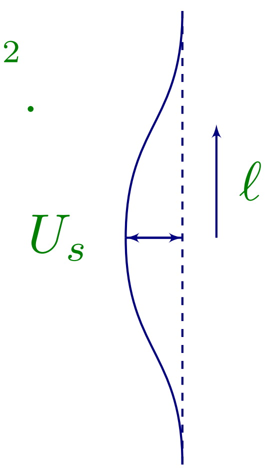
From the diffusion equation, one can obtain the typical length scale ℓ:

(1) $$\ell^2 = \frac{2K_m}{U_0}x + \ell_0^2$$

- K_m is the turbulence coefficient for momentum
- ℓ_0 the initial length scale
- U_0 background hub-height velocity

Assumption: In the far wake the ensemble average will be Gaussian. then U becomes:

(2) $$\underbrace{U(z)}_{\text{Wake velocity}} = \underbrace{U_0(z)}_{\text{Upstream velocity}} - \underbrace{U_s f(z)}_{\text{Velocity deficit}}$$ where $f = e^{-\frac{1}{2}\left(\frac{z}{\ell}\right)^2}$.



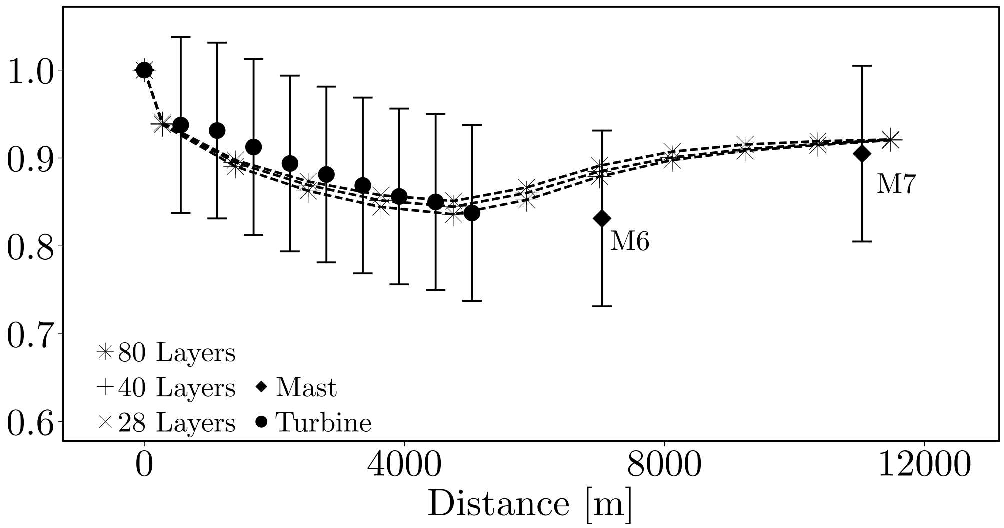
Using (2) we can obtain U_s from the thrust equation:

$$\frac{1}{2} C_t\, A_0\, U_0^2 = W \int_0^{z_{\max}} U(U_0 - U)\,\mathrm{d}\,z$$

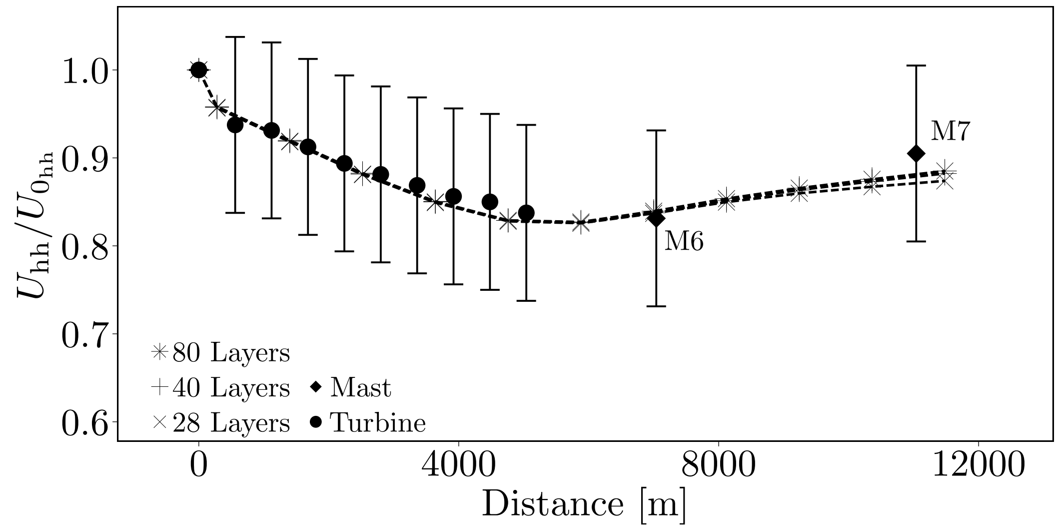
- C_t is obtained from the thrust curve
- W is the width of the wake
- z_{max} is the height of the domain

