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Using Remote Sensing and Radar MET Data to Support Watershed Assessments Comprising IEM

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Abstract: Meteorological (MET) data required by watershed assessments that comprise Integrated Environmental Modeling (IEM) have traditionally been provided by land-based weather (gauge) stations; although these data may not be most appropriate for describing adequate spatial and temporal resolution if the MET stations are too few, too far away, or operating improperly. To complement land-based stations, remote sensing and radar satellite data are being increasingly used in obtaining synoptic data with the spatial and temporal resolution required for site-specific and/or event-based assessments. This study compares and contrasts the viability of automating the use of radar satellite data and land-based gauge stations to support MET data collection for IEM applications, especially at those locations where gauge stations prove to be inadequate. Specifically, the North American Land Data Assimilation System (NLDAS) and NEXRAD (NEXt generation RADar) Multisensor Precipitation Estimates (MPE) are compared with gauge data at Milwaukee and Manitowoc, Wisconsin USA. NLDAS contains automatic quality control (QC), uses hourly gauge station data and modeled precipitation, provides estimates at hourly intervals with a 1/8th-degree resolution, and provides time series at specified locations. MPE contains data QC'ed by human forecasters, combines radar-based estimates with hourly gauge station data on a 4-km grid, provides all spatial data by time increment, and is based on newer algorithms than NLDAS. Results of the comparison showed excellent correlation between gauge and radar data at Milwaukee, while the Manitowoc results strongly suggested using radar over gauge data.

Keywords: Stage IV NEXRAD; MPE; NLDAS; scale; spatiotemporal

1. INTRODUCTION

Hydrologic and fate-and-transport components of watershed models are driven by precipitation, with the main sources originating from land-based precipitation gauges, Doppler weather radar, and satellite sensors (Moreau et al., 2009). Ground-based gauges are not associated with all watersheds and catchments; in fact, many watersheds do not have meteorological (MET) stations, are under-represented by MET stations, or have MET stations that are too far away to adequately represent the spatial and temporal distribution of precipitation. Price et al. (2013) note that precipitation gauge and weather radar data remain the best options for most watershed modeling applications within the United States, and although precipitation gauge data can be assumed to represent the most accurate source of information at the exact location of the gauge, precipitation is known to be highly variable spatially and areal totals are often poorly represented by point gauges (Strangeways, 2007; Starks and Moriasi, 2009; Tobin and Bennett, 2009). To provide options for watershed modelers, our intent is to automate the process of supplying MET data for watershed assessments, especially in areas where MET stations are too few, too distant, or operating improperly. The objective is to compare precipitation data associated with radar-based stations to that associated with ground-based gauge

stations to evaluate the efficacy of using either one to support watershed modeling within an integrated environmental modeling context.

2. METHODS AND MATERIALS

This study compares the North American Land Data Assimilation System (NLDAS) and NEXRAD (NEXt generation RADar) Multisensor Precipitation Estimates (MPE) to gauge data to evaluate the reliability of radar and gauge precipitation data by estimating and comparing correlation coefficients and conditional probabilities of precipitation occurrence according to distance between NLDAS and MPE radar stations and ground-measured gauge stations. We examine the overall reliability of radar and gauge precipitation data with the intent of providing options of using radar or gauge data in the modeling of stream flow in river basins.

Evaluations were performed in two areas: Manitowoc River Basin and Milwaukee area in Wisconsin, USA. In each, MPE and NLDAS (Phase-2) radar data were compared to gauge data at Manitowoc (44.133°N, 87.667°W) and Milwaukee (42.955°N, 87.904°W) which are approximately 135 km apart (Figure 1). Urban impacts (e.g., buildings) are minimized, as these locations are away from major structures. Ground-measured gauge data were obtained from the National Climatic Data Center (NCDC); we used hourly precipitation data from 2002 to 2011. We are going to apply radar data for modeling stream flow in the Manitowoc River Basin. Although additional gauges are available in or around the Manitowoc River Basin, they had relatively short records or only contained daily data and were excluded from the analysis.

