A wind drift correction for radar rainfall products

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1. Introduction

Quantitative precipitation estimation (QPE) by meteorological radar is affected by many uncertainties that cause radar-derived values to deviate from surface measurements. Errors in rainfall estimates arising from such factors as attenuation, beam blockage and range effects have been the subject of many studies, and a variety of schemes exist to mitigate them (Villarini and Krajewski, 2010). Such studies, however, neglect the horizontal motion of hydrometeors below the radar measurement volume, which can result in the misplacement of precipitation at the surface. This effect is known as "wind drift".

The RainGain project aims to increase cities' resilience to extreme rainfall events by improving flood forecasting over small urban catchments. For this application, a 100m-gridded radar rainfall product is desired. At 100m resolution the effects of wind drift can be severe (Collier, 1999), with significant downstream impacts for hydrological modelling. This work describes the design, coding and evaluation of a real-time wind drift correction on the UK radar post-processing system (Radarnet) for use in production of a high-resolution composite for RainGain.

2. Theory

There are two possible approaches to correcting for wind drift in radar data. The prognostic approach involves tracing the path of a falling hydrometeor from the surface upwards until it intersects the lowest radar scan. The fall time for this path is calculated, and the measurement from the appropriate time is placed at the surface (Lauri et al. 2012). The diagnostic approach is to correct for instantaneous fall streak profile (FSPR): the parabolic arc visible in RHI scans in sheared wind fields (Mittermaier et al. 2004). The diagnostic correction requires only the latest wind and reflectivity data, and is thus better suited to the Radarnet architecture.

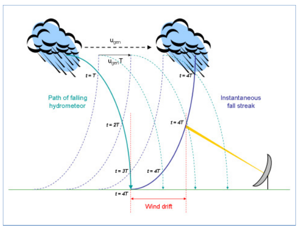

Figure 1: Schematic of wind drift as observed by radar in a wind field with constant vertical shear.

The new algorithm is an extension of that proposed by Mittermaier et al. (2004) to adjust fall streak profiles above the melting layer. The displacement due to wind drift (as marked in figure 1) is simply the integral of horizontal wind speed over increments of time. Assuming an analytical form for wind speed, and replacing time with an integral over height, displacement is fully described by:

$$\Delta x = \int_{h_b}^{0} \frac{u(h) - u_{gen}}{w(h)} \mathrm{d}h$$

Before FSPR correction, all radar PPIs in a single volume are synchronised to the composite validity time:

$$\Delta x_{synch} = u(h_b) \times (t_{comp} - t_{scan})$$

3. Implementation

The wind drift correction is applied to quality-controlled PPIs from the UK C-band radar network. A bulk advection scheme is used to calculate displacements on a pixelwise basis using the equations above.

3.1 Approximations

To calculate FSPR requires certain assumptions. In this work it is assumed that the wind profile has constant vertical shear, so that wind speed is a linear function of height. Particle fall speed is assumed to be 1m/s in the snow layer, rising linearly to 5m/s in rain through a melting layer extending 700m below freezing level (Lauri et al., 2012). Lack of data regarding winds in the vertical plane requires that their effects on fall speed are neglected. The horizontal wind speed at generating level is calculated from the linear wind profile using an estimate of generating height at 2.8km above freezing level (Mittermaier et al. 2004).

3.2 Ancillary data

The additional data required for the wind drift correction are obtained from radar volume metadata (scan times, elevations and grid properties) and from UKV forecast model fields (wet bulb freezing level and 3D-gridded horizontal winds). Pixelwise wind profiles are calculated between model levels at heights of 1km and 5km.

3.3 Sensitivity

The effect of the constant shear profile assumption on wind drift displacements was simulated for beam heights of up to 6km, by comparing displacements calculated from the 1-5km shear to those obtained from full 63-level model profiles. The average accrued error was found to be of order 1km in the rain layer, rising significantly for radar measurements in snow (figure 2).

4. Evaluation

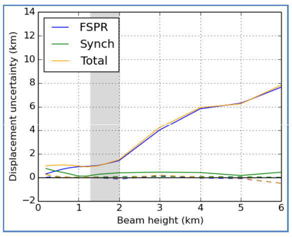

Figure 2: Simulated bias (dotted) and RMSE (solid lines) of constant shear displacements for a 2km freezing level.

Analysis of the sensitivity of wind drift to assumptions on the wind profile suggested that whilst the correction may not produce measurable benefits at 100m, positive effects might be visible on a coarser grid. The algorithm was tested at 1km as well as 100m resolution. Hourly radar accumulations were compared with those measured by rain gauges at five intensity thresholds.

The results of a 4 month study on 1km products are shown in figure 3. Both POD and FAR are improved at all but the highest intensities, demonstrating a reduction in the "double penalty" effect that results from misplaced radar surface precipitation. The decrease in skill for higher intensity, smaller scale events suggests that the total displacement error may be larger than 1km.

As expected from the sensitivity study, which showed RMS errors of order 1km even at the lowest beam heights, correction for wind drift displacement by the method described provides no benefit on 100m grid. The difference in long term statistics between drifted and undrifted fields is small, with the slight detrimental impact likely due to the smoothing of small-scale features during regridding. However the improvements at 1km suggest the method, in theory, is sound.

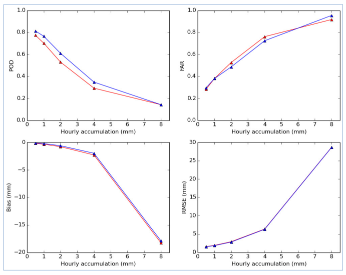

Figure 3: 4 month gauge comparison statistics for drifted (blue) and undrifted (red) hourly radar accumulations at 1km resolution.

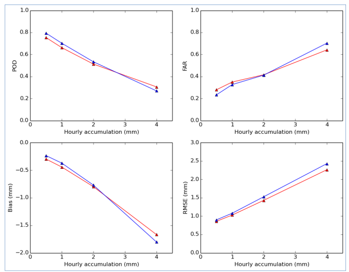

Figure 4: 2 month gauge comparison statistics for drifted (blue) and undrifted (red) hourly radar accumulations at 100m resolution.

5. Conclusions

The results presented here suggest that the wind drift correction has skill for low to moderate rain rate events on kilometre-scale grids. Qualitative performance is improved in terms of increased POD and slightly decreased FAR, and there is no significant impact on quantitative statistics.

At 100m the correction shows no skill. This supports the conclusion of the sensitivity studies, that cumulative uncertainties in the calculation of wind drift displacement cause final placement errors of order 1km even at low beam heights, so that quantitative improvements cannot be expected on sub-kilometre grids.

The limiting factors in accuracy of the proposed wind drift correction are the assumptions on the wind profile. Further work in this area could focus on more detailed parameterisation of horizontal winds, particularly at low levels, where boundary layer effects may be significant.

References

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