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# Comparison of Harmonic, Geometric and Arithmetic Means for Change Detection in SAR Time Series

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## Abstract

The amplitude distribution in a SAR image can present a heavy tail. Indeed, very high-valued outliers can be observed. In this paper, we propose the usage of the Harmonic, Geometric and Arithmetic temporal means for amplitude statistical studies along time. In general, the arithmetic mean is used to compute the mean amplitude of time series. In this study, we will show that comparing the behaviour of the Harmonic, Geometric and Arithmetic means, enables a change detection method along SAR time series.

## 1 Different means for SAR imagery

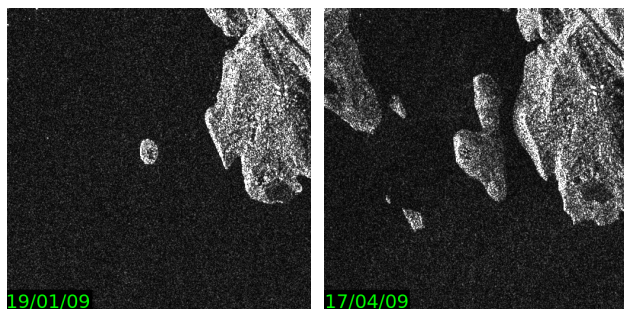
Different temporal means can be computed between two amplitude SAR images. In this paper, we will focus on the Harmonic Mean  $\mathcal{HM}$ , the Geometric Mean  $\mathcal{GM}$ , and the Arithmetic Mean  $\mathcal{AM}$  :

$$\mathcal{HM}[x, y] = \frac{2}{\frac{1}{x} + \frac{1}{y}}, \quad (1)$$

$$\mathcal{GM}[x, y] = \sqrt{xy}, \quad (2)$$

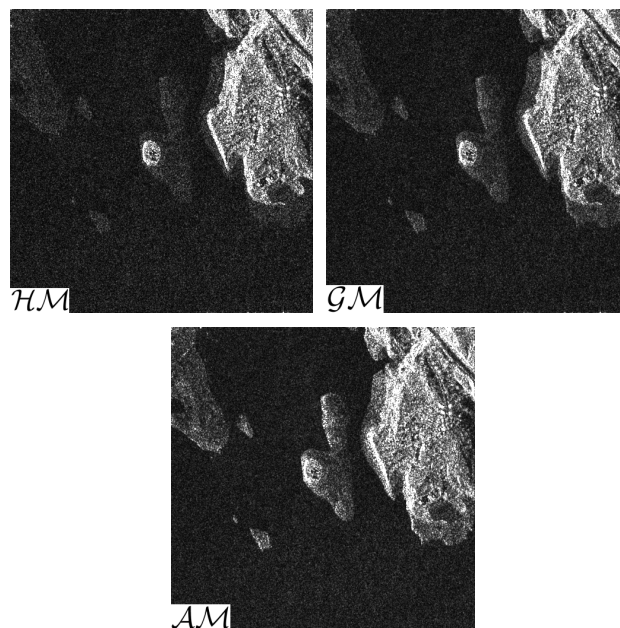
$$\mathcal{AM}[x, y] = \frac{x + y}{2}. \quad (3)$$

We will focus on two Stripmap TerraSAR-X amplitude images (see **Figure 1**), acquired over the Serre-Ponçon lake in the south of France.



**Figure 1:** TerraSAR-X amplitude images. Left : 19/01/09. Right : 17/04/09.

Between the two acquisitions, the water level of the lake changed. Thus, the shore position changed between the two dates. In those areas, the amplitude is lower in the first acquired image than in the second because of the ground apparition. We present in **Figure 2** the Harmonic, Geometric and Arithmetic means between the two amplitude images presented in Figure 1.



**Figure 2:** Upper Left : Harmonic Mean. Upper Right : Geometric Mean. Down : Arithmetic Mean.

The Arithmetic and Harmonic means between the two amplitude images are very different (see Figure 2) near the shore of the lake. We can observe that the Arithmetic mean is higher than the Harmonic mean for the pixels where amplitude changed because of the water level change. This is due to the fundamental order relation between the different means :

$$\mathcal{HM}[x, y] \leq \mathcal{GM}[x, y] \leq \mathcal{AM}[x, y]. \quad (4)$$

The different means are very close from each other when the amplitude value is similar in the two amplitude images. The differences between the means are only enhanced when the texture of the amplitude images changes between the two dates. We can also observe that the contrast between the Harmonic mean and Arithmetic mean is higher than the contrast between the Geometric mean and Arithmetic mean.

