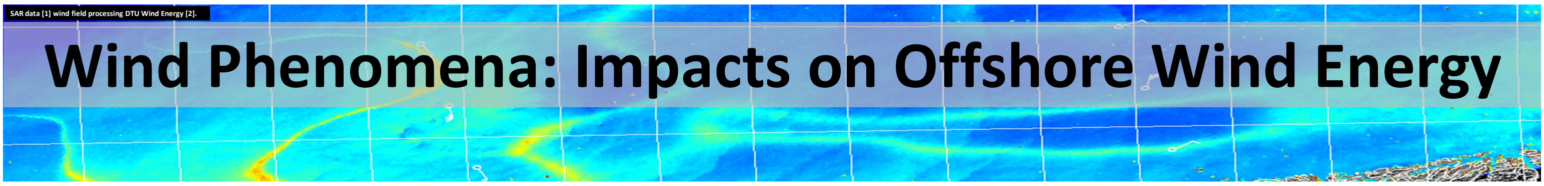
Centre for renewable Energy Systems Technology, CREST

Sarah Ollier, Simon Watson
s.ollier@lboro.ac.uk

Loughborough University



Wind Phenomena: Impacts on Offshore Wind Energy

1… Phenomena in the Marine Atmospheric Boundary Layer (MABL)

The MABL is the lowest 100 m – 3 km of the marine atmosphere, in contact with and influenced by the sea and coastal land surfaces. Air flowing from land to sea in this transition zone experiences changes in atmospheric stability resulting from changes in physical surface properties (fig.1.). These stability changes lead to wind phenomena:

Figure 1: The coastal MABL, adapted from © Copyright Rudi Winter and licensed for reuse under Creative Commons Licence.

Low Level Jets (LLJ): Low level turbulent and persistent high speed winds.

Roll Vortices (RV): Counter-rotating turbulent rolls which form and persist in the MABL.

Atmospheric Gravity Waves (AGW): Coast-sea flow is displaced by topographic obstacles and waves persist in stable conditions.

Mesoscale gust fronts: High speed wind gust from convective storms.

Squalls: localised high speed wind gusts and precipitation.

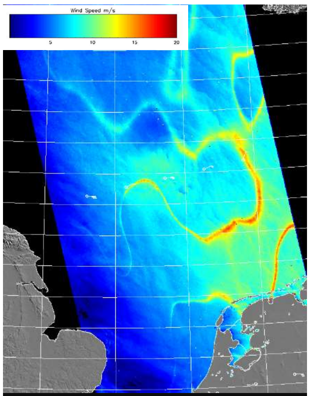
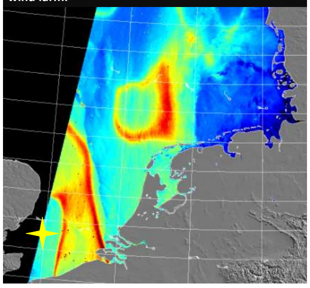


Figure 3: Gust Fronts near Greater Gabbard. SAR data [1] wind field processing DTU Wind Energy [2]. Yellow cross - approx location of Greater Gabbard wind farm.



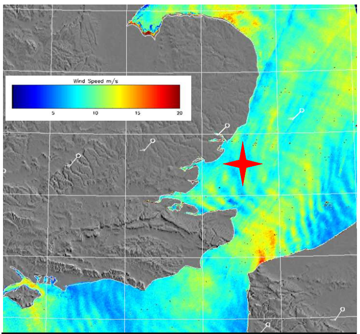


Figure 2: Atmospheric Gravity Waves over Greater Gabbard. SAR data [1] wind field processing DTU Wind Energy [2]. Red cross - approx location of Greater Gabbard wind farm.

2…Implications for the Offshore Wind Industry?

There are limited examples of potential +/- implications of phenomena on turbine energy output and fatigue loading:

Low Level Jets (LLJ): Directional shear reduced onshore wind farm performance, whilst enhanced wind speeds increase wind power density [3].

Roll Vortices (RV): led to periodic turbine loading and power output variations in in onshore wind farms [4], frequent RV are expected in stable offshore wind farm regions.

Atmospheric Gravity Waves (AGW): 0.6 ms^{-1} decreases in wind speed were associated with small AGW passage through theoretical wind farms [5].

Mesoscale gust fronts: associated increases in ocean wave height impacted turbine structures, whilst intermittent wind speeds may reduced energy capture efficiency [6].

