An error-based selection criterion to mitigate the effects of C-band attenuation in the UK radar composite

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Introduction

Radar composites are increasingly being used in data assimilation, forecast verification and flood monitoring (e.g. Macpherson 2001) thanks to the high spatio-temporal resolution and coverage they provide. Such applications, however, can be extremely sensitive to input uncertainties, and as such there is increasing pressure on the radar community to provide data of high accuracy and precision. In networks with significant overlap, such as in the UK, it is therefore essential to exploit the redundancy of information by selecting the best possible data for radar composites.

Radar Composites

Composite quality depends on how individual radar data are selected and combined. A single scan or weighted average can be used, with criteria or weightings traditionally based on "nearest radar" or "maximum reflectivity". Until recently the UK post-processing system (RADARNET) used reflectivity measurements from the scan with the lowest available beam height to calculate surface rain rate. This generally performs well, but can cause problems in strongly attenuating situations.

A New Criterion

In this work we propose a composite data selection criterion designed to improve composite accuracy in cases of strong attenuation, whilst maintaining the performance of a "nearest radar" criterion in more typical circumstances. The criterion is derived by analysing the propagation of measurement uncertainties through the successive corrections and transformations required to obtain a surface rain rate. We evaluate this new criterion through case studies and gauge comparisons.

Rain Rate Error Estimation

To calculate error, we model the final rain rate estimate as a chained function of measured reflectivity through an attenuation correction, a VPR adjustment and a ZR conversion. It is necessary to restrict the analysis to quantifiable errors. For single polarisation radar, this means that errors due to imperfect quality control are neglected.

Attenuation

The input error on reflectivity has a random component due to signal strength and a bias due to attenuation. The attenuation correction removes this bias, but leaves a random error component related to the magnitude of correction applied.

Vertical Profile of Reflectivity

The adjustment for inhomogenous VPR is multiplicative and independent of reflectivity. The random error on attenuation-corrected reflectivity is propagated by simple Taylor expansion, and remains random. An additional systematic bias must be introduced at this stage, to account for the inaccuracy in our estimated vertical profile. Since the form of this inaccuracy is unknown, a simple VPR error profile is defined to increase quadratically with height and range (Szturc et al. 2011; Berenguer and Zawadzki 2008; Bellon et al. 2005).

Reflectivity to Rain Rate Conversion

The final step requires propagation of both a random and a systematic term through a power-law (Marshall-Palmer) relation. This is done by taking the literal difference in rain rate introduced by the bias, then perfoming a Taylor expansion around the bias-corrected result to propagate the random component.

Final Error-Based Criterion

Applying the theory above to the RADARNET processing chain yields the following expression:

$$\left(\frac{\Delta R}{R}\right)^2 = \left(1 - \nu^{\frac{1}{b}}\right)^2 + \left(\frac{\nu^{\frac{1}{b}}}{b}\right)^2 \left[1 + \left(\frac{\ln 10}{10}\right)^2 \beta^2 A^2\right] \left(\frac{\ln 10}{10}\right)^2 \Delta Z_{dB}^2$$

where A is the applied dB attenuation correction, b is the Marshall-Palmer exponent, M is the number of pulses averaged to obtain the input reflectivity, and v is the function of height and range that defines the error in our estimated VPR. The compositing quality index is defined as a decreasing function of error.

Gauge Comparison: Paired Statistics

Data from the month of June 2012 were reprocessed using the "height-only" (Ctrl) and quality-based (QI) compositing methods, to generate radar composites and hourly accumulations. These were then compared with co-located hourly gauge accumulations over the same period using traditional statistics: POD, FAR, bias (radar minus gauge) and RMSE. The equitable Heidke Skill Score was also used to assess overall performance. The results are shown in the table below.

Threshold (mm)	Gauge events	Bias (mm)		RMSE (mm)		POD		FAR		HSS	
		Ctrl.	QI	Ctrl.	QI	Ctrl.	QI	Ctrl.	QI	Ctrl.	QI
0.5	18061	-0.24	-0.26	1.17	1.19	0.80	0.78	0.26	0.25	0.70	0.69
1.0	9887	-0.39	-0.41	1.38	1.41	0.75	0.74	0.32	0.32	0.67	0.66
2.0	4178	-0.82	-0.83	1.96	1.99	0.62	0.60	0.38	0.39	0.60	0.59
4.0	982	-1.92	-1.87	3.46	3.44	0.39	0.40	0.48	0.50	0.44	0.44
8.0	95	-5.77	-5.49	8.61	8.50	0.25	0.29	0.59	0.65	0.31	0.32

The new compositing method makes very little difference to quantitative statistics for accumulations below 4mm. As C-band attenuation becomes significant at rain rates of around 4mm/h, little effect is expected at low accumulations. Above 4mm quality-based compositing significantly reduces gauge-radar bias, with a 5% reduction in radar underestimation for gauge accumulations above 8mm. Above 8mm there is a clear increase in POD, but also in FAR, which is likely due to clutter breakthrough in the composite. However, maintenance of the Heidke Skill Score at 0.32 suggests that the effects of this new method are dominated by increases in true detections rather than false alarms.

