Spatial Variability in Differences between Multi-sensor and Raingage Precipitation Estimates within the Central United States

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Introduction

Many studies have shown that raingage-adjusted radar data provide an improved estimate of precipitation over radar-only estimates for the midwestern United States (e.g. Huff 1967, Wilson 1970, Brandes 1975, Hildebrand et al. 1979). Multi-sensor precipitation estimates (MPE) have been examined for various regions of the United States (e.g., Stellman et al. 2001; Westcott and Kunkel 2002; Jayakrvbishnan et al. 2004; Westcott et al. 2005), but were based upon a preliminary MPE algorithm. A major upgrade to the MPE Stage III/IV algorithm was implemented in February 2002. Recent research by Westcott et al. (2007) showed that the MPE Stage III/IV precipitation estimates for the midwestern United States are generally lower than gage estimates for higher precipitation amounts and MPE are higher than gage estimates for low precipitation amounts. This was found at both monthly and daily time scales and for spatial scales of 4x4 km grid cells and for county averages (areas of about 250x250 km). The percent difference in the MPE versus gages estimates also appeared to vary from county to county across the midwestern United States (Westcott et al. 2007). The variance in space of the difference between MPE and gage precipitation estimates was only partially explained by variation in precipitation amount. This study further investigates the effect of season and, because of the large north-south extent of the study area, the effect of latitude upon the variability in precipitation estimate agreement.

Data

Precipitation data were collected from several sources for this study. Daily gridded (4x4 km grid cells) StageIII/IV MPE were obtained in near real-time from the National Centers for Environmental Prediction (NCEP) through May 2005 and from the National Weather Service (NWS) beginning in June 2005. Daily quality-controlled NWS cooperative raingage (QC_Coop) data were obtained from the National Climatic Data Center (NCDC). These data were used to compute monthly county-averaged precipitation amounts for 858 counties in nine states located in the midwestern United States (Fig. 1). Terrain effects on radar measurements are relatively minimal in this region. The analysis interval covers the period February 2002 – October 2006. The following describes these data sets.

Gridded Multi-sensor Precipitation Estimates

Gridded daily (0600 - 0600 CST) MPE precipitation estimates based on NWS WSR-88D 10-cm radars and on hourly rain gage observations were used to compute county averages for 858 counties in the midwestern United States. On average, there are about twenty (approximately 4x4

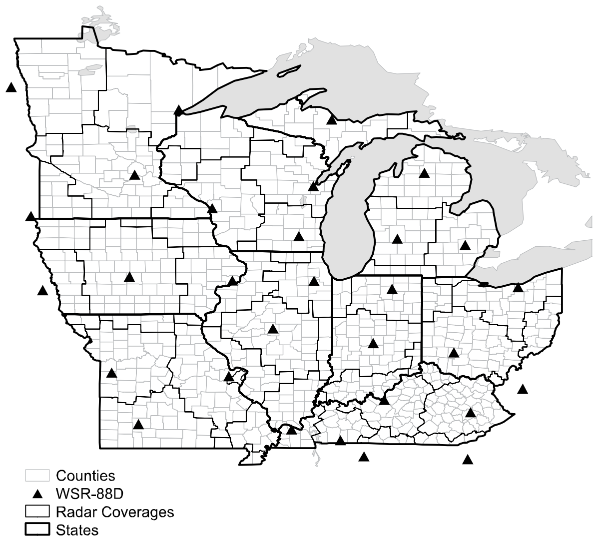

Figure 1. Study Area. WSR-88D radars are indicated by triangles. The radar coverage areas are indicated by thin black lines and state boundaries by heavy black lines. Counties are indicated by gray lines.

km) grid cells per county). The gridded radar precipitation fields for the study region are a composite of data from 30 WSR-88D radars (Fig 1). A summary of possible radar and raingage errors is provided in Fulton et al. (1998). A detailed description of the WSR-88D precipitation algorithm can be found in Fulton et al. (1998) and Seo (1998). The Stage III/IV MPE algorithm and various improvements to it are described in Seo and Breidenbach (2002), and Fulton et al. 2003).

