Using Artificial Intelligence to improve rainfall measurements from the UK weather radar network

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1. Introduction

Flooding from **severe weather cost the UK economy £1.6 billion** in the fiscal year 2015/2016, and both **the occurrence and severity of severe weather events are expected to increase due to climate change**.

To help the Environment Agency, emergency services and local authorities monitor and react to severe weather events, the Met Office weather radar network provides **a rainfall map across the UK with a resolution of 1km, every 5 minutes**.

This level of spatial and temporal resolution is not achievable by any means other than surface-based weather radar.

Weather radar measurements can be contaminated with echoes from obstacles on the ground, such as hills, buildings, radio masts, or wind turbines, collectively known as "clutter".

In fact, as part of its commitments towards Net Zero carbon emissions, **the UK will continue to build more and larger on-shore and off-shore wind farms over the next few decades**.

This will increase the negative impact of wind turbines on data quality.

This problem is not unique to weather radar – the government recently awarded £3.8 million in contracts to mitigate the impacts of wind turbines on UK air defence systems.

2. The impact of clutter

The surface rainfall rate can be measured most accurately if the radar observation is made close to the surface. In the presence of clutter contamination, a higher-altitude observation must be used (Figure 1), but this significantly increases the uncertainty.

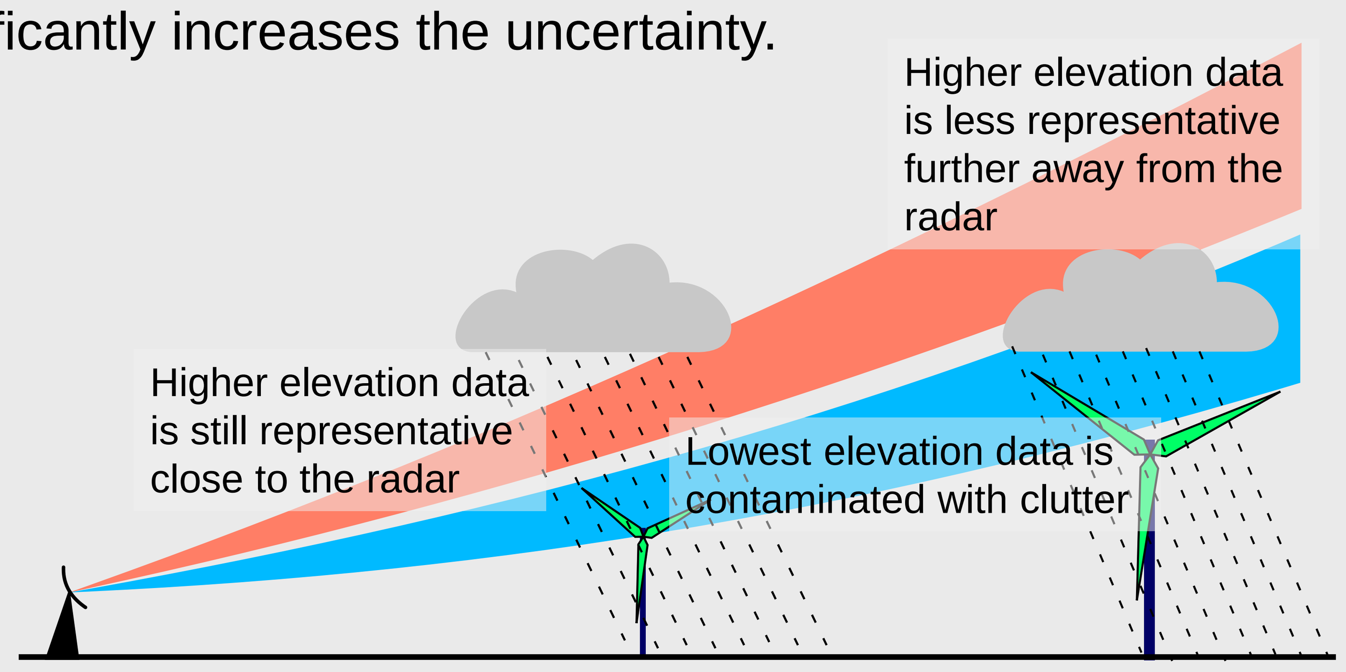

Figure 1. If a small turbine is found close to the radar, a higher altitude measurement may be sufficient to estimate the surface rainfall. Further away from the radar, the higher altitude measurement may not be representative of the surface rainfall. (not to scale)

3. Doppler filtering

The radar measurements can be transformed into the frequency domain (also called the Doppler spectrum). This shows the contribution from each velocity component - e.g. stationary ground clutter appears zero-velocity, while rain moving towards the radar contributes a higher radial velocity component.

