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Correcting for wind drift in high resolution radar rainfall products: a feasibility study

Caroline Sandford *

Met Office, Fitzroy Road, Exeter, Devon EX1 3PB, UK

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SUMMARY

Increasing demands from emergency responders for accurate flood prediction, particularly in cities, have motivated consistent increases in the resolution of urban drainage models. Such models are now primarily limited by the accuracy and resolution of the initialising rainfall field. Surface rainfall estimates from radar, traditionally derived at scales of order 1 km, are now requested at grid lengths of 100 m to drive improvements in the outputs of these models.

Deriving radar precipitation products on grids at the sub-kilometre scale introduces new requirements for the processing of reflectivity measurements into surface rainfall rates. A major source of uncertainty is the physical distance between the radar measurement and the surface onto which precipitation falls. Whilst adjustments to account for inhomogeneity in the vertical reflectivity profile have been extensively investigated, the effects of horizontal displacement have not.

This paper discusses the issue of wind drift, first by outlining the need for correction, and then by evaluating the corrections available for impact at the required scale. One correction is detailed and its sensitivity evaluated with respect to the assumptions necessary in its derivation. These sensitivities are verified by trials on the Met Office operational radar processing system, where errors on wind drift displacement estimates are shown to be of order 1 km or more. This is significantly greater than the grid length desired by hydrological users. The paper therefore concludes by suggesting further research necessary to ensure the accuracy of radar precipitation estimates at sub-kilometre resolution.

1. Introduction

Quantitative precipitation estimates (QPEs) from meteorological radar are well-established as inputs to nowcasting and hydrological models (Cole and Moore, 2008; Tilford et al., 2002; Vivoni et al., 2006), thanks to the high coverage and spatio-temporal resolution that radar networks provide. As models have increased in complexity the expectations on radar data have become more stringent (Emmanuel et al., 2012). In particular, the possibility for radar to obtain accurate measurements at very high spatial resolution has led to increasing demands in the fields of urban hydrology and flood forecasting (Veldhuis et al., 2012).

Radar QPEs are derived from reflectivities measured hundreds or thousands of metres above ground level, and correcting for this displacement is key to obtaining accurate surface rain rates. The numerical adjustment for non-homogeneous vertical profile of reflectivity (VPR) is known to be uncertain, and has been the subject of numerous studies (Berenguer et al., 2008; Kirstetter et al., 2013; Kitchen et al., 1994). Implicit in these studies is the assumption that a vertical profile corresponds to the physical path traced by hydrometeors as they fall from the radar beam to ground level. In a non-zero wind field, however, particle fall paths are not vertical, and vertical extrapolation leads to errors in surface rainfall placement. This effect is termed “wind drift”.

The impact of horizontal drift has been considered in some non-operational contexts. In studying rainfall measurements at short range, for example, Harrold et al. (1974) found that a simple correction for surface winds in the rain layer could significantly reduce discrepancies between radar and rain gauge over small catchments. Potential hydrological effects are discussed by Collier (1999), who characterises the contribution of wind drift to QPE error at several resolutions. The paper concludes that beyond a certain point, increasing radar resolution to capture small scale rainfall features could actually decrease the accuracy of the final product if the wind profile is not accounted for.

The RainGain project is an international collaboration aiming to improve pluvial flood forecasting in urban environments. All aspects of flood forecasting are considered, from rainfall measurement through modelling to operational management. Fine scale

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* Tel.: +44 1392 884425.
E-mail address: caroline.sandford@metoffice.gov.uk

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variability in the urban context is increasingly well-captured by hydrological models, which can accurately assess the local impacts of precipitation and predict flood locations. The limiting factor in the success of these models is the accuracy and resolution of the radar-derived rainfall field (Gires et al., 2012; Schröter et al., 2011).

As a RainGain contributor, the Met Office is currently pursuing research into high resolution radar QPE, with the aim of generating accurate radar rainfall estimates over two pilot catchments on a 100 m grid. At the 100 m scale, and for localised flooding applications, the impact of wind drift cannot be ignored. However, such fine resolution in the final product sets stringent requirements on the accuracy and precision of a wind drift correction. It is essential that this correction is capable of resolving wind drift displacements on the product grid scale.

Few algorithms exist to quantify or correct for radar wind drift. Mittermaier et al. (2004) identify horizontal drift of order 10–20 km where the radar samples above freezing level (typically at ranges exceeding 100 km). The authors propose a correction for fall streak profile in the snow layer using Met Office mesoscale model wind profiles. A similar algorithm is tested on the Finnish operational rain rate composite by Lauri et al. (2012), which extends the original wind drift model to the melting and liquid layers, using a simple drop fall speed profile to calculate total displacements. Neither algorithm is assessed for accuracy on a fine scale grid.