Recovery

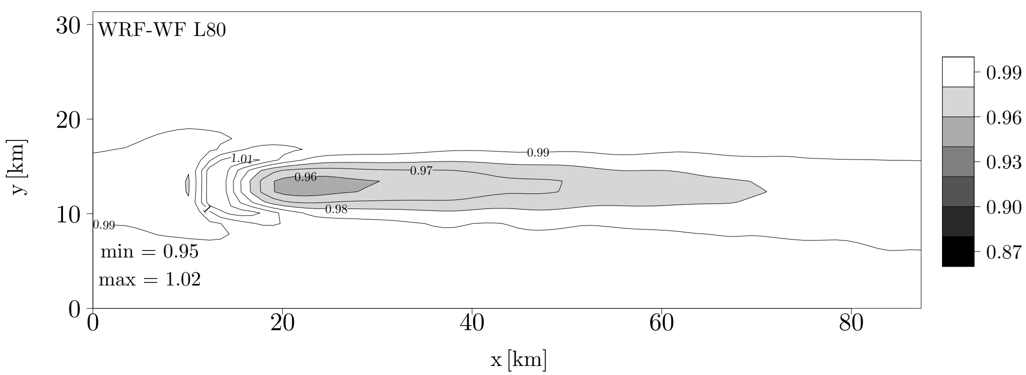
WRF-WF



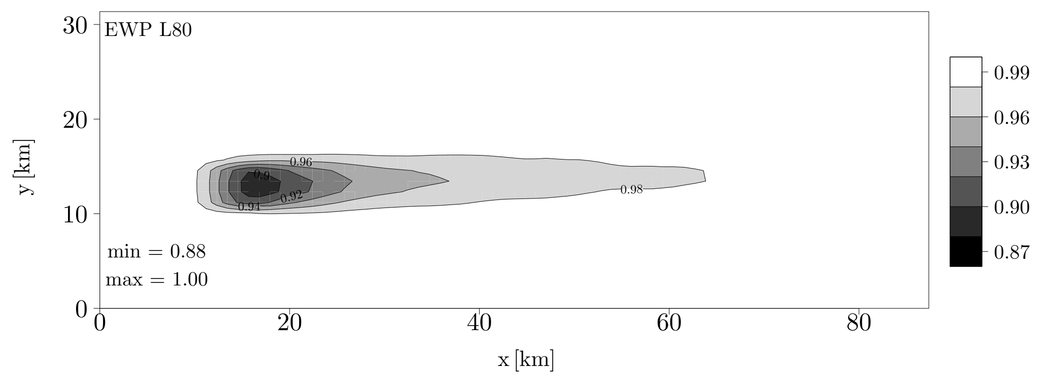
EWP



INTERACTION: friction velocity u_{star}



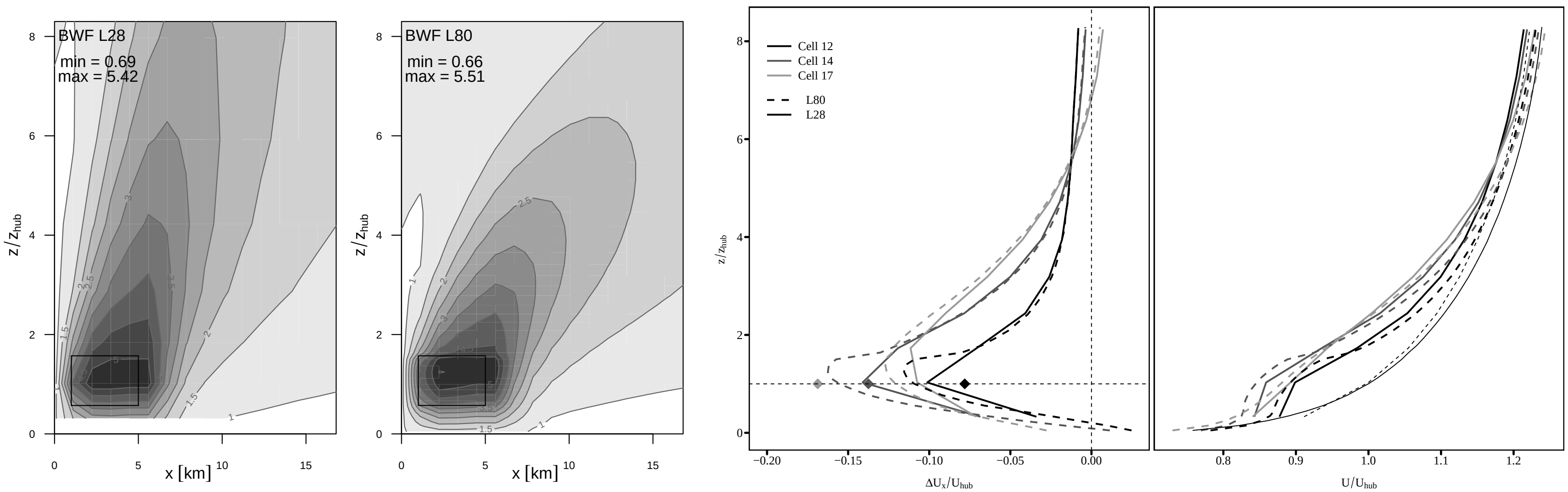
55 km



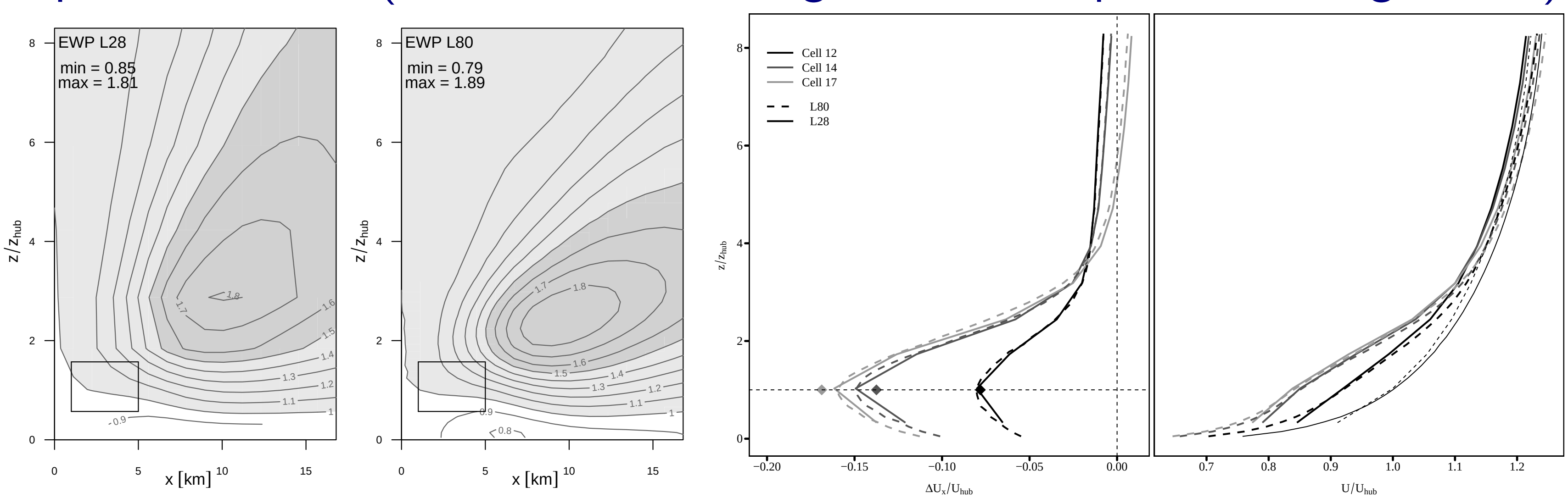
50 km

Wind Farm Parametrizations, Horns Rev I

1) Drag formulation f(Δz). Sub grid scale wake expansion achieved with additional turbulence kinetic energy source term.



2) Drag formulation, but does not depend on Δz. Explicit wake expansion (diffusion equation). Assumption: inside a grid cell additional turbulence and enhanced dissipation balance (due to its small length scale compared to the grid size).