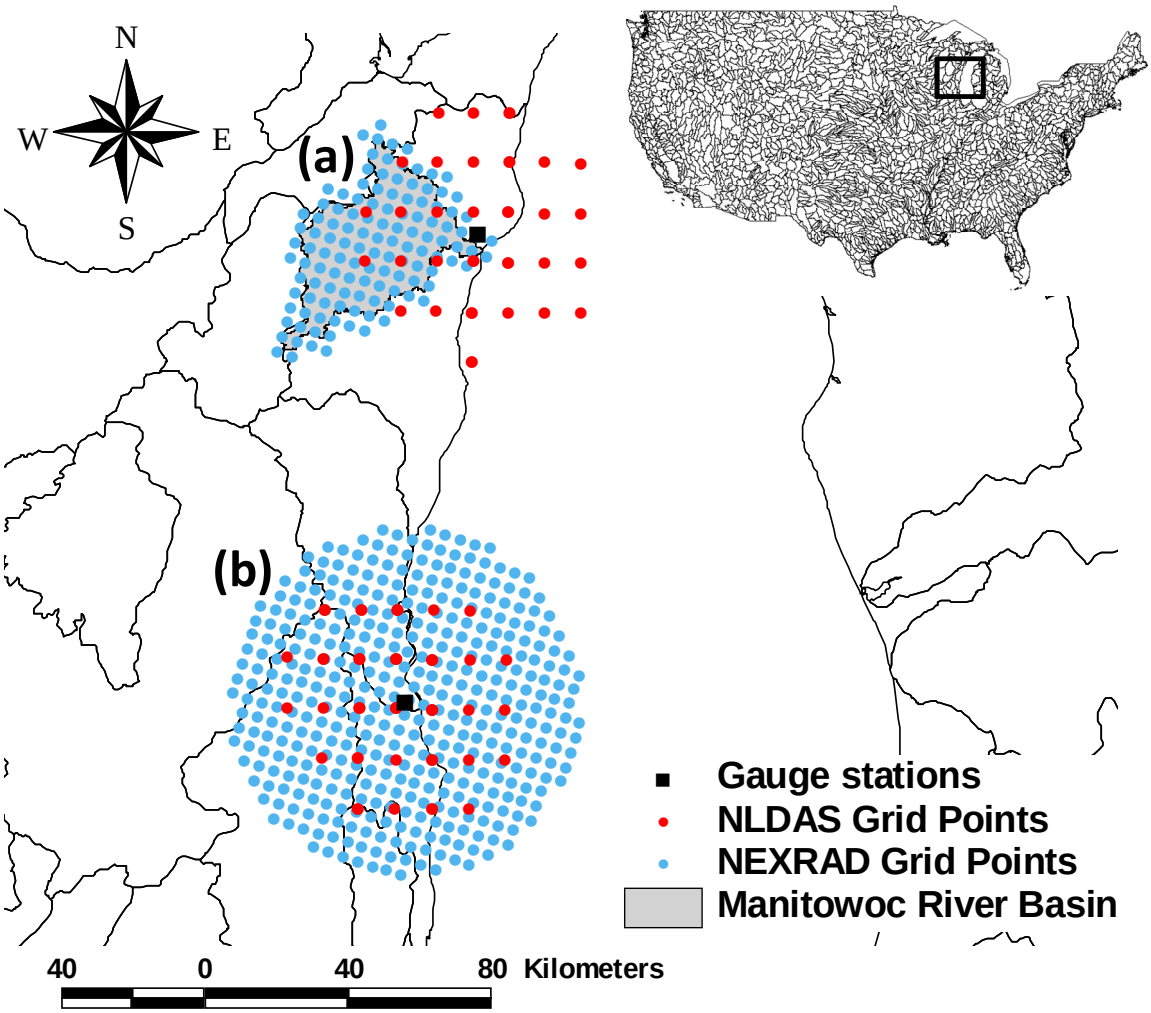

Figure 1. Distribution of gauge station and radar grid on (a) Manitowoc and (b) Milwaukee areas

NLDAS has created surface meteorological forcing data sets from the best available observations and re-analyses. NLDAS hourly data are widely used by various communities in modeling, research, and applications, such as drought and flood monitoring, watershed and water quality management, and case studies of extreme events (Vollmer et al., 2012). NLDAS consists of four land models executing in parallel in uncoupled mode, common hourly surface forcing, and common streamflow routing, all using a 1/8th-degree grid over the continental United States (Mitchell et al., 2004).

