Peak 1-Hour Rain Rates from 6-Hour QPF

Ryan Kittell
National Weather Service, Los Angeles/Oxnard, California

1. Introduction

Rainfall intensity, commonly quantified by 1 hour rainfall rates, has long been a useful tool in the Flash Flood Warning process (Doswell et al. 1996). Of particular interest in southern California, recent studies (Canon et al. 2008) have also shown the useful relationship between 1 hour rainfall rates and debris flow activity in and around recently burned areas. As a result, the National Weather Service Weather Forecast Office in Oxnard, California (LOX) has received a recent increase in demand for highest 1 hour rainfall rate, or peak rainfall rate (PRR), one could expect.

While real-time PRR data from rain gauges and radar estimates, and six hour quantitative precipitation forecasts (QPF) from predictive services and numerical models are readily available, PRR guidance and forecasts are relatively sparse. With a goal of producing readily available PRR guidance, this study tries to bridge the gap between abundant QPF and vastly lacking PRR guidance by developing a simple relationship between them.

2. Methodology

The basic way to quantify the relationship between rainfall accumulated for a six hour period (R6) and peak one hour rainfall rates within that six hour period (PRR) is by a ratio (C_{RR}):

$$C_{RR} = PRR / R6 \qquad (1)$$

The ratio C_{RR}, which we will call the rain rate ratio, is ultimately what we are trying to find. As a starting point, it is useful to note the range of possible values of C_{RR}. In a situation where rain falls for the entire six hour period, at a perfectly constant or steady hourly rate, the ratio C_{RR} would equal 1/6 or roughly 0.17. On the other end of the range, where rain falls for only one hour in the six hour period, C_{RR} would equal exactly 1. Making a general assumption that all values within this range of possibilities are equally likely, a starting point value is the middle point between these extremes, or $C_{RR} = 0.58$. The data from this study will aim to find an improved value of C_{RR} based on actual data.

Rainfall data was compiled from the Automated Surface Observing System (ASOS) and Remote Automated Weather Station (RAWS) networks in Los Angeles, Ventura, Santa Barbara and San Luis Obispo Counties - which includes a geographically diverse set of locations. The data covered 10 separate events from April 2010 through March 2011, including multi-day December 2010 and March 2011 events that produced flash flooding. Rainfall totals were accumulated for six hour periods (R6) at the synoptic times of 0-6Z, 6-12Z, 12-18Z, and 18-24Z for each station in the two networks. For each six hour time period, the highest one hour rainfall total or peak rainfall rate (PRR) within that period was also noted. Only six hour periods with measurable rain for at least three of the six hours were used in an attempt to remove any artificial bias from the fixed synoptic time blocks methodology, and to focus on more longer duration rain events. Six hour periods were ignored in cases of any missing or egregious rain values in the data. After applying these rules, a total of 2,819 six hour time periods of this relatively short sample period (one year) were used.

It should be noted that while one of the rules used in selecting the data (rain must fall in at least three of the six hours) effectively removes the possibility of $C_{RR} = 1.0$, the upper range of these values is still very close to 1.0 since situations with 2 or more hours of light rain and 1 hour of heavy rain are possible.

3. Results

Figure 1 shows a basic scatterplot of six hour rainfall totals (R6, horizontal axis) versus peak one hour rainfall rates (PRR, vertical axis) for the sample set. The two straight lines mark the extreme ends of possible ratio values (gentler line $C_{RR} = 0.17$ and the steeper line $C_{RR} = 1.00$) as mentioned earlier, which create a cone of possible points. This figure shows a tendency of the sample set towards lower ratio values, with most points closer to the $C_{RR} = 0.17$ line (bottom line) than the $C_{RR} = 1.00$ line (top line). This tendency is also demonstrated by the sample-wide raw average (0.38) and median (0.40) values of C_{RR} being less than the midpoint 0.58 of possible values. All of this suggests that the rain in the sample set tends to fall more steadily in a given amount of time than in one short burst.