Technical aspects EWP scheme

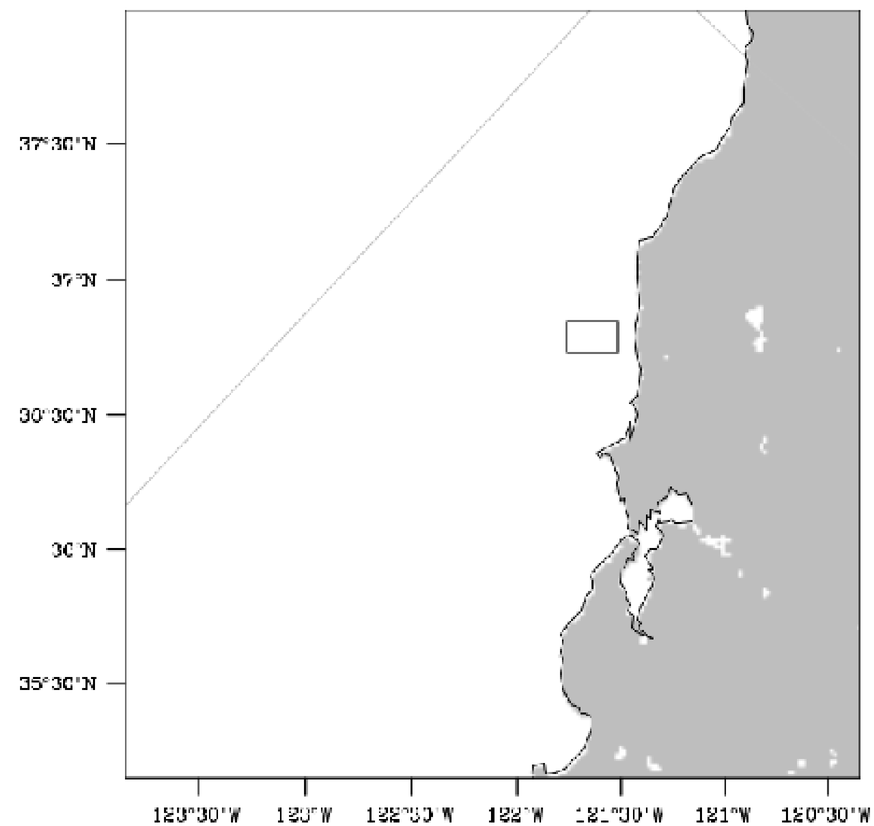
- Real cases
- Nested runs
- Rotated grids
- Shared memory + Distributed memory

Additional option: "Coupling" of microscale models $T_m = f(U, \theta)$

External stay, UCLA

Real Case complete 2009, Californian Coast

200 7MW turbines. Hub height 125 m and the radius is 63 m.



