Gust formation during a windstorm in the light of Doppler lidar observations and large-eddy simulations

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Motivation and strategy

Extratropical cyclones...

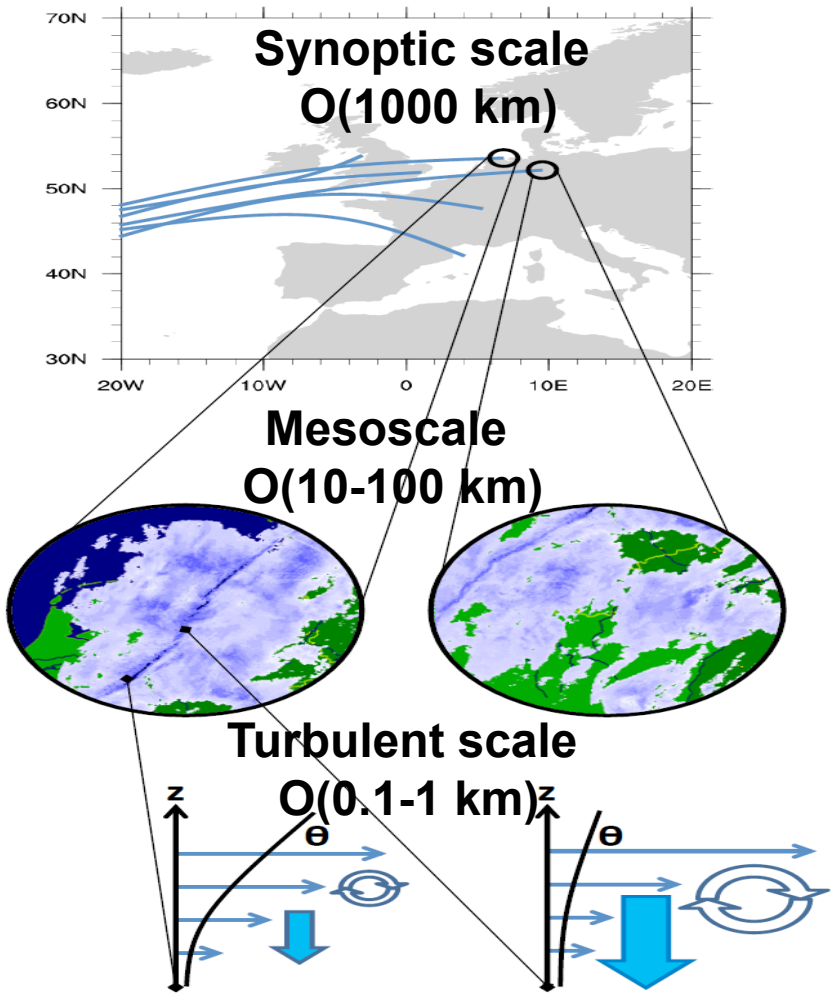
- natural hazards in Europe
- due to **peak winds = gusts**

Predictability: multi-scale problem

1. Synoptic scale
Global ensemble reforecasts
(Pantillon et al. 2017, NHESS)

2. Mesoscale
Convection-permitting ensemble
+ statistical post-processing
(Pantillon et al. 2018, QJRMS)

3. Turbulent scale
Doppler lidar observations
+ large-eddy simulations



Wind and Storms Experiment (WASTEX)

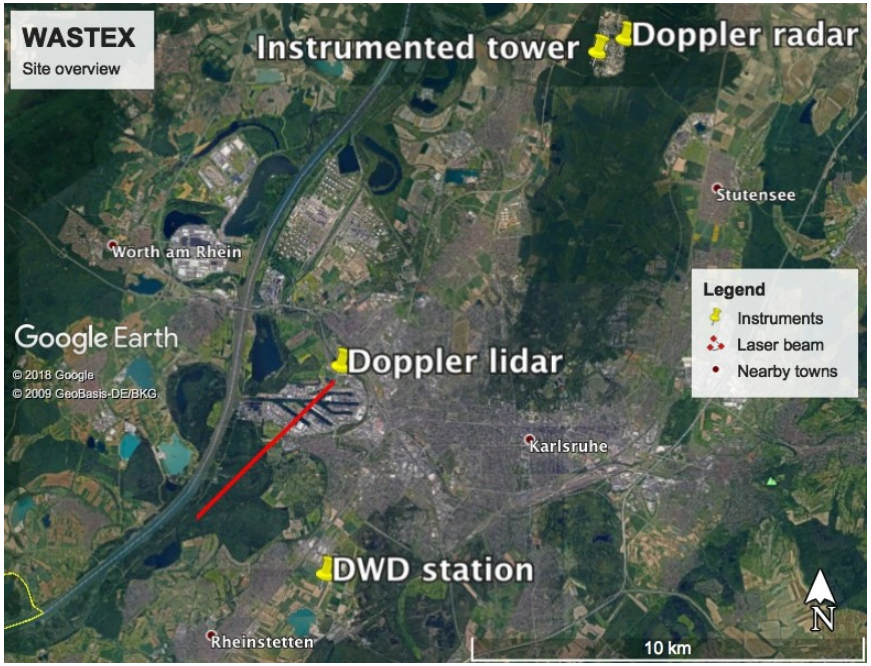
Field campaign in winter 2016-17
to observe the formation of gusts
during the passage of windstorms

