4B.7 CORRECTING RADAR DERIVED RAINFALL RATES AT THE SURFACE USING DOPPLER VELOCITIES

Steven A. Lack* and Neil I. Fox
Atmospheric Science Program
University of Missouri-Columbia, Columbia, Missouri

1. INTRODUCTION

It is ideal for hydrologists, especially urban hydrologists, to incorporate precipitation information from radar observations in their models rather than using scattered point measurements from rain gauges. However, precipitation estimates derived from radar need to be accurately represented on the surface for such applications. This study is a simplified examination of the error in surface precipitation caused by the wind drift of precipitation. This problem was originally discussed by Gunn and Marshall (1955), but has only been alluded to in publications a few times over the last 50 years. With the use of Doppler wind velocities and some simplified assumptions, it is possible to generate a correction scheme to represent precipitation at the surface based upon the advection of raindrops by the wind given by the radar. Allowing for wind drift in high spatial resolution radars can lead to the desired enhanced accuracy of rainfall estimates for applications in urban hydrological modeling (Collier, 1999).

2. METHODOLOGY

The background problem to this theoretical advection of precipitation is to calculate the contribution from individual gridded data squares (pixels) to other nearby squares. This is accomplished by taking a Cartesian grid of reflectivity and overlaying u and v components of the wind, given by the Doppler radar, and applying some simplified expressions relating these variables. From the given data, calculations of droplet fall speed can be made within an individual grid square leading to the wind drift in the x and y directions of the droplets, which results in a given pixel's contribution to another grid location. Finally, each square in a new grid is summed based on the contributions from the other nearby squares in the system yielding a new distribution of reflectivity, or rainfall rate, at the surface.

The first step in the process to generate a new field of surface rainfall rate by taking into account wind drift is to calculate a fall time for the drops within one pixel. This is accomplished by assuming that all droplets within one pixel have one average droplet diameter. By making this assumption, one can apply any Z-R relationship to convert reflectivity to a rainfall rate that is assumed uniform throughout the entire pixel. An equation (1) relating rainfall rate (R) in mmh^{-1} to fall speed (Vf) in ms^{-1}, derived from Lacy (1977), can be incorporated.

$$Vf = 4.5\, R^{(1/9)} \qquad (1)$$

As a side note, other equations relating reflectivity to fall speed may be substituted in place of (1) within the program. Once fall speed is calculated, the time it takes for a droplet to fall a certain distance can be found. The example shown later will be constant elevation gridded data (CAPPI); however, a simple scheme to take into account elevation angle has also been incorporated so that raw radar data can eventually be substituted.

The individual pixel contribution to other pixels is determined by simply multiplying the wind speed in the u and v directions by the fall time. The wind speed is determined by making an assumption on the shape of the wind profile from the surface to the elevation of the radar beam or CAPPI. Given the dimension of a single pixel a critical radius of

* *Corresponding author address:* Steven A. Lack, University of Missouri-Columbia, Atmospheric Science Program, 373 McReynolds Hall, Columbia, MO, 65211; email: salfg4@mizzou.edu

influence can be determined by finding the magnitude of the combined u and v wind components. If the critical radius is greater than the dimension of the individual square, the contribution to the original pixel is zero. This means that all of the precipitation from that square is being advected to a different location and most likely contributes to more than one other pixel within the given area.

Once the critical radius is found for each pixel, it must be determined which pixels contribute to each individual pixel. In most cases multiple pixels will contribute to a single pixel, unless the wind is calm in a given column making the critical radius zero resulting in no wind drift effect. Given the distance each area of precipitation travels in the x and y directions, the fraction of overlap onto other grid squares is calculated using simple geometry, and these overlapping areas are represented as fractions of the original square's reflectivity to a new pixel. All the fractions over one grid square are summed yielding a new reflectivity at that grid square. Once each pixel in the given grid is accounted for, the new field can be compared with the original field of reflectivity, or rainfall rate, and the errors associated with wind drift can be illustrated.

3. EXAMPLE OF CORRECTION

The following example is taken from the C-POL radar outside of Sydney, Australia used during the 2000 Summer Olympics (Fox et al. 2001). The u and v components of the wind and the reflectivity are all at a constant elevation. The wind components were obtained using the adjoint wind retrieval scheme of Sun and Crook (1994). The CAPPI in the following example was taken at 2500 meters above radar level and the pixel size is 2km x 2km. Using lowest elevation scans can also be implemented in the program code, and it is expected that as the distance away from the radar increases, height increases, and the effect of wind drift should also increase. The data presented is just one example to show the results of the simplified correction scheme.

