High resolution numerical modeling of low level wind-shear over the Nice-Côte d'Azur airport

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1. Introduction

Detection and prediction of hazard weather phenomena occurring at sub-kilometric scale in the boundary layer (e.g. wind shears, micro-bursts, turbulence) have a particular importance for the security and the control of air traffic when they take place in the surrounding of large airports. Currently, the observational meteorological network and the operational numerical weather prediction models do not have the spatial and temporal resolutions necessary to observe and forecast them precisely. As a consequence, dedicated measuring systems such as wind lidars and wind profilers have been installed on airport platforms to detect wind shear events. Unless a large number of instruments can be installed at a given location, the detection of hazard phenomena cannot be performed without combining available observations with other sources of information. For example, at Hong-Kong and Juneau (Alaska) international airports (Morse et al. 2004; Lau and Choy 2005), a weather hazard alert system has been designed based on a climatological statistical study between weather conditions in the surroundings of the airport and a number of measurements from local sensors (anemometers, wind lidar, wind profilers). High resolution numerical modeling has also demonstrated its capability for describing complex mesoscale flows in the boundary layer influenced by orography and land/sea contrasts (Schmidli and Poulos 2006; Szeto and Chan 2006; Chan 2006). Another area of investigation in order to better constrain numerical models is the development of high resolution data assimilation systems that provide an optimal combination of information from observations and numerical forecasts. Current operational and pre-operational data assimilation systems in weather services describe horizontal scales between 2.5 and 10 km (Barker et al. 2004; Honda et al. 2005; Fischer et al. 2005). For a dedicated use at Dubaï airport, Shaw et al. (2008) installed an operational system assimilating data from satellites, radiometers, wind profilers, radar and surface observations with the Advanced research and Forecast (WRF) model (Shamarock et al. 2005) at 7 km resolution. In a recent feasibility study, Warner et al. (2007) combined multiscale data assimilation systems to describe the wind flow from the synoptic scale down to a scale of 5 m around the Pentagon building.

Our study is a preliminary investigation towards mesoscale data assimilation at high resolution (between 500 m and 2.5 km) for the detection and prediction of boundary layer weather hazards important for air traffic. It uses a mesoscale research model "Meso-NH" (Lafore et al. 1998) that has been developed in collaboration between Météo France (CNRM) and the Centre National de la Recherche Scientifique (Laboratoire d'aérologie) and used successfully to describe a wide range of mesoscale phenomena (Richard et al. 2003; Lemonsu et al. 2006; Drobinski et al. 2007). We will evaluate the capability of Meso-NH to describe wind shear phenomena that take place frequently over the Nice Côte d'Azur International airport which is located in a complex geographical environment. In Section 2 we describe the wind shear phenomena occurring in the vicinity of this airport together with the geographical domains considered for the numerical simulations. Section 3 presents the experimental set-up for a specific date of interest (12 March 2005). Results are described and compared to available observations in Section 4. Finally, conclusions and perspectives from this preliminary study are given in Section 5.

2. Wind shear phenomena over Nice airport

The Nice Côte d'Azur International Airport is the third French civil airport with an activity of 10

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millions passengers a year. It is located South of the Alps along the Mediterranean sea (French Riviera) (Fig. 1). The airport is halfway between two capes : the Antibes cape on the West and the Ferrat cape on the East where a surface weather station is installed (Fig. 1). The highest mountain in the vicinity of the airport is 1600 meters high (noted as "Greolières" in Figure 1) and it is surrounded by several hills that culminate at 800 m. The Var river valley opens on to the west side of the airport runway where a UHF Doppler radar wind profiler is installed.

This geographical configuration regularly leads to land-sea breeze phenomena. Therefore, the wind climatology over the airport is mostly oriented along a north-south axis whereas over the Ferrat cape the wind direction has a preferential west-east orientation. This represents the most frequent case of vertical wind shear over the airport: the contrast between the low level wind channeled by the Var river valley and the westwards synoptic flow. Such wind shear phenomena takes place approximately below a height of 500 m.

