Spatiotemporal Distribution of Clouds Observed by MODIS Quality Assurance in the Brazilian Northeast

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Abstract. *To estimating and monitoring land use and land cover is crucial the presence of good quality data. Our objective was to assess the temporal and spatial distribution of quality data retrieved by the MODIS sensor between the years 2000 and 2017, specifically in Bahia State, located in the Brazilian Northeast region. We used 411 images to account the presence of good quality, marginal and most probably cloudy data. The results showed that the east of Bahia State, inserted in the Atlantic Forest, presented a large concentration of failed pixels. The west region presented the most predominant good quality data, except in the beginning and end of the year, when increase the monthly precipitation. The conclusion is that the Quality Assurance provided by MODIS allows separating pixels with clouds and quality problems for further analysis.*

1. Introduction

Northeast Brazil (NEB) is the region with the largest dry tropical rainforest in South America (SILVA et al., 2018), however, the region is strongly affected by land cover degradation due to inadequate management and environmental problems related to global climate change (MARENGO et al., 2016; SANTOS et al., 2011). Thus, the monitoring of the land use and land cover changes is crucial for the correct detection of land degradation, to support decision making to mitigate impacts of these processes.

Over the past decades, Remote Sensing products have become an important source of information for monitoring land cover changes. Due to the possibility of acquiring data over large geographic extensions, such products allowed a better understanding of the processes that occur in these areas (ANDERSON, 2004).

However, when dealing with images generated from Remote Sensing, the radiation detected by the sensor may contain the mixture of different targets response and atmospheric effects. Thus, the presence of noise may cause changes in reflectance values, preventing analysis and results (LU et al., 2007). In this sense, the absence of clouds and shadows is fundamental for land cover mapping and monitoring. (RUDORFF et al., 2010).

The Moderate Resolution Imaging Spectroradiometer (MODIS) is an instrument that is currently flying aboard the Terra and Aqua spacecraft. The data provided by the sensor is widely used in the global monitoring of terrestrial ecosystems, due to large observing swaths and polar orbit that allows daily or each 2-days images (JUSTICE et al., 2002; KRAATZ et al., 2017). In addition to the atmospheric and geometric corrections already present in the available data, the quality assurance (QA) is provided, pixel-by-pixel, on the conditions of the data produced. The use of QA may be for the purpose of data analysis, selection or screening (DIDAN et al., 2015).

The aim of the present study was to assess the temporal and spatial distribution of quality data retrieved by the MODIS sensor between the years 2000 and 2017, specifically in the Bahia State, located in the Brazilian Northeast region.

2. Material and Methods

2.1. Study Area

The Bahia State occupies the sixth position among the Brazilian states with the largest territorial extension. Atlantic Forest - AF, Caatinga (Savanna-steppe) - CA and Cerrado (Savanna) – CE biomes predominate the state, whose rainfall ranges from more than, approximately, 1000 mm/year to less than 600 mm/year among the biomes (Figure 1) (KOUSKY, 1979, ALVARES et al., 2013).

Moreover, the climate typology of the state is characterized by a diversity of domains, with high rainfall variability due to the different meteorological systems acting in this region, such as the Intertropical Convergence Zone (ZCIT), Cyclonic Vortices (VCAN), South Atlantic Convergence Zone (ZCAS), breezes and winds, also a relief consisting of plains, valleys, mountains and mountains (MOLION and BERNARDO, 2002).

