Accuracy assessment of daily TRMM rainfall over an unmonitored Amazonian floodplain

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Abstract. Amazonian floodplains are among the most diverse and productive ecosystems in the world. Today, these sensitive zones are facing increasing human pressures and augmentation of extreme hydrological events. In large unmonitored regions, such as the low Amazonian basin, remote sensing appears as a solution to gather hydrological data. In this study, we aimed at building two rainfall datasets over the period 1998-2016: one issued from interpolation of remotely sensed rainfall (TRMM 3B42 v7 daily product), the other issued from the common Thiessen method applied to *in situ* rainfall records. Validation against an *in situ* gauge, installed for research needs, shows (i) a low correlation (ii) that rainfall computed from TRMM data presents a lower accuracy (higher NRMSE). When comparing both datasets amongst themselves, statistics indexes are analogous that one computed during the validation. An analysis of inter-annual rainfall highlights that TRMM sensor failed in retrieving the 2010 dry event. Over the studied period TRMM exhibits a trend to decrease, statistically significant at 1%. However, there is no evidence of such a trend when analyzing the rain interpolated from the *in situ* gauges. In view of monitoring large, wild, international basins, such as the Amazon, there is a crucial need to improve the use of the Earth Observation data, to evaluate their quality and to combine with *in situ* data.

Keywords: TRMM, Amazon, Rainfall, Thiessen, interpolation

1. INTRODUCTION

The Amazon basin is the largest watershed in the world (6.2 million km²). Its discharge can reach 270,000 m^3s^{-1} (Gallo and Vinzon 2005). The Amazon River runs through more than 6,700 km. The Amazon basin covers 4/10 of South America (Goulding et al., 2003). Inside the Amazon, wetlands and floodplains cover a huge area recently estimated to 800,000 km² (Melack and Hess, 2011). Amazonian floodplains play an important role in the spread of flows (Paiva et al., 2012), in sediment transfer (Mangiarotti et al. 2013), in cycles of chemical elements (Moreira-turcq et al. 2013). They are considered as hotspot of biodiversity (W. Junk et al., 2004).

Anthropogenic pressures and climate changes threaten the Amazonian floodplains. Population rapidly increased from 6 to 20 million in Brazilian Amazonia from 1960 to 2010

(IBGE,2016). Economic development modifies landscapes in multiple ways: dam constructions (Ferreira et al. 2014), waterways projects (Soito and Freitas 2011) or oil exploitation (Zurita-Arthos and Mulligan 2013). Regarding climatic changes, the Amazon basin recently faced to a succession of extreme hydrological events (droughts in 2005, 2010, floods in 2009, 2012, 2014) (Filizola et al. 2014; Marengo et al. 2011; Satyamurty et al. 2013).

Hence, there is a crucial need to better monitor Amazonian floodplains. However, due to difficult access and huge extent, data scarcity and low accuracy are often major problems to be faced, when monitoring Amazonian wetlands. Most of meteorological stations in Brazil are located along rivers. Few data are available on floodplains. This distribution leaves large areas without any information: Calmant et al. (2009) counted one WL gauge in the Amazon Basin for 7,200 km². *In situ* gauges maintenance is complicated and costly. In addition, politics relation inside the country and between Amazon countries has influence on data collect and exchange.

In this context, monitoring systems based on remotely sensed observations are an efficient alternative. In the last decades, the use of remotely sensed products for hydrology has been significantly intensified: land-cover mapping from optical imagery (Yengoh et al. 2014), flood extent through imagery from synthetic aperture radar (SAR) (Chapman et al. 2015), dynamics of water stock (Schmidt et al. 2008), evapotranspiration estimation (Mu et al. 2007), global Digital Elevation Models (Farr et al. 2007). Inland radar altimetry furnished numerous success: hydrologic studies (Paris et al. 2016; Da Silva et al. 2012), modeling (Paiva et al. 2013; Pinel et al., 2015), monitoring water bodies (Santos da Silva et al. 2014). Rainfall is also estimated, by instance from the Tropical Rainfall Measuring Mission (TRMM) (Huffman and Bolvin 2014), or from GSMaP product (GSMaP 2013).

