Journal of Hydrology 527 (2015) 292–304

Contents lists available at ScienceDirect

Journal of Hydrology

journal homepage: www.elsevier.com/locate/jhydrol

A consistent gauge database for daily rainfall analysis over the Legal Brazilian Amazon

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ARTICLE INFO

Article history:
Received 14 May 2014
Received in revised form 8 April 2015
Accepted 9 April 2015
Available online 5 May 2015
This manuscript was handled by Andras Bardossy, Editor-in-Chief, with the assistance of Uwe Haberlandt, Associate Editor

Keywords:
Rainfall variability
Geostatistics
Rain gauge
Spatial structure
Legal Brazilian Amazon

SUMMARY

Reliable precipitation information provided by rain gauge networks is invaluable for applications ranging from climatological studies to validation of remote sensing rainfall estimates. Daily precipitation data from 235 tipping bucket gauges in the Legal Brazilian Amazon are quality controlled for the period 1998–2009 by comparing precipitation time series from individual rain gauges with neighboring stations. Within a geostatistical framework, optimal distances for the comparison between stations are identified while considering the density of the network and the spatial structure of the precipitation. The number of rain gauges used as neighboring rain gauges varies between 2 and 57. Each gauge station is compared to nearby gauge stations using fourteen climate and statistical indicators. A proposed variability index allows for the detection of 'suspicious' precipitation data before more detailed analysis of the nature of the issue and the time period of concern in the time series. The internal consistency of the database is examined through the use of variograms and cross validation. The sensitivity of the effectiveness of the quality control procedure to the comparison distance is examined. These results are positive and this demonstrates that the spatial structure of daily rainfall is better sampled. The cross validation confirms that the quality control procedures improved the consistency of the database. Finally, the spatial consistency of the rainfall database is assessed through a classification of the seasonal regimes in the Legal Brazilian Amazon.

1. Introduction

In the Legal Brazilian Amazon, precipitation monitoring is essential for hydrologic and climatic applications, which range from hazard forecasting (Espinoza et al., 2011) to the evaluation of regional and global atmospheric model simulations in the context of global warming (Cook et al., 2012). Quantitative estimation of rainfall is complex due to its high spatial and temporal variability. Atmospheric dynamics explain the high spatiotemporal variability of rainfall in Amazonia. At the interannual scale, rainfall in the Amazon basin is impacted by the El Niño-Southern Oscillation (ENSO), where the El Niño phase of ENSO decreases rainfall in the Amazon and the La Niña phase increases rainfall (Souza et al., 2000). High sea-surface temperatures in the north and tropical Atlantic Ocean influence the location of the Intertropical Convergence Zone (ITCZ), which in turn affects seasonal rainfall regimes (Kodama, 1992; Nobre and Shukla, 1996; Kayano et al., 1997; Marengo, 2004; Espinoza et al., 2009). During the austral summer, the sea surface temperature over the South Atlantic area is warmer than in the North Atlantic area and the ITCZ shifts southward, leading to increased amounts of precipitation over the Amazon. The South Atlantic Convergence Zone (SACZ), which is more pronounced during austral spring and summer, affects precipitation regimes in the southeast Amazonian region. Part of the interannual and seasonal rainfall variability in the Amazon region is related to synoptic-scale atmospheric dynamics. Data from the Atmosphere Boundary Layer Experiment (ABLE-2B) (Greco et al., 1990; Greco, 1994) demonstrates that

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http://dx.doi.org/10.1016/j.jhydrol.2015.04.012
0022-1694/

Mesoscale Convective Systems (MCSs) contribute up to ~80% of precipitation at the regional scale during the rainy season. This study focuses on daily temporal scales and regional spatial scales.

Given its quasi-global coverage, satellite remote sensing of precipitation is an essential tool for assessing rainfall variability over Amazonia. Converting satellite measurements into quantitative precipitation estimates (QPE) is challenging, however, as underlined by the Program to Evaluate High Resolution Precipitation Products (Turk et al., 2008) led by the International Precipitation Working Group (IPWG; see http://www.isac.cnr.it/~ipwg/). The uncertainty structure of satellite rainfall products is recognized as a major issue in determining the usefulness of satellite rainfall estimates. This characterization is needed for climate analysis (Stephens and Kummerow, 2007). More specifically, this is critical over land areas for use in hydrological modeling of natural hazards and water resources management (Grimes and Diop, 2003; Lebel et al., 2009).