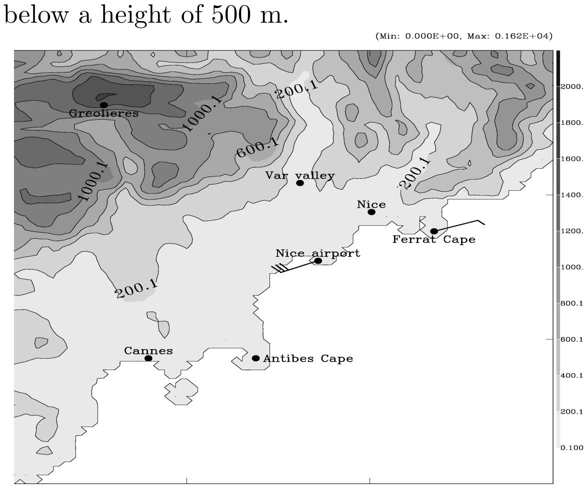

Figure 1: Orography at 0.5 km resolution (in m) in the surroundings of the Nice airport together with observed 10-m wind (in kt) at two weather stations on 12 March 2005 at 15 UTC

Horizontal wind shear situations (named "reversal wind"), taking place as a local phenomena preconditioned by the large scale flow pattern, are more difficult to detect and forecast. Two main horizontal wind shear patterns are observed at the Nice airport. The first one corresponds to a situation where the Alpine arc deflects a north-westerly synoptic flow in two branches. The first part is channeled through the Rhône valley (west of the Alps) down to the Mediterranean sea where it takes a westerly orientation, whereas the other part goes round the Alps by the East and comes out to the Mediterranean sea through the Genoa valley. The collision between these two opposite flows creates a "reversal wind" that can move from Genoa to Nice and generate a rapid wind direction change over the airport. The second phenomena (named "recirculation") takes place in the Genoa gulf under strong westerly synoptic flow over the Mediterranean sea. The flow takes a northerly direction over the Ligurian sea to circle the Apennine mountains and, prevented from penetrating the Po Valley (due to a low Froude number), turns into an easterly component. A mesoscale vortex is thus generated in the Genoa gulf that can reach Nice Airport, thereby leading to a rapid wind direction change. Numerical simulations presented afterwards are run on a meteorological situation (12 March 2005) favorable to the occurrence of this second horizontal wind shear phenomena.

3. Study and numerical simulation

The capacity of the numerical model Meso-NH to simulate horizontal wind shear situations in the vicinity of Nice airport is done for a case of "recirculation" that has been observed on the 12th March 2005. This situation was chosen from a preliminary study done at a Météo-France regional service by Bidet and Schwartz (2006). A similar case study, observed during the Mesoscale Alpine Programme (MAP) field campaign, was successfully simulated by Rotunno and Ferretti (2003). Figure 1 displays the observed 10-m wind at two stations for this day at 15 UTC when the horizonal wind shear is clearly visible. Indeed over the Nice airport there is a strong westerly flow (14 m.s^{-1}) in opposition to the easterly flow blowing over the Ferrat cape (3 m.s^{-1}). During the 12th March 2005, observations at Nice airport show two wind direction changes (Figure 3). Between 09 UTC and 10 UTC, the wind direction shifts from west to east and keeps this orientation until 15 UTC where it comes back to west. A similar wind rotation is present for each station along the Mediterranean coast from Genoa to Nice with a time lag, which means that the wind shear moves from the Genoa gulf to Nice during that day.

a. Model configuration

The simulations have been carried out with the three-dimensional non-hydrostatic model Meso-NH described in Lafore et al. (1998) and Stein et al. (2000). The model integrates a system of conservation equations based upon the anelastic formulation. The equations are integrated using 4th order centered and Piecewise Parabolic Method (PPM) temporal schemes respectively for momentum and scalars. The model contains a comprehensive set of physical parameterization schemes to describe subgrid scale processes. In particular, the turbulent scheme is based on a prognostic turbulent kinetic energy equation to diagnose eddy diffusivity coefficients with the physical mixing-length of Bougeault and Lacarrère (1989).

b. Numerical set-up

In order to represent both synoptic and fine-scale structures in the airport surroundings, a two-way grid-nesting procedure has been adopted with 10 km and 2.5 km horizontal resolutions. Such resolutions correspond to those of the current operational limited area weather prediction model ALADIN (10 km) and of the future operational (end 2008) high resolution limited area model AROME (2.5 km) at Météo-France. The nested domains are shown in Figure 2. The coarser grid is large enough to encompass synoptic systems over the entire Alpine mountain range, whereas the second grid is centered near Turin and covers the Côte d'Azur and the Genoa gulf together with the Southern Alps. The vertical grid is identical for both domains and has 60 levels stretched between 10 m near the ground to 1000 m at the top of the model domain located at 14 km high (rigid lid with an absorbing layer to prevent the reflection of gravity waves). The physical packages are the same at 10 km and at 2.5 km, except for the convection scheme that is not activated in the 2.5 km simulation. The model time steps are respectively 20 s and 5 s for the coarse and fine resolutions.