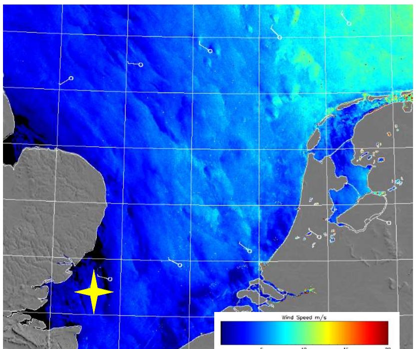


Figure 4: Ocean squall close to Greater Gabbard. SAR data [1] wind field processing DTU Wind Energy [2]. Yellow cross - approx location of Greater Gabbard wind farm.

3… Using satellite images to identify wind phenomena at offshore wind farms

Synthetic Apeture Radar (SAR) from polar orbiting satellites produces high resolution images (3-100m) of the sea surface. wind speed and direction can be calculated from the **sea-surface wind imprint**, although incorporating external wind data produces more reliable wind directions. [7] provides a detailed review of SAR data and the methodologies for wind speed and direction retrieval from SAR.

Whilst various studies detect wind phenomena in the MABL using SAR, they have not been investigated in detail in relation to offshore wind farms. Consequently, the impact of offshore wind phenomena on **wind turbine condition** and **energy outputs** has not been fully assessed.

Preliminary results (Figures 2-5) show examples of phenomena detected in ENVISAT [8] images from 2007 – 2011 around **Greater Gabbard wind farm** as a precursor to investigating the impact on turbines.

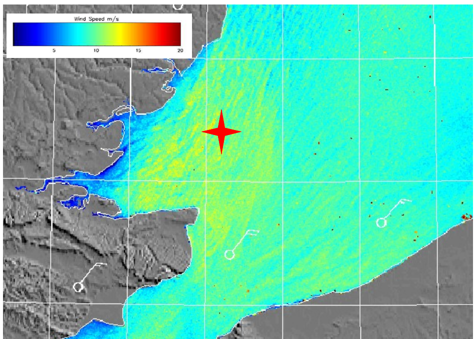


Figure 5: Roll Vortices over Greater Gabbard. SAR data [1] wind field processing DTU Wind Energy [2]. Red cross - approx location of Greater Gabbard wind farm.

4… Next steps –phenomena climatology and Impact assessment

Figures 2 – 5 are a subset of results confirming that mesoscale phenomena are occurring regularly around Greater Gabbard and other wind farms. This research will continue to identify mesoscale phenomena in SAR images in and around wind farms up to 2016 and build a climatology with mast data and a mesoscale model (WRF).

In addition, the impact of phenomena on wind farm health and performance will be assessed with a case study of Greater Gabbard wind farm using SCADA data.

5… Research implications

Short term.. Continued identification and verification of phenomena and their impacts on offshore wind farms will help build a better understanding of the offshore wind climate.

Long term…. Better **positioned**, effective and **sustainable** offshore windfarms.

[1] ESA, "What is Sentinel-1," 2016. [Online]. Available: https://earth.esa.int/web/guest/missions/esa-operational-eo-missions/sentinel-1. [Accessed: 28-Oct-2016].
[2] DTU-WE, "ENVISAT surface wind field processing." Danish Technical University (DTU) Department of Wind Energy, 2016.
[3] W. Gutierrez, G. Araya, P. Kiliyanpilakkil, A. Ruiz-Columbie, M. Tutkun, and L. Castillo, "Structural impact assessment of low level jets over wind turbines," *J. Renew. Sustain. Energy*, vol. 8, no. 2, 2016.
[4] A. Smedman, "Occurrence of roll circulations in a shallow boundary layer," *Boundary-Layer Meteorol.*, vol. 57, no. 4, pp. 343–358, 1991.
[5] R. B. Smith, "Gravity wave effects on wind farm efficiency," *Wind Energy*, vol. 13, no. 5, pp. 449–458, 2010.
[6] S. Brusch, S. Lehner, and J. Schulz-stellenfleth, "Synergetic Use of Radar and Optical Satellite Images to Support Severe Storm Prediction for Offshore Wind Farming," *IEEE J. Sel. Top. Appl. Earth Obs. Remote Sens.*, vol. 1, no. 1, pp. 57–66, 2008.
[7] K.-F. Dagestad, *et al.*, "Wind retrieval from synthetic aperture radar -an overview," *Proc. SEASAR 2012. Eur. Sp. Agency, ESA*, 2013.
[8] ESA, "What is Envisat?," European Space Agency, 2016. [Online]. Available: https://earth.esa.int/web/guest/missions/esa-operational-eo-missions/envisat. [Accessed: 25-Sep-2016].

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