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Adjustment of wind-drift effect for real-time systematic error correction in radar rainfall data

Qiang Dai [a,b,c,*], Dawei Han [b], Lu Zhuo [b], Jing Huang [d], Tanvir Islam [e,f], Shuliang Zhang [a,c]

[a] Key Laboratory of VGE of Ministry of Education, Nanjing Normal University, Nanjing, China
[b] WEMRC, Department of Civil Engineering, University of Bristol, Bristol, UK
[c] Jiangsu Center for Collaborative Innovation in Geographical Information Resource Development and Application, Nanjing Normal University, Nanjing, China
[d] State Key Laboratory of Hydrology-Water Resources and Hydraulic Engineering, Hohai University, China
[e] NOAA/NESDIS Center for Satellite Applications and Research, College Park, MD, USA
[f] Cooperative Institute for Research in the Atmosphere, Colorado State University, Fort Collins, CO, USA

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A B S T R A C T

An effective bias correction procedure using gauge measurement is a significant step for radar data processing to reduce the systematic error in hydrological applications. In these bias correction methods, the spatial matching of precipitation patterns between radar and gauge networks is an important premise. However, the wind-drift effect on radar measurement induces an inconsistent spatial relationship between radar and gauge measurements as the raindrops observed by radar do not fall vertically to the ground. Consequently, a rain gauge does not correspond to the radar pixel based on the projected location of the radar beam. In this study, we introduce an adjustment method to incorporate the wind-drift effect into a bias correlation scheme. We first simulate the trajectory of raindrops in the air using downscaled three-dimensional wind data from the weather research and forecasting model (WRF) and calculate the final location of raindrops on the ground. The displacement of rainfall is then estimated and a radar–gauge spatial relationship is reconstructed. Based on this, the local real-time biases of the bin-average radar data were estimated for 12 selected events. Then, the reference mean local gauge rainfall, mean local bias, and adjusted radar rainfall calculated with and without consideration of the wind-drift effect are compared for different events and locations. There are considerable differences for three estimators, indicating that wind drift has a considerable impact on the real-time radar bias correction. Based on these facts, we suggest bias correction schemes based on the spatial correlation between radar and gauge measurements should consider the adjustment of the wind-drift effect and the proposed adjustment method is a promising solution to achieve this.

1. Introduction

The radar measurement has to be carefully processed to adjust for a series of physical fundamental problems such as ground clutter, anomalous propagation, signal attenuation (including radome wetting), beam blockage, and vertical variability of the reflectivity (Jordan et al., 2000; Ulbrich and Atlas, 2002; Michelson and Sunhede, 2004; Berne et al., 2005; Anagnostou et al., 2006; Campos et al., 2006; Germann et al., 2006; Villarini et al., 2008; Villarini and Krajewski, 2010). Volumetric estimations of rainwater via radar are subject to systematic biases in nature (Austin, 1987; Smith et al., 1996; Dai et al., 2014). After the aforementioned processes, real-time correction of the biases in radar–rainfall data using reference rainfall information, such as from a rain gauge, is an essential step (Collier et al., 1983; Collier, 1986; Smith and Krajewski, 1991). The performance of bias correction is extremely important to hydrological applications with radar data as input or for measuring initial conditions. The real-time bias correlation schemes can be carried out for the entire study area or just for the local domain, both of which are used by the National Weather Service (NWS) system (Hudlow, 1988; Fulton et al., 1998). The mean-field correction schemes use a uniform bias for the whole study area (Smith and Krajewski, 1991; Anagnostou and Krajewski, 1998; Seo et al., 1999), while the local correction schemes consider the spatial variation of radar measured bias (Wilson, 1970; Brandes, 1975; Collinge, 1991; Seo and Breidenbach, 2002a, 2002b).

* Corresponding author at: Water and Environmental Management Research Centre, University of Bristol, 93 Woodland Road, Bristol BS8 1US, UK.
E-mail addresses: q.dai@bristol.ac.uk, dqgis@hotmail.com (Q. Dai).

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For these bias correction methods, the spatial matching of precipitation patterns between radar and gauge networks is a significant premise. However, due to wind effects, the raindrops observed by the radar do not always fall vertically. In other words, wind can cause the drift of raindrops to induce an inconsistent spatial correlation between radar and gauge measurements. Several previous studies have tried to solve this issue (Collier, 1999; Mittermaier et al., 2004; Lack and Fox, 2005, 2007; Lauri et al., 2012; Dai and Han, 2014; Dai et al., 2013). However, as of yet, no one has considered this problem for real-time bias corrections. To obtain correct spatial correlations, adjustment for the wind effect on radar–gauge comparisons should be carried out. This should be undertaken after the aforementioned physical processes and before bias correction. The current study integrates the wind-drift adjustment method and bias correlation schemes to produce a displacement-based bias correlation. We simulate the movement of raindrops in the air using the downscaled three-dimensional hourly wind data from the weather research and forecasting model (WRF). Then, the final locations of radar–measured raindrops on the ground are estimated, which are used to construct the new radar–gauge pairs. A real-time local bias correction method is introduced that considers the spatial and temporal sampling errors in radar and gauge measurements. The adjusted spatial relationship of radar and gauge data is used to correct the bias in the radar data.

This paper is organized as follows. Section 2 describes the data and models used in this study. Section 3 introduces the adjusted method for wind-drift effects, and Section 4 describes the real-time bias correction scheme. The results and discussion of the proposed scheme are given in Section 5. Conclusions and future work are summarized in Section 6.