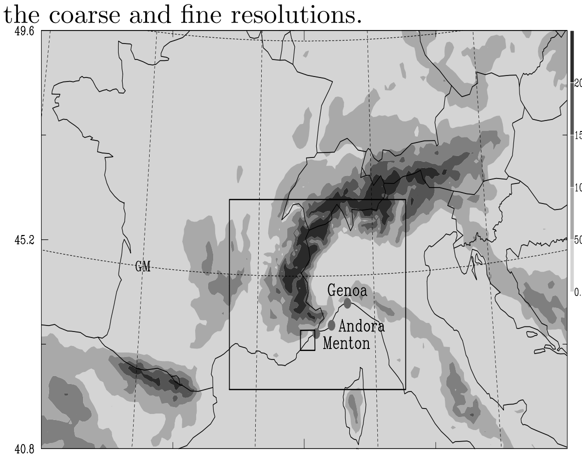

Figure 2: Domain of the 10-km simulation together with corresponding orography. The large black square represents the 2.5 km domain of simulation. The small black box corresponds to the domain shown in Figure 1.

The models have been integrated for 24 hours starting from 12 March 2005 at 00 UTC. Two sets of initial and boundary conditions were considered for the 10 km simulations. For the first set (CEPan), ECMWF analyses were interpolated to provide the initial conditions and the lateral forcing every 6 hours. For the second set (ARPan), analyses from the Météo-France global model ARPEGE were used instead.

4. Results

We first examine statistics of 10-m wind speed errors at five weather stations along the Mediterranean coast between Nice and Genoa located in Figures 1 an 2. Results are summarized in Table 1 in terms of bias (Bias) and standard deviation (Sd) for the wind speed (ff) and the wind direction (dd). The statistics have been performed using hourly or three-hourly observations for the duration of the model runs (24h) for both CEPan and ARPan initial conditions. The statistics are only presented for the 10 km model runs since they do not significantly differ at 2.5 km.

Station	Bias ff	Sd ff	Bias dd	Sd dd
Genoa (1)	0.49	0.99	43.41	23.40
Genoa (2)	0.38	1.42	23.20	28.92
Andora (1)	3.19	1.72	55.31	49.29
Andora (2)	2.42	1.24	60.43	80.05
Menton (1)	-1.11	1.37	14.34	118.33
Menton (2)	-1.14	2.17	14.06	118.28
Ferrat (1)	-0.05	2.64	-32.74	77.47
Ferrat (2)	0.35	3.87	-31.78	79.91
Nice (1)	2.68	3.27	-2.30	81.99
Nice (2)	2.80	3.31	-8.46	81.90

Table 1: Statistics of errors in wind intensity (ff) in [m/s] and direction (dd) in [Deg.] for the 10 km simulations at selected stations along the Mediterranean coast (12 March 2005). (1) corresponds to the CEPan simulation and (2) to the ARPan simulation

Except at "Menton" station, there is a general tendency for the model to underestimate wind intensity. The standard deviation ranges between 1 and almost 4 m/s. Regarding wind direction, the lowest bias is observed at Nice but, as shown on time series hereafter, this is due to a compensating effect between an underestimation at the beginning of the simulation and a strong overestimation in the middle on the integration. The "Genoa" station is characterized by the lowest bias because it is the only one that does not exhibit abrupt direction changes during the day. The "Menton" station that has a negative bias in terms of wind intensity is also associated with the largest standard deviation for wind direction. These results are explained by the fact that during the first 7 hours of the day, the wind intensity is very low (less than 1 m/s) inducing an ambiguity on observed wind direction. Statistics produced by the CEPan run are in average slightly better than those produced by the ARPan run. The temporal evolution of the 10-m wind direction at Nice location obtained for the CEPan and ARPan simulations is compared to available observations in Figure 3 for the 10-km grid and in Figure 4 for the 2.5 km grid.

