

## 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

DTU-Risø Campus

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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 description included in WRF.

→ A new parametrisation had to be developed from scratch.

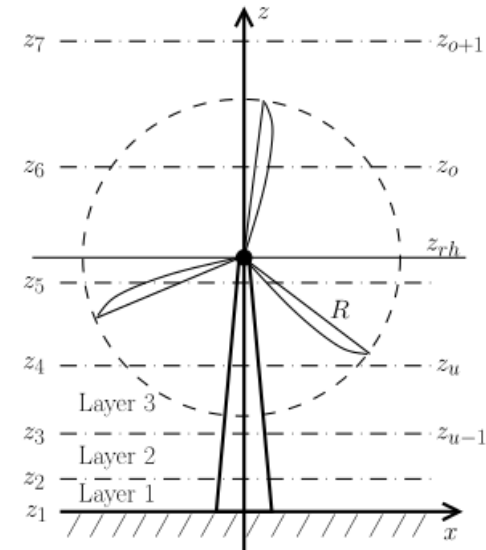
This month (hopefully) the introduction/validation of the parametrisation will be submitted.

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):

$$T_k = \frac{C_t N_{ij} A_k V_{h,k}^2}{2 (\Delta x)^2 \Delta z_k} \begin{cases} C_t = \min(7C_p/4, 0.9) \\ N_{ij} \text{ the number of turbines in the grid} \\ A_k \text{ turbine blade intersecting with level } k \\ V_{h,k} \text{ horizontal velocity} \end{cases}$$



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

$$\frac{\partial tke_k}{\partial t} = \frac{\partial tke_k}{\partial t} + C_{tke} \frac{N_{ij} A_k V_k^3}{(\Delta x)^2 \Delta z_k} \begin{cases} \text{Where } tke = \overline{u_i'^2}/2, i \in 1, 2, 3 \\ C_{tke} = C_t - C_p \end{cases}$$

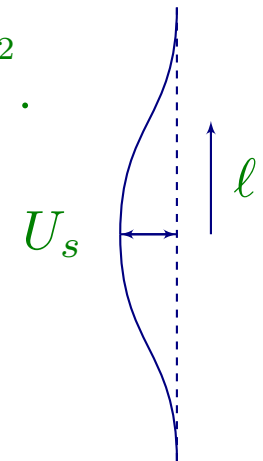
# 1) Wind Farm parametrisation ("EWP" Wind Farm)

From the diffusion equation, one can obtain the typical length scale  $\ell$ :

$$(1) \quad \ell^2 = \frac{2K_m}{U_0}x + \ell_0^2 \quad \left\{ \begin{array}{l} K_m \text{ is the turbulence coefficient for momentum} \\ \ell_0 \text{ the initial length scale} \\ U_0 \text{ background hub-height velocity} \end{array} \right.$$