Because the differences between the different means are related to temporal changes, this enables change detection using the method described in the next part.

## 2 Application : Change detection

### 2.1 Background

Several Change detection techniques are dedicated to image pairs and can not be extended to time series, as the classical Log–Ratio (LR) operator [1] between two amplitude images  $x$  and  $y$ , defined by :

$$\text{LR} = \log\left(\frac{x}{y}\right). \quad (5)$$

We can notice that the Log–Ratio operator is a traditional operator, and still improved today [2].

Temporal means have already been used for change detection in SAR time series, using the GLRT [3] (Generalized Likelihood Ratio Test), defined as :

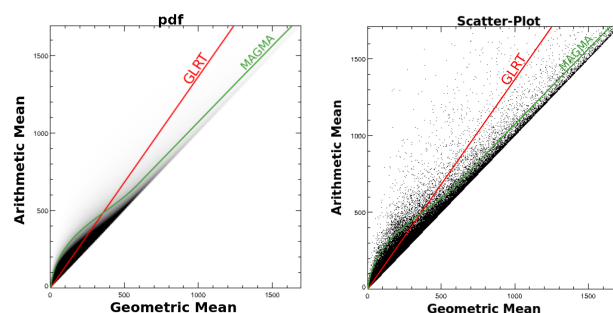
$$\text{GRLT} = \frac{\mathcal{GM}}{\mathcal{AM}}. \quad (6)$$

Using the GRLT, the ratio between Geometric and Harmonic temporal means of time series is compared to a threshold  $\lambda$  in order to detect changes [3]. We will show in the next part how the method we developed improves the simple thresholding of the GLRT, using Information–Theory methods for SAR imagery [4].

### 2.2 The MAGMA Change detection method

The MAGMA (Method for Arithmetic and Geometric Means Analysis) change detection method is based on amplitude statistics and temporal means comparison, using Information–Theory based methods. The different steps are described in the following.

1. Considering two SAR amplitude images and their respective amplitude distribution, which are modeled by Fisher distributions, the first step is the computation of the joint probability density function (pdf) between the Arithmetic and Geometric means (see **Figure 3, left**). This estimation is performed using a variable change from the two SAR amplitude images to the Arithmetic and Geometric means, using a Jacobian operator.
2. Given this *a priori* pdf, one can select pixels out of the statistics in the observed scatter–plot (see **Figure 3, right**) between the Geometric and Arithmetic means of the two amplitude images (area over the green line in Figure 3, right).



**Figure 3:** Left : Simulated pdf between Arithmetic and Geometric means for two Fisher distributions. Right : Observed Scatter–Plot. The red lines represent the GLRT threshold. The green lines represent the MAGMA method threshold for changes.

This area selection in the simulated pdf can easily be done manually, but it can as well be done automatically by applying a specific guide (see Figure 3, right). The shape of the guide is automatically fitted to the given amplitude distributions, in order to detect changes. This technique can be compared to Information–Theory based methods used for change detection in SAR imagery [4].

We can observe that the GLRT [3] method would have selected changes by applying a linear function in the pdf (see red line in Figure 3, right), with respect to the threshold  $\lambda$ . Thus, this linear selection would generate false alarms for small amplitude values, as it will be shown in the next part where the change detection methods are compared. This linear selection shape is very different than the shape obtained by the MAGMA method, using a pdf simulation. The MAGMA method can also be applied to the comparison of the Harmonic mean and Arithmetic mean instead of the Geometric mean and Arithmetic mean. The same steps are followed, from the pdf simulation to the change detection from the observed scatter–plot.

