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Características e desafios de geração do NDVI para o Brasil a partir de dados do satélite de órbita geostacionária Meteosat-10¹

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RESUMO

O monitoramento da cobertura do solo a partir de indicadores ambientais possibilita melhor conhecimento dos processos biofísicos e ecológicos, auxiliando na compreensão da dinâmica do uso da terra e na tomada de decisão. Satélites em órbita polar, em sua maioria, fornecem o NDVI (*Normalized Difference Vegetation Index*) com média resolução espacial (250 m a 1 km) a partir de composições de imagens (7, 10 ou 16 dias). Por outro lado, satélites em órbita geostacionária podem fornecer o NDVI com baixa resolução espacial (1 a 3 km) e alta resolução temporal (10 a 25 minutos). Particularmente, o MSG (*Meteosat Second Generation*) mostra-se eficiente para o monitoramento da vegetação a partir do índice NDVI para regiões da África, apresentando alta correlação espacial com dados de satélites polares, sendo utilizado na análise e detecção do estresse hídrico da vegetação e da fenologia com vantagens significativas na análise de séries. No entanto, para o Brasil, existem limitações que precisam ser conhecidas para o desenvolvimento do produto NDVI MSG com qualidade. Este artigo tem como objetivo apresentar como o MSG é utilizado para o monitoramento de processos da superfície a partir do NDVI, com o intuito de identificar os desafios inerentes no desenvolvimento do produto para o Brasil. Para tanto, são apresentadas as principais características do NDVI, o histórico do produto de cobertura global e uma discussão sobre os principais desafios do NDVI MSG para o Brasil, relacionados às características de baixa resolução espacial, visada sobre o Brasil, correções atmosférica e geométrica e características da imagem pancromática e canais espectrais.

Palavras chave: Meteosat-10, NDVI, índice ambiental.

Characteristics and challenges of NDVI generation to Brazil from Meteosat-10 geostationary orbit satellite data

ABSTRACT

Monitoring land cover from environmental indicators enables a better understanding of biophysical and ecological processes, helping to understand the dynamics of land use to make decisions. Polar orbit satellites, for the most part, provide NDVI (*Normalized Difference Vegetation Index*) products with medium spatial resolution (250 m to 1 km) from image compositions (7, 10 or 16 days). On the other hand, geostationary orbit satellites provide NDVI with low spatial resolution (1 to 3 km) and high temporal resolution (10 to 25 minutes). Particularly, the MSG is efficient for the monitoring of vegetation from the NDVI index for regions of Africa, having a high spatial correlation with data from polar satellites, have been used in the analysis and detection of water stress of vegetation and phenology with significant advantages in the time series analysis. However, for Brazil, there are limitations that need to be known for developing NDVI MSG product quality. This paper aims to present how the MSG is used to monitor surface processes from the NDVI vegetation index, in order to identify the challenges inherent in product development for Brazil. For this, the main features of the NDVI are presented, the history of the global coverage product and a discussion about the main challenges of the NDVI MSG for Brazil, related to low spatial resolution on Brazil, atmospheric and geometric corrections and characteristics of the panchromatic image and the spectral channels.

Keywords: Meteosat-10, NDVI, environmental index.

¹ Article extracted from Thesis.

Introduction

Monitoring land cover using environmental indicators allows a better understanding of biophysical and ecological processes (Filho et al., 2012), contributing with better understanding of the soil use dynamics (Ferreira et al., 2006; Delgado et al., 2012) and taking managers' decision, as well as serving as subside for definition of public politics (Aguiar et al., 2011). Particularly, NDVI (Normalized Difference Vegetation Index) is defined by the ratio of the normalized difference of spectral bands reflectances of the NIR and RED (Tucker, 1979), and represents an efficient indicator for vegetation monitoring due to its simplicity and narrow relation with productivity (Tian et al., 2015), being considered the most popular index for studying vegetal health and cultures production (Atzberger, 2013). The Equation 3.1 presents the calculus of NDVI as proposed by Tucker (1979), i.e.:

$$NDVI = \frac{NIR-RED}{NIR+RED} \quad (1)$$

where RED and NIR represent, respectively, the reflectances of the spectral bands of the red and the near infrared being the index characteristics defined from particularities of reflectance from each one of those bands. The RED band presents high reflectance in exposed soils and low reflectance in soils with large vegetal coverage; on the other hand, the NIR band has low reflectance in exposed soils and high reflectance in soils with high vegetal coverage. This way, the highest values of NDVI reflect higher vigor and canopy photosynthetic capacity of the vegetation, while lower values for the same period reflect vegetal stress, resulting in chlorophyll reduction and alterations in the internal leaves structure (Tucker et al., 1979).

NDVI constitutes an important environmental variable for the study of the characteristics of the soil surface, being useful for estimating agricultural productivity (Picoli et al., 2009), heat flow (Andrade et al., 2014), precipitation in areas with different types of coverage (Nicácio et al., 2009), some soil attributes for same cultivation (Zanzarini et al., 2013) and soil mix mapping (Ahmad et al., 2010), among others. Through time series of NDVI it is possible to analyze the variability of meteorological conditions in the soil surface coverage and its relation with the other environmental indicators (Barbosa et al., 2006a; Fensholt et al., 2009; Tian et al., 2015; Barbosa et

al., 2015), as well as the identification of phytophysiognomies.