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

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

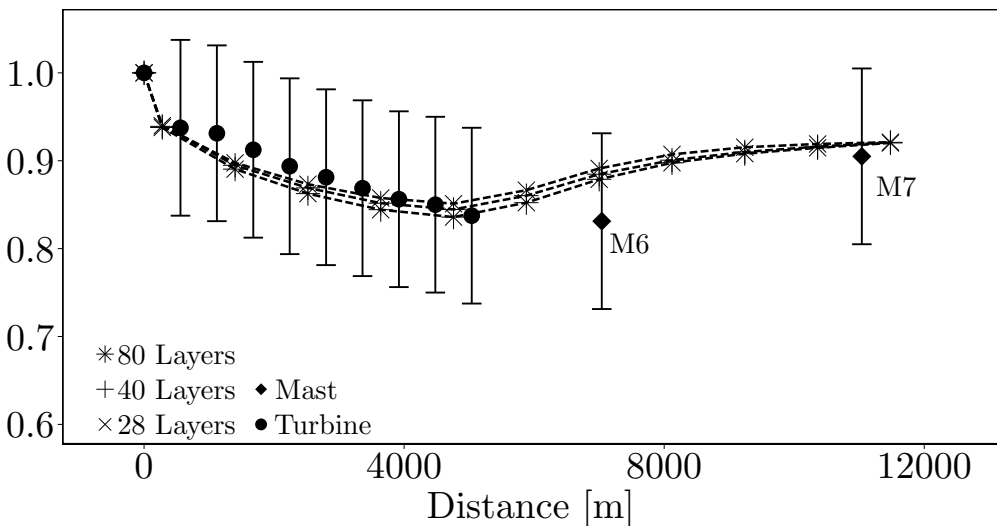


Using (2) we can obtain  $U_s$  from the thrust equation:

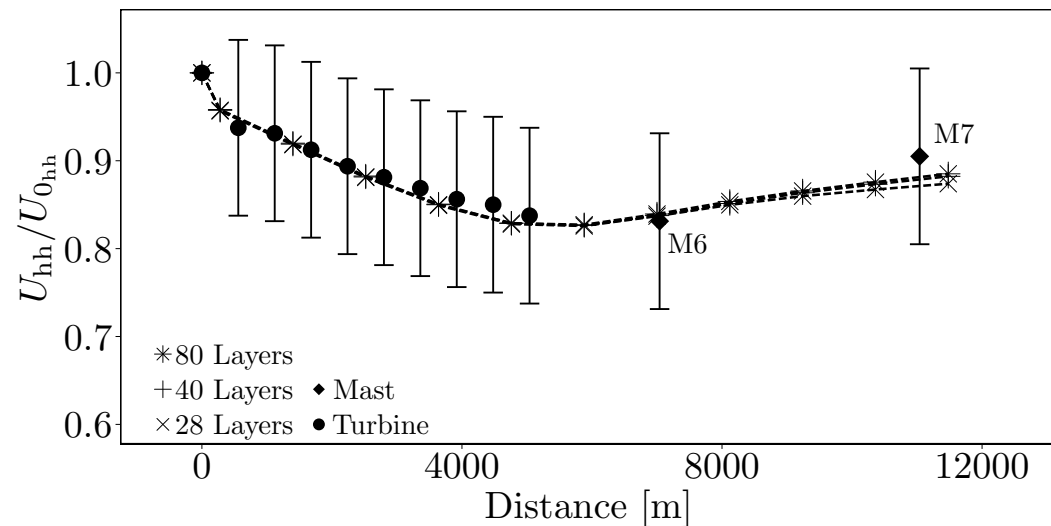
$$\frac{1}{2} C_t A_0 U_0^2 = W \int_0^{z_{\max}} U(U_0 - U) dz \quad \left\{ \begin{array}{l} C_t \text{ is obtained from the thrust curve} \\ W \text{ is the width of the wake} \\ z_{\max} \text{ is the height of the domain} \end{array} \right.$$