Hydrometeorological Automated Data System (HADS) hourly gage data are employed to adjust the radar data in near real time. Approximately 800 HADS gages are located within the analysis region, with the number increasing over the sample period. These are typically tipping bucket gages. The gages are operated by various agencies, including the United States Army Corps of Engineers, the U.S. Geological Survey, the Bureau of Land Management, and the NWS. Automated Surface Observing System (ASOS) gages may be included in both the HADS and QC_Coop data. The ASOS comprise up to about 10% of the QC_Coop data. The QC_Coop gage data used as the reference standard are otherwise independent of the gages used in the adjustment algorithm. NWS is currently developing automated raingage quality-control tools for use with the HADS by hydrologists at the River Forecast Centers (Kondragunta and Shrestha 2006; Kitzmiller et al. 2007). The amount of real-time manual quality-control of the gage data for the 2002-2006 time period is not well documented.

Quality Controlled Cooperative Gage Data

The QC_Coop daily data, available approximately three months after the fact, were obtained from NCDC. The gages employed are mainly standard 8-inch (20-cm) non-recording gages. Only gages having 90 percent or more data reported during the period were used. There were approximately 1500 cooperative gages reporting during this period. About 775 of the 858 counties in the study region contained at least one quality-controlled raingage. This resulted in an average of about two gages per county in counties with gages, or about one gage per 800 km^2. Reporting times of the cooperative gages vary, with some at midnight, many between 05:00 and 9:00 LST, and a few at other times of the day. Observation times reported by the cooperative observers can vary from day to day. All gages, regardless of observation time, were employed in computing the QC_Coop monthly county averages.

For this study, the QC_Coop data were the reference standard for examining the utility of the MPE gridded fields to provide similar quality monthly county precipitation measurements, but in near real-time. Although the QC_Coop data are not without inaccuracies due to wind-dependent under catch, gage exposure, and observer errors, these errors were expected to be relatively smaller than radar errors, and smaller than for gage data not subjected to rigorous quality control. Monthly values were examined, largely for ease in analysis of an area extending from 36° N – 49° N latitude, and also so that issues related to differences in observation times of the cooperative gages were minimized. For all precipitation estimates, average monthly totals of 0.0 mm were eliminated from the analysis. In the relatively humid midwestern United States, 0.0 mm monthly totals are rare, but some 70 – 100 counties often do not contain a reporting QC_Coop gage.

Results

Monthly trends

Time-series of monthly county-averaged monthly totals estimated by MPE and QC_Coop data, and differences between the estimates are presented in Figure 2. Examining the study region as a whole, the county-averaged MPE data and QC_Coop compared very well (Fig. 2a), particularly after the first year of use of the new Stage III/IV algorithm. The percent difference between gage and MPE amounts was computed as:

$$(\text{Gage} - \text{MPE}) / \text{Gage} \times 100. \quad (1)$$

Overall, the median percent difference was 6%. During the first 12 months it was 12%, and during the last 12 months, 4%. Overall, there was no difference in the median percent differences between cold months of November to February versus the warm months of May to August.

Spatial variability by season

Figure 3a and b present the summertime (May 2006 - August 2006) QC_Coop county averaged precipitation amounts and the percent differences in QC_Coop and MPE precipitation, respectively. A general increase in precipitation amount from northwest (Minnesota) to southeast (Ohio and Kentucky) can be discerned. When looking at percent differences, there is a general pattern of differences greater than 12.5%

