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Article

Modelling Airport Pollutants Dispersion at High Resolution

Claire Sarrat [1,†*], Sébastien Aubry[1] and Thomas Chaboud[1], Christine Lac[2,]

[1] ONERA, 2 avenue Édouard Belin 31055 Toulouse, France; claire.sarrat@onera.fr
[2] CNRM Météo France; christine.lac@meteo.fr
* Correspondence: claire.sarrat@onera.fr; Tel.: +33-5-62252898
† This paper is an extended version of our paper published in ECATS 2016.

Abstract: Local air quality is a major concern for the population regularly exposed to high levels of air pollution. The airport, mainly due to its aircraft engines activities during taxiing and take off, is often submitted to heterogeneous but important concentrations of NOx and PM. The study suggests an innovative approach to determine the air traffic impact on air quality at the scale of the airport, its runways and terminals, in order to be able to locate the persistent high concentrations spots. The pollutants concentrations at 10 m resolution and 1 s time step are calculated in order to identify the most affected areas of an airport platform. A real day of air traffic on a regional airport is simulated, using real data as aircraft trajectories (from radar streams). In order to estimate the aircraft emissions, the Air Transport Systems Evaluation Infrastructure (IESTA) is used. Regarding local air quality, IESTA relies on the non-hydrostatic meso-scale atmospheric model Meso-NH using grid-nesting capabilities with 3 domains, for this study. The detailed cartography of the airport distinguishes between grassland, parking and terminals, allowing to compute exchanges of heat, water and momentum between the different types of surfaces and the atmosphere as well as the interactions with the building using a drag force. The dynamic parameters like wind, temperature, turbulent kinetic energy and pollutants concentration are computed at 10 m resolution over the 2×4 km airport domain. The pollutants are considered in this preliminary study as passive tracers, without chemical reactions. This preliminary study aims at proving the feasibility of high scale modelling over an airport with state of the art physical models.

Keywords: Airport; Local Air Quality; Local Scale

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1. Introduction

Local air quality is a major concern for all the mega-cities but also for regional metropolises. The population is indeed more and more subject to health-damaging levels of air pollution. In the same time, European air transport system is facing the challenge of a paradoxical injunction : increasing the global air traffic to answer the increasing international demand and reducing the emissions to reach the 2020 ACARE goals. At the scale of the airport, the air quality is an issue for both neighbourhood and airport users (workers or travellers). This issue is becoming more and more important with the increase of the air traffic and airport activities.

At the regional scale, these impacts have been studied previously using Chemistry and Transport Models (CTM) by Arunachalam et al. (2011)[1] or Rissman et al. (2013)[2]. The aim of these studies was to assess the impact of aviation on the synoptic air quality ; they usually conclude that airports are secondary contributors after the other sources of pollutants as road traffic or industries.

At the local scale, several modelling tools are used as Gaussian or Lagrangian models (ADMS, EDMS, LASPORT, described by Hirtl et al., 2007[3]) to study the long-term impact of aviation on air quality. They compute the pollutants concentrations as a response to an analytical equation. Those models perform well for mean annual budget and stable or neutral boundary layers conditions. Moreover, most of the time, the emissions of the aircraft are simply simulated as Landing Take-Off (LTO) cycles (Peace et al., 2006[4] ; Farias et al., 2006[5]). Thus, they don't allow a precise representation of

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spatio-temporal heterogeneities of the airport concentrations.
In this study, a new approach is proposed to study the impact of air traffic on air quality at the local scale. In fact, a simulation is performed at very high spatio-temporal resolution using an Air Traffic System model (IESTA) coupled with a meteorological model (Meso-NH). This paper first describes the IESTA and Meso-NH models and their coupling, and secondly how this coupling enables to calculate the pollutants concentration at 10 m resolution in order to identify the most affected areas of an airport platform during a real day of intense traffic. As this preliminary study aims at proving the feasibility of high-scale modelling over an airport with state of the art physical models, the conclusion describes the limitations and the perspectives of this work.

2. Models description

This study uses the coupling between the Air Transport System model IESTA for aircraft trajectories and emissions and the meteorological model Meso-NH. These two models are described hereafter.