# Recovery

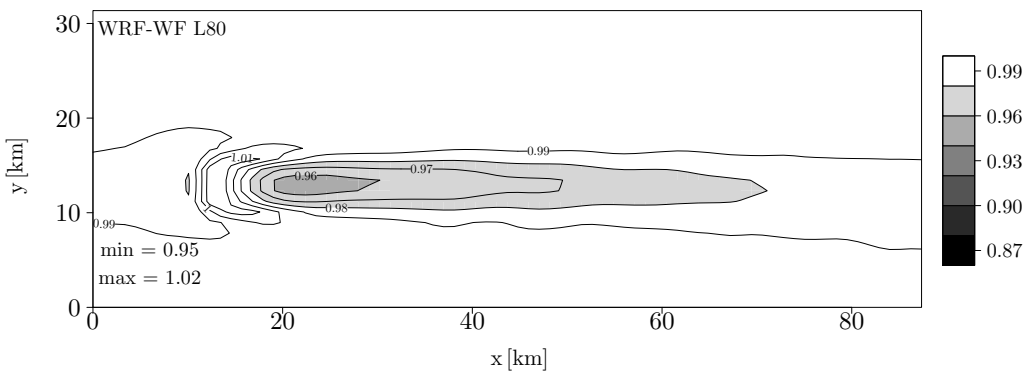
WRF-WF



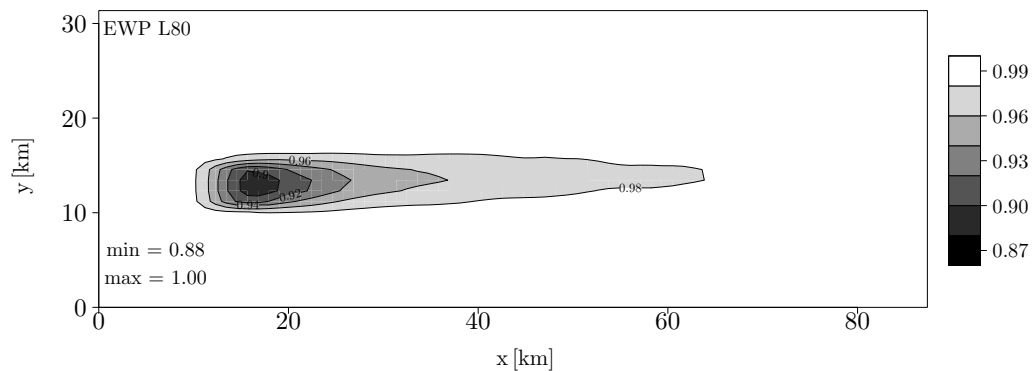
EWP



# INTERACTION: friction velocity $u_{star}$



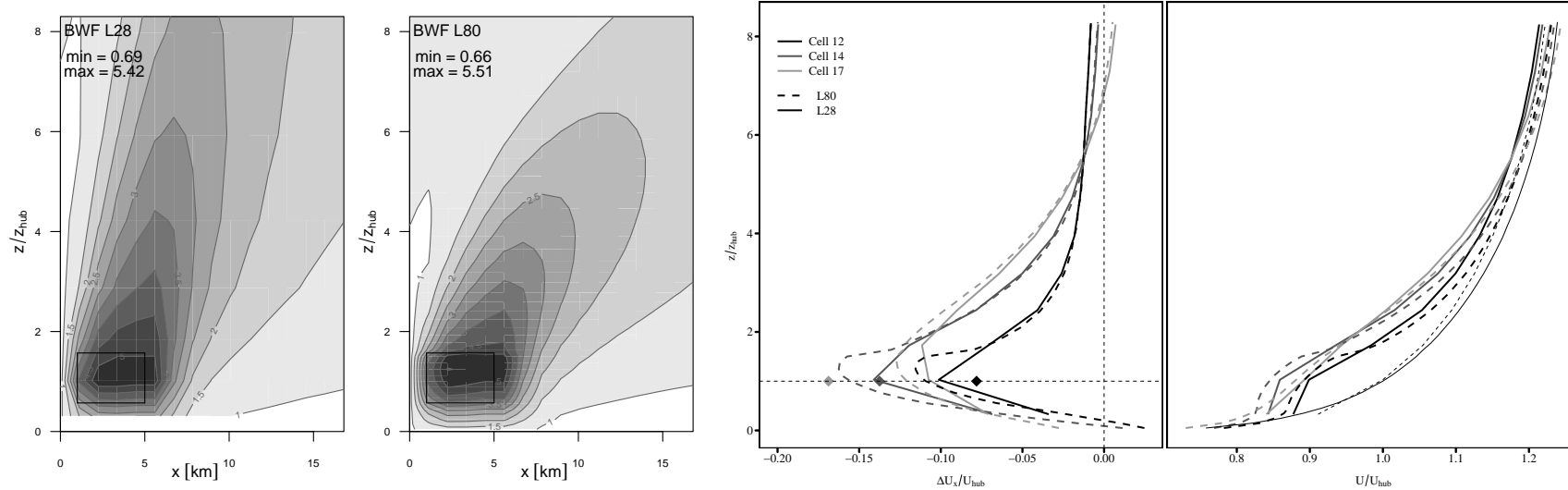
55 km



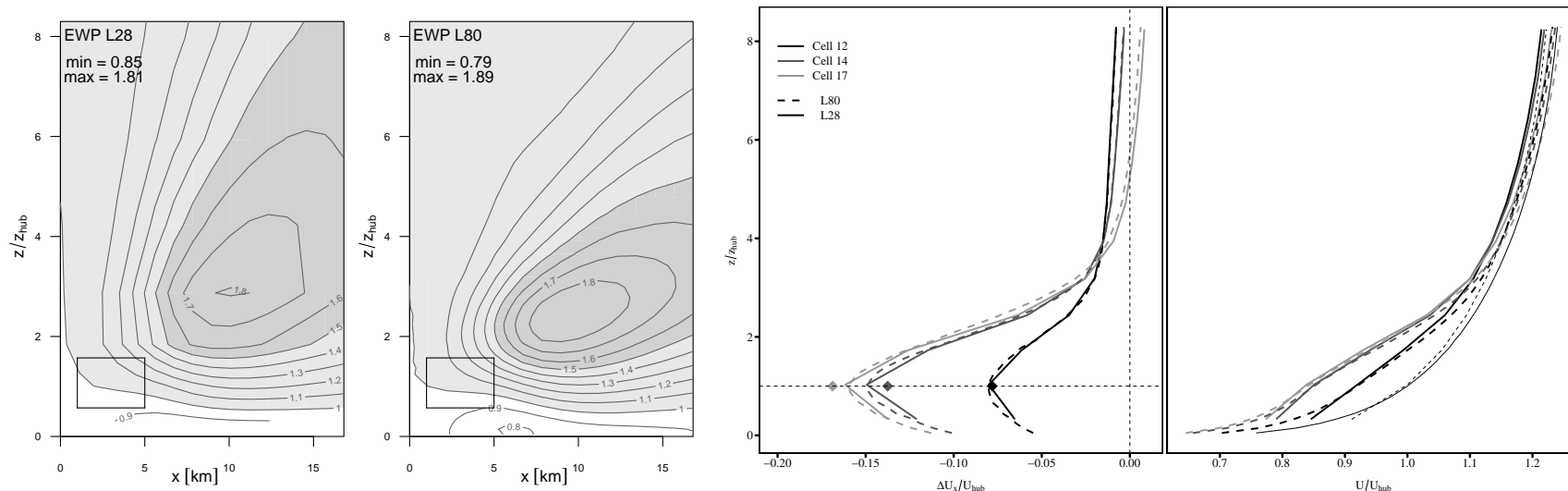
50 km

# Wind Farm Parametrizations, Horns Rev I

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



2) Drag formulation, but does not depend on  $\Delta z$ . 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