WindTracer scanning **Doppler lidar**

- Radial wind: dx~70m, range<8km
- Vertical scans 0-15° elevation /10s

+ KIT 200 m **instrumented tower**
+ KIT C-Band **Doppler radar**
+ DWD **surface station**

→ *6 IOPs for 12 extratropical cyclones*



Overview of WASTEX site

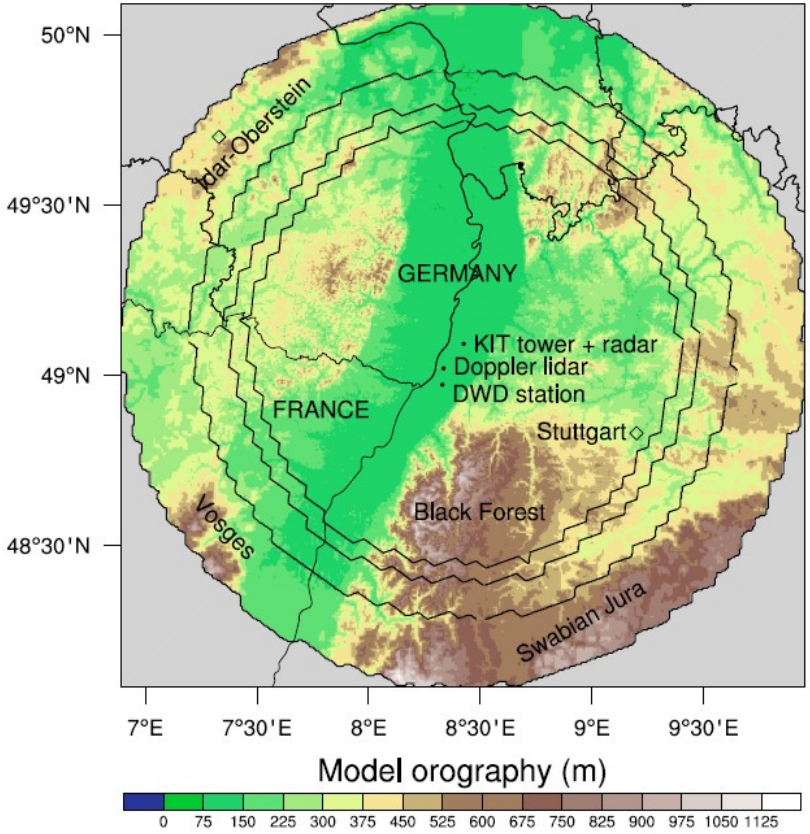
ICON large-eddy simulations

Setup based on HD(CP)^2 runs
(Heinze et al. 2017; Marke et al. 2018)

- 4 nested circular domains
- Grid spacing 623/311/156/78 m
- 150 vertical levels
- Initial/lateral boundary conditions 2.8 km COSMO-DE analysis

→ Limited output due to data size!

+ 20-member 2.8 km COSMO-DE operational ensemble forecast
(Gebhardt et al. 2008; Peralta et al. 2012)