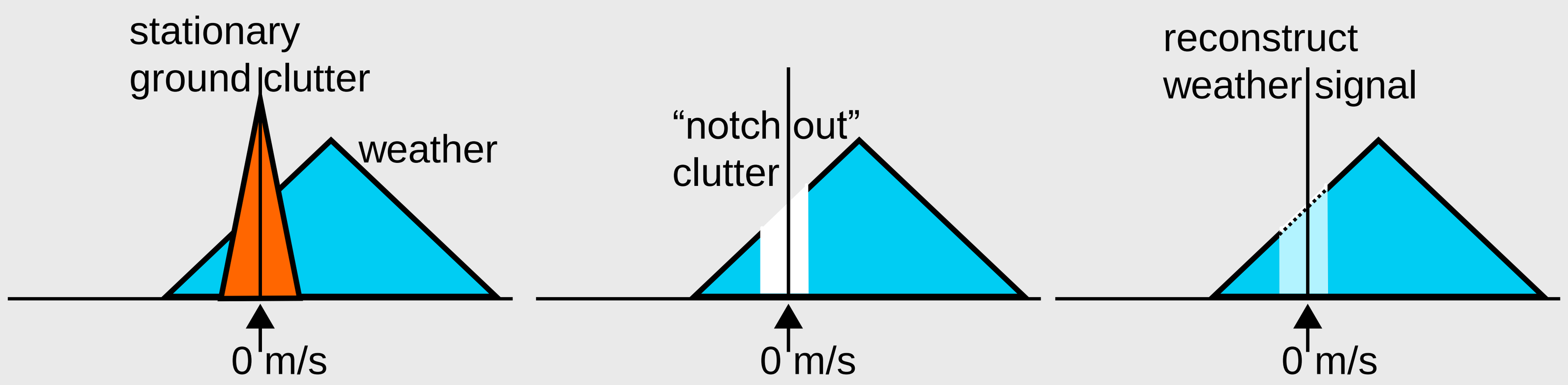

Figure 2. Ground clutter (zero radial velocity) signal can be removed from the measurement and the original weather signal can be reconstructed.

The zero-velocity component can be filtered out (Figure 2) to remove clutter contamination, but in some cases, this can lead to rainfall that is moving perpendicular (zero-radial velocity) to the radar to be erroneously removed. Worse, clutter contamination from wind turbines can have non-zero velocity components due to the moving blades (Figure 3).

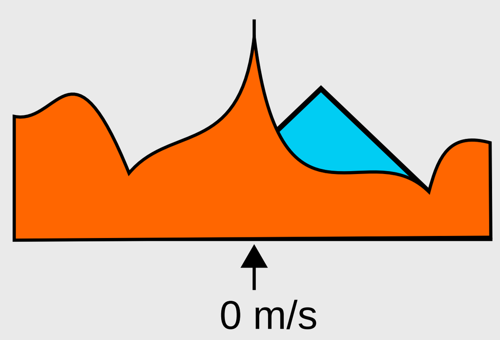

Figure 3. Unlike ground clutter, the signal from a wind turbine field has significant multimodal non-zero velocity components.

4. Using machine learning to detect clutter

To improve the data quality, a machine learning (ML) algorithm was developed [1] to determine when it is appropriate to apply a Doppler filter and when to switch it off.

The training dataset was built by systematically combining observed signals of precipitation with observed signals of ground clutter, which captured the spatial distribution of real-world clutter contamination, as shown in Figure 4. This contrasts with simulated data, where it is difficult to include the real-world spatial variability of clutter.

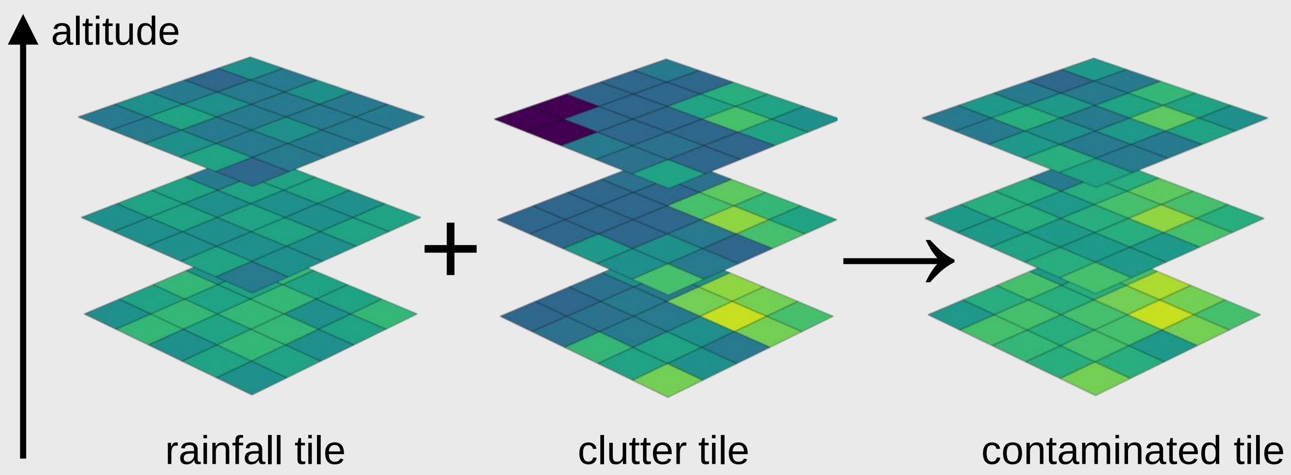

Figure 4. Rainfall and clutter signals at multiple altitudes are systematically combined to produce contaminated tiles with a known ground-truth.