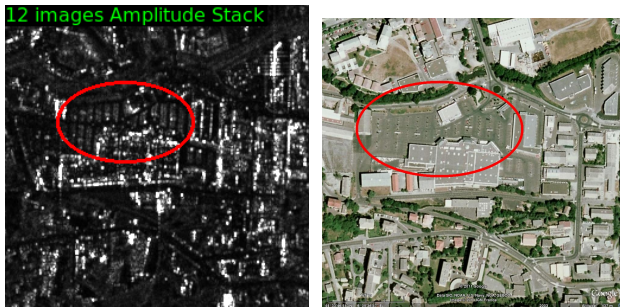
### 2.3 Change detection example

This example of change detection using the MAGMA method uses two Stripmap TerraSAR–X products,



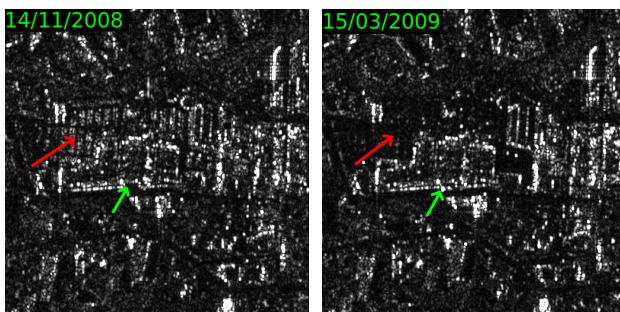
acquired over a commercial center near the Gap city in the south of France. The results obtained with the MAGMA method will be compared to the results obtained by thresholding the Log-Ratio image and the result obtained with the GLRT method.

For ground interpretations, the specific area is presented in **Figure 4**, where an amplitude stack (Geometrical mean) of 12 similar TerraSAR-X products is compared to an optical image. The stack contains the two products that will be used. We can observe a large parking area in front of the commercial center.



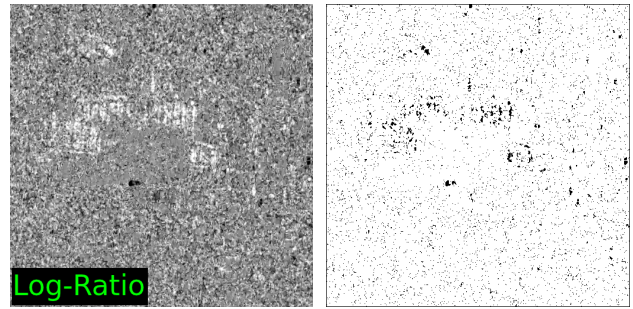
**Figure 4:** Left : Amplitude stack (Geometric mean) of 12 TerraSAR-X products. Right : corresponding GoogleEarth optical image. The parking area is circled in red.

For this example, we only use two TerraSAR-X products. The two acquisition dates are respectively 14/11/08 and 15/03/09 (see **Figure 5**). The second date corresponds to a Sunday when the commercial center was closed. Changes are due to human activity around the commercial center, like cars disappearing over the parking area.



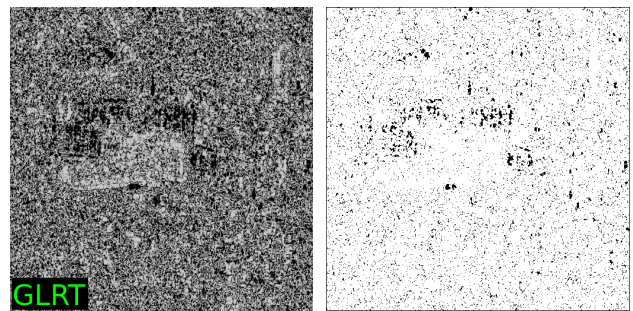
**Figure 5:** Left : Amplitude image, 14/11/2008. Right : Amplitude image, 15/03/2009. The green arrows indicate an appearing bright item. The red arrows indicate the parking area where cars disappear at second acquisition date.

First, we present in **Figure 6** the Log-Ratio image and the associated change detection result. This result was generated by thresholding the absolute value of the Log-Ratio (threshold = 2.1). We can observe that the change map presents a high number of isolated pixels which are false detections.



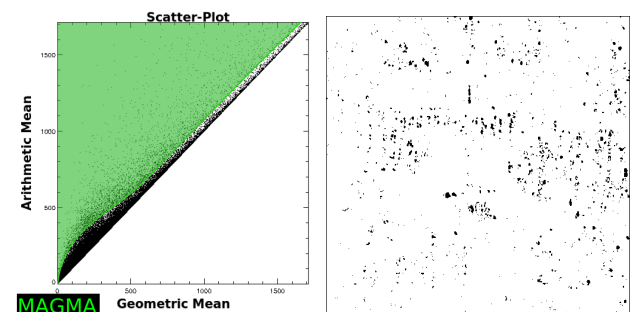
**Figure 6:** Left : Log-Ratio image (cf. equation 5) computed from the two amplitude images presented in Figure 5. Right : Change map obtained with a 2.1 threshold over the absolute Log-Ratio image, changes are represented in black.