Sensors inside orbital satellites are being extensively used in vegetation monitoring for the last decades. Satellites in polar orbit, most of the times, provide NDVI products with medium spatial resolution (250 m to 1 km) from images compositions (7, 10 or 16 days) (Solano et al., 2010; Tian et al., 2015). On other hand, satellites of geostationary orbit provide NDVI product with low special resolution (1 to 3 km), but with daily time resolution (Fensholt et al., 2006; Barbosa e Ertük, 2009a). This can be explained basically due to the difference of time resolution between polar satellites and geostationary satellites: while the majority of satellites in polar orbit provide one to two readings of the pixel per day, the geostationary orbit can provide one observation every 5 to 25 minutes. This way, the presence of clouds in the moment of surface observation by the polar satellite can be invalidate the pixel data, while the geostationary orbit satellite will have other opportunities to make a reading without clouds interference during the day.

The Meteosat-10 geostationary orbit satellite is part of the series of MSG satellites (Meteosat Second Generation) of the EUMETCAST (EUMETSAT's Multicast Distribution System) European consortium, whose objective is to provide trustful data for applications of weather monitoring and weather forecast to the member countries (EUMETSAT, 2016). MSG stands as the first series of geostationary satellites in the world with RED and NIR bands very useful for monitoring of the Earth's surface and with high temporal resolution (Schmetz et al., 2002). In practice, the MODIS (MODerate Resolution Imaging Spectroradiometer) with polar satellites Terra and Aqua can get up to 32 observations daytime in a period of 16 days; however, because of cloud coverage at the time that it produces the reading (global average of 50 to 60%), the average of samples with considerable quality is only 1 to 5 in the period, being made available the product of the highest NDVI value with the lowest angle of view (Solano et al., 2010). On the other hand, given a time window of 4 hours in high hours' solar illumination (10:00 to 14:00 local time) for the MSG, it is possible to obtain up to 16 samples in a single day (Fensholt et al., 2006).

However, the bands used for obtaining the NDVI suffer influences that take place due to geometric and atmospheric conditions, that should be considered in order to obtain a better quality index. The bands present anisotropic reflectance characteristics, such that the NDVI value depends on the geometry of observation, specifically solar

and angles of view. As the variation of angles (azimuthal and zenithal) of the Sun and of view happens, even in a homogeneous surface, changes in the shading of the vegetation and the soil surface occur, which influence the value of the resulting NDVI (Fensholt et al., 2006). At the same time, the reflectance of these spectral bands suffer weather influences in the way Sun-surface-sensor due to interaction (reflection, absorption, refraction) with dynamic aerosol, tropospheric aerosol, ozone, water vapor and clouds (Vermote et al., 1997). In fact, geometric correction techniques were developed due atmospheric geometric influence and atmospheric correction techniques that are used in the correction of reflectance for obtaining the NDVI product coming from different sources, such as remote sensing satellite MODIS (Vermote and Vermeulen, 1999), SPOT-VGT (*Satellite Pour l'observation de la Terre-Vegetation*) (Wolters et al., 2016) and AVHRR (Advanced Very High Resolution Radiometer) (Vermote and Claverie, 2013).

In addition, the use of MSG to Brazil implies in the investigation of the influence of features that represent relevant challenges for obtaining the best quality NDVI. This paper aims to present a review on the NDVI MSG in order to identify and discuss the key challenges to obtaining the product for Brazil. To this end, it presents characteristics of the influences of geometric and atmospheric conditions on the NDVI and a review on the NDVI MSG development and applications. Then, the main challenges of the index for Brazil are discussed, i.e.: low spatial resolution, where the pixel MSG features mix of different classes of land use; relatively high the angle of view, which influences the accuracy of surface reflectance; the use of fusion techniques of bands, in order to increase the spatial resolution of the product; and the spectral differences of the SEVIRI (Spinning Enhanced Visible and Infrared Imager) bands with the bands of the polar satellites most used for monitoring soil surface.

NDVI and the influences of geometric and atmospheric conditions

The correction of the angular effects allows a much more accurate data comparison

between different locations and times of the year (Proud et al., 2014), and can be described as models that calculate the influence of geometry of the scene on a data series (Wanner et al., 1995). The main advantages of the treatment of angular effects are potentially higher accuracy compared to simple models (Koukal et al., 2014; Proud et al., 2014) and the additional information extraction (Wanner et al., 1995; Lyapustin et al., 2012; Moura et al., 2015).

To this end, taking into account a surface covered in sparse vegetation, reflectance in the RED band is anisotropic enough compared to the NIR, being greater in the scatter direction (backward scattering), due to the fact that coverage plant and soil are illuminated. On the other hand, the reflectance in the direction of forward scatter (forward scattering) is weaker, as a larger part of the vegetation and soil is shaded. Moreover, in areas of dense vegetation, the treetops are seen as a rough surface and thus the band NIR reflectance is more isotropic, being only slightly higher toward the back scattering. NIR reflection already in the direction of forward scattering is greater, because a portion of the radiation is transmitted through the canopy and thus is reflected by the soil and leaves (Fensholt et al., 2006). Calculating the NDVI towards forward dispersal, the combination of low reflectance of RED, and relatively high reflectance in the NIR, generates higher NDVI values, in contrast to the back dispersion. So, during the day, the bidirectional reflectance of the NDVI for most vegetated and homogeneous surfaces usually features the shape of a bowl (bowl-shaped), with a decrease of NDVI values as increases solar angles and view (Fensholt et al., 2006).

