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Radar rainfall estimation for flash flood forecasting in small urban watersheds

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Abstract

Radar rainfall estimation for flash flood forecasting in small, urban catchments is examined through analyses of radar, rain gage and discharge observations from the 14.3 km^2 Dead Run drainage basin in Baltimore County, Maryland. The flash flood forecasting problem pushes the envelope of rainfall estimation to time and space scales that are commensurate with the scales at which the fundamental governing laws of land surface processes are derived. Analyses of radar rainfall estimates are based on volume scan WSR-88D reflectivity observations for 36 storms during the period 2003–2005. Gage-radar analyses show large spatial variability of storm total rainfall over the 14.3 km^2 basin for flash flood producing storms. The ability to capture the detailed spatial variation of rainfall for flash flood producing storms by WSR-88D rainfall estimates varies markedly from event to event. As spatial scale decreases from the 14.3 km^2 scale of the Dead Run watershed to 1 km^2 (and the characteristic time scale of flash flood producing rainfall decreases from 1 h to 15 min) the predictability of flash flood response from WSR-88D rainfall estimates decreases sharply. Storm to storm variability of multiplicative bias in storm total rainfall estimates is a dominant element of the error structure of radar rainfall estimates, and it varies systematically over the warm season and with flood magnitude. Analyses of the 7 July 2004 and 28 June 2005 storms illustrate microphysical and dynamical controls on radar estimation error for extreme flash flood producing storms.

Keywords: Flash flood; Rainfall; Weather radar

1. Introduction

Radar rainfall estimation for flash flood forecasting in small, urban catchments is examined through analyses of radar, rain gage and discharge observations from the 14.3 km^2 Dead Run drainage basin in Baltimore County, Maryland (Fig. 1; see [21,13]). Analyses are based on 36 storm events during the 2003–2005 period. The 2003 study period contained an unusually large number of heavy rainfall events, which contributed to the record annual rainfall accumulation in Baltimore of 1574 mm, breaking the record set in 1889 (see also [20]). The 2004 observing period includes the 7 July 2004 storm that produced the flood of record in Dead Run. The second largest flood peak in Dead Run during the 2003–2005 period resulted from a storm on 28 June 2005.

The flash flood forecasting problem [8,6,10] requires rainfall estimates at "small" spatial scales (1 km or finer) and "short" time scales (1–15 min). These space and time scales approach those at which the fundamental governing equations coupling rainfall and infiltration are developed. Advances in rainfall estimation for flash flood forecasting will bridge the gap between land surface modeling and space–time variability of rainfall.

In this study, rainfall analyses are based on volume scan reflectivity observations from the Sterling, Virginia WSR-88D (Weather Surveillance Radar-1988 Doppler) radar

