TRIPLE-PRT DOPPLER RADAR : MINIMIZATION OF THE IMPACT OF GROUND CLUTTER FOR BETTER DOPPLER VELOCITY RECOVERING

Nicolas Dejax*, Nicolas Gaussiat, Pierre Tabary,
METEO-FRANCE, Toulouse, France

1. Introduction

A major obstacle to the observation of the lower layers of the atmosphere by radar is the presence of clutter: radar echoes that interfere with observation of desired signals on the radar display. At lowest elevations, the return echoes from the ground tend to dominate the useful signal from the precipitation, especially near the mountains. To overcome this problem, a simple method is to filter the clutter (which has zero Doppler and low spectral width) from the signal after performing a Fourier transformation of the I and Q time series of the received signal. However, this technique is not directly applicable to Météo France radars, which transmit pulses non-regularly spaced in time. This particular transmission mode, called triple-PRT, where PRT stands for Pulse Repetition Time, has the enormous advantage of allowing the measurement of the Doppler velocity unambiguously up to maximum range[1].

A 3-PRT scheme is prone to dealiasing errors that mainly depend on:
- The Signal to Clutter Ratio (SCR)
- The triplet of PRT
- The dealiasing technique used

The errors are not independent, consequently, to improve the quality of the Doppler velocities, all aspects need to be considered together in order to design an optimal dealiasing and filtering solution.

In this paper, the contribution of each error sources are studied as well as their interactions. All the results presented have been produced from I and Q time series simulated at very high temporal resolution and re-sampled at PRF_1 = 550Hz , PRF_2 = 489Hz and PRF_3 = 440Hz.

2. Simulation of 3-PRT signal radar

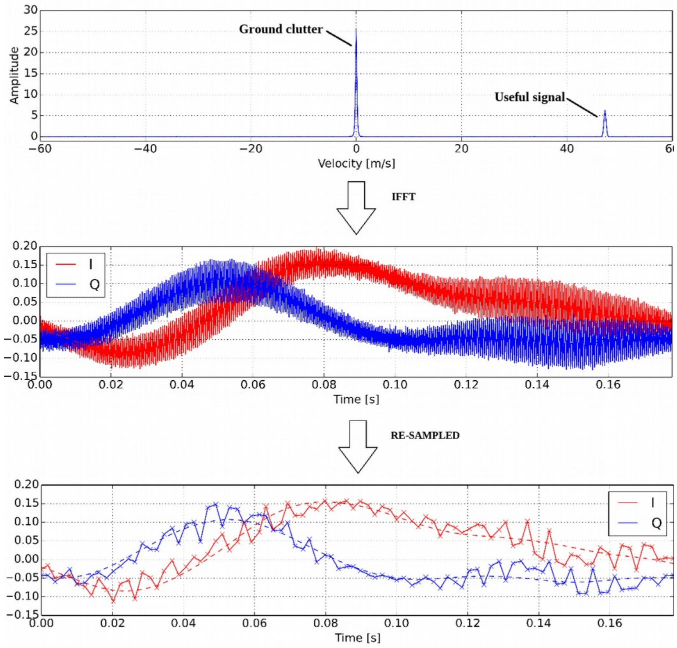
All the results in this poster have been produced from simulated radar signals.

As S. Zrnic showed in [2], we first draw the radar signal in the spectral domain according to the desired parameters (velocity of the target, Signal to Clutter Ratio, Signal to Noise Ratio, etc.). Then, by applying an Inverse fast Fourier Transform, we get the corresponding uniformly sampled I and Q time series.

The last step consist in re-sample the signal following the 3-PRT scheme.