2.1. Air Traffic System model : IESTA

In order to estimate the aircraft emissions, the Air Transport Systems Evaluation Infrastructure (IESTA) is used (Aubry et al., 2010[6], Sarrat et al., 2012[7]). IESTA is a set of numerical models dedicated to the design and modelling of innovative air transport systems and their evaluation, in particular for environmental impacts (noise, fuel consumption, emissions and air quality). From the observed radar aircraft trajectories, the meteorological conditions and the aircraft performances, IESTA simulates the air traffic system, i.e. the aircraft and engines state vectors, allowing to compute thrust, fuel flow and emissions at 10 m resolution and with one second time step. In fact, the Aircraft module of IESTA is able to closely follow the real 4D (spatio-temporal) aircraft trajectories given the aircraft types, using the total energy equations of flight mechanics. It generates a complete state vector for each of the simulation time steps, including the engines required thrust. In this study, the Engine module is not used with the full thermodynamic modelling for each engine, because of a too large number of aircraft to simulate (824 engines a day). Instead, taking the thrust, aircraft speed and weather parameters as input, several methods are used to compute pollutants emissions indices : for turbofans, ICAO Engine Emissions Databank interpolations ; for turboprops, FOI database. Thus, fuel consumption and emission indices are computed for different species (NOx, SO_2, VOC, CO, CO_2) at every point of each engine trajectory.

2.2. The meteorological model : Meso-NH

IESTA is coupled off-line with the non-hydrostatic meso-scale atmospheric model Meso-NH, a research model developed jointly by the French Research Center for Weather Forecast and the Laboratoire d'Aérologie. The prognostic variables of Meso-NH as horizontal and vertical wind, turbulence (through the Turbulent Kinetic Energy, TKE), or any passive or reactive scalar variable, in addition to temperature and vapour content, allow a detailed description of the dynamical situation up to very high horizontal resolution, i.e. 10 m in that case study. Meso-NH has been chosen for its high level of physical parametrisation. The radiative transfer is computed using the long-wave and short-wave transfers from the operational radiation code of the European Center for Medium-Range Weather Forecast (ECMWF). A 3D turbulence scheme is used to compute the prognostic Turbulent Kinetic Energy (TKE) (Cuxart et al. 2000[8]).

The surface variables are computed with the interactive land-surface scheme SURFEX (Masson et al., 2013[9]). A detailed cartography of the airport distinguishes grassland from parking and building, allowing to compute exchanges of heat, water and momentum between the different types of surfaces and the atmosphere according to a vegetation scheme (ISBA from Noilhan et al., 1989[10]) or a urban

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scheme (TEB from Masson et al., 2000[11]. The surface-atmosphere interactions with the building is taken into account through a drag force described by Aumond et al., 2013[12]. In fact, the following terms are added to the momentum equations :

$$\frac{\partial u}{\partial t} = -C_d A u \sqrt{u^2 + v^2} \tag{1}$$

The dynamic parameters like wind, temperature, turbulent kinetic energy and pollutants concentrations are computed at 10 m horizontal resolution over the 2×4 km airport domain. The pollutants are considered in this preliminary study as passive tracers, without chemical reactions.

3. Models set-up

3.1. Building the emissions database

In order to compute the emissions database based on real observed data, the aircraft radar streams recorded on September 10th, 2010 are analysed in order to correct and complete the trajectories.
About 400 aircraft trajectories and 824 engines state vectors are computed from the radar data. Another methodology is applied for a few exceptions such as the piston-engines aircraft, which are not yet implemented in IESTA ; some engines used in the traffic are not ICAO-certified or listed in the FOI tables. For that kind of engines, the corresponding trajectories are, for the most part, allocated to equivalent aircraft, or simply ignored if their contribution is deemed negligible.
The emissions of these 824 engines are computed using interpolation in the ICAO tables rather than the IESTA thermodynamic model because of a large variety of engines types. The emissions of NOx, CO, CO_2, SO_2 and smoke number are computed at a one second time step. As the available data don't include aircraft APU emissions, the ICAO/CAEP Airport Air Quality Manual (ICAO, 2011[13]) is used to allocate APU emissions to realistic areas and periods. This manual states that an accepted modelling for short-haul aircraft is an APU operating during 45 min and emitting a total of 700 g NOx, 30 g UHCs, 310 g CO and 25 g PM10. As expected, the NOx emissions are the highest near the runway, where the aircraft take off, but also near the parking at the gates as shown in Figure 1, mainly due to APU emissions.
The emissions from other sources than aircraft are provided by a 1 km resolution database at the hourly time step.