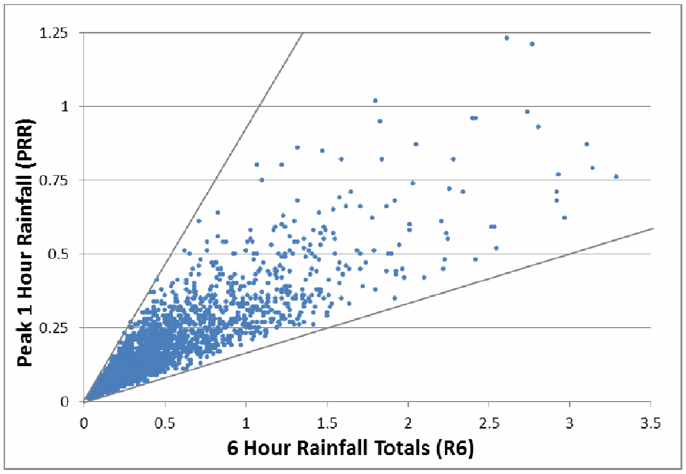

Figure 1 - Six hour rainfall totals (R6) versus associated peak one hour rainfall rates. The lines indictate the range of possible points.

The data also suggests that the tendency toward steady rain is more prevalent for higher rainfall totals. Figure 2 highlights this by clearly showing the downward trend of C_{RR} values with higher six hour rainfall totals – closely following an exponential decay. The low C_{RR} value for light amounts (R6=0.00-0.10) is a consequence of removing samples with less than 3 hours of rain in the six hour period, and ignoring this rule results in a much higher ratio for these light accumulations (on the order of 0.7) that fits the apparent curve better.

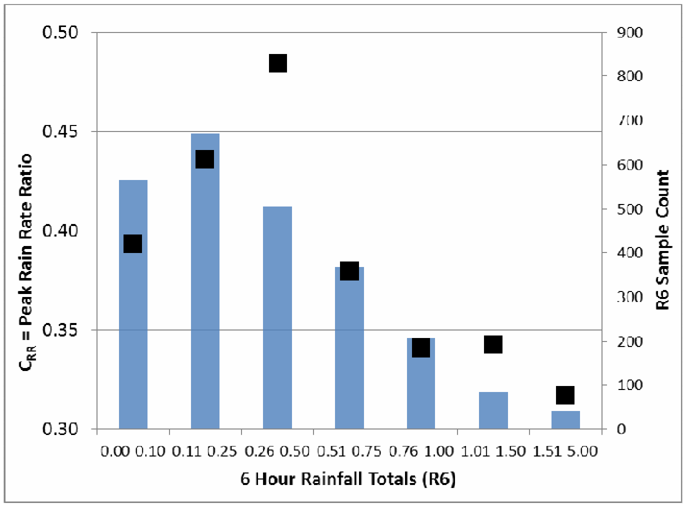

Figure 2 – Bars indicate the average value of the rain rate ratio (C_{RR}=PRR/R6) for the given ranges of six hour rainfall totals. The squares indicate the number of six hour samples used in the given ranges of six hour rainfall totals.

4. Applications

The raw average and median values of C_{RR} suggests a simple 40% rule of thumb can be helpful in operational forecasting. By simply multiplying this rule of thumb to six hour rainfall forecasts and model guidance (QPF), an expected peak one hour rainfall rate (PRR) can easily be obtained. For example, if QPF calls for 1.00 inch of rain in six hours, the highest one hour rainfall rate one could expect is 0.40 inches per hour. Conversely, expectations of PRR can easily be converted into six hour QPF by dividing PRR by 40%. For example, if a forecaster expects a given storm system to bring flash flooding to the area with peak one hour rainfall rates near 1 inch per hour, the forecasted six hour rainfall amounts for that storm should be around 2.50 inches.

