6[TH] INTERNATIONAL CONFERENCE ON FLOOD MANAGEMENT
September 2014 - São Paulo - Brazil

# POINT TO AREA RAINFALL RELATIONSHIPS USING RADAR DATA

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**ABSTRACT:**

Point to area rainfall relationships are useful in drainage systems planning and design, especially when lumped simulation tools are applied or distributed rainfall patterns are not available in the study areas. In order to proper evaluate and consider the effective spatial distribution, several different point to area relations have been used over the world, including famous US Weather Bureau`s and Miller`s relations, based on the conventional rainfall records and considering frequency, surface area and storm duration dependence. In the last 10 years new relations were constructed using radar data, after the benefits of this spatial high resolution monitoring technique. This article presents the development of a point to area relation considering the last 10 years of radar monitoring in the upper part of Tiete River basin where the city of Sao Paulo (Brazil) is located, addressing different goals such as drainage system assessment and scenarios modelling.

Sao Paulo meteorological radar tracks a 250km radio area producing rainfall maps at 3.000m constant altitude (CAPPI) each ten minutes. These data area consisted and correlated with a ground stations network and stored in *ascgrid* files with 2 x 2 km spatial resolution. Using an algorithm to select rectangular surface averaged rainfall from 50 to 2500 km² and durations from 1 to 24 hours curves where produced and adjusted to reflect point to area reduction factor as functions of the surface area and duration. Resulting values where combined to regional IDF relationship established after long time series station in the basin, in order to associated return periods. Resultant curves where compared to traditional ones and other relations established with radar data.

## 1. INTRODUCTION

Urban drainage systems are often assessed with the support of mathematical models that simulate the hydrologic processes of watershed systems, channel and pipe systems and operating and managing strategies. Those models consider system topology as input data as well as precipitation, the main driving force of the processes involved. Considering intensity, distribution and frequency can suffer changes related to natural and anthropic interventions (Tripathi and Dominguez, 2013), the best approach to precipitation should consider real observed patterns in terms of intensity, spatial and temporal distribution. Hydrological regular observations based on ground gauge stations are punctual information that only considers intensity and time distribution while weather radars make available also spatial patterns along the events. For practical purposes, design storms employed in planning and evaluation of drainage systems consider statistical values obtained from rain gauge stations and a ARF (area reduction factors) also known as Point-To-Area relationship to consider the real effective amount of precipitation over the catchment area. The most famous ARFs were established in TP-29 publication of US Weather Bureau (Bureau, 1958) and after that several studies using this methodology were carried out in United States and all over the world. The methodology employed considered a rain gage network and some method for spatial interpolation in order to consider the mean value over the area. Resulting curves are usually in function of the catchment area **A** and storm duration **D**, as depicted **Erro! Fonte de referência não encontrada.** obtained from Miller (1973).

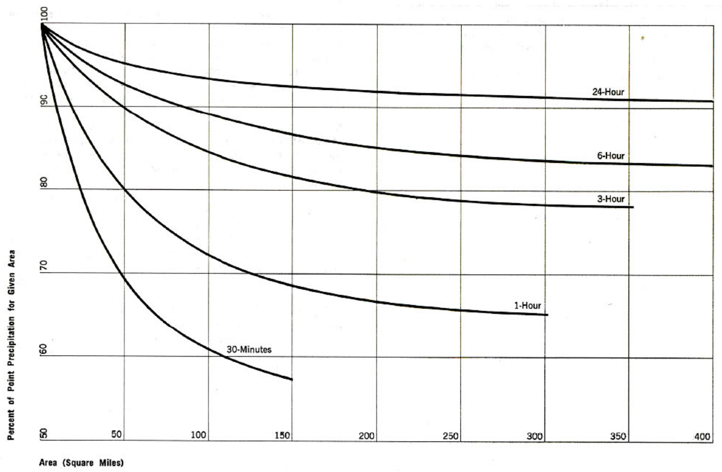


**Figure 1 - ARF as presented by Miller (1973)**

The use of meteorological or weather radar improved not only the spatial observations but also the precision of the measurements regarding to time and rain depth, especially when combined with automatic ground stations to verify and calibrate and led to better evaluations of ARF. The use of local radar data can also reflect particular interferences like topography, coast and valley effects altitude.