NEXRAD is a network of 178 Doppler weather radars (WSR-88D) across the United States from which high-spatial resolution precipitation estimates are derived; when adjusted, based on gauge data using the MPE algorithm, the result is gauge-conditioned data (Price et al., 2013). MPE is an instantaneous precipitation-rate product derived from the infrared data of the geo-stationary EUMETSAT satellites by continuously recalibrating the algorithm with precipitation data from polar orbiting microwave sensors. MPE contains data that are quality controlled by human forecasters, combines radar-based estimates with hourly gauge station data on a 4-km grid, provides spatial data by time increment, and is based on newer algorithms than NLDAS.

Table 1. Precipitation occurrence and total precipitation of radar and gauge data (2002-2011)

Range (mm/hr)	Manitowoc						Milwaukee					
	MPE		NLDAS		Gauge		MPE		NLDAS		Gauge	
	Count	Depth (mm)	Count	Depth (mm)	Count	Depth (mm)	Count	Depth (mm)	Count	Depth (mm)	Count	Depth (mm)
0 - 0.1	6611	174.9	10661	238.7	0	0.0	10623	245.5	13010	253.3	0	0.0
0.1 - 1	5675	2185.1	7044	2610.1	1313	560.3	6674	2433.3	6127	2306.7	3194	1301.2
1 - 5	1829	3725.9	2118	4261.2	766	1545.8	2083	4279.4	2188	4603.0	1724	3499.1
5 - 10	170	1110.5	114	729.9	77	513.8	140	909.4	205	1328.1	219	1473.7
10 - 100	25	383.2	11	133.2	48	952.0	9	123.3	24	317.5	58	984.8
>100	0	0.0	0	0.0	14	2815.6	0	0.0	0	0.0	0	0
	14310	7579.6	19948	7973.0	2218	6387.6	19529	7990.9	21554	8808.6	5195	7258.8

Table 1 and Figure 2 summarize precipitation occurrence and total precipitation amounts for ground-measured gauge stations and MPE and NLDAS radar grid points in the Milwaukee area and Manitowoc River Basin. Table 1 presents precipitation occurrence and total precipitation of areal-averaged radar and gauge data at Milwaukee and Manitowoc. Figure 2 presents the distribution of precipitation by method (i.e., MPE, NLDAS, and gauge), by location (i.e., Milwaukee and Manitowoc), and by intensity. Figures 2a and 2b distribute results by precipitation occurrence and precipitation volume, respectively.

3. RESULTS AND DISCUSSION

A three-part evaluation was implemented to compare NLDAS and MPE radar precipitation data to gauge data in the Milwaukee area and Manitowoc River Basin. First, correlation coefficients were determined between radar grid points, and between radar grid points and gauge locations. The distance between points refers to the distance between each point relative to every other, not just the adjacent point (see Figure 1). Second, conditional probabilities were determined between NLDAS, MPE, and gauge locations. Finally, precipitation occurrence and amounts for NLDAS, MPE, and gauge locations were compared.

