

# Images processing techniques applied to the Kapildui weather radar

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## 1 Introduction

In this article, it is going to be shown one of the lots of the many jobs that are being carried out in a group of investigation of the Faculty of Engineering of Bilbao (UPV/EHU) in narrow relationship with Euskalmet (Basque Agency of Meteorology), since these are responsible for the operative. The group of investigation is formed by some students of Technical Engineering of Telecommunication, specialty in Systems of Telecommunication, who are under the supervision of an Industrial Engineer, Doctor and teacher in the Faculty of Engineering of Bilbao, and count with the help of a worker of the company “ADASA”, as technical adviser. At the same time, this work is part of a bigger project called “Radar Project”, whose aim is to improve the operative of the meteorological radar of Kapildui and it is composed of several subprojects that are about filters, textures or Baltrad.

The work here presented, consists principally of the analysis of both temporary and spatial variations of the data offered by the radar of Kapildui, in order to get patterns of the above mentioned variations. This study is focused on the polarimetric variables, especially the variable  $Z_H$  (horizontal reflectivity) and, due to its sensitivity to changes of the system, the variable ZDR (differential reflectivity). For this, several image processing techniques are used, which will be explained later.

Therefore, two lines of study can be distinguished. On the one hand, there will be established a typical variation pattern of the temporary signals throughout time to be able to observe its evolution and obtain meteorological information and be able to detect irregular or anomalous performances that meteorological radars could take with it, and even eliminate them thanks to the processing of images. This is, it is look for a monitoring of the system.

On the other hand, a filter based on textures technology is presented, capable of differentiating meteorological structures of non-meteorological ones through the spatial variations. This filter, works with the variable  $Z_H$  and its main aim consist in increasing the quality of the data offered by the meteorological radar of Kapildui.

It is considered that a PPI has got a high quality when it only contains meteorological information but, in fact, it is not like that, because at the same time they contain non-meteorological information that, although its percentage of appearance is not very high, it can confuse the observer. Therefore, it is looking for emphasize the meteorological signals and filter the non- meteorological information.

The radar of Kapildui is a polarimetric meteorological radar, which are radars that work with dual polarization (vertical and horizontal) instead of using only horizontal or vertical polarization. For this reason, the polarimetric radars give bigger information about the hydrometeors than the non-polarimetric and they allow to define, between other things, the appearance and the form of the hydrometeor. It is located on the top of Kapildui’s mountain at the south of the Basque Country (Spain), with coverage in all the Basque land and it belongs to the Basque Meteorological Agency (Euskalmet) and the Directorate of Emergencies and Meteorology, Security department of the Basque Government (DAEM).

The most significant characteristics of this radar system are:

- CDP07 antenna with a reflector of 6,1 m of diameter.
- Klystron TXC 1500: C Band (4-8 GHz) transmitter with a 250 KW solid state modulator.
- RXC 1500C digital receptor, including ASPEN signal processor.
- Dual polarization.
- Software used: Ravis and Rainbow.

## 2 Metodology

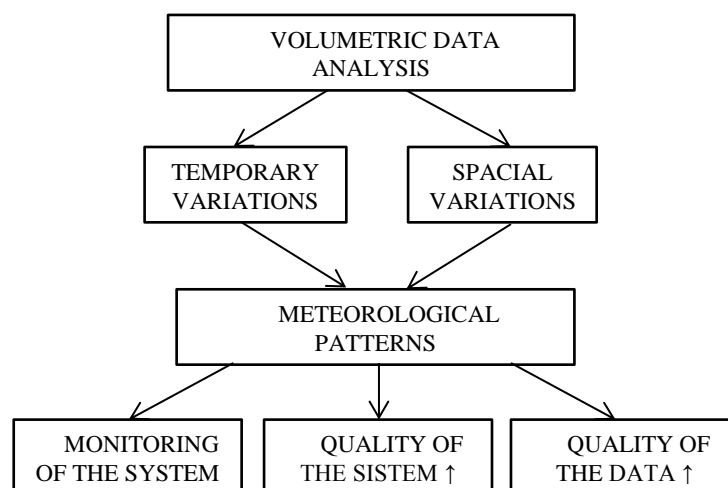


Image 1: diagram

To achieve both goals, a series of functions has been realized with MATLAB, which is a mathematical software that offers an environment of integrated development (IDE) with a proper computer language (language M) and that offers large number of services.

The functions will allow to distinguish between a normal pattern of functioning associated with a meteorological situation and patterns that are not meteorological. This will be achieved thanks to both statistical and visual tools, such as: the PPIs and their differences, the proper tool to observe and to analyze azimuthal changes or the noise filters. Thanks to them, all kinds of situations will be able to be analyzed.

To do this work, a large number of study cases have been studied, some common for both studies like storms, and others specific for each work line. In case of temporary variations, the analysis focuses on the study, at system level, of the Single Point Calibration (SPC) and other meteorological situations, at data level, like attenuations and second trips in cases of convective precipitation. However, for the spatial variations study, the analysis focuses on both clear air and convective precipitation situations in which appears noise made, for example, by biological echoes (birds) or by the Sun at sunrise and nightfall, and in which it is appreciated residual ground clutter.

