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Atmospheric Measurement Techniques Discussions

Interactive comment on "Fuzzy logic filtering of radar reflectivity to remove non-meteorological echoes using dual polarization radar moments" *by* D. R. L. Dufton and C. G. Collier

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We would like to thank the reviewer for their constructive review and comments; we've taken them on board and amended the paper accordingly. Below we list the reviewer's points in italics, followed by our response and then the amendments we have made to the paper in blue.

1. "I don't see substantial novelty in the proposed fuzzy logic scheme. The use of radial texture parameters is already proposed in some commercial radar software packages. The only new thing at my knowledge is perhaps the use of a range dependent correction applied to the texture parameters."

The aim of the paper is to provide evidence for the use of such filtering on short duration field campaign datasets, where training data can be limited. As you mention the method we have chosen is not new, and has been demonstrated previously on larger datasets from static radar installations, but as you also mention it is useful to refine these methods and provide additional examples of their usage. To our knowledge the range dependent variation of window texture fields has only previously been demonstrated by Gourley et al (2007) for Φ_{DP} and Z_{DR}, here we provide evidence for the range dependent variation of radial textures and also show it is applicable to the ρ_{hv} texture field also.

2. "The training data set (one or two hours of data depending on echo type) is very small and is not representative at all of the large variety of possible weather situations and sources of non-meteorological signals. The latter is particularly true for biological scatterers."

As we have mentioned in our responses to the other reviewers the training dataset is deliberately small due to the small overall dataset we have available from the field campaign and our wish to use the same technique for other field deployments which may be limited in their duration. In this way the filter is targeted to the period of year of the field campaign and we use training data which reflects the conditions experienced during that campaign. We accept that this limits the applicability of the filter to other seasons where other weather conditions may also be present but this is not its primary purpose. Regarding biological targets, they are often the hardest to identify due to the lack of ground truth data available. In the paper we have had to draw on other research and intuition to identify echoes that are most likely to be of biological origin. Therefore creating a training dataset which covers all possible biological echoes, without effective ground truth verification, is not possible and we can only train the filter to identify echoes which are commonly considered to be biological.

3. “The evaluation is very limited and very subjective. Only three specific cases and the accumulation over the 3-month COPE observation period are considered. No attempt has been made to quantify the performance of the scheme. Accumulation over long durations is certainly one of the things to do for checking the quality of non-met echo removal but it seems that only one rain-gauge is used is the evaluation.”

Apologies for our lack of clarity regarding rain gauges, we have used 20 rain gauges spaced across the Cornish peninsula, within 50km of the radar, to evaluate the non-met echo removal. In the paper we chose to highlight the rain gauge most impacted by the filter, which is located within a wind farm. For this gauge the radar observed numerous non-met echoes leading to highly spurious radar rainfall accumulations far in excess of the gauge precipitation (a bias of 8.72). The filter reduced this by 96% to a bias of 0.33. Analysis of the other 19 rain gauges shows very little variation in rainfall accumulation as a result of the filter, with reductions in accumulation ranging from 1 to 13 percent for these gauges. These gauges show systematic under measurement by the radar as a result of partial beam blockage; overshooting and attenuation, which still require correction (as mentioned in the paper, section 4.3). As such we are confident the filter is performing well and not creating a large number of false negatives (i.e. removing rainfall where it should be present), we have amended the paper to clarify this.

In addition to our rain gauge analysis, we also evaluated the filter during its development using performance metrics. The critical success index, CSI (Wilks, 2011) was used with a validation dataset containing challenging identification cases (wind farm and rainfall mix, insect and convection mix etc) and more general situations (ground clutter in clear air, widespread rainfall). Across these validation runs the CSI of the filter when detecting rainfall was 0.93, while it was 0.76 and 0.72 for ground clutter and insects respectively. Ultimately these numbers are conditional on the validation dataset used and only really useful for a comparison between filters, as such we have not included this information in the paper and prefer instead to present typical examples from which the reader can gain more information about the true performance of the filter.

Using the 3 month accumulation we have also looked at the impact of the filter on echo occurrence (Fig. 1). Not only does the filter remove the ground clutter, some of which has an echo occurrence of over 90%, it also removes the near field ‘halo’ of insects and noise which lead to the elevated echo occurrence percentages within 20km of the radar. We have added this figure and supporting text to the paper to provide a second metric for long duration evaluation of the filter.

Added: “19 additional rain gauges across the Cornish peninsula were used to provide additional verification of the filter, and show non-meteorological echoes to be an insignificant error source for their locations. All of the rain gauges show a systematic under measurement by the radar due to as yet uncorrected beam blockage, attenuation and beam overshooting. At these locations the filter reduces the radar accumulations by less than two percent for 13 of the sites and between three and thirteen percent for the remaining six sites, showing the filter does not systematically remove precipitating echoes.”

And added: “Accumulated rainfall statistics for the campaign also highlight the benefit of the filter. Prior to filtering, echoes occur in over 90% of low elevation scans in those range gates associated with high topography (Fig. 10), while a zone of above average number of observed echoes occurs within 20km of the radar, closely mirroring the coastline to the north west of the radar, which is indicative of a high occurrence of biological scatterers. After filtering these features are removed, with echoes occurring around 40% of the time, except in regions of beam blockage and where ground clutter dominates the radar reflectivity observations.”

4. “Fuzzy logic schemes are generally used complementary to other clutter removal methods like Doppler filtering or static clutter maps. Did you consider using some additional complementary methods?”

