Wind farms and the weather

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The KNMI ('Royal Dutch Meteorological Institute') is responsible for providing weather forecasts and issuing weather warnings for the Amsterdam FIR (Flight Information Region), which not just extends above Dutch territory but also includes a large part of the Southern North Sea. As a result, oil rigs and offshore wind farms play an important role in our operations as a weather office. Observations from weather stations on these rigs and farms are crucial in the process of making accurate weather forecasts for this region, however, as they disturb radar signals and affect the weather itself, the increasing number of wind farms could become a challenge in the future.

From oil rigs to wind farms

For more than half a century oil and gas have been extracted from the sediments under the North Sea, generating the need for oil rigs and other platforms. The KNMI has been responsible for providing weather forecasts and warnings for ships and offshore personnel since the nineties, with some of the platforms equipped with meteorological instruments. Observations from these offshore weather stations became essential for meteorologists, not just to monitor the local weather conditions, but also because they can provide a strong indication of future weather conditions over land when weather systems approach from the west or north.

With the transition to sustainable energies and therefore the gradual decommissioning of the platforms used for oil and gas extraction, two offshore weather stations have already been taken down, with more expected to be retired in the future. Fortunately, the deployment of wind farms in the North Sea has opened up a way to continue these measurements. The first wind farm, a group of wind turbines in the same location used to produce electricity, came online in 2007, just offshore from Egmond aan Zee. Since then, five more farms have been built and during the next decade many more wind farms are scheduled to be built offshore the Dutch coast **(figure 1).** As part of the Maritime Information Service Point (MISP) project, the KNMI will be allowed to place meteorological instruments on the accompanying platforms. An example of this is shown in **figure 2.**

▲ *Figure 1: present and planned wind farms offshore the Dutch coast, source: windopzee.nl*

▲ *Figure 2: anemometer, windvane and other instruments attached to a tower on a wind farm platform, source: KNMI*

Anomalous propagation echoes

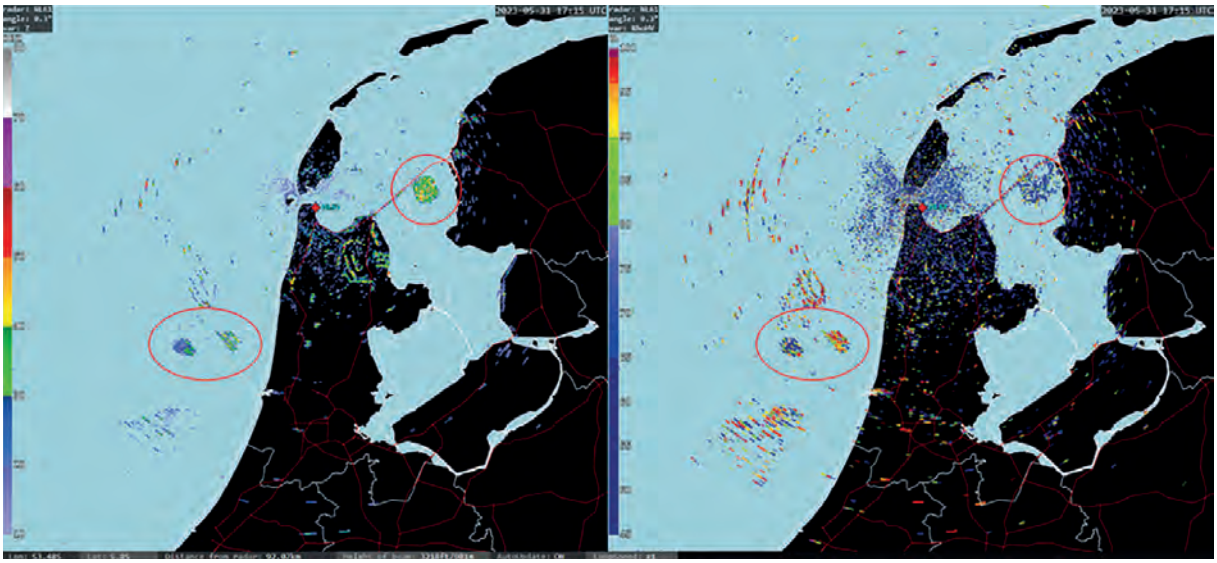
The presence and planned future expansion of wind farms in the North Sea does pose a challenge when using radar images under certain atmospheric conditions. When radar beams pass through a layer that has a high atmospheric stability, for example due to a strong temperature inversion, the beams will bend downward more than normal (this is called super-refraction). In some cases a process called 'ducting' can occur; a special super-refractive condition such that the radar beam gets trapped or 'ducted' within this layer. This can cause the radar beams to hit the wind farms and show their reflections as stationary false radar echoes (or anomalous propagation echoes). An example of such echoes is shown in **figure 3**.

With the future wind farms becoming much bigger, they will likely generate a lot more reflections on the radar products used by our meteorologists as well as our clients. This will happen especially during spring time when warm (continental) airmasses are moving over the cold North Sea water, creating a stable boundary layer, similar to a nocturnal boundary layer over land. Although Dual Polarization Radar products are actually able to determine whether reflections are caused by precipitation or anthropogenic objects, one has to be careful to not filter too much or aggressively in cases where there are actual (isolated) storms active in the area. Therefore meteorologists should always be aware of the locations of these wind farms, in order to not make a wrong assessment.

