Comparative assessments of the latest GPM mission's spatially enhanced satellite rainfall products over the main Bolivian watersheds

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Abstract.
The new IMERG and GSMaP-v6 satellite rainfall estimation (SRE) products from the GPM mission have been available since January 2015. With a finer spatial resolution of 0.1°, these products should provide more accurate information than their latest widely adapted (relatively coarser spatial scale, 0.25°) counterpart (TMPA product). The present study is a novel attempt, in which the relative performance evaluation of these new products (IMERG and GSMaP) is done by comparing their rainfall estimations with rainfall gauges data of the years 2014 and 2016 in Bolivia. The comparisons were done on annual and monthly scales over the three main national watersheds (Amazon, La Plata and TDPS) at both wet and dry seasons. To observe the potential enhancement in rainfall estimates bring by these two recently released products, the widely used TMPA product is also considered in the analysis. The results differ from product to product as well as from season to season, in spite of these, the results are also influenced by the geographic variations of the considered regions. Generally, the performances of all the products increase during the wet season over all three Bolivian watersheds. TMPA and GSMaP-v6 are the more and less accurate products over the region. Slightly less accurate than TMPA, IMERG can almost fulfill its main objective which is to ensure TMPA rainfall measurements.

Keywords: IMERG, GSMaP-v6, TMPA, Rain Gauges, Watershed

1. Introduction

Accurate rainfall estimation is a crucial to monitor long and short terms environmental variations relying on the rainfall. Drought and flood scenarios can be predicted or understood from the rainfall analysis (Hussain et al., 2016) to protect local environment and population security. Over remote regions, few meteorological stations are available and are unevenly distributed due to difficulties of access for installation and maintenance. Over the last few decades, numerous Satellite Rainfall Estimates (SREs) were made available from different organisms allowing a high quality rainfall monitoring over the same periods. Nowadays, a new generation of SREs is made available to insure continuity in rainfall monitoring, facing previously SREs deficiencies in relation to sensors aging. Two SREs groups which are derived from the Global Precipitation Monitoring (GPM) mission launched on February 27, 2014 are now available. They are the Integrated Multi-satellitE Retrievals for GPM (IMERG) and the GPM Global Satellite Mapping of Precipitation (GSMaP v6). Available at a 0.1° and half-hourly and hourly temporal scales, respectively, they offer the opportunity to capture finer local rainfall variations in space and time. Data are available from March 2014 to present. However, IMERG and GSMaP-v6 products were released early January 2015 and thus, few studies assessed their potentiality yet. *Liu, 2016* compared IMERG, with TRMM Multisatellite Precipitation Analysis (TMPA) on a global scale at monthly temporal step. Differences between IMERG and TMPA estimates are related to surfaces type and precipitation rates with a tendency for IMERG to better capture major heavy precipitation regions. Over India, on a daily scale and using rain gauges as references, IMERG is more suitable to represent monsoon rainfall than GSMaP-v6 and TMPA gauges adjusted versions while GSMaP-v6 slightly outperformed IMERG and TMPA over low rainfall Indian regions (Prakash et al., 2016). Over Iran, in comparison with gauges measurements, IMERG daily estimates are more accurate than TMPA considering categorical and quantitative statistical analysis (Sharifi et al., 2016). Over China in comparison with rain gauges estimates, IMERG monthly estimates are more accurate than TMPA (Chen and Li, 2016) and same observations were made at daily and sub daily scale (Tang et al., 2015). Due to small numbers of publications about GPM derived SREs there is still a need for more assessment studies in other regions of the globe. This is even true when considering GSMaP-v6 as there is only one study reported on its accuracy assessment (Prakash et al., 2016). In this context we assessed for the first time IMERG and GSMaP-v6 over Bolivia using a gauge network of 247 rain gauges. Bolivia is a very interesting region for such studies as it includes very wet Amazon region and the very dry Altiplano regions and thus SREs can be assessed for both heavy and low rainfall amounts and intensity. Regions are separated by the Andean cordillera resulting in high elevation variation ranging over the country from few hundred meters to more than 6000 m. Thus, variable rainfall processes are observable and the SREs ability can be evidenced in relation to dominant rainfall processes. Here, IMERG and GSMaP-v6 are assessed for the first time in Bolivia at monthly and seasonal scales considering the three main hydrological watersheds separately, Altiplano, Amazon and Paraguay during wet and dry seasons. In previous studies (Blacutt et al., 2015; Satgé et al., 2016), TMPA v7 was found as the most accurate SREs over the country and thus it is considered to observe the potential enhancement brought by IMERG and GSMaP-v6 products.