An example of a simulated radar signal in presence of ground clutter can be seen below. The velocity of the target is set to 47 m/s. The triple-PRT time signal represented is re-sampled with PRF_1 = 550Hz , PRF_2 = 489Hz and PRF_3 = 440Hz. *(PRF = 1/PRT)*

Contact information:
Email adress: nicolas.dejax@meteo.fr
Office number: +33561079223



(Figure 1 : Example of a simulated signal radar)

3. Presentation of two dealiasing methods

From the staggered time series I and Q, three pulse pair estimations of the velocity can be calculated:

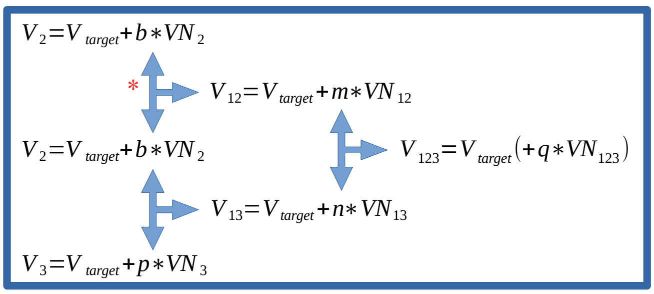
$$\begin{aligned} V_1 &= V_{target} + k * VN_1 \\ V_2 &= V_{target} + b * VN_2 \quad \text{with} \quad (k, b, p) \in \mathbb{N} \\ V_3 &= V_{target} + p * VN_3 \end{aligned}$$

Where $VN_i \propto PRF_i$ is the Nyquist velocity. $i \in [1,2,3]$

The aim of a dealiasing method is to recover the velocity of the target « V_{target} » from these 3 estimations. In this document, two methods are compared.

3.1 Subtractive method

This method is the one currently used at Météo-France. It performs successive double-PRT dealiasing as follows:



(Figure 2: Analysis of the subtractive method)

Therefore, to understand how we get the full unfolded velocity V_{target}, we just need to understand how a double PRT dealiasing works. The procedures of dealiasing for V_1 and V_2 (see * on the figure 2 above) is done by two main operations:

- **Subtraction** $V_1 - V_2$:

$$\Rightarrow \quad V_1 - V_2 = k * VN_1 - b * VN_2$$

$$\Rightarrow \quad V_1 - V_2 = b(VN_1 - VN_2) + c * VN_1 \quad \text{with} \quad k = b + c$$

- **Refold** $V_1 - V_2$ **into** VN_1

$$\Rightarrow \quad b(VN_1 - VN_2) + c * VN_1 \pm VN_1$$

For $|c| \leq 1$, we can recover « b » and calculate the unfolded velocity of the target $V_{12} = V_{target}$. If $|c| > 1$, then the recovered velocity is $V_{12} = V_{target} + m * VN_{12}$ with an extended equivalent Nyquist velocity VN_{12} which can be estimate as:

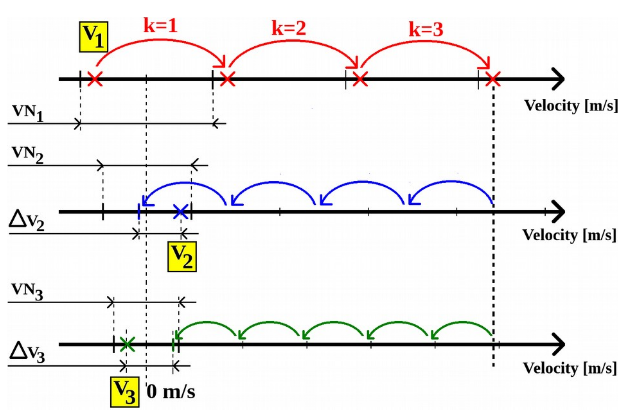
$$VN_{12} = \frac{(VN_1 * VN_2)}{(VN_1 - VN_2)}$$

3.2 Brute force method

The dealiasing procedures of this method is as follows:

- Generate the set of all possible aliases of V_1 within the desired velocity interval ([-60;+60] m/s for Météo France radars)
- For each alias, simulate the aliasing into VN_2 and VN_3 (V_2' and V_3')
- The alias that is chosen (k_{best}) is the one that leads to the smallest quadratic error: $\varepsilon = \Delta_2^2 + \Delta_3^2$

  (With $\Delta_2 = V_2 - V_2'$ and $\Delta_3 = V_3 - V_3'$)



(Figure 3: Analysis of the brute force method)

If $\Delta_i > VN_i/2$ then we have to correct the term to get the real error : $\Delta_i = \Delta_i - VN_i/2$

4. Assessment protocol

At this moment, many parameters have to be set: the dealiasing method and the 3 Pulse Repetition Frequencies (PRF).

