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EVALUATION OF THE METEO-FRANCE OPERATIONAL PRECIPITATION RADAR NETWORK CAPACITY FOR THE REFRACTIVITY MEASUREMENT

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INTRODUCTION

The refractivity can be measured by weather radar, and it is function of meteorological parameters, as the temperature, the water vapor pressure and the air pressure. The radar refractivity measurement is obtained by an estimation of the refractive index, which is depending of the change in the two-way travel time Δt of electromagnetic waves between the radar and ground targets (Fabry et al. 1997). This could be useful for convection prediction through the measurement of moisture in the boundary layer, particularly in pre-storm conditions. Until now such measurements have only been performed by coherent radars (Fabry et al. 1997; Fabry 2004; Fabry 2006) but European weather radars are mostly equipped with non-coherent magnetron transmitters, for which the phase of the transmitted pulse is random, and the frequency can drift over time, mainly due to temperature variations. Previous studies give an analytical expression of the refractivity measurement by a non-coherent drifting frequency magnetron radar (Boudjabi and Parent du Châtelet 2009; Boudjabi et al. 2011). However, the measurement of radar refractivity remains sensitive to phase ambiguities, which can cause significant measurement errors. These sensibilities to the phase aliasing are directly linked to the radar frequency, to the range integration between the radar and the ground target, and to the time sampling of the radar (Besson et al. 2011).

The main objective of Météo-France is to evaluate the capacity of their radar Operational Network (ARAMIS) to perform a good refractivity measurement. Indeed, the network is heterogeneous in frequency (S-, C- and X-Band), contains both analog and digital radars types, and also single or dual polarization. Moreover, the sampling cycle of each radar, due to the speed antenna rotation, is different between the oldest and the newest generation recently implemented.

In this study, refractivity measured by precipitation radars is compared with in situ measurement. This aims to identify measurement problems specifically related to the radar type. It is also investigateed the possibility of the dual polarization radars to lift the phase ambiguity, and so improve the quality of the radar refractivity measurement.

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1. PHASE AND REFRACTIVITY RELATIONSHIP

The propagation speed of an electromagnetic wave depends on the material through which it travels, and waves travel slightly more slowly through the atmosphere than in a vacuum. The ratio of the speed of light in vacuum to the speed of light in any medium is termed the refractive index *n*, which is more easily expressed as the refractivity *N* (Bean and Dutton 1968) defined as follows:

$$N = (n - 1) \times 10^6 \qquad (1)$$

which is related, at the microwave frequencies, to meteorological parameters through (Smith and Weintraub 1953):

$$N = 77.6\frac{P}{T} + 3.73 \times 10^5 \frac{e}{T^2} \qquad (2)$$

where *T* is temperature (in K), *P* is the air pressure (in hPa) and *e* is the water vapor pressure(in hPa).

Changes in refractivity along a path from the radar to a target are linearly related to phase changes of the target by

$$\Delta\Phi = \frac{4\pi f r}{c}\Delta n \qquad (3)$$

where f is the radar frequency and c is the speed of light. In addition to this dependence on the refractive index, the phase of a target is also a function of the distance from the radar, as well as the physical properties of the target itself.

2. DATA AND METHODS

In order to establish the capacity of the Météo-France radar operational network to perform a good quality refractivity measurement, it is realized a three hours experimentation on the radar of Trappes to study the impact of the antenna's rotation speed on the radar refractivity restitution. This radar is a Doppler and dual polarization C-band frequency, and allows different speed antenna rotation and pulse widths. Thus, the experimentation exploitation is based on an increase of the rotation speed of the antenna, from $6°.s^{-1}$ to $24°.s^{-1}$. This increase is realized with two different pulse widths (1 and 2µs). The usual functioning of the radar is a $6°.s^{-1}$ rotation speed of the antenna with a 2µs pulse width.

The aim of this experiment is to evaluate the impact of fast speed rotation, at different pulse width on the quality of refractivity estimate. This question is essential for the exploitation for radar operational network. Indeed, in the first hand, an increase of the speed rotation lead to decrease the time between two overpass over the same ground target, and so decrease the phase aliasing probability (Besson et al. 2011). In the other hand, the decrease of the pulse width lead to have a better space resolution, leading to have a better localization of the ground target.

The second aspect of this work is to study the possibility offer by the dual polarization to lift aliasing problems by comparison between the horizontal and vertical refractivity signatures.

3. SPEED ANTENNA ROTATION

To study the degradation of the radar restitution, the refractivity and the phase time variation are selected to evaluate the impact of the speed rotation acceleration. The nominal radar exploration is $6°.s^{-1}$ speed rotation. It is chosen to compare the speed increase PPI with this nominal PPI, and this, for the two pulse width (1µs and 2µs)

In the first step of the study, a ground target is chosen. This pixel is located at 3800 meters and 2° from the North of the radar. Figure 1 illustrates the refractivity time series (a) and the phase change time series (b).