Then, we present in **Figure 7** the GLRT image and the associated change detection result. This result was generated by thresholding the GLRT (threshold = 0.7). Once again, we can observe that the change map presents a high number of false alarms in the areas corresponding to low amplitude values.



**Figure 7:** Left : GLRT image (cf. equation 6). Right : Change map obtained with a 0.7 threshold over the GLRT image, changes are represented in black.

Finally, we present in **Figure 8** the results obtained with the MAGMA method.

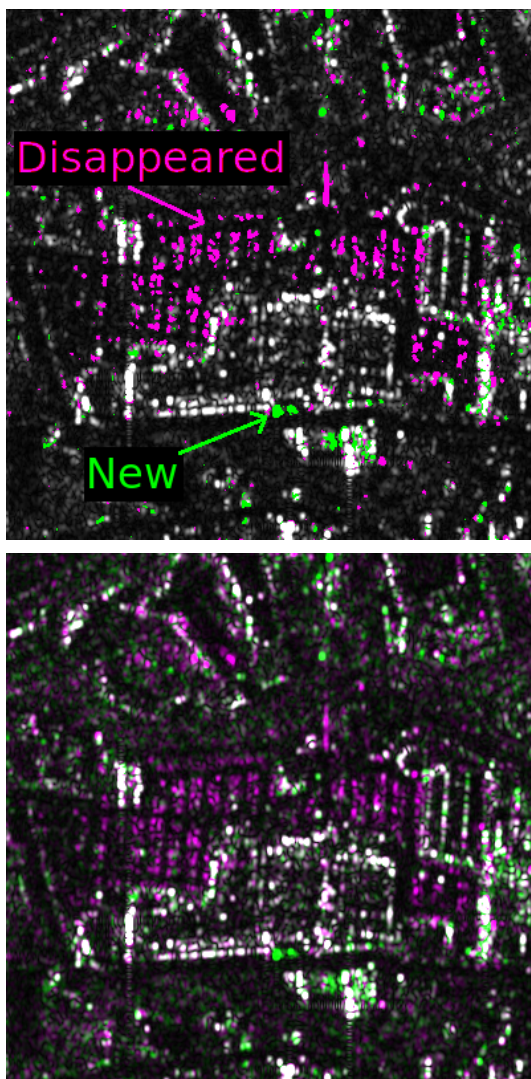


**Figure 8:** Left : Scatter-Plot where pixels selected as changes are located in green areas, according to the MAGMA method. Right : Results obtained with the MAGMA method, where detected changes are represented in black.

We can observe that the results obtained by the MAGMA method present less false detections than the results obtained using the Log-Ratio method or the GLRT method. Moreover, the relevant changes are detected and the related areas are more precisely delimited.

We can simply extend the MAGMA change detection method by considering whether the detected pixel is brighter or darker in the new image. Thus, changes can be classified as a new reflective item or as a disappeared item. We present in **Figure 9** the classified results obtained using the MAGMA method, compared to a RGB coloured composition between the two amplitude images.

We can observe on Figure 9 that the cars parked in front of the commercial center are clearly detected as changes and are classified as disappeared items.



**Figure 9:** Up : Classified changes detected by the MAGMA method (In Green : New items. In Purple : Disappeared items). Down : RGB coloured composition (R : 14/11/2008, G : 15/03/2009, B : 14/11/2008).

### 3 Conclusion

We can conclude that the study of the Harmonic mean, Geometric mean and Arithmetic mean, enables several applications like change detection for SAR imagery. Thus, we developed the MAGMA (Method for Arithmetic and Geometric Means Analysis) change detection method.

As shown in this paper, the MAGMA method improves the Maximum Likelihood techniques like GLRT [3], using Information-Theory concepts [4] to detect changes between SAR amplitude images. The major improvement consist in a lower false detection rate, especially in low amplitude areas. The second improvement consist in a better location of the changes in clearly delimited areas, which enables precise interpretations.

Further developments will concern the automatization of the change detection, focusing on the determination of the best shape for the guide to apply to the Scatter-Plot to detect changes. A second research topic will be the extension of the MAGMA method from images pairs to time series. Indeed, the means are operators which can easily be used with more than two images. The change detection would be performed using the same MAGMA method based on pdf simulation. Moreover, the changes could be classified regarding their intensity or frequency.

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