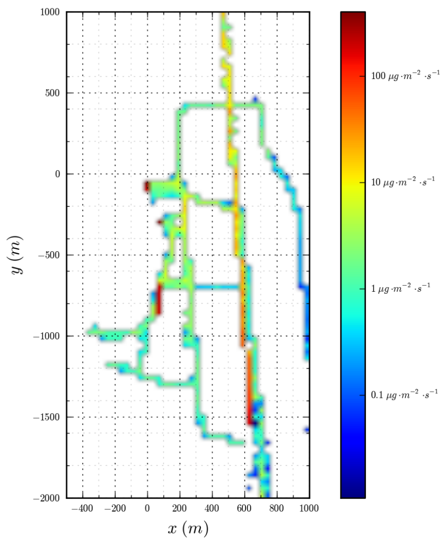

FIGURE 1. Surface flux of NOx emissions (μg/m^2/s) on September 10th, 2010

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3.2. Initialisation and land surface data

The Meso-NH model is used with a 3 nested domains of simulation configuration, at 250 m, 50 m and 10 m horizontal resolutions. The vertical grid contains 120 levels for all the domains, with a higher resolution near the ground and stretching above 3000 m. The first level is at 2 m above ground, while 55 levels are included within the first thousand meters. Three domains of simulation (Figure 2) are built, in nesting two-ways, allowing the downscaling from the large scale boundaries conditions, up to a 10 m resolution domain, as well as the upscaling flow.

The meteorological situation is initialised using the French Numerical Weather Prediction model, AROME (Seity et al., 2010[14]) analysis at 2 km resolution and 6 :00 UTC. Meso-NH is also forced at the large scale boundaries by AROME every three hours. Thus, AROME provides the initialisation and forcing for the dynamical and thermodynamical variables (wind, potential temperature, humidity, etc.) as well as the soil variables (ground water content, surface temperature . . .) initialisation.

Three domains of simulation (Figure 2) are built, in nesting two-ways, allowing the downscaling from the large scale boundaries conditions, up to a 10 m resolution domain, as well as the upscaling flow.
The land surface parameters are key data for high resolution modelling of the Atmospheric Boundary Layer (ABL).SURFEX computes surface fluxes for each type of cover according to the characteristics of each tile (albedo, roughness, texture, urbanization, nature, etc.). The land surface covers of both larger domains are given by the Ecoclimap database derived from the Corinne Land Cover 2000 data (Faroux et al., 2013[15]).
The smaller domain represents the airport area itself, with a 10 m resolution and 3×4.5 km width. The surface occupation data come from the OpenStreetMap (OSM) database, which has been converted to the SURFEX surface types. The three main covers as shown on Figure 2c are the parking and roads, the nature (grassland and crops) and the building (terminals, train station, hangars. . .) where a drag force is applied according to Aumond et al., 2013[12] and Bergot et al., 2016[16].

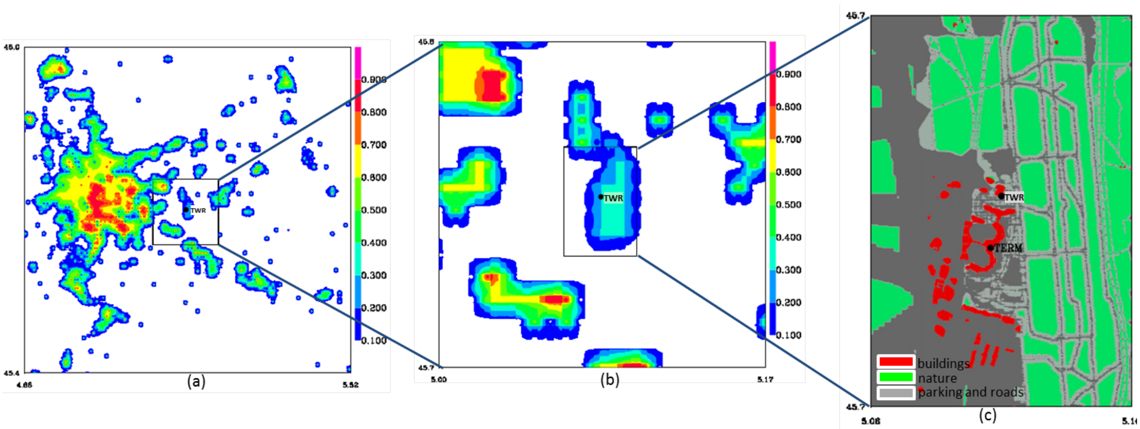

FIGURE 2. Fraction of urban cover on the three domains of simulation interacting in two-ways nesting two ways : (a) 250 m resolution, width=67.5×67.5 km ; (b) 50 m resolution, width=13.5×13.5 km ; (c) 10 m resolution, width=3×4.5 km

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4. Results

4.1. Dynamic situation

The simulation starts at 6 :00 UTC on September 10th and runs for 3600 seconds only, because of a very high CPU consumption. This period represents the maximum of aircraft traffic.
For this day, the weather conditions are anticyclonic, with high radiation and increasing temperatures. The simulated wind presents low values (less than 2 m/s) over the three domains of simulation (Figure 3), and the direction is from north-west. During this short period between 6 and 7 UTC, the wind module and direction from Meso-NH are in good agreement with the observations recorded near the control ToWeR (TWR) during the campaign (as shown in Figure 4).

