Triple-PRT Doppler Radar: Minimization of the Impact of Ground Clutter for Better Doppler Velocity Recovery

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

Abstract

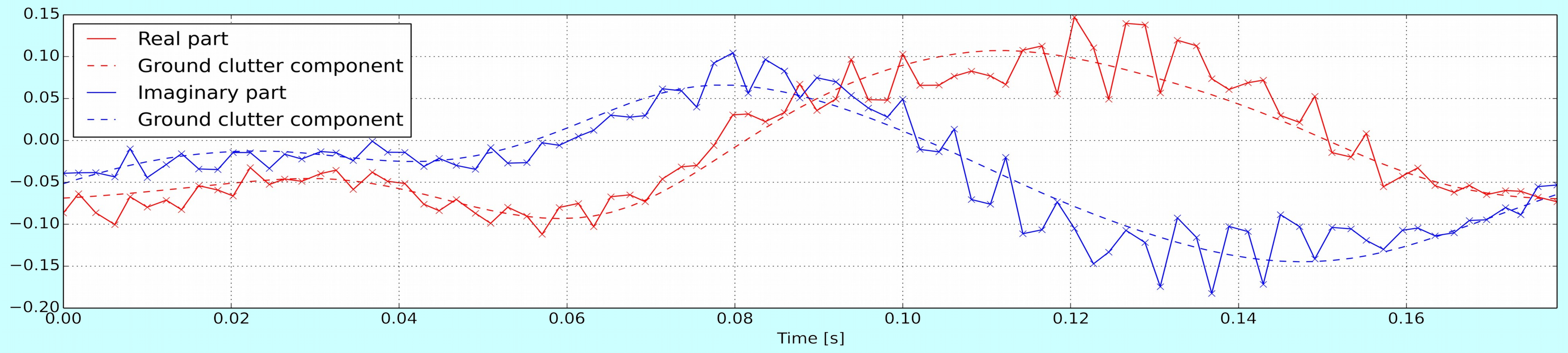
A major obstacle to the observation of the lower layers of the atmosphere by radar is the presence of clutter: radar echoes that interfere with observation of desired signals on the radar display. At lowest elevations, the return echoes from the ground tend to dominate the useful signal from the precipitation, 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

Consequently, to minimize the impact of ground clutter, all aspects need to be considered together in order to design an optimal solution. In this poster, the contribution of each of the sources of error will be presented as well as their interactions.

Simulated signals

All the results in this poster have been produced from simulated radar signals[2]. An example of a simulated radar signal in presence of ground clutter can be seen below. The triple-PRT time signal represented is sampled with $PRF_1 = 550$Hz , $PRF_2 = 489$Hz and $PRF_3 = 440$Hz. *(PRF = 1/PRT)*



(Figure 1: I and Q time series of a triple-PRT signal radar in presence of ground clutter)

Dealiasing Methods

From the staggered time series, we have three pulse pair estimations of the velocity:

$$V_1 = V_{target} + k * VN_1$$
$$V_2 = V_{target} + b * VN_2 \quad \text{where} \quad VN_i \propto (PRF_i, f_0), \quad k, b, p \in \mathbb{N}$$
$$V_3 = V_{target} + p * VN_3$$

The aim of a dealiasing method is to recover the velocity of the target « V_{target} » from these 3 estimations. Two methods are compared:

Subtractive Method

This method performs successive double PRT dealiasing as follows:

$$V_2 = V_{target} + b * VN_2$$
$$V_{12} = V_{target} + m * VN_{12}$$
$$V_1 = V_{target} + k * VN_1 \qquad V_{123} = V_{target} + (q * VN_{123})$$
$$V_{13} = V_{target} + n * VN_{13}$$
$$V_3 = V_{target} + p * VN_3$$

The double PRT dealiasing is done by 2 main operations:

- subtraction $V_1 - V_2$

$\Rightarrow k * VN_1 - b * VN_2$

$\Rightarrow b(VN_1 - VN_2) + c * VN_1$ with $k = b + c$

- refold ($V_1 - V_2$) into VN_1

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

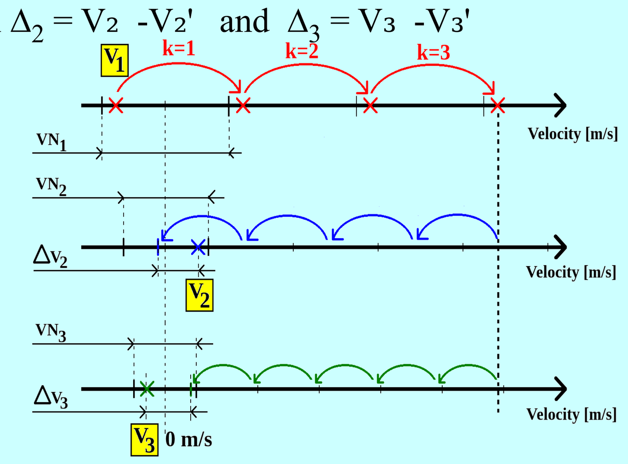
For $|c| \le 1$, we can recover « b » and calculate the unfolded velocity of the target V_{target}.

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 $\Delta_3 = V_3 - V_3'$



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

Results

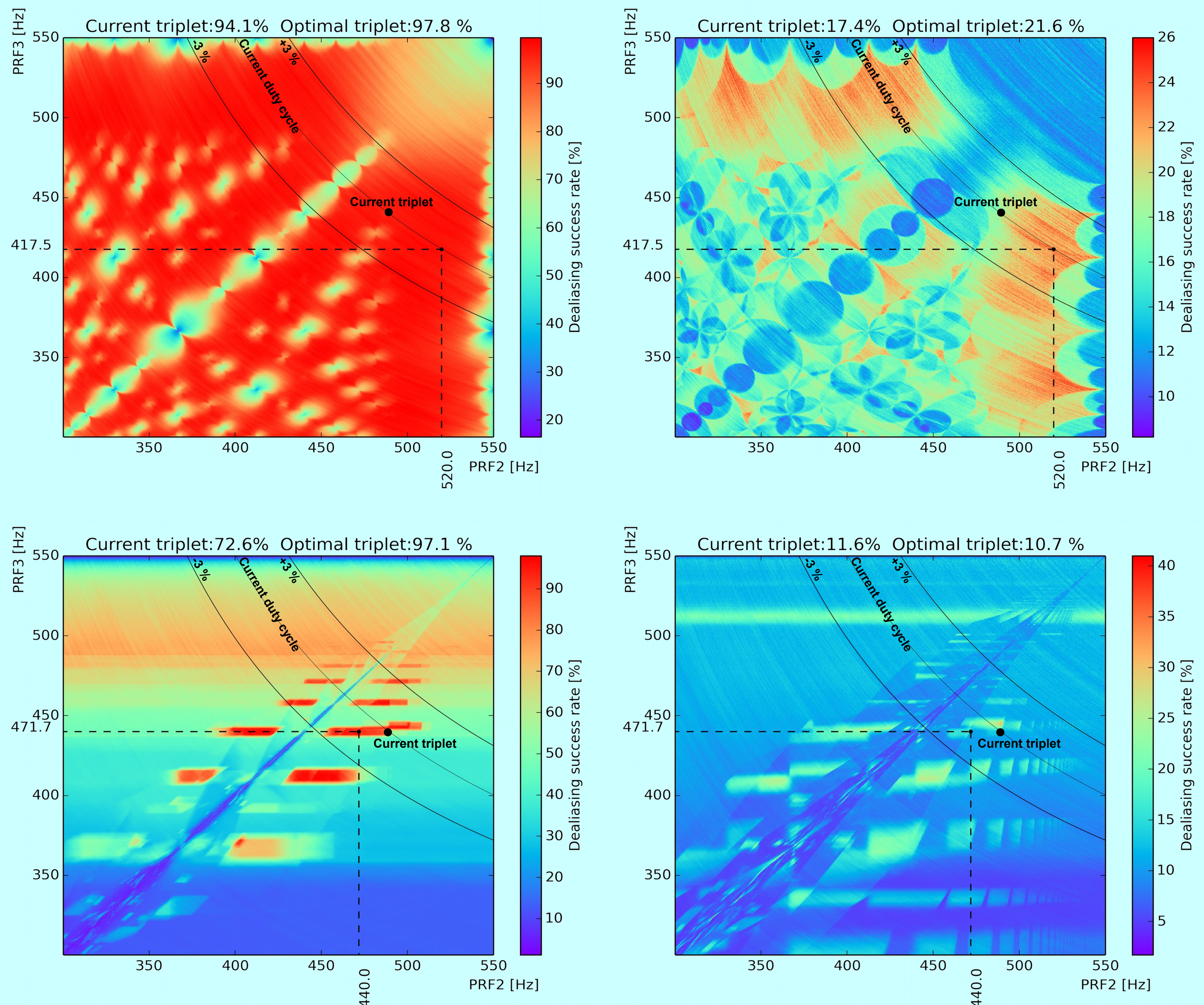
The figures below show the performance of both dealiasing methods for two different values of Signal to Clutter Ratio (SCR) and for various values of PRTs. Each pixel represents a Triplet of PRF, PRF_1 is fixed to 550, and PRF_2 and PRF_3 vary from 300 to 550 Hz.