Thank you for the suggestion. During our assessment of the filter and identification of suitable training data we used ordnance survey maps to identify likely clutter targets;

however no static map data has been incorporated into the filter itself. We can see the benefit of this for permanent installations, where longer durations of data are available to build up statistical clutter maps such as the echo occurrence map presented above. We will explore their usage further in our longer field deployments where possible.

The radar also generates a Doppler filtered reflectivity field using FFT filtering. However analysis shows this to be prone to the zero velocity isodop filtering error mentioned in the paper and also prone to systematic under correction of near field ground clutter, leading to overestimation of rain rates in these areas. The Doppler filter is also unable to remove clutter from the wind farm. As such we have not used this field in the analysis.

5. “Disturbances from Radio Local Area Networks are not mentioned in the review of possible non-met signals and not addressed in the paper. They are however a growing source of perturbations, at least in Europe. Is your scheme appropriate for removing such disturbances?”

At present isolated gates affected by interference are removed by the post-classification de-speckling using connected component analysis (section 3.2.3), but this does not deal with larger areas or entire radials which are contaminated. We have not attempted to include them in the filter due to the extremely limited number of example cases available (only a few hundred range gates at most). However the fuzzy scheme presented here should be capable of filtering these larger signals provided they have a distinct enough signature in the variables used. For example we have seen isolated cases of ship based radar producing radial spikes of interference which have anomalously high magnitudes of Z_{DR}, yet with very high ρ_{hv}. This should aid in their identification using the filter. An azimuthal or vertical connectivity measure may also be required as an additional input to support their identification in the future.

6. “The paragraph 1.1.3 on the use of differential phase shift does not make appear very clearly what can be inferred for this parameter.”

Thank you, we have amended the paragraph and added additional information to improve its clarity.

Added: “Therefore, where Φ_{DP} is observed to be monotonically increasing with low noise, rainfall can be inferred, while variable signals with large fluctuations are indicative of non-meteorological scatterers.”

7. “The range dependent correction described in 3.1.1 should be better justified and described. The impact of beam broadening on the radial texture field is not so straightforward.”

As you suggest the impact of beam broadening on the texture fields is not straightforward and the range dependent corrections in 3.1.1 are based on an empirical analysis of the data and a fitted correction curve. The data analysed clearly supports the range variance of the texture fields, and the use of a correction to allow for range invariant comparison of observations. To clarify we use 12, 1.5 degree elevation scans from the 17th August to derive this correction. By taking the average texture across these as a function of range, a polynomial can be fitted that is then used to remove the range dependent texture observed (Fig. 2). We have not attempted to derive a theoretical relationship for the correction, though that may be an interesting research idea for the future.

8. “The impact of the filter on the 3-month accumulation should be better analysed and quantified, for example by comparison with several rain gauges.”

See response to comment 3 above.

References

Gourley, J. J., Tabary, P., Parent du Chatelet, J. (2007). A fuzzy logic algorithm for the separation of precipitating from nonprecipitating echoes using polarimetric radar observations. Journal of Atmospheric and Oceanic Technology, 24(8), 1439-1451.

Wilks, D. S. (2011). Statistical methods in the atmospheric sciences (Vol. 100). Academic press.

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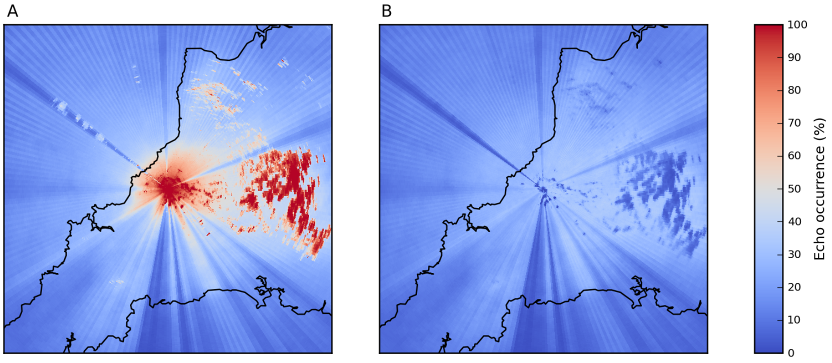

Fig. 1. Percentage of times each range gate contains a measurable reflectivity echo during the COPE campaign (1132 scans total). A is unfiltered and B filtered. See revised paper (Fig 10.) for details.

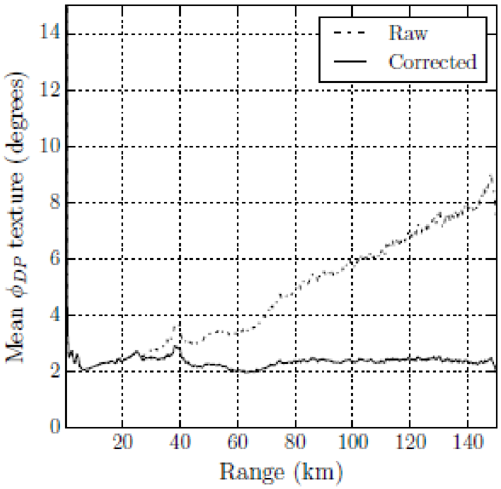

Fig. 2. Mean differential phase texture from 12 low elevation scans containing widespread rainfall below the melting layer. Correction normalises the texture to allow direct comparisons irrespective of range.