Atmospheric Research 186 (2016) 26–42

Contents lists available at ScienceDirect

Atmospheric Research

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

Evaluating satellite-derived long-term historical precipitation datasets for drought monitoring in Chile

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ARTICLE INFO

Article history:
Received 5 August 2016
Received in revised form 3 November 2016
Accepted 7 November 2016
Available online 11 November 2016

ABSTRACT

Precipitation is a key parameter for the study of climate change and variability and the detection and monitoring of natural disaster such as drought. Precipitation datasets that accurately capture the amount and spatial variability of rainfall is critical for drought monitoring and a wide range of other climate applications. This is challenging in many parts of the world, which often have a limited number of weather stations and/or historical data records. Satellite-derived precipitation products offer a viable alternative with several remotely sensed precipitation datasets now available with long historical data records (+30years), which include the Climate Hazards Group InfraRed Precipitation with Station (CHIRPS) and Precipitation Estimation from Remotely Sensed Information using Artificial Neural Networks-Climate Data Record (PERSIANN-CDR) datasets. This study presents a comparative analysis of three historical satellite-based precipitation datasets that include Tropical Rainfall Measuring Mission (TRMM) Multi-satellite Precipitation Analysis (TMPA) 3B43 version 7 (1998–2015), PERSIANN-CDR (1983–2015) and CHIRPS 2.0 (1981–2015) over Chile to assess their performance across the country and for the case of the two long-term products the applicability for agricultural drought were evaluated when used in the calculation of commonly used drought indicator as the Standardized Precipitation Index (SPI). In this analysis, 278 weather stations of in situ rainfall measurements across Chile were initially compared to the satellite data. The study area (Chile) was divided into five latitudinal zones: North, North-Central, Central, South-Central and South to determine if there were a regional difference among these satellite products, and nine statistics were used to evaluate their performance to estimate the amount and spatial distribution of historical rainfall across Chile. Hierarchical cluster analysis, k-means and singular value decomposition were used to analyze these datasets to better understand their similarities and differences in characterizing rainfall patterns across Chile. Monthly analysis showed that all satellite products highly overestimated rainfall in the arid North zone. However, there were no major difference between all three products from North to South-Central zones. Though, in the South zone, PERSIANN-CDR shows the lowest fit with high underestimation, while CHIRPS 2.0 and TMPA 3B43 v7 had better agreement with in situ measurements. The accuracy of satellite products were highly dependent on the amount of monthly rainfall with the best results found during winter seasons and in zones (Central to South) with higher amounts of precipitation. PERSIANN-CDR and CHIRPS 2.0 were used to derive SPI at time-scale of 1, 3 and 6 months, both satellite products presented similar results when it was compared in situ against satellite SPI's. Because of its higher spatial resolution that allows better characterizing of spatial variation in precipitation pattern, the CHIRPS 2.0 was used to mapping the SPI-3 over Chile. The

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http://dx.doi.org/10.1016/j.atmosres.2016.11.006

Keywords:
Precipitation
Chile
Drought
Agriculture
CHIRPS 2.0
PERSIANN-CDR
TMPA 3B43 v7

results of this study show that in order to use the CHIRPS 2.0 and PERSIANN-CDR datasets in Chile to monitor spatial patterns in the rainfall and drought intensity conditions, these products should be calibrated to adjust for the overestimation/underestimation of rainfall geographically specially in the North zone and seasonally during the summer and spring months in the other zones.

1. Introduction

Precipitation is one of the key parameters for climate monitoring, particularly to detect climatically-extreme events such as drought, which impacts most regions of the world. A simple definition of drought is an extended period of abnormal dryness that has negative impacts on agricultural and water resources (WMO, 1986). Conceptually, there are several different sectoral definitions of drought that are defined by the duration of the precipitation deficit including short-term meteorological drought (spanning days to weeks), agricultural drought (month to several months), and hydrological drought (months to years) (Wilhite and Glantz, 1985). According to IPCC (2013), changes in the patterns of precipitation is expected globally over the next few decades. The change in precipitation patterns coupled with the sustained increase in global temperature since 1880 and the anthropogenic factors due to human activities (e.g. increased emission of the Green House Gasses and land use change such as cutting down forests to create farmland) is likely to increase the frequency and intensity of natural disasters like drought throughout the world (IPCC, 2013; Loon et al., 2016). Knowledge of the amount and spatial variability of precipitation historically is important to map and monitor drought condition globally. In situ-based rainfall measurements at weather station locations have traditionally been used for this application, but the number, geographic distribution, and length of record of these measurements are often lacking in many countries including Chile. The creation of such datasets is challenging because it is costly to maintain a dense network of weather stations over a long period of time as a result, there are often spatial gaps and a lack of local resolution in the rainfall data and the drought patterns mapped from these point-based weather station data using spatial interpolation techniques. Many weather stations have a relatively short or incomplete historical record of observations, which is problematic for determining the magnitude of specific precipitation deficit period and the severity of the corresponding drought.