For each triplet (↔pixel), we calculate a mean dealiasing success rate using 500 folded velocities V1, V2, V3, computed from 500 simulated I and Q time series with a velocity reference of the target randomly taken between -60 and 60m/s. We consider the dealiasing a success if the difference between the retrieved and reference velocity is less than 2m/s.

SCR = 6dB **SCR = 3dB**

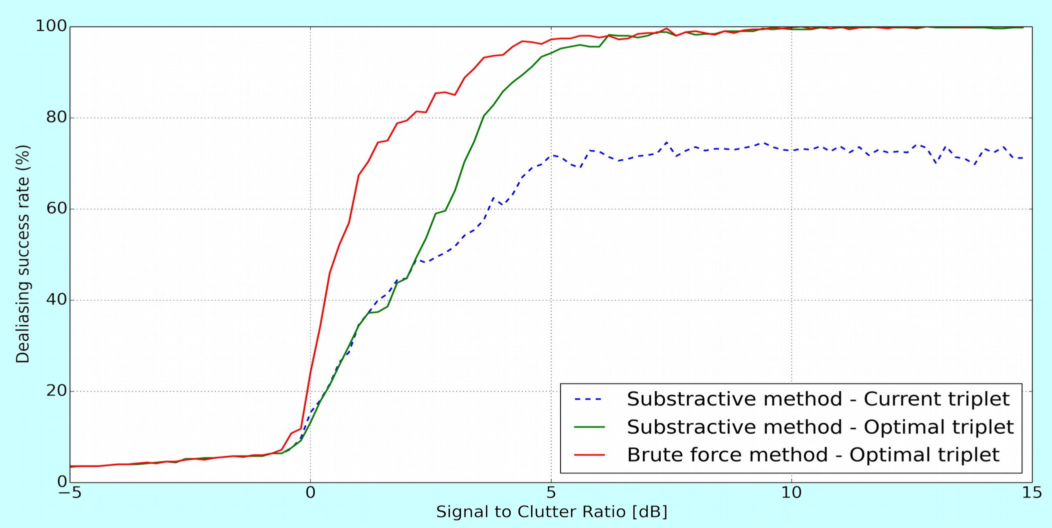
Brute force Method
Optimal triplet :
$PRF_1 = 550$ Hz
$PRF_2 = 520$ Hz
$PRF_3 = 417$ Hz

Subtractive Method
Optimal triplet :
$PRF_1 = 550$ Hz
$PRF_2 = 471$ Hz
$PRF_3 = 440$ Hz



(Figure 2: Dealiasing success rates for two different dealiasing methods and two Signal to Clutter Ratios)