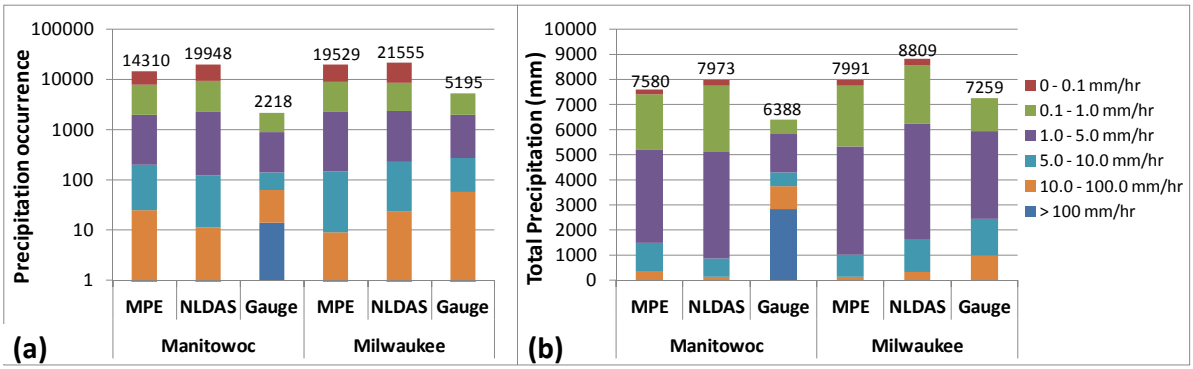

Figure 2. Comparison of (a) precipitation occurrence and (b) total precipitation between radar and gauge data

Scatter plots for correlation coefficients of precipitation, according to distance between radar grid points and between radar grid points and gauge locations in the Manitowoc River Basin and Milwaukee area are presented in Figure 3. Figures 3a and 3b present cross-correlation of precipitation amounts between MPE and NLDAS approaches at Manitowoc and Milwaukee, respectively. Figure 3c presents the spatial correlation of precipitation amounts for the MPE grid points at Manitowoc and Milwaukee, and Figure 3d presents the spatial correlation of precipitation amounts for the NLDAS grid points at Manitowoc and Milwaukee. Because there are more MPE than NLDAS grid points, there is a higher density of MPE results in Figure 3c, as compared to Figure 3d (see Figure 1). Figure 3e presents the cross-correlation of precipitation amounts between the MPE grid points and gauging stations at Manitowoc and Milwaukee. Figure 3f presents cross-correlation of precipitation amounts between the NLDAS grid points and gauging stations at Manitowoc and Milwaukee.

For the MPE and NLDAS results in Figures 3a through 3d, the correlation curves are continuous and decreasing, as expected, with maximum correlation coefficients near unity for adjacent points and gradually decreasing as distance increases between points. Similarly, in Figures 3c and 3d there is a stronger spatial correlation between radar-measured precipitation data when the points are closer to each other and with correlations near unity at adjacent points, then decreasing as distance between points increases. In Figures 3e and 3f, correlation coefficients between radar-measured precipitation data and gauge precipitation data in the Manitowoc River Basin show low values (<0.4 for MPE and <0.1 for NLDAS in Figures 3e and 3f, respectively) between points at all distances, while those in the Milwaukee area continue to have higher correlation coefficients for MPE and NLDAS data (>0.8 on MPE and >0.75 on NLDAS in Figures 3e and 3f, respectively), especially at nearer distances. A noticeable difference in correlation coefficients between NLDAS radar data and gauge precipitation data in Manitowoc River Basin is shown in Figure 3f, suggesting unreliable data in the temporal pattern and/or absolute values. In this case, the Manitowoc gauge data are suspect because the Milwaukee location, where the same approach is used, follows the same trend in magnitude and shape as the NLDAS and MPE approaches (see Figures 3a through 3d).