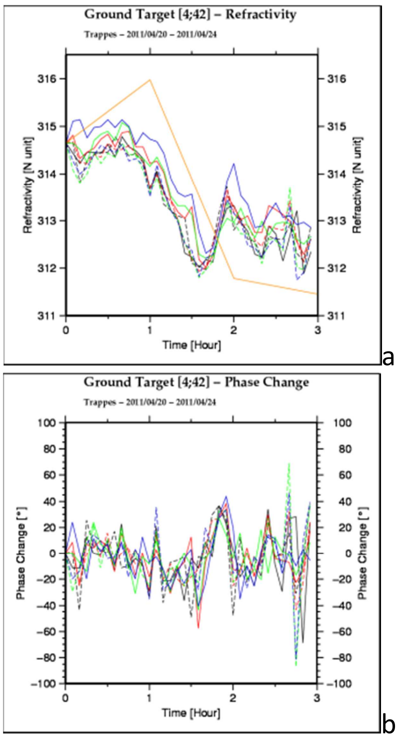

Figure 1 : Time series of the (a) the refractivity (N units) and (b) phase change (°). The solid line correspond to a 1µs pulse width, and the dashed line to a 2µs pulse width. The black, red, green and blue lines correspond respectively to a 6, 12, 18 and $24°.s^{-1}$ rotation speed of the antenna. The orange solid line (a) correspond to the insitu refractivity calculate from automatic weather station.

First of all, it can be noticed that the insitu refractivity, calculated from automatic weather station are in agreement with the radar refractivity measurement. Indeed, the strong decrease of the refractivity (from time 1 to time 2) is observed for the two datasets, and intensities of refractivity changes are in accordance.

As it can be observed on fig. 1a, the increase of the rotation speed leads to a difference lower than 0.6 N units for a 1µs pulse width, and 0.3 N units for a 2µs pulse width.

The correlation observed, for a same pulse width, between a speed rotation of $6°.s^{-1}$ and 12, 18, or $24°.s^{-1}$ are respectively equal to 0.97, 0.96 and 0.97, for a 2µs pulse width, and respectively equal to 0.94, 0.93 and 0.94 for a 1µs pulse width.

Concerning the phase change (fig. 1b), the correlation between the nominal speed ($6°.s^{-1}$) and the other speeds are always closed to 0.65 to 0.7 for a 2µs pulse width, and 0.3 to 0.5 for a 1µs pulse width. These worse correlation coefficients are normal, indeed the refractivity is the derivative of the phase change, and therefore the phase change is subject to noise.

For a ground target well define, these observations confirm that the rotation speed does not have an impact on the quality of the refractivity measurement by radar.

To extend these observations, it is decided to perform this work on a larger pool of ground target. The selection of ground target is based on phase stabilities during the three hour experiment. A ground target is selected when the probability to have a phase variation between successive measurements separated by 5' intervals, lower than 90° is higher than 99% (not shown). This criterion leads to select a pool of about 5000 ground targets around the radar.

On this pool of ground targets, it is calculated a Nash-Sutcliffe coefficient (Nash and Stucliffe 1970), between the nominal speed and the increasing speed. These coefficients are summarized in table 1 and 2, respectively for the refractivity and phase change time series.

Table 1 : Nash- Sutcliffe coefficients obtain for the refractivity time series.

	$6°.s^{-1}$	$12°.s^{-1}$	$18°.s^{-1}$	$24°.s^{-1}$
2µs	1	0.99999994	0.99999988	0.99999976
1µs	1	0.99999994	0.99999988	0.99999982

Table 2 : Nash- Sutcliffe coefficients obtain for the phase variation time series.

	$6°.s^{-1}$	$12°.s^{-1}$	$18°.s^{-1}$	$24°.s^{-1}$
2µs	1	0.99999917	0.99999797	0.99999768
1µs	1	0.99999905	0.99999857	0.99999797

As previously, the impact of the speed antenna can be totally neglected on the refractivity, as well for a 1µs pulse width as for a 2µs pulse width.

Moreover, the impact of the speed observed on the phase change for a particular ground target, can be also neglected for the pool of selected data.

It can therefore be assumed that, in order to decrease the sampling time for the refractivity, the rotation speed of the antenna could be increased. This decrease of the sampling time will lead to reduce the phase aliasing rate, and increase the quality of the restitution of the refractivity measurement.

4. DUAL POLARIZATION

The dual polarization of precipitation radar could be a useful information for solve phase aliasing problems. Indeed, if only one polarization (horizontal or vertical) is impacted by a phase aliasing, the second polarization could be used in order to improve the restitution of the refractivity measurement.