### 2.1 Tools to control the results of the temporary variations

1. Differences from the PPIs: To obtain these differences a subtraction is realized between two consecutive PPIs. Thanks to these it will be possible to observe if some anomaly exists in the information and if these are meteorological or not.
2. Stacked histograms: This option with which it is possible to work represent in the axis “x” the azimuth and in the axis “y” the quantity of frequencies. These, for certain azimuth distribute the frequencies of the values obtained in the PPI. They will be analyzed between other things to verify if some azimuthal preference exists.
3. Differences from the histograms: Frequently the differences of the PPIs have been analyzed in the shape of histograms stacked. But in this case what is realized is the difference of the proper histograms, being able to observe in this way with positive values the information that appear in the following information file and with negative values the information that they eliminate.

### 2.2 Noise filter

Talking about the filter, first of all there were studied the diverse filters of textures already implemented in Matlab, but the result was not been expected for this study.

Finally, it was decided to carry out an own tool, which is called “noise filter” and is based on texture technology because this is a new technique and very useful in meteorology for clutter removal. Depending on the scale that the image is observed, it is necessary to study the neighborhood of a group of pixels, because the texture of a pixel is not definite. Because of this, the images processing filters associated with textures are based on this behaviour, like the present case, which studies a pixel along with its adjacent ones.

It is a graphic tool that interacts with the user, so that he will be in charge of introducing the 3 parameters of entry of the noise filter without the necessity of modifying the code:

- Threshold (TRH): threshold value that in the first step will determine what is useful data and what is noise →  $X > \text{TRH}$  = useful data.
- Window (W): the wished size of the window or mask of the filter that will cover the data array. A square window will form and its dimension will have to be an odd number, because the operations of the filter revolve around the central point of the window and it is easier to define it when it is a question of odd numbers.
- Pattern (P): minimal size that there must have the structures or meteorological patterns in which we are interested.

In short, it is an iterative and smart filter, since it filters in several steps by means of combination of the different parameters already seen.

### 2.2.1 Functioning of the filter:

We start from the array in which are saved all the values of reflectivity of the same elevation previously chosen, whose dimensions are 400x300.

Firstly, all the values of the array are compared with the TRH value selected previously. A new array of '0's and '1's will be created, so that in case that the array value  $< \text{TRH}$ , a '0' will be written at the same position, indicating that it is not a useful data. In the opposite case, it will be replaced by the value '1' that indicates that is a useful data.

Once the array has been completed, the mask of selected size will go across this array point by point, from left to right, up and down, counting the number of '1' that are in the space covered by the mentioned mask. Again, another array will be created in which the number of '1' contained in the mask will be indicated. For each position of the mask, the number of '1' will be saved at the equivalent point to the center of that mask.

Finally, this number of '1' will be compared with the P value, creating the definitive array. When number of '1'  $< P$ , the mentioned value will be replaced by 'NaN', and in the opposite case, by the reflectivity value corresponding to the original array.

This last array will be the one that is represented graphically in the PPI.

### 2.2.2 Definition of the filter:

To define the adequate filter, a process consisting of 3 steps has been carried out:

1. Configuration: consist in the combination of the different entry parameters in order to obtain a possible ideal filter, which emphasizes the meteorological information and eliminates the rest, as much as possible.  
Preferably, it is going to carry out in clean air situations, due to is the best situation to appreciate the quality error and if these are eliminated or not.
2. Stability: the filter established in the previous step will be tested in different situations, both clear air with errors and precipitations, with the aim to observe its performance and effectiveness.
3. Apply de filter twice VS once: it is offered the possibility of applying the filter more than once, well the same filter or two filters with different parameters, to improve the results offered by the same one.

## 3 Results

### 3.1 Results of the temporary variations

In this first example, it is observed a situation of anomaly caused by the SPC. This anomaly is defined as a fall of the system and takes place, for example, when some control is out of rank and the system is interrupted by precaution or when some type of maintenance is going to be carried out and is necessary to interrupt it. This interruption causes a fall of 2dB in the value of the ZDR, but this value will be restored after the SPC. This behaviour happens in all the files of fall of the system that have been studied. In the PPIs and its differences this change of colors is appreciated due to the calibration.