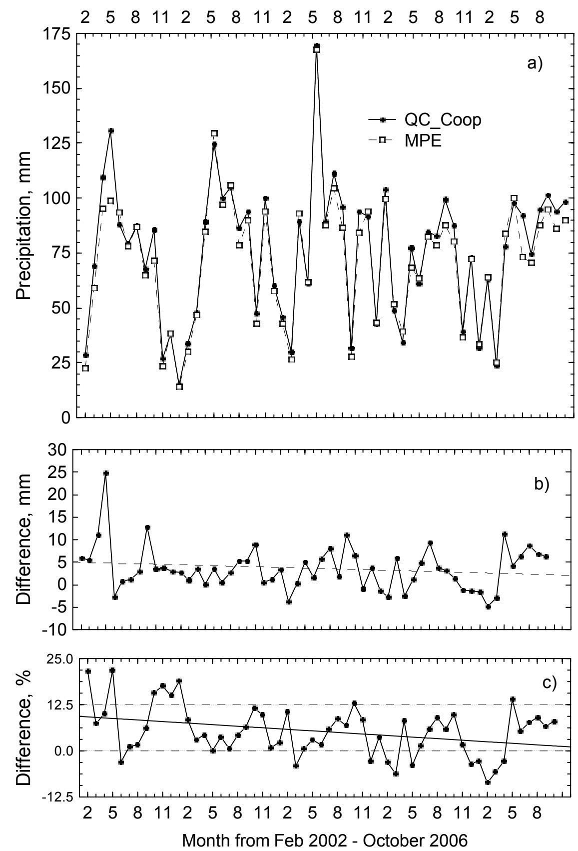

Figure 2. Median of QC_Coop and MPE county-averaged monthly precipitation totals for the 9-state study area for February 2002 to October 2006, b) median of difference in QC_Coop and MPE values, and c) median of percent difference. Dashed lines indicate linear regressions.

close to many of the radars (*note triangles*). Near some radars, county differences of greater than 25% can be found. Overall the pattern of percent differences is similar in the northern and southern latitudes.

Figure 4a and b present the wintertime (November 2005 - February 2006) QC_Coop county averaged precipitation amounts and the percent differences in QC_Coop and MPE precipitation, respectively. Wintertime precipitation totals are considerably less than those in the summer. Similar to the summer months, there is a marked west to east increase in precipitation. The difference field differs from that found for the summer.

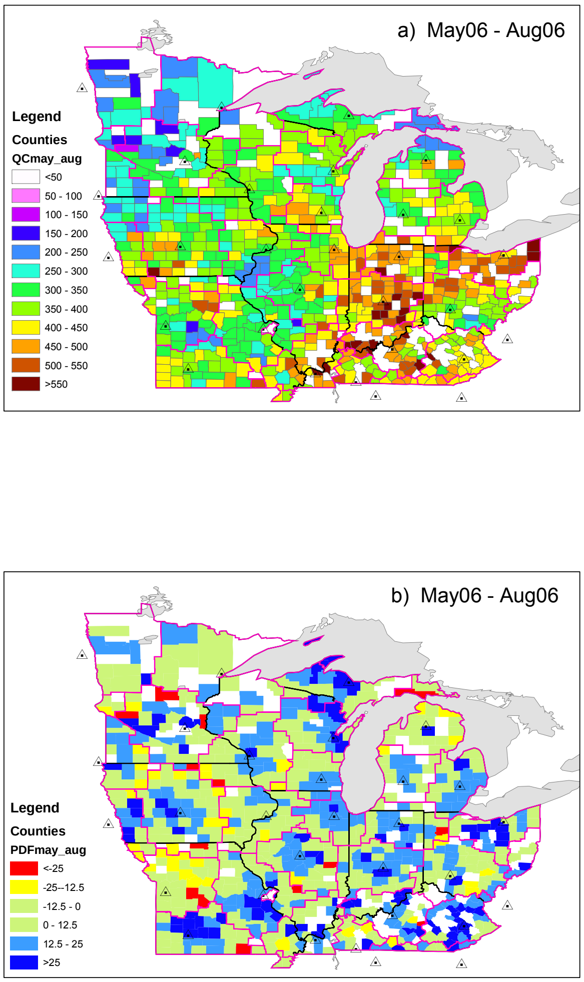

Figure 3. County-Averaged a) QC_Coop Precipitation (mm) and b) Percent Difference in QC_Coop and MPE precipitation for May-August 2006.

In the winter months, the percent difference in QC_Coop and MPE precipitation estimates indicates that QC_Coop values are higher than MPE values for the northern latitudes. In the central and southern regions, where precipitation values are larger, there are fewer counties with larger MPE values (positive differences). Figures 3 and 4 are for a single season, but they generally reflect the difference patterns found in the 5 years of data examined.