Figure 1 shows the behavior of the NDVI, RED and NIR of a pixel MSG during the day, as the variation of view and solar angles. The sample is an annual agriculture area and without contamination of clouds in Chapadão do Céu county, State of Goiás (02/03/2014). The observed NDVI variation as the variation of solar angles (azimuthal and zenithal); as the satellite is geostationary, the angles of view (azimuthal and zenithal) are constants. It is possible to identify the change in the behavior of the NDVI for the range of 10:45 to 13:15 h, in the shape of an upside-down bowl (bowl-shaped), and their variation of reflectance of RED and NIR due variation of solar angles (azimuthal and zenithal).

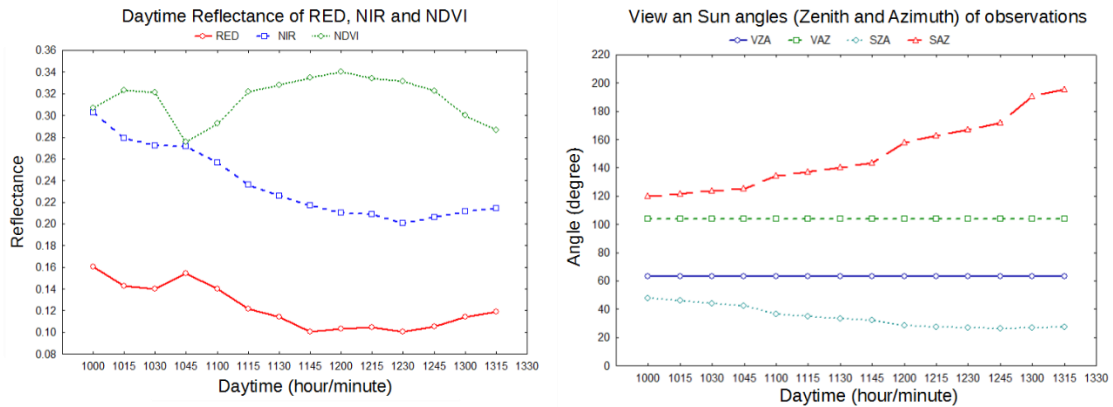


Figure 1. Behavior in time of observation angles (right) and reflectance of RED and NIR channels and the NDVI (left) during the day of a sample of the MSG satellite in an area of annual farming without contamination of clouds in the municipality of Chapadão do Céu, State of Goiás, day 02/03/2014, 10:00 to 13:15 range Brasilia Time. Being VZA View Zenith Angle, VAZ View Azimuth Angle, SZA Sun Zenith Angle e SAZ Sun Azimuth Angle.

The estimation of BRDF (Bidirectional Reflectance Distribution Function), on surfaces with vegetation cover is made from models that differ in the details that describe the physical processes responsible for the diffusion of light, which is due to the type of ground cover and the number of observations necessary to derive the model parameters (Wanner et al., 1995). Thus, physical models describe the diffusion of light explicitly and empirical models through mathematical functions. Naturally, the physical models are considered more complex than their similar empirical. In terms of complexity, semiempirical models are between these two: they are mathematically simpler by keeping its key features, and require few input parameters and estimate calculation samples (Wanner et al., 1995; Schaaf et al., 2002). The semiempirical of kernel driven model aims to represent the surface through the linear assumption of a set of kernels that together complement each other to represent the characteristics of reflection from the surface. So, basically, the reflectance of the surface is seen as a combination of two different kernels (Roujean et al., 1992): the kernel of geometric dispersion, that considers the diffuse reflection from the surface and canopy shading effects and the kernel of volume dispersion, that considers the reflection and absorption of the leaves of the trees of a canopy.

Atmospheric correction, on the other hand, considers the effects of interaction of solar radiation to the Earth's atmospheric layers, in order to provide better accuracy in measurements of reflectance of the surface. In fact, a proportion of the radiation received by the sensor corresponds to the radiation reflected or scattered by the

atmosphere that has not even interacted with the surface. Similarly, part of the radiation reflected by the surface is attenuated by scattering and absorption in the atmosphere. In addition, dynamic atmosphere aerosols, such as water vapor, ozone and AOT (Aerosol Optical Thicknes) affect atmospheric processes (absorption and diffusion) that modify the solar radiance reflected by a target when seen from space (Rahman and Dedieu, 1994; Vermote et al., 1997). Most of the solar radiation measured by satellite sensors correspond to radiation reflected by the atmosphere and clouds (23%), while a small part corresponds to the reflection from the surface of the soil (7%) (Trenberth et al., 2009). Thus, it is very important to know the atmospheric characteristics for estimating the interference caused to the signal measured by the sensor, obtaining, this way, more precise information of the surface reflectance (Tucker, 1979; Vermote et al., 1997; Jones and Vaughan, 2010).

The modeling of these effects uses complex mathematical equation and have high computational cost, so simulation techniques to estimate and atmospheric correction are preferred (Vermote et al., 1997). Such techniques for the correction of each pixel, require input parameters related to dynamic aerosol from the atmosphere (AOT, ozone and water vapour) and the view angles and illumination (azimuthal and zenithal) (Kotchenova et al., 2008). The 6S (Second Simulation of a Satellite Signal in the Solar Spectrum) is an advanced radiative transfer code designed to simulate the reflection of solar radiation using a surface-atmosphere-sensor system for a wide range of conditions spectral and geometric, atmospheric (Vermote et al., 1997).