5. Results

This technique has worked very well for stationary ground clutter, as shown in Figure 5. The bright spots in the left panel are areas with known ground clutter contamination, which have been removed on the right.

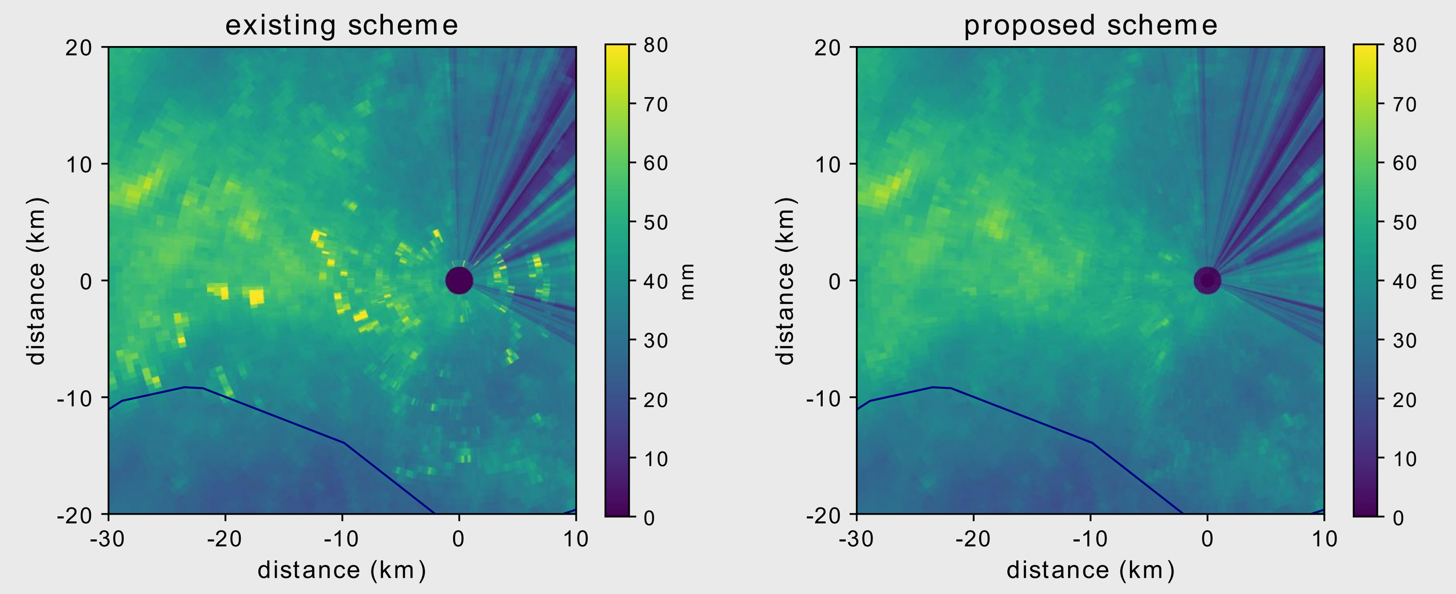

Figure 5. 6-day accumulation of rainfall. Left panel: the existing scheme, right panel: the new ML scheme.

This new scheme has **doubled the number of observations that are used at the lowest elevation in cluttered areas**, while also **reducing the amount of contamination** in the surface rainfall map. This first stage of the work will be released operationally on the UK weather radar network mid-2022, and will significantly reduce clutter contamination in the UK composite.

6. Next steps

The next stage of the work consists of extending the ML scheme to detect clutter contamination from wind turbines.

A dataset has been collected that contains radar echoes from known wind turbines near the Thames estuary and near the Isle of Man, and a convolution neural network using pre-trained feature detectors is able to classify pure signals of rainfall, ground clutter or wind turbines, **with an accuracy above 96% (99.7% accuracy if only rain and wind turbines are considered).**

Further work to produce a working implementation that will successfully detect rainfall contaminated with wind turbines is ongoing.

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[1] Husnoo et al. (2021) A Neural Network Quality-Control Scheme for Improved Quantitative Precipitation Estimation Accuracy on the U.K. Weather Radar Network, Journal of Atmospheric and Oceanic Technology, 38(6), 1157-1172 (https://doi.org/10.1175/JTECH-D-20-0120.1).