The aim of this article is the evaluation of ARF relationships by the use of Sao Paulo Meteorological Radar that monitors the Upper Tiete River Basin, in the State of Sao Paulo, Brazil. Through the evaluation of 8 rain events in the last 10 years and considering different sub catchments areas from 50 to 2500 km² and durations from 1 to 24 hours, curves where produced and adjusted to reflect point to area reduction factor as functions of the surface area and duration

## 2. LITERATURE REVIEW

ARF methods of estimating spatial rain distribution are often affected by errors can that result in major unnacurate design storms which can have important impacts on subsequent flood risk estimates, due to different factors (Wright et al., 2014). Usually ARF are computed considering a fixed point, dividing the average precipitation by the maximum precipitation in that point. Another aproach is to consider the so called storm-centered, that are calculated for especific storms by dividing an observed area-averaged accumulation by the maximum observed point accumulation from that storm. After the above mentioned TP-29 (Bureau, 1958) and Miller (1973), that resulted in the well known Eq. 1 (Asquith and Famiglietti, 2000) in wich $Z_e$ is the average precipitation over the selected area, $Z_T$ is the point precipitation or the design storm depth for recurrence period, in inches, t is the duration of the storm in hours; and A is the area in square miles, one can consider teorethical evaluations of ARF as shown in Sivapalan et All (1998) or sthocastical, as shown in Bachi (1996).

**Eq. 1** $$ARF = \frac{Z_e}{Z_T} = 1 - e^{-1.1t^{0,25}} + e^{(-1.1t^{0.25} - 0.01A)}$$

Durrans et all (2002), conducting studies based on radar data conclude that precipitation frequency estimates developed from radar rainfall are smaller than gauge-based estimates, although the cause for that difference remained unconcluded. Other results can be found in Gill (2005), Rodriguez et all (2013) and Jolly et all (2008). Jolly et all, (2012) compared classical formulations considering 2 and 3 parameters (Eq. 2 and Eq. 3) with the one expressed in Eq. 1, using radar data and a storm-type categorization considering convective and frontal storms. Authors concluded that the spatial decay is considerably larger than the ones given by the Myers (1980), remarking that the comparisons are not rigorous if considered the different types of storms. Authors concluded also that convective storms have a rapid decay. In Brazil, recent studies conducted by Barbalho (2012) based on ground rain gauges network and discharge observations of urban watershed areas pointed to significant differences between observed data and international experience, with the remark that the conclusions were constructed over a short time series.

**Eq. 2** $$ARF = \frac{aD^b}{(c+A)^d}$$

**Eq. 3** $$ARF = a + b\ln(a) + c\ln(d) + d\ln(R\max)$$

Finally, Wright et all, (2014), conducting a critical examinations over ARF methodology concluded that traditional ARF formulation are not representative of the extreme rainfall because they do not consider different storms and different storm types and can lead to overestimation of flood risk and overdesign of infrastructure. Authros pointed that rainfall from tropical storms tends to be spatially larger and of longer duration than rainfall from organized thunder storm systems making storm ARFs decay less rapidly with increasing area. Other important considerations like influence of topography and urban areas are also pointed as limitations to ARF transfering from one region to anohter.

## 3. ARF ESTIMATES BASED ON SAO PAULO RADAR DATA

The studies of ARF were conducted to establish a local relationship for urban drainage planing and design using simulation models that can consider topographic and antropic factors as well as diferent storm types. For this study 8 critical storm events (Table 1) were selected, covering durations from 0,5 to 24 hours, and return period from 2 to 100 years. Radar estimates were merged to a rain gauge network of 25 stations (ROCHA FILHO et al., 2013), considered as representative of aproximatelly 6.000 km² of the total watershed area(Figure 2). Data were taken in ASCII grid files representing 43 x 73 cells of 2 x 2 km², totalizing 1539 cells (Figure 3). Partial areas were computed considering circles of 8 up to 100 km radius centered in the cell that recorded the pointmaximum precipitation, following the procedure referred as *storm-centered*. To consider only the frontal systems, all events with a standard variation related to the average were discarded. Return period were estimated with the use of IDF equation establisehd for the standard station in the area, as shown in Martinez Jr et all (1999).