Conversion of QPF to PRR can be easily automated as well by either using the simple 40% rule, or taking the tendency toward steady rain for higher rainfall totals into account by using the logarithmic line of best fit function:

$$C_{RR} = -0.06 \ln(QPF) + 0.35 \tag{2}$$

The National Weather Service in Oxnard (LOX) has already integrated this into operations by directly taking their six hour QPF gridded forecasts and applying an equation similar to equation 2 to generate PRR gridded forecasts (see Figure 3).

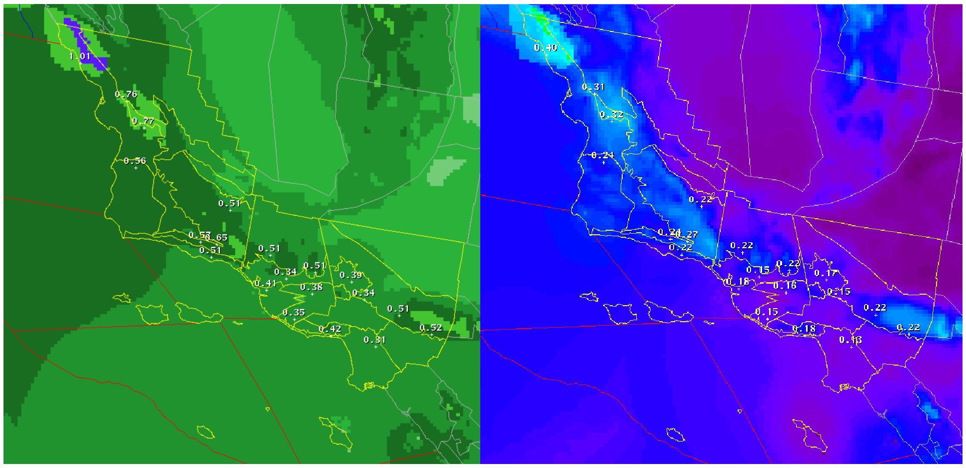

Figure 3 - The left image shows a gridded QPF forecast from the National Weather Service, Los Angeles/Oxnard Office. The image to the right is a gridded PRR forecast derived from the left image using an equation similar to equation 2.

5. Case Study

Two unique storms impacted southern California in April 2012, which provided an opportunity to test the above findings on an independent dataset. The first storm moved through on April 11 and generally produced 0.50-1.00 inches of rain, with a few locations receiving nearly 2.00 inches. This storm was not particularly convective and did not produce any lightning strikes in the LOX county warning area (CWA). The second storm was more convective, with over 1,000 cloud-to-ground lightning strikes detected in the LOX CWA and adjacent waters. As a result, rainfall totals were highly variable with lower amounts around 0.30 inches, while many stations received between 2 and 3 inches.

After following the same filtering rules for including six hour observations in the dataset, and ignoring periods of light rainfall (six hour totals under 0.10 inches), 69 six hour observations were analyzed for the April 11th storm, while 89 observations were used for the April 13th storm.

Figure 3 shows the distribution of C_{RR} ratios for the April 11th storm. The vast majority of C_{RR} ratios lie within one range bin of the 40% rule of thumb, with pronounced peaks in the 0.30 and 0.40 bins. While the figure shows the most common ratios fall in the 0.25 to 0.35 range, which might seem lower than expected, the median and average C_{RR} ratio of 0.37 and 0.41 respectively are very close to the 40% rule of thumb.

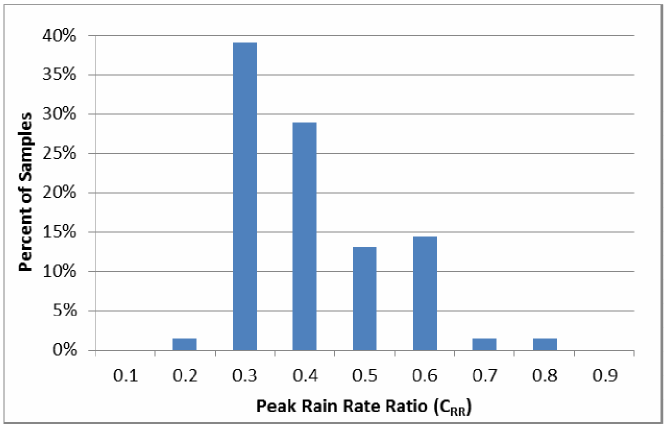

Figure 3 – The distribution of rain rate ratio values (C_{RR}=PRR/R6) for the April 11, 2012 storm. Each bin is calculated for a 0.10 range, centered on the labeled value.