For the following, we call a "configuration" the combination of one of the both dealiasing methods and one triplet of PRF.

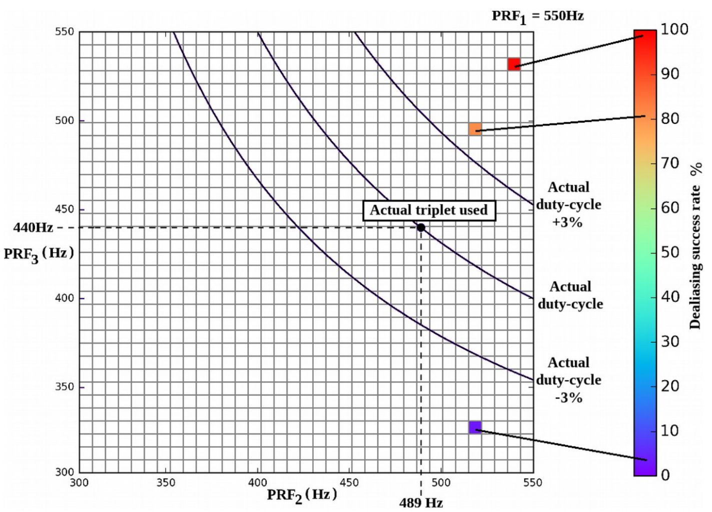
In order to compare the performances, for all possible configurations, we calculate a dealiasing success rate using 1000 folded velocities V1, V2, V3, computed from 1000 simulated I and Q time series with a velocity reference of the target randomly taken between -60 and 60 m/s (desired velocity interval at Météo France)

We consider the dealiasing a success if the difference between the retrieved and reference velocity is less than 2 m/s.

In this paper, the studies have been produced in order to be applied on the C band French Radars (f_0 = 5,625GHz). The actual triplet of PRF used is: PRF_1 = 550Hz, PRF_2 = 489Hz and PRF_3 = 440Hz. The dealiasing method currently in used is the subtractive method.

Considering $PRF_1 > PRF_2 > PRF_3$, as the radar range also depends on the maximum frequency of the triplet, the PRF_1 is fixed to his maximum actual value: 550Hz.

To see immediately the performances of all configurations, we create an image where each pixel represents a Triplet of PRF, PRF_1 is fixed to 550, and PRF_2 and PRF_3 vary from 300 to 550 Hz. For each pixel (↔triplet), we calculate the corresponding dealiasing success rate.



(Figure 4: Shape of the results)