2. Study area and data source

Two kinds of rainfall datasets are used in this study: weather radar and dense rain gauge network available through the British Atmospheric Data Centre (BADC). The Brue catchment in Somerset, south-west England (51.08°N and 2.58°W), is chosen as the experimental catchment for this study. The maps of the Brue catchment and locations of rain gauges and radar pixels are shown in Fig. 1. In the left map of Fig. 1, 49 rain gauges are shown in blue dots, which are tipping bucket gauges (TBRs) with 0.2 mm resolution (Dai et al., 2014). There are 9 × 8 radar pixels in the map with 2 km as the pixel size. Among them, 52 pixels are overlapped by the Brue catchment, and 28 pixels are covered with the most area. One can observe there are at least one rain gauge in each of 28 radar pixel cells, increasing to two gauges along two parallel southwest to northeast lines across the catchment. The radar data are from the Wardon Hill radar, located at a range around 40 km from the center of the catchment. The right map of Fig. 1 shows the river network and the terrain elevation of the catchment. It can be seen from the figure that the elevation of the catchment is from about 35 m to 190 m above the sea level.

The dataset used to drive WRF model to downscale the wind data is taken from the ERA-40 reanalysis data produced by the European Centre for Medium-range Weather Forecasts (ECMWF). ERA-40 is assimilated from many sources using a three-dimensional variation assimilation system with a 6-h analysis cycle.

To evaluate the performance of the proposed scheme, 12 typical events with around 24 h duration are chosen from the period when all the above mentioned datasets are available, which are listed in Table 1. To avoid bringing in new uncertainty, we do not adopt any methods to fill the gap if part of radar pixels or rain gauges record missing data. Table 1 shows the event ID, start, end time and duration of the events, together with the accumulated event rainfall. The accumulated values are calculated using gauge measurements. To better compare the estimated real-time biases among different events, the selected events all have fixed duration of 24 h. To be consistent with the ECMWF data, the start and end times are set to 00, 06, 12 and 18 UTC.

3. Adjustment for the wind drift effect

To adjust the inconsistent spatial relationship between radar and gauge measurements, we need to simulate the trajectory of raindrops observed by radar and their final location on the ground. There are four major factors that influence the magnitude of the wind-drift effect: three-dimensional wind fields from the radar

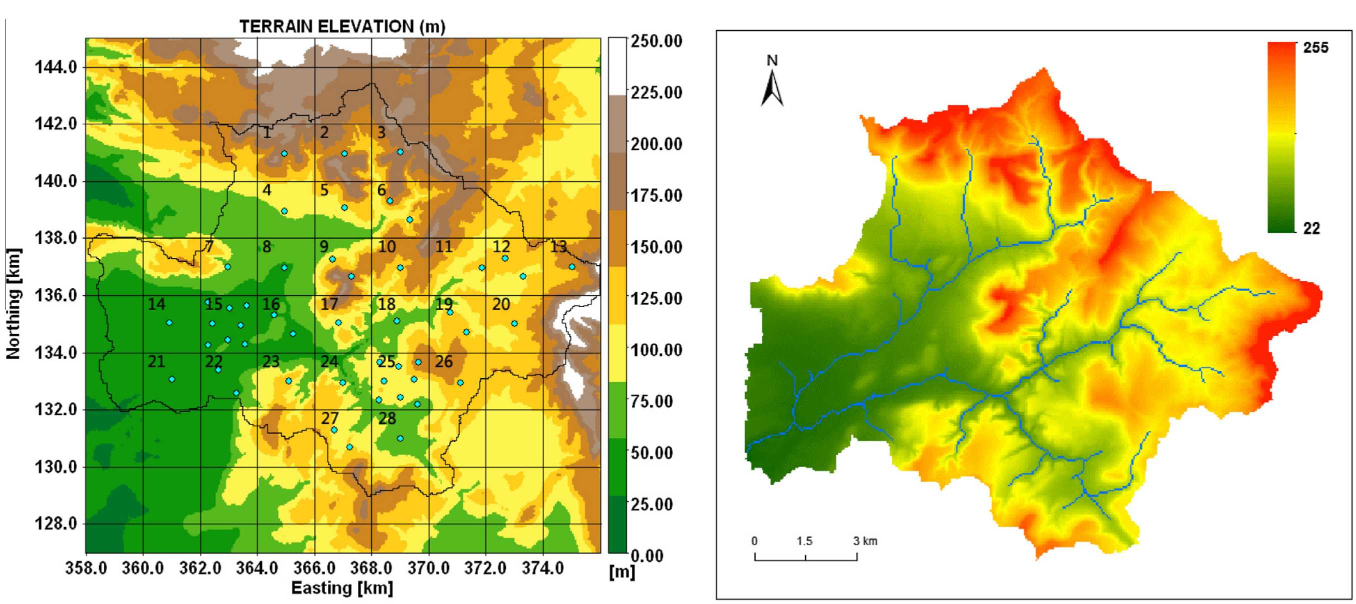

Fig. 1. Maps of the study area. The left map shows the rain gauge network and radar pixels (2 × 2 km). The indexes of the radar pixels are labeled in the map. The circle dots represent the rain gauge locations. The right map displays the rive network and the terrain elevation of the catchment. Both maps are drawn based on the British National Pixel coordinate system.