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A radar-model coupled approach to produce real time high resolution 3-D wind fields over Paris' major airports in the context of the FLYSAFE Project.

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1 Introduction

The French operational radar network, named ARAMIS, has undergone several modifications over the past years (Parent-du-Châtelet and Guiméra, 2003). Main changes include the deployment of additional radars to fill the gaps within the coverage (bringing the total number of radars to 24 in 2006), and implementation of dual-polarization and Doppler processing into operations. Our objective is to take advantage of this extended coverage to derive real-time 3D wind and reflectivity fields from a combination of radar data and outputs inferred from a high resolution numerical model. In this analysis data from virtual Doppler radars will be simulated from the model forecast and combined with those of the ARAMIS network to retrieve the 3D airflow and quantitatively assess wind-shear, gust fronts and updrafts in the vicinity of Paris' two major airports. The aim of this paper is to investigate the feasibility of this approach by first assessing the quality of the retrieved wind fields synthesized from the ARAMIS network using radar observations and numerical outputs of a severe storm that occurred over Paris on June 23 2005. This study is part of the atmospheric component of the FLYSAFE project, which aims at supplying commercial airliners with a better knowledge of their atmospheric environment near major airports.

2 Experimental design and radar network

We consider a Cartesian domain measuring ~ 160 km x 160 km in the horizontal with 2.5 km resolution in x and y and 0.50 km in the vertical (Fig. 1). This area is centered on Trappes C-band polarimetric Doppler radar (Gourley et al., 2006), which is situated about 30 km to the southwest of Paris. It encompasses Paris' Charles de Gaulle (CDG) and Orly airports respectively located ~ 45 km to the southeast and ~ 20 km to the northeast of Trappes. This experimental domain is also covered by 3 additional Doppler radars sited at Arcis, Falaise, and Abbeville (Fig. 2). Each radar performs a complete volume scan in 15 minutes (three 5-minute cycles) but distinct scanning strategies are being used for each instrument (Table 1). Doppler velocities are retrieved following the triple-PRT scheme proposed by Tabary et al. (2006). Overall, this configuration allows for an excellent multiple-Doppler coverage of the greater Paris area (Fig. 3). Extensive regions of multiple-Doppler measurements are available between 1.5 km and 8 km altitude. Triple- and quad-Doppler measurements are achieved between 2.5 and 6 km altitude over ~100% of the domain. A major limitation of this configuration lies in the lack of coverage below 1 km resulting from large distances between radars.

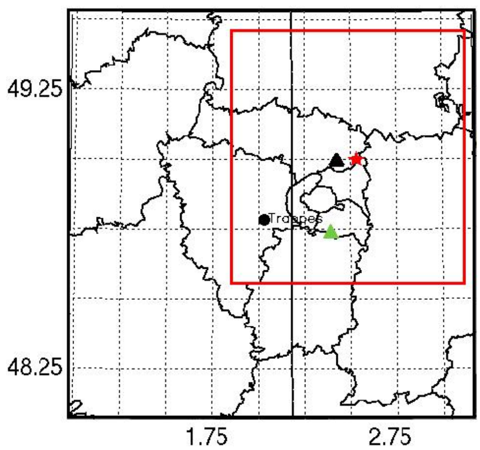

Figure 1: Experimental domain. The location of Paris' CDG and Orly airports are indicated by the red star and the green triangle, respectively. The black triangle displays the location of a virtual radar at Villiers le Bel. The red box shows a ~ 100 km x 100 km subdomain centered on CDG.

3 Data and analysis issues

About 5 hours of Doppler observations collected by the French operational radar network are used to infer the kinematic and precipitation structure of a severe storm that brought torrential rainfall and disrupted air traffic in

Table 1. Elevation angles (°) used in the scanning strategy of each radar.																		
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	4.5	0.4	8.5	5.5	0.8	1.5	4.5	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							Cycle 1			Cycle 2			Cycle 3		
Abbeville*	0.4	1.1	0.4							* the same cycle is repeated every 5 minutes								

the greater Paris area on 23 June 2005. Pseudo-Doppler observations at 1-h intervals were also derived from a numerical simulation of this event performed with the Meso-NH model (Lafore et al. 1998). A nearest neighbor interpolation of the model grid values surrounding each observation point was used to simulate the radar sampling. A virtual radar was also simulated at Villiers le Bel (15 km west of CDG airport), to investigate the impact (added value) of an extra radar on the reconstruction of the low-level airflow (Fig. 1).

