A coupled WRF-PALM numerical simulation with parameterized wave effects

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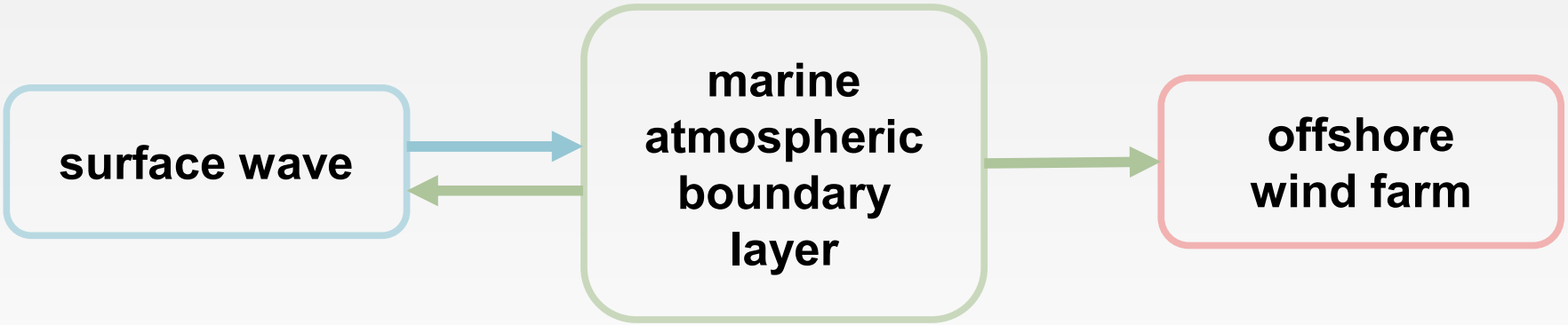
Motivation

- **Motivation**
  - Waves affect mean wind and turbulence.
  - Meso-scale forcing need to be considered to simulate realistic conditions.



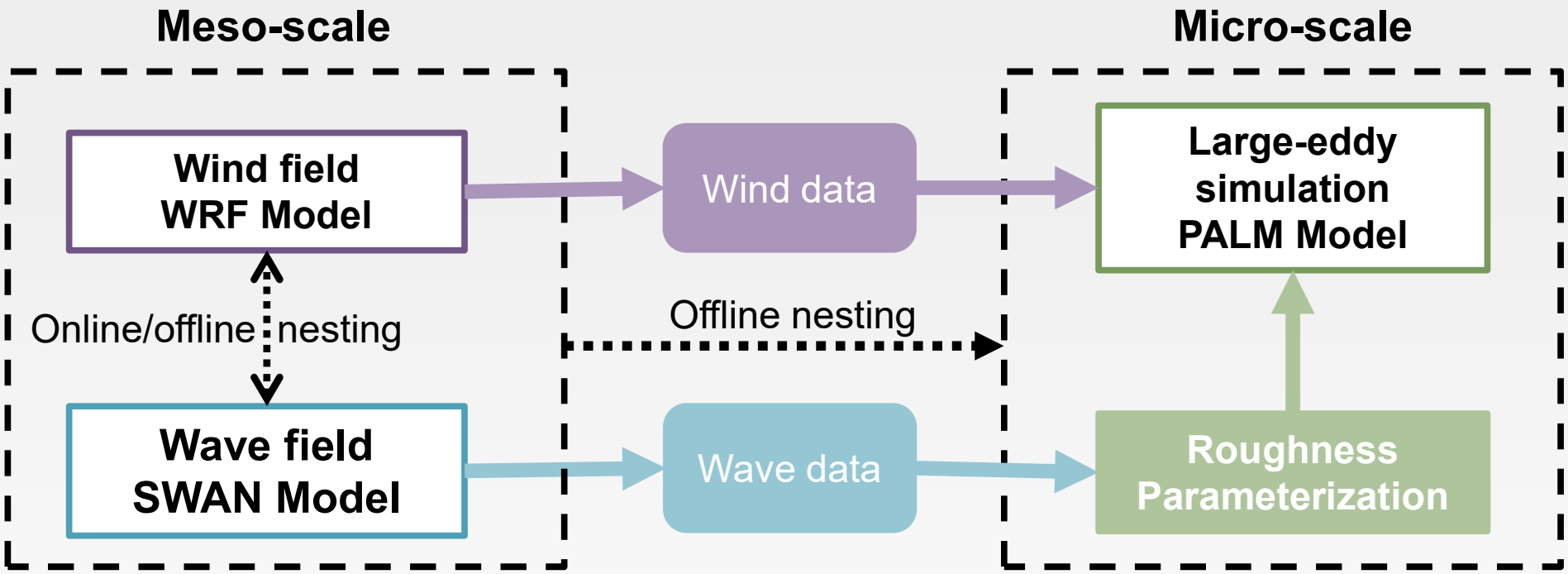
- Height
- Speed
- Direction

- Mean speed
- Turbulence

- Power output
- Structural loads

Modelling

- **Model chain**



WRF: https://ral.ucar.edu/solutions/products/weather-research-and-forecasting-model-wrf

SWAN: https://www.tudelft.nl/citg/over-faculteit/afdelingen/hydraulic-engineering/sections/environmental-fluid-mechanics/research/swan