The technique presents a good performance on homogeneous lambertian surfaces and anisotropic (Kotchenova and Vermote, 2007), particularly used in the MODIS atmospheric correction algorithm (Qu et al., 2014). However, the code performs a simulation and can require considerable time, as soon as the execution of the algorithm 6S can become infeasible to near real-time applications. On the other hand, the SMAC (Simplified Method for the Atmospheric Corrections) is a method based on simplified analytical formulas for atmospheric correction, less accurate than the 6S, however, has the advantage of faster processing (Rahman and Dedieu, 1994).

History of NDVI MSG

Even before the launch of MSG, its potential for monitoring of soil surface properties and biospheres' applications was highlighted, specifically the vegetation, from the RED and near-infrared channels (Govaerts, 1998). Studies had showed a high correlation between the maximum NDVI MSG compared to AVHRR and SPOT-VGT, emphasizing better efficiency of the MSG images to eliminate the contamination by clouds, because repetition of images; However, studies related about atmospheric effects and geometric corrections to obtain the NDVI MSG (Ewrs and Lacaze, 2008).

Initial investigations used the composition of images using the maximum value, in order to minimize the influence of clouds, being possible the identification of interference due to satellite illumination geometry or even aerosol contamination of fires (Barbosa et al., 2006b). Later, Barbosa and Ertürk (2009a) presented an algorithm of extracting the maximum, medium and minimum values of NDVI, demonstrating that this product could be used for monitoring the spatial dynamics of vegetation coverage.

Fensholt et al. (2006) studied the BRDF in various vegetation types and different geometric conditions of obtaining the NDVI MSG. To this end, they made use of the SMAC algorithm for atmospheric corrections, and the parameters of atmospheric conditions (water vapor, aerosol and ozone) were obtained from daily MODIS products (MOD08 and MYD08) (Hubanks et al., 2015). The results showed a clear difference of anisotropy of the RED and NIR bands, as the variation in solar and angles of view in different classes of vegetation, influencing directly the NDVI value observed. The technique presented as advantageous characteristic, regarding polar satellites, the generation of the index in smaller

time intervals, provided that appropriate geometric and atmospheric corrections be made (Fensholt et al., 2006). Deepening on atmospheric correction of the RED and NIR bands (Proud et al., 2010a) identified that the SMAC algorithm produces good results compared to the 6S algorithm accuracy, only solar angles smaller than 30° and in good weather conditions (water vapor $2 \text{ gm/cm}^2 <$ and ozone $< 0.25 \text{ cm/Atm}$). However, through the analysis of error compared to the results of the 6S, equations for error correction of the main variables common to both were entered, as atmospheric transmission algorithms (gaseous and non-gaseous), surface albedo and reflectance atmosphere (Proud et al., 2010b).

In this period, Ertürk et al. (2010) presented an NDVI product available in daily and decade interval can be obtained by direct link (via satellite) or via the home page of EUMETSAT (Eumetsat, 2011). For both, it's necessary at least 10 samples without contamination of clouds in the day to calculate the geometric correction using the BRDF semiempirical of kernel driven model (Roujean et al., 1992). In order to minimize errors of calculation, the BRDF was calculated on the basis of maps of land use, being used tables type LUTs (Look Up Tables) to provide the respective values of isometric, geometric, volumetric and speculate kernels.

Later, Proud et al. (2014) proposed the geometric correction from an algorithm similar to BRDF MODIS algorithm used for generation of the albedo product (Schaaf et al., 2002). However, while in the MODIS this weight value depends on several input parameters (aerosol, cloud type and shading), for the proposed method, the NBAR (BRDF-Adjusted Reflectance), the weight value depends on the zenith view and solar angles, in that the greater the sum of the angles, less the weight of the sample. Atmospheric correction algorithm SMAC was used, taking into account error adjustments, as presented in Proud et al. (2010b). It was possible to identify that NDVI MSG data are satisfactory to regions of Africa with temporal resolution of five days showing higher quality data than polar satellites, such as MODIS, due to the high amount of quality samples, even in the period of rains due cloud cover (Fensholt et al., 2011).

Other applications with the NDVI MSG are related to the use for estimation of surface temperature, validated with data from weather stations (Nieto et al., 2011); drought monitoring, assuming a gradual evolution of vegetation stress identified with the use of pertinence of fuzzy logic (Rulinda et al., 2010); the seasonal variation of vegetation and soil moisture (Rasmussen et al., 2011), to estimate the temperature of the soil and

vegetation through the negative relationship with the corresponding NDVI values; the phenological monitoring to identify stages of crop development (Sobrino et al., 2013); the evaluation of the synergy between the MODIS satellites and MSG with use of the advantages (spatial and temporal) of each satellite (Zhao et al., 2014).

Specifically, for Brazil, even at a high angle of view, the NDVI MSG presents great potential for applications, however, are little investigated, due lack of reliability in the data and operational difficulties in obtaining and processing of data geostationary satellites. In fact, if applications summarize on product review (Borges, 2010), in the estimate of emissivity and calculation of surface temperature (Dana and Ferreira, 2010) and in obtaining from the NDVI image composition by the maximum value (Barbosa et al., 2006b). However, some studies seek to better know this given, whether through analysis of spatial characteristics of NDVI compared to polar satellites (Silveira et al., 2015) for application in the study of phenology and land use (Correia and Silveira, 2015).