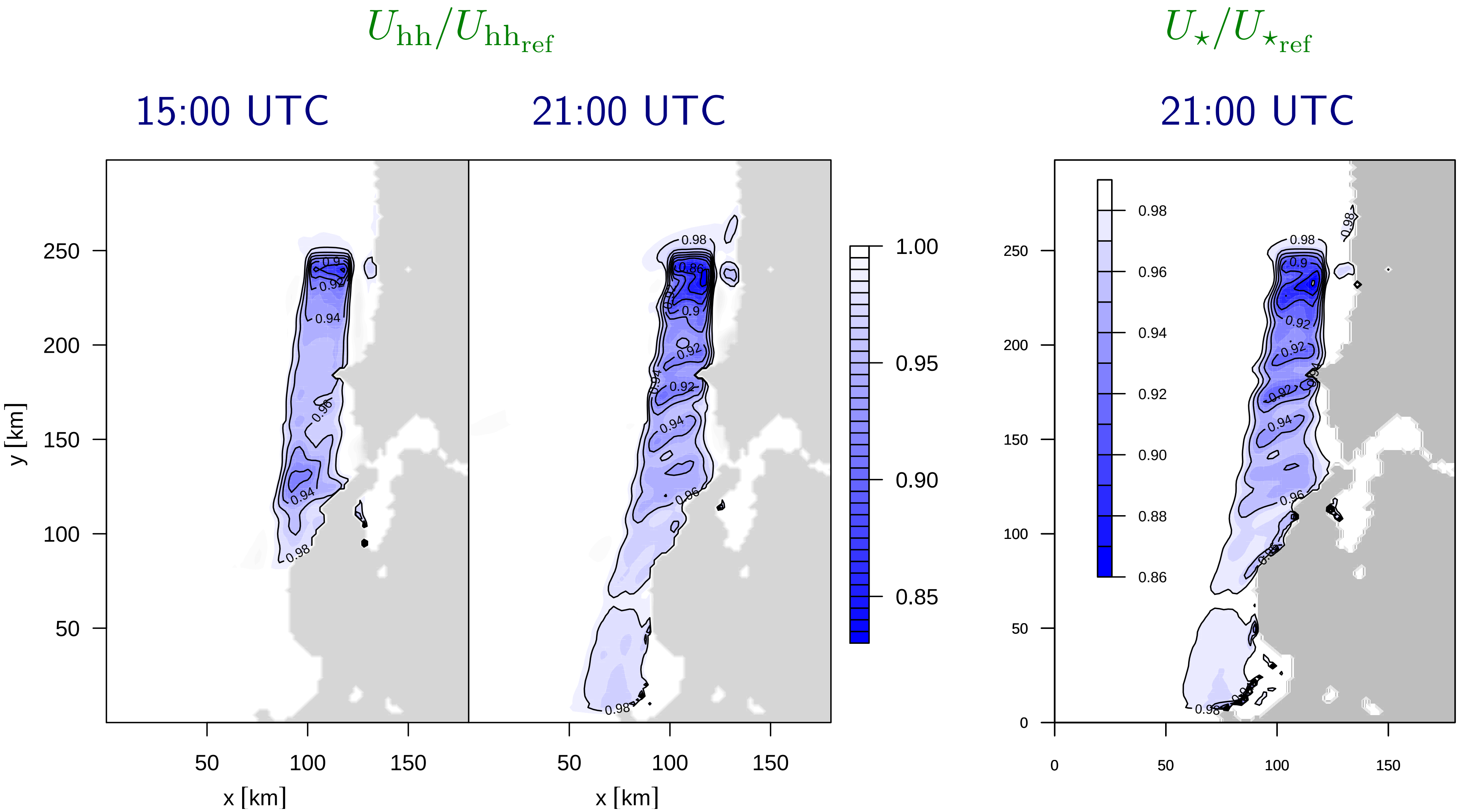
Expensive:

D1: 6 km (230×250×60)
D2: 2 km (259×250×60)

For the IC and BC we use NARR (North American Reanalysis 32 km) data only.

Preliminary Results, January 1st 15h steady conditions

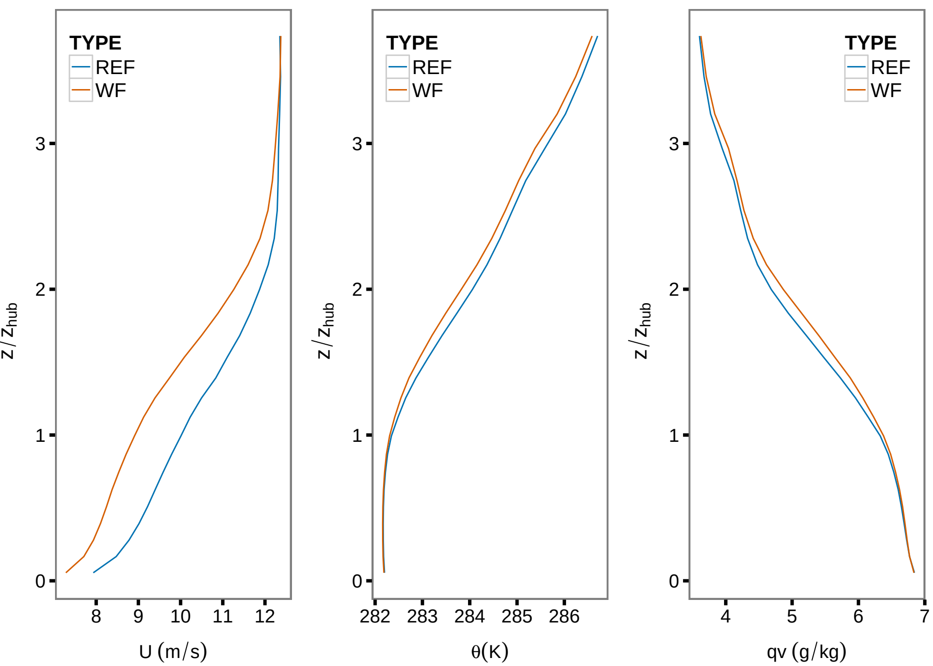
$$|U| = 10\,m\,s^{-1} \pm 2\,m\,s^{-1}$$
$$\theta \;=\; 265^\circ \;\; \pm 10^\circ$$



