Improvements of the Doppler measurements quality inside
the French radar network and experimentation of a national
low levels wind shear mosaic

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Abstract

The French operational radar network ARAMIS consists in 24 radars (8 S-band and 16 C-band), among which 23 are equipped with a staggered triple-PRT Doppler scheme [1] allowing to solve the range–velocity dilemma. The Doppler observations are assimilated operationally in the French numerical weather prediction (NWP) model, AROME. They are also used to produce wind profiles above the radars (VAD wind profiles) and to retrieve 3-D wind fields [2] in areas with sufficient radar overlapping.

In 2009, a major study was carried out to evaluate and improve the quality of Doppler measurements [3]. It was shown that the amount of spurious velocity data was particularly important in both strong convection and clear air situations. Results of this study have however shown that this problem could be solved by increasing the pulse repetition frequencies (PRF) of the radars. This new Doppler scheme, which will be soon deployed within the entire operational network, will allow collecting better quality Doppler velocities in all weather conditions.

More accurate radial velocities will allow for a better identification of small scale phenomena such as wind bursts, convergence lines, or mesocyclones. Different simple algorithms that provide an estimation of the strength of the low-level wind-shear have been defined and tested on simulated data and on individual radar systems.

A nation-wide low level (<\approx1500 m) wind-shear indicator mosaic is also currently tested and will be produced in real time for demonstration by the Summer of 2010.

1. Improvement of the Doppler measurements quality inside the French radar network

Staggered pulse repetition time (PRT) schemes are known for their ability to solve the long-lasting range–velocity dilemma [4]. In 2005, a triple-PRT (Pulse Repetition Time) Doppler scheme was introduced in the French operational network [1] with the objective to provide dealiased radial velocities (up to 60 m s⁻¹) up to 250 km and the constraint to keep the mean PRT at the same initial level (1/333 Hz for C-band radars). To evaluate the quality of this new triple-PRT scheme, we estimated the Dealiasing Success Rate (DSR). This value is the percentage of pixels that are correctly dealiased on a radial velocity image. It is calculated as follows:

- First a median filter (5 by 5 km) is applied to the radial velocity image. This filtered velocity is assumed to be the reference.
- Then, a pixel of the original radial velocity map is qualified as an “error” if the absolute difference between its value and the corresponding filtered velocity value is higher than the Nyquist velocity associated to the maximum PRF ($V_N$).
- The DSR is equal to: (number of pixels – number of errors)/number of pixels.
- The Cartesian 1 km² radial velocity PPIs produced with the triple PRT Doppler scheme have a DSR of about 90% in average but 4 years of operations have shown that the DSR can be much less (60%) in clear-air or convective situations (cases of low-SNR and / or large spectrum widths).
A major study was carried out in 2009 to evaluate and improve the quality of the Doppler measurements by reducing the rate of dealiasing errors.

Tests of increased PRFs (mean PRF increased from about 330 Hz to 470 Hz for the recent C-band radars, 330 Hz to 350 Hz for the old C-band radars and 260 Hz to 400 Hz for Nîmes S-band radar) and reduced Nyquist extended velocity (V_{NE}) from 60 to roughly 45 m.s\(^{-1}\) have been performed on all types of radars inside the network.

These tests have demonstrated a slight increase in the DSR for the old C-band radars (by about 5%). The reduction of the rate of wrong measurements with the new configurations is a lot more significant (at least 15%) for the recent C-band radars and for Nîmes S-band radar.

For example, the DSR changed from 83% to 98% from the current mode to the new proposed mode on a convective case observed by the S-Band Nîmes radar (see FIG. 1).

FIG. 1. Radial velocity images with two different PRFs modes. Left : low PRFs (17% errors). Right: high PRFs (2% errors). Nîmes radar at 2.4°. 20090715 at 0000 UTC. The circles are at 100 km and 200 km from the radar.

The new configuration will be progressively introduced operationally from mid-2010.

2. Wind-shear algorithms

Better velocity measurements will allow to better detect small scale phenomena like shear lines, convergence. We decided therefore to test different wind-shear algorithms from the Cartesian (1*1 km) operational radial velocity PPIs. Then, a wind-shear mosaic algorithm was chosen and evaluated.

2.1 Cartesian, radial and azimuthal wind-shear algorithms

These algorithms were applied to the radial velocity after elimination of ground clutter and after a median filtering of at least 5*5 km: the filtered velocity is equal to the median velocity inside a 5*5 km square around the pixel. The calculation is done only if at least 1/3 of the pixels inside the square are available.

For individual radial velocity PPI we calculated:

- a “Cartesian” wind-shear:
  For each Cartesian pixel (1*1 km), its value WS (m/s/km) is obtained from equation (2)
  \[
  WS = \max \left( |V(N) - V(S)|, |V(E) - V(W)| \right) / 2
  \]
  \[\text{(2)}\]
  were N, S, E, W are the Northern, Southern, Eastern, and Western pixels.

- “Radial” and “azimuthal” wind-shears:
  
  For each Cartesian pixel (1*1 km),
  - the azimuth \(\alpha\) and range \(r\) are computed and the nearest polar pixel inside a (1°, 1 km) resolution grid is identified
  - the values of the polar pixels \(V(\alpha, r+1), V(\alpha, r-1), V(\alpha+1, r), V(\alpha-1, r)\) are deduced from the nearest Cartesian pixels
  - the “radial” wind-shear is obtained from the absolute difference : \(|V(\alpha, r+1) - V(\alpha, r-1)|\) divided by the distance between the corresponding pixels
  - the “azimuthal” wind-shear is obtained from the absolute difference : \(|V(\alpha+1, r) - V(\alpha-1, r)|\) divided by the distance between the corresponding pixels
2.2 Wind-shear mosaic algorithm

To get a global view of the wind-shear occurrence on all the country, we decided to create a mosaic from radial velocity PPIs of all Doppler radars.