PALM: https://palm.muk.uni-hannover.de/trac/wiki

Modelling

- **WRF simulation**

Simualtion period

2015-6-25 12:00:00 -

2015-6-27 12:00:00

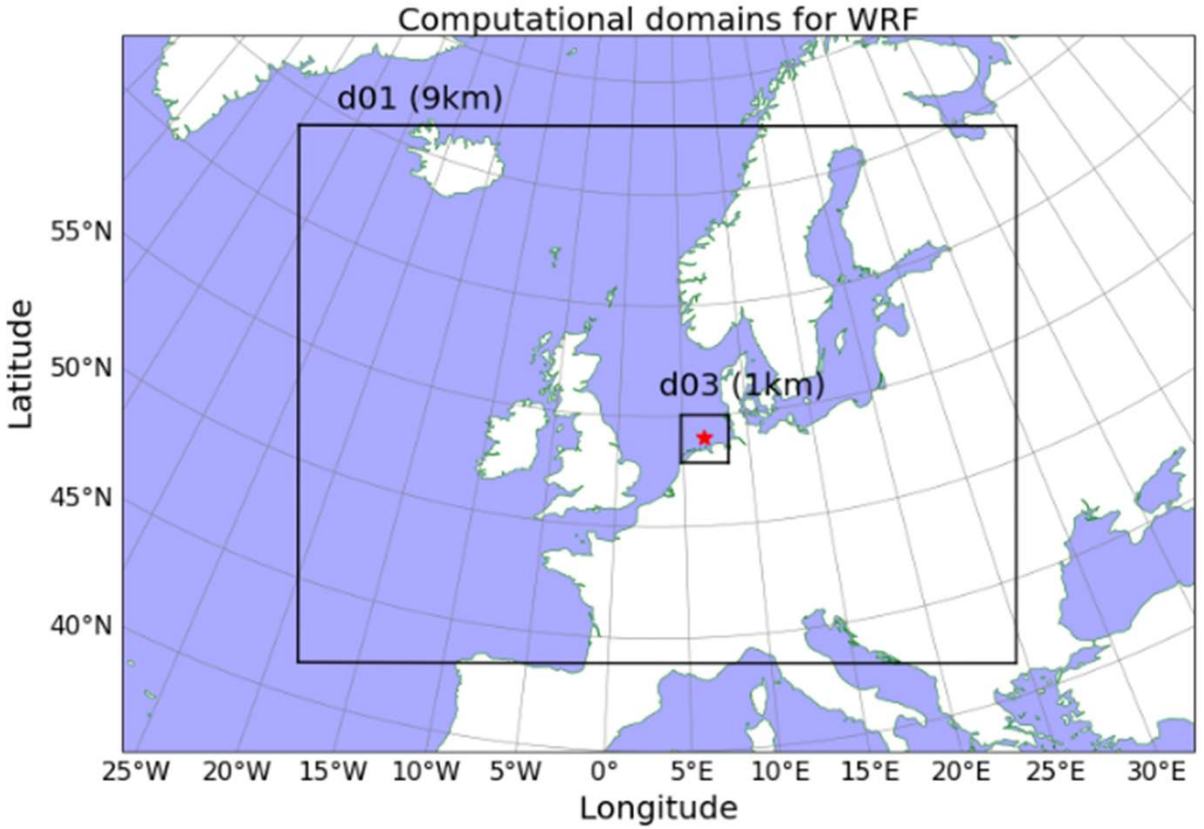
Resolution

d01: 9km, 3h

d03: 1km, 10min

FINO1 position

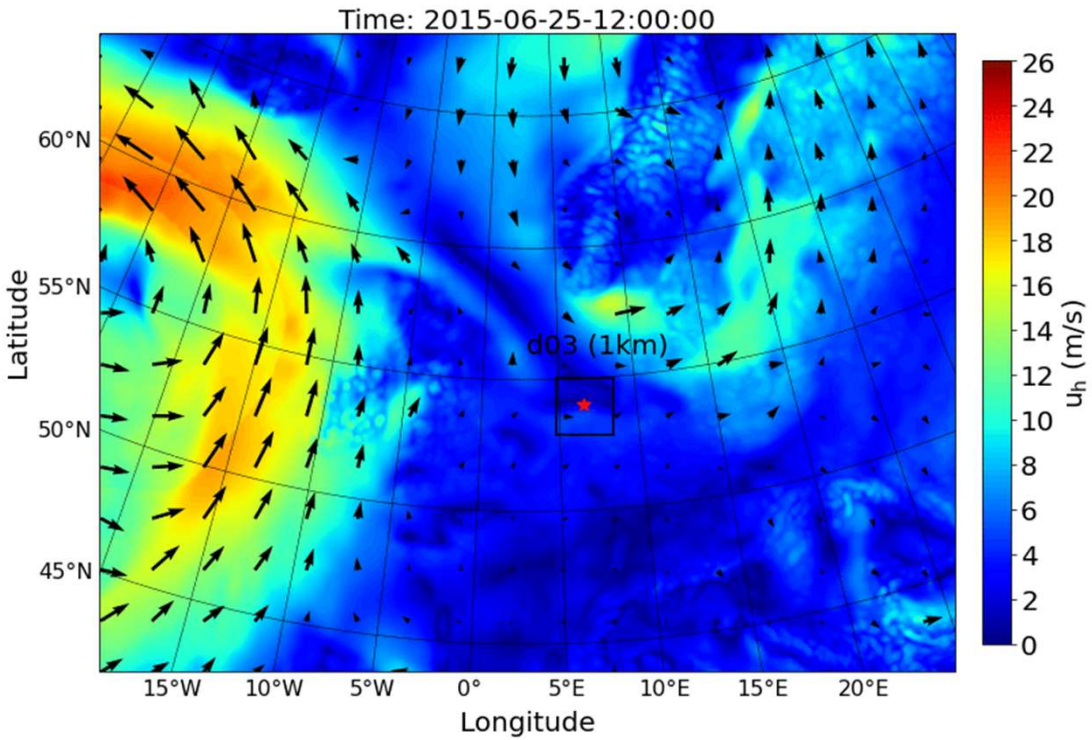
(E6.588, N54.015)