Knowing the resolution at which wind drift cannot be neglected, this paper considers limitations on the conditions under which a wind drift correction can be expected to be effective. The question is investigated by assessing the sensitivity of wind drift displacements to the assumptions necessary in their derivation. The candidate algorithm and its implementation are described in Section 2. Section 3 documents a sensitivity study into the effects on wind drift displacements of assumptions on the vertical wind profile. Further assumptions and approximations are discussed in Section 4. These studies indicate the correction is unlikely to be of use at sub-kilometre resolutions, but may still benefit radar products on coarser grids. The results of a trial on operational radar data in Section 5 are shown to be consistent with sensitivities identified in previous sections.

2. The wind drift correction algorithm

2.1. Context and overview

The UK radar data processing system (Radarnet) ingests polar radar volume scans on a five-minute cycle. Scans are quality-controlled to remove non-meteorological echoes, and then corrected for the effects of attenuation and VPR (Harrison et al., 2000). Polar-to-Cartesian conversion is applied in compositing polar rain rates onto the UK national Cartesian grid.

Since one of the benefits of a wind drift correction is the potential for more accurate VPR determination (Mittermaier et al., 2004), the candidate algorithm is applied immediately before correction for VPR in the Radarnet processing chain. The algorithm takes as input a full radar volume containing 4–5 polar plan position indicator (PPI) scans, as well as ancillary data relating to attenuation and range. The data are adjusted in situ and output in the same polar format. This is in contrast to the work of Mittermaier et al. (2004) and of Lauri et al. (2012), who apply corrections to radar CAPPIs (constant-altitude PPIs) and Cartesian composites respectively.

The wind drift correction is executed on a pixelwise basis in the following steps:

1. Calculation of horizontal displacement along orthogonal Cartesian axes.
2. Translation of input cell centroid.
3. Regridding of input value to output cells.

Each radar pixel is adjusted as a whole: a process which assumes constant average parameters throughout the cell volume. This use of a bulk advection scheme has the advantage of imposing independence between the horizontal displacement of an input cell and the value it contains. With this independence it becomes possible to apply the same displacement field to several different quantities simultaneously, provided they all occupy the same input grid. Thus derived fields such as range and level of attenuation, which are required on Radarnet for later processing, can be adjusted alongside reflectivity at a reduced computational cost, and their values remain spatially consistent with the reflectivity measurements to which they correspond.

The alternative to bulk advection would be to use a drop sorting scheme for the adjustment of reflectivities. Lack and Fox (2005) investigate a scheme using 25 drop size bins for each pixel, relating the fall speed of each bin to average drop diameter, and compare their results to those from a bulk advection scheme. Although not its main focus, the paper does not identify any significant difference between these methods across a variety of CAPPI heights and spatial resolutions. This result further justifies the choice of a bulk advection scheme.

2.2. Fall streak profile adjustment

Horizontal displacements due to wind drift can be calculated in one of two ways. Prognostic corrections involve tracing the path of falling hydrometeors upwards, from the surface to intersection with the lowest radar scan. The fall time for this path is calculated and the reflectivity measurement from the appropriate time placed at the surface. A prognostic approach is described in detail by Lauri et al. (2012) and illustrated in their Fig. 4.

The alternative approach, used in this paper, is to adjust for instantaneous fall streak profiles (FSPRs): the parabolic arcs intersecting a series of particle fall paths at the same point in time. These arcs are visible in range-height indicator (RHI) scans in sheared wind fields (Mittermaier et al., 2004 Figs. 1 and 2). In this paper, Fig. 1 illustrates the difference between prognostic and diagnostic models. Where a prognostic correction assumes zero horizontal velocity at the surface, the diagnostic algorithm effectively shifts the zero-velocity reference point to the generating level. This diagnostic approach has the advantage of requiring only the latest wind and reflectivity data, rather than a full timeseries of radar volumes.

Mittermaier et al. (2004) calculate FSPRs above the melting layer using a wind profile with constant vertical shear, and demonstrate that UK mesoscale model wind and wet bulb freezing level forecasts are sufficiently accurate to calculate this displacement. Their algorithm is extended here to adjust for hydrometeor drift in the melting and liquid layers, extrapolating the linear wind profile to the surface and using a drop fall speed profile that increases linearly through the melting layer (Lauri et al., 2012).

The horizontal extent of an instantanous fall streak is calculated by integrating horizontal velocity $u(h)$ over fall time with respect to the generating level (h_{Gen}):

$$\Delta x_{fspr} = \int_0^t (u(h) - u_{Gen})dt = \int_{h_b}^0 \frac{u(h) - u_{Gen}}{w(h)} dh \qquad (1)$$

where $w(h)$ is the drop fall speed at height h, h_b is the height of the radar beam axis at the measurement location and u_{Gen} is the horizontal wind speed at the generating level. Despite the increasing importance of wind drift correction with range, Eq. (1) does not account for beam broadening. In the context of a bulk advection