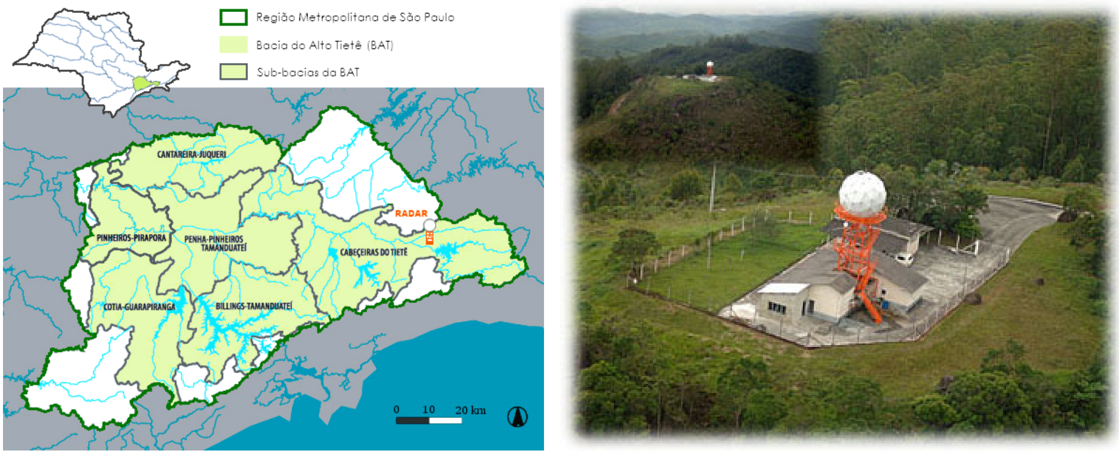


**Figure 2- Sao Paulo city Area and Tietê River Basin, Sao Paulo Weather Radar**

**Table 1- Selected Events for ARF Computation**

| Event | Start | End | Duration (h) | Average Return Period[1] (yr.) |
|---|---|---|---|---|
| May2005 | 23/5/05 0:10 | 26/5/05 1:00 | 73 | 7,6 |
| Feb2007 | 5/2/07 15:30 | 12/2/07 0:00 | 152 | 18,1 |
| Dec2007 | 18/12/07 17:10 | 21/12/07 1:00 | 56 | 2,2 |
| Sep2009 | 6/9/09 6:10 | 10/9/09 14:50 | 105 | 14,4 |
| Dec2009 | 7/12/09 10:10 | 9/12/09 4:00 | 42 | 3,8 |
| Jan2010 | 20/1/10 18:10 | 22/1/10 18:00 | 48 | 7,4 |
| Jan2011 | 10/1/11 18:10 | 12/1/11 18:00 | 48 | 58,7 |
| Mar2013 | 9/3/13 0:00 | 10/3/13 23:50 | 48 | 99 |

[1]Computed over 24-hour most intensive interval

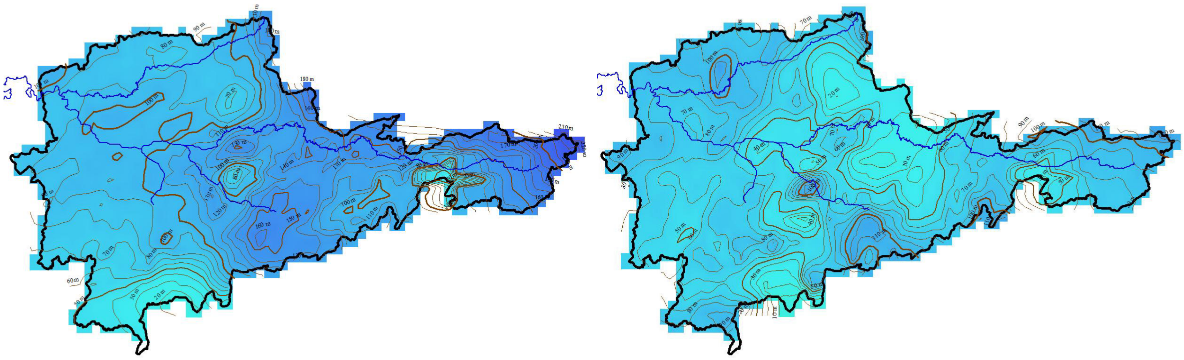

**Figure 3 – 24h Accumulated Rainfall for events (a) May/2005 and (b) Sep/2007**

Data processing resulted in 880 values for ARF, considering different area and duration for the storm. Values that resulted in Return Period (Tr) over then 200 years were discarded due to limitations in the IDF equation employed. To eliminate convective effects (as illustrated in Figure 3b), intervals with standard variation to the average were also discarded. Points considered can be shown in Figure 4 from where it can be concluded that not only Area and Duration but also the return period plays a role in ARF for Sao Paulo area.