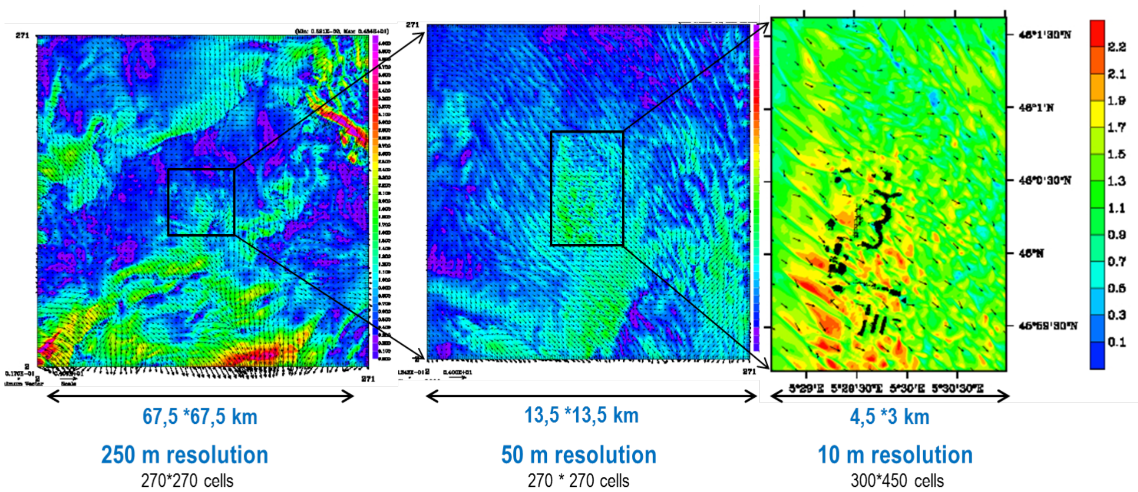

FIGURE 3. Simulated wind modules and direction over the three domains of simulation 2 m above ground (the first level of simulation), at 7 :00 UTC.

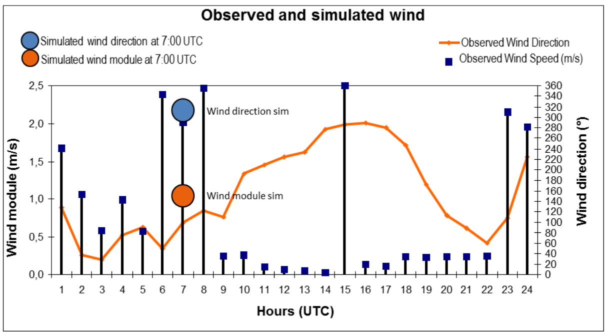

FIGURE 4. Observed wind time series (module and direction) and comparisons with the simulation output at 7 :00 UTC (orange and blue circles).

The Turbulent Kinetic Energy (TKE) as well as temperature and wind are impacted by the surface land cover. In fact, the buildings have a strong impact : they increase TKE and temperature, while the vertical wind is positive upstream (due to building obstacles) and negative downstream, thanks to the applied drag force. This phenomenon is shown in Figure 5 which represents a vertical cross section of the vertical wind component across the airport and between ground and 1000 m. Locally the vertical wind is positive and enhanced by the presence of the airport terminals. The vertical

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mixing is consequently enhanced near the buildings and modified, which should noticeably impact the pollutants concentrations and dispersion.

