PERFOMANCE EVALUATION OF SPECKLE FILTERS FOR PADDY RICE AREAS BASED ON SENTINEL-1 SATELLITE IMAGES

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ABSTRACT

RADAR IMAGES ARE INCREASINGLY USED FOR MONITORING AGRICULTURAL AREAS. FOR IRRIGATED RICE CULTIVATION, DUE TO FACT RADAR IMAGING HAS THE ADVANTAGE OF INTERACTING WITH THE FLOODED FIELDS AND FACILITATING THE IDENTIFICATION OF THESE AREAS. RADAR IMAGES HAVE INHERENT CHARACTERISTIC OF MULTIPLICATIVE NOISE THAT REQUIRES A SPECIAL FILTERING TREATMENT TO IMPROVE CLASSIFICATION RESULTS. THEREFORE, IN THIS STUDY, FIVE DIFFERENT SPECKLE FILTERS WERE EVALUATED FOR THEIR ABILITY TO SUPPRESS NOISE AND PRESERVE IMAGE QUALITY. INITIAL RESULTS SHOWED THAT LEE AND GAMMA MAP FILTERS HAVE GOOD NOISE SUPPRESSION CAPABILITIES AND PRESERVE DETAILS IN HOMOGENEOUS RICE FIELDS.

KEY WORDS — SAR, BAND C, REMOTE SENSING, CROP MAPPING.

1. INTRODUCTION

Rice is one of the most important grains cultivated by humanity. According to Food and Agriculture Organizations of the United Nations (FAO), from 1994 to 2020 the rice was the tenth commodity most produced in the world (660 million of tons). In Brazil, the average annual productivity it's around by 11,2 millions of tons, with Rio Grande do Sul (RS) and Santa Catarina (SC) states with highest yield, 8 and 1,2 million tons, respectively [1].

Due to the dynamics of rice crop development, it is necessary to monitor the entire harvest, that is, several months. Therefore, in some periods, especially in the rainiest months, crop monitoring based on optical data may be restricted due to the presence of clouds.

To overcome this situation for agricultural monitoring, the use of synthetic aperture radar (SAR) images is being increasingly used, as it provides a time series with greater data consistency, that is, an image every 12 days for Sentinel-1A [2], [3]. Despite the lower interference of atmospheric effects such as clouds, smoke and particles in the SAR images, naturally they present a noise called speckle that can disturb the classification or detection of targets.

Speckle noise is common phenomena in all coherent imaging systems such as SAR images. The source of this noise is attributed to random interference between the coherent returns emitted by the numerous scatters present on a surface, on the scale of one wavelength of the incident radar wave (i.e. a resolution cell). Speckle noise is often an undesirable effect, thus, speckle filtering turns out to be an important pre-processing step for detection/classification optimization [4].

In this context, in the present study a comparison is made among five different speckle filters (Boxcar, Frost, Gamma Map, Lee and Median) to investigate their ability to reduce speckle noise over rice paddy cultivation areas, without losing significant detailed information.

2. MATERIAL AND METHODS

2.1. Study area and reference samples

The study area of this study covers the cities of Turvo, Meleiro and Araranguá, which are three of the largest producers of irrigated rice in the southern region of SC [5]. The region is characterized by medium/large rural properties size with loam and clayey soils that are ideal for irrigated rice agriculture in the pre-germinated system, which is characteristic in 90% of the region.

Based on agricultural calendar [1], in SC southern regions the irrigated rice cultivation extends from August to April. Therefore, the cycle starts in August to November with soil preparations and sowing, which makes this period interesting to identify rice cultivated areas with SAR data due to the low backscatter response (absence of plant density and flooded fields formation).

As reference map, the shapefile archive provided by [5] regarding the irrigated rice areas for Brazil was used. The classification was performed by experts' visual interpretation based on Sentinel-2 data and *in situ* validation. For SC state, the survey period refers to 2019/2020 harvest, thus this agricultural year was taken as reference for the filters analysis.

A thousand points were randomly selected with a 40-meter buffer within the homogeneous areas indicated as "irrigated rice" by the reference map. In order to avoid the effect of edges and pixel selection outside the homogeneous area, an inner buffer of 60m was applied.