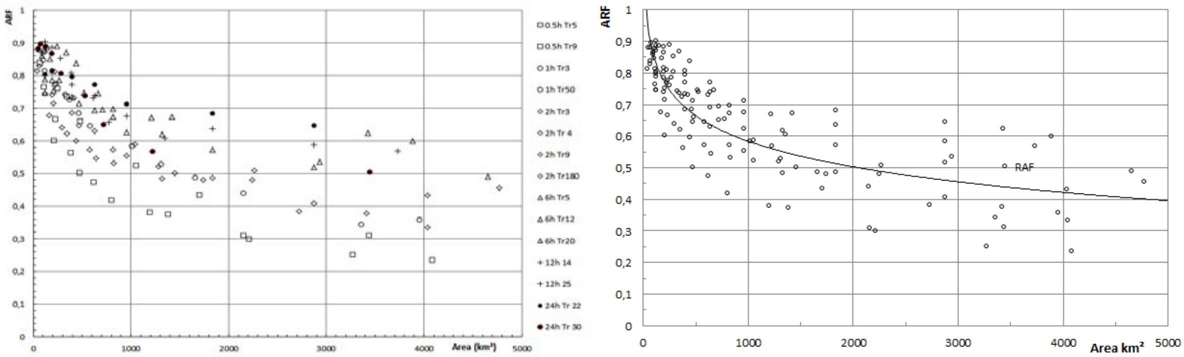


**Figure 4 – Results in function of (a) Duration and Return Period and (b) average curve**

Figure 5 shows the comparison with Eq. 1 data and it can be seen that rainfall decays faster and deeper with the area increase, confirming results from Wright (2014) and Jolly (2008). When adjusted to 3-parameter equation as in Eq. 3, results has a medium index of determination (0.88) and a standard deviation of 0.165, suggesting the existence of other parameters involved in the phenomenon. The resulting values for the coefficients ( a = 1,17  b =-0.099  c = 0.053  d = 0.0115) suggest also the small dependence with the storm magnitude and frequency. Values are close, but not equal to the ones found by Jolly (a = 1.0824 b = -0.0922 c = 0.1212 d = -0.0943).

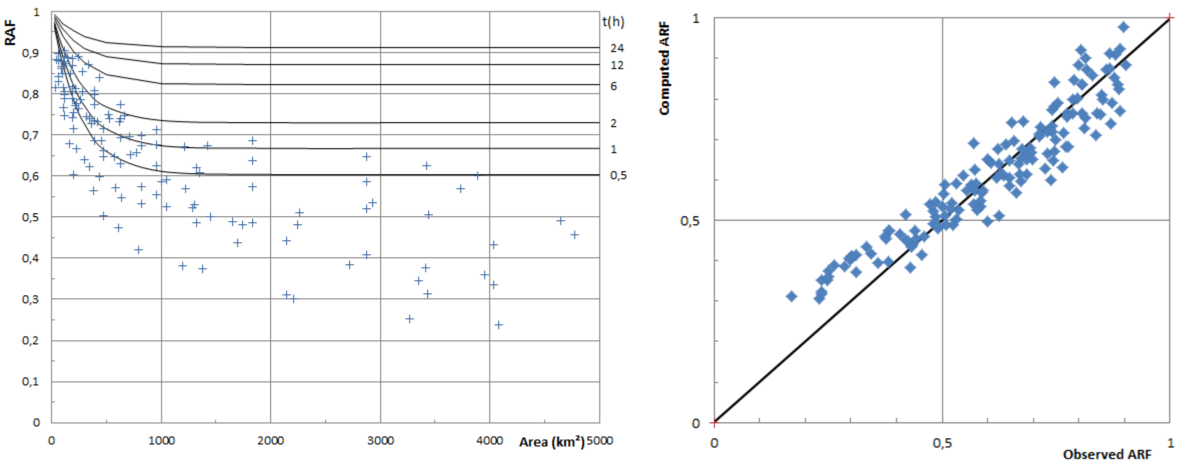


**Figure 5 – (a) Observed ARF compared to Eq. 1 data and (b) adjusted to Eq. 3**

## 4. DISCUSSION

Weather radar stations are more and more frequent in weather and hydrological monitoring. Radar records can supply with enough accuracy input data for hydrological models but ARF still are important tools for estimates of design storms employed in designing and risk evaluation of drainage systems. The use of radar demands also rain gauges networks to evaluate radar accuracy radar and calibrations, as well as constant evaluation and analysis.

Results for Sao Paulo show that duration, storm type and local characteristics like topography, altitude and urban changes in the micro-climate can affect rain spatial distribution and made ARF vary from standards over the world. Theses variations can overestimate design storms and led to unappropriated results in terms of resulting watershed, affecting a long chain of procedures, including risk evaluation. Results here presented also point that ARF is strongly dependent of area and duration but cannot proof the dependency with the storm magnitude, as pointed by some authors.

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