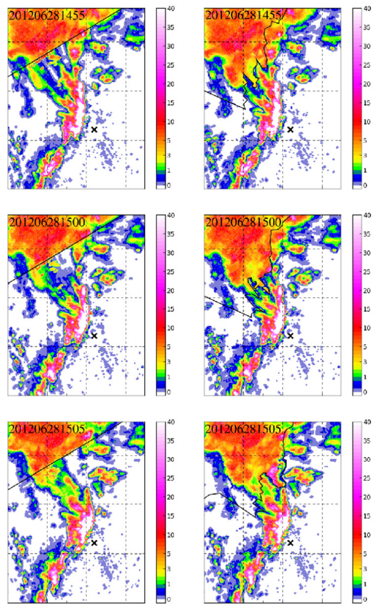

Figure 2: Rain rate cutouts over Northumberland from composites generated using height-based (left) and quality-based (right) data selection criteria, over the period bracketing 1500UTC on 28 June 2012.

Case Study: Newcastle Super Storm

Heavy rain during the last week of June 2012 caused severe flooding at many UK locations, particularly in the North-East of England. On the afternoon of 28 June an intense squall line hit Newcastle-Upon-Tyne at approximately 1500UTC. The radar at High Moorsley, 20km to the South, experienced attenuation strong enough to produce complete beam extinction over a period of around 15 minutes, obscuring a 10 degree wide sector to the North of the squall line. This area is also covered by the Munduff Hill radar situated 100km to the North.

Figure 2 shows rain rate cutouts over the affected region during the period of extinction. The cutouts to the left have been generated using a height-based compositing criterion, whilst those to the right were constructed by maximum quality index. The cross shows the location of the High Moorsley radar, and the black line the approximate data selection boundary between High Moorsley and Munduff Hill.

The height-based composites show clearly the effects of attenuation, with large discontinuities in rain rate at the radar field boundary. By allowing obscured data to be taken from Munduff Hill, the quality-based composites give a much more realistic image of the precipitation field. Some regions previously considered "dry" are replaced by rain rate measurements exceeding 30mm/h.

Gauge Comparison: Sampling Distributions

Beyond very short range, UK radar accumulations have been shown to underestimate systematically with respect to rain gauges (Kitchen and Jackson 1993). This problem increases at high rain rates due to C-band attenuation, resulting in a radar rain distribution that undersamples at high accumulations.

To evaluate whether the new compositing method mitigates this problem, hourly radar and gauge accumulations were obtained for the month of June 2012. This was a challenging period for the radar network due to exceptional rainfall across the UK, with accumulations exceeding 200% of the 1981-2010 average in a significant number of regions.

The distribution of hourly accumulations measured by rain gauges over the trial period is compared with those observed by the two radar compositing methods. Each of the three datasets is sorted by value in order to obtain three sampling distributions, and a set of quantiles is defined to ensure that high accumulations are adequately sampled. Values at these quantiles are then extracted from each of the radar accumulations, and plotted against the corresponding quantile from the gauge distribution (figure 1).

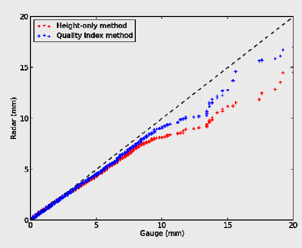

Figure 1: Quantiles of monthly rainfall distributions sampled by height and quality-based compositing methods, plotted against corresponding quantiles of the gauge distribution.

It can be seen that both radar curves deviate from the 1:1 line at high accumulations, but that the quality-based method is closer to the line than the "height-only" criterion. This suggests that by selecting less attenuated data, the new criterion can decrease radar undersampling of these high values.

Conclusions

The error-based compositing criterion improves composite data selection at high rain rates by three independent measures: improved quantitative statistics, reduced radar undersampling of intense precipitation events, and visible improvements. For these reasons it has been implemented on the UK operational system, and the method submitted for publication.

There is scope for additional work in investigating whether this scheme, with a refined VPR error model and in the presence of improved attenuation estimation and quality control, could be used to construct a robust theoretical model of rain rate error. Such work could be feasible in the context of dual-polarisation networks.

References

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