2.2. Satellite data and time series choice

Due to the practicality geo data analysis and processing, the Google Earth Engine (GEE) platform was chosen to perform the algorithms used in this research. The GEE was introduced to further enhance the usability of satellite imagery for large scale applications, providing global-scale and analysis-ready earth observation data as well cloud computing infrastructure required [6].

The 'COPERNICUS/S1_GRD_FLOAT' image collection was used. This was adopted because the images were filtered and the data must be in linear value (not in decibels) to do this process. Each tile/image of this collection is already pre-processed with Sentinel-1 toolbox [6] using the following steps: i) Apply orbit file (update orbit metadata), ii) GRD border noise removal (removes low intensity noise and invalid data on scene edges), iii) Thermal noise removal (removes additive noise in sub-swaths), iv) Radiometric calibration and v) Terrain correction with SRTM 30 meter DEM (orthorectification).

A total of 10 images were acquired with an interval of 12 days between them (3 for August and October, 2 for September and November). The most representative image by month was produced using minimal pixel value to final evaluation of filters.

2.3. Speckle filters

Five different filters were applied to the representative image for further performance evaluation in terms of speckle reduction and resolution preservation. Among the filters, three are classified as adaptive (Frost, Gamma MAP and Lee) and two as non-adaptive (Boxcar and Median).

Speckle filtering works by the movement of a kernel window over each pixel on the image along the entire image. The kernel window moves and applies a mathematical calculation and also substitutes the value of the window central pixel [7]. In this paper a kernel size with 5x5 window was adopted.

The Boxcar filter has good performance in speckle reduction in homogeneous areas; however, it degrades the spatial resolution due to the indiscriminate averaging of pixels in non-homogeneous areas [8].

The Median filter does not account for the particular speckle properties of the image. This filter is successful at removing pulse and spike noise while retaining step and ramp functions. [7], [8].

The Frost filter is an adaptive and exponentially weighted averaging filter based on the coefficient of variation which is the ratio of the local standard deviation to the local mean of the degraded image [7].

The Gamma filter is a Maximum A Posteriori (MAP) filter based on a Bayesian analysis of the image statistics. It assumes that both the radar reflectivity and the speckle noise follow a Gamma distribution. The "superposition" of these distributions yields a K-distribution which recognized to match a large variety of radar return distributions of land and ocean targets [4].

Lee's smoothing filter is adaptive to the local statistics in an image, however, it is an isotropic adaptive filter which cannot remove noise in the edge region effectively. Lee filter is reportedly superior in its ability to preserve prominent edges, linear features, point target, and texture information [8].

2.4. Filters evaluation

Five metrics were used to evaluate the performance of filters in speckle noise reduction and image quality preservation. The choice of these metrics is due to the possibility of evaluation without a "pure" image, that is, an image totally free of speckle noise, since the calculation methodology of all of them uses only parameters of the images before and after the filtering [9].

The Speckle Suppression Index (SSI), widely used in the literature, corresponds to the ratio between the normalized standard deviations of the image after and before filtering [11]. The SSI is reliable only when the filter simultaneously has good mean-preservation properties. To solve these issues, some authors [8], [9], indicates the Speckle Suppression and Mean Preservation Index (SMPI) evaluation together with SSI.

To solve some of the drawbacks of existing measures, two statistical indexes was proposed by [10], namely the Mean Preservation Index (MPI) and the Mean Preservation Speckle Suppression Index (MPSSI). This last was suggested because SMPI has a limitation related to normalization.

Low score of these four metrics (SSI, SMPI, MPSSI and MPI) indicates a high level of speckle noise reduction in the output image. To the other hand, to quantify resolution degradation in image, the Signal to Mean Square Error Ratio (S/MSE) ratio was used. For best results, the SMSE ratio should be maximized, in the other words, the larger S/MSE value indicating the better despeckled image resolution results [11].

3. RESULTS AND DISCUSSION

Initially the filters were applied over the entire collection of images in order to verify the impact of filtering on the time series for 5 different targets: irrigated rice, water bodies, forest, buildings and grasslands (Figure 1a, b, c). It was found that the Boxcar, Frost and Median filters smoothed the mean more intensely for all targets, while for the Gamma Map and Lee filters a less expressive smoothing. By the way, this results empathizes the great importance of focusing in initial stage for rice fields identification.