Challenges for generation of NDVI MSG to Brazil

Low Spatial Resolution

The pixel MSG has increased spatial resolution compared to polar orbiting satellite data and, consequently, generalization of NDVI value (Silveira et al., 2015). Once, for the pixel MSG, even in a region that represents a large area of the same class of land use, has within the pixel areas of other classes in lower proportion. For example, a pixel MSG classified as pasture possibly has some small areas of other classes of use, as natural

vegetation or agriculture. In this way, the pixel MSG represents reflectance of a mix of different land-use classes.

As an example, Figure 2 shows a MSG pixel classified as pasture in a region of State of Goiás, in Brazil, with predominance of pasture lands, as the classification of Map TerraClass 2013 (Brasil, 2013). As the MSG pixel corresponds to an area of 3 x 3 km and the MODIS pixel RED and NIR bands an area of 250 x 250 m, the MSG pixel corresponds to an array of pixels MODIS. The image shows the topographic variation of area, data generated from SRTM (Shuttle Radar Topography Mission) with topographic exaggeration (x 3). Through the range of vegetation index realizes that the MODIS NDVI is substantially greater than the NDVI MSG and can represent the characteristics of the vegetation with greater reliability. Already the MSG phenological characteristics generalization has increased to represent the entire area with a single value of NDVI.

Such feature can limit applications of MSG data when it requires cartographic characterization, especially in areas with greater diversity of land use classes. In addition, because the pixel size it's necessary consider that the occurrence of subpixel clouds (clouds with the lower area the area of the pixel). These clouds cannot be detected by clouds mask algorithms, but influence the reflectance of RED and NIR bands and, consequently, the value of NDVI (Proud et al., 2014). To this end, a reliable alternative would be using the panchromatic band for identification of subpixel clouds, from the use of land use maps and pre-defined thresholds (Bley and Deneke, 2013).

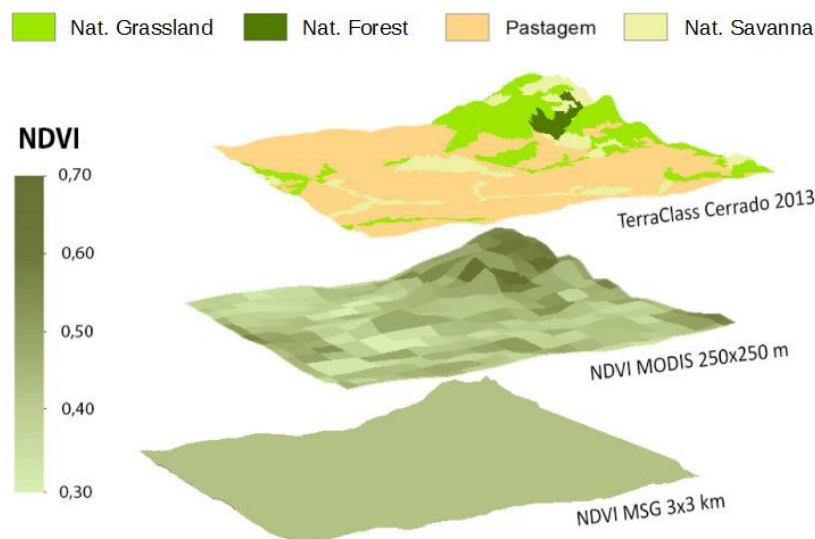


Figure 2. Spatial resolution of one pixel MSG (3 x 3 km) with predominance of pasture, compared to the MODIS NDVI product (250 x 250 m) in the area. We used the classification of TerraClass 2013 Cerrado

(BRAZIL, 2013), topographic data SRTM (Shuttle Radar Topography Mission) with topographic exaggeration (x 3).

View Over Brazil

MSG covers much of Brazil enabling the use of its products and spectral bands for various types of applications. The same has been used in Brazil for generation of NDVI (Barbosa et al., 2006b; Barbosa and Ertük, 2009a; Borges, 2010; Barbosa et al., 2014; Silveira et al., 2015), estimation of soil temperature (Nieto et al., 2011), characterization of clouds and storms (Barbosa and Ertük, 2009b; Da Cruz, 2009; Barbosa et al., 2011, 2012). Such applications have been developed, in its most, in areas of study that are

located in the Northeastern and Southeastern regions, which feature smaller angles of view and, consequently, higher image quality. However, the EUMETCAST system provided images exclude the entire state of Acre and part of the West of the State of Amazonas for being located in extreme regions of the SEVIRI sensor (angle of view greater than 75°). Figure 3 presents the map of target angle variation of MSG for Brazil. Good part of Brazil features high view angle, above 60° , and in these conditions there is a drop in the quality of the results of geometric and atmospheric correction algorithms.