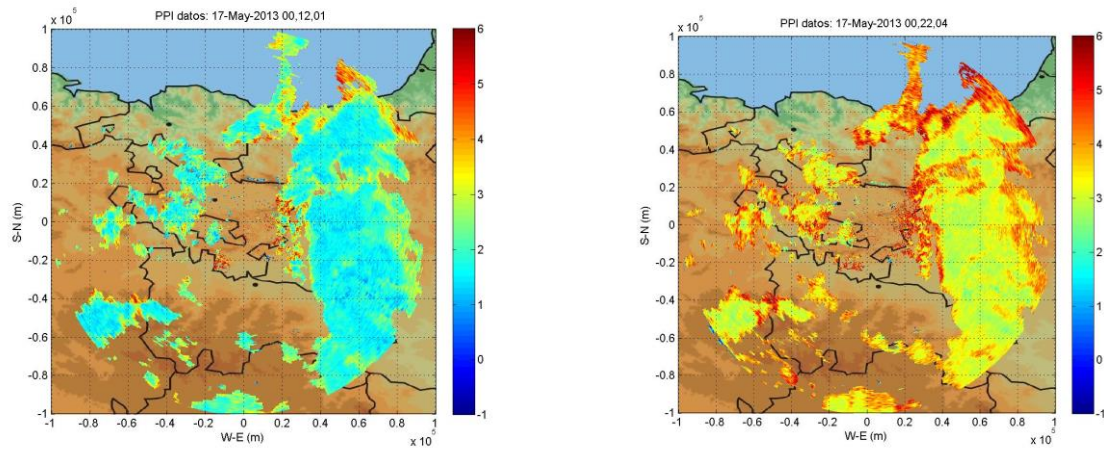


Image 2: PPIs of anomaly of SPC.

On having analyzed the stacked histograms, we observe the azimuth changes that this irregularity carries and we see in its differences how values of ZDR between 3 and 5 dB appear and the values between 1 and 3 dB disappear.

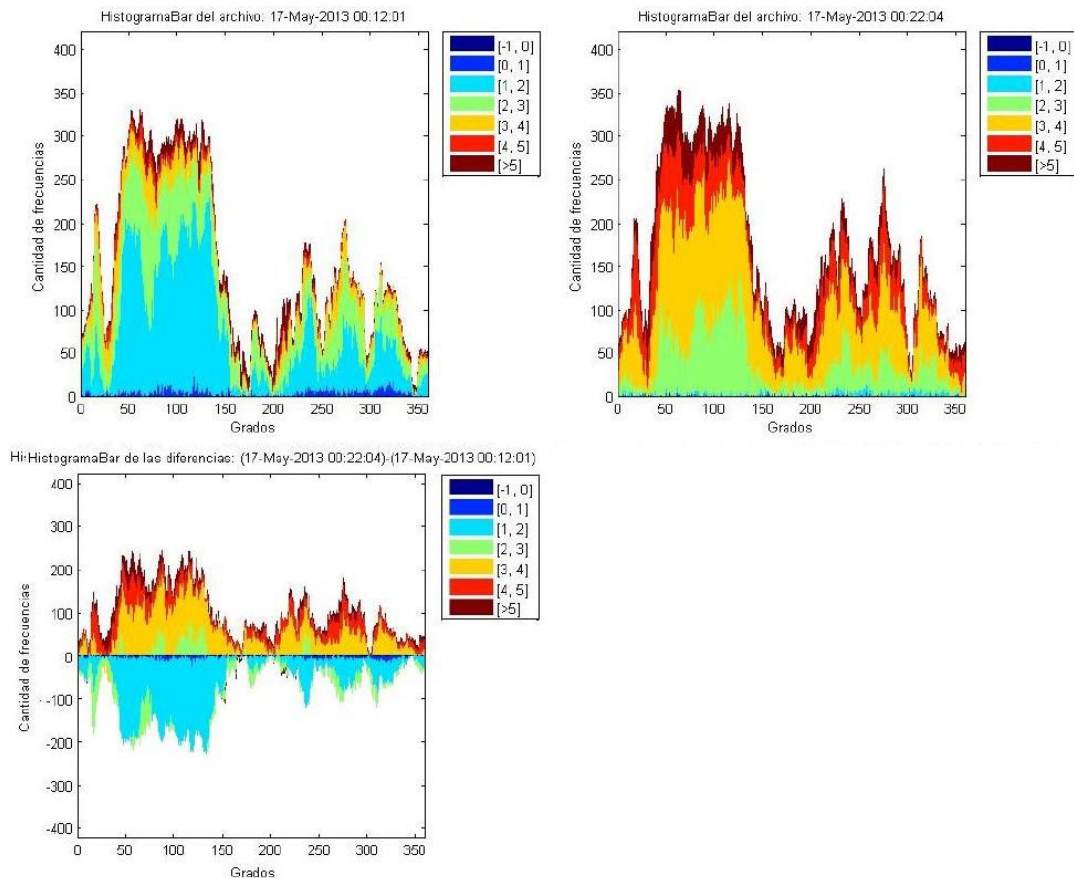


Image 3: Histograms and their differences of anomaly of SPC.

Next we can observe an example in which exist both attenuations in the radom, caused when the storm is located just on top of the radom of the radar, and sectorial attenuations, caused also by the storm but in a situation in which is approaching to the radar. Observing the PPIs, in the case of the attenuation in the radom, it is appreciated that the attenuation is not homogeneous along the 360° of the radom. On the other hand, in the differences of the PPIs it is possible to appreciate the called “mirror effect” because of the abundant precipitation and to its movement.