The effects of wind drift can be examined given a reflectivity sample (Fig 1) and u and v components of the wind velocity (Fig 2 and Fig 3). To keep this a simplified example it is assumed that this is a stratiform case, with Z-R given by (2), and each pixel has one typical rainfall rate value so that (1) can be applied.

$$Z = 200R^{1.6} \tag{2}$$

The original sample used is shown below in Figure 1. It is important to note the general location of the higher reflectivity within the original data set for comparison with the wind drift correction.

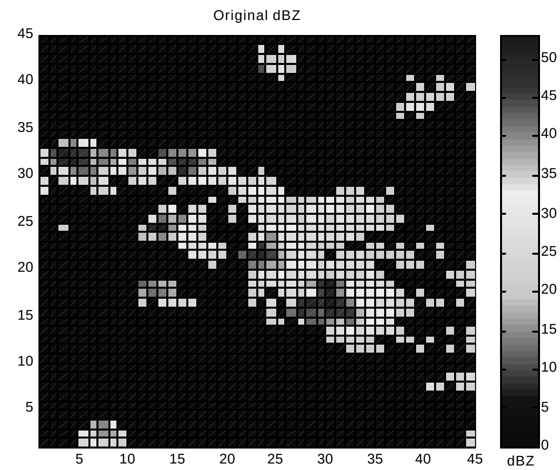

Fig 1. *The original dBZ from one time step in a 45 x 45 grid with each pixel representing a 2 km grid square (pixel).*

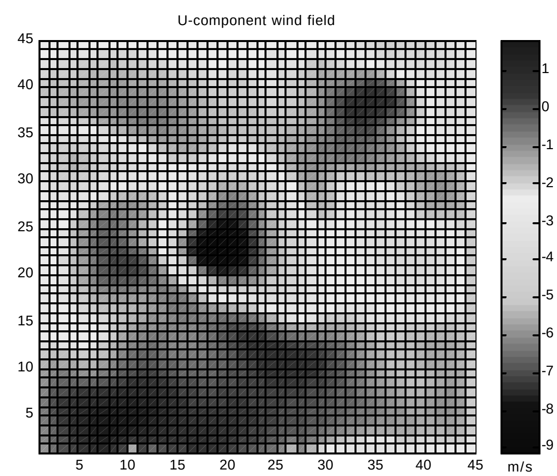

Fig 2. *The u-component of the wind field in ms^{-1} using an adjoint wind retrieval scheme.*

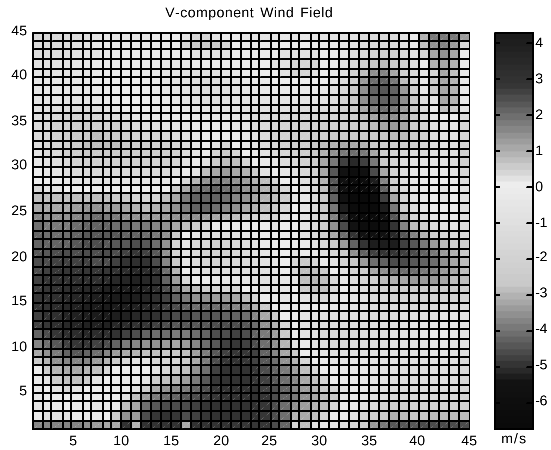

Fig 3. *The v-component of the wind field in ms^{-1}.*

Figure 4 represents the reflectivity at the surface after the wind drift correction has been applied. There is a noticeably larger area of significant reflectivity within the entire sample area. The enlargement is most noticeable in the cells that are located apart from the main line of reflectivity in the center of the image. For instance, the northernmost isolated cell and the southernmost isolated cell appear to spread out significantly due to wind drift of precipitation. It is also noticeable where gaps are present in the original and are subsequently filled in when the correction is applied, such as in the eastern and central portion of the images.

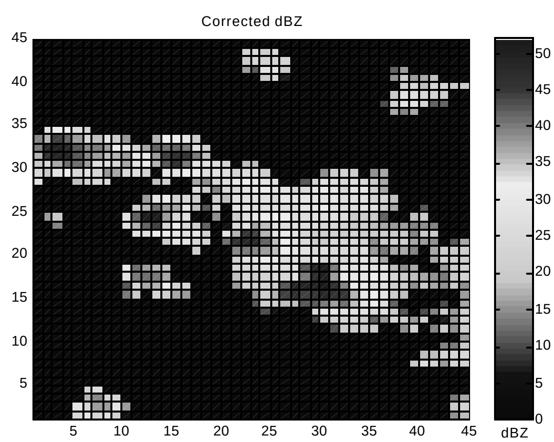

Fig 4. *The corrected dBZ from the same above time step, using a linear wind profile that decays to zero at the surface.*

The dispersion of reflectivity in the isolated storm cells in this example is just one feature of the error when including wind drift. There is also a pronounced edge effect where the wind is acting to advect the precipitation from the origin toward regions where precipitating clouds are not found. Figure 5 shows this edge effect quite well on the northeastern edge of the main line of precipitation activity. The errors show up quite large because where there is no return from the original sample at 2500 meters, there is, in fact, precipitation falling at the surface in the given location. Just the opposite is observed in the central regions of the sample area where there is a negative error resulting from precipitation being advected away from a region that originally had a significant return before the correction was applied. In the case of a training event with storms moving roughly over the same region, the edging effect could result in large errors over the duration of the event along the edge of reflectivity if the correction scheme is not applied.