Domain of ICON-LES simulations

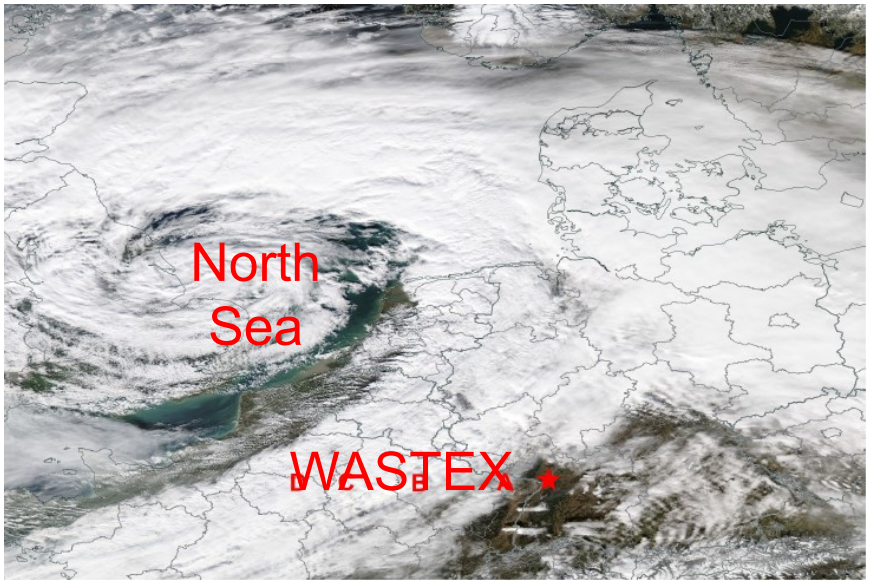
Case study during WASTEX

Cyclone “Thomas” on 23 Feb 2017

- Part of a storm series
- First hits Ireland and UK (“Doris”)
- Cold front crosses Germany

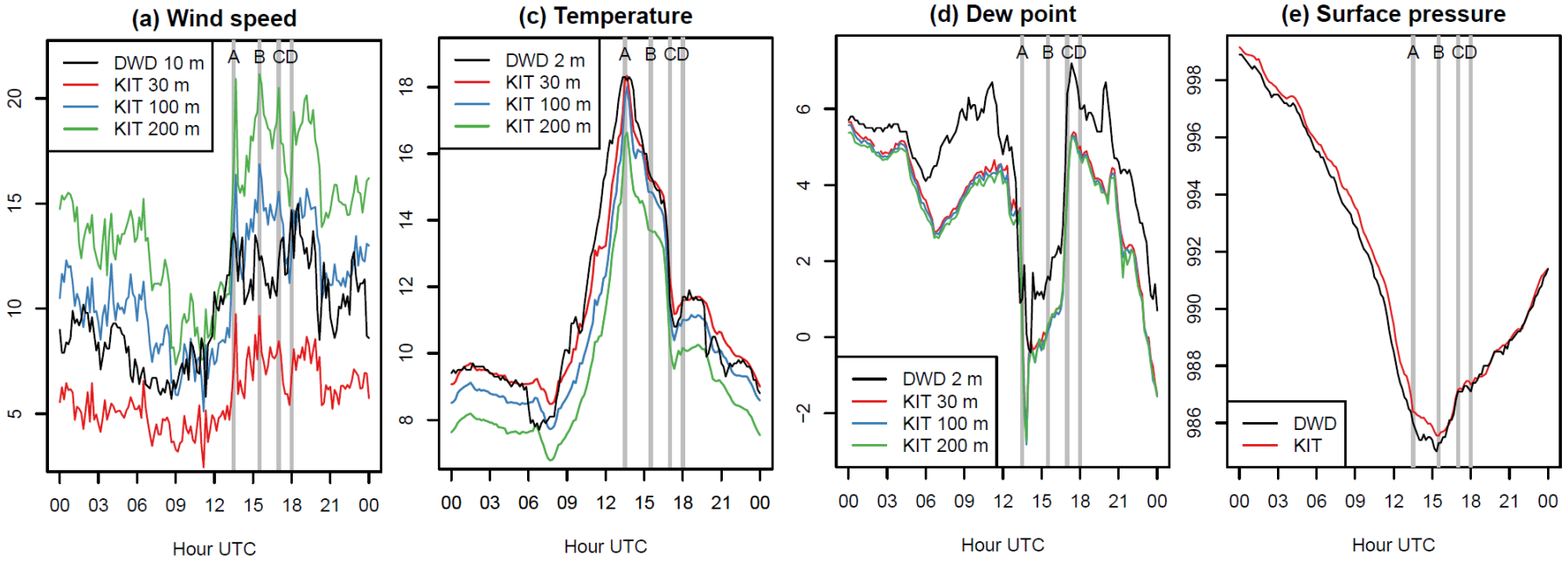
→ **2nd most severe windstorm** over Germany in 2016-17

