REACTIV Algorithm

Rapid and EAsy Change detection in radar TIme-series by Variation coefficient

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EO Browser Custom Script submission

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REACTIV

1   Script Introduction

This code was developed at Onera as part of the **MEDUSA** project. It is a visualization of a stack of SAR images highlighting change detection. Exploiting the HSV, it focuses on the temporal dimension for calculation and does not rely on any spatial computation. For this project, Sentinel-1 IW VV-VH images were used, with the exploitation of the two polarizations. The orbit was also fixed whether to ASCENDING or to DESCENDING when manipulating time-series.

Its ultimate objective is to synthesize activity information embedded into a temporal data profile, all within a single colored image, emphasizing the presence or absence of significant change in bright colors.

2   Intents & Motivations

Difficult to interpret because of their geometry and speckle noise, SAR images are however very useful and effective in change detection. Until the advent of Sentinel-1 data from the Copernicus program, access to temporal stacks of data was scarce, and most algorithms focused on the spatial component of images. The recent context of big data opens many possibilities for SAR image processing, and one of the most remarkable is the access and the analysis of time-series. Exploiting the time dimension can be useful for filtering speckle noise. Indeed, in the absence of change, we have access, in a single pixel, to N realizations of a random signal.
In the algorithm proposed here, we wish not only to improve the signal-to-noise ratio, but also to detect all the pixels for which a change occurred between the first and the last observation date. These generic changes can be either short changes in time (e.g. boats) or longer/permanent changes (e.g. a construction site, new buildings).

The REACTIV algorithm can display insights in different circumstances and be useful in multiple geographical contexts, such as monitoring of:

- **port areas**, for highlighting maritime shipping routes;

- **urban areas**, for the observation of city sprawl

- **environment**, to quickly map changes in forest cover;

- **agricultural practices**, to monitor the occupation of cultivated plots and improve cultivation methods.

Hence, considering these ideas, the REACTIV visualisation tool needs to consider several aspects of the data:

- the most obvious, **the change**. Changes must be easy to identify, locate and interpret. This implies that the visualization must also see the objects

that are not undergoing modification. All the buildings will have to be seen in order to quickly situate those that have appeared;

- **time**: Detecting a change is important, but knowing when it occurred is also useful. It is not possible to represent all the information in a unique image, so we made the choice, when it is a long change, to color-code the date of the most intense activity, among all the possible dates.

3 Data Description

To make better sense of the rest of our results, we will thoroughly define our data as well as its parameters.

Given a tensor P of shape (w, h, d, T), we have:

- w elements on the x-axis;

- h elements on the y-axis;

- d elements on the z-axis;

- T elements on the 4th axis (i.e the temporal axis);

The x-axis and y-axis are the spatial axes. The z-axis corresponds to the polarimetric axis. For Sentinel-1, two polarimetric channels are available on most areas, then $d = 2$. We consider the VV polarization as the index 1 and the VH as the index 2.

Hence, we can define this tensor P as being an ensemble of $w - by - h - by - 2$ temporal pixels of dimension T written as p_{ijl} where (i, j) are the pixel's coordinates on the x and y-axis of P, l is the selected polarization and $p_{ijl}^{(t)}$ is the pixel's value on timestep t. According to this definition, we can then consider the following:

$$\forall i \in [\![1..w]\!], j \in [\![1..h]\!], l \in \{1; 2\}, \text{we have } p_{ijl} = \{p_{ijl}^{(1)}, p_{ijl}^{(2)}, ..., p_{ijl}^{(T)}\}$$

Additionally, the temporal dimension of every pixel is assumed to be identically-sized and is timestamped with timestamps defined as follows:
$\{\tau^{(1)}, \tau^{(2)}, ..., \tau^{(T)}\}$