Accurate historical precipitation data and effective drought monitoring tools are of considerable interest for Chile. The IPCC (2013) indicate that precipitation is expected to decrease in the near-future in the central part of Chile, which is a primarily agricultural area within the country. Studies made during the last years from North to Central Chile found important results about drought frequency. A trend in the increase of drought frequency in the Coquimbo region of northern Chile, particularly in Limarí Valley was identified (Meza, 2013). Also, was found that a rainfall deficit of 40% had a return interval of approximately once every 4 years in the northern, semi-arid Coquimbo region of Chile and a 22-year return interval in the more humid O'Higgins regions of central Chile (Núñez, et al., 2011). Lately, Zambrano et al. (2016) evaluated agricultural drought using satellite-based vegetation index data and found that in the Bío-Bío region (South-Central Chile) over the last sixteen years had experienced three drought event during the 2007–2008, 2008–2009 and 2014–2015 growing seasons. All these studies were carried out using precipitation data obtained from a limited number of weather stations across Chile. These results could be extended both on the spatial and temporal scale to improve the findings using accurate satellite long-term precipitation datasets.

Satellite datasets are becoming increasingly important to fill in the spatial and temporal data gaps for climate-based applications such as drought monitoring. Several global remotely sensed datasets now have historical records spanning 18 years or more, and lately the long-term products having more than 30 years which are appropriate for climate studies and represent a viable information source in many parts of the world. One widely used remotely sensed precipitation dataset has been acquired by the Tropical Rainfall Measuring Mission (TRMM), which is jointly supported by National Aeronautics and Space Administration (NASA) and Japan Aerospace Exploration Agency (JAXA). The TRMM precipitation datasets (Huffman et al., 2007) spans since November 1997 until present, although the mission comes to its end on April 2015, but thanks to its successor the Global Precipitation Measurement (GPM) which is the continuity of TRMM the dataset have continued. The Global Precipitation Measurement (GPM) is an international satellite mission to provide next-generation observations of rain and snow worldwide starting from temporal resolution of three hours and at spatial resolution as high as 0.1–30 min. Other precipitation datasets have been produced using a combination of infrared (IR) and passive microwave (PMW) observations from multiple satellite sensors using different precipitation estimation methods. These include Precipitation Estimation from Remotely Sensed Information using Artificial Neural Networks (PERSIANN) (Hsu et al., 1997) and Climate Prediction Center Morphing (CMORPH) technique (Joyce et al., 2004). Most products have short-term data and have been evaluated in different part of the world such as: South America (Salio et al., 2015), Colombia (Dinku et al., 2009), Saudi Arabia (Almazroui, 2011), Greece (Nastos et al., 2016), Ethiopia (Duan and Bastiaanssen, 2013), China (Guo et al., 2016b), India (Shah and Mishra, 2015), Iran (Moazami et al., 2016) and Himalayas (Bharti and Singh, 2015) and many other more (Dinku et al., 2007; Kenawy et al., 2015; Pipunic et al., 2015; Tan et al., 2015).

The study of climate change and climate variability requires a long-record data to permit the evaluation of climate and associated natural disasters like drought. The National Research Council (NRC) defined the Climate Data Records (CDR) as time-series measurements of sufficient length, consistency, and continuity to determine variability and climate change (National Research Council, 2004). Thus, two new satellite products for long-record precipitation studies were considered in this study. They are the Precipitation Estimation from Remotely Sensed Information using Artificial Neural Networks-Climate Data Record (PERSIANN-CDR) (Ashouri et al., 2015) and CHIRPS 2.0 (Funk et al., 2014) datasets which both have more than 30-year records of data. Both products represent potentially valuable data sources for monitoring drought in data-limited countries such as Chile because they have an adequate length of record to detect and quantify drought conditions within a longer historical context. These products are relatively new and still there are only a limited number of studies evaluating their performance of estimating the amount and spatial distribution of precipitation. Miao et al. (2015) evaluated PERSIANN-CDR over China and found that the agreement between the dataset with in situ measurements in dry regions is not strong. Ashouri et al. (2015) tested PERSIANN-CDR during the Hurricane Katrina (2005) and the flooding on Sydney, Australia (1986); and found in both that PERSIANN-CDR is performing reasonably well when compared to radar and ground-based