

Unexpected vertical wind profiles over the North Sea – on the route of the windjammers

Anthony Kettle, post. doc., University of Bergen



Over the past two decades there has been a number of offshore wind energy projects developed in the Baltic and North Sea areas, in many cases along the sea routes that that were once plied by large sailing vessels between Europe and other parts of the world. These offshore wind energy projects have been spawned by initiatives by European governments to develop sources of clean renewable energy to overcome problems with present energy sources that are based on fossil fuels and nuclear technology. However, the development of offshore wind energy is not without risks.

Offshore wind turbines have hub heights that extend up to 100m – comparable with large commercial airliners. They have to be carefully designed not only to generate electricity profitably but also stay in operation with little maintenance over a 20 year lifetime in a turbulent wind field whose gust characteristics and short term variability are not completely known. It is important to understand the structure of the wind profile in the lower atmospheric layer not only to assess the available wind resource but also to understand the nature of the fatigue damage that accrues to a wind turbine during operation. Presently, wind turbines are designed and evaluated using simplified parameterizations of vertical wind speed. Decades of land-based tower measurements have built up a paradigm that the wind speed profile should increase approximately exponentially with height with modifications to take account of heating or cooling effects at the land-air interface. The oceanographic measurements that have been conducted from research vessels in the lowest 30m of the atmosphere over the open ocean have tended to confirm this paradigm. This body of measurements is mathematically formalized within Monin-Obukhov theory, which gives a set of self-consistent rules to understand the structure of the lower atmosphere and the fluxes of heat, water vapor, and momentum from the ocean surface. However, recent measurements at high meteorological towers at offshore wind farm locations in northern Europe have begun to reveal unexpected features in the vertical wind speed profile. FINO1 is one such mast among several now located around the North Sea (Figure 1a).

FINO1 was constructed in 2003 just north of the island of Borkum as part of a German government initiative to construct many wind parks in the far offshore region to meet a request for more renewable energy in the country's future energy mix.