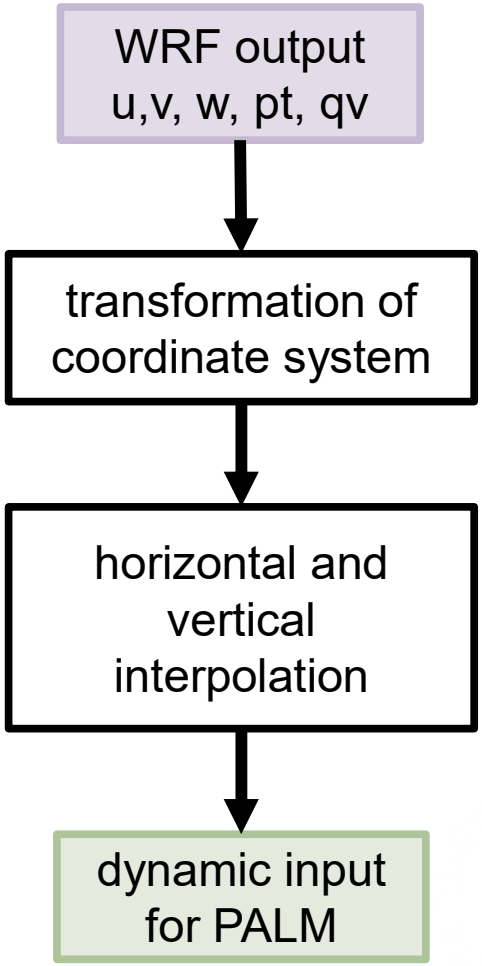


Modelling

- **WRF simulation**

Horizontal wind speed contour at 90m height

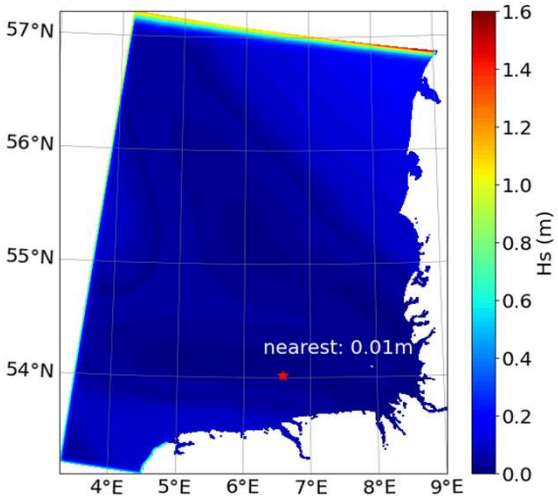




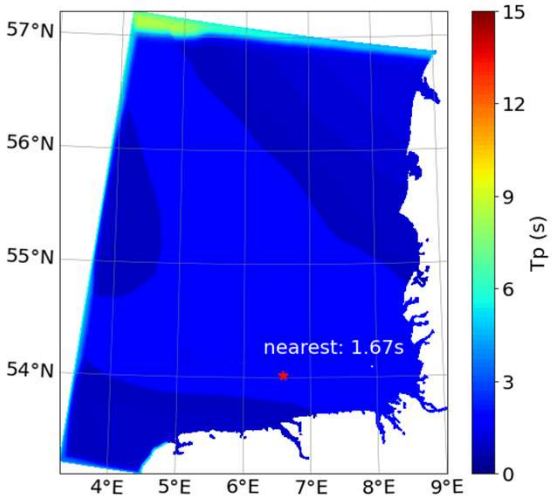
Modelling

- **SWAN simulation**

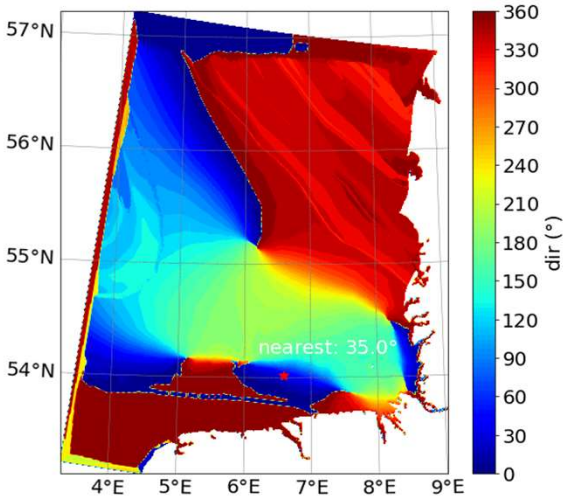
SWAN output Hs, Tp, dr → transformation of coordinate system → horizontal interpolation → Dynamic input for PALM