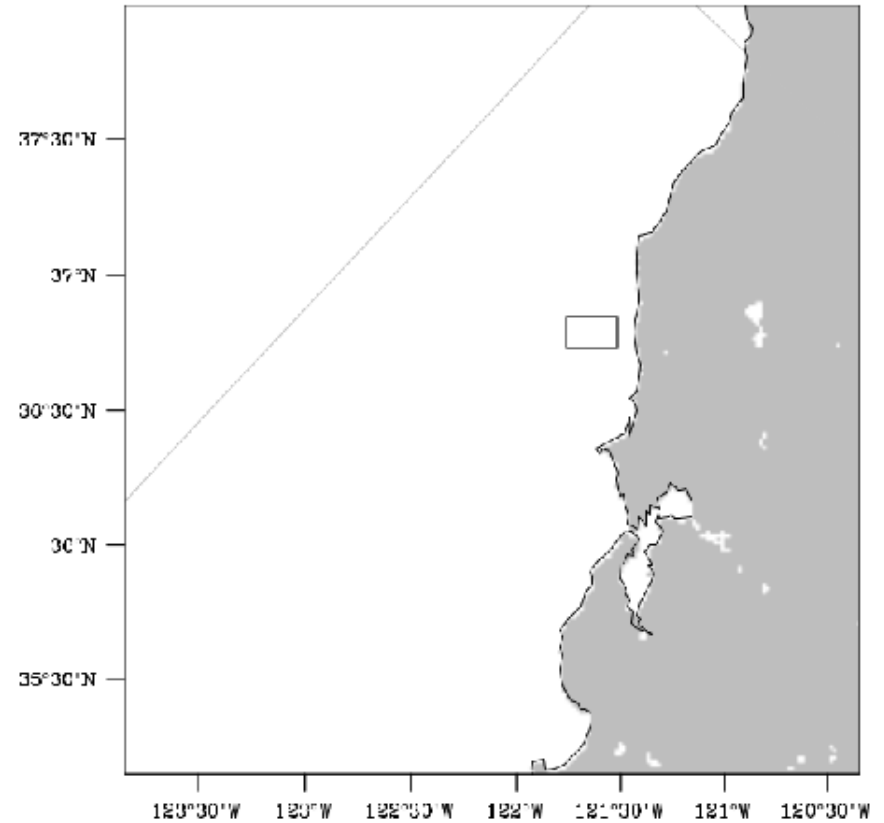
Real Case complete 2009, Californian Coast

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 1<sup>st</sup> 15h steady conditions