2. Study Area

Bolivia is located in central South America with an extent close to 1.100.000 km^2. Elevation ranged between 75 and 6549 m following an increase east-west pattern from the Amazon to the Altiplano region. Bolivia can be divided in three main watersheds: The Titicaca, Poopó, Desaguadero, Salar system (TDPS), La Plata and Amazon with a superficie of approximately 149 000, 226 000 and 716 000 km^2, respectively. The Altiplano region is trapped between the occidental and oriental cordillera at a mean elevation of 4000 m with mean slope value of 4.7°. The climate over the region is semi-arid with mean rainfall of 350 mm. According to SRTM and TMPA 3B43 data the Amazon region is located at a mean elevation of 680 m for a mean slope value of 5.3° with a mean annual rainfall of 1550 mm (1998-2015). Finally, the La Plata region presents a mean elevation of 1350 m for a mean slope value of 7° region for a mean annual rainfall of 850 mm (1998-2015).

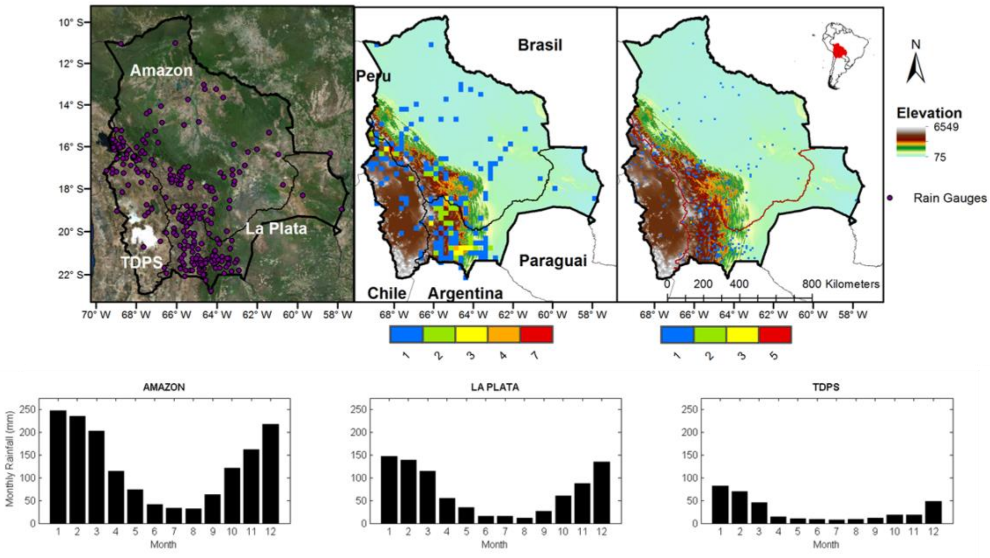

Figure 1. The study area with the number of rain gauges included in studied 0.25° and 0.1° pixels (up) and mean monthly rainfall amounts derived from TMPA for the 1998-2015 period (down).

3. Data Sets

TMPA is a product of the National Aeronautics and Space Administration (NASA) in collaboration with the Japan Aerospace Exploration Agency (JAXA). It provides rainfall estimate on a 0.25° spatial resolution over the 50°N to 50°S at a 3 hourly temporal scale. PMW radiometers are used to estimate rainfall rates. IR data from the Climate Prediction Center (CPC) of the National Weather Service/NOAA (CPC-IR here-after), from the Meteorological Operational satellite program (MetOp) and from the 0.07° Grisat-B1 are used to fill the gaps between PMW measurements (Huffman and Bolvin, 2014). There exists a Real Time version (TMPA-RT v7) only based on PMW and IR data and an adjusted version (TMPA-Adj v7) using gauge-based data from Global Precipitation Climatology Centre (GPCC) and Climate Assessment and Monitoring System (CAMS). In this study we used the TMPA-3B43 corresponding to monthly accumulation of TMPA-Adj v7.