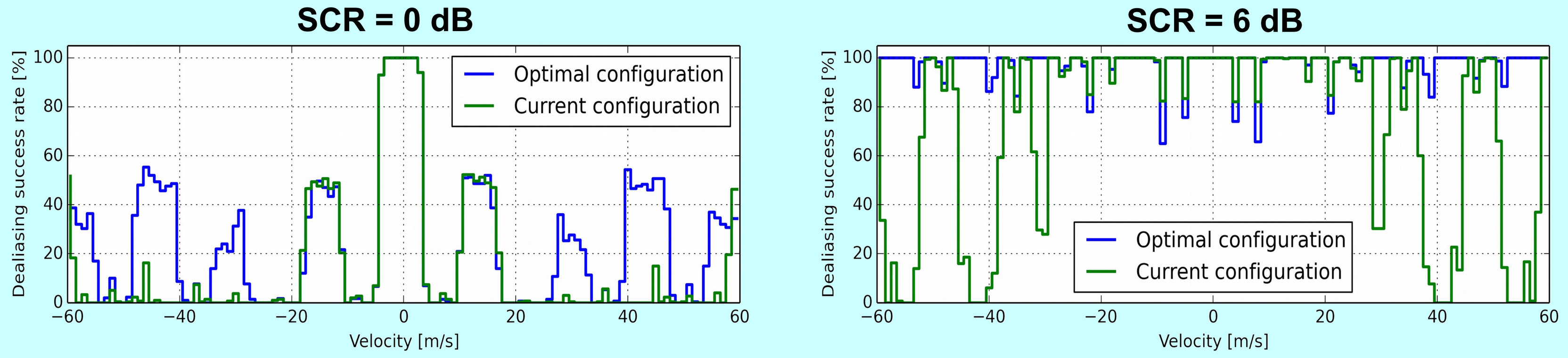
With this graph, it is easy to spot which triplets are the most resistant to ground clutter. The performance of the best triplet of each method as a function of the SCR is represented in more detail in the figure on the right. The dashed line shows the current triplet used. As can be seen, the current configuration is not optimal and its performance could be improved by changing both the dealiasing method and triplet.



(Figure 3: Comparison of performances for different configurations)

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: subtractive method with PRF_1=550Hz, PRF_2 = 489Hz and PRF_3=440Hz
- The optimal configuration: brute force method with PRF_1=550Hz, PRF_2 = 520Hz and PRF_3=417Hz

SCR = 0 dB **SCR = 6 dB**



(Figure 4: Comparison of the distribution of the dealiasing success rate over the velocity interval [-60;+60] m/s for two different values of Signal to Clutter Ratio and two different configurations)

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.