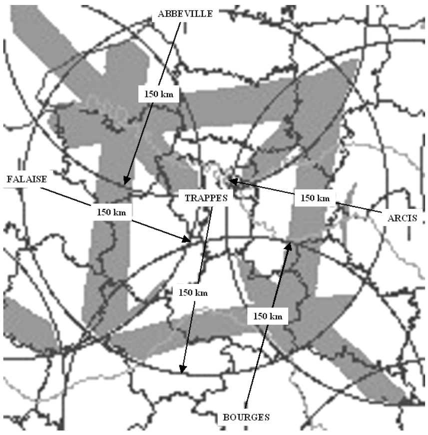

Figure 2: Location of the radars of the French Aramis network around Trappes. The Bourges radar, which is not yet Dopplerized, is not used in this study. Large grey bands indicate the regions where radar inter-comparisons are performed on a daily basis.

Both real and pseudo Doppler data are interpolated in the Cartesian grid and ingested in the MUltiple-Doppler Synthesis and Continuity Adjustment Technique (MUSCAT) analysis developed by Bousquet and Chong (1998). MUSCAT embodies a fully variational approach that allows for the simultaneous solution of the three Cartesian wind components via a global minimization, in a least-squares sense, of an ensemble of three cost functions that represent (1) an optimal least-squares fit of the observed radial Doppler velocities to the derived wind component, (2) a least-squares adjustment with respect to mass continuity, and (3) a second-derivative constraint to minimize small-scale windvariations (i.e. noise). This methodology eliminates

the main drawbacks of iterative techniques commonly employed in multiple-Doppler analysis of airborne and ground-based radar observations, and allows wind information to be reliably extracted in regions along the baseline connecting a pair of ground-based radars (Chong and Bousquet, 2001). Finally, synthesized reflectivity and component airflow fields are subject to a two-pass Leise filter to further eliminate poorly-resolved small-scale features.

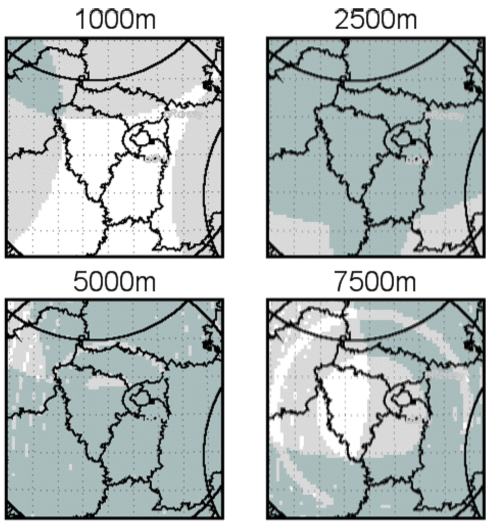

Figure 3: Doppler coverage as a function of height. Shading indicates dual-Doppler (grey, only 2 radars) and multiple-Doppler (green, >2 radars) areas.

4 Evaluation of the method

4.1 Real data analysis

Figure 4 presents the horizontal wind and reflectivity fields as inferred from the analysis of data collected on 23 June 2005 at 15:30 (1500m, Fig. 4a) and 16:30 (2500m, Fig. 4b). At 15:30 an eastward propagating convective line oriented NW to SE and characterized by reflectivity values up to 60 dBZ was observed above Trappes radar. A large growing cell was also observed ~50 km ahead of the main line to the SE. The associated retrieved circulation shows a strong SW'ly flow ahead of the line and W'ly to NW'ly winds behind. Farther upstream the air was apparently forced to flow around the growing updraft associated with the isolated cell that developed SE of Paris. At 17:00 (Fig. 4b), the line of thunderstorms has entered its dissipating stage but embedded convection still occurred in the northern and southern parts the domain. Many small scale structures including locally strong convergences could be observed in the wind field as a result of the interactions between the decaying convective line and new growing cells. Overall, these results show that despite the relatively coarse sampling ensuing from both the limited exploitation modes and large distances between radars, one can retrieve the detailed characteristics of extreme events from the French operational radar network.