significant wave height



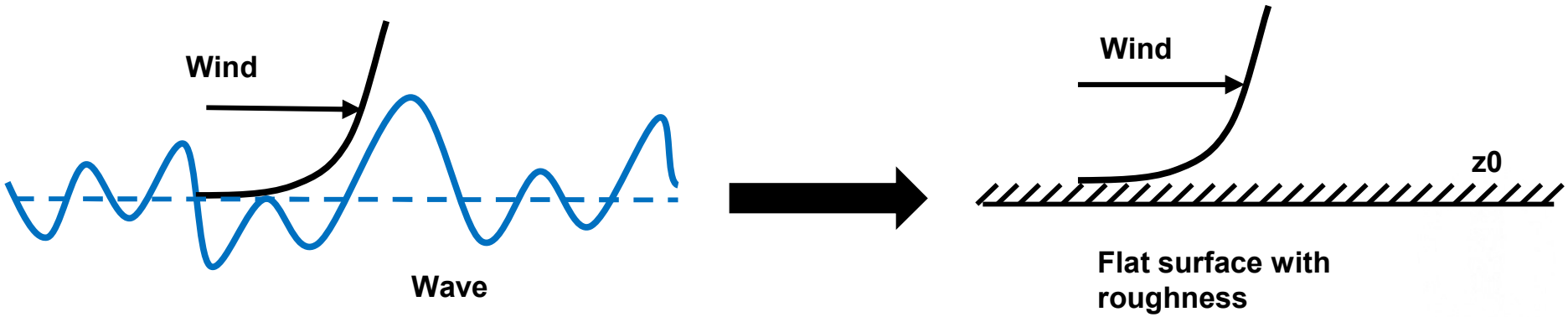
peak wave period



peak wave direction

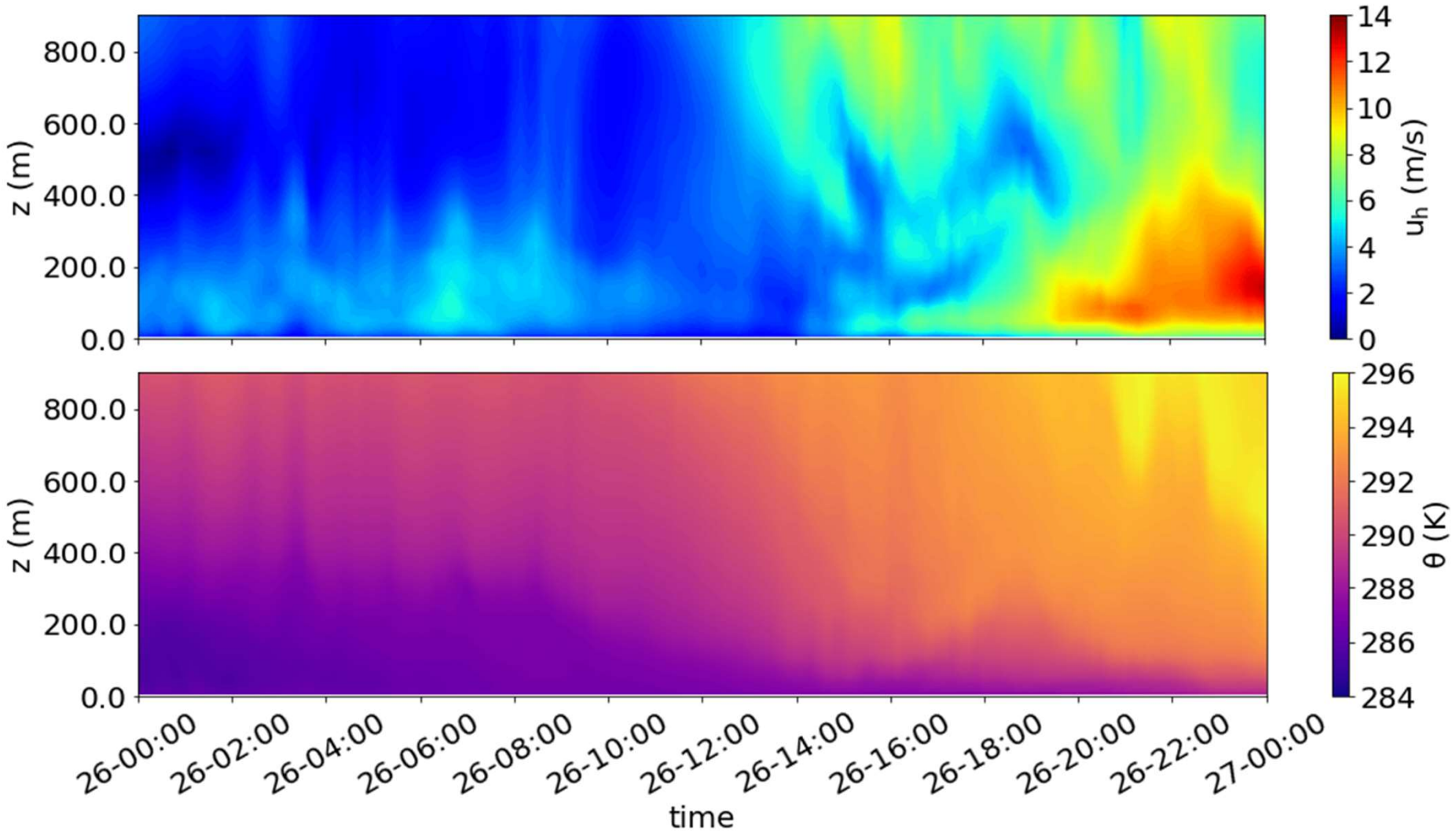
Modelling

- **Parameterization of wave effects**
  - Use of parameterization method based on roughness length to calculate friction.
  - The roughness length z0 decides the momentum exchanged at surface and is defined at every grid point.
  - z0 is calculated based on wave properties (wave height, phase speed and wind-wave misalignment) by an empirical formula.
  - The 2D wave-modified roughness length field is used as a boundary condition.