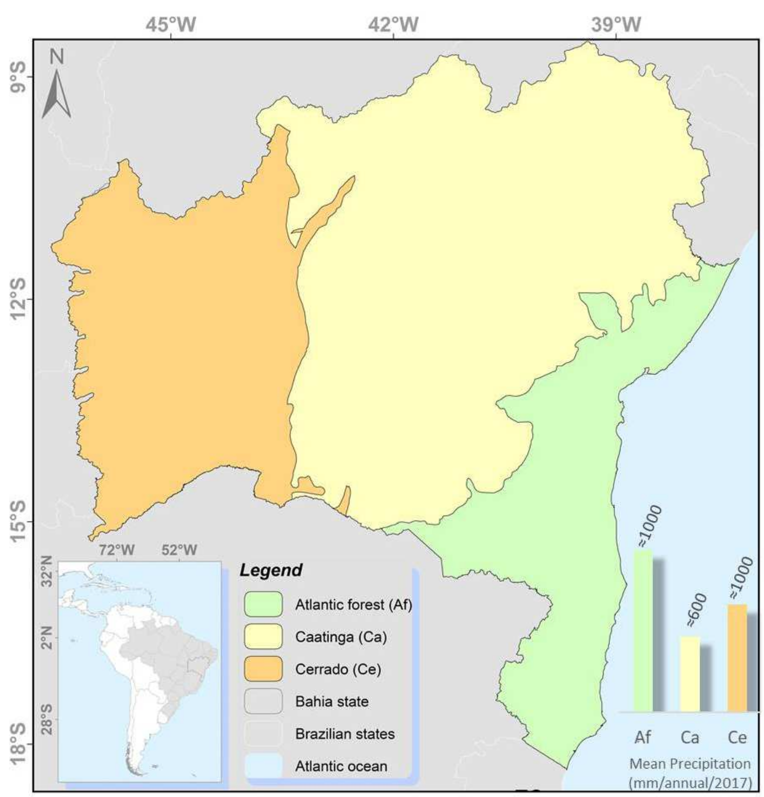

Figure 1 – Study area, biomes and rainfall ranges, located in the Brazilian Northeast.

2.2. Methodological Procedures

The MODIS sensor offers several ready-to-use products such as surface reflectance, surface temperature, net primary productivity and vegetation indices (BORGES and SANO, 2014). Among the products, the MOD13Q1 provides the vegetation index images (NDVI and EVI), including the spectral bands used for the generation of these indices: blue, red, near infrared and a band located in the middle infrared range, in addition to quality assurance (QA).

The product is available as biweekly, monthly and annual mosaics, with spatial resolutions in 250 m, 500 m and 1 km, whose are temporarily selected to provide cloud-free data by selecting pixels with maximum NDVI value. The product is generated considering the nadir adjustment to avoid distortion due to data compression in the pixels located at the image edges (DIDAN et al., 2015).

Thus, all QA data were acquired in the 16-day compositions in the spatial resolution of 250 m, for the period from 2000 to 2017, referring to the tiles H13V10, H13V09, H14V10, H14V09 covering the entire state of Bahia. All data were obtained from the EarthData – NASA (https://ladsweb.modaps.eosdis.nasa.gov), totalizing 411 images obtained for the entire study period, representing approximately 15.2 GB of files.

The QA data is presented in numeric values (bits) that summarize the quality of the pixel. A bit can only assume binary values, i.e. 0 and 1, so 8-bit combinations form 1 Byte. Considering only the first two bits contained in QA (Figure 2), they provide four different combinations (00, 01, 10, and 11) that correspond to a particular type of pixel condition. These four different combinations can be described as: good quality pixel, marginal quality pixel, most probably cloudy and non-produced pixel due to other reasons than clouds (Table 1). Thus, to classify the QA images, firstly we convert to binary values from decimal values and in sequence we selected only the first two bits.