$$|U| = 10 \text{ m s}^{-1} \pm 2 \text{ m s}^{-1}$$

$$\theta = 265^\circ \pm 10^\circ$$

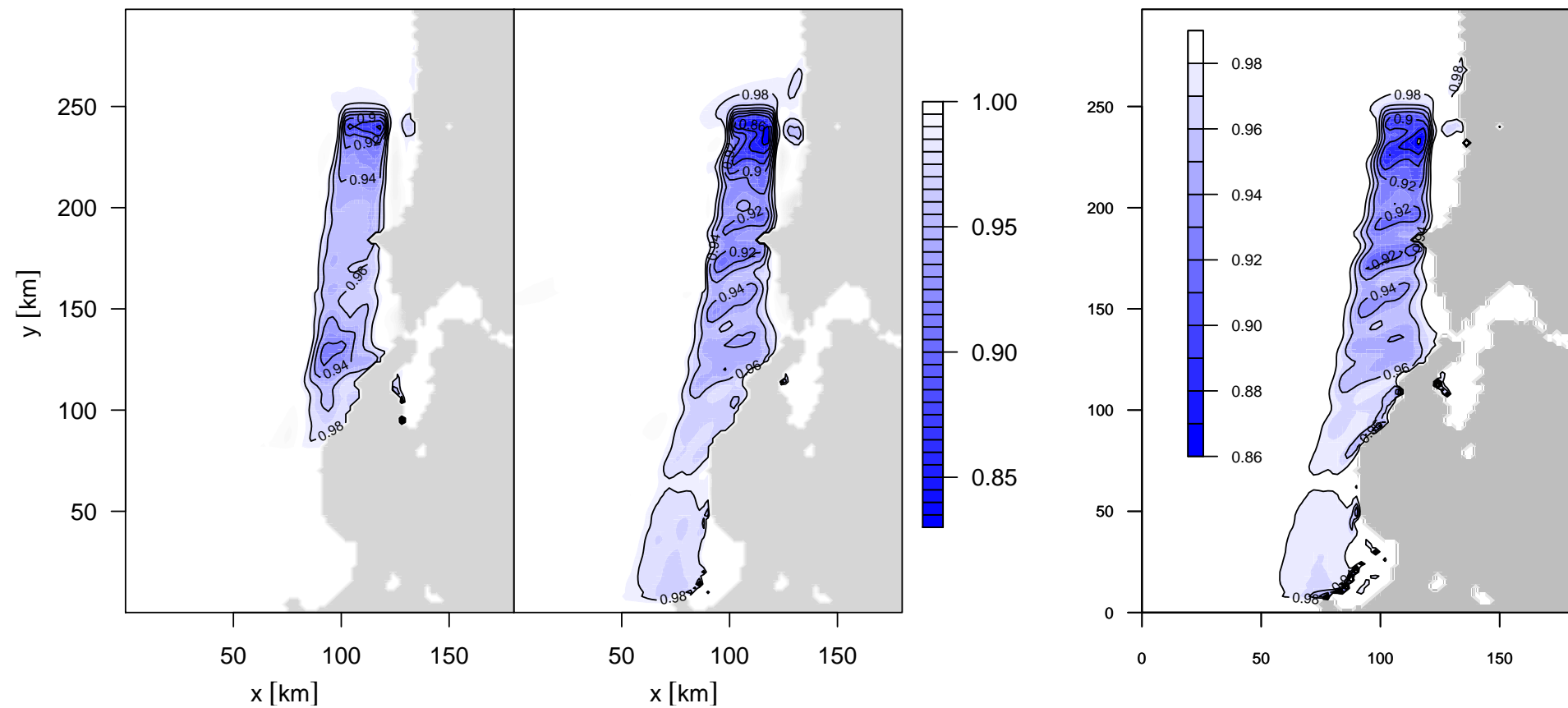
$$U_{\text{hh}}/U_{\text{hh\_ref}}$$

$$U_{\star}/U_{\star\text{ref}}$$

15:00 UTC

21:00 UTC