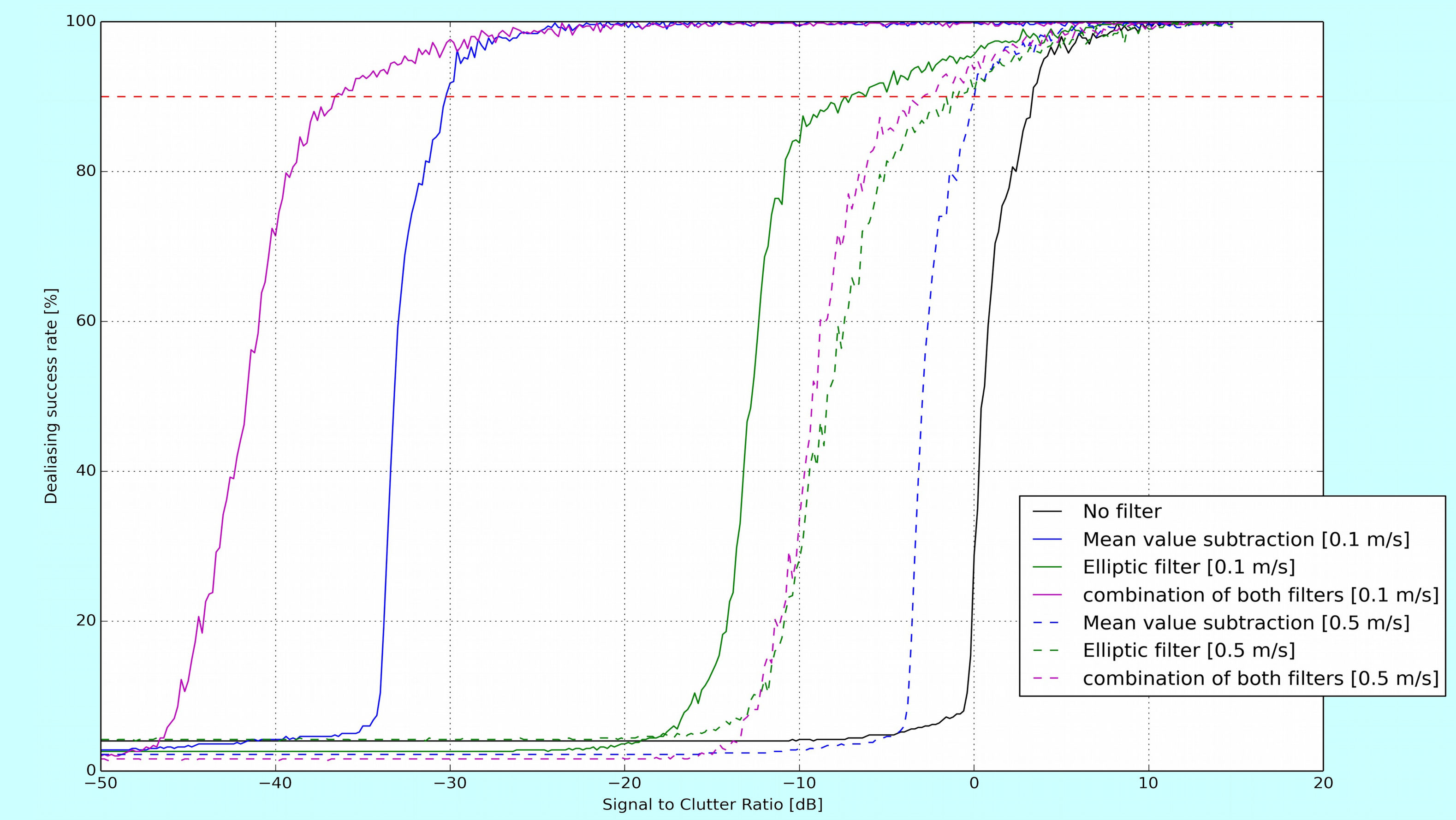
Ground Clutter Filtering

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).

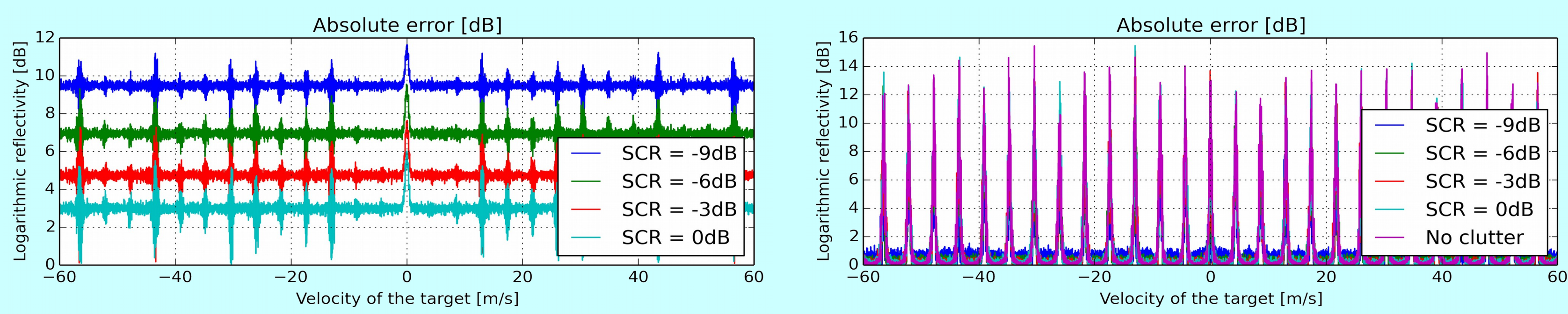
We took the example of an Elliptic filter of order 5, the cut off velocity is set to 0.25m/s. The gain of the use of such filters is represented below.



(Figure 5: 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. The impact of filter on the measure of reflectivity is represented below.



(Figure 6: Errors on the measure of reflectivity before and after the application of the both filters for different values of SCR)

As we can see, the high value of sampling period (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.

Conclusion and Future Developments

In this poster, 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

*Contact information: Nicolas DEJAX
Email address: nicolas.dejax@meteo.fr
Office number: +33561079223

METEO FRANCE
Toujours un temps d'avance