Integrated Multi-satellite Retrievals (IMERG) is a product of NASA. Rainfall estimates algorithms involve components from the previous algorithms of TMPA, CMORPH and PERSIANN rainfall estimates. IMERG uses both PMW (Table 1) and IR sensors available from Low earth orbital and geostationary satellite, respectively. Firstly, rainfall estimates are derived from PMWs using the Goddard profiling algorithm 2014 (GPROF2014) (Kummerow et al., 2015) and IR rainfall estimates are provided by the CPC. Then, the CMORPH–Kalman filter Lagrangian time interpolation is used to produce half-hourly estimates from PMW and IR estimates. Finally, an adjustment of rainfall estimates is made by using GPCC monthly precipitation. Three stage levels of IMERG rainfall estimates are: The Early and Late run only use PMW and IR data while the final run includes the GPCC adjustment. All the products are delivered at half-hourly, daily and monthly scales on a 0.1° spatial resolution. In this study, we used the IMERG Final Run (called IMERG hereafter).

GSMaP-v6 is a product of the Japan Science and Technology (JST) agency under the Core Research for Evolutional Science and Technology (CREST). GSMaP-v6 uses a combination of PMW and IR data from CPC. The algorithms used to retrieve the rainfall rate from PMWs utilize brightness temperature. IR data from CPC merged at 4km are used to increase the temporal and spatial resolutions. To do so, a Kalman filter refined PMW rainfall estimation propagation by using the atmospheric moving vector derived from two successive IR images (Ushio et al., 2009). In comparison to the previous GSMaP v5, GSMaP-v6 includes new algorithms to enhance rainfall estimates over land as well as ocean (Yamamoto and Shige, 2014). GSMaP-v6 is available in the form of near to real time and post adjusted versions. In this study the authors have used the post adjusted version of GSMaP-v6 gauge which is gauge adjusted by using daily CPC global rain gauge data set.

The *Servicio Nacional de Hidrología y Meteorología* (SENAMHI) of Bolivia is in charge of the national hydro-meteorological network stations. For this study, SENAMHI provided the daily rainfall data of 247 stations over the regions for the 2014-2016 period. TDPS, La Plata and Amazon regions count with 37, 111 and 99 rain gauges, respectively (Figure 1). The stations are distributed on 233 SRE 0.1° and 187 SRE 0.25° spatial resolution pixels.

4. Methodology

For the inter-comparison with TMPA-3B43, the GSMaP-v6 and IMERG were resampled to the 0.25° spatial resolution. To do so, GSMaP-v6 and IMERG were first sampled from 0.1° to 0.05° resolution, then the rainfall at the 0.25° is obtained by taking the mean of rainfall value of the 5 pixels (0.05°) included into the 0.25 resolution pixel. At each rain gauge location, monthly rainfall series were derived from the gauges and the corresponding TMPA-Adj v7, IMERG and GSMaP-v6 pixels. All hourly GSMaP-v6 was cumulated for each month at 0.1° and 0.25° resolution. IMERG and TMPA-3B43 3 are delivered at monthly step and thus are directly used to derive monthly temporal series at 0.25° and 0.1° resolution. When various gauges were available on a single pixel (Figure 1), the mean rainfall value of all gauges is computed.

First, annual rainfall maps were generated from IMERG, GSMaP-v6 at both 0.1° and 0.25° scales and from TMPA-Adj at 0.25° resolution to highlight SREs ability in representing regional patterns (Figure 2). Then, SREs are assessed at the monthly scale by comparing monthly SREs and gauges estimates. Comparisons between gauges and SREs are done for each watershed by computing CC, Bias and RMSE for dry and wet seasons. Wet and dry seasons extent from November to March and from April to October, respectively (Figure 1). RMSE and Bias are computed in percentage to allow comparison between watersheds as rainfall amounts differ from one to another watershed (Figure 1). For IMERG and GSMaP-v6, indexes are computed at both 0.1° and 0.25° scales to observe the potential enhancement introduced by the lower 0.1° resolution. Finally, CC, RMSE and Bias are computed for each pixel to analyze the effects of spatial variability on SREs performance (Figure 3).

