Journal of Hydrology (2008) **351**, 1–12

available at www.sciencedirect.com

ScienceDirect

journal homepage: www.elsevier.com/locate/jhydrol

Comparison of gage and multi-sensor precipitation estimates over a range of spatial and temporal scales in the Midwestern United States

Nancy E. Westcott [a,*], H. Vernon Knapp [b], Steven D. Hilberg [a,*]

[a] *Illinois State Water Survey, Center for Atmospheric Science, 2204 Griffith Drive, Champaign, IL 61820, United States*
[b] *Illinois State Water Survey, Center for Watershed Science, 2204 Griffith Drive, Champaign, IL 61820, United States*

Received 15 November 2006; received in revised form 12 October 2007; accepted 17 October 2007

KEYWORDS
WSR-88D;
MPE multi-sensor precipitation estimate;
Precipitation;
Raingage

Summary An intercomparison of radar-estimated precipitation and gage precipitation at a monthly time scale with a county spatial resolution was undertaken for a nine-state region of the Midwestern United States. Daily gage and radar-estimated precipitation data also were examined at the county and grid cell scale for several smaller regions. Precipitation data were collected from February 2002 to August 2005 from three sources: (1) gridded radar (stage II, RDR) and multi-sensor precipitation estimates (MPE) based on the stage III/IV algorithm developed by the Office of hydrology/NWS River Forecast Centers, (2) quality-controlled National Weather Service (NWS) cooperative gage (QC_Coop) data from the National Climatic Data Center (NCDC), and (3) gage data from three high density networks in Illinois. Both the QC_Coop and high density gage data were employed as the reference standard.

Sixty-four percent of QC_Coop versus MPE county-averaged monthly precipitation estimates agreed to within ±25%, with a median difference of 5.6% (QC_Coop greater than MPE) for the Midwest region. The difference between gage and MPE monthly values decreased somewhat through the 41-month period of study, and the correlation between monthly estimates increased, averaging 0.80.

Data from three regional gage networks indicated that on a daily basis, network-averaged MPE and gage data also agreed to within about ±25%, and the MPE values tended to be lower than gage amounts at higher precipitation values. When examining multiple gages within single MPE grid cells, it was found that the number of gages employed in computing the gage average did not appreciably affect the correspondence between MPE and gage precipitation amounts. This also was found examining monthly values at the county level. For daily precipitation at the grid cell scale, for daily networked-averaged precipitation for each of the regional networks, and for monthly county-averaged precipitation

* Corresponding authors. Tel.: +1 217 244 0884; fax: +1 217 244 0220.
E-mail address: nan@uiuc.edu (N.E. Westcott).

0022-1694/$ - see front matter
doi:10.1016/j.jhydrol.2007.10.057

values across the Midwest, MPE values are often larger than gage values for lower gage precipitation totals, and as precipitation totals increase, MPE values are more likely to be the same or smaller than the gage value.

Introduction

Spatially representative precipitation estimates are crucial inputs for hydrologic models estimating soil moisture and ultimately crop yields, and for flood forecasting. Monitoring of developing conditions of excessive wetness or dryness requires timely access to precipitation data. The National Weather Service's Cooperative Observer Network (CON) is the core climate observing network of US, with an average spacing between rain gages in the central US of about 30 km. However, fully quality-controlled data are not available until several months after observations are taken. A small subset of CON stations report observations to a local NWS office daily, and these observations are transmitted along with other NWS products. These ''real-time'' CON data are quite valuable for climate monitoring purposes, but the spatial resolution (about one station every 70 km in the central US) is often inadequate to identify local areas of anomalous conditions, particularly during the warm season when convective rainfall predominates. Furthermore, data are sometimes inaccurate because of the minimal amount of quality-control that is possible.