In this study, we aimed to detail two spatial interpolation schemes in view of generating rainfall dataset over an unmonitored Amazon floodplain and comparing them. First method consists in applying the Thiessen method to *in situ* rainfall gauges freely available over the study zone. Second scheme consists in interpolating the TRMM 3B42 v7 daily product over the floodplain. Both of generated dataset are validated against a rainfall gauge located in the floodplain, and compared amongst themselves. We also asses the temporal inter annual variations of the rain over the period simulated. This analysis permits investigation of the validity of each method, evaluating the possibility of using similar schemes on a larger scale or in other analogous places.

2. MATERIAL & METHODS

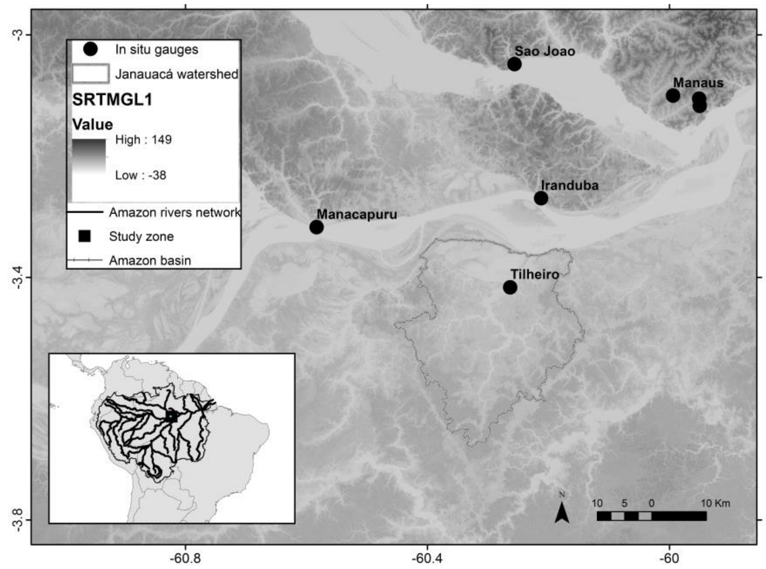
2.1. Study zone

2.1.1. Janauacá

The Janauacá Floodplain is located between 3.20°S-3.25°S and between 60.23°W-60.13°W, along the right margin of the Solimões River, (Fig. 1). It is composed of one lake connected with the Solimões River. This latter is a white water river, whereas Igarapés draining the south of the watershed present properties closer to black waters. According to the rain gauge data in Manacapuru (3.31°S, 60.26°W), at about 40 km from the study, the mean annual rainfall is 1976 mm/year over the period 2006-2009 (Bonnet et al. 2011). The river water level mean annual fluctuation reaches 12.2 m when considering the 2006-2011 period. The Solimões River presents a mono-modal flood with water level rising from mid-November until mid-June. According to altimetric data (Pinel et al., 2015), the water surface slope along the reach between Manacapuru and the water junction with the Negro River is in mean 2 cm/km, over the years 2006-2012.

2.2 *In situ* rainfall gauges

The Brazilian National Water Agency (ANA) freely makes available rainfall records through the hidroweb website (http://hidroweb.ana.gov.br/). Characteristics of the rainfall gauges are summarized in the table of figure 1b. All these pluviometers are manually read gauges (400 cm² orifice size with a total capacity of 5000 cm³ and a resolution of 0.2 mm). Uncertainties in rainfall data are difficult to evaluate. For research needs, a rainfall gauge was installed in the floodplain. The meteorological station (Davis Vantage Pro) automatically recorded daily rainfall during one year. According to the constructor, the rain collector has an accuracy of 5 %.