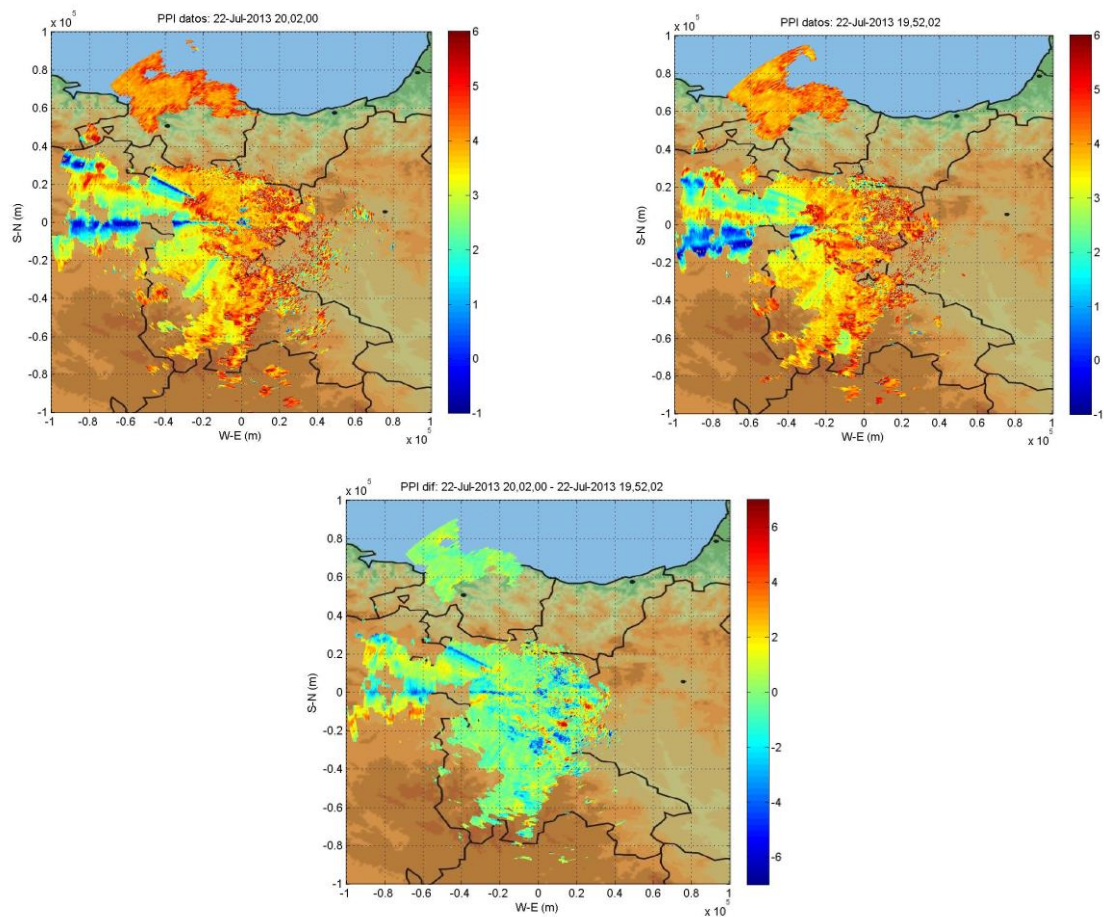


Image 4: PPIs and their differences of attenuations.

In the histograms you can also appreciate this lack of homogeneity of the attenuation in the radom. In other words, the attenuation it is not equal in 360 azimuth grades. This absence of homogeneity would not be appreciated in any histogram, but it can only appreciate in those that study the information of an azimuthal form. In addition, we appreciate this anomalous temporary variation in both attenuations.

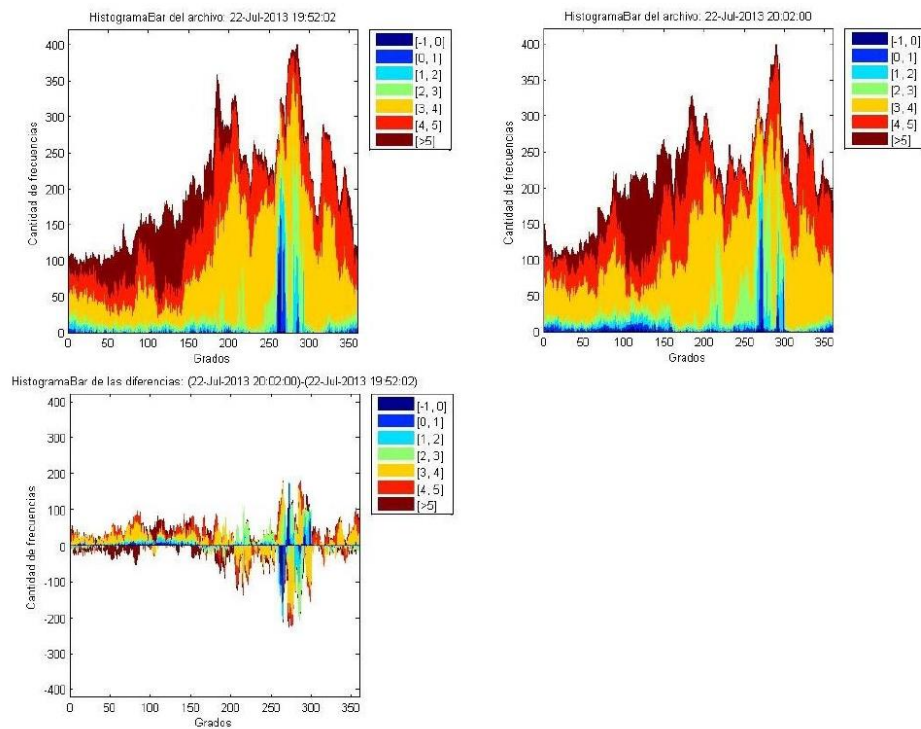


Image 5: Histograms and their differences of attenuations.