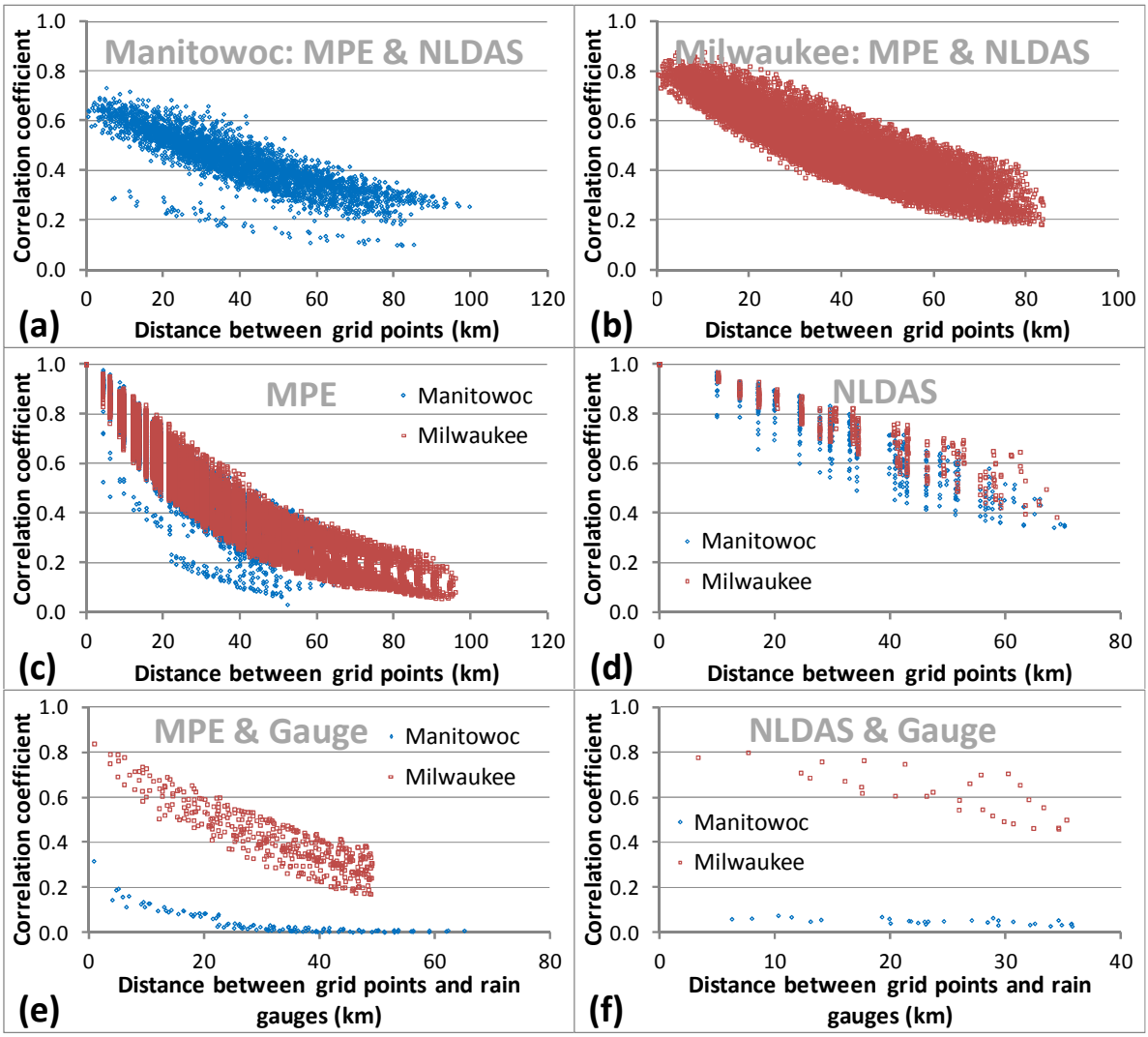

Figure 3. Cross-correlation of precipitation amounts between MPE and NLDAS grid points in (a) Manitowoc and (b) Milwaukee; spatial auto-correlation of precipitation amounts between grid points associated with (c) MPE and (d) NLDAS; and cross-correlation of precipitation between radar grid points (e) MPE and gauge stations and (f) NLDAS and gauge stations.

Scatter plots for conditional probability of precipitation occurrence (i.e., non-zero recorded precipitation amounts) between MPE and NLDAS radar grid points, and between radar grid points and gauge locations appear in Figure 4. Figure 4a presents the conditional probability that the NLDAS grid point will record precipitation when the MPE grid point does [i.e., P(NLDAS>0 | MPE>0)]. On the other hand, Figure 4b presents the conditional probability that the MPE grid point will record precipitation when the NLDAS grid point does [P(MPE>0 | NLDAS>0)]. When directly comparing the results within each figure for Milwaukee and Manitowoc, there is good overlap between the MPE and NLDAS results, regardless of the order in conditional probability, indicating consistency between the radar approaches at different locations. When comparing across figures, the conditional probability in Figure 4a is noticeably larger than in Figure 4b which signifies that more recorded precipitation occurred at the NLDAS grid points than the MPE grid points.