4 Script Description

The HSV space consists of 3 components: the Hue, the Saturation and the Value. We detail below how these three components are used in the representation.
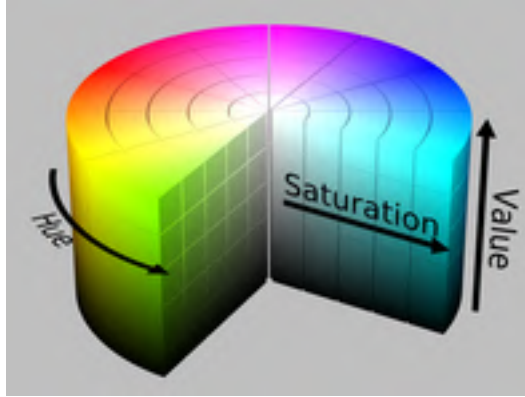
Figure 1: HSV Cylinder

4.1 The Hue component: the time dimension

The **Hue** component represents which color of the *color wheel* is used. The Hue component encodes the dating information of the event. Thus, when a change is displayed, we can approximately know when it occurs in the observed period.
The calculation of the Hue component follows: given the hue value of a pixel
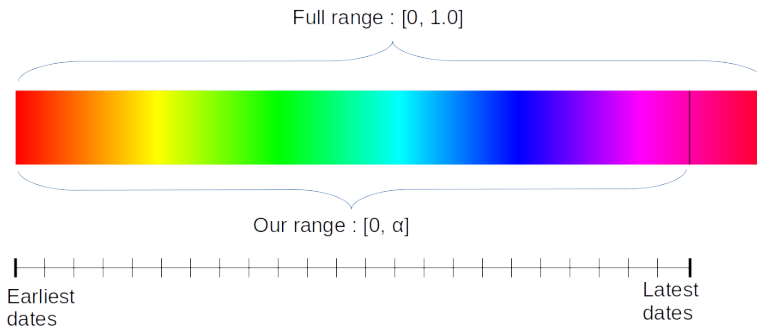

Figure 2: Custom Hue Range

of xy-coordinates (i, j), we define the Hue value as being:

$$hue(i, j) = \frac{\tau^{(m)} - \tau^{(\mathrm{argmax}_t(p_{ij.}))}}{\tau^{(m)} - \tau^{(1)}}$$

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In other words, we select the time index of maximum signal value for the pixel p_{ij} across all polarisation l. We then calculate a time difference between the maximal time index and this time index, that we then divide by the difference between the maximal and minimal time index. To simplify, we rescale the relative time measure of change event to be between 0 and 1.

Additionally, the original Hue color range is defined as a number between $0°$ and $360°$ (or, as used in our implementation, a number between 0 and 1). However, as seen in figure 2 on the preceding page, we notice huge resemblance between the extreme start color of the spectrum and its extreme end (both different shades of red). For that matter, we decided to fix, using a multiplicative constant, the maximum value of the interval to α, with α being here 0.9. We do so by simply multiplying the final Hue value by 0.9 to reduce the initial [0,1] range to a simpler [0, 0.9] range.

4.2   The Saturation component: change intensity

The **Saturation** component, responsible for how intense the color picked by the hue value will be, is bound to the change intensity: the bigger the change, the more saturated the color will appear. This means that white spots on the map represents places with low changes over time. As displayed in figure 3, the
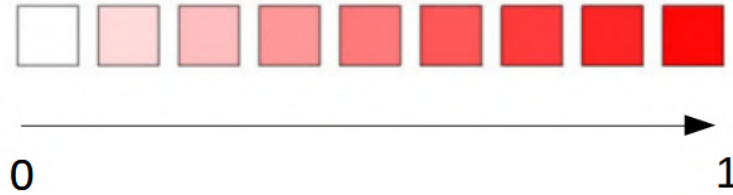

Figure 3: Color Saturation Scale

value of saturation is situated between 0 and 1. The closer to 1, the more vivid the color; oppositely, the closer to 0, the duller the color. The calculation of the saturation involves a certain number of parameters:

- $L = 4.9$: the number of looks, set as a known constant for Sentinel-1 data;

- $\mu = 0.2286$: deduced from L, it corresponds to the variation coefficient for speckle data

- $\alpha = 0.1616$, is the standard deviation of the speckle data..

