13B.5 OPERATIONAL MULTIPLE DOPPLER WIND SYNTHESIS OVER FRANCE

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1. Introduction

Although dual- and multiple-Doppler wind retrieval have been performed for more than 25 years in research mode (e.g., Chong et al. 1987), operational applications of Doppler measurements remain essentially limited to single-Doppler analyses, such as Velocity Azimuth Display analysis (VAD, Browning and Wexler 1968), or manual analysis of radial velocity PPIs (Plan Position Indicators). The main explanation for this lack of multi-radar products is principally related to the "Doppler dilemma" ensuing from the inverse relationship between the unambiguous range and the unambiguous velocity (Doviak and Zrnic 1993), which constrains most national weather services to restrict their Doppler measurements to short range (~ 100 km) in order to mitigate velocity ambiguities resulting from the aliasing of radial velocities outside of the Nyquist interval. Because the structure of most operational radar networks is characterized by extensive (~ 200 km or more) radar baselines, the Doppler dilemma thus negatively impacts on the size of overlapping areas where airflow can be successfully reconstructed and does not allow for adequate dual- or multiple-Doppler wind synthesis. Thanks to recent advent of multiple-PRT (pulse repetition time) schemes, which have been successfully tested and deployed within operational radar networks (Tabary et al. 2006; Torres et al. 2004), it has however become possible to bypass this limitation and to achieve extensive Doppler coverage while keeping velocity aliasing at a marginal rate. This achievement brings new perspectives in terms of operational Doppler measurement exploitation, including the ability to routinely retrieve 3D airflow in cloud systems in a fully operational framework.

Since November 2006, real-time analysis of multiple-Doppler data collected by the French operational radar network are performed and evaluated over the greater Paris area using the well-established MUSCAT (multiple-Doppler synthesis and continuity adjustment technique) algorithm initially proposed by Bousquet and Chong (1998). The resulting 3D wind fields, which permit to continuously map the dynamic structure of rain events at multiple scales, are being archived to build a weather database. The aim of this study is to present and evaluate examples of such real time analyses that were performed during 2007 winter and spring seasons in various (both stratiform and convective) weather conditions.

2. The French radar network

The French operational weather radar network, named ARAMIS (Application Radar a la Météorologie Infra-Synoptique), was built in the early 90's for rain detection purposes. In 2002, an upgrade program, called Programme Aramis Nouvelles Technologies en Hydrometeorologie Extension et Renouvellement (PANTHERE), was initiated in partnership with the French Ministry of Environment to densify this network (Parent et al. 2003) and implement Doppler and dual-polarimetry capabilities. As of today, 7 new Doppler radars have been installed, 2 have been replaced, and a numerical receiver has been developed to dopplerize the older radars. By the end of 2007, the network will comprise 24 Doppler radars (Fig. 1) covering about 95 % of the French territory with radar baselines ranging from ~180 km in the northern part of the country down to less than 60 km in the southern part. The triple-PRT scheme proposed by Tabary et al. (2006) is operationally deployed within the entire network yielding an extended Nyquist velocity of ~ 60 $m.s^{-1}$ up to a range of 250 km.

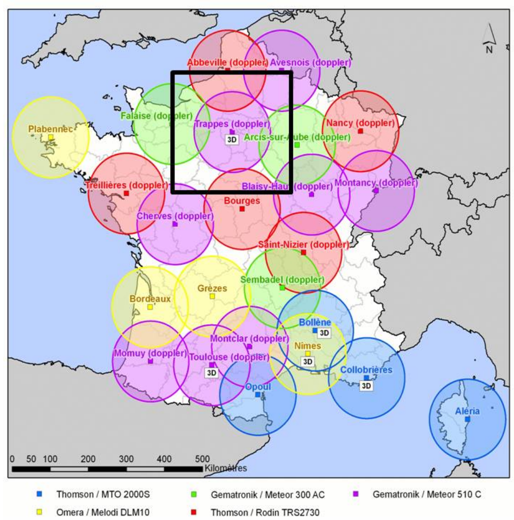

Figure 1: Map of the French radar network as of December 2006. Label "3D" indicates radars that use a volumic operation mode. The 100 km range of measurement is shown by circles. Colors indicate the kind of radars. The square indicates the approximate location of the 320 x 320 km^2 used for operational 3D wind retrieval.