→ **3rd most intense windstorm** locally during WASTEX



MODIS image at 1225 UTC 23 Feb 2017

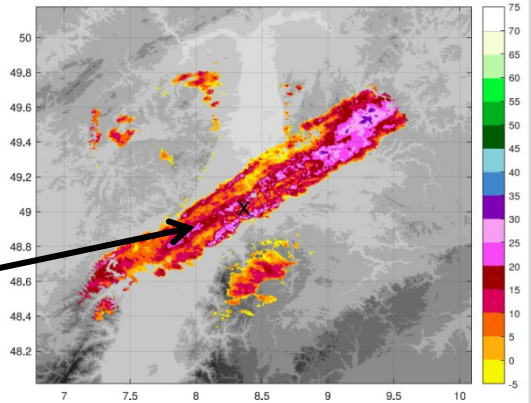
Observations KIT tower + DWD station



Chronology of wind peaks

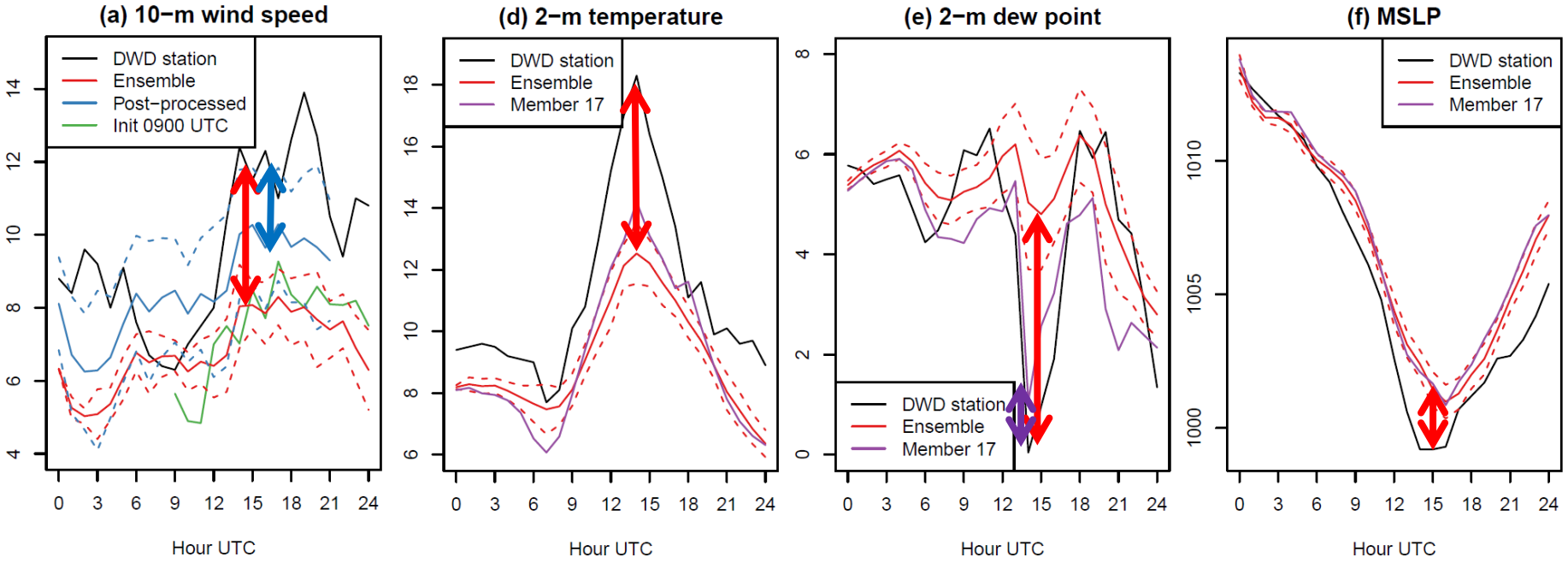
A. peak in temperature + drop in dew point = ???
B. pressure minimum = passage of cold front
C. drop in temperature + jump in dew point = rain
D. (and more) = isolated showers

→ *What produces the first wind peak?*



Radar at 1645 UTC (dBZ)