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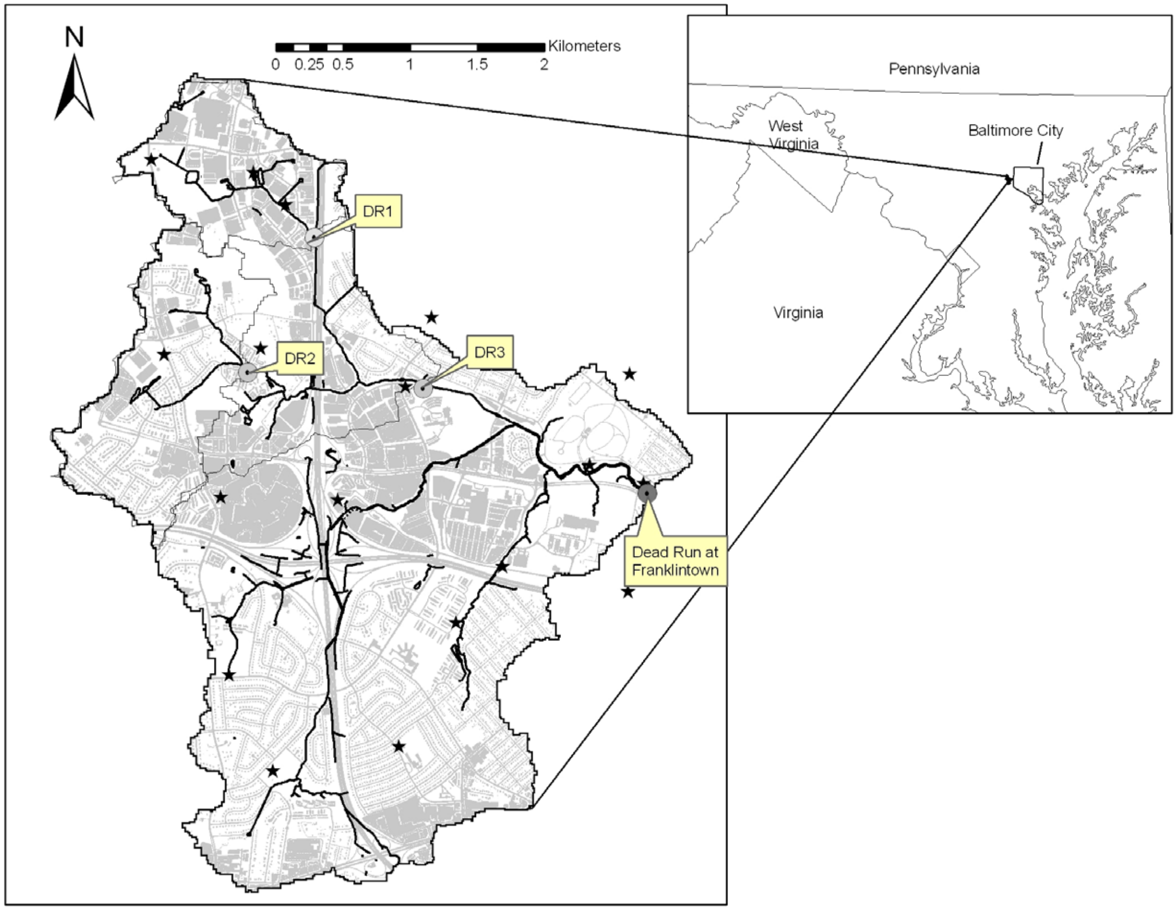

Fig. 1. Overview of the Baltimore study region. The basin boundary for the 14.3 km^2 Dead Run watershed is outlined. Rain gages are denoted by stars. Locations of the DR1, DR2, DR3 and Franklintown stream gages are shown. Grey scale indicates regions of impervious cover in Dead Run.

and storm total rainfall accumulations from a network of 18 double-gage platforms in the Dead Run watershed (Fig. 1). The Sterling WSR-88D radar is approximately 70 km from the Dead Run watershed. We also include analyses based on observations from a Joss-Waldvogel disdrometer. Discharge observations at 1–5 min time interval from a network of stream gages in the Dead Run watershed are used to relate radar rainfall estimates to flood response over basin scales ranging from 1.2 to 14.3 km^2.

The rainfall distribution for flood-producing storms in urban environments can exhibit large variability in time and space [14,15,3,23,11,24,19–21]. A focus of this study is examining the capability to resolve the spatial and temporal distribution of rainfall from WSR-88D reflectivity observations for flash flood forecasting.

The flood of record in Dead Run occurred on 7 July 2004 and was produced by rainfall accumulations with return intervals exceeding 100 years at time scales of 1–2 h. The second largest flood peak in Dead Run during the 2003–2005 observing period occurred on 28 June 2005 and was produced by rainfall accumulations of 75–100 mm, which were concentrated in the DR1 sub-basin of Dead Run (Fig. 1) during a time period less than 1 h. A focus of this study is radar rainfall estimation for storms that produce extreme rainfall and flash floods (see [12] for additional discussion). A detailed intercomparison of the radar and rain gage observations from the dense Dead Run rain gage network for significant warm season rain events during the 2003–2005 observing period is presented in Section 2. In Section 3, we examine the microphysical and dynamical controls on radar estimates of extreme rainfall through analyses of the 7 July 2004 and 28 June 2005 storms. A summary and conclusions are presented in Section 4.

2. WSR-88D rainfall estimation

In this section, we examine WSR-88D rainfall estimates for 36 storms during the 2003–2005 observing period (Tables 1 and 2). Volume scan reflectivity data (Archive Level II; see [9,1]) from the Sterling WSR-88D, which have a time resolution of 5–6 min and spatial resolution of 1 km in range by 1° in azimuth, were obtained for 23 storm events during the 2003 observing period, 12 events during the 2004 observing period and one event for the 2005 observing period. For each event, the basin-averaged storm total rainfall exceeded 5 mm. Storm total rainfall observations from the Dead Run rain gage network (Fig. 1) are used to examine the multiplicative bias in radar rainfall