### 3.2 Results of the spatial variation

#### 3.2.1 Results of the filters of textures of MATLAB

This is the list of filters that have been analyzed. Next, the results of the same ones appear, although some of them were discarded almost from the first moment because they were not offering suitable results as for what this work refers, without emphasizing the meteorological structures. They divide into two groups, linear and not linear:

<u>LINEAR</u>	<u>RESULTS</u>	<u>NOT LINEAR</u>	<u>RESULTS</u>
<ul style="list-style-type: none"> <li>• Average</li> <li>• Disk</li> <li>• Gaussian</li> </ul>	Smoothed of the information	<ul style="list-style-type: none"> <li>• Maximum</li> <li>• Máx NSEO</li> </ul>	They realize a zoom of the meteorological structures, enlarging so much the biggest like the smallest
<ul style="list-style-type: none"> <li>• Unsharp</li> </ul>	It emphasizes the gradients or points in which there happen important changes (bigger differences)	<ul style="list-style-type: none"> <li>• Minimum</li> </ul>	It emphasizes the areas of biggest reflectivity.
<ul style="list-style-type: none"> <li>• Mottion</li> <li>• Prewitt</li> <li>• Laplacian</li> <li>• Log</li> <li>• Sobel</li> </ul>	Discarded	<ul style="list-style-type: none"> <li>• Range</li> </ul>	Similar to the maximum but not so drastic
		<ul style="list-style-type: none"> <li>• Median</li> </ul>	Discarded

Table 1: Results of the filters of textures of MATLAB

#### 3.2.2 Results of the noise filter

• Configuration: after realizing approximately 30 configurations, it is estimated that a suitable filter is that whose entry parameters are:  $W=5 \times 5$ ,  $TRH=0$  and  $P=13$  (50%). In spite of having realized this process in situations of clean air, the results are presented in a stormy situation, which are the ones that we are more interested in. We see how it offers suitable results, eliminating noise but keeping the meteorological structures.

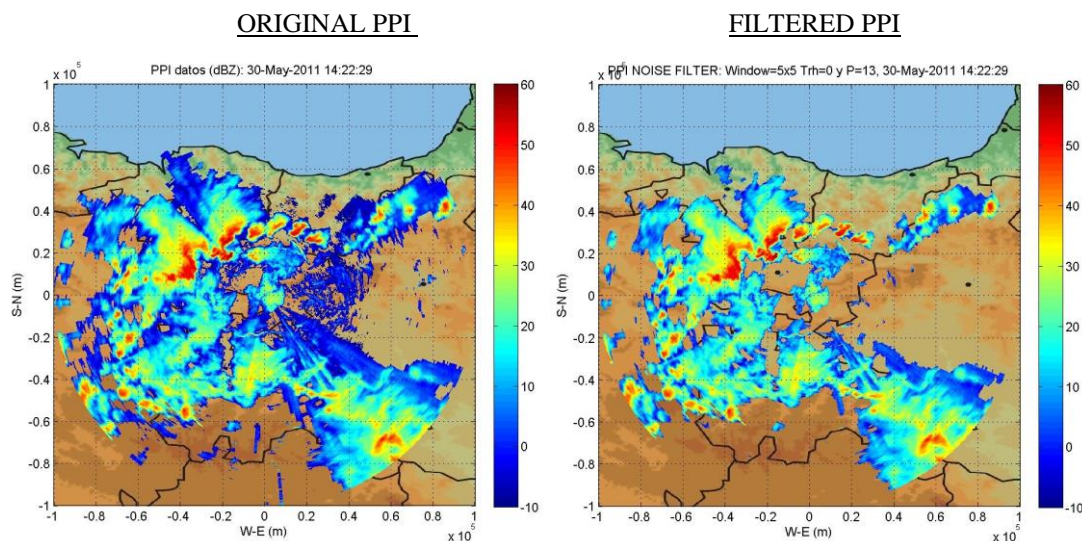


Image 6: original PPI and filtered with configuration  $W=5 \times 5$ ,  $TRH=0$  y  $P=13$  (50%).

• Stability: in this case, the previous filter has been applied approximately on 60 cases, and it is believed that the filter is stable in each and everyone of the presented situations. Two cases are showed below:

Firstly, two situations of clean air where you can see how the filter is very effective as the majority of the points considered noise and not wished are eliminated. Numerically, we verify that the remaining points suppose respectively 0.15 and 0.09% of the whole; therefore it is a completely valid result.