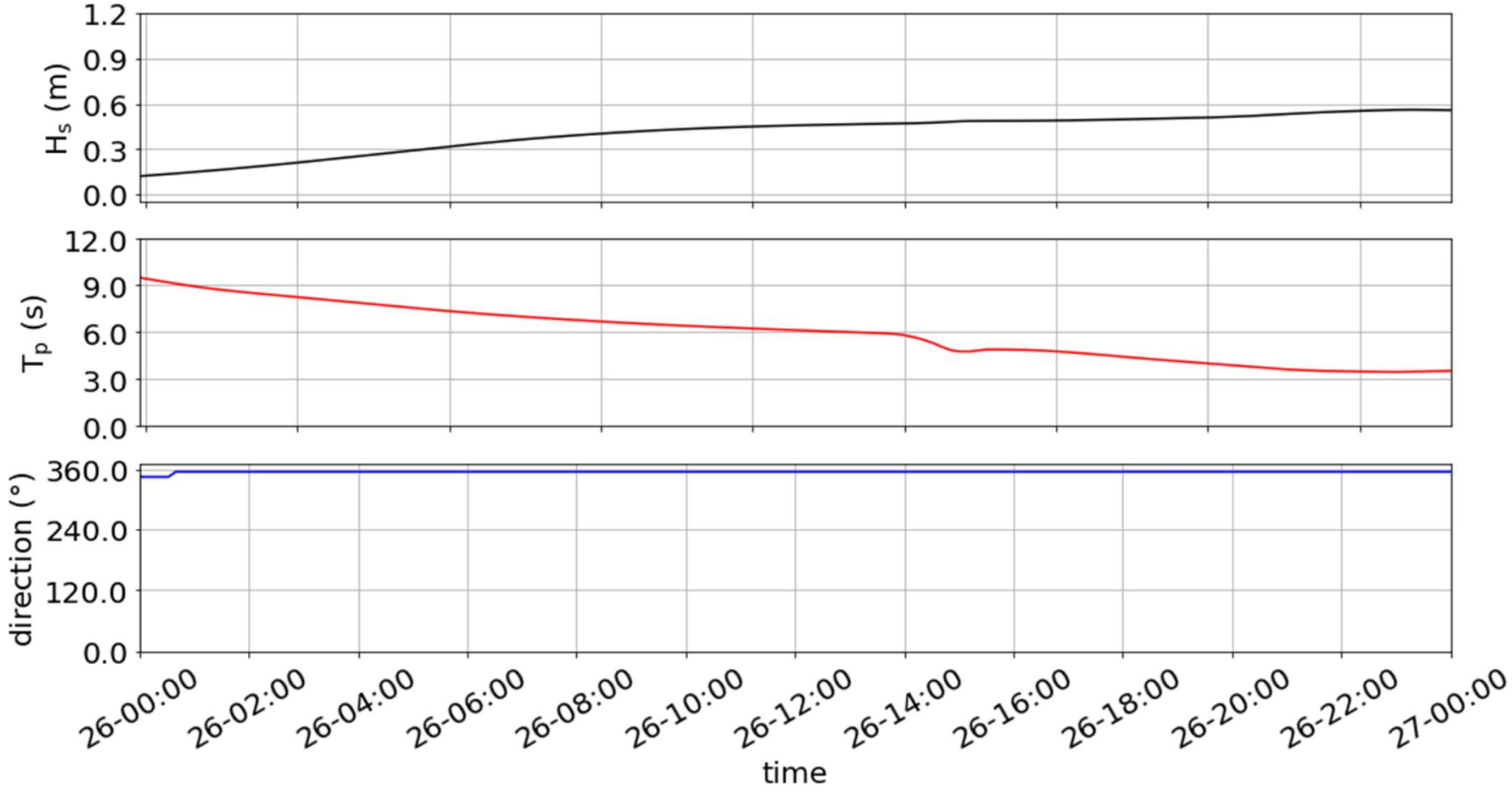
Modelling

- **Wind profile and stability condition**



Modelling

- **Wave properties**



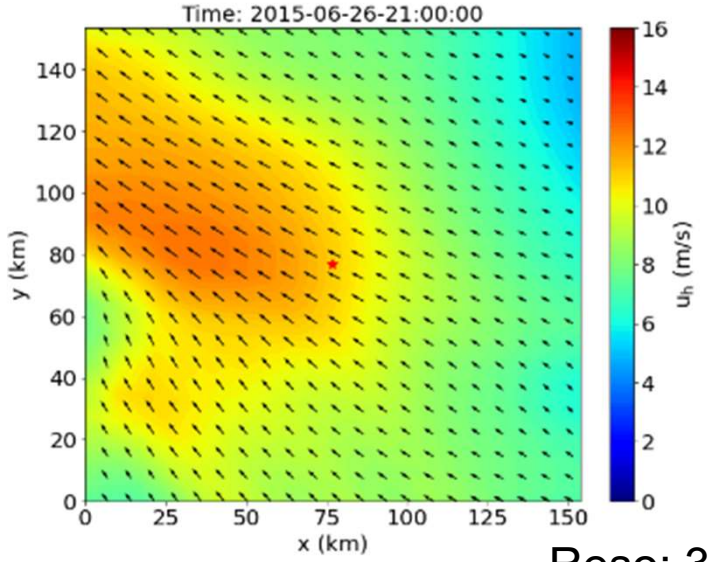
Results

- **Dynamic downscaling**

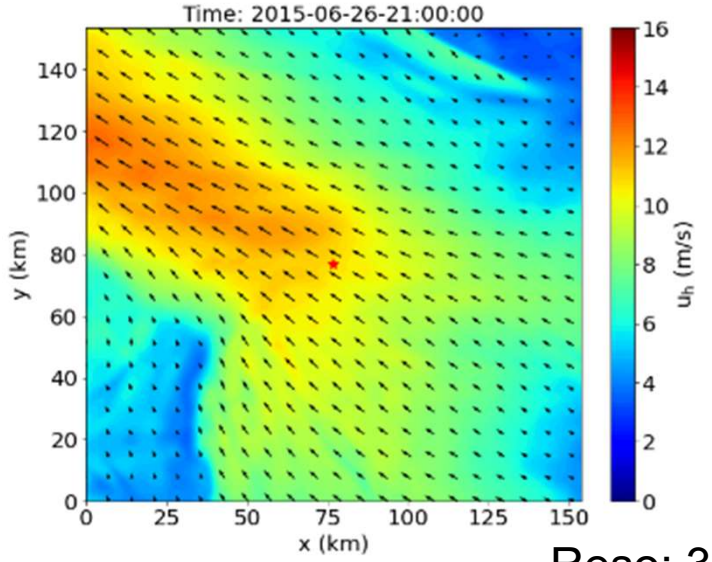
Reso: 9km

Reso: 1km

WRF-d01



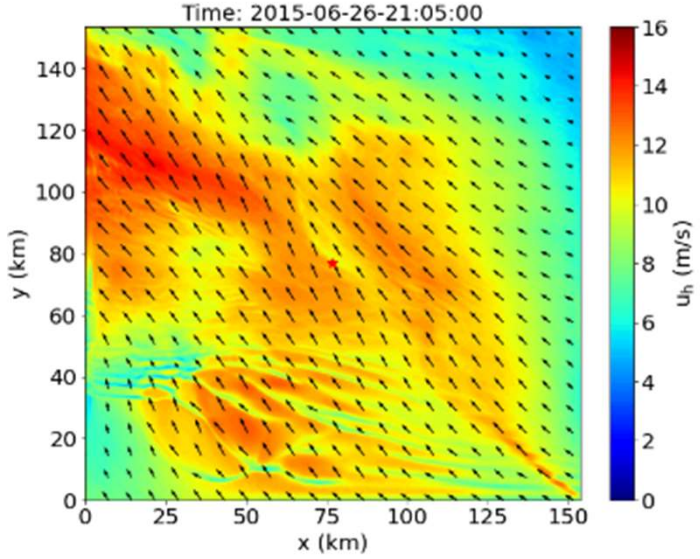
WRF-d03



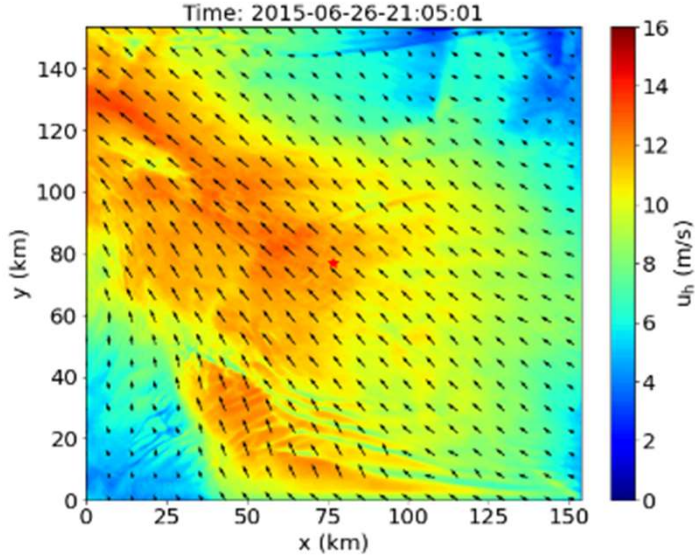
Reso: 300m