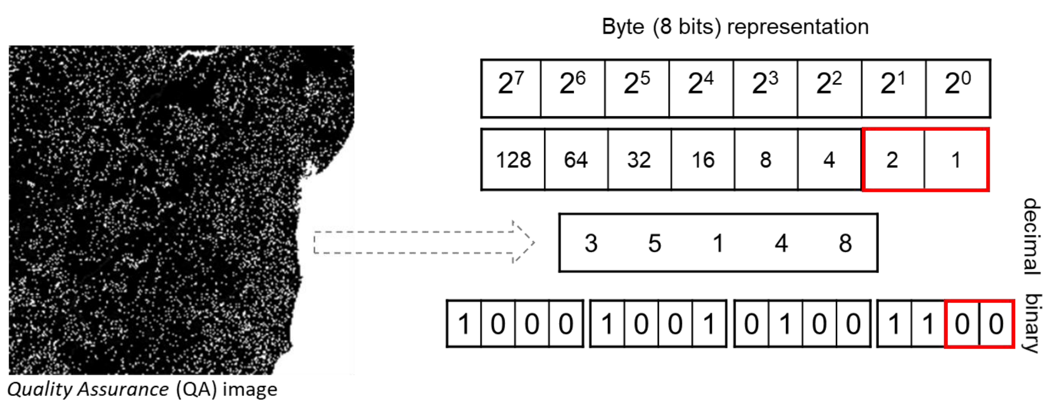

Figure 2 – Example of selecting bits in the quality assurance

Table 1 – Image description of VI Quality.

Bit	Parameter	Value	Interpretation
0–1	Quality	00	IV produced with good quality
		01	IV produced, but check other QA
		10	Pixel produced, but most probably cloudy
		11	Pixel not produced due to other reasons than clouds

Source: Didan et al. (2015).

3. Results and Discussion

The extraction of quality pixel parameters allowed counting the good quality, marginal and probably most cloudy pixels data (Table 2). To discussion, the results were divided in three regions representing the biomes, which the AF is the most affected region by marginal and probably clouds. Considering the temporal series, the standard deviation had a variation of, approximately, 52% to AF, 22% to CA and 23% to CE in good quality pixels. In other words, in specific years, the AF region had only 18% of pixels classified as good quality by MODIS assurance.

Table 2 – Average and standard deviation of pixel accounted during 2000 and 2017 years, divided by biomes.

	2000 - 2017					
	Average			Standard deviation		
	Good quality	Marginal	Probably cloudy	Good quality	Marginal	Probably cloudy
Atlantic forest	784,355	544,769	519,185	410,470	184,397	288,583
Caatinga	3,415,512	866,674	635,103	796,673	384,616	527,342
Cerrado	2,158,350	238,498	96,637	485,227	302,329	265,181

Observing the mean percentage of data (Table 3), we have noticed that the good quality data is inversely proportional of biomes location, that this the coastal region is strongly affected by clouds, while west region is less affected. CA is a transitional region between AF and CE biomes.

Table 3 - Pixel percentage based on time series average.

	2000 - 2017		
	Percentage (%)		
	Good quality	Marginal	Probably cloudy
Atlantic forest	41.87	29.08	27.71
Caatinga	68.93	17.49	12.82
Cerrado	86.49	9.56	3.87

According to Palharini et al. (2017), when analyzing the classification of clouds in northeastern Brazil, a strong cloud signal was observed over coastal areas. This can be explained by the fact that winds are generally perpendicular to the coast and carry a lot of moisture from the ocean to the continent, contributing to the formation of shallow clouds.

Visually is observed in the temporal profile (Figure 3) patterns of good quality pixels distribution during the years in all regions. Except for the beginning and end of each year, the amount of good quality is most predominant in the middle of the year, being even more distinct in CE (Figure 3b).