The conditional probability that the MPE grid point will record precipitation when the gauge station does [P(MPE>0 | Gauge>0)] is shown in Figure 4c. On the other hand, Figure 4d presents the conditional probability that the gauge station will record precipitation when the MPE grid point does [P(Gauge>0 | MPE>0)]. The conditional probabilities for Milwaukee in Figures 4c and 4d are similar, signifying that the recorded precipitations at MPE grid points and gauge stations are similar. The conditional probabilities for Manitowoc in Figure 4c, however, are noticeably larger than in Figure 4d

which signifies that more recorded precipitation occurred with MPE grid points than gauge stations; it also suggests less consistency between MPE grid points and gauge stations.

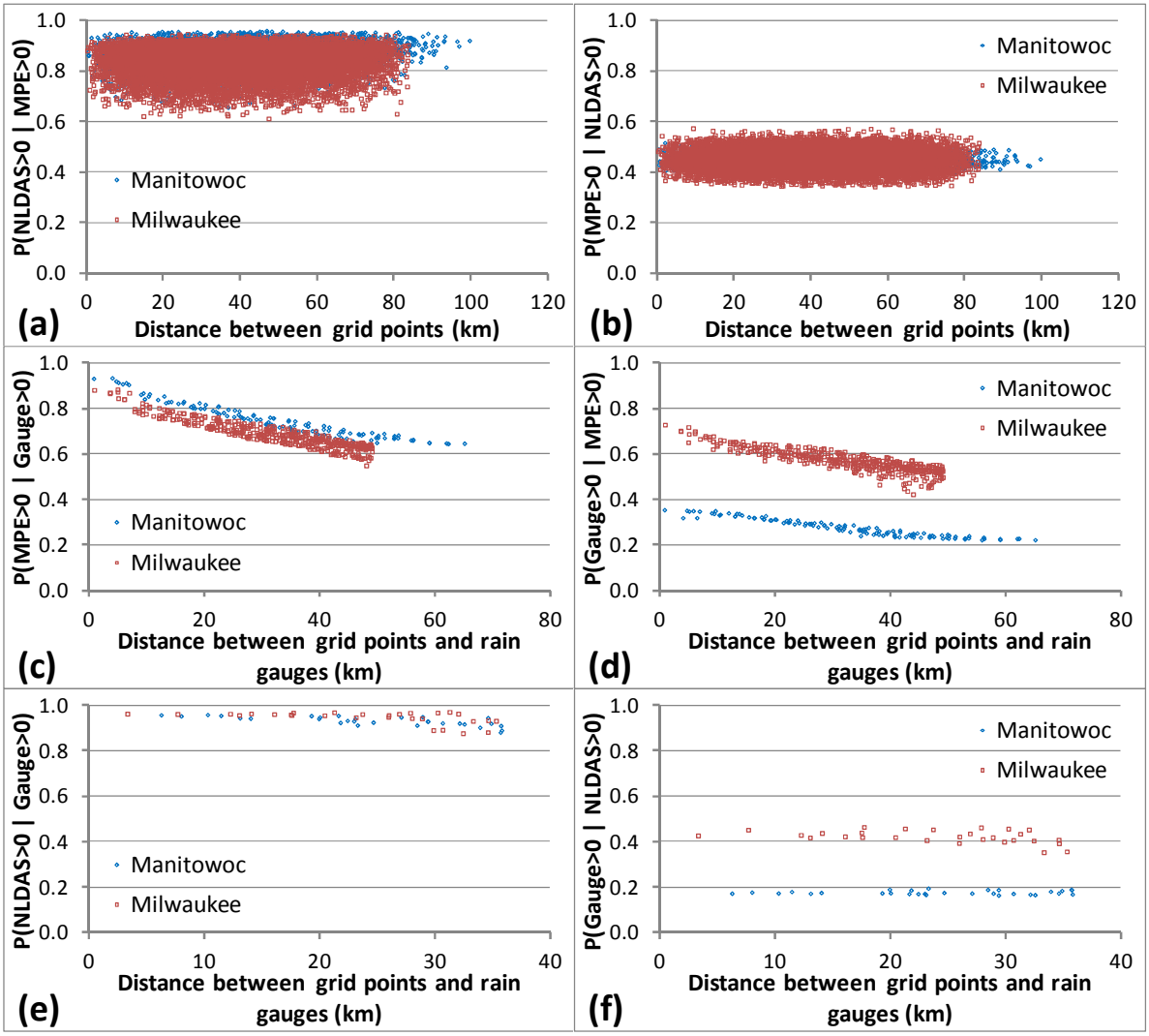

Figure 4. Conditional probability of precipitation occurrence between (a) NLDAS and MPE grid points [P(NLDAS>0 | MPE>0)]; (b) MPE and NLDAS grid points [P(MPE>0 | NLDAS>0)]; (c) MPE grid points and gauge locations [P(MPE>0 | Gauge>0)]; (d) gauge locations and MPE grid points [P(Gauge>0 | MPE>0)]; (e) NLDAS grid points and gauge locations [P(NLDAS>0 | Gauge>0)]; and (f) gauge locations and NLDAS grid points [P(Gauge>0 | NLDAS>0)].

The conditional probability that the NLDAS grid point will record precipitation when the gauge station does [P(NLDAS>0 | Gauge>0)] is shown in Figure 4e, while Figure 4f presents the conditional probability that the gauge station will record precipitation at the same time as the NLDAS grid point [P(Gauge>0 | NLDAS>0)]. Conditional probabilities for both Milwaukee and Manitowoc (Figure 4e) are noticeably larger than in Figure 4f which signifies that more recorded precipitation amounts occurred at the NLDAS grid points than the gauge stations at both locations. From the Figure 4 analysis, it can be concluded that precipitation occurrence is most frequent in NLDAS, moderate in MPE, and lowest in gauge data.

Similar results can be found in Figure 2 and Table 1, as they illustrate that NLDAS shows the most frequent precipitation and highest amounts, while gauge data demonstrate a substantially lower frequency and lowest amounts. The radar stations recorded approximately four and eight times more events at Milwaukee and Manitowoc, respectively, than gauge stations by capturing more low-