The first step, in order to describe and establish the usefulness of the dual polarization, is to compare the behavior of the two radar polarizations. Figure 2 illustrated the percent of vertical phase change lower than [-90°; 90°] in function the percent of horizontal phase change lower than [-90°; 90°] for ground targets observed during three days.

The correlation coefficient between the two different polarizations is R=0.94. However, it can be observed a difference between radar polarizations. So, for a chosen ground pixel, the behavior of the vertical or horizontal polarization may be not strictly similar.

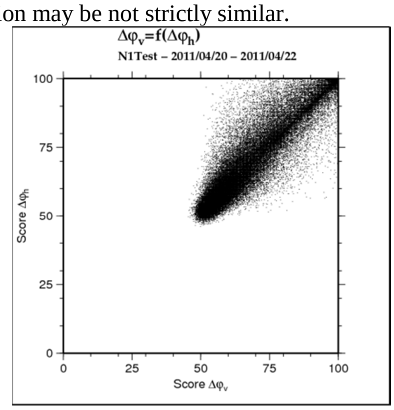

Figure 2 : Vertical phase change in function of the horizontal phase change.

To confirm the previous purpose, it is chosen to illustrate (Fig. 3) the time series of the radar refractivity restitute from the horizontal (red solid line) and vertical (blue solid line) polarizations.

As it can be observed, the two radar refractivities are confounded from the beginning of the time series to the step 12. At this time, refractivities are not confounded until to the end of the time series. It can be supposed that at this time an aliasing problem occurred and biases the horizontal or/and vertical refractivity restitution.

This observation is confirmed by the Figure 4, illustration of the phase change time series for the two refractivities. Indeed, the two curves are confounded except at time 12. The first difference corresponds to the divergence between the refractivity restitution. Indeed, both phase changes are closed to 180°, and so are probably biases by an aliasing problem.

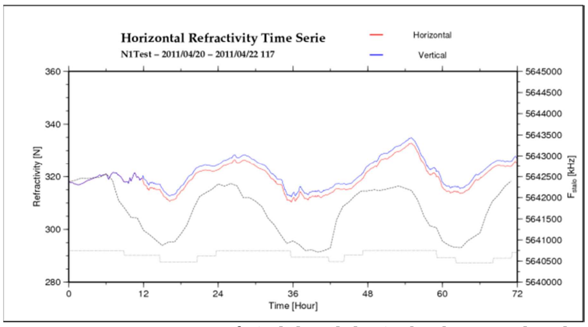

Figure 3 : Time series of (solid red line) the horizontal radar refractivity, (solid blue line) the vertical radar refractivity, (solid black line) the insitu refractivity. The dash black line corresponding to the local oscillator frequency.

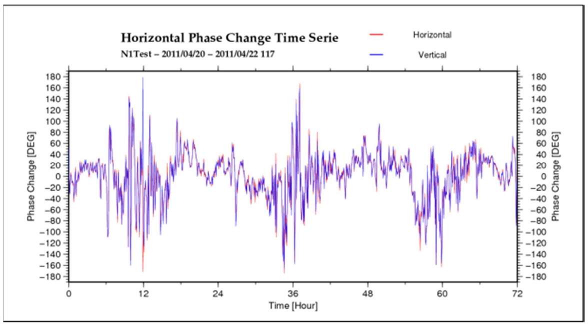

Figure 4 : Time series of (solid red line) the horizontal phase change and (solid blue line) the vertical phase change.

5. CONCLUSION

Measurement of the radar phase leads to an estimation of meteorological parameters through the measurement of the refractivity. The present study describes the possibility to improve the radar measurement.

The first main issue was to establish the pertinence of the increase of the radar antenna rotation speed in order to avoid or decrease phase aliasing problems. Phase aliasing problems increase with the radar frequency (perceptible in the S-band, serious in the C-band and more serious in the X-band). Indeed, the time sampling is the principal factor able to decrease these problems.

It is illustrated in this study that the antenna speed antenna does not have any impact on the restitution of the refractivity measurement. Thus, the increase of the speed rotation can be implemented, in order to decrease the time between two measurements, and so decrease the probability to have a measurement biased by an aliasing problem.

Concerning the dual polarization, this study highlights the possibility to use this technology in order to correct some aliasing problems. Indeed, horizontal and vertical polarizations measure the same fluctuation of the atmosphere, but, are not identically impacted by these fluxes, and by the shape of the ground target. Then a difference can be observed on the phase change between the two polarizations. Thus, if the differences between the two phase changes are higher than π, it can be advanced that almost one of the two polarizations is impacted by an aliasing problem.

This work need to be improved, principally in the identification of phase aliasing problem, and also in the selection of the polarization used to correct the aliasing problem.

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