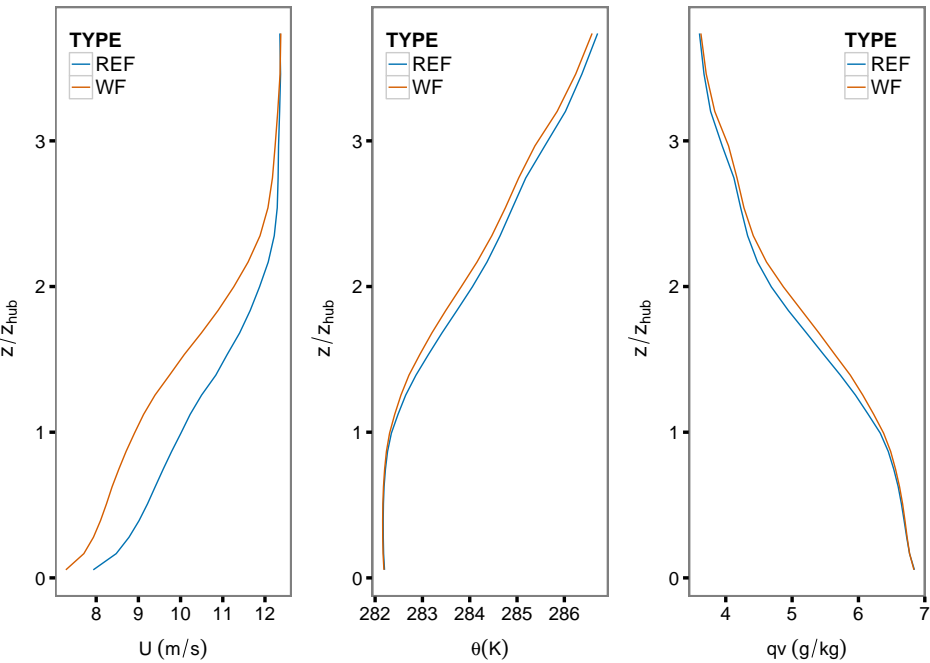
21:00 UTC



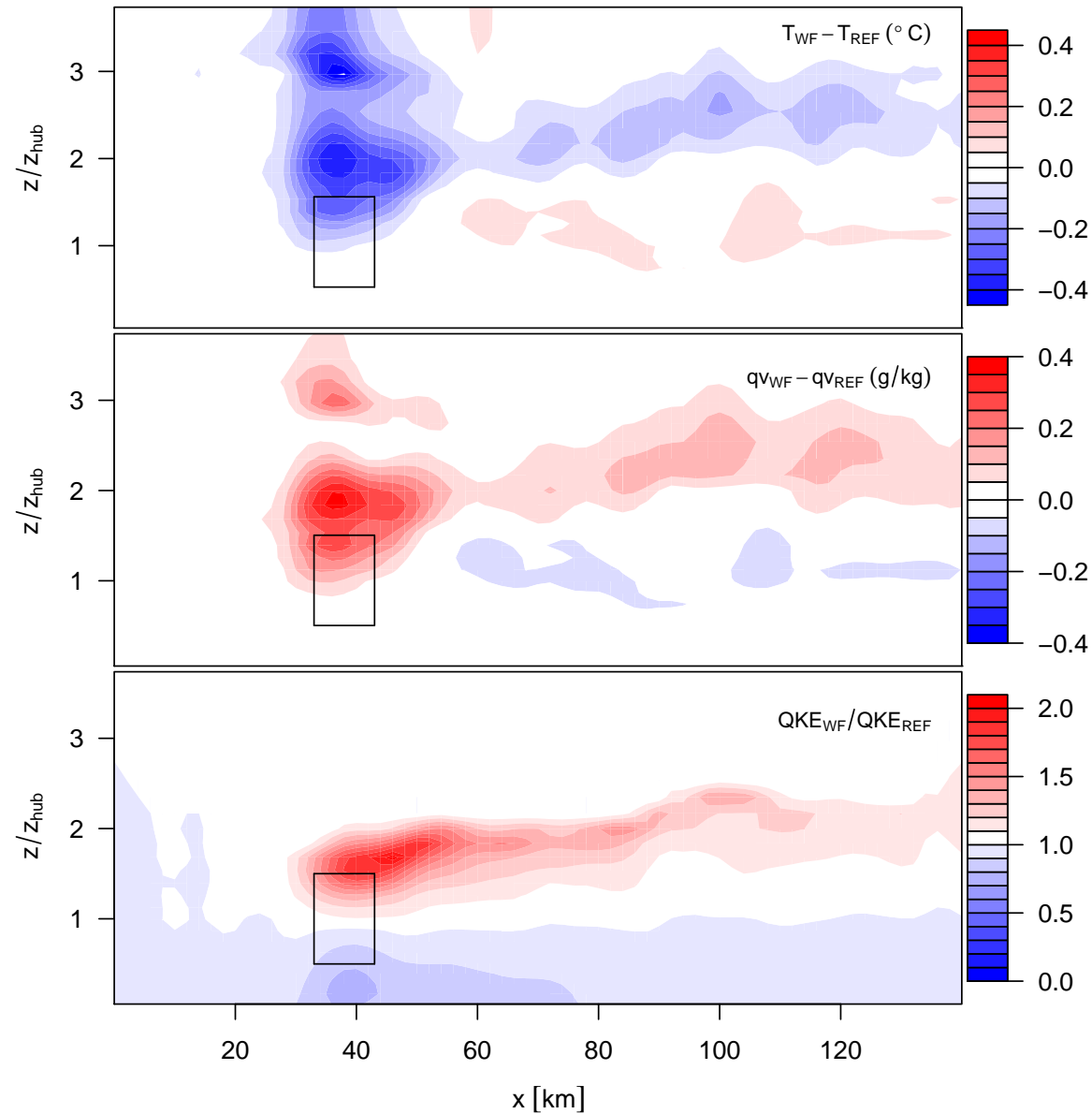
Total extension: 250 km (98%)

# Preliminary Results, January 1<sup>st</sup> 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.