For many purposes, for example the prediction of corn yields (Westcott et al., 2005), real-time or near-real-time precipitation summed by month and county over a large area such as the central Midwest is desired. Sometimes daily data are required over small areas within counties, such as small watersheds, however. Rain gage networks have been employed for such studies, but rain gage networks are costly to operate. In many locations where hydrologic models are used, rain gage density is insufficient and better spatial resolution of gages would improve model results. For example, real-time gage data are used as input into a river forecast model to evaluate potential actions to be taken to control water levels on rivers with dams such as for the Fox River watershed in northeastern Illinois (Knapp, 1998; Knapp et al., 1991).

Radar estimates of precipitation provide much improved spatial resolution ($\sim 4 \times 4$ km grid cells). Radars, however, have known problems related to the nature of the reflectivity-rainfall relationship, the location of the radar beam within the precipitating cloud, and other problems due to calibration, hail, anomalous propagation and ground clutter. These errors often are not uniformly distributed over the radar coverage area, because errors vary from storm to storm, and with distance from the radar. Errors also may vary from radar to radar. Many studies have shown that adjusting radar with gages can improve the radar measurements of precipitation (e.g. Huff, 1967; Wilson, 1970; Brandes, 1975; Hildebrand et al., 1979). Hildebrand et al. (1979) indicated that for convective precipitation and for gage densities of about one gage per 250–300 km^2 ($\sim 16 \times 16$ km), gage-alone and gage-adjusted-radar hourly rainfall estimates were of similar accuracy ($\sim$30%) when compared with precipitation from gages with a density of one gage per 30 km^2 ($\sim 5 \times 5$ km). They also indicated that for densities sparser than one gage per 250–300 km^2 (which is the case for the real-time observing network), gage-adjusted radar-rainfall estimates for convective situations may be more accurate than gage-alone estimates.

A number of recent studies have compared the gage precipitation with precipitation derived from the stage III (WSR88D plus gage) multi-sensor data (Stellman et al., 2001; Westcott and Kunkel, 2002; Jayakrvbishnan et al., 2004). These studies examined observations made prior to 2002. Stellman et al. (2001) indicated that for an area in Georgia, summer MPE values were of a similar magnitude to the gage estimates, but wintertime estimates considerably underestimated precipitation. For Texas, (Jayakrvbishnan et al., 2004) found a considerable underestimation of annual precipitation by MPE during 1996–1997, but a trend towards overestimation of annual precipitation by the MPE compared to gages for 1998 and 1999. Westcott and Kunkel (2002) found for 1997–1999 and 2001 that county-averaged precipitation for July was underestimated by the MPE compared to QC_Coop data in the early years of record, but with a noticeable improvement in 2001. This improvement came after upgrades to the radar system software and ground clutter maps (Personal communication, Timothy Crum, NWS Focal Point for WSR-88D Operational Issues, 2002).

In February 2002, a major upgrade was implemented by the National Oceanic and Atmospheric Administration's (NOAA) National Weather Service (NWS) Office of Hydrology and River Forecasting Centers, for computation of multi-sensor precipitation estimates, from the stage III to the stage III/IV MPE algorithm. In 2005, NOAA launched a web page allowing easy access to these $\sim 4 \times 4$ km gridded daily precipitation estimates for the contiguous United States (http://www.srh.noaa.gov/rfcshare/precip_analysis_new.php). With easier access to these measurements, it is desirable to examine the more recent MPE measurements in comparison with gage data. Kitzmiller et al. (2007) provides further documentation on the availability and status of current MPE products.

It is the intent of this paper to examine gridded precipitation estimates based on WSR-88D radar and gages for counties in the central Midwest region, and to determine how well they compare on a monthly time scale with precipitation estimates based on QC_Coop gage data, for February 2002 to August 2005. In addition, gridded data will be examined on a daily time scale in comparison with several regional gage networks to further evaluate the correspondence between multi-sensor and gage data.

Data and analysis

Precipitation data were collected from several sources for this study: (1) daily gridded WSR-88D radar (stage II, RDR),