Representation in operational forecasts

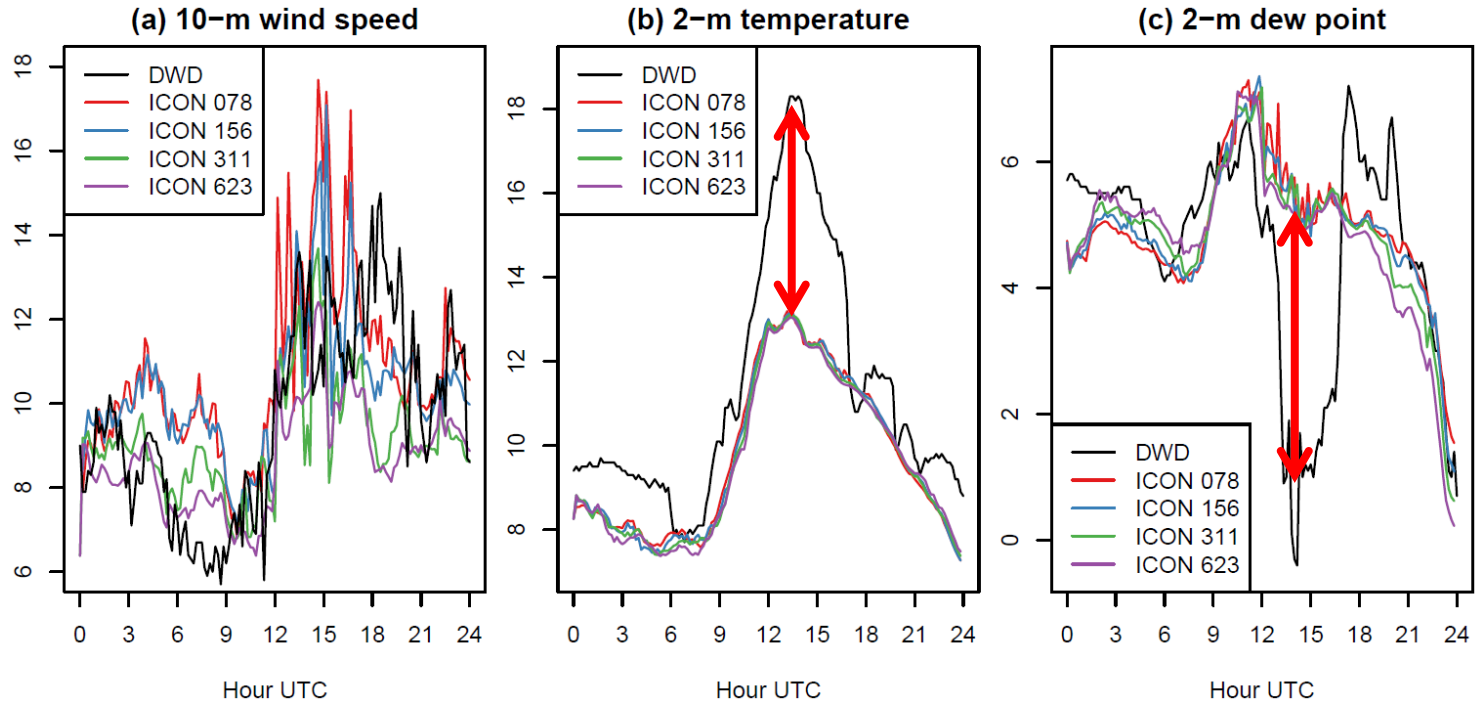


COSMO-DE ensemble forecast: init. 00 UTC 23 Feb 2017, dx = 2.8 km

- wind: poor evolution + underestimation (reduced with **post-processing**)
  Thanks Sebastian Lerch!
- temperature: large underestimation
- dew point: sudden drop largely missed (except **ensemble member 17**)
- pressure: cyclone slightly too weak