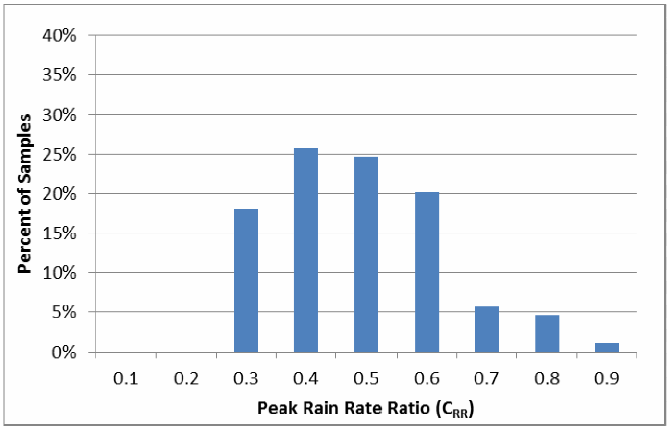

Figure 4 – The distribution of rain rate ratio values (C_{RR}=PRR/R6) for the April 13, 2012 storm. Each bin is calculated for a 0.10 range, centered on the labeled value.

Figure 4 shows a similar distribution chart of C_{RR} ratios for the April 13th storm. While the 0.40 range bin is most common, the peak is far less pronounced than in the April 11th case, and with little difference in the prevalence of C_{RR} ratios lying between 0.25 and 0.65. Because this storm produced a large number of thunderstorms, one can easily conclude that a number of stations in the sample set received short intense bursts of rainfall which would skew the C_{RR} ratios toward higher values. This is supported by the median and average C_{RR} ratio of 0.47 and 0.48 respectively, which are both higher than the 40% rule of thumb, and the less convective April 11th storm.

6. Limitations and Further Study

While the results of this study are promising, they are ultimately limited. The sample set of one year and ten storm events may not cover a diverse enough set of storms to accurately represent a climatic normal, despite the nearly 3,000 six hour samples used. The data used are diverse in local geography, but may not represent other parts of the nation. Further studies with longer datasets that include other areas would address these issues. While rain observations with thunderstorms were not filtered out, the intense one hour rainfall rates and relatively shorter durations under thunderstorms will likely result in C_{RR} ratios that differ from the average found in this study – as the case study suggests. Lastly, the strict usage of synoptic time cutoffs to partition storm systems into six hour blocks led to some samples containing rapid changes inside these arbitrarily assigned six hour windows, which likely led a high bias of C_{RR} - though this bias should have been lowered through the averaging of many samples.

7. Conclusion

This study found that the peak one hour rainfall rate in a six hour period can be roughly estimated by 40% of the total six hour rainfall amount. This simple 40% rule of thumb provides an easy bridge between the abundantly available six hour rainfall forecasts/guidance (QPF) and peak one hour rainfall rates (PRR). The apparent tendency of this relationship to decrease with higher six hour rainfall totals adds an extra degree of information that can easily be automated with the supplied Equation 2. It is the hope that the information gleaned from this study will help forecasters, and their users, to make better decisions with better guidance of expected rainfall intensity.

References

Cannon, S.H., Gartner, J.E., Wilson, R.C., Bowers, J.C, Laber, J.L., 2008. Storm rainfall conditions for floods and debris flows from recently burned areas in southwestern Colorado and southern California. *Geomorphology*, 96, 250–269.

Doswell III, C.A., Brooks, H.E., Maddox, R.A., 1996. Flash Flood Forecasting: An Ingredients-Based Methodology. *Weather and Forecasting*, 11, 560-581