3. Experimental setup

We consider a Cartesian domain measuring 320 km x 320 km x 12 km centered on Trappes C-band polarimetric Doppler radar that is located ~ 30 km to the southwest of Paris city (Fig. 1).

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Table 1. Elevation angles (°) used in the current scanning strategy for all radars.

Tilt N°	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Trappes	90	7.5	0.8	1.5	4.5	0.4	9.5	6.5	0.8	1.5	3.6	0.4	8.5	5.5	0.8	1.5	2.5	0.4
Arcis	4.0	1.1	0.4	-	-	-	3.0	1.1	0.4	-	-	-	2.0	1.1	0.4	-	-	-
Falaise	1.6	1.1	0.4	-	-	-	Previous cycle repeated						Previous cycle repeated					
Abbeville	0.4	1.1	0.4	-	-	-	Previous cycle repeated						Previous cycle repeated					
Avesnes	1.6	1.0	0.4	-	-	-	Previous cycle repeated						Previous cycle repeated					

Table 1: VCP of the 5 radars covering the greater Paris area. A super cycle (18 tilts) is composed of three 5' cycles (6 tilts).

As of today, this area is also covered by 4 additional C-band Doppler radars respectively located at Arcis, Falaise, Abbeville, and Avesnes (Fig. 1). The average distance between Trappes radar and each of these 4 radars is ~180 km. The vertical resolution of the domain of analysis is set to 500 m. The horizontal resolution is set to 2.5 km to be consistent with unavoidable smoothing inherent to radar beamwidths and baselines of ~1° and ~180 km, respectively. The detailed radar coverage within this experimental domain is shown in fig. 2. All radars perform a complete volume scan in 15 minutes (a supercycle) according to the operation mode demonstrated in Table 1. Except for the Trappes radar, the current VCP consists in 2 to 5 elevation angles and is radar specific.

Data consist in operational PPIs of Doppler velocity and reflectivity projected on a 1 km^2 Cartesian grid, which are synchronized with respect to the ending time of the current 15' supercycle to account for the non-simultaneity of measurements. Spurious reflectivity and radial velocity data are removed using a threshold on the pulse-to-pulse fluctuation of the reflectivity and a 5x5 km² median filter, respectively. Once pre-processed, data are interpolated into the retrieval Cartesian grid using a fixed horizontal influence radius of the Cressman weighting function R_H of 3 km and a variable vertical radius of influence R_V equal to 1° (beamwidth of the ARAMIS radars). In this configuration, R_V varies as a function of range so that the search for data points extends farther out at long range compared to short range. At long range, this also allows to indirectly take into account the lost of resolution resulting from beam broadening. Once interpolated, data are ingested in the MUSCAT analysis (Bousquet and Chong 1998; Chong and Bousquet 2001).

4. Example of operational wind synthesis

A qualitative evaluation of the multiple-Doppler winds reconstructed in this operational framework is provided through the analysis of radar data collected within two weather events observed in February and May 2007.