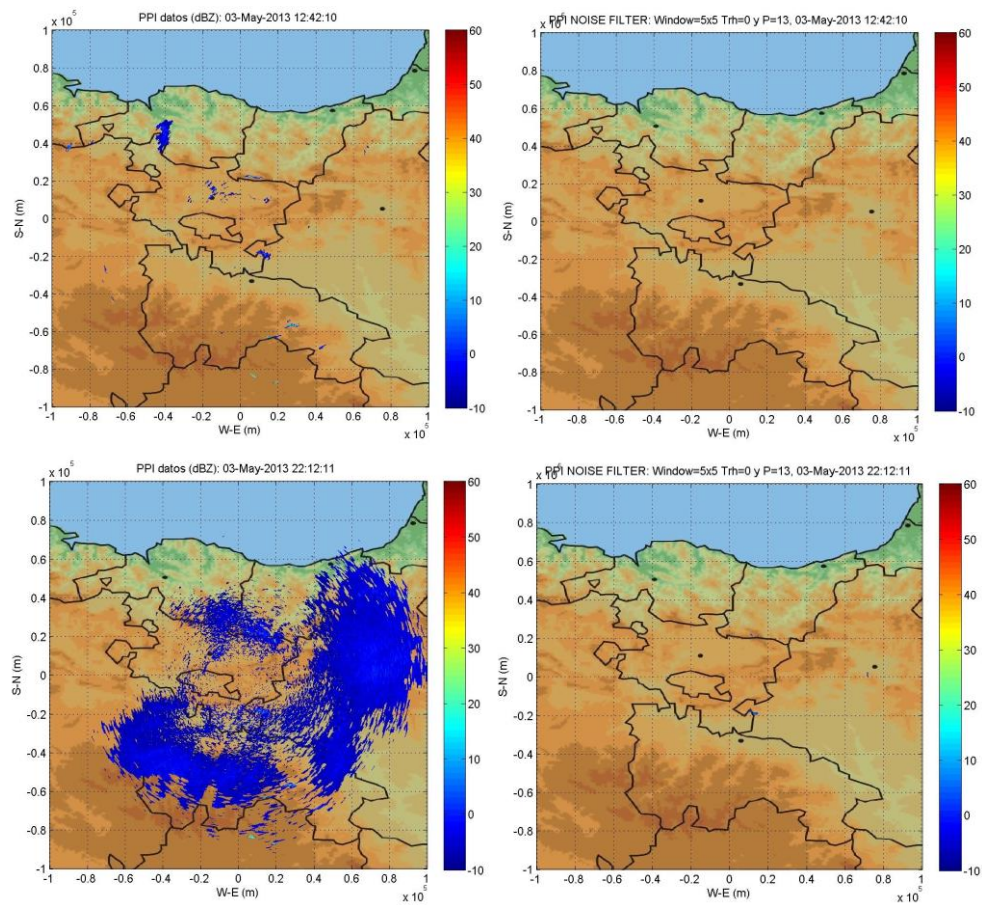


Image 7: original and filtered clean air PPIs with configuration  $W=5 \times 5$ ,  $TRH=0$  y  $P=13$  (50%).

The second case treats precipitation situations: the first one, a stratiform precipitation and the second, convective precipitation (thunderstorms). In this case it is not viable to calculate the number of remaining points because it is not a question of eliminating all of them as in the previous case. Anyway, we can verify visually how it eliminates the noise but it maintains the information concerning the precipitation, therefore once again it achieves the aim.