4. Results

4.1. Annual scale

Figure 2 represents the annual rainfall maps for IMERG, GSMaP-v6 and TMPA-Adj v7 for the 2014-2015 hydrological year. Over the region, regarding to annual maximum a great discrepancy is observed between SREs. A maximum value close to 3000, 5000 and 6400 mm.years^{-1} is observed for GSMaP-v6, TMPA and IMERG. These high values are related to the special strong ENSO anomaly which occurred during this year causing historical flood in the Amazon watershed. TMPA and IMERG seem more sensitive to extreme rainfall than GSMaP-v6. Highest values are observed in the central Amazon part where a regional hotspot rainfall is well detected by all SREs. On a general way, GSMaP rainfall pattern is smoother than IMERG and TMPA. For example, over the TDPS, GSMaP has better captured the typical north-south decreasing rainfall patterns. TMPA and IMERG rainfall patterns are very close as they include very similar sensors to retrieve rainfall. However, it is noteworthy that TMPA presents some spurious pixels with anomalous rainfall amounts relative to their neighboring pixels. This is clearly observable over the southern western parts. These pixels are well removed on IMERG estimates. This feature was already observed in China (Chen and Li, 2016). Here and over China this occurs over low rainfall amount region showing TMPA difficulty over arid regions.

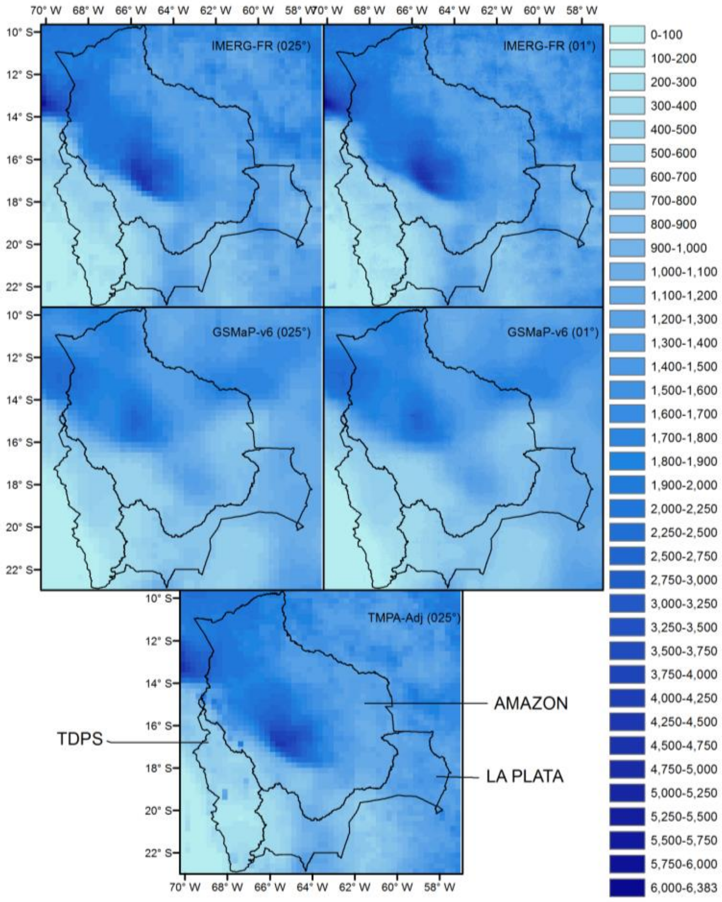

Figure 2. Annual rainfall pattern for all SREs. Rainfall amounts are in mm.

4.2. Monthly scale

Table 1 presents the results at monthly scale. TMPA presents relative homogeneous results all other the domain regarding to the considered regions and temporal scales. However, TMPA performance is slightly better and worst during the wet and dry seasons, regarding to RMSE values. During dry seasons, rainfall amounts are lower and shorter in time that made their detection complicated by PMWs sensors. During wet season, for all considered regions, TMPA-3B43 presents CC superior to 0.7, RMSE close to inferior 50% and Bias value into the -10% 10% intervals. These specific values were previously defined as objective value to insure a good performance of SREs at monthly scale (Satgé et al., 2016). Results over the TDPS were confirmed previously founding for the 2005-2007 period (Satgé et al., 2016) with similar CC, RMSE and Bias values. Thus, the change in calibration procedure due to the end of TRMM Precipitation Radar estimates in October 2014 does not have significant impact on TMPA rainfall estimates over Bolivia.