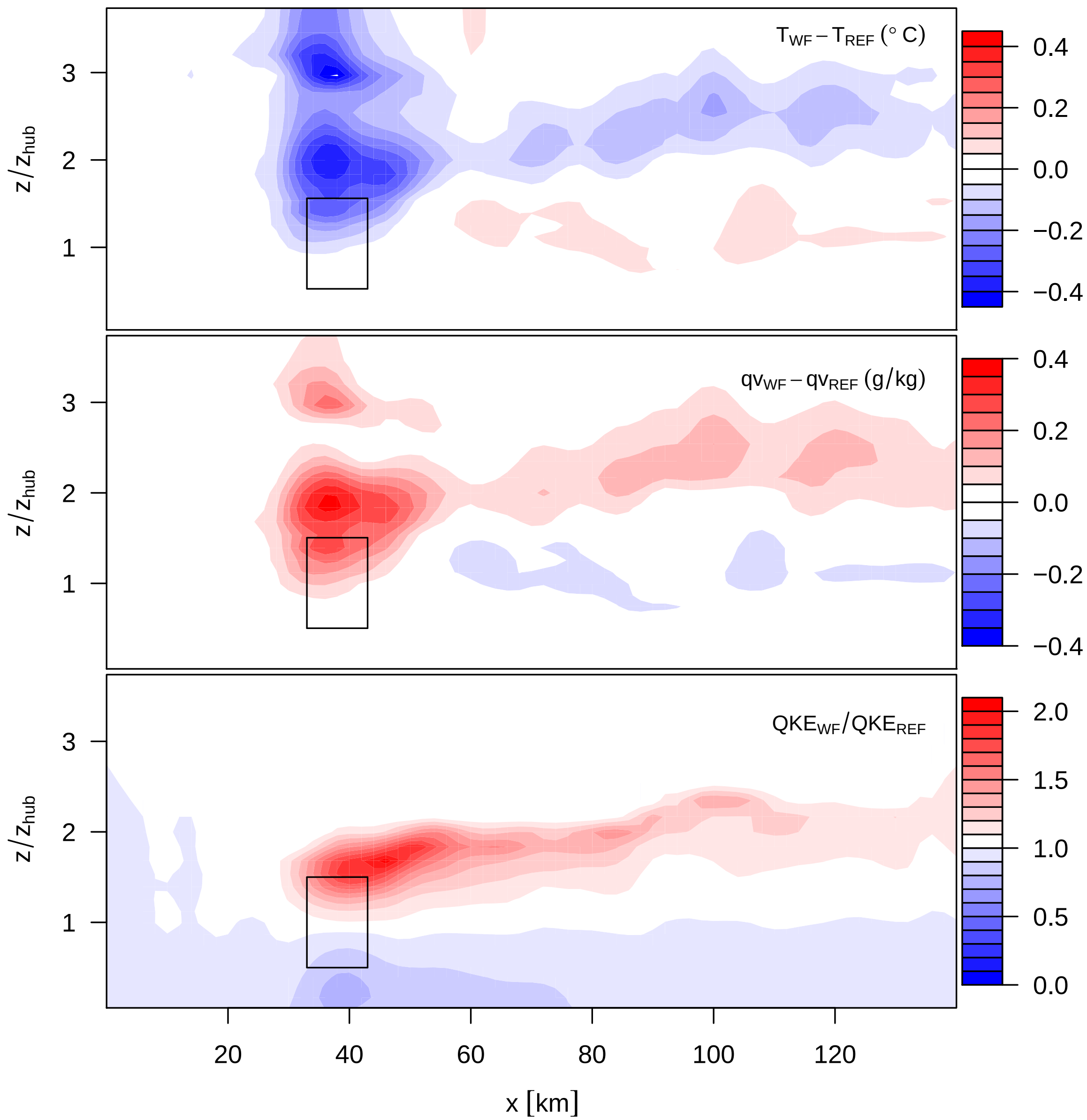
Total extension: 250 km (98%)

Preliminary Results, January 1^{st} 15h steady conditions

9h average in the WF



9h average of cross section through the WF



Cold/moist air is transported upwards into the inversion layer, causing cooling and moisturing of the inversion layer. We notice the horizontal advection 100 km downstream.