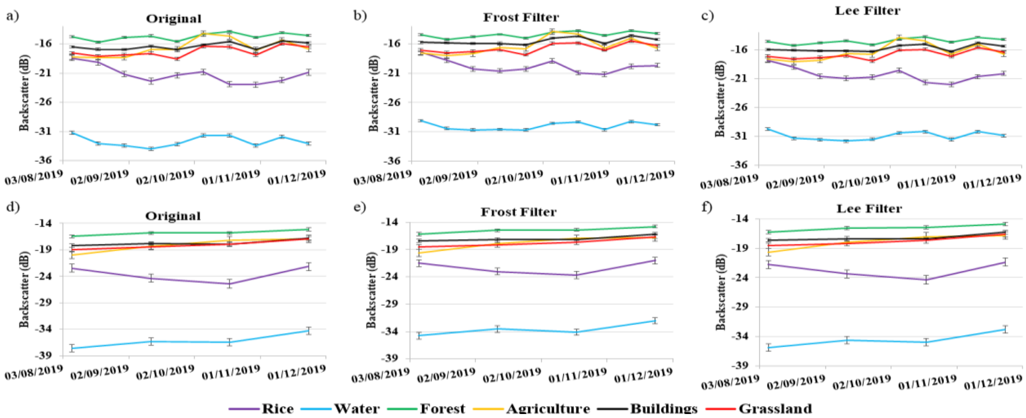

Figure 1. Time series filter comportment by two different approaches to five targets.

The impact of selecting the most representative image of the minimum pixel values was also explored (Figure 1d, e, f). A similar behavior as the one described above was observed in relation to the smoothing by the filters. However, it was also possible to observe that when using the most representative image of minimum values for

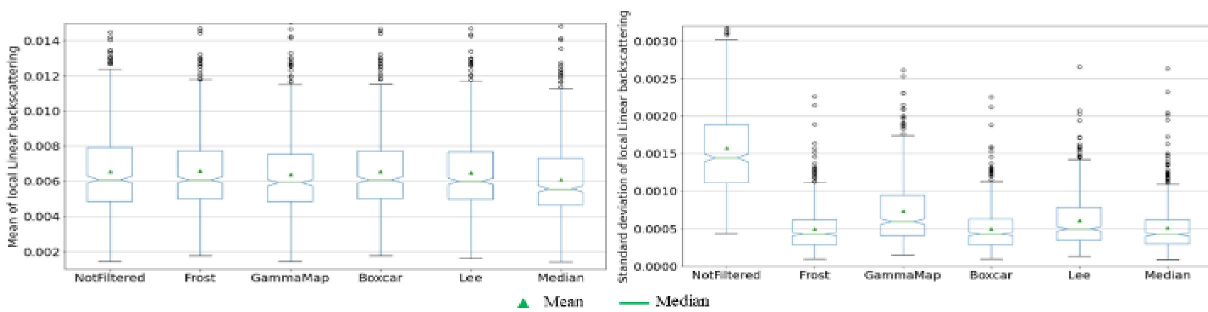

Figure 2. Mean and Standard Deviation behavior for irrigated rice fields by applied filter.

each month the values remained practically constant throughout the series, that is, a smaller variation was observed among the months, which makes it interesting for an initial classification of irrigated rice areas, as well as distinguishing other targets (mainly water and forest).