Then, to calculate the saturation value, we do the following algorithm:

1. Calculation of variation coefficient for each polarisation (VV and VH) by computing the quotient of their temporal standard deviation over their temporal average, obtaining $\gamma_{VV} = \dfrac{std_{VV}}{avg_{VV}}$ and $\gamma_{VH} = \dfrac{std_{VH}}{avg_{VH}}$;

2. Selection of the maximum between the two variation coefficients: $\gamma_{max} = max(\gamma_{VV}, \gamma_{VH})$;

3. Plugging this maximum in the following formula: $R = \dfrac{\gamma_{max} - \mu}{10 * \alpha} + 0.25$;

4. Clamping the R value between 0 and 1.

Formally speaking, the saturation value of the pixel (i, j) is defined as being:

$$saturation(i, j) = \frac{\max\left(\dfrac{\sigma_{ij1}}{\mu_{ij1}}, \dfrac{\sigma_{ij2}}{\mu_{ij2}}\right) - \mu}{10 * \alpha} + 0.25$$

4.3   The Value component: usual radar intensity

Finally, to keep the usual SAR Image look, the **value** component ranging from dark to bright, with respect to the color picked by the hue value, represents the maximum value of the input signal over both polarisation. We empirically found that this setting does not output a very pleasant image: for that matter, the intensity has been averaged with the mean max signal of the pixel at each timestep. This provides sufficient details for change to be localizable but also contextualized, i.e. for surroundings to be recognizable.
Formally speaking, we define the value component for a pixel of xy-coordinates (i, j) as being:

$$value(i, j) = \frac{I_{max} + \bar{I}_{max}}{2}$$

where we have:

- $I_{max} = \lambda * \max_{(l,t)}(p_{ij})$ is the maximum signal value for the given pixel across every polarization and timestep;

- $\bar{I}_{max} = \lambda * \dfrac{\sum_{n=1}^{T} max(p_{ij1}^{(n)}, p_{ij2}^{(n)})}{T}$ is the average over each timestep maximal signal value between both polarization;

- $\lambda = 0.8$ is a scalar coefficient used to reduce saturation that can happen and to have a more pleasant image. It has been selected on a pure empirically manner.

5   Script applicability

This script was developed using the Sentinel Hub EO Browser and explored the potential of time series analysis using the *timespan* option of the platform.

The script has an adaptive linear change detection range that is expressed in relative values, i.e. between 0 and 1 (0 being closer to the start of the temporal

Figure 4: Color Value Scale

stack and 1 being closer to the end). This enables our algorithm to perform over different periods, of different sizes and to have somewhat comparable results. Additionally, it does not suffer from resolution issues as no spatial computation is performed: it is a fully temporal analysis algorithm and hence is not subject to any problem that may happen when processing spatial SAR information.

Furthermore, the PolSAR aspect of the algorithm is not crucial to its functioning: it has been tested on single polarisation data as well by isolating VH and VV data channels for Sentinel-1 imagery.

6 Representative cases

The script is accessible at the following link: https://sentinelshare.page.link/raR1. To illustrate the advantages of our method, we elected the following examples as displays of the potential of REACTIV for PolSAR imagery:

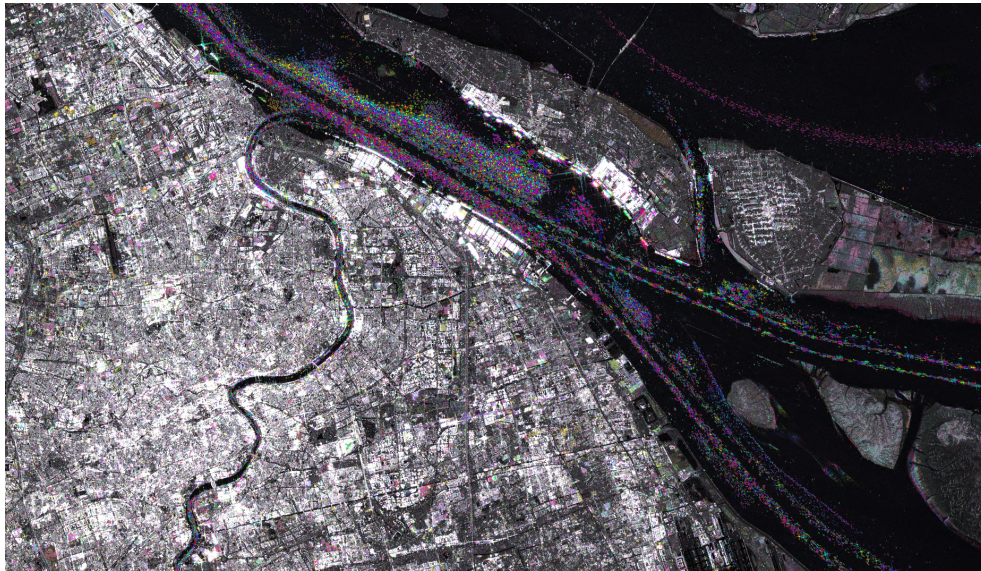## 6.1 Maritime Routes: Shanghai Port

Figure 5: Shanghai port with REACTIV from 2018-01-01 to 2020-09-11

Thanks to the REACTIV method, maritime routes are very explicit. Additionally, the time dimension represented by the chosen color seems to indicate that the northern entry path to the port is only opened during certain parts of the year as only red and shaded blue boats appear to be there.

6.2 Vegetation monitoring: Shanghai Wetlands

Situated close to the Chongming Dongtan birds national nature reserve in Shanghai, the Shanghai wetlands are a very distinct ecosystem that is usually flooded with water on seasonal occasions, inducing huge variability in its environment and in its dielectric properties, crucial for SAR imagery. This variability is expected to be found and to be localised. As we can see in figure 6 on the following page, we do have change being detected cohesively across the different subsurfaces of wetland. This is manifested by regions portrayed as green for some and pink for others. When checking the Hue range in figure 2 on
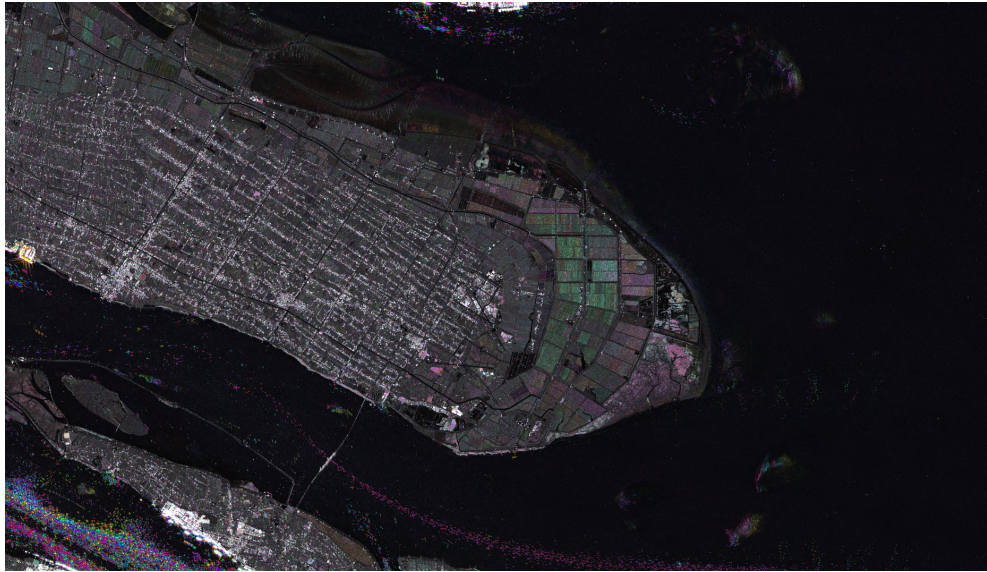
Figure 6: Shanghai Wetland with REACTIV from 2018-01-01 to 2020-09-11