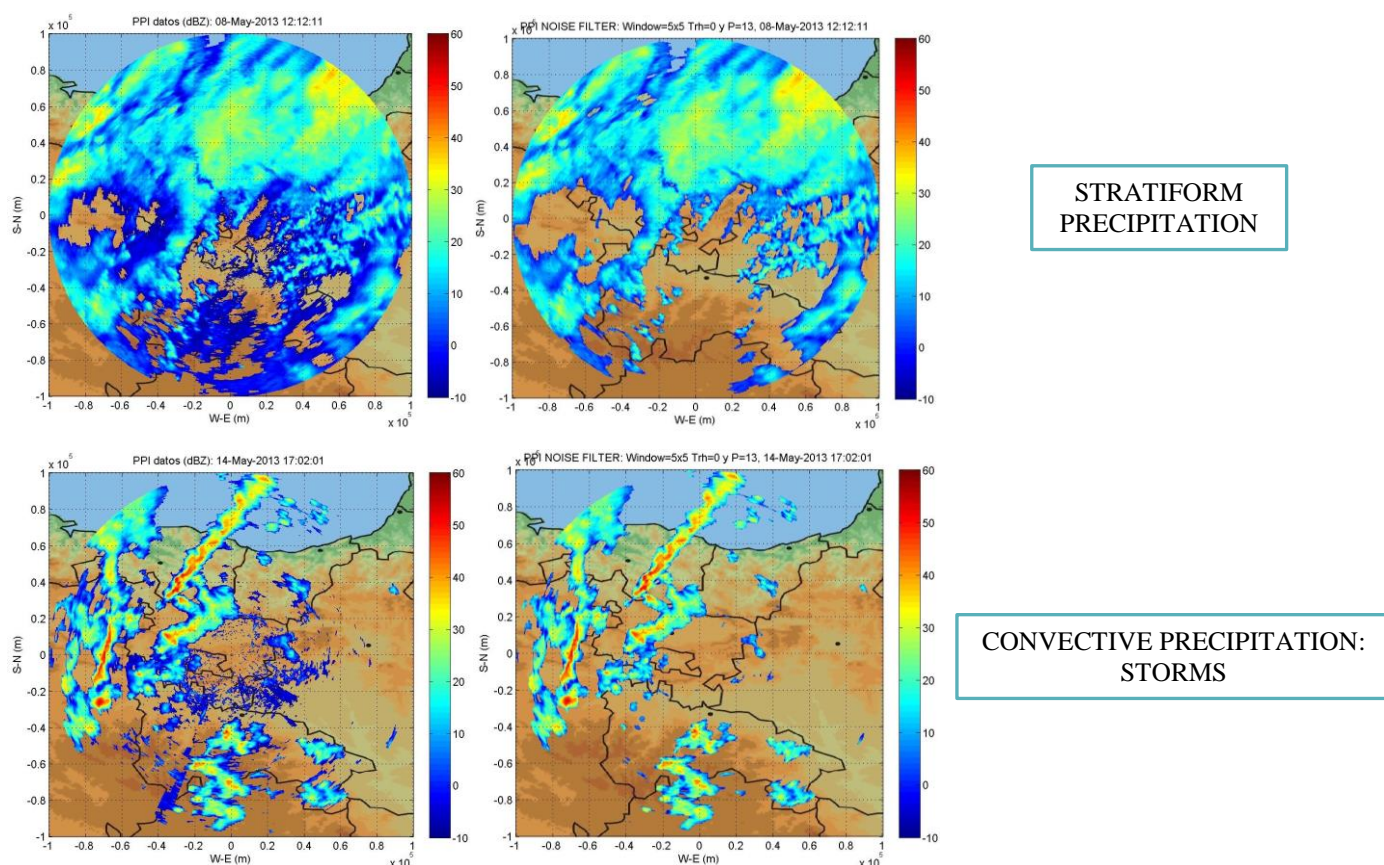


Image 8: original and filtered precipitation PPIs with configuration  $W=5 \times 5$ ,  $TRH=0$  y  $P=13$  (50%).

• 2 times VS once: this part of the process consist on comparing the results that the established as ideal filter offers with the application of two consecutive filters, well the same filter or two filters with different parameters.

In this case, first of all it appears the result of applying the ideal filter once in a stormy situation, which we have seen previously. The second image is the product of applying 2 filters with the configuration here showed. It is verified that it offers better results, due to it eliminates the residual values on an intelligent way.

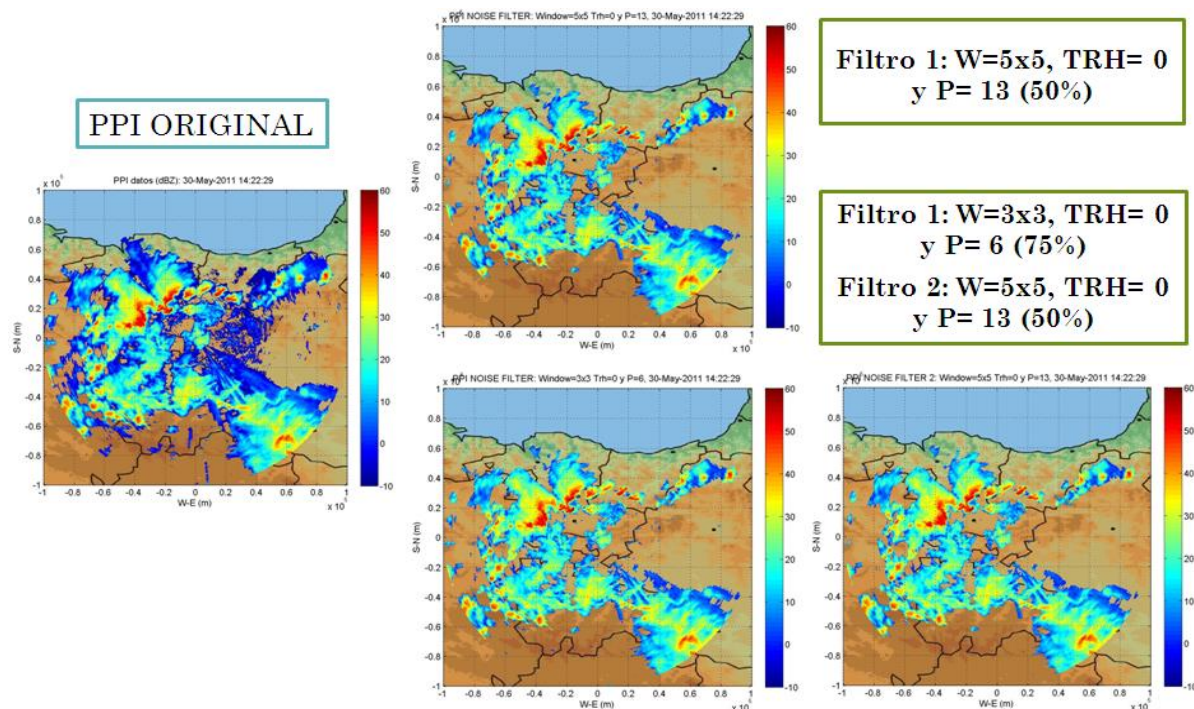


Image 9: PPIs filter 1 time VS 2 times.