Reso: 300m

PALM-d01



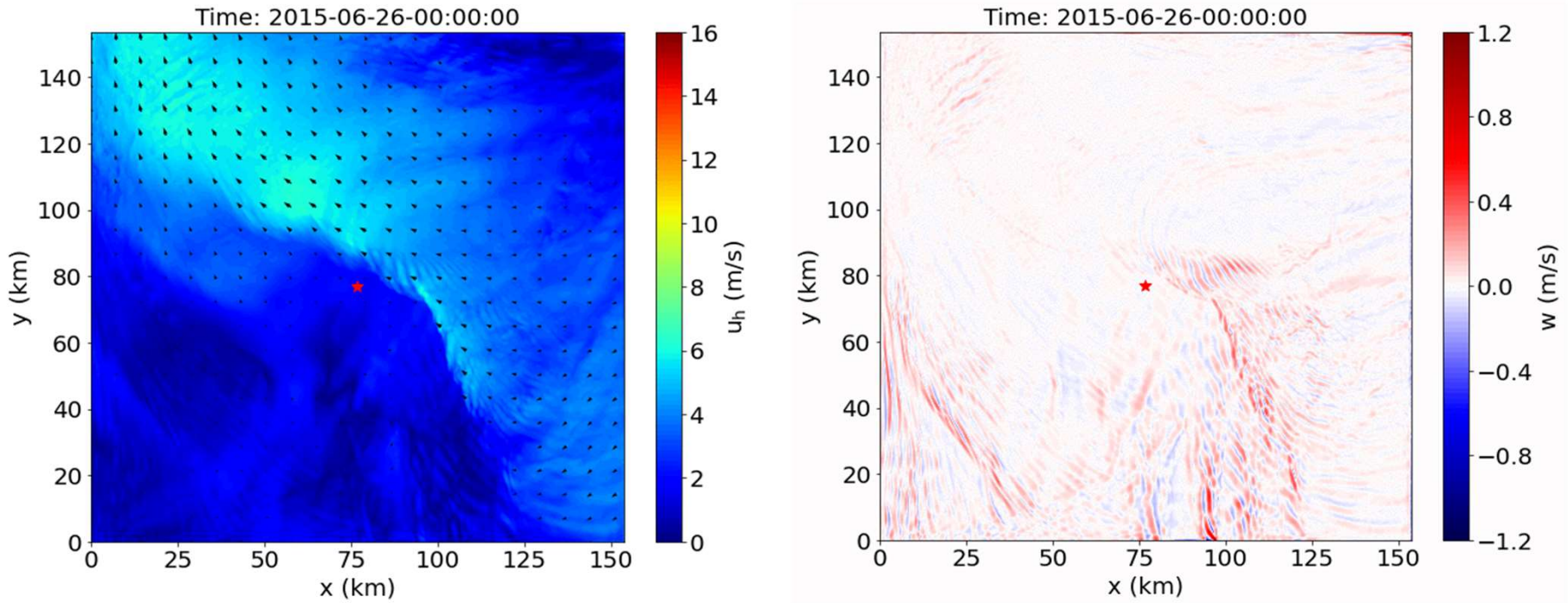
PALM-d03



Horizontal wind contours at 100m height

Results

- **Meso-micro coupled simulation**
  - Driven by realistic wind-wave conditions and covering large space and long time.
  - Reproduce atmospheric motions ranging from cyclones with hundreds of kilometers to turbulent structures of only several meters.