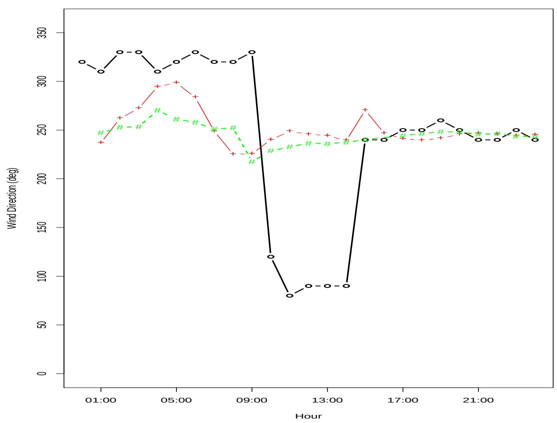

Figure 3: Time evolution of observed (black solid line with (o) symbols) and 10-km modeled (green dashed line with (#) symbols for CEPan and red solid line with (+) symbols for ARPan) wind direction at "Nice airport" station during the 12 March 2005 from 00 UTC to 24 UTC.

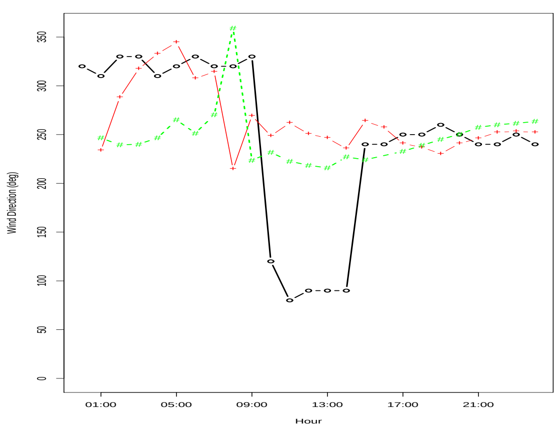

Figure 4: Same as Figure 3 for the 2.5 km simulation

Observations show that the wind direction that was around 330 Deg. (north-westerly flow) during the night (drainage flow in the Var river valley and land breeze circulation) changes rapidly at 09 UTC to a value of 90 Deg. (easterly flow) and then turns back to a westerly flow between 14 UTC and 15 UTC. The CEPan 10-km run maintains a rather constant flow direction during the day around 250 Deg. The ARPan run has a similar behavior but there is slight change in direction between 06 UTC and 09 UTC. However, it has not the correct intensity and this wind veering is too slow. The runs at 2.5 km do not improve significantly with respect to the observed time series. It can be noticed that the ARPan run tends to settle during the first hours of integration a more pronounced north-westerly flow than at 10 km due to a better description of the Var river valley. Both 2.5 km simulations show the capacity of the model to produce more rapid wind rotations. The CEPan run shows a 100 Deg. change between 08 UTC and 09 UTC whereas the ARPan run produces a 60 Deg. change one hour earlier. Examination of the simulated 10-m wind field at 2.5 km when the "reversal wind" is observed over Nice (14 UTC) highlights the capacity of the model to simulate easterly winds along the Mediterranean coast in a large-scale south-westerly flow over sea. However it is located too far east with respect to observations (Figure 5). This is the reason why we also examine the temporal series of wind direction for the weather station "Andora" located 100 km east of Nice (Figures 6 and 7). All runs show the capacity of Meso-NH to simulate a rapid wind rotation from west to east between 08 UTC and 09 UTC. The observed 10-m wind remains contant after this shift, whereas all Meso-NH runs make the wind turn back to the west direction latter during the day. The 10 km CEPan simulation maintains the easterly wind until 20 UTC whereas the 10 km ARPan run simulates a wind rotation to the west at 16 UTC. This difference in behavior reflects clearly on the statistics (Table 1) where the standard deviation for CEPan is almost half the ARPan value. Wind direction changes in the 10 km CEPan run around 12 UTC are associated with low wind intensities. The 2.5 km runs are more similar (being less influenced by different initial and boundary conditions) and demonstrate the capacity of Meso-NH at high resolution to produce sharp rotations in agreement with observations and to maintain at this location the easterly flow during a longer period (simulated but unobserved wind direction change around 20 UTC).