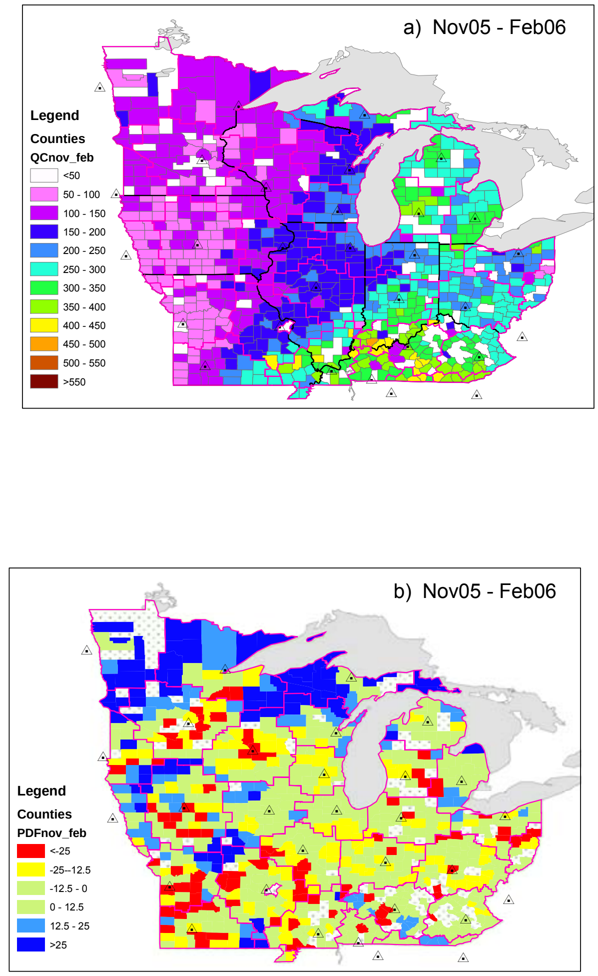

Figure 4. County-Averaged a) QC_Coop Precipitation (mm) and b) Percent Difference in QC_Coop and MPE precipitation for May-August 2006.

Variance by season and latitude

During the cold months of November through February, precipitation is largely non-convective or stratiform in nature, associated with low pressure systems and fronts, and frequently snow. During the warm months of May through August, precipitation is dominated by convective activity. Convective events generally have larger gradients in precipitation amounts and reach higher into the atmosphere than the more widespread stratiform events (e.g. Klazura et al. 1999). At far distances, the height of the radar beam extends higher into the atmosphere so that convective events may be better sampled than the lower stratiform events. The transition months, March and April (spring) and September and October (fall) when both convective and non-convective activity are common are only briefly included in this analysis.

In summer and winter, median precipitation amounts are the most different, averaging 45 mm in the November-February months and 97 mm in the May to August 2002-2006 period. The study region extends from 36° N to 48° N latitude. Differences in the northernmost (≥ 44° N) and southernmost (<40° N) regions might be expected, because convective activity will occur earlier in the spring and later in the fall in the southernmost region.

When examining precipitation data only by season, however, there is little difference in the median percent difference between county-averaged monthly MPE and QC_Coop values (Table 1). Median values range from 2% in the spring, to 5% in the winter and summer seasons, to 9% in the fall. When latitude is considered, however, the median percent difference between county-averaged monthly MPE and QC_Coop values in the northern latitudes was 14%, in the central region (40 - 44° N), 5%, and in the southern latitudes, 3%. Positive values again indicate that the QC_Coop values are larger than the MPE values.

During the summer, the percent differences between QC_Coop and MPE were similar between regions. This is generally consistent with the spatial pattern presented in Figure 4a. The difference between regions was most apparent in the November-February months, when the median percent difference between county-averaged monthly MPE and QC_Coop precipitation was 28% in the north, 3% in the central region, and 1% in the south.

Figure 5 presents the distribution of percent differences in QC_Coop and MPE values by precipitation amount for the warm months for the northern, central and southern regions. One can see that the central and southern regions have proportionally more counties with large precipitation totals than does the northern region. For all three regions however, when lower QC_Coop precipitation amounts are found, there is a tendency for the MPE amounts to be greater than the QC_Coop amounts, and for higher precipitation amounts, the QC_Coop amounts are generally larger than the MPE amounts. In the summer months the proportion of percent differences between QC_coop and MPE amounts was relatively evenly divided in the 3 categories, of <-12.5%, >12.5 and -12.5 to 12.5%.

In the winter months (November-February), the number of counties with small precipitation amounts is much greater in all 3 regions (Figure 6). In the central and in particular the southern regions, low precipitation amounts are still often associated with large MPE amounts. This is not the case in the northern latitudes. For all categories of precipitation amount, the QC_Coop amounts are greater than the MPE amounts in the northern region.