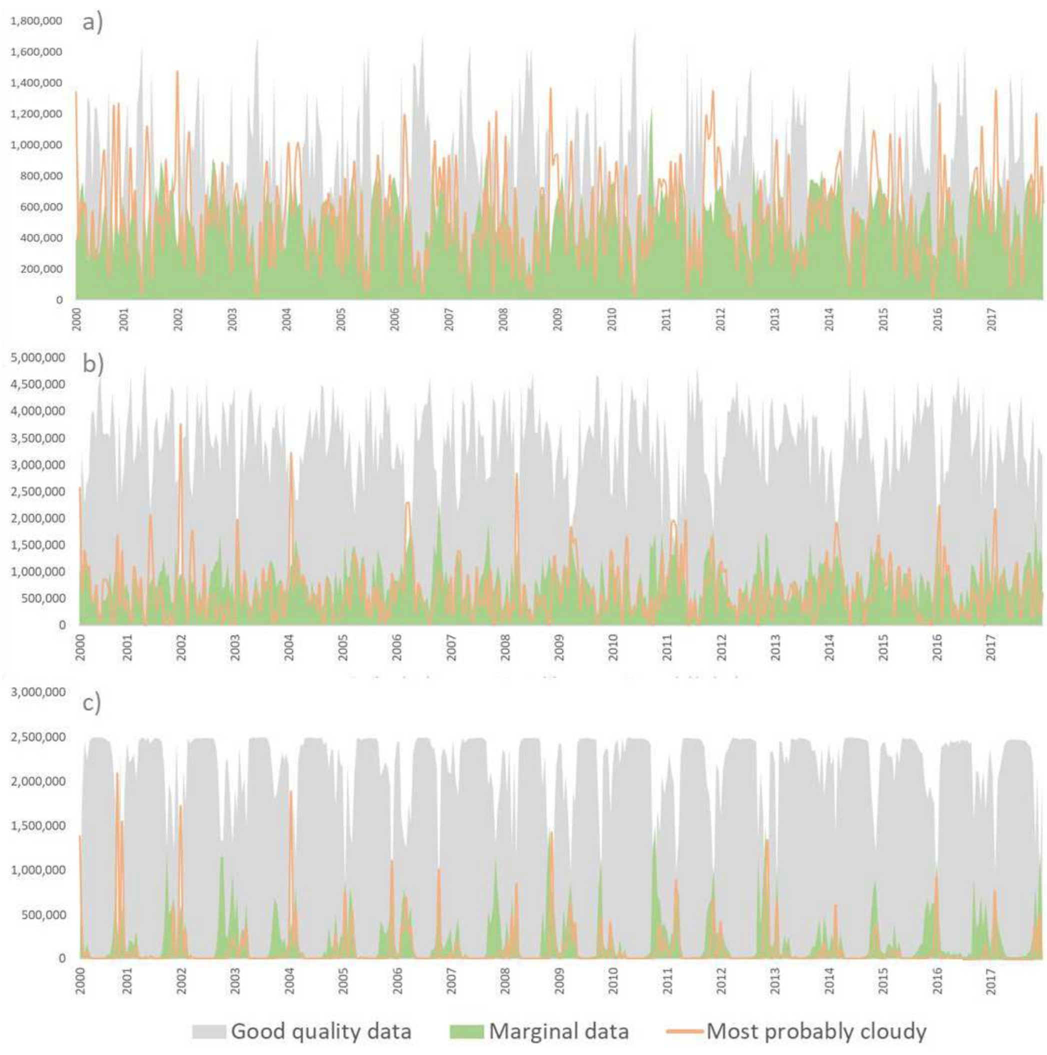

Figure 3 – Temporal profile of MODIS quality assurance between 2000 and 2017 years. Where: a) Atlantic Forest, b) Caatinga, and c) Cerrado biomes.

Analyzing individually the 2017 year and comparing with monthly precipitation obtained by TRMM (Tropical Rainfall Measuring Mission) data (Figure 4), we observe that the presence of marginal and most probably cloudy data follows the trend of increasing monthly precipitation, i.e. the beginning and end of the year, in the CE (Figure 4c).

However, this trend has shown inversely in the AF (Figure 4a). In other words, the predominantly wettest months was also the less affected by pixels classified as marginal and most probably cloudy data. Meanwhile, CA shows a higher variation during the year, although also follows the trend of decreasing good quality data and increase of monthly precipitation in the beginning of the year.