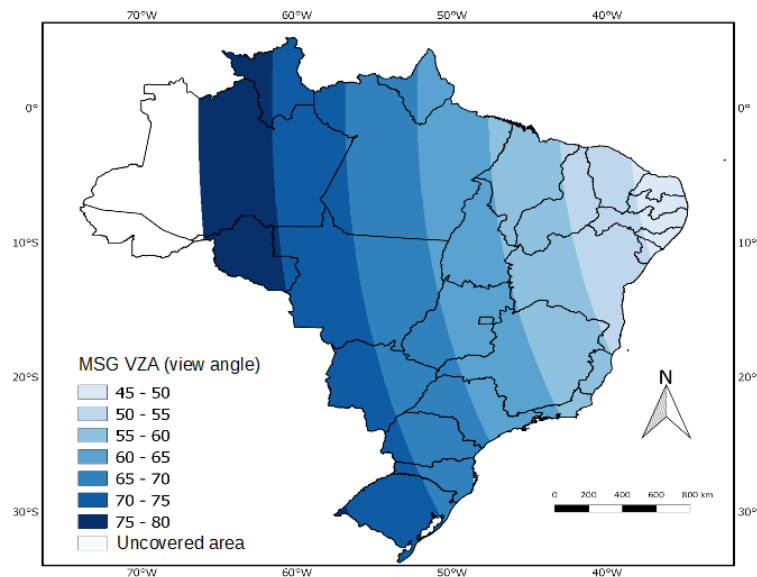


Figure 3. Map of target angle variation, in degrees, of the MSG (MSG VZA) for Brazil, excluding areas not covered due view angle greater than 75° , corresponding to the State of Acre and Amazonas West.

The pixel MSG has spatial resolution of 1 km nadir for panchromatic and 3 km for the other bands. However, the accuracy of this data decreases as the angle of view, that's because the pixel will present a larger area of instant sensor object on the surface of the soil, known as GIFOV (Ground Instantaneous Field of View). For the MSG this degradation of resolution is linear up to 65° , and increases exponentially above that value. Figure 4 illustrates this feature, where a pixel located 0° latitude and longitude (VZA = 0°) has a spatial resolution of 3 x 3 km, same resolution multispectral images provided by EUMETSAT. To the observation of a pixel with longitude 55° (VZA = 55°) is a modification of the spatial resolution for 6.1 x 3.3 km (EUMETSAT, 2015),

caused due the increased GIFOV. This entails increasing the correlation between the pixels close, since the reflectance value of a pixel has also information of its neighboring pixels (Cracknell, 1998). In this way, to target high angles occurs a considerable mix between neighborhood pixels which, consequently, decreases the quality of the information of that pixel.

This characteristic also influences the quality of the panchromatic band, which will present a larger GIFOV as increasing the angle of view. Consequently, when assessing the merger of bands (panchromatic and multispectral), in order to increase the spatial resolution of the NDVI MSG, the results may not be satisfactory.

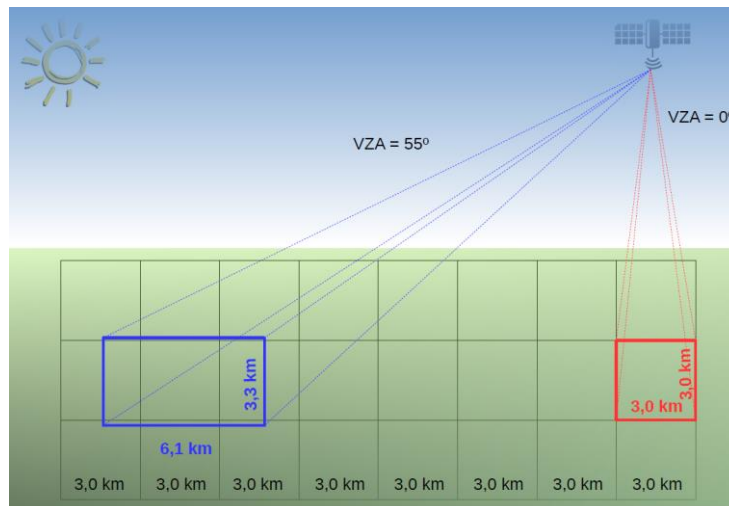


Figure 4. Illustration of the variation of GIFOV (Ground Instantaneous Field of View) of the MSG to a pixel in the nadir ($VZA = 0^\circ$), with spatial resolution of 3×3 km, and another 0° latitude and 55° longitude ($VZA = 55^\circ$) with 6.1×3.3 km

Atmospheric and geometric corrections

Regarding atmospheric correction, the algorithm SMAC only presents quality results for low angles of view (smaller than 30°), which makes the application to the Brazil (Proud et al., 2010a). To this end, an alternative is the SMAC-fixed, which introduces amendments to the method for calculating SMAC in order to reduce the differences compared to the 6S. Despite improvements, there are still conditions under which the technique has low precision, especially when the zenithal angle of view or solar is high (greater than 60°), is still important to check the weather conditions before the conclusions data from SMAC-fixed (Proud et al., 2010b).

On the other hand, the 6S provides better quality results for angles up to 80° (Vermote et al., 1997), making the entire area of the SEVIRI sensor monitored by Brazil, which features smaller than 75° angle. However, as this algorithm represents a simulation, the run time is significant, especially if it is considered that the atmospheric correction is made in each pixel every 15 minutes, range that corresponds to the temporal resolution of MSG in a practical study, Proud et al. (2010b) evaluated a MSG image cropped to Africa and part of the Middle East, with the channels of RED, NIR and shortwave on a dedicated computer and high speed requires approximately 25 seconds of run time for SMAC, and 6S this time would be more than 20 minutes. As the MSG provides images every 15 minutes, it's meant that the 6S is unable to process the data fast enough, demonstrating that the 6S is not suitable for the atmospheric correction in near-real time to large datasets

(Proud et al., 2010b). An alternative is to use LUT based on the results of the 6S algorithm, and reflectance bands entrance and geometric conditions (view and illumination angles) and main atmospheric parameters (AOT, ozone and water vapor), and generate like output the atmospheric correction parameters (x_a , x_b , and x_c) (Lee et al., 2015); This technique is used for atmospheric correction algorithm of the daily product MOD09 reflectance (Vermote and Vermeulen, 1999).