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Regarding to IMERG, at the 0.25° and global scale, statistical results are very close to TMPA-3B43 and thus IMERG will keep going measuring rainfall at same accuracy level than TMPA-3B43. However, some discrepancies are observed along the considered regions. Over the Amazon region IMERG and TMPA-3B43 present very close Bias, CC and RMSE and thus perform quite similarly. However, over La Plata and TDPS regions, TMPA-3B43 is slightly more accurate than IMERG with higher CC, lower RMSE and Bias values. Over these regions, reference rainfall amounts are lower than in the Amazon (Figure 1) and gauges are located over high relief regions (Figure 1). Thus, IMERG is more sensitive to local relief and rainfall intensities than TMPA-3B43. These differences are presented in figure 3 where CCs are much higher for TMPA-3B43 than IMERG all over the La Plata region jointly with a lower proportion of pixels with RMSE value superior to 50%. Future improved IMERG algorithm should focus on those specific features (Rainfall amount and relief) to reach at least same performances than TMPA-3B43. Passing from 0.1 to 0.25° scale does not has have significant influence on rainfall estimates accuracy with quite similar CC, RMSE and Bias values at both 0.1 and 0.25°. The spatial aggregation of SREs gridbox was already found to be unsignificant over the Altiplano (Scheel et al., 2011).

GSMaP-v6 is the least accurate considered SREs over the region with very high RMSE value superior to 100 %, Bias values inferior to 20 % and lowest CC value than TMPA-3B43 and IMERG. The lower annual rainfall estimate observe for GSMaP-v6 in comparison to TMPA-3B43 and IMERG (Figure 2) is confirmed by negative bias value at both 0.1° and 0.25° scale. GSMaP-v6 underestimates monthly rainfall at global scale and over the Amazon and La Plata regions at seasonal scale and for both dry and wet periods. Actually, the Amazon and La Plata count with larger numbers of negatively biased pixels than over the TDPS region. GSMaP-v6 is more suitable over the arid TDPS region with bias value closer to 0 and lower RMSE values. On a general way, GSMaP accuracy is lower during dry season with higher Bias and RMSE value than for the wet season. GSMaP performs better at the native 0.1° resolution than at the resampled 0.25° scale.

Table 1. Monthly CC, RMSE and Bias for TMPA, IMERG and GSMaP-v6

		TMPA 3B43			IMERG (0.1° - 0.25°)						GSMaP-v6 (0.1° - 0.25°)					
		Bias (%)	CC	RMSE (%)	Bias (%)		CC		RMSE (%)		Bias (%)		CC		RMSE (%)	
Bolivia	All	2.7	**0.79**	**88.0**	**1.3**	5.7	0.77	0.77	94.0	89.7	-21.7	-20.1	0.63	0.63	145.1	140.0
	Wet	3.6	**0.76**	62.3	**0.6**	4.9	0.72	0.73	70.4	67.2	-20.0	-18.5	0.55	0.57	110.2	106.5
	Dry	**1.4**	**0.74**	125.5	2.6	7.0	0.74	0.74	124.4	**118.4**	-25.1	-23.3	0.56	0.55	206.6	197.8
Amazon	All	2.1	**0.76**	80.0	**1.4**	6.8	0.76	0.75	82.9	78.7	-28.3	-26.4	0.55	0.55	151.9	143.6
	Wet	4.6	**0.74**	56.6	**3.0**	7.9	0.72	0.71	61.7	58.7	-26.9	-25.2	0.45	0.47	120.1	113.0
	Dry	-1.2	0.70	110.9	**-0.6**	5.3	**0.71**	0.70	109.4	**103.1**	-30.7	-28.4	0.46	0.45	199.0	189.3
La Plata	All	**3.5**	0.81	**84.0**	5.1	8.2	0.75	0.76	98.1	93.4	-16.7	-14.1	0.76	0.76	111.6	105.7
	Wet	2.4	0.71	**63.5**	**0.8**	4.5	0.63	0.64	76.5	74.0	-15.3	-12.4	0.64	0.65	84.4	80.9
	Dry	**6.2**	0.82	102.5	16.2	17.3	0.77	0.80	106.9	**97.7**	-20.6	-18.5	0.74	0.77	159.3	145.5
TDPS	All	**1.3**	**0.85**	**70.9**	-3.9	-2.6	0.75	0.76	93.4	90.9	6.7	9.5	0.66	0.67	93.4	93.1
	Wet	**-2.3**	**0.76**	**55.6**	-15.3	-10.8	0.64	0.63	79.5	76.7	6.7	9.2	0.58	0.61	72.2	70.9
	Dry	**8.4**	**0.85**	**84.9**	19.3	13.8	0.74	0.79	97.2	93.9	6.6	10.1	0.51	0.51	127.8	131.8