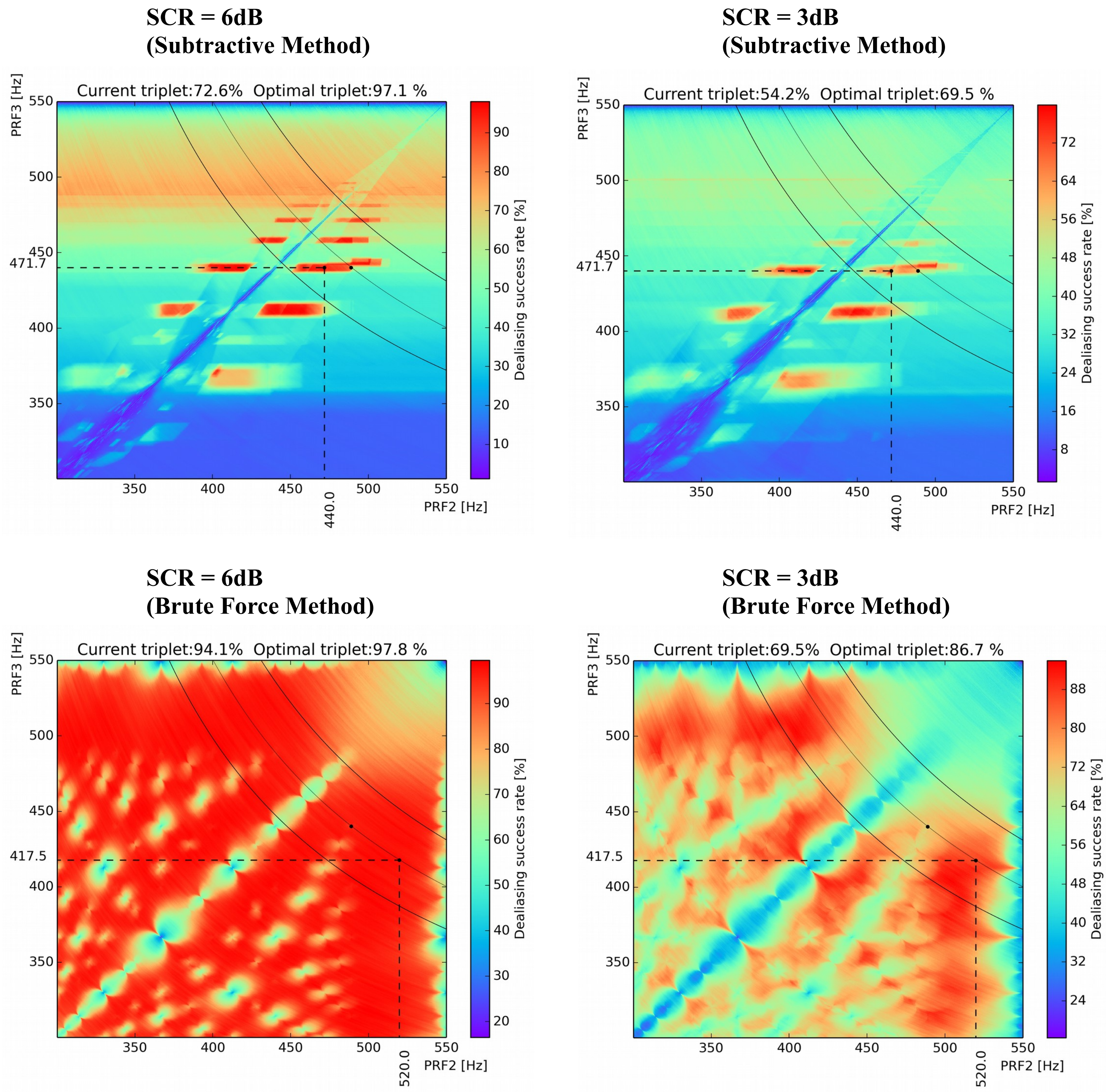
Above we can see the form of the results, the black lines are the duty cycle iso-curve at -3% and +3% around the current value. The duty cycle (PRF_{moy}) is calculated as follows:

$$PRF_{moy} = \frac{1}{PRT_1 + PRT_2 + PRT_3}$$

This parameter has already been optimized for reflectivity, that's why we'll search an optimized triplet which has a duty cycle close to the actual value (less than ± 3 % different here).

5. Results

The figures below show the performance of both dealiasing methods for two different values of Signal to Clutter Ratio (SCR).



(Figure 5: Dealiasing success rates for two different dealiasing methods and two Signal to Clutter Ratios)

With this graph (figure 5), it is easy to spot which triplets are the most resistant to ground clutter. We measure an optimal triplet for both dealiasing method:

- Subtractive method:

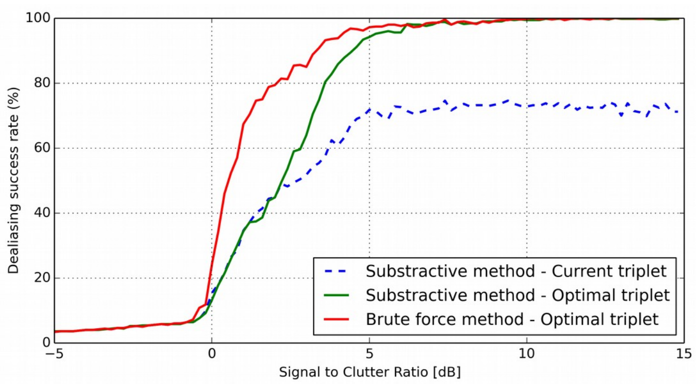
$Triplet_{OPT\_S}$: PRF_1=550Hz PRF_2 = 489Hz and PRF_3=440Hz

- Brute force method:

$Triplet_{OPT\_B}$: PRF_1=550Hz PRF_2 = 520Hz and PRF_3=417Hz

These two optimal triplets are represented with dashed line on the figure above.