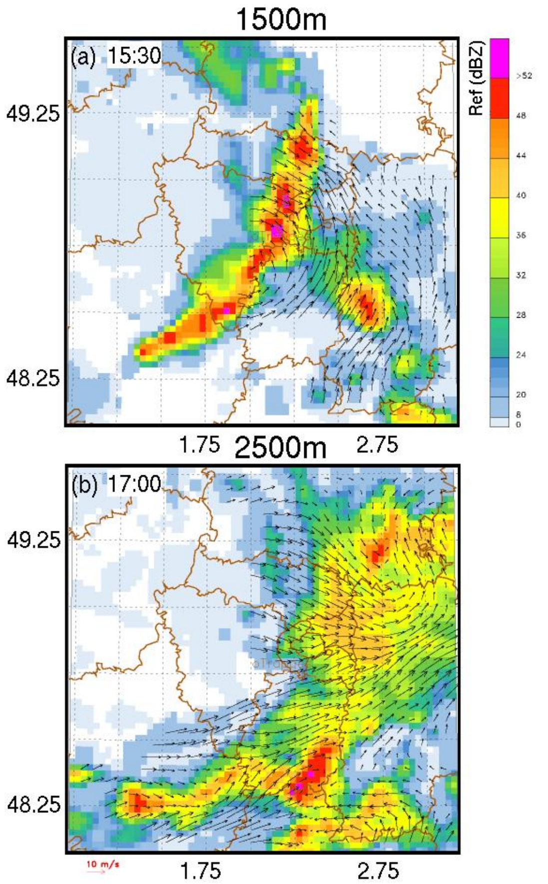

Figure 4: Multiple-Doppler radar analysis of airflow (vectors, key at lower left) and radar reflectivity (key at far right) on 23 June 2005 at (a) 3:30 PM and 1.5 km MSL and (b) 5 PM and 2.5 km MSL within a 160km x 160km domain centered on Trappes radar (48.8N, 2E).

4.2 Numerical data analysis

In order to further evaluate the potential of the retrieval method, a 3D wind field was reconstructed from the virtual sampling of the Meso-NH simulation. A first wind synthesis was performed from the 4 Doppler radars of the ARAMIS network (Fig. 2). A second analysis was also conducted using an additional, virtual, radar located at Villiers le Bel (Fig. 1). Figure 5 presents both the reconstructed (Fig. 5a) and simulated (Fig. 5b) wind and reflectivity fields at 2.5 km MSL at 5PM corresponding to the first analysis (the two-pass Leise filter applied to the synthesized wind field was also applied to the model data). According to these horizontal cross-sections the method seems able to reproduce the simulated wind field with imperceptible discrepancy. Note that except for a strong fetch of SW'ly flow in the southern part of the domain, the modeled flow and precipitation patterns (Fig. 5b) exhibit considerable differences with those deduced from radar observations. These large differences were observed at all times. Although we do not expect the model to generate convection at the time and location it actually occurred, the magnitude of the differences between the model and the radar-derived airflow prevent us from merging these two datasets, as initially planed.

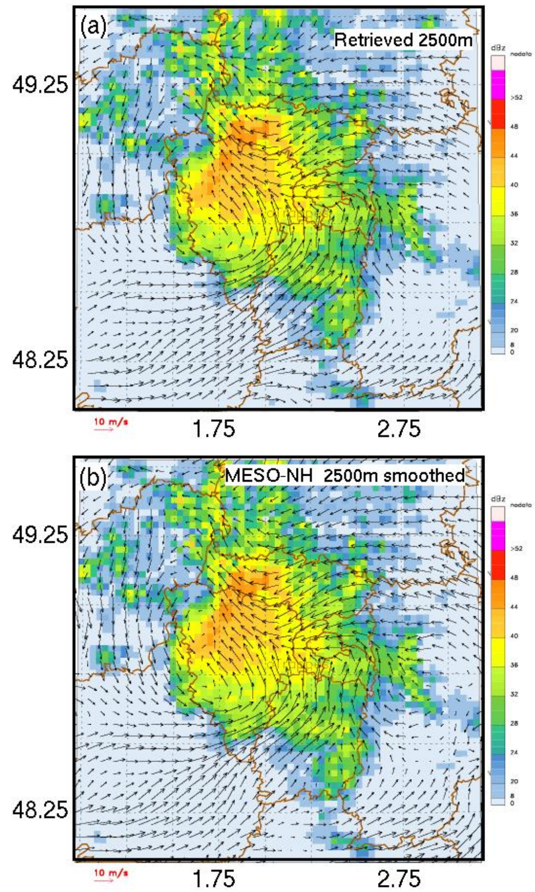

Figure 5: Horizontal cross-sections of the flow and reflectivity structures at 5 PM and 2.5 km MSL as deduced from MUSCAT (a) and numerical modelling (b).