intensity, drizzle events (i.e., <10 mm/hr) (Figure 2). Drizzle generates precipitation amounts that are below the detection limit of ground gauges (i.e., 0.254 mm), as substantiated in Table 1; that is, radar catches more small storms (<10 mm/hr) but fewer large storms (>10 mm/hr). Although the gauge stations exhibit more occurrences for 10 – 100 mm/hr events than radar stations (Figure 2 and Table 1), the radar and gauge stations in the Milwaukee area are consistent in not recording any events >100 mm/hr (Table 1). This is unlike Manitowoc where the gauge data include abnormally large precipitation intensities (>100 mm/hr; Figure 2) and precipitation amounts (2815.6 mm) representing 44% of the total precipitation (6387.6 mm) (Table 1). The summary results in Figure 2 indicate a large difference in proportions of precipitation intensity between radar and gauge data for Manitowoc, suggesting that radar precipitation data could be more reliable than gauge data in Manitowoc River Basin.

4. SUMMARY

This study evaluates the reliability of using radar and gauge precipitation data in watershed modeling by estimating and comparing correlation coefficients and conditional probabilities of precipitation occurrence according to the distance between radar and gauge stations. Evaluations were performed in two areas: Manitowoc River Basin and Milwaukee area in Wisconsin, USA. In both, NLDAS and MPE radar approaches and gauge stations were used and compared. Results indicated that precipitation occurrence is most frequent in NLDAS, moderate in MPE, and least frequent in gauge data. This was mainly caused by drizzle in radar data which generates precipitation lower than detection limits of the ground-based gauge, although it affected the total precipitation amount less than it did precipitation occurrence. With respect to location, large differences between radar and gauge data in precipitation occurrence and total precipitation were found in Manitowoc River Basin, but not the Milwaukee area. The discrepancy was because the gauge station reported frequent occurrences of abnormally large precipitation intensities (>100 mm/hr; total amount of 2815.6 mm). Spatial correlations between gauge and radar data were also suspect, suggesting that the use of radar rainfall data may be an acceptable alternative to the ground-based gauge data for the Manitowoc River Basin. The results also suggest benefits from automating the collection process of radar data as an additional option in watershed modeling.

5. ACKNOWLEDGMENTS

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