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Idealised simulations of open cellular convection and horizontal wind fluctuations over the North Sea

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The Weather Research and Forecasting (WRF) model was used to study the skill, sensitivity and limitations of a mesoscale model in predicting wind speed fluctuations on time scales of tens of minutes to hours. The work was motivated by the severely variable wind conditions that are often observed at the Horns Rev wind farm in the Danish North Sea.

From a wind energy perspective, such fluctuations present challenges for both electricity transmission system operators, who must ensure reliability of the electricity grid, and wind farm operators, who must avoid financial losses associated with sudden and unexpected dips in wind power. Good forecasts of the onset of severely variable wind conditions are one way of increasing preparedness for such events.

WRF was first used to model an episode of intense wind fluctuations that was observed at an offshore meteorological mast near the Horns Rev wind farm on 23-24th October 2002. WRF was able to reproduce large fluctuations in horizontal wind speed with a similar frequency to that of the observed wind fluctuations.

Building on this result, WRF was then set up in an idealised framework as a simple simulation of wind blowing over water. The initialisation of the model was based on the actual conditions during a severely variable wind event over the North Sea. The benefit of running the model in an idealised mode was that individual aspects of model performance could be clearly isolated.

During the first few hours of simulation, WRF produced unrealistic fluctuations in wind speed that were dominated by the horizontal grid spacing of the model. After 4 to 5 hours, realistic open cellular convection developed, with large fluctuations in horizontal wind speed similar to those observed in the real case. The structure of the convective cells had a spatial scale of about 30 km, which corresponded closely to cloud patterns seen in a visual satellite picture from the same event. The scale of the cells was largely invariant to changes in the horizontal grid spacing, suggesting that the wind speed fluctuations were driven by realistic physics. Running the model at a horizontal resolution of 1 km was sufficient to capture the main spatial structure of the cells. Having ascertained that the idealised model could simulate realistic physical patterns in atmospheric convection, it was then used to explore the sensitivity of the modelled convection patterns to the initial conditions, including sea surface temperature and the shape of the initial temperature profile.

The simulations in this study were idealised and cannot directly represent the real atmosphere. However, they have implications both for real modelling and for understanding the real atmosphere. They demonstrate that a mesoscale model is capable of realistically capturing fluctuations in horizontal wind speed on time scales as short as about an hour. The sensitivity of the open cellular convection to the shape of the temperature profile indicates that to properly forecast the frequency and amplitude of fluctuations in horizontal wind speed, the temperature and relative humidity should be well resolved throughout the boundary layer.