To quantitatively assess the quality of the retrieved airflow, vertical profiles of the mean and standard deviation of the differences between synthesized and simulated wind components were constructed for the sub-domain CDG shown in Fig. 1. The comparison of these profiles shows the effective performance of MUSCAT, which provides extremely stable results. Errors in the three components are quite comparable in magnitude: between 1 km and 8 km MSL mean values are less than 0.5 m s^{-1}, while standard deviations remain within 1 m s^{-1}. The impact of the additional radar (plain lines vs. dotted lines) is particularly significant at the lowest and highest levels, i.e., in regions where only single- or dual-Doppler observations are operationally available.This virtual radar allows covering ~ 60% of the domain at 500 m MSL (vs. no coverage) and ~90% at 1 km MSL (vs. 50%, Fig. 6c). Below 1 km MSL the results

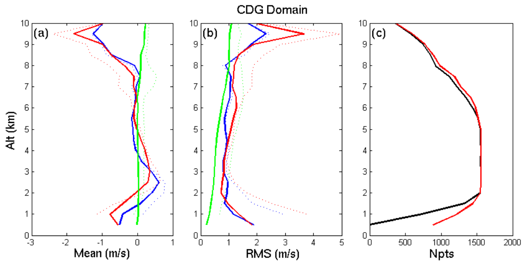

Figure 6: Height profiles of the mean (a) and standard deviation (b) of the differences between synthesized and simulated u (blue), v (red), and w (green) components of the wind within the sub-domain CDG shown in Fig. 1 with (plain curve) and without (dotted curve) the virtual radar. (c) Number of resolved grid points with (red) and without (black) Villiers radar.

are poorer in the 4-radar configuration but are dramatically improved when the extra radar is used. Figure 7 presents a meridional cross-section of the airflow along latitude 2.20°E (slightly east of Trappes, Fig. 1). In the 4-radar configuration (Fig. 7a), the method is able to flawlessly reconstruct the vertical wind shear simulated by the model (Fig. 7b) but the low-level convergence cannot be captured due to the lack of radar coverage near the ground. The addition of the (virtual) Villiers radar (Fig. 7c) allows to successfully bypass this limitation and to further improve the quality of the synthesis at mid-levels thanks to the better depiction of the low-level boundary conditions. Overall, these outstanding results attest of the ability of the algorithm to retrieve the complex air circulation associated with severe storms.

5 Summary and discussion

Using real and simulated data we have shown that it was possible to reconstruct the detailed 3D airflow within severe convective systems from the French operational radar network. We have also shown, however, that the radar configuration in the greater Paris area does not allow capturing the low-level convergences generally associated with severe storms due to the lack of coverage in the lowest layers. While this limitation could be easily bypassed by the mean of an extra radar, the addition of a new instrument near Paris city is not planned for the near future. Another way to avoid this limitation is to simulate a virtual radar from a model forecast and to combine these data with those of the ARAMIS network to retrieve the 3D wind structure at high spatial and temporal resolutions. In order to improve the match between the model and radar data the forecast can be corrected for eventual phase errors through shifting of the precipitation and velocity fields, which maximizes the cross correlation between radar and model data (Bousquet et al., 2006). Although such corrections may help to achieve a better agreement between the radar and model data, the initial quality of the forecast remains critical. For instance, the magnitude of the differences between the model simulation and the radar observations used in this study definitely prohibited us from applying this approach, as it would have resulted in unrealistic composite wind fields. Météo-France's new high resolution operational model for short term forecasting AROME (Ducrocq et al., 2005), which will soon assimilate radar velocity and reflectivity data, should provide realistic forecasts that could be used to evaluate this new approach. First applications of this method based on outputs from a development version of AROME will be shown and evaluated during the conference.

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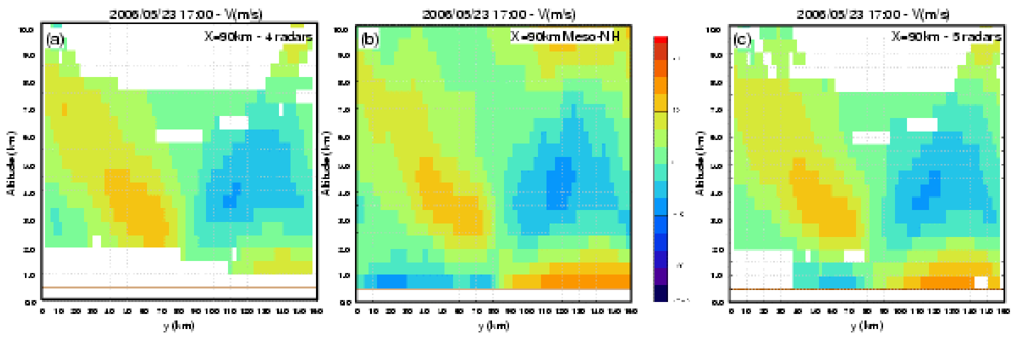

Figure 7: Meridional cross-section of airflow (m/s) along longitude 2.20°E (cf. horizontal projection of the section in Fig. 1b). (a) 4-radar configuration, (b) Reference (Meso-NH), (c) 5-radar configuration.