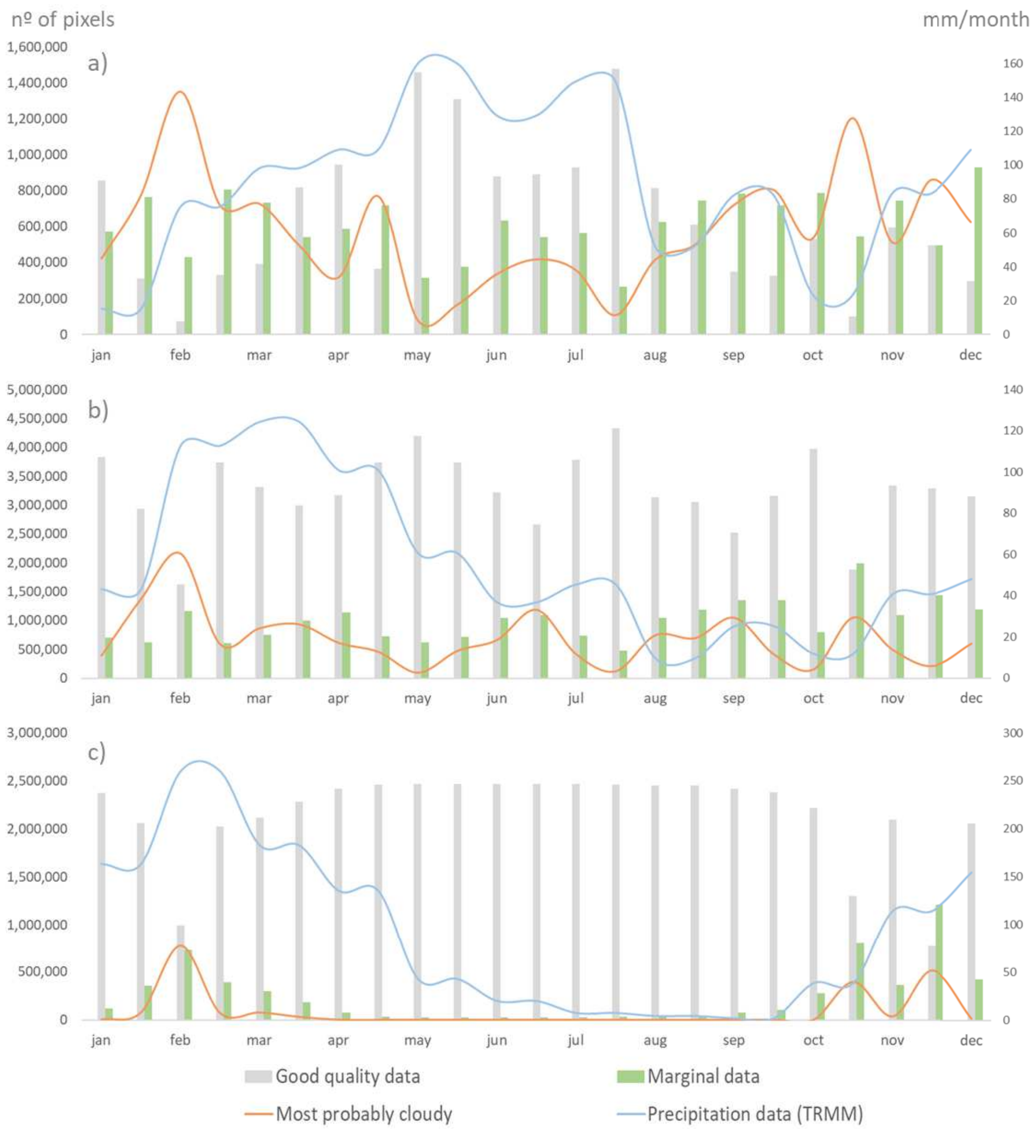

Figure 4 – Temporal profile of MODIS quality assurance between 2017 year. Where: a) Atlantic Forest, b) Caatinga, and c) Cerrado biomes.

In Figure 5, is represented the count of times that one pixel, in the period of the 23 QA images considered in the 2017 year, presented good quality (Figure 5a) and flaws (Figure 5b and 5c). As seen, in the east of the state, located the AF biome, is observed a high number of pixel failures, with a frequency of less than four (4) times that the pixel was classified with good quality.