Station label	Lat.	Lon.	Name	First record	Last record
359005	-3.11	-59.99	Manaus1	7/1/1997	5/31/2016
359007	-3.11	-59.95	Manaus2	3/1/2007	5/31/2016
360000	-3.12	-59.95	Manaus3	1/1/1961	9/30/2016
360001	-3.32	-60.58	Manacapuru	6/1/1972	4/30/2016
360005	-3.05	-60.26	São Joao	11/1/2003	6/30/2016
360006	-3.27	-60.22	Iranduba	10/1/2014	4/30/2016
Tilheiro	-3.42	-60.26	Tilheiro	8/27/2010	8/27/2011

Figure 1. (a) Study site with the locations of available rainfall gauges with background SRTM Global 1 arc-second (SRTMGL1), (b) Table of the characteristics of the rainfall gauges used

2.3 Remotely sensed rainfall

The National Aeronautics and Space Administration (NASA) and the Japanese Aerospatiale Agency launched the TRMM satellite on November 1997. The TRMM produces estimates of precipitation based on remote sensing over the period 1998-2016. The product of the 3b42 algorithm has a spatial resolution of 0.25° x 0.25°, a temporal resolution of 3h. In this study, we used the daily averaged release of the version 7. Description of this version of algorithm can be found in (Huffman and Bolvin 2013). The TRMM estimates are believed to be considerably more reliable than those obtained from other satellites (Satgé et al. 2016). This product is commonly used as forcing dataset in hydrological modeling, especially in data space regions as the Amazon (e.g. Paiva et al. 2013).

2.3 DEM derived from SRTMGL1

In a previous work, Pinel et al. (2015) proposed a systematic approach over Amazonian floodplains to generate topographic data from the global 1 arc-second SRTM V3.0 dataset (SRTMGL1). The latter is a joint product of the National Geospatial-Intelligence Agency and the NASA. Data were collected during 11 days in February 2000 and a near global DEM was generated. Since 2015, the SRTMGL1 had been freely released for South America. SRTM data products have been validated on continental scales: the absolute and relative vertical accuracies over South America are 6.2 m and 5.5 m, respectively (Rodriguez et al., 2006). Besides the bias introduced by interferometric errors, SRTMGL1 data present an elevation ranging above the bare earth and below the maximum canopy height (Carabajal and Harding 2006), because of the incapacity of C-band radar in reaching the bare earth. Pinel et *al*. (2015) controlled against *in situ* data that RMSE diminished from 4.6 m to 1.7 m for the SRTMGL1 DEM and the corrected DEM, respectively. Local watershed extracted from the corrected DEM has a area of 786 km².

2.2. Method

2.2.1. Overview of the method

Daily rainfalls are estimated through the method of Thiessen polygon (Han and Bray 2006). First step is to average the three stations in Manaus. Five datasets of Thiessen polygons are implemented: D1 generated from the three gauges, D2 from Sao Joao and Manaus, D3 generated from Manaus and Manacapuru, D4 generated from Sao Joao and Manacapuru, and D5 from all the gauges. Each Polygon of each dataset is extracted over the Janauacá watershed, and area is computed then turned into a ratio of the polygon extracted over the watershed area. For each dataset, daily rainfalls are computed as the averaged rainfalls issued from a polygon pondered by the area ratio. Finally, Janauacá rainfall is computed as rainfall computed from D5 dataset. Depending on the availability of every gauge, gaps are filled with rain issued from the other datasets. This dataset is denoted Rain_Thies.

In order to generate Rainfall from TRMM sensor, TMPA pixels covering the lake are extracted over the watershed; area is computed then turned into a ratio of the polygon extracted over the watershed area. Rainfall records are computed as the averaged TRMM values pondered by the ratio of the sub-zone are they cover. This dataset is denoted Rain_TRMM, hereafter.