page , we notice that green is located around the first third of the time interval, meaning around the end of 2018 while the pink values are located at the end of the interval, meaning the end of 2020. These similar yearly periods show how the REACTIV method successfully captured a seasonal and periodical event within the Shanghai wetlands.

6.3   Urban sprawl: Wuhan City

Figure 7: Wuhan city with REACTIV from 2018-01-01 to 2020-09-11

Given recent events and the efforts deployed by the Chinese government to build emergency hospitals, the city of Wuhan displayed interesting results with regards to change detection tasks. Most recent buildings, plots with colors of the end of the Hue spectrum (i.e. shades of pink) are noticeable throughout this map. One particular example is the Huoshenshan Hospital located on the Zhiyinhu Boulevard. As displayed in figure 8 on the following page, we notice violet (shaded dark-pink) which represents high activity spike in the last months of recording, which correlates with the city's plans to build emergency hospitals. Other locations around the city have similar color spots that most probably also are constructions built in the context of COVID-19.
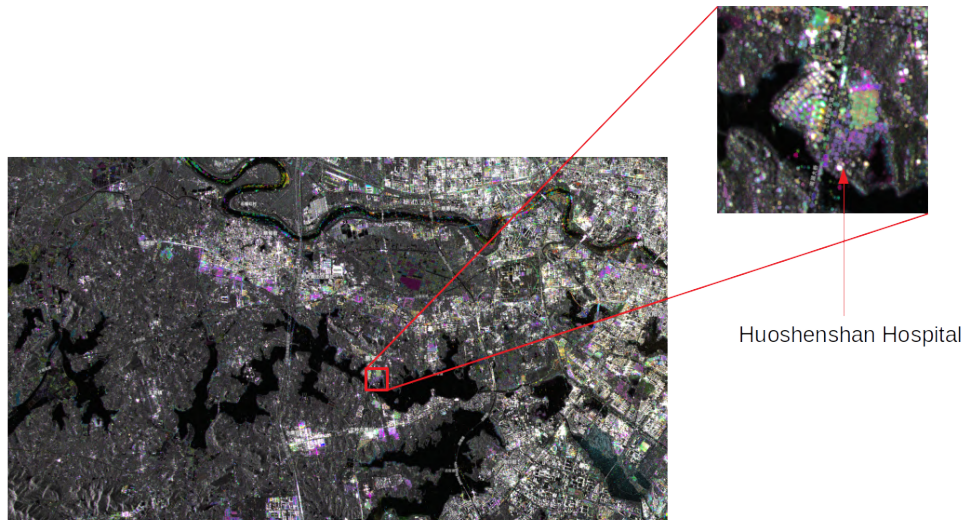
Huoshenshan Hospital

Figure 8: Wuhan Hospital zoomed-in

7   References & Credits

The REACTIV method was developed and presented in [1]. Additionally, a french paper has also been redacted: [2] which received the first price of the french CFPT congress. Finally, existing code implementing this method can be found in the following link with Python and GEE implementations.

References

[1] Elise Colin Koeniguer, Alexandre Boulch, Pauline Trouve-Peloux and Fabrice Janez. *Colored visualization of multitemporal data for change detection: issues and methods*. EUSAR, 2018.

[2] Elise Colin Koeniguer, Jean-Marie Nicolas, Beatrice Pinel-Puyssegur, J.-M. Lagrange and Fabrice Janez. *Visualisation des changements sur séries temporelles radar : méthode REACTIV évaluée à l'échelle mondiale sous Google Earth Engine*. (French) RFPT, N. 217-218, 2018