Using two-dimensional continuous wavelet transform to detect differences among primary forest, water bodies, clouds and cloud shadows on remote sensing images of an Amazon rain forest region

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Abstract

One issue in practical uses of remote sensing imagery is to map clouds and cloud shadows. Often the clouds can be confused with snow, sand or straw cover. Moreover, the shadows of the clouds can be confused with water bodies. In this way, we are using Two-Dimensional Continuous Wavelet Transform (CWT2D) in order to identify differences between primary forest, water bodies (lakes and rivers) from clouds their shadows. The site is located at the Uatumã Reserve (USDR) in Central Amazonia. We use CWT2D to detect per scale differences among patterns of the surface texture. The results show the existence of statistically significant differences among the distinct classes of areas mentioned above.

Motivation

The main land use and land cover of the earth surface are: agricultural crops, urban areas, forests, pasture land, wetlands, among other areas that generate different landscape settings with different textures whose analysis has received increasing attention. The texture is usually associated with structural patterns of the target and most often consists of repetitive patterns whose disposition can be periodic or random [5]. A question of scientific interest is to investigate the interrelationships between the variability of the spectral response of the targets observed by remote sensing imagery and the variability in surface. The solution of this issue has great potential for application in the investigation of environmental issues in the Amazon. In order to understand the effects of this dynamic of use and cover of the earth upon the hydrological and biogeochemical cycles is necessary to perform the mapping of deforestation as well as of the use and cover which have been chosen for these areas. In this sense, the Brazilian Institute for Space Research (INPE) develops six forest monitoring systems to the Brazilian Amazon, the Detection of Selective Logging (DETEX), Project Mapping Forest Degradation in the Brazilian Amazon (DEGRAD) the Amazon Deforestation Monitoring Project (Prodes), Near Real Time Deforestation Detection project (DETER), Monitoring of Vegetation Fires (Queimadas) [1] and the Project Qualification Deforestation in the legal Amazon (TerraClass), except DETER and Queimadas Projects, all other use Landsat-like images. However, given the weather conditions of this region for persistent cloud cover that remains even in the dry season, which occurs from June to November in most part of the basin. Even the images with higher temporal resolution, obtained by satellites such as MODIS, used in DETER and Queimadas projects in many of these areas there is little chance of obtaining cloud free images. For these projects accurately assess the changes occurring in the land occupation, they need to have estimates of net floor area for the mapping of what was demanded, which requires removing the areas covered by clouds and their shadows projected on the images. It seems to be a simple and intuitive procedure to distinguish between clouds and the ground. Nevertheless, the clouds can be confused with sand or straw cover. Furthermore, the shadows of the clouds can be confused with water bodies.

Experimental site

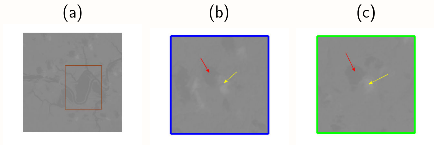
The experimental site is located in the Uatumã Sustainable Development Reserve in Central Amazonia, approximately 150 km northeast of the city of Manaus, Amazonas State. The research area in the Reserve is within the *terra firme* forest area on a plateau of 130 m altitude (above mean sea level) [2].

Dataset

We used two Landsat 5/TM scenes obtained in wet season (2011/01/12) belonging to path/row 230/61 and 230/62. Those data were atmospheric corrected using LEDAPS system and provided by Global Land Survey (GLS) datasets. The GLS datasets are a collection of orthorectified, providing near complete coverage of the global land area [4]. We selected the band 4 ($0.76-0.90\mu m$) due the spectral response of the water, clouds and shadow. In that band the spectral response of the clouds are highs and water and shadow spectral response are low. These spectral characteristics can facilitate the distinction between targets.

Infrared band ($0,76-0,90\mu m$) of Landsat 5 image of the lake in the UATAMÃ region. (a) Zoom in the lake region; (b) Zoom to region A with clouds and its shadows; (c) Zoom to region b with clouds and its shadows. The yellow arrow indicates the cloud, and the red arrow indicates cloud shadow regions, around these marks the space series are take out.

(a) (b) (c)



2D Continuous Wavelet Transform

The CWT2D is applied to the data, its equation can be written as

$$\begin{aligned} W(a,\theta,\vec{x_0}) &= a^{-1}\int_{\Re^2} d^2\vec{x} \quad s(\vec{x}) \quad \overline{\psi(a^{-1}\, r_{-\theta}(\vec{x}-\vec{x_0}))}, \\ &= a\int_{\Re^2} d^2\vec{\xi} \quad \exp(\imath\vec{x_0}\vec{\xi})\, s(\vec{\xi}) \quad \overline{\hat{\psi}(a\, r_{-\theta}(\vec{\xi}))}, \end{aligned}$$

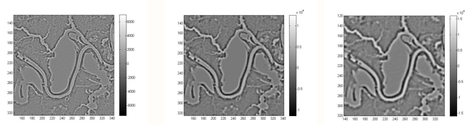
where $W = W(a,\theta,\vec{x_0})$ represents the wavelet coefficients, s is a two-dimensional signal (picture), a is the scale parameter and the vectors $\vec{x}$ and $\vec{x_0}$ corresponds to the position and translational images respectively. The wavelets used in this study are the traditional Morlet and Mexican hat ones. To compute the partial variance, we select in the original image the space positions corresponding to the lake, cloud and cloud shadows surfaces. After that, we extract, in the CWT2D result corresponding to fixed values of θ and scale, the real part of the wavelet coefficient at the same space positions. Then, we compute the variance of these wavelet coefficients. This process is repeated to all scale and rotation parameters.

Results and discussions

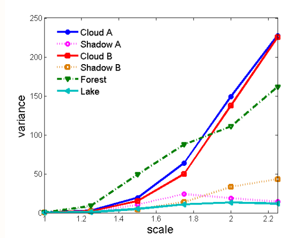
On this study we analysed different rotation parameter θ and we verify that $\theta = 45^o$ represented the best identification of the lake, cloud, and clod shadow region by a visual identification of the regions on the scalogram considering all the scales. Therefore, all analysis presented here are related to a rotation parameter $\theta = 45^o$. We present the scalograms for study image focus on scale variations using mexican hat wavelet to identify the contours. Colormaps varies according to the scales.

Mexican hat wavelet:

(a) $a = 1.0$ (b) $a = 1.5$ (c) $a = 2.0$



Variance per scale compute from the real part of the wavelet coefficients:



It shows the results of applying CWT2D of Morlet to the images just for the regions of the surface of the lake, cloud, cloud shade and forest. In each chart, the angle θ is oriented in the specific direction of 45^o. All points of each line are the result of calculating the variance of the real part of the wavelet coefficients in a specific range.

Conclusion

It was possible to investigate the existence of patterns of variability of vegetation, lake surface, cloud and areas with cloud shadows and its possible detectability on areas of interest from scalogram analysis based on the Two-dimensional Continuous Wavelet Transform (CWT2D) coefficients. Furthermore, we investigated the existence of possible patterns of variability of vegetation texture for different rotation angles of the Morlet's CWT2D for a specific range from the use of a satellite image. These results suggest the possibility of discrimination of different surfaces. The results are encouraging for the development of future specific pattern detection studies of failures in vegetation cover and cloud cover detection. More targeted studies are also needed in this context.

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