Table 1. Median percent difference between county-averaged monthly QC_Coop and MPE values for the midwestern United States by season and latitude for the February 2002- October 2006.

	November - February	March - April	May - August	September – October	Total	Sample
North	28	13	7	12	14	7837
Central	4	0	6	9	5	18377
South	1	1	3	7	3	18100
Total	5	2	5	9	5	44314
Sample	13163	7787	15586	7778	44314	

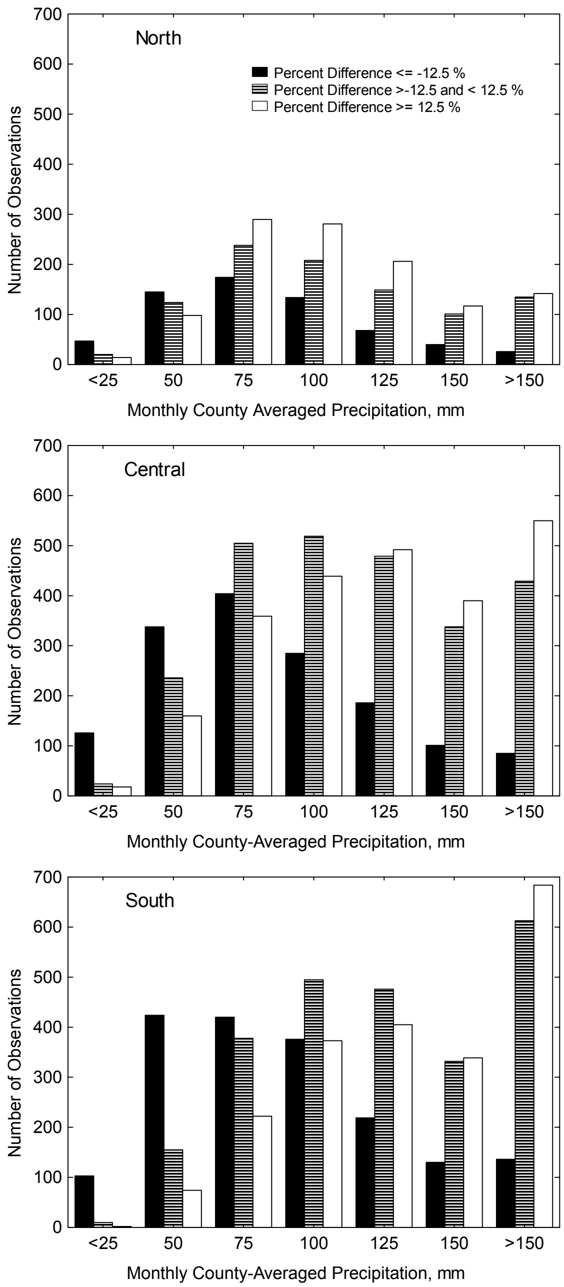

*Figure 5. Distribution of monthly county-averaged QC_Coop precipitation for warm season months (May-August) 2002-2006, for the north, central and southern regions grouped by percent difference [(gage-MPE) / gage *100] in gage and MPE amount: ≤-12.5% (black), -12.5 to 12.5% (striped), and ≥12.5% (white).*