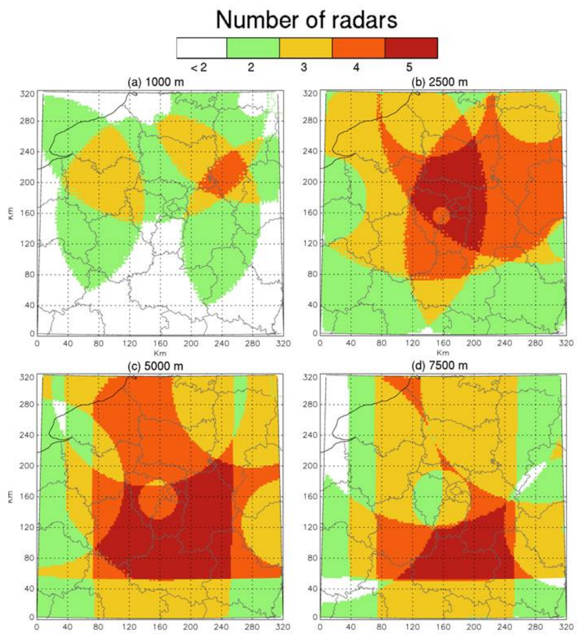

Figure 2: Doppler radar overlapping at various heights within the experimental domain shown in Fig. 1

The first case consists in a long lasting frontal precipitation event that crossed the French territory on 14 February 2007. This system, which produced continuous rainfall over Northern France for about 24 hours, was consistently sampled by all 5 radars covering the greater Paris area. Reflectivity and wind direction at 2 km MSL, as inferred from the analysis of radar observations collected at 06:00, 11:00, and 14:00 UTC are shown in Fig. 3.

During the first 12 hours, the situation remained fairly stable and was characterized by moderate precipitation developing in a relatively uniform southwestly flow (Fig. 3a). Around 11:00 UTC (Fig. 3b), a distinct flow regime appeared in the northwestern part of the domain as winds rapidly turned to north-westerly. This change corresponds to the arrival of a cold front within the domain of analysis. By 14:00 UTC (Fig. 3c), the front has progressed eastward, resulting in the expansion of