There are other errors not accounted for in this scheme for obtaining surface rainfall rate from elevated reflectivity. Of these, evaporation below cloud is one. If it is assumed that there is cloud cover over this entire region, evaporation below cloud base is less likely to occur, especially for large returns signifying large drops, resulting in a higher confidence for the correction scheme.

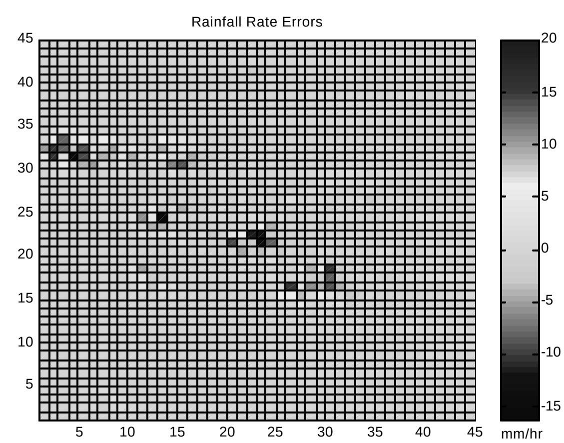

Fig 5. *The difference between the original rainfall rate and the corrected rainfall rate from Fig 1 and Fig 2 respectively.*

Although the largest error results from precipitation being advected over regions where there is originally no echo and vice versa, convergence and divergence within a storm can also lead to appreciable error. Given actual measurement of the u and v components of the wind velocity, regions having significant convergence and divergence will appear within a sample. In regions of convergence there is an increase of precipitation causing an underestimation of point surface rainfall in the absence of the correction. Conversely, in areas of divergence, smaller or even negligible rainfall rates occur at the surface. Original scans of reflectivity do not show possible areas where there could be enhancement due to convergence or diminishment in regions of divergence; however, these regions are important when applying precipitation amounts in hydrological models.

4. SUMMARY AND FUTURE WORK

Using simplified assumptions makes it easy to display the importance of using wind drift to accurately represent rainfall at the surface. Although wind drift does not account for high errors over time during stratiform precipitation, it is highly important in convective events. In cases of training thunderstorms, there is a definite storm edge effect. This edge effect causes rainfall accumulation errors over regions where the wind advects precipitation over an area that there is no reflectivity present on the active radar scan and away from areas in which an echo is present. Wind drift also results in enhanced precipitation in areas of local convergence and precipitation deficits in areas of divergence within a storm. Enhancing Z-R relationships by acquiring enhanced drop size distributions can only give an accurate representation of rainfall at the surface if wind drift is accounted for. In instances of rapid hydrological response, for example in urban areas, the instantaneous error in surface rainfall rate may be significant.

The program to correct for wind drift is malleable to accompany a variety of different assumptions. In the above examples it was assumed that the wind speed decayed linearly with height to zero at the surface. The above examples also used constant elevation plots; however, additional code can be added to account for different elevation angles. In the near future more complex wind profiles will be used that take into account estimations of surface wind fields. Also, drop size distributions will be added so that drop sorting can be accounted for within a single pixel. The incorporation of evaporation below cloud base will also be attempted in future trials. Eventually, this correction scheme will be applied to models to assess possible uses in hydrological applications. In order to achieve this accumulated rainfall totals will be examined in addition to single time steps.

REFERENCES

Collier, C.G., 1999: The impact of wind drift on the utility of very high spatial resolution radar data over urban areas. *Phys. Chem. Earth (B)*, **24**(8), 889-893.

Fox, N.I., M.W. Sleigh and C.E. Pierce, 2001: Forecast Demonstration Project Sydney 2000: Part 1: An overview of the project and the participating systems. *Weather,* **56,** 397-404.

Gunn, K.L.S. and J.S. Marshall, 1955: The effect of wind shear on falling precipitation. *Journal of Meteorology*, **12**, 339-349.

Lacy, R., 1977: Climate and Building in Britain, *Building Research Establishment Report*, Department of the Environment, Her Majesty's Stationary Office, London.

Sun, J. and N.A. Crook, 1994: Wind and thermodynamic retrieval from single-Doppler measurements of a gust front observed during PHOENIX II. *Mon. Wea. Rev.,* **122**, 1075-1091.