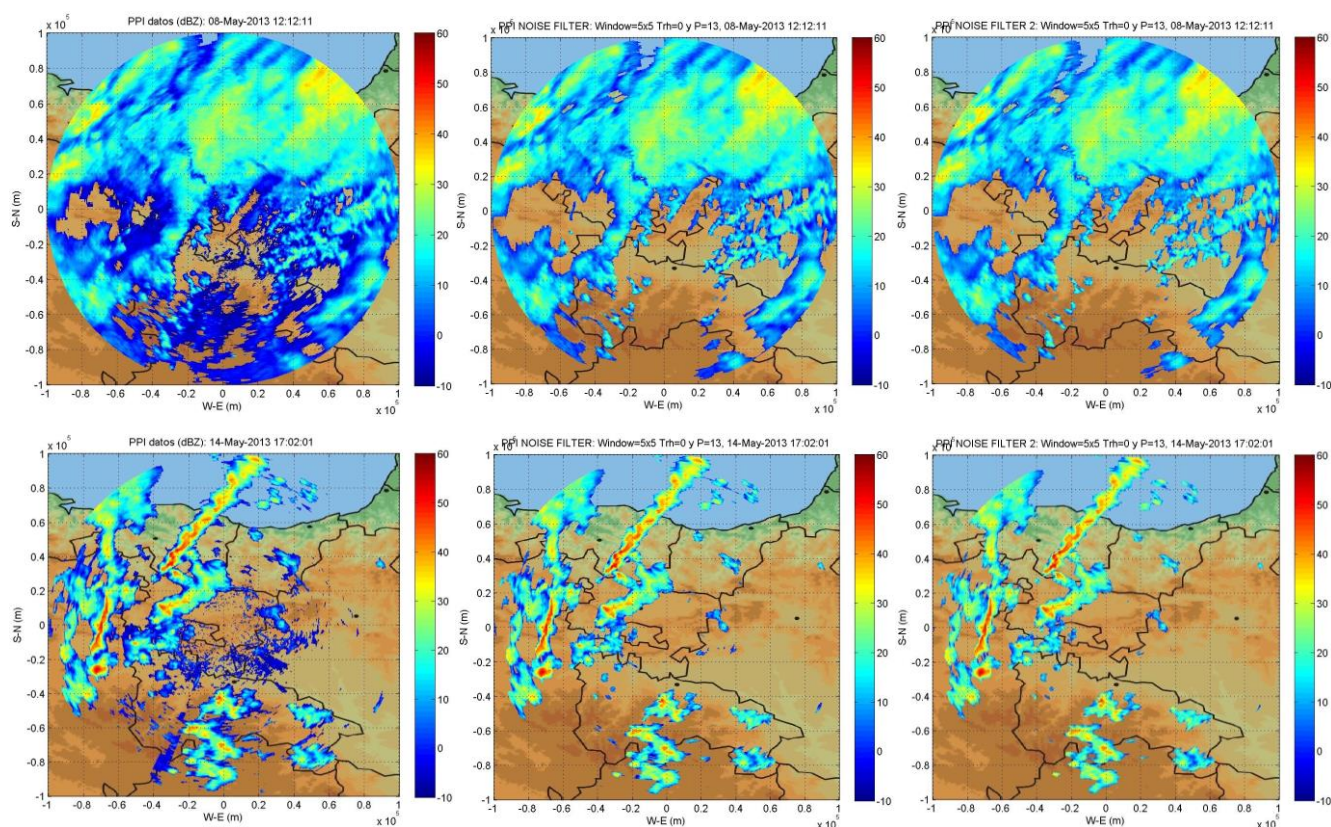


Image 10: precipitation PPIs filter 1 vez VS 2 veces.

#### 4 Conclusion

As for the attenuations in the radom, it is possible to conclude that, in the moment in which the attenuation appears, the low values of ZDR will increase. However, in the moment in which the attenuation disappears, as we have seen in the example, these values will decrease. In the situations of sectorial attenuations, the low values of ZDR will be changing in azimuth due to the movement of the thunderstorms. And analyzing the examples of the SPC, one concludes that in case of the fall of system, the high values of ZDR appear and the lows disappear.

On the other hand, a new tool to work and study the information has been used: the histograms that study the information on an azimuthal way. These have helped us to diagnose and understand the behaviour of certain anomalies that with other tools was not possible.

As for the developed noise filter, one concludes that it fulfills the expectations, settling like ideal filter that whose parameters are:  $W=5 \times 5$ ,  $TRH=0$  y  $P=13$  (50%).

In addition, to obtain even better results, it is possible to combine this filter with other with different parameters, so that the final configuration would be the following one:

Filter 1:  $W=3 \times 3$ ,  $TRH=0$  y  $P=6$  (75%)

Filter 2:  $W=5 \times 5$ ,  $TRH=0$  y  $P=13$  (50%)

On the other hand, big results can be obtained combining the potentials of the filters of textures of MATLAB, not only in what it refers to data quality but as for other meteorological products, since they stand out characteristics of the meteorological structures such as the severity, being this an excellent information for other studies like the relative ones to the tracking of thunderstorms.

## Acknowledgement

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