→ *mesoscale dynamics not well predicted altogether*

Representation in large-eddy simulations

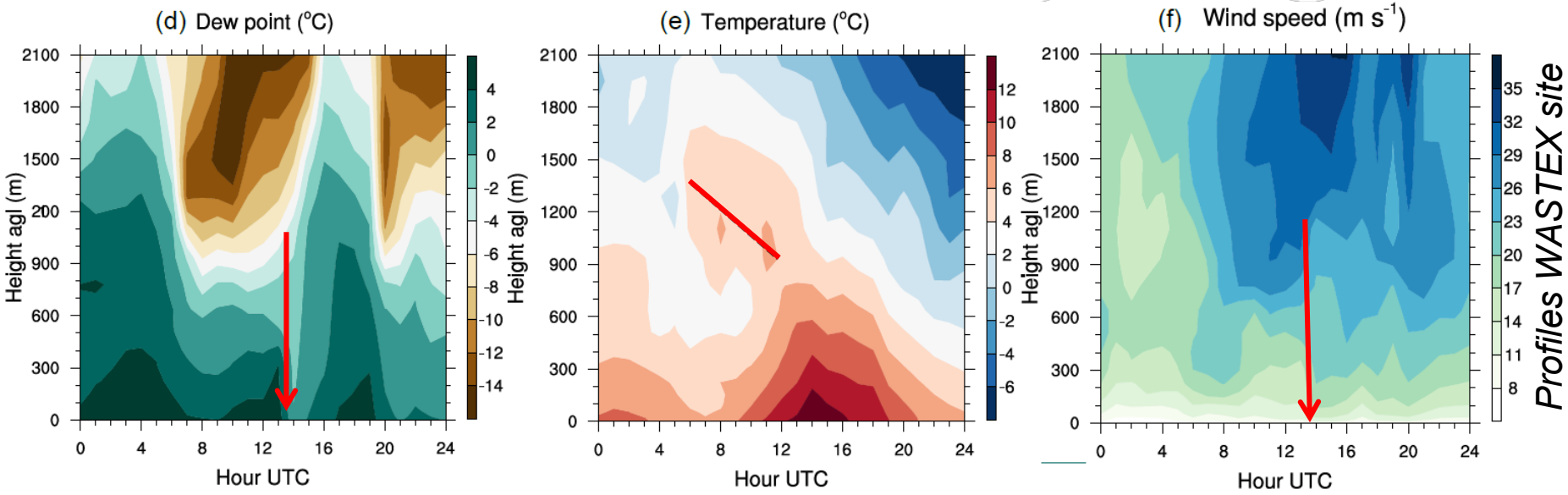


ICON simulations: init. 00 UTC 23 Feb 2017, dx = 623/311/156/78 m

- wind: better evolution and intensity than COSMO-DE forecasts ☺
- temperature and dew point: just as good as COSMO-DE forecasts 😐

→ *large-eddy simulations inherit limitations from parent model*

What produces the first wind peak?

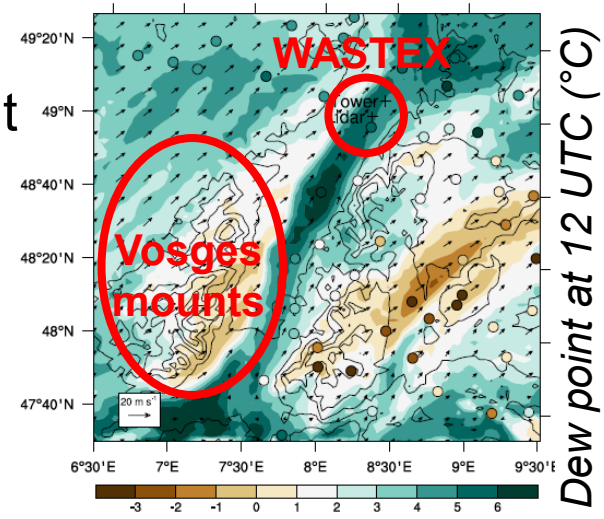


Insights from successful ensemble member 17

- Downward mixing of dry layer = drop in dew point
- Temperature inversion = prevents earlier mixing
- Downward mixing of low-level jet = 1st wind peak

→ *reminiscent of the breakthrough of foehn*

→ *combination orography + BL convection + shear*



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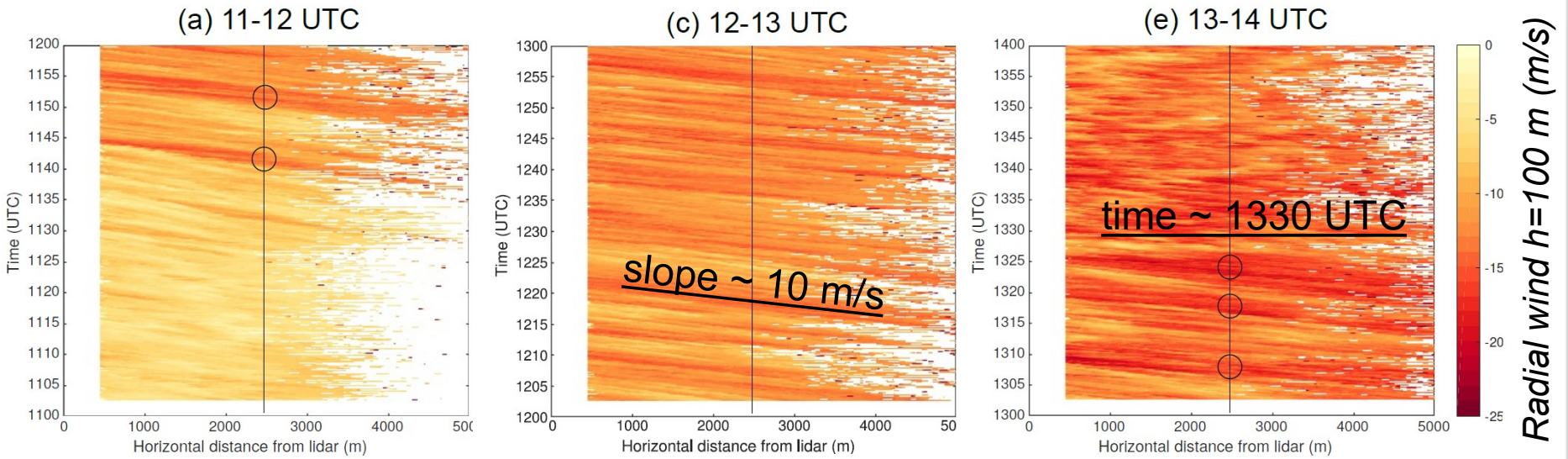
Florian Pantillon et al.