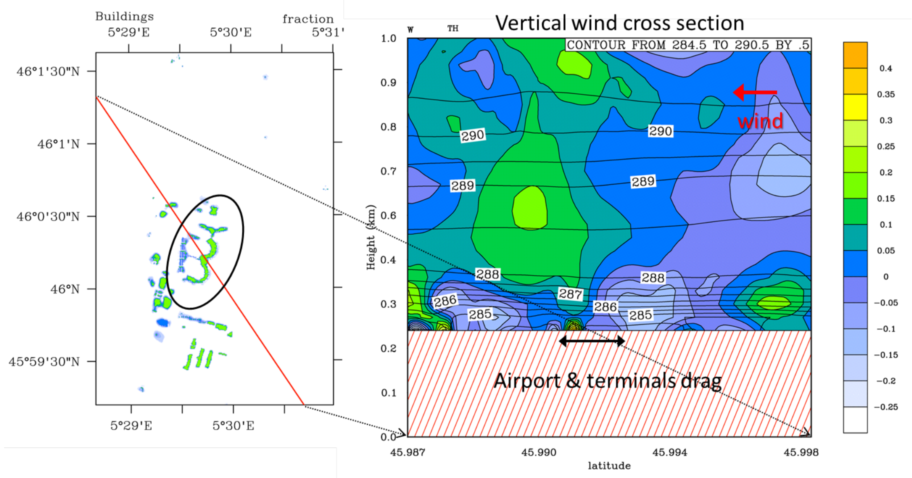

FIGURE 5. (a) Surface building fraction and (b) Vertical cross-section of the wind vertical component in m.s^{-1}.

4.2. NOx dispersion

In this preliminary study, the only chemical species is NOx, taken into account as a passive scalar. As shown in Figure 6, NOx concentrations over the small domain of simulation (10 m resolution) are heterogeneous and higher next to the northern boundary, due to the advection of pollutants from the larger domain and the road traffic emissions. In fact, the wind from North-North-West, albeit low, brings a plume with high level of NOx (Figure 6). The airport itself seems affected by NOx concentration around 50 ppbv, at 6 :30 UTC highs are located right next to the terminals and parking, where aircraft's engines and APUs are operated longer (Figure 6a). Later, while the air traffic starts to increase, at 7 :00, the concentrations are higher along the runway, where aircraft take off.

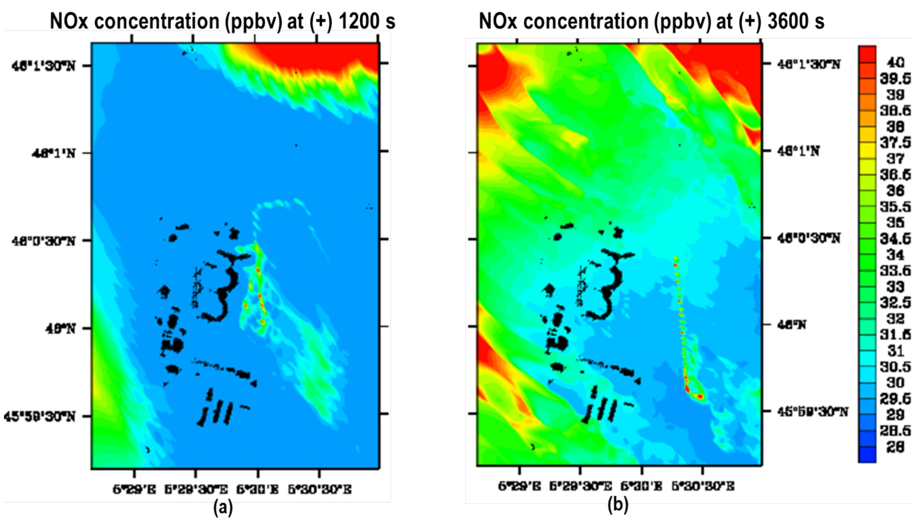

FIGURE 6. NOx concentration at 2 m above ground, (a) at 6 :30 UTC and (b) at 7 :00 UTC. The buildings are represented (black)

5. Conclusion

A real day of air traffic over a regional airport is simulated using the coupling of two state-of-the-art models : IESTA, modelling the aircraft trajectories and engines emissions, and Meso-NH, modelling the atmospheric dispersion at 10 m horizontal resolution. In this preliminary study, the NOx are considered as passive tracers and the simulation lasts only 3600 s. The coupling of the two models demonstrates the ability to satisfactorily represent not only the emissions (engines, APU), but also the NOx peaks due to northern advection and emissions on both terminals' parking and taxiing areas. Moreover, the meteorological dynamic (low winds and buildings interactions) provides an innovative approach to airport air quality studies at high spatio-temporal resolution.
The next step for this study is first to continue the simulation along the day, in order to determine the evolution of the concentrations in and around the airport. Secondly, the reactive chemistry with photochemistry and ozone-VOC interactions should be added to simulate more realistic behaviour. These improvements need a lot of computing time with supercomputers but will be done in the next few months.

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