The performance of the optimal triplet of each method as a function of the SCR is represented in more detail in the figure below. The current configuration used is also represented (blue dashed line).

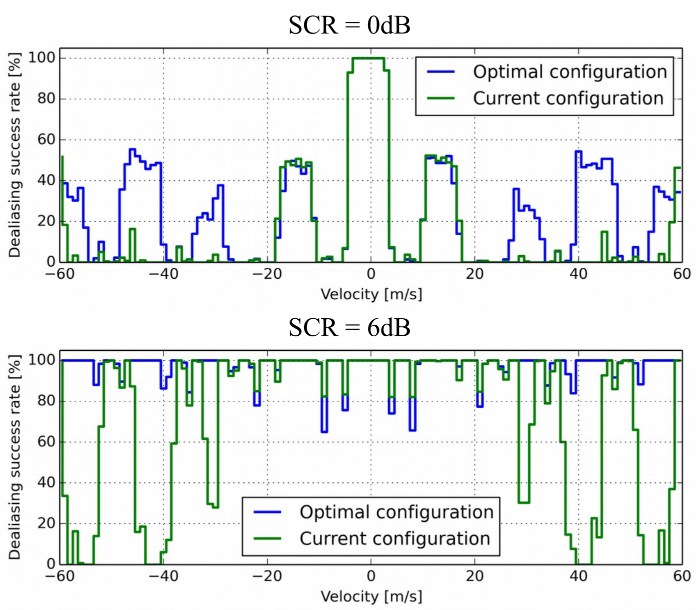


(Figure 6: Comparison of performances for different configurations)

As can be seen, the current configuration is not optimal and its performance could be improved by changing both the dealiasing method and triplet. Indeed, the optimal configuration is reach by the brute force method at his optimal triplet ($Triplet_{OPT\_B}$).

We also analyze the distribution of the dealiasing success rate as a function of the velocity of the target to recover. This enables us to check that the gain of performance spreads evenly over the velocity interval. Two cases are compared:

- The current configuration
- The optimal configuration



(Figure 7: Distribution of the dealiasing success rate over the velocity interval [-60;+60] m/s)

For absolute velocities less than 30 m/s, the performances of both configurations are quite the same. However, up to 30 m/s, we can clearly observe that the use of the optimal configuration enables to reach much better dealiasing success rates.

6. Add of a high pass filter

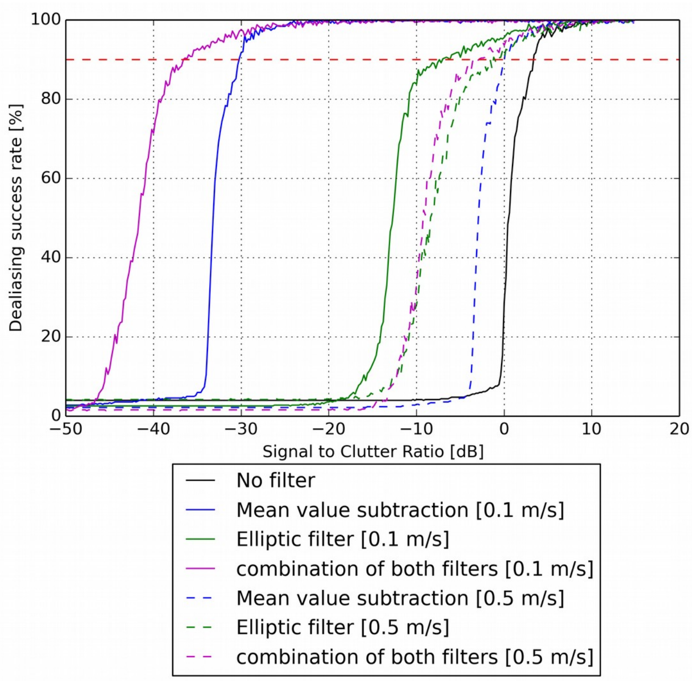
Next, we assume that the optimal configuration is used (brute force method with PRF_1 = 550Hz, PRF_2 = 520Hz and PRF_3 = 417,5Hz).