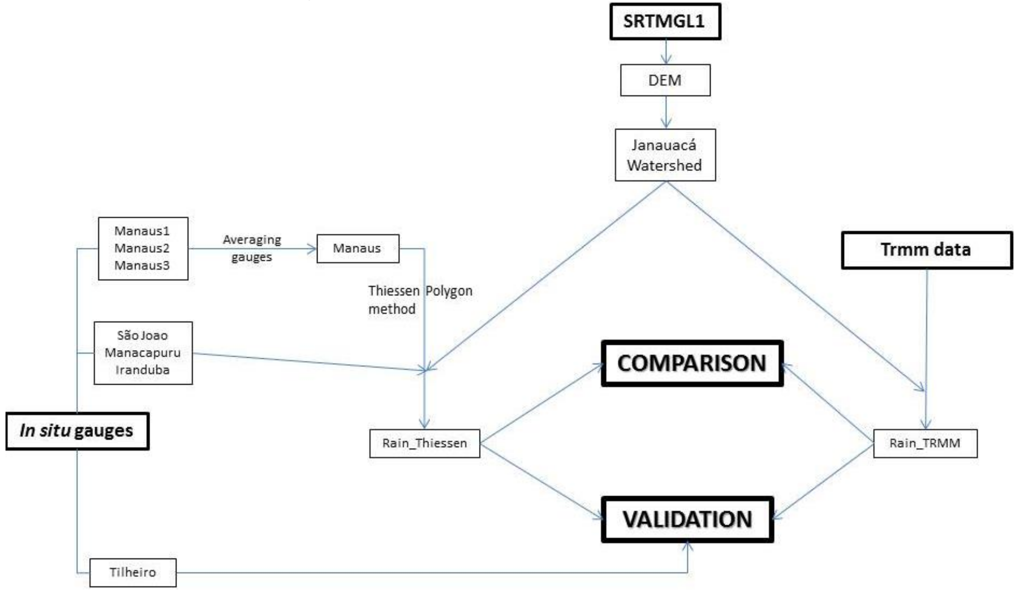


Figure 2. Overview of the method to generate, compare and validate daily rainfall measurements

2.2.2. Validation and comparison

Validation of the generated datasets of rainfalls (x dataset, in this paragraph) is performed against measurement (y dataset, in this paragraph) from the *in situ* gauge installed in the lake. Each dataset is analyzed under different temporal scopes: daily and monthly cumulated values. The assessment between generated series (x) and reference one (y) is estimated through four criterions: the Pearson correlation coefficient that gives insight about the correlation between both series, the NRMSE of the x and y, the Mean, and the Standard Deviation (SD) of the difference between the datasets (x) and (y). Comparison between both generated datasets (Rain_Thies and Rain_TRMM) is similarly performed. A trend analysis in rainfall series and its significance is assessed using the Mann–Kendall test.

3. RESULTS AND DISCUSSION

3.1. Method

Correlation between any gauges located in Manaus was superior to 0.6. However, values were highly variable from a gauge to another. Hence, we decided to average only two of the three gauges. These two gauges were daily chosen as those presenting le lowest differences in the rainfall record. Although 42 km away, Manacapuru and Iranduba gauges present a low correlation coefficient (0.35).

3.2. Validation against *in situ* installed gauge

Validation against *in situ* gauge clearly shows a poor correlation with simulated datasets (Table 1). Discrepancies between daily- and monthly time step are explained through the NRMSE formula. At a daily time step, NRMSE for both datasets remains similar and Rain_Thies presents the lowest NRMSE (16%). At a monthly time step, NRMSE values are 41 % and 53 % for Rain_Thies and Rain_TRMM. Hence, our investigations show that Rain_Thiess presents the best accuracy, when controlled against *in situ* data.

Table 1. Accuracy assessment of the generated rainfalls gauges against *in situ* gauge

	Rain_TRMM	**Rain_Thies**	**Rain_TRMM**	**Rain_Thies**
Time step	**Daily**		**Monthly**	
Cor. coef.	0.06	-0.01	0.02	0.05
NRMSE (%)	17	16	53	41
Dif. Mean (mm)	-0.88	-2.03	-14.37	-23.86
Dif. SD (mm)	14.59	13.23	166.85	126.82

3.3. Comparison between both generated measurements

Comparison between both dataset also shows a poor correlation, independently from the time step. NRMSE between both datasets remains similar to one computed during validation (Table 2) and is increasing with the time step. Rain_TRMM presents a trend to decrease over the last decade (Fig. 3a). The Mann–Kendall test rejected the null hypothesis of “Trend absence” at the 1% significance level. Nethertheless, this phenomenon is not confirmed by Rain_Thies. Fig. 3b shows a slight decreasing trend, but Mann–Kendall test fails in rejecting the null hypothesis of “Trend absence”. The negative trend of rainfall in the Amazon basin is still discussed (Gloor et al. 2013) and depends on the scale, on the location in the Amazon (Marengo 2004). We also note that Rain_TRMM failed in retrieving the well-known 2010 dry event.