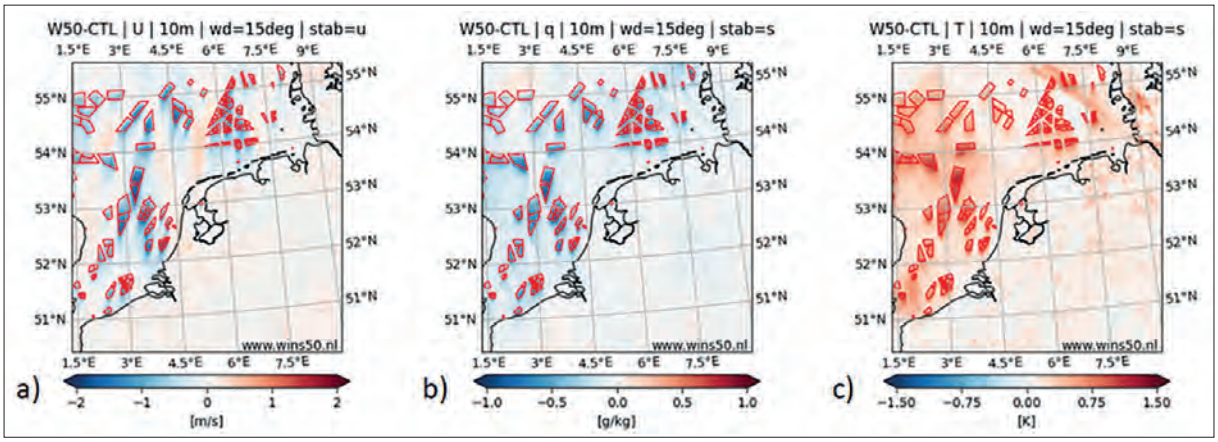
Affecting the weather

The increasing number of wind farms also poses another challenge. As much as we know about their yield generated under certain wind conditions, our knowledge on how wind farms or single wind turbines affect weather conditions themselves is limited. Last year however, a study was performed together with the Wageningen University, using our local high resolution weather model Harmonie, which showed some interesting results. They compared year-long model runs with and without parameterized wind farms, in order to determine how to improve local wind forecasts, power production and the effects on the near-surface wind, temperature and humidity.

They found a significant decrease in wind speed as far as 50-150 kilometers downstream of the wind farms **(figure 4a),** especially during conditions with a high stability (warm air over a cold surface). Additionally the wind turbines caused an increase in turbulence, enhancing the atmospheric mixing in the boundary layer. This will inevitably also change the temperature and humidity profiles of the affected downstream atmospheric layer. For example, in a stable boundary layer with cold and moist air near the surface, increased mixing would result in higher temperatures and lower humidity close to the surface (**figure 4b & c**), potentially causing visibilities to improve or low clouds (stratus) to dissolve. On the other hand, adding mixing to a stable but very moist layer trapped below an inversion, could also result in the formation of stratus clouds. The satellite images in **figure 5** show an example of the first process.



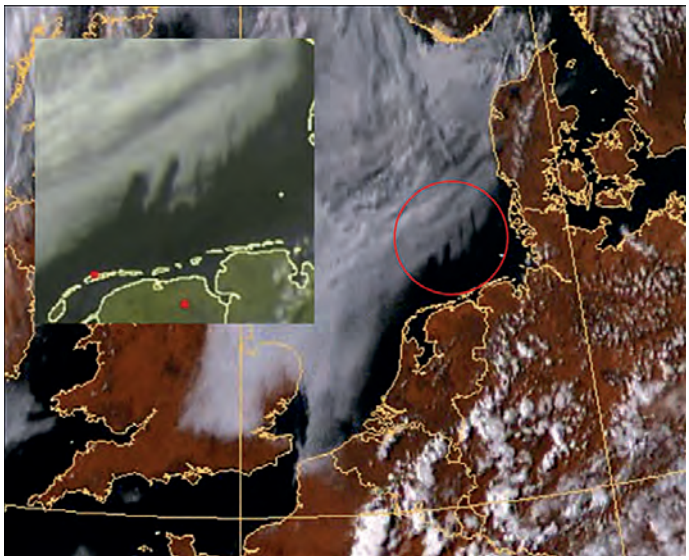
▲ *Figure 3: radar reflectivity (left) and correlation coefficient (right), red circles indicate the location of the wind farms, blue colors (or any other colors except red) for the correlation coefficient indicate non-meteorological echoes. Source: KNMI*



▲ *Figure 4: model output wins50, showing the anomalies of the 10 m wind (left), specific humidity (center) and temperature (right), source: https://wins50.nl/imagelibrary/*

Induced lightning?

A final challenge, something we still have very little experience with, is the possibility of wind turbines inducing lightning. During cases with isolated showers containing supercooled droplets/ice, the presence of wind turbines could, similarly to AIL (Aircraft Induced Lightning), have an effect on the triggering of lightning. In addition to their impressive height of about 200 meters (including the blade), the rotation of the blades and the used materials could also play a role in altering the electric fields. Although there have been instances where wind farms or even individual turbines seemed to have played a role in the onset of lightning, there is still ongoing debate about this.



▲ *Figure 5: visible satellite image around 14:00 UTC on the 13th of May 2023, source: Meteosat (edit)*