Regarding the geometric correction, the semiempirical of kernel driven model presents satisfactory results for representation of the coverage of the surface of the soil (Wanner et al., 1995; Ertürk et al., 2010). To this end, it is necessary to define the geometric and volumetric kernels that best represent the soil cover. And, in studies for MSG, Roujean models were evaluated in the NDVI product EUMETSAT (Ertürk et al., 2010) and the model Li-Sparse Ross-Thick (Proud et al., 2014), which is similar to that used to estimate of the MODIS albedo (Schaaf et al., 2002). The geometric kernel Li-Sparce models the geometry of bodies of surface (trees) like as sparse distribution, as the angles of observation and view. The volumetric Ross-Thick kernel models the tree volume with higher density of leaves, as the angles of observation and view. These models are acceptable for geometric correction for Brazil, mainly in grazing areas for presenting few trees and more density of leaves (Bruziguessi, 2016).

Panchromatic image features

From the panchromatic image and multispectral channels (which are part of the frequency spectrum of the panchromatic image) use different techniques of fusion of bands to get a picture of the multispectral channels with the same spatial resolution than the panchromatic band (Amro et al., 2011; Vivone et al., 2014; Alparone et al., 2015). Because of limitations of the detectors and scanning the MSG provides a panchromatic image that modifies the coverage area as the time of day, and the movement from East to West. As Brazil is located further west of the latitude of the MSG, with angle of view ranging from 40° to 80°, the panchromatic images with coverage over Brazil are generated from 14:00 h to 17:00 h, GMT. Figure 5 presents a sequence of panchromatic images in the range of 11:00 to 14:00 h.

It is noticeable that complete coverage on the Brazil occurs from the 14:00 h, excluding areas not covered, corresponding to the State of Acre

and Amazonas West. In fact, the panchromatic image can be used to increase the spatial resolution of the multispectral channels, but it's necessary to know that the time interval in which this image is generated for the Brazil is limited.

However, the time window commonly used for obtaining the NDVI is 10:00 to 14:00 h local time. In this way, the use of the panchromatic band for the improvement of the spatial resolution of the NDVI MSG should take into consideration this difference of intervals to obtain this datas. On the other hand, considering the time window of 3 hours of panchromatic band data, is can generate up to 12 high resolution images, which may assist in decreasing the influence of clouds on merger of bands.

In addition, the fusion algorithms of bands commonly operate in satellite imagery in panchromatic and multispectral bands are generated at the same time, being necessary to identify alternatives for the noise caused, mainly due to the difference of cloud cover images, does not result in an image with less quality.

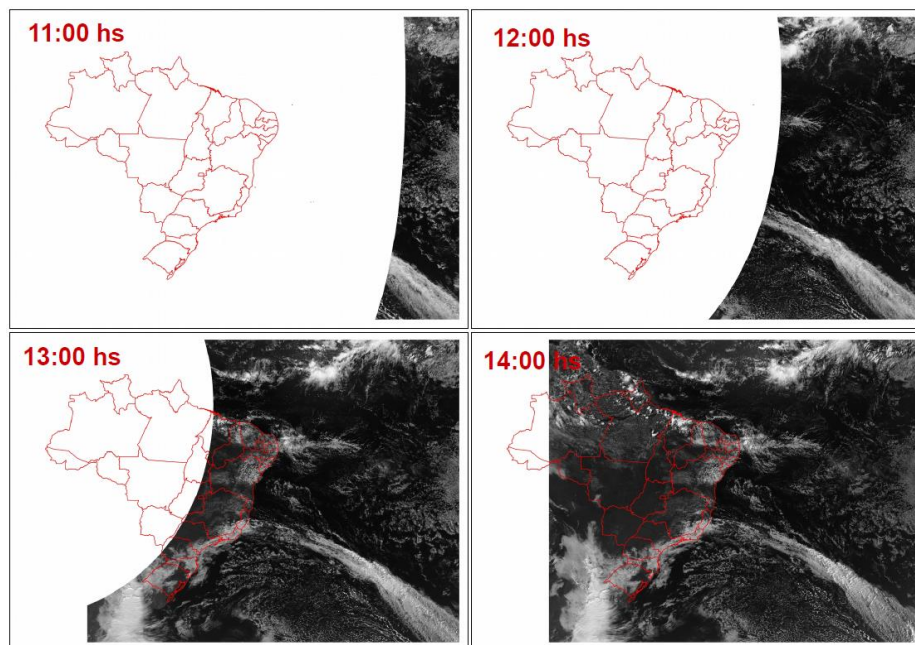


Figure 5. Panchromatic band scan dynamics of MSG on the Brazil in the range of 11:00 to 14:00 h, GMT, excluding state of Acre and Amazonas West.

Characteristics of spectral channels

The polar satellites most used for monitoring of the surface are the MODIS and Landsat-8. To these RED and NIR channels satellites, used for the NDVI, very similar characteristics, as shown in Figure 6: they are narrow, with bandwidth of 50 nm to the RED and 35-40 nm for the NIR, and with little difference between the limits top and bottom for RED (630-

680 nm Landsat-8 and 620-670 nm MODIS) and NIR (845-885 nm Landsat-8 and 841-876 nm MODIS).