Table 2. Comparison of the generated rainfalls gauges

Gauges	**Rain_TRMM**	**Rain_Thies**	**Rain_TRMM**	**Rain_Thies**	**Rain_TRMM**	**Rain_Thies**
Time step	**Daily**		**Monthly**		**Annual**	
Cor. coef.	0.00		-0.07		0.43	
NRMSE (mm)	8		26		34	
Dif. Mean (mm)	-0.93		-29.83		-317.53	
Dif. SD (mm)	15.88		161.64		566.10	

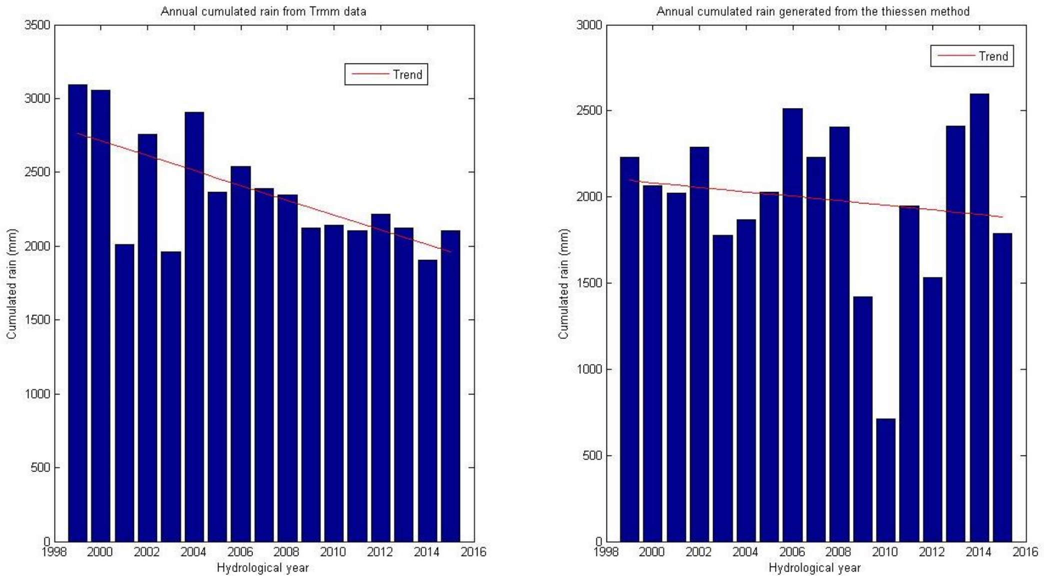


Figure 3. Inter-annual variation of rainfall (a) case of Rain_TRMM, (b) case of Rain_Thies

4. CONCLUSION

Amazonian floodplains are among the most productive ecosystems in the world. Today, these zones are facing increasing anthropization and augmentation of extreme hydrological events. In this region, there is a lack of readily available hydrological data. Parallelly, the on-going development of free remotely sensed data offer the possibility in monitoring these zones.

In this study, we aimed at building two rainfall datasets over an Amazonian floodplain: one issued from interpolation of remotely sensed rainfall (TRMM 3B42 v7 daily product), the other issued from the common Thiessen method applied to *in situ* rainfall records. Validation of both datasets, performed against *in situ* records, highlight a low correlation (ca. 0.01) and a lower accuracy of the interpolated rainfall issued from TRMM data. Then comparing amongst themselves, both datasets appear to be uncorrelated. Depending of the time step used (daily, monthly, annual), discrepancies between both datasets fluctuate: NRMSE increases with the time step. Focusing on annual inter-variations (over the period 1998-2015), it appears that TRMM do not succeed in retrieving a well-known dry event (2010). TRMM also presents a trend to decrease. This tendency is statistically validated: the Kendall-Mann test rejected the null hypothesis of “Trend absence” at the 1% significance level. However, this phenomenon is not confirmed by Rain_Thies, as the Mann–Kendall test failed in rejecting the null hypothesis of “Trend absence”.

In view of monitoring large, wild, international basins, such as the Amazon, it is necessary to improve the use of the Earth Observation data, to evaluate their quality and to combine them with *in situ* data.

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