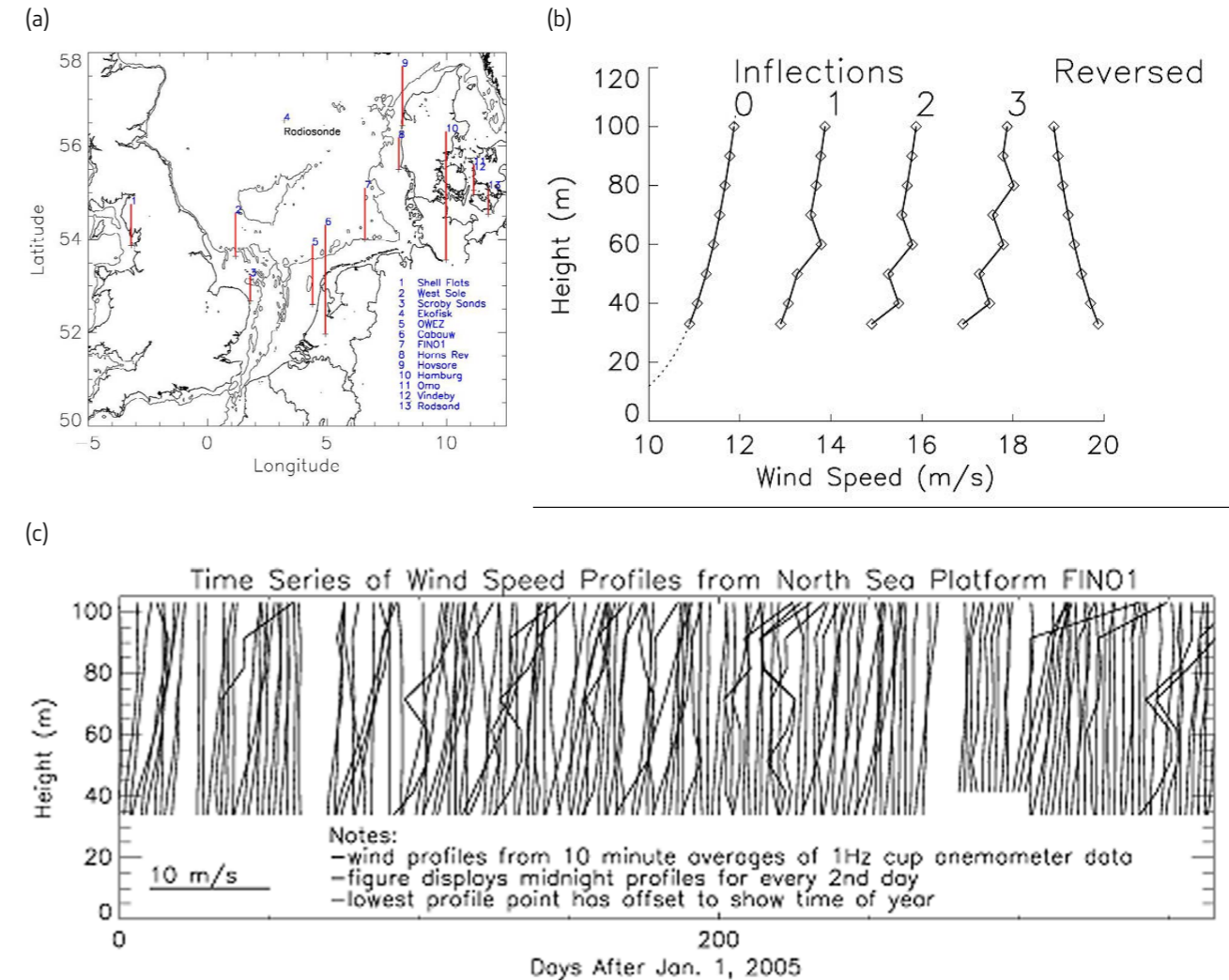


Figure 1 (a). Location of FINO1 in the southern North Sea with other high meteorological masts and installations in northwest Europe, (b) wind speed vertical profiles (10 minute average of 1Hz data) at midnight for every second day of 2005, and (c) schematic diagram of the possible number of wind speed inflections and vertical profile configurations from a vertical array of 8 cup anemometers.



The FINO1 mast has instrumentation that stretches from the seabed up to 100m into the atmosphere over the sea surface. The measurement project has provided new and important insights into the dynamics of atmospheric and oceanographic processes in the North Sea, as well as wave processes that are important for the design of offshore marine structures. For offshore wind energy, one of the surprises has come from the analysis of the vertical array of cup anemometers that shows the presence of inflections or 'kinks' in the vertical wind profile especially for certain wind speeds and directions. The cascade diagram in Figure 1b illustrates that the measured wind speed profile can sometimes be complicated. The vertical array of 8 cup anemometers on the FINO1 mast can show up to three inflection points and even reversed profiles as shown in the schematic in Figure 1c. Some of the other high offshore meteorological towers in the Baltic Sea and North Sea have revealed similar features. The problem is associated mostly with internal boundary layers that propagate from nearby coastal areas and cause a two-layer or decoupled boundary layer at the location of the offshore mast. The height of the internal boundary layer depends on distance from the coast as well as the turbulent mixing

effects of wind speed. Low level offshore jets in offshore regions have also been observed. Internal boundary layers had previously been recognized for the enclosed Baltic Sea, but the documentation from FINO1 site is unexpected given the prevailing westerly winds and the long distance to the nearest the coastal area. The issue is a potential challenge to offshore wind energy in the construction of larger turbines to take advantage of generally higher winds aloft at the expense of the complicated and potentially damaging turbulent flow patterns.

In addition to the offshore meteorological masts, extra information sources about internal boundary layers over the ocean are available from earlier studies of coastal air pollution, radar propagation, and aircraft turbulence that stretch back through the Cold War and before. Even the old-time windjammers have their message for the modern offshore energy industry with practical advice in Maury's classic book on Sailing Directions of 1852 to beware of the wind shadow zones that can extend far over the horizon. Further information about the complicated wind profiles in coastal regions and historical background into their investigation is presented in A.J. Kettle, Unexpected vertical wind profiles in the boundary layer over the southern North Sea, *Journal of Wind Engineering and Industrial Aerodynamics*, 134, 149-162, 2014.



Line Båserud

What is your scientific background?

I graduated at Geophysical Institute, University of Bergen with a MSc in meteorology in 2013. During my master project I started to work with the characterization and application of the turbulence measurement sensor adapted to the Small Unmanned Meteorological Observer (SUMO). After this I worked for 9 months as a research assistant in the experimental meteorology group at GFI, continuing the activities of my master project in a collaboration project between GFI and Statoil. In addition I gained experience in the quality control and basic data analysis of the FINO3 offshore data set.

What topic is addressed in your PhD?

The topic of my PhD is the investigation of boundary layer turbulence using direct measurements from Remotely Piloted Aircraft Systems (RPAS). I will work with both SUMO and a new quadcopter system that was purchased recently at GFI. The goal will be to improve our understanding of turbulence and turbulent exchange processes under different atmospheric conditions. The main focus areas of my PhD project will be stable and convective boundary layers and the interaction between the atmospheric boundary layer (ABL) and wind turbines, in particular single turbine wake effects.

Why do you address this topic?

With the increasing focus on renewable energy, and in particular the fast development of wind energy, knowledge of the interaction between the ABL and wind turbines become more and more important. The development of small RPAS during the last years has made these highly flexible platforms suitable sensor carriers for measurement of the relevant atmospheric parameters. The goal is to improve our understanding of the transition periods between the different boundary layer regimes, and to capture the downstream extent of wind turbine wakes as a function of synoptic situation and atmospheric stability. This will provide wind turbine producers and wind farm operators with data sets and knowledge that will in the future increase the life time and power output of wind turbines and wind farms.

How is your work linked to NORCOWE?

This PhD project is linked to WP1, and will focus on the further development, qualification and application of novel and promising measurement platforms for wind energy applications such as wind turbine wake studies. The data collected by the RPAS will complement the other measurement platforms already used within NORCOWE, such as wind lidars, microwave temperature profilers, scintillometers and sodar/RASS.