The time and space resolutions were determined by:

- the aim of the product: detecting low-to mid-level (z<1500m) horizontal shear and convergence lines
- the operational scanning strategy of the radars: only the lowest elevation angles are repeated every 5 minutes.

We decided therefore to create a mosaic characterising the horizontal wind-shear from 0 to 1500 m above ground, with a 1*1 km horizontal resolution and a 5 min temporal resolution.

Three different mosaics were computed, one for each wind-shear algorithm presented in section 2.1. Every 5 minutes, the following steps are executed:

- For each available radial velocity PPI of all Doppler radars: ground clutter elimination, median filtering of the radial velocity and time synchronisation with the end of the 5 min-cycle
- Calculation of the wind-shears (Cartesian, radial and azimuthal)
- Projection of the wind-shears values inside a 3D (X,Y,Z) grid with a 1*1 km horizontal resolution (X,Y)
- Calculation of the height above ground for each wind-shear value
- For the 3 wind-shear algorithms, the final wind-shear value inside the mosaic is the maximum wind-shear among all the available values from 0 to 1500 m above ground.
- The maximum reflectivity inside the vertical column is also computed and the contours of maximum reflectivity above 35 dBZ are then plotted on the wind-shear maps.

An illustration of the radar coverage, with for each pixel, the number of available radar PPIs inside a vertical column from 0 to 1500 m above ground is given FIG. 2. Few areas are covered by more than one radar excepted in a small area in the South-Eastern part of France. The coverage is generally poor near the radars because of the ground clutter.

![Radar coverage](attachment:image.png)

**FIG. 2.** Radar coverage on 2009/10/21 at 1145 UTC: for each pixel, number of available radar PPIs (at a 5 minutes resolution) inside a vertical column from 0 to 1500 m above ground.

3. Results

3.1 Validation of the different wind-shear algorithms on simulated data

Wind fields data were simulated from the French community non-hydrostatic mesoscale atmospheric model, Meso-NH [5]. We obtained radial velocity PPIs from a radar simulator [6], the radar being simulated at Nice airport. The model was initiated from the analysis of the French non-hydrostatic regional NWP model, AROME, on 2009,
March 24th. This is a typical case of wind-shear for this area stemming from the opposition of a North-Western synoptic flow with an North-Eastern flow in the low levels (see FIG. 3).

The wind-shear is slightly visible with the radial shear algorithm (not shown here) and clearly represented by the azimuthal algorithm, as expected because the orientation of the shear is in the azimuthal direction. The Cartesian algorithm also represented well the wind-shear.

FIG. 3. Left: radial velocity (m/s) at 0.5° of elevation, with blue colors for winds towards the radar and red colors for wind away from the radar. The arrows indicate the directions of the confronting winds. Right: azimuthal wind-shear (m/s/km). Simulated data from Meso-NH model, Nice radar (cross) on 2009/03/24 at 1500 UTC.

3.2 Test of the different wind-shear algorithms on individual radar PPI data

FIG. 4. Left: radial velocity (m/s) at 0.4° of elevation with red colors for winds toward the radar, blue colors for winds away from the radar. Right: radial wind-shear (m/s/km). Trappes radar, 2009/01/19 at 1500 UTC. The black circle is at 100 km from the radar.

The wind-shear algorithms were also tested on individual radar PPI data from real radial velocity data. An example is shown on FIG. 4 for Trappes radar on a case with two parallel squall lines. All the wind-shears algorithms detected the convergence lines as illustrated with the radial wind-shear.

It appeared on another case that the Cartesian wind-shear tends to overestimate the wind-shear close to the radar because of the strong azimuthal variation of radial velocity inside the 1*1 km pixels.

3.3 Wind-shear mosaic

From all the individual PPIs of wind-shear, we built a national low-level mosaic as described in section 0. An example of the mosaic is illustrated FIG. 5 on 2010/03/30 at 0635 UTC. A convergence line (inside the white circle) is well indicated by a North-South oriented and 80 km-long band of strong radial wind-shear (over 7.5 m/s/km), ahead of a convective cell (reflectivities over 45 dBZ). For this case a 13*13 km median filter had to applied on the radial velocity because of a high false alarm rate.
The radial velocity and the radial wind-shear for the Hautmont tornado case (2008/03/08) that had caused lots of damages in the North of France are illustrated on FIG. 6. A radial velocity dipole (inside the white circle) attests the presence of a meso-cyclonic circulation in the region where the tornado was reported. A signature is also visible in the radial wind-shear.

4. Conclusion and perspectives

Several wind-shear detection algorithm have been tested in this study. Radial and/or azimuthal wind-shears are often able to identify convergence lines or to give a signature in a tornado case. However, it was sometimes necessary to adopt a 9*9 km or even 13*13 km median filter on the radial velocity to improve its quality in order to avoid the wind-shear false alarms. The quality of the operational radial velocity should be improved soon thanks to the new configurations that will be implemented this year.

The next step is the real time experiment of a low-level wind-shear mosaic planned for this summer. The wind-shear maps will be compared with:

- the local temporal variation of wind measured from ground sensors
- convergence maps built at a 15 minute temporal resolution and 2.5*2.5 km horizontal resolution from the 3D wind field product

References