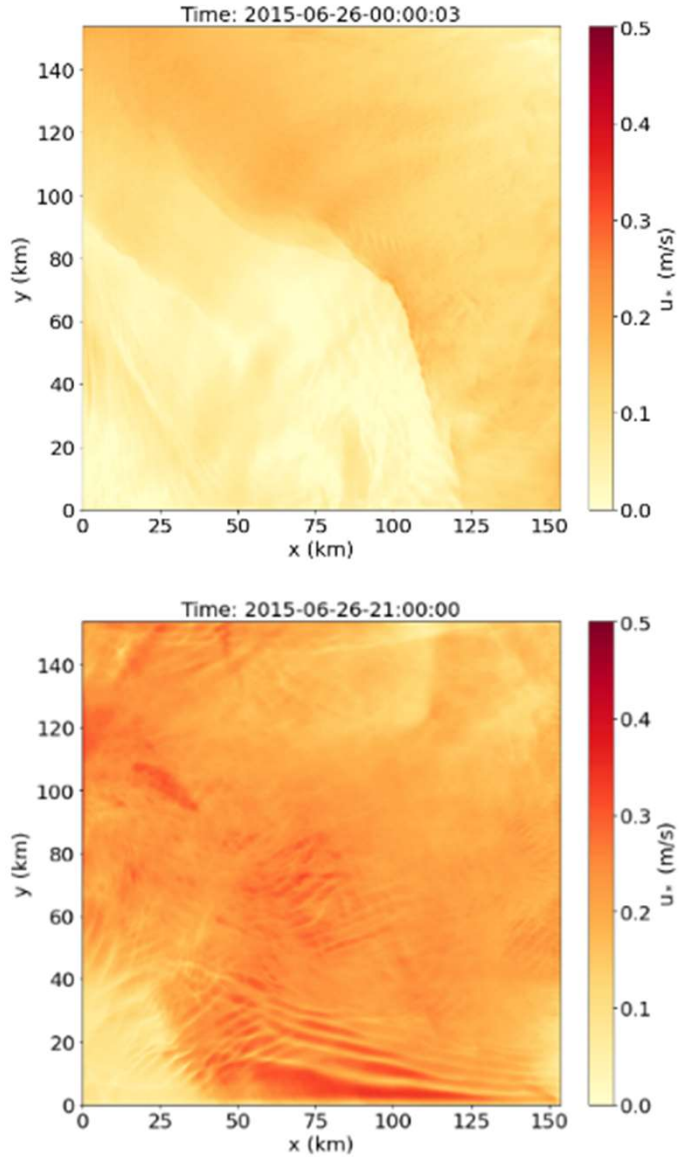


Horizontal and vertical wind contours at 100m height from PALM-d03

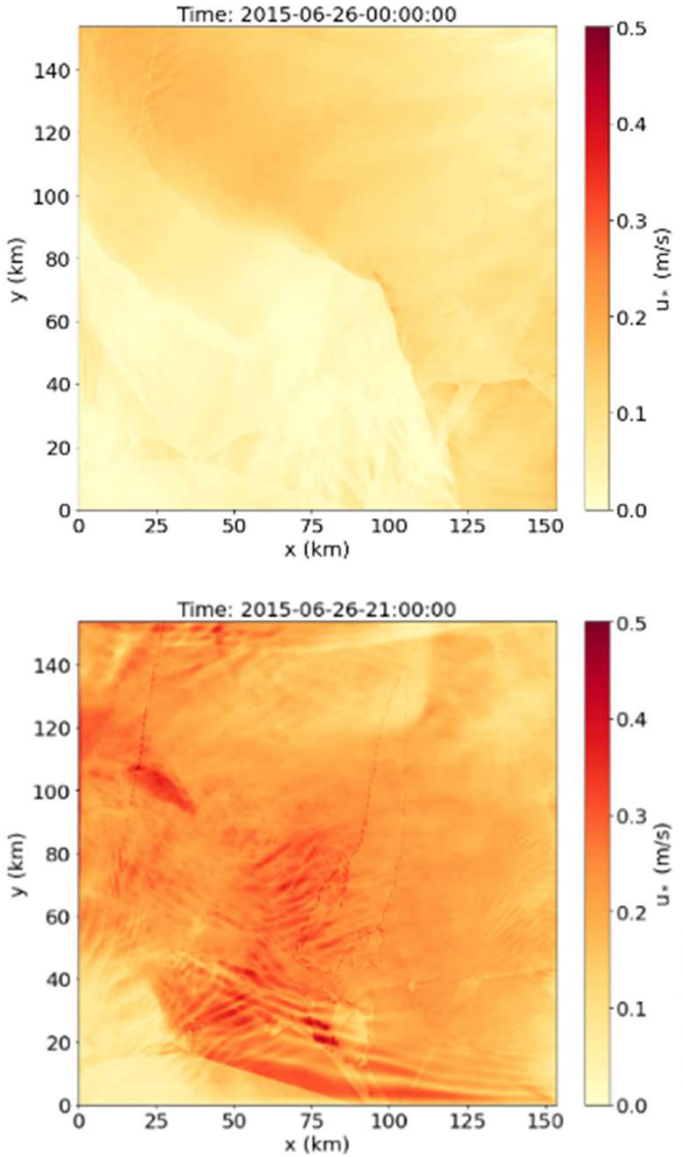
Results

- **Influence of wave effects**

homogeneous roughenss



wave modified roughness



Firction velocity contours from PALM-d03 and PALM-d03_w

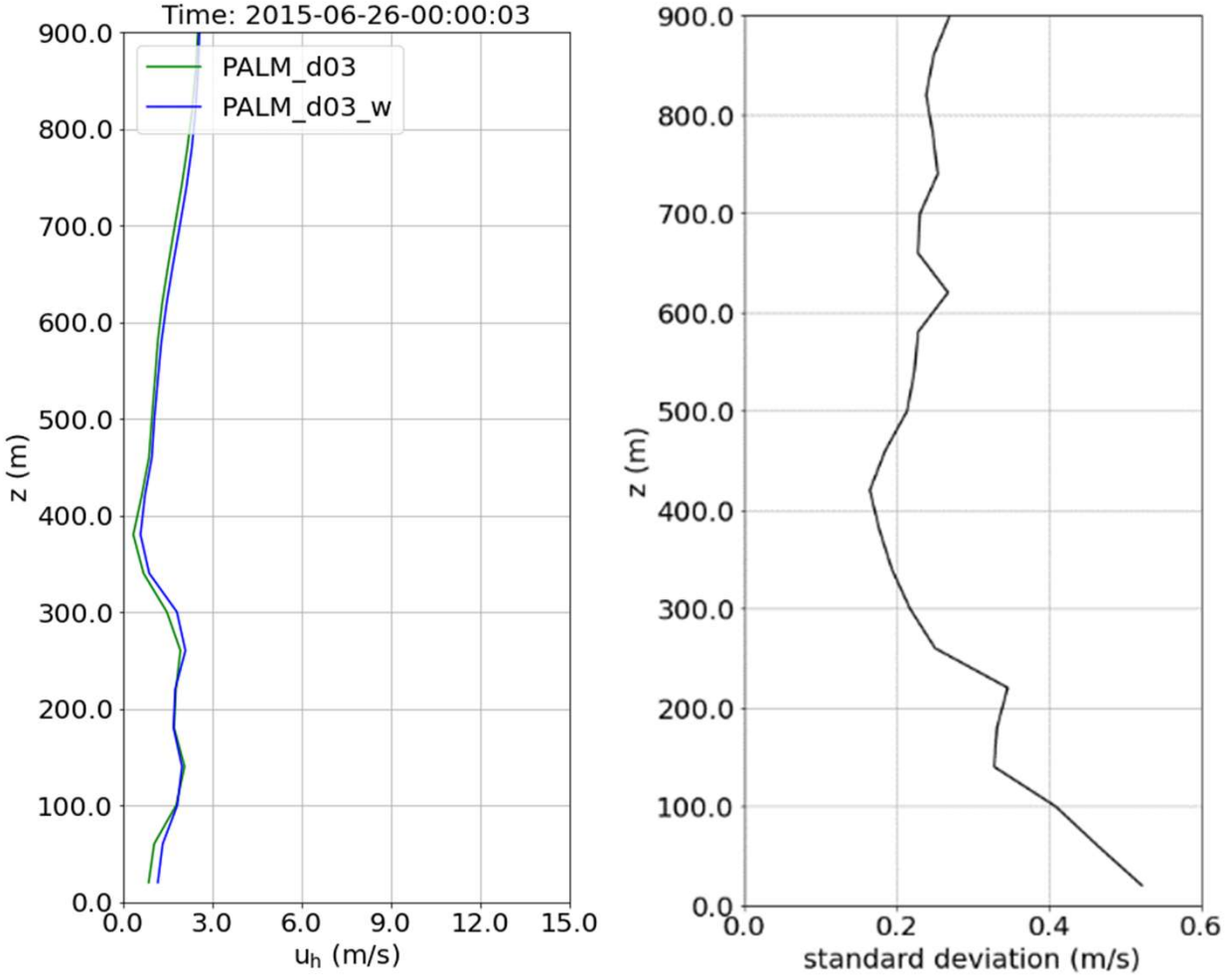
Results

- **Influence of wave effects**

  - The waves affect the wind speed in the whole boundary layer, especially near the sea surface.

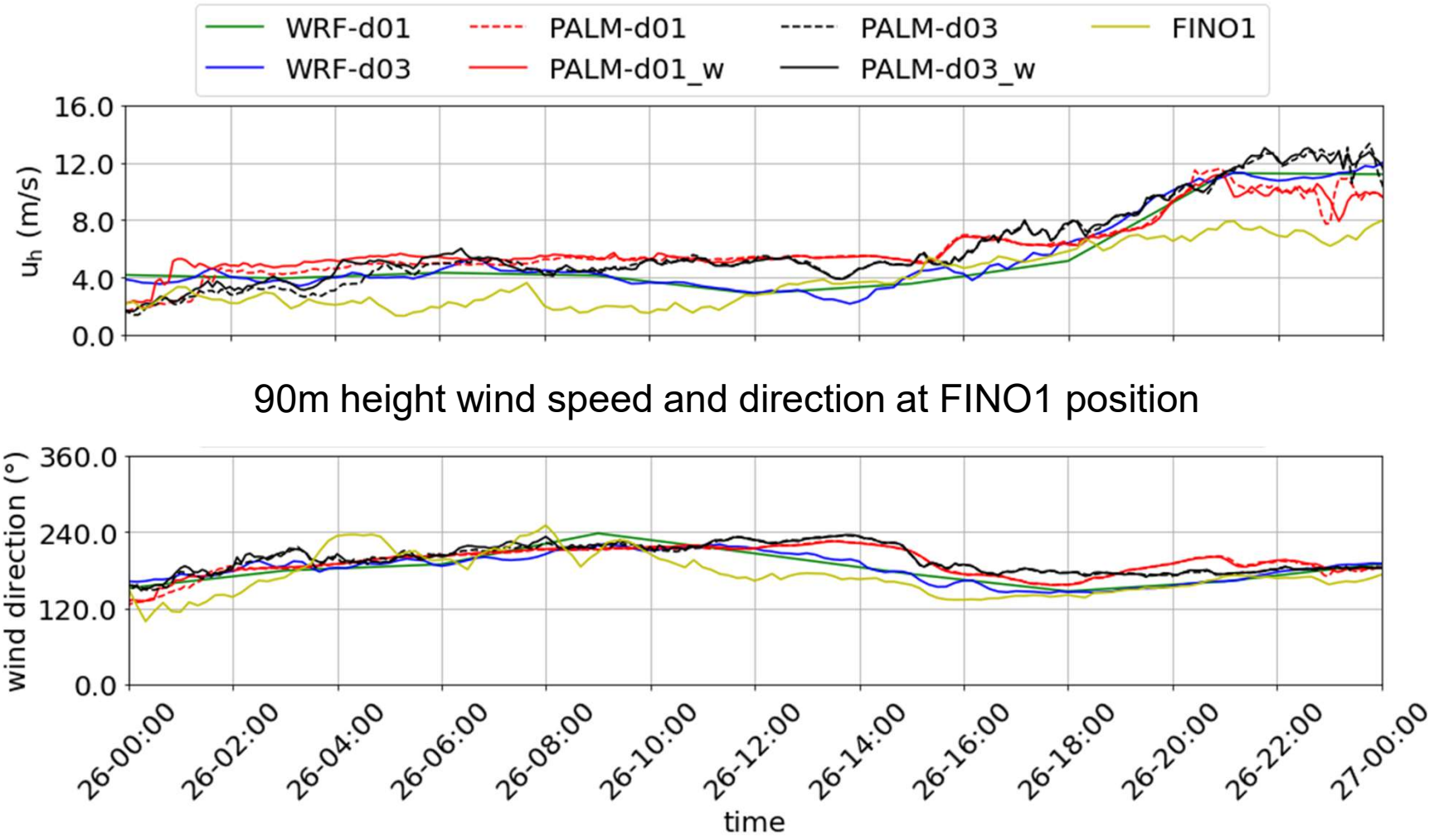
  - The wind speed variation caused by the waves is about 0.2 ~ 0.5m/s in the present case.

wind speed profile evolution and standard deviation



Results

- **Comparison with FINO1 data**



90m height wind speed and direction at FINO1 position

Conclusions

- **Present work**
  - A WRF-SWAN-PALM model chain is built and realizes the simulation driven by realistic environmental conditions including meso-scale forcing and wave effects.
  - The wind variation caused by the waves are mainly near the surface but could strongly affect the power output of a wind farm.
- **Limitations**
  - The empirical formula for wave effect parameterization may depends on the specific area of concern.
  - Need more observational data are required to check the performance of the current simulation model.
- **Future work**
  - Use WRF and SWAN results with higher mesh resolution to drive micro-scale simulations and compare with Lidar and SCADA data.