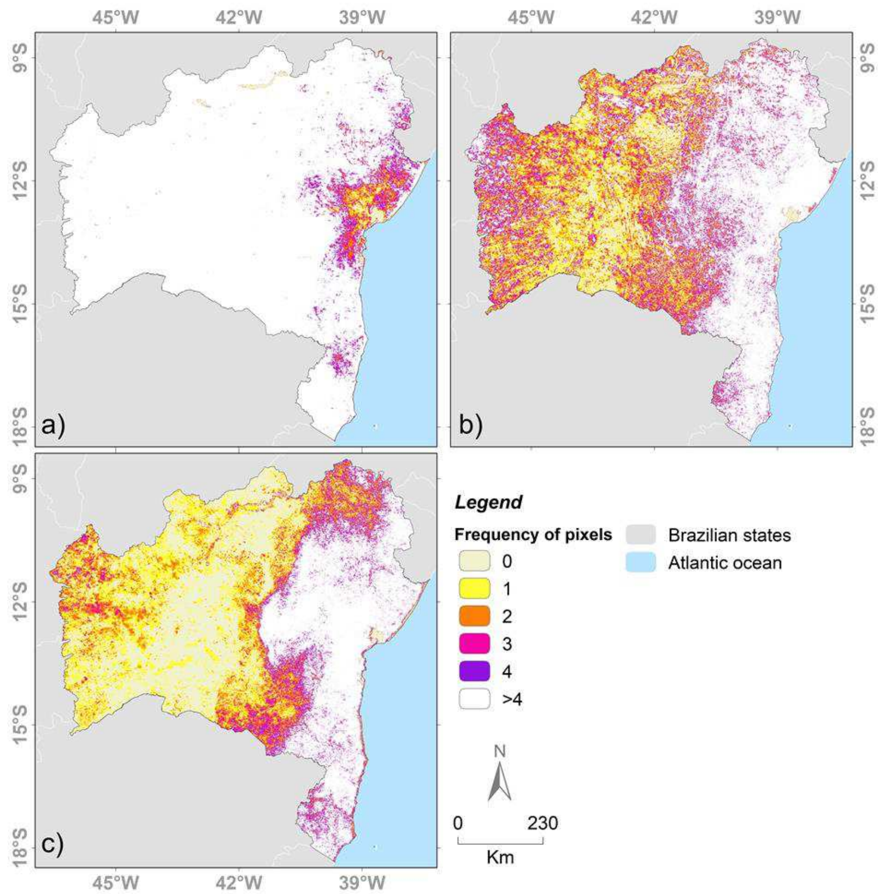

Figure 5 – Map of Bahia State classified by frequency of pixel, considering 23 Quality Assurance images in the 2017 year. Where: a) representing the frequency of pixels classified with good quality data, b) marginal data, and c) most probably cloudy data

Spatially, we observe monthly the great spatial and temporal variability of pixels that have dubious quality and / or probable incidence of clouds in 2017 year (Figure 6). Especially in the eastern part of the state, where the Atlantic Forest biome is inserted, there is not a single month with good quality pixels for the entire region. Only in May is observed the increase in the availability of better-quality data.

However, considering the monitoring of land use and land cover in the state, is evident the restriction on the use of low temporal resolution by Remote Sensing products. In this manner, operational systems, as SOS Mata Atlântica (FUNDAÇÃO SOS MATA ATLÂNTICA, 2017), due to the difficulty in obtaining cloudless orbital images for the Northeastern states, partial areas of Bahia State were added only after five years after the first land cover mapping.

Similarly, Sano et al. (2007) verified the influence of cloud cover on a Landsat TM and ETM + dataset in the Brazilian Cerrado and, as a result, it was found the lowest influence of cloud cover when compared to the Brazilian Amazon. However, cloud-free Landsat data acquisition (at least 10% of cloud cover) is severely affected during the rainy season, which may restrict studies related to seasonal changes in the Cerrado's natural vegetation or in monitoring of the vegetation cover.