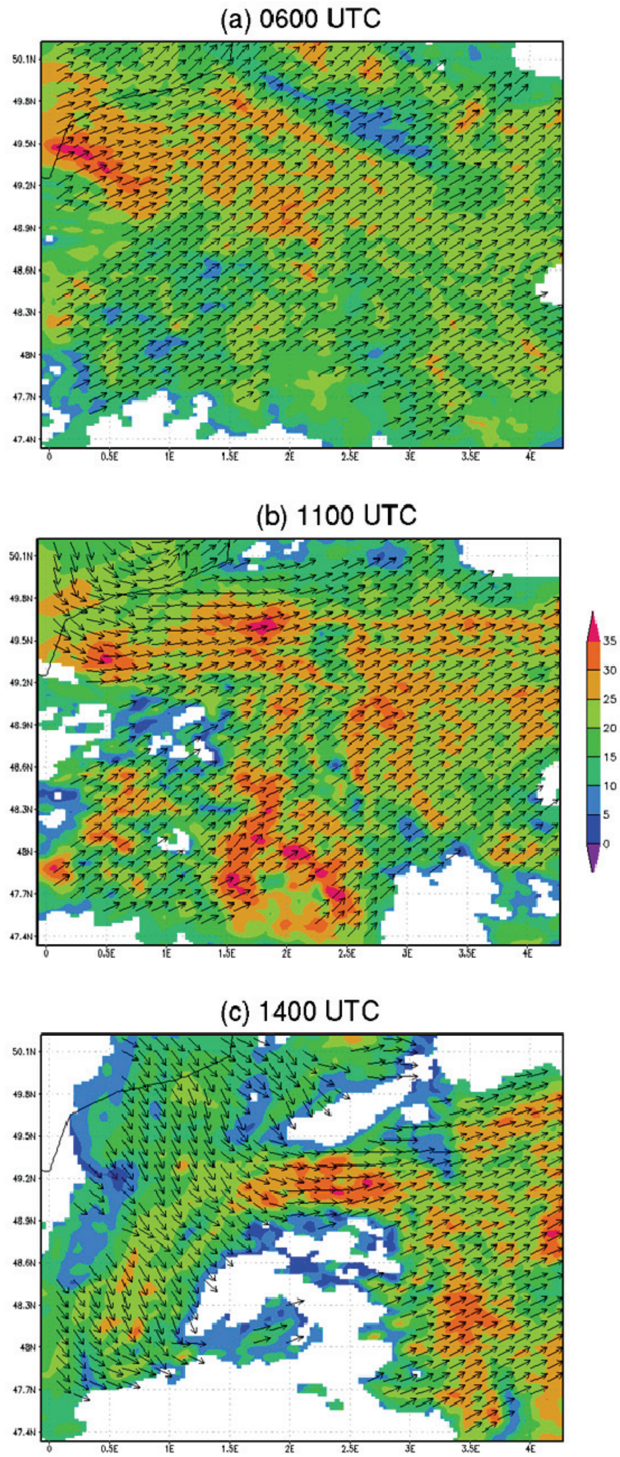

Figure 3: Wind direction (vectors) superimposed on radar reflectivity (shaded) at 2.0 km MSL within the experimental domain shown in Fig. 1, as derived from multiple-Doppler analysis of radar data at (a) 06:00 UTC, (b) 11:00 UTC, and (c) 14:00 UTC on 14 February 2007. One every fourth vector is plotted.

northwesterly flow over half of the experimental area. By 16:00 UTC (not shown), the front has crossed the domain of analysis and northwesterly could be observed within the entire domain. Although detailed observations of the kinematic structure and evolution of a front by the means of research radars have already been performed in the context of fields experiments this is the first time that similar observations are performed in a fully operational framework. A comparison between the wind fields reconstructed during this event and high resolution model outputs can be found in Bousquet et al. (2007).

The second event consists in a severe hail storm that hit Paris city on 4 May 2007 and significantly disrupted air traffic control at Paris' Charles de Gaulle and Orly airports. Figure 4 presents the reconstructed airflow superimposed on the reflectivity at 1.5 km MSL, as inferred from the analysis of radar data collected between 1600 UTC and 1900 UTC. The reflectivity structure shows several intense convective cells characterized by reflectivity values up to 55 dBZ developing in a somewhat uniform northeasterly flow (Fig. 4b). Of particular interest is the observation of both the mature (Fig. 4a-b) and dissipative (Fig. 4c-d) stages of the cells. Figure 5 that shows the associated retrieved vertical velocity at 1700 UTC (Fig. 5a) and 1800 UTC (Fig. 5b) reveals the existence of well-defined updrafts in the order of a few $m.s^{-1}$ ahead of the most intense cells. These results are in good agreement with many conceptual models and previously documented airflow structure within convective systems.

5. Conclusions

Thanks to the recent deployment of a new multiple-PRT scheme within the French radar network ARAMIS, it has become possible to defeat the long lasting 'Doppler dilemma' and to achieve extensive Doppler coverage while keeping Doppler velocity aliasing at a marginal rate. This ability to collect Doppler measurements at long range brings new perspectives in terms of exploitation of operational Doppler measurement, including the ability to routinely retrieve 3D airflow in an operational framework. In this context, an ongoing experiment has been set up in late 2006 to derive real-time multiple-Doppler winds over Northern France in a totally automated way. The potential of these operationally-synthesized wind fields has been briefly evaluated using data collected during both a long lasting frontal precipitation event and a severe hail storm. We showed that information inferred from these wind fields can be definitely relied upon to achieve consistent mapping of the dynamic structure of rain events at multiple scales, as well as to easily spot key flow features, such as convergence or wind shifts, whose detection present a strong interest for short term forecasting and model verification (Bousquet et al. 2007). Of particular interest was the ability of the wind retrieval algorithm to generate both realistic convergence and upward motions, whose detection presents a major interest in terms of forecasting applications.