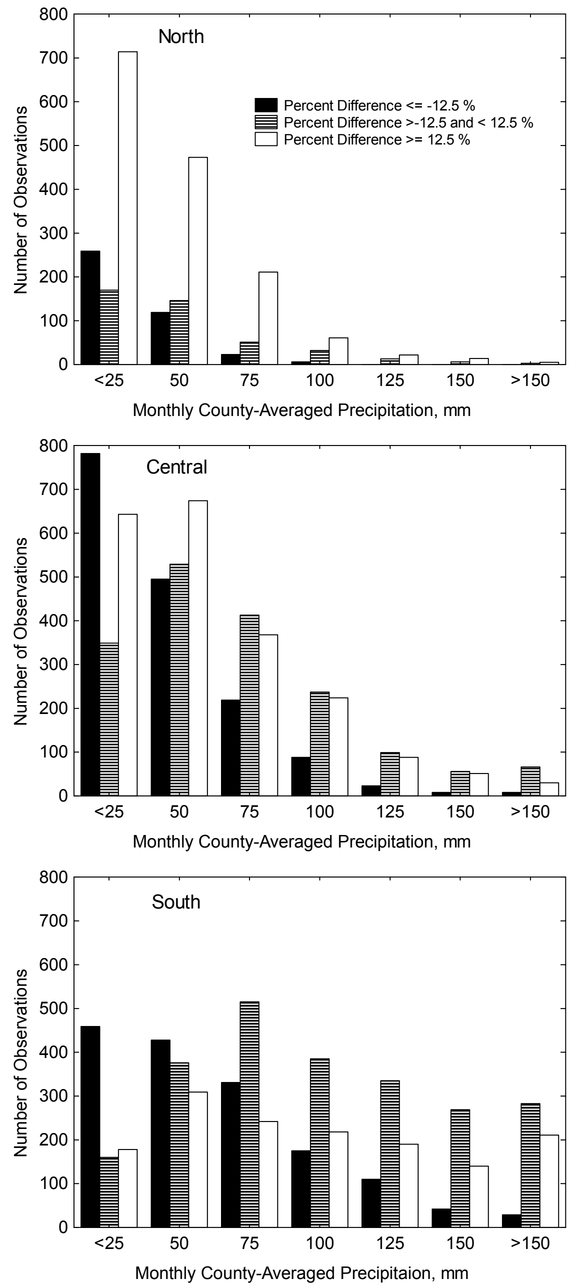

*Figure 6. Distribution of monthly county-averaged QC_Coop precipitation for cold season months (February-November) 2002-2006, for the north, central and southern regions grouped by percent difference [(gage-MPE) / gage *100] in gage and MPE amount: ≤-12.5% (black), -12.5 to 12.5% (striped), and ≥12.5% (white).*

In the northern latitudes during the winter months when snow is common, the majority of percent difference values (54%) were greater than 12.5%, with 42% greater than 25%. The skewed distribution of higher MPE values was present but not as pronounced in the transition months (not shown) in the northern region. In the southernmost region for all four seasons, it was most common for the percent differences to be within +/- 12.5%. This also was true for the central latitudes. Unlike the northern region, there was no evidence of a large underestimation of precipitation by the MPE as compared to the QC_Coop values in the southern portion of the study region.

Discussion and Conclusions

A comparison of county-averaged monthly values of QC_coop and MPE data indicated that overall, the MPE values agreed with the QC_Coop gage values, with a median percent difference of + 6%, with 65% of the MPE precipitation values falling within +/- 25% of the QC_Coop value, and 89% within +/- 50%. During warm season months of May to August, the median percent difference between QC_Coop and MPE values was + 5%, with 68% of the MPE values within +/- 25% of the QC_Coop value, and 92% within +/- 50%. During the winter months, the median difference again was +5%, with 58% of the MPE within +/- 25% of the QC_Coop value and 82% within +/- 50%.

Possible causes leading to the spatial and temporal variability in percent differences have been investigated. In a previous study Westcott et al. (2007) found that neither the number of gages employed in computing QC_Coop areal averages nor the areal coverage per gage affected the agreement between QC_Coop and MPE values. It was found that for higher amounts of precipitation (e.g., > 100 mm) that the QC_Coop values tended to be larger than the MPE values and for low QC_Coop values (e.g. monthly rainfall < 50 mm) that the QC_Coop values tended to be smaller than the MPE value.

Here, QC_Coop and MPE percent differences again were examined, and they were found to differ by latitude and by season. Other studies (e.g. Klazura et al. 1999, and Brown, et al. 2007) observed that for non-convective stratiform precipitation, when the radar beam overshoots the top of the precipitation layer, radar precipitation estimates can greatly underestimate precipitation. Within the Midwest region, this affect may partially explain the large difference in MPE and QC_Coop values in the northernmost latitudes. The generally poorer results for the northern region also may be related to use of tipping bucket gages to adjust the radar measurements. In comparison to standard non-recording gages, tipping bucket gages are known to underestimate snowfall (e.g., Groisman et al. 1999) which is more prevalent at higher latitudes.

While this examination of differences in QC_Coop and MPE values was performed on monthly data, such differences are a composite of similar differences arising from daily time scales and for individual grid cells. For northern latitudes where stratiform precipitation is common, the MPE algorithm appears to greatly underestimate precipitation, particularly in the winter months when snow is frequent. The MPE algorithm appears to be most appropriate for summer months and at latitudes where convective activity is common.

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