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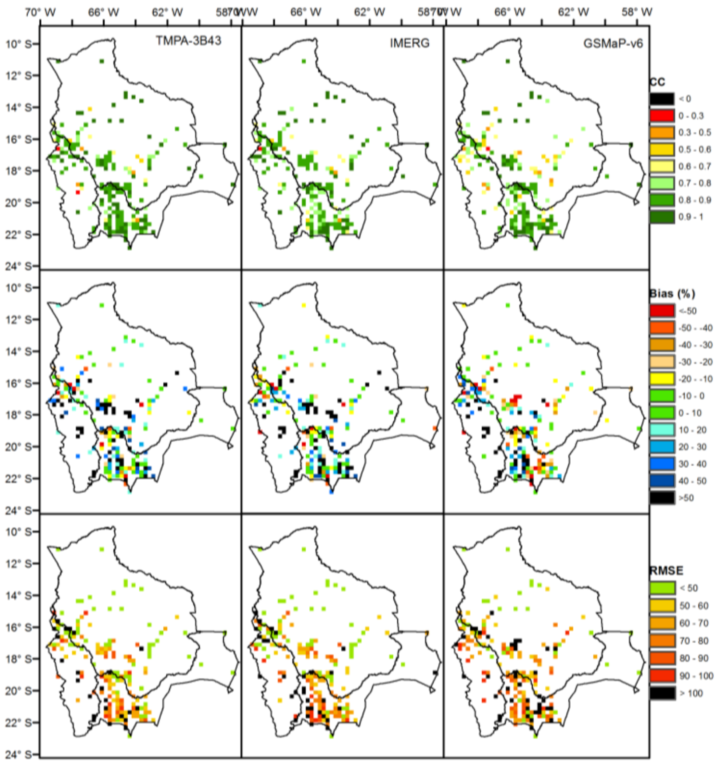

Figure 3. Spatial pattern of CC, Bias and RMSE between rain gauges and SREs monthly precipitation for the 2014-2016 period.

5. Conclusion

The new GPM rainfall products were assessed for the first time over Bolivia at the monthly scale considering the three main watersheds. On a general way, all assessed SREs are more accurate during the wet season. TMPA-3B43 and GSMaP-v6 are the more and less accurate SREs over the regions, respectively. At the regional scale IMERG has achieved its main objective which is keep going TMPA rainfall measurement. However, some discrepancies were observed when considering different rainfall features regions. Over the wet Amazon region, IMERG performs similarly to TMPA while TMPA is slightly more accurate than IMERG over the semi-arid and arid TDPS and La Plata watersheds. These differences seem to be related to rainfall intensity and topographic features as IMERG potentiality slightly decrease over arid and elevated regions. The main advantage of IMERG and GSMaP is the higher spatial resolution of 0.1° that offers the opportunity to observe small local rainfall pattern variations. Even if these two new SREs took advantage of a larger PMWs and IR sensors for their respective rainfall estimates, they do not provide the most accurate estimate. Thus, we hope this study will prove quite helpful in near future for the enhancement of current algorithms used in IMERG and GSMaP-v6.

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