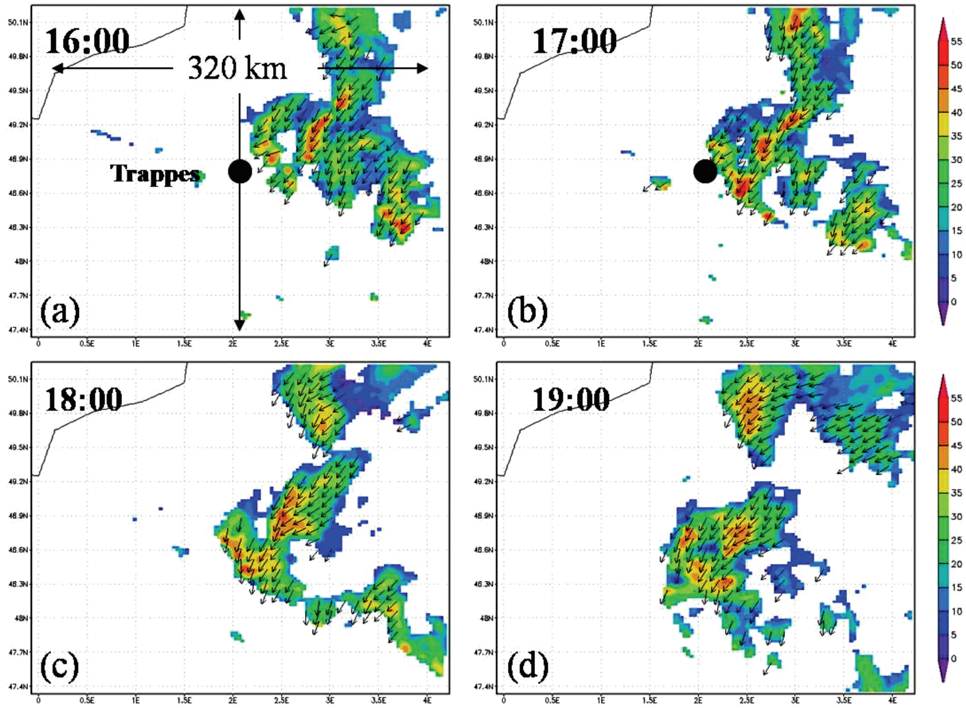

Figure 4: Wind direction (vectors) superimposed on radar reflectivity at 1.5 km MSL at (a) 1600, (b) 1700, (c) 1800, and (d) 1900 and, within the 320x320 km^2 experimental domain shown in Fig. 1, as derived from multiple-Doppler analysis of radar data at 17:15 UTC on 4 May 2007. One every fourth vector is plotted.

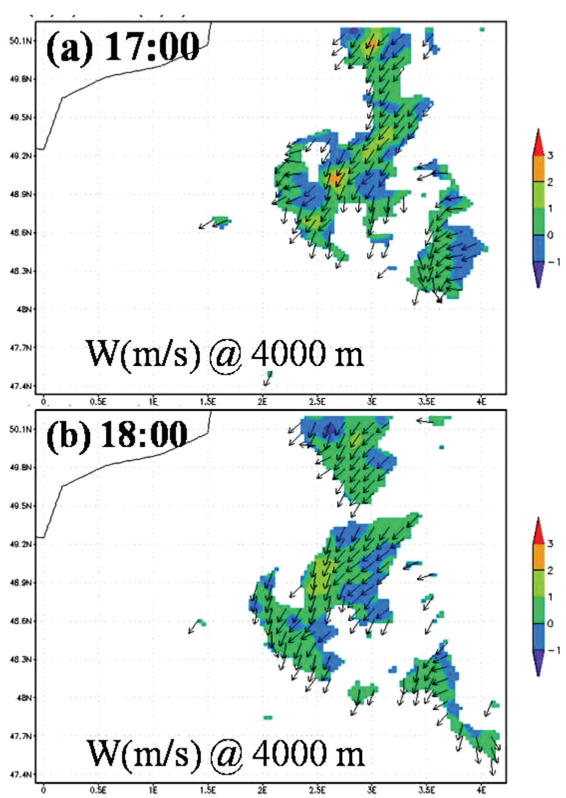

Figure 5: As in Fig. 4 except for retrieved vertical velocity at (a) 1700 and (b) 1800 UTC

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