Boundary-layer winds: Doppler lidar

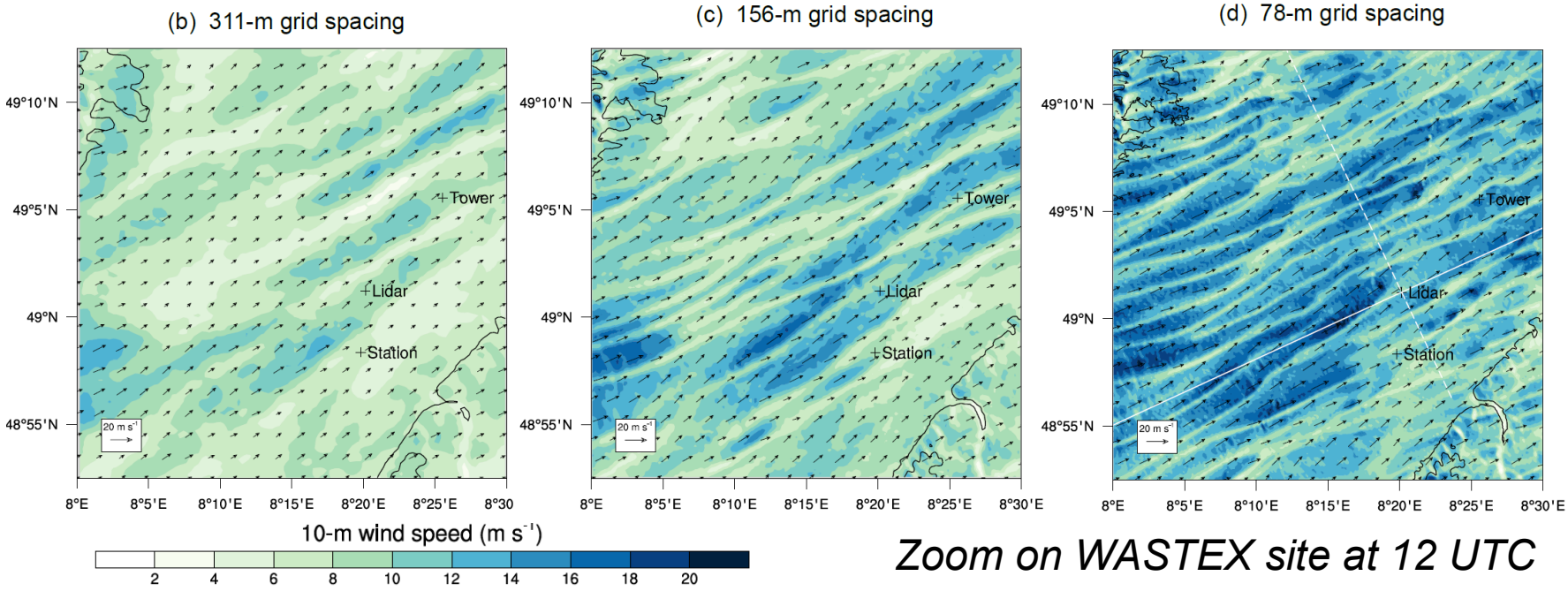


Focus on storm onset 11-14 UTC

- Regular stripes = coherent structures advected by background flow
- Disappear at time of 1st wind peak (downward mixing of low-level jet)
- 2-h period of convective instability and moderate wind shear (Ri<0)