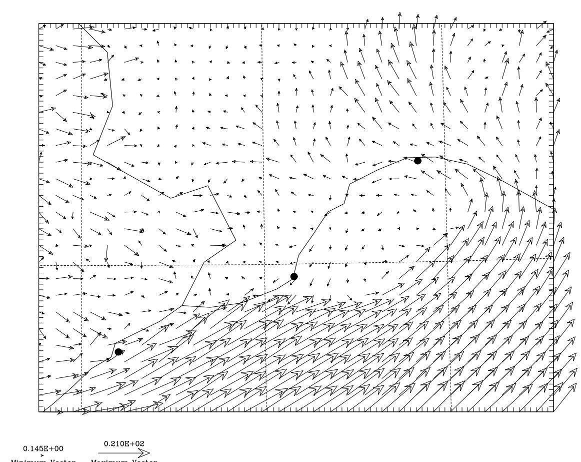

Figure 5: Simulated 10-m wind at 14 UTC for the 2.5 km Meso-NH run (CEPan). Black dots along the coast represent the locations of Nice, Andora and Genoa (from west to east)

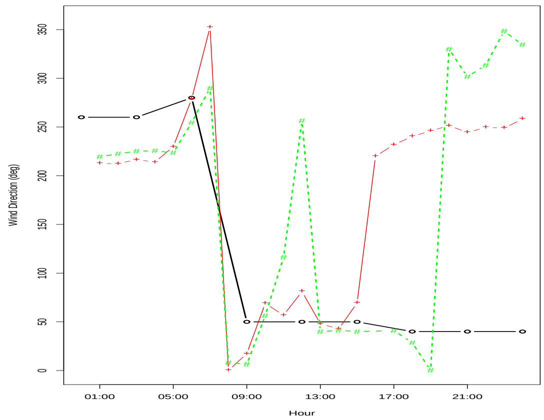

Figure 6: Same as Figure 3 but at "Andora" station.

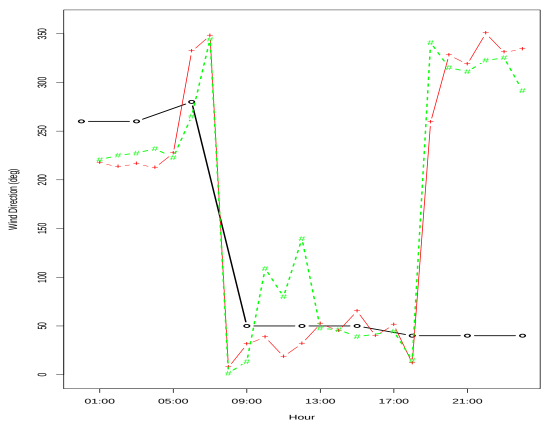

Figure 7: Same as Figure 4 but at "Andora" station.

5. Conclusions

The location of Nice Côte d'Azur airport makes it vulnerable to various types of weather hazards (vertical or horizontal wind shears, microbursts) that need to be better detected and predicted for increasing air traffic security. In this framework, a numerical study has been undertaken to assess the capacity of high resolution modeling to forecast such phenomena. Numerical simulations with the Meso-NH model at 10 and 2.5 km resolutions and lasting one day have been performed over the region of interest. By using, for the coarse resolution model, either Météo-France ARPEGE or ECMWF analyses, it has been found that the high resolution simulations of a low level horizontal wind shear observed at Nice airport on the 12th March 2005 are rather insensitive to this large-scale initialization. Simulations at both 2.5 km and 10 km are able to simulate a rapid wind rotation along the coast of the French Riviera originated from the development of a mesoscale vortex over the Genoa gulf, but the location is too far east, preventing the wind shear to reach the Nice airport where it was observed. The benefit of the high resolution has been noticed at Nice airport where there is a hint of a change in direction around 9 UTC that is totally missed with the 10 km model. Similarly, at the weather station of Andora, the easterly flow is maintained during a longer period with the ARPan run at 2.5 km than with the ARPan run at 10 km.

This preliminary study will be pursued in various directions :

- Additional meteorological situations corresponding to other types of wind shear observed at Nice airport will be simulated
- Comparisons with the UHF wind profiler available at Nice airport will complement model validations
- The interest of increasing the model resolution to sub-kilometric scales will be assessed
- The benefit of initializing Meso-NH with high resolution analyses at 2.5 km from the new Météo-France assimilation system of the AROME model will be evaluated

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