MODELING AIRPORT AIR QUALITY AT HIGH RESOLUTION

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Abstract. In this study, a new approach to study the impact of air traffic on air quality is proposed. The pollutants concentrations are calculated at 10 m resolution using a Large Eddy Simulation (LES) model in order to identify the most affected areas of an airport platform. A day of air traffic on a regional airport is simulated, using real data as aircraft trajectories from radar streams and observed meteorology, NOx, O3 and PM10 data. In order to estimate the aircraft emissions the Air Transport Systems Evaluation Infrastructure (IESTA) is used. IESTA is coupled with the non-hydrostatic meso-scale atmospheric model Meso-NH using grid-nesting with 3 domains and LES capabilities. 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 buildings using a drag force. The dynamic parameters like wind, temperature, turbulent kinetic energy and pollutants concentrations are computed at 10 m resolution over the 2 x 4 km airport domain. The pollutants are considered in this preliminary study as passive tracers, without chemical reactions.

Keywords: Airport, air quality, local scale

INTRODUCTION

The airport air quality is a major concern 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. These impacts have been studied previously using Chemistry and Transport Models (CTM) by Arunachalam et al. (2011) or Rissman et al. (2013). The aim of these studies was to assess the impact of aviation at the regional scale; they usually concluded that airports are secondary contributors after the other sources of pollutants as road traffic or industries. At the local scale, several tools are used as Gaussian or Lagrangian models (ADMS, EDMS, LASPORT) giving the pollutants concentration as a response to an analytical equation. While those models perform well for mean annual budget and for stable or neutral boundary layers conditions, they don't allow a precise representation of spatiotemporal heterogeneity of the airport concentration. Moreover, most of the time, the emissions of the aircraft are simply simulated as Landing Take-Off (LTO) cycles (Peace et al., 2008; Farias et al., 2006).

A new approach to study the impact of air traffic on air quality at the local scale is proposed here. In fact, a simulation is performed at very high spatiotemporal resolution using an Air Traffic System model (IESTA) coupled with a meteorological model (Meso-NH). This paper describes how the IESTA-Meso-NH 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.

MODELS DESCRIPTION

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, Sarrat et al., 2012). 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 (spatiotemporal) 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, SO2, VOC, CO, CO2) at every point of each engine trajectory.

Meteorological model: Meso-NH
IESTA is coupled off-line with the non-hydrostatic meso-scale atmospheric model Meso-NH using grid nesting with 3 domains and Large Eddy Simulation (LES) capabilities. The detailed cartography of the airport distinguishes between grassland, parking and building, 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 (Aumond et al., 2013). The dynamic parameters like wind, temperature, turbulent kinetic energy and pollutants concentrations are computed at 10 m resolution over the 2 x 4 km airport domain. The pollutants are considered in this preliminary study as passive tracers, without chemical reactions.

MODELS SET-UP

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 analyzed 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 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.

Aircraft emissions of these 824 engines are computed using the interpolation in the ICAO tables rather than using the IESTA thermodynamic model because of a large variety of engines types. The emissions of NOx, CO, CO2, SO2 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) 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.

The emissions from other sources than aircraft are provided by a 1 km resolution database, used in the two largest domains.

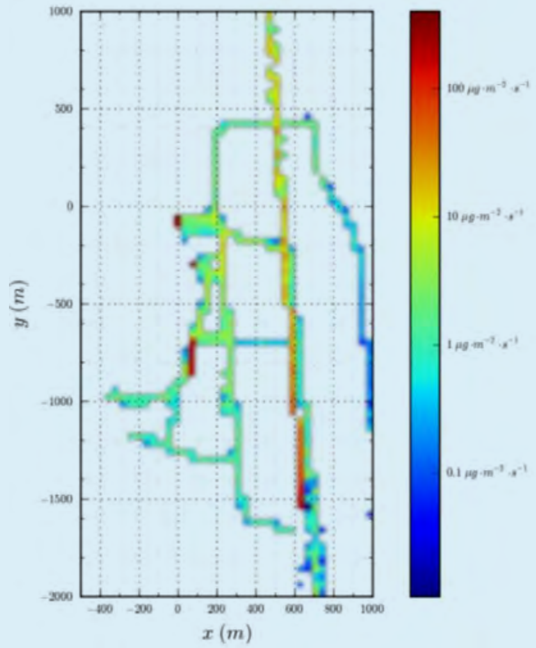


Figure 1: Surface flux of NOx emissions (μg/m2/s) on September 10th, 2010

Initialization and land surface data of Meso-NH

The meteorological variables are initialised by the French weather forecast model analysis AROME at 2 km resolution, at 6:00 UTC. They are also forced by AROME at the large scale boundaries every three hours. In fact, AROME provides the initialisation and forcing for the dynamic variables (wind, potential temperature, humidity, etc.) as well as for the land surface variables (ground water content, surface temperature…).

For the passive tracers, like NOx, the initial conditions are given by the observations made at a station a few kilometres upstream the airport. A zero gradient condition is applied at the large scale boundaries.

Three domains of simulation (Figure 2) are built, in nesting two ways, allowing the downscaling from the large scale boundaries conditions to a Large Eddy Simulation (LES) model at 10 m resolution.

The land surface parameters are key data for high resolution modelling of the Atmospheric Boundary Layer (ABL). Meso-NH 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 CORINE Land Cover 2000 data (Faroux et al., 2013). The smallest 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 have been converted to the Meso-NH types of land cover. The three main covers as shown on Figure 2c are the parking and roads, the nature (grassland and crops) and the buildings (terminals, train station, hangars…