→ *Suggests boundary-layer rolls*

Boundary-layer winds: ICON



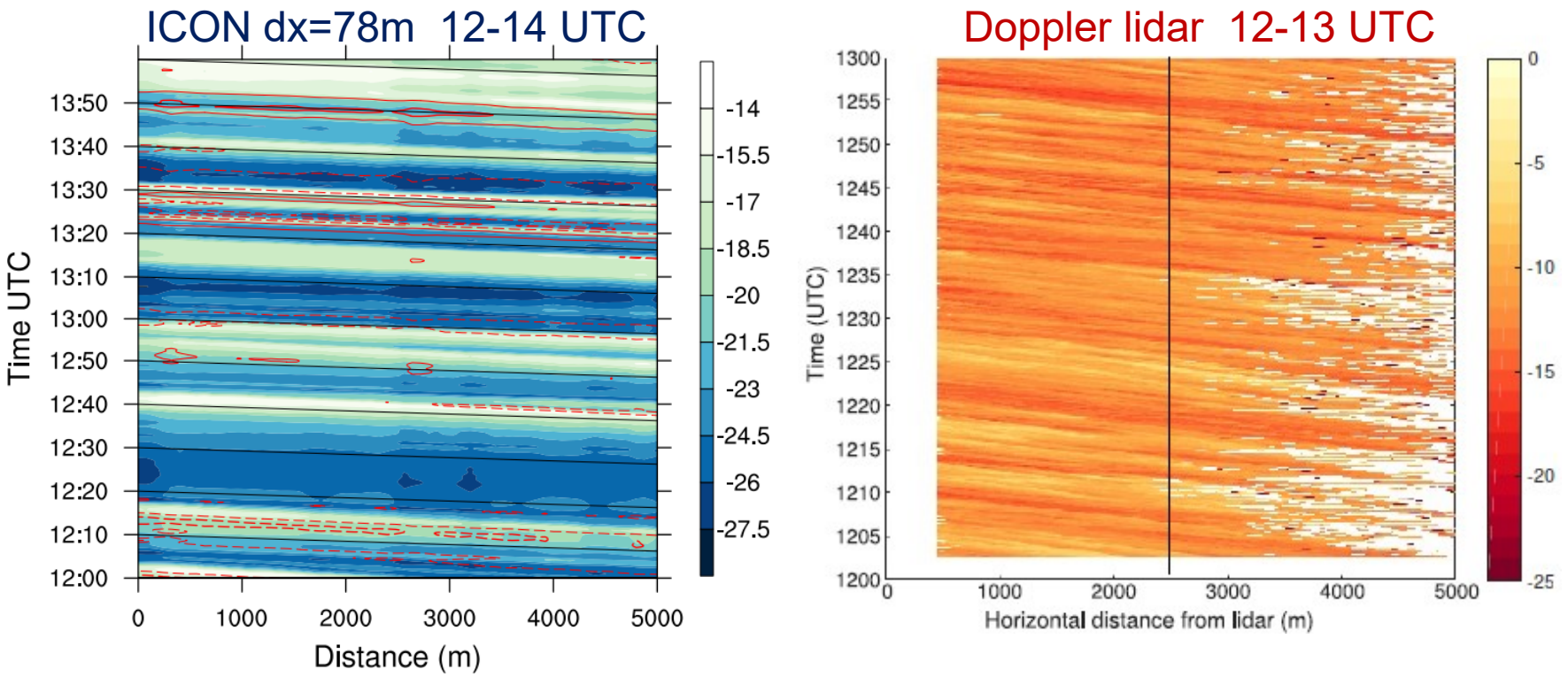
Zoom on WASTEX site at 12 UTC

Arrival of elongated structures over the WASTEX site at 12 UTC

- Wind intensity increases with resolution (barely seen in 623-m run)
- Structure size ~scales with grid spacing (no convergence with 78 m)

→ *Also suggests boundary-layer rolls*

Model vs. obs: “virtual Doppler lidar”



Hovmöller plots of radial wind speed at 100 m agl (m/s)

- Modelled structures qualitatively explain observed stripes but too coarse
- Power spectra (not shown): dx~10 m required to fully resolve structures

Conclusions

Gusts during windstorms are challenging to measure and to model

= motivation for **Doppler lidar observations** + **large-eddy simulations**

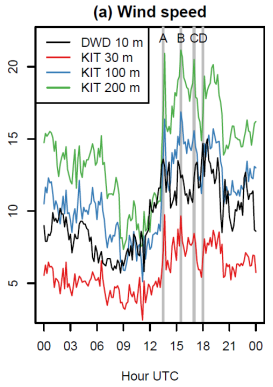
Four wind peaks during storm “Thomas” on 23 Feb 2017

- 1st ~ downward mixing of low-level jet and dry layer

→ *Largely missed by convection-permitting forecasts…*

- 2nd-4th ~ cold front, precipitation line, showers

→ *Large-eddy simulations improve wind intensity!*



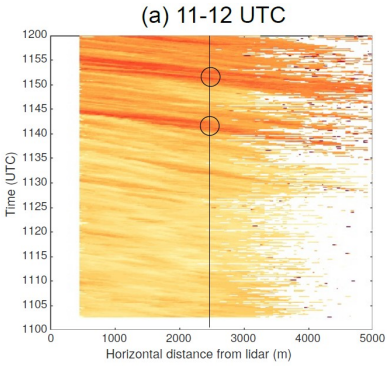
Coherent wind structures found during storm onset

- Long-lasting structures in Doppler lidar observations

→ *Allow anticipating strong gusts minutes in advance!*

- Elongated structures in large-eddy simulations

→ *Not captured by gust parameterizations…*



Pantillon et al. 2019, MWR (Early Online Release)