On the other hand, MSG has a bandwidth of 150 nm for RED and 140 nm for the NIR, covering a spectral region well wider than the same channels from MODIS and Landsat-8. This represents a difference relevant to the NDVI MSG when compared with MODIS NDVI and NDVI Landsat-8, and can result in an index of vegetation

a bit different if considered the same geometric and atmospheric conditions.

The panchromatic channel of MSG (400-1.100 nm), on the other hand, covers the spectral

region from RED (560-710 nm) and NIR (740-880 nm), so these channels can be used in the process of fusion of bands, so get the MSG high NDVI spatial resolution.

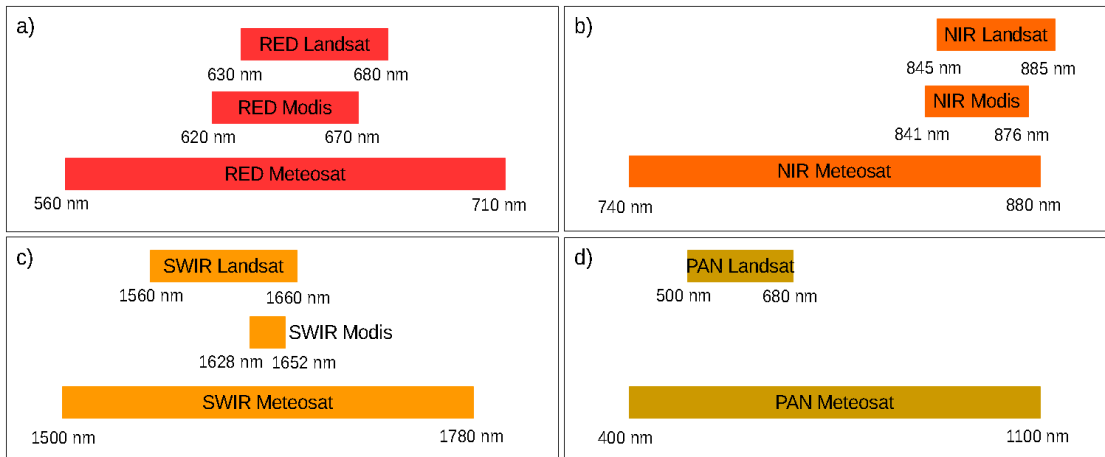


Figure 6. Visual comparison between channels (a) RED (red), (b) NIR (near infrared), (c) SWIR (shortwave infrared), and (d) PAN (panchromatic) MSG satellites, MODIS and Landsat-8.

Conclusion

The MSG is a geostationary orbit satellite temporal resolution quite favorable for various environmental applications. It represents the first series of geostationary satellites that has the RED and NIR spectral bands, allowing the NDVI and the monitoring of the surface of the ground in near-real-time, with daily imaging perspective. Several studies present applications of NDVI MSG to phenology and related environmental parameters mainly about Africa. However, the MSG covers a large part of Brazil, enabling use for environmental monitoring with high temporal resolution, allowing you to see the surface of the ground in gaps during the day without cloud cover.

Although, due to the atmosphere and influence of surface have on the reflectance measured by the sensor, obtaining the best quality MSG NDVI demands the application of geometric and atmospheric correction, and extensive studies related. The geometric correction using semiempirical of kernel driven model is the most used with MSG, providing satisfactory results for low angles of view. However, due to the high angle of view for Brazil, and the consequent increase of the GIFOV, it's necessary evaluate which geometric kernel and volumetric models may provide better results. In addition, the atmospheric correction is very important for the MSG, used two very different alternatives, SMAC and 6S techniques. However, for high angle of view the 6S presents itself as the best alternative, being viable in near-real time processing through the use of LUTs.

Even though the multispectral bands have a spatial resolution considered low (3 km at nadir), the panchromatic band allows bands of NDVI images (RED and NIR) with lower spatial resolution (1 km at nadir), which allows increasing the pixel resolution daily 3 MSG NDVI km to 1 km, extending the possibilities of application of this product. Although, due to the dynamics of the panchromatic band generation MSG it's necessary to identify a better way to use it to improve the spatial resolution of the multispectral data without increasing the noise. Due to the high angle of view, it is necessary to assess the quality of the resulting product, because of the considerable increase in the GIFOV and the mix of pixels.

As described by Fisher (1997) in the article titled "The pixel: the snare and a delusion" the pixel obtained by remote sensing presents complexities that cannot be ignored, and it is important that the commitment to research in order to provide better understanding of particularities and thus recognize their own limitations. This is no different to the MSG data, which introduces features and specific limitations that should be considered for obtaining the NDVI MSG product for Brazil. The knowledge of such particularities can be useful for that, in processing steps, may make it possible to obtain a product with greater reliability and quality, as well as recognizing the limitations of the product generated. In addition, you can use this study as a reference for obtaining the NDVI data from the new satellite series GOES (Geostationary Operational Environmental Satellite), which also covers Brazil, but with a lower angle of view and, from the ABI sensor

(Advanced Baseline Imager), which features as advantages lower spatial resolution (500 m to 2 km) and a channel of reflectance of blue, which allows the use of techniques for elimination of noise, such as air pollution and other aerosols.

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