Rain gauges provide generally reliable point measurements of precipitation. Given the variety of potential sources of error in satellite-based rainfall estimates, a practical solution is to evaluate satellite QPE with respect to an external, independent reference rainfall dataset derived from rain gauge networks. Error estimation in both gauges and satellite rainfall estimates is a complex task. It is therefore usually not addressed by investigators in intercomparison exercises (Ebert, 2007). While rainfall estimation by gauges is usually subject to a low measurement error (e.g., Ciach and Krajewski, 1999) because of the direct nature of the measurement, rain gauge estimates may be affected by instrumental error. The point-based nature of gauge measurement introduces sampling errors that cannot be neglected when computing areal mean rainfall estimates matching the resolution of satellite estimates. This issue may be overcome by using geostatistical techniques (Kirstetter et al., 2013; Roca et al., 2010), provided that the rain gauge network correctly samples the spatial structure of rainfall. A few erroneous stations may disrupt the ability of the network to properly sample this structure (Kirstetter et al., 2010). Before comparing the satellite QPE to rain gauge data over the study area, quality-control techniques must be applied and then the rain gauge network data can be interpolated to estimate reliable reference values.

The objective of this study is to build a reference daily precipitation database from 1998 to 2009 rain gauge data in the Legal Brazilian Amazon (Fig. 1). It is known that rain gauge data quality control cannot be fully automated especially when no exogenous reference is available to control the gauge time series. An option is to compare each station with its neighbors looking for abnormal differences. Such approach assumes homogeneity between stations and its efficiency depends on the gradients in precipitation and the station network density as shown in Kirstetter et al. (2010). Several global precipitation products resulting from recognized protocols for quality control (QC) of ground observations are available in the literature (Schneider, 1993; Rudolf et al., 1994; Chen et al., 2008). However the criteria used at the global scale to discriminate the errors of rainfall time series are not specifically designed for to the unique and large area covered by the tropical Amazon rainforest. The effect of predefined settings such as the neighborhood sizes for comparison between stations are evaluated in this study. Climate and statistical indicators are computed at the daily, monthly and yearly scale to meet the critical homogeneity assumption.

Fig. 2 shows a flowchart of the methodology. Several techniques are combined in a geostatistical framework. They involve five statistical indicators and nine climate indicators, five of them adapted from the work of Alexander et al. (2006), which define the "variability index," or *VI*. After screening, the stations involved in high differences with their neighbors are sorted. This leads to a series of suspicious stations that are critically analyzed with great care in a second step. Only obvious issues in recorded time series (e.g. abnormal long period of 0 records) trigger the decision to discard the station. The application of the QC protocol to identify 'suspicious' data provides a sounder database of ground rainfall. It is assessed using the Leave One Out Cross Validation technique (LOOCV) and variograms (Delrieu et al., 1988; Creutin et al., 1997).

The paper is organized as follows: Section 2 introduces the rain gauge network, Section 3 describes the geostatistical approach and the variability index, Section 4 shows application of the *VI* and a sensitivity study to the comparison distance in the neighborhood, Section 5 discusses the construction of a rainfall database (where assessment is provided by variograms and LOOCV and whose consistency is assessed from a climatological analysis of annual rainfall regimes in the Legal Brazilian Amazon), and Section 6 provides concluding remarks.

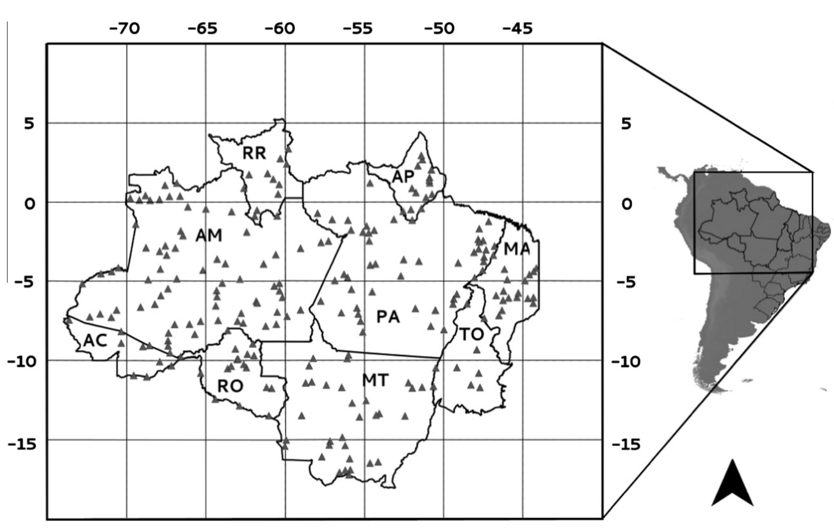

Fig. 1. Network of ANA rain gauges used in the Legal Brazilian Amazon, which includes the Brazilian states of Amazonas (AM), Acre (AC), Roraima (RR) Rondônia (RO), Pará (PA), Maranhão (MA, west of 44°W), Amapá (AP), Tocantins (TO) and Mato Grosso (MT).