Since the ground clutter signal has zero Doppler and narrow spectral width it correspond to low frequencies. Therefore an easy way to remove the contribution of ground clutter is to subtract the mean value of the I and Q time series. A high pass filter could also be applied but the non uniform sampling of the radar signal does not allow direct application of a filter.

Since the non uniform sampling scheme is made of 3 staggered uniform time series, a sub-optimal approach is to apply the same regular filter on the three uniform time series with the period (PRT_1 + PRT_2 + PRT_3).

We took the example of an Elliptic filter of order 5, the cut off velocity is set to 0.25m/s.

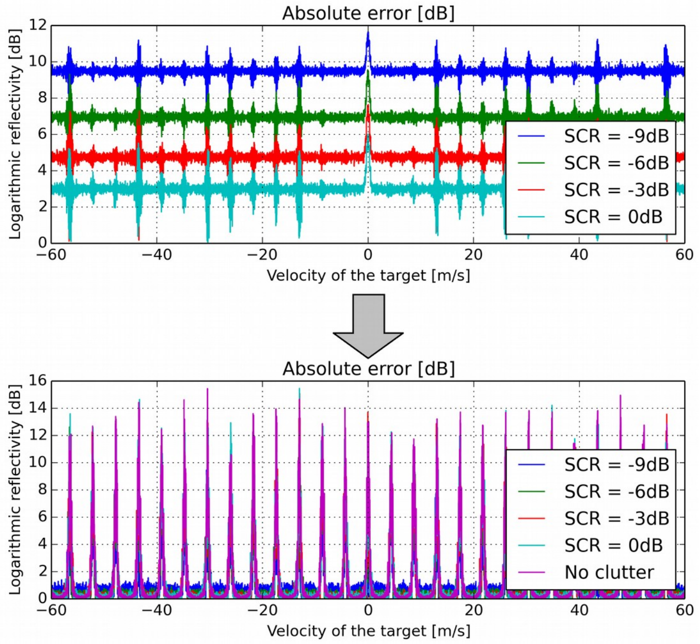
The two approaches are studied: the mean value subtraction and the elliptic filter. The gain of the use of such filters is represented below for two different spectral width of ground clutter.



(Figure 8: Dealiasing success rate as a function of signal to clutter ratio for two different widths of ground clutter and two filters)

As predicted, the filters are much more efficient when the width of the ground clutter is low, in this case only, these filters can be very useful. On the contrary, the filters are almost useless when the width of ground clutter is higher than 0.5m/s.

The main problem of applying a filter on the series at the period $PRT_1 + PRT_2 + PRT_3$ is that all the velocities which are aliased inside the stopband will be filtered. This drawback can be seen on the measure of reflectivity that is represented below.



(Figure 9: Measure of reflectivity before and after the application of the both filters)

As we can see, the high value of sampling period ($T_e = PRT_1 + PRT_2 + PRT_3$) creates a lot of peak of errors corresponding to the value aliased in the 0 m/s value. Apart from these values, the measure of reflectivity is well improved.

7. Conclusion and future developments

In this paper, we presented a new way to perform the optimization of triplet of PRF and the dealiasing method. In our case, the studies showed that the current configuration is not optimal. Indeed, we get significant improvement by using the brute force method with another Triplet of PRF.

We have produced some first results of simple filtering solutions, the performance for low ground clutter width are promising. Future studies should be done for the case of real radar signals in order to measure the true performance of the filter.

Finally, concerning the reflectivity, the application of the filter was found to be non optimal because it had a destructive impact on the radar signal. Studies have to be done to find another way to apply filter which could be less destructive on the signal.

References

[1] Tabary, P., F. Guibert, L. Perier, and J. Parent-du-Chatelet, 2006: *An Operational Triple-PRT Doppler Scheme for the French Radar Network*. J. Atmos. Oceanic Technol., 23, 1645–1656.

[2] Dušan S. Zrnić, 1975: *Simulation of Weatherlike Doppler Spectra and Signals*. Journal of Applied Meteorology, Volume 14, Issue 4 (June 1975) pp. 619-620