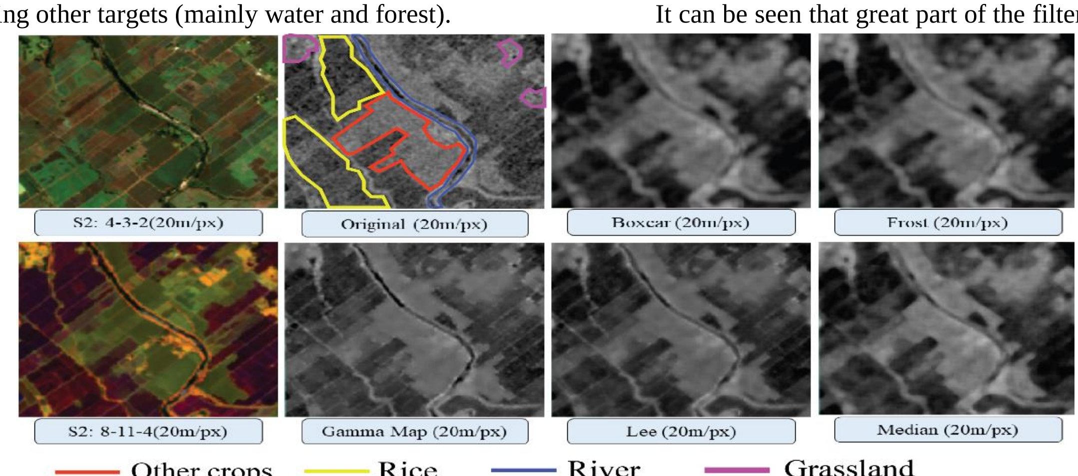

Figure 3. Visual comparison between optical composition, non-filtered and filtered SAR images

In early stages, rice fields can be easily detected and separated from other non-rice areas in the SAR images due to the significant backscatter difference between flooded areas and non-flooded areas, because the recorded SAR signal is very low due to specular reflection from the flooded fields. [3].

As emphasized in the previous topics, the target of interest for this study is irrigated rice, therefore, the impact of filters on the mean and the standard deviation in the homogeneous areas in the rice fields was verified (Figure 2). It is noteworthy that good filters have the ability to preserve the mean like the original image and reduce the standard deviation, since the filtered image has less noise, which consequently reduces the standard deviation [7], [8].

It can be seen that great part of the filters was able to maintain the mean of irrigated rice areas very close to the one obtained for the unfiltered image. However, it is observed that the Median filter tends to underestimate the mean, reducing the values in relation to the original image. Regarding the standard deviation, it is observed that the filters were efficient in reducing it, and it is also noteworthy that the Frost, Boxcar and Median filters presented similar results (greater reduction of the standard deviation), while the Gamma Map and Lee filters present slightly higher values, which indicates the production of images more similar to the original (unfiltered). These results reaffirm the behavior obtained in the analysis of the impact of filters on the time series.

Regarding the metrics, it can be seen that the Boxcar, Frost and Median filters presented the lowest average values for SSI (0.32, 0.32 and 0.35) and SMPI (0.33 the three), while the Gamma Map and Lee filters showed values slightly higher, 0.48 and 0.39 (SSI), respectively, and 0.47 and 0.39 (SMPI). These results indicate that the first three have a greater ability to suppress speckle in homogeneous areas, while the last two, despite also effectively reducing noise, still preserve some characteristics of the original image.

However, when evaluating the MPI and MPSSI, it is observed that the greater suppression of speckle caused by the Boxcar, Frost and Median filters also causes a loss in image quality, mainly by the Median filter, which has the highest values for these two indices. In addition to these results, the S/MSE corroborates the loss of quality in the images filtered by the Boxcar, Frost and Median filters, since they present the lowest values for this metric (23.7, 23.7 and 20.09 respectively), while the Gamma Map filters and Lee tend to better preserve detail and resolution (24.8 and 25.3, respectively).

This evaluation has a great importance, especially for regions where the cultivation of rice areas occurs in small rural plots, since the expressive loss of resolution can cause the eradication of these areas in the image. In this way, the Lee and Gamma Map filters, in addition to having good Speckle noise suppression, also ensure greater preservation of fine details in the image (Figure 3), which makes them more suitable.

By visual comparison based on Figure 3, the results highlighted above can be observed, because despite the good smoothing produced by the Boxcar, Frost and Median filters, there is a significant loss of resolution. On the other hand, the Gamma Map and Lee filters have the ability to well preserve image details (i.e. river/riparian forest and forest fragments).

4. CONCLUSIONS

By this exploratory study it is possible to conclude that rice areas can be more easily identified in SAR images in early stages, mainly at seedling and flooding. The most representative SAR image by month can be used to distinguish rice from other targets.

Boxcar, Frost and Median filters have the capability to heavily suppress the speckle in rice areas, however detailed features can be extinct due resolution loss. On the other hand, Gamma Map and Lee Filters also has a great speckle suppression capability and preserve fine details in image, which is more suitable for identifying small rice fields. In the future, an edge preservation evaluation must be performed to improve the assessments.

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