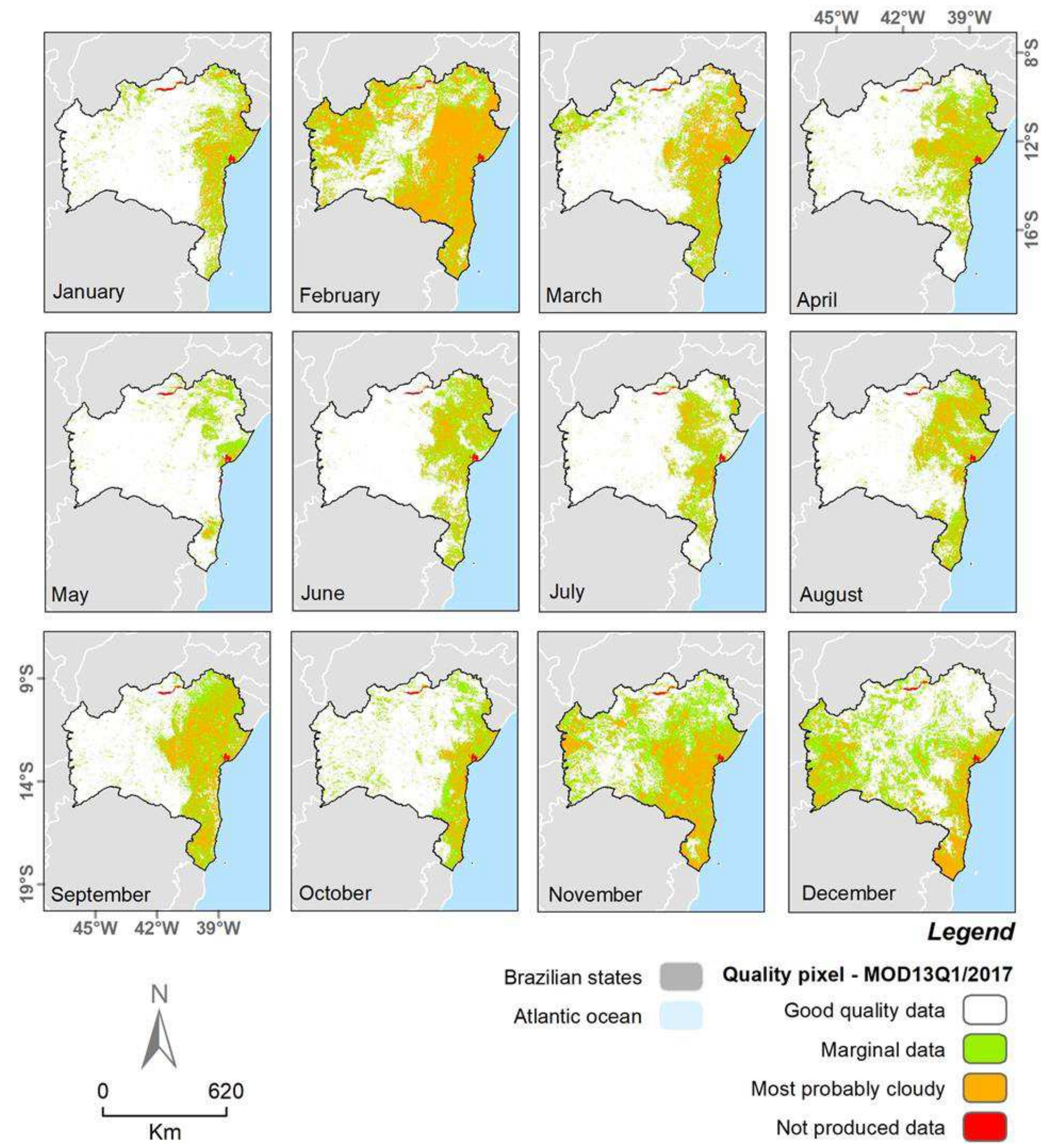

Figure 6 – Quality assurance observed spatially and monthly in the 2017 year.

4. Conclusion

The images of quality assurance presented in the product MOD13Q1 were of great importance to know, a prior, the spatial and temporal distribution of pixels with good and dubious quality data. Thus, in Bahia State, the Atlantic Forest biome is strongly affected by clouds, while Cerrado biome is less affected. We recommend checking for good quality data when performing studies that use Remote Sensing products, once the high predominance of clouds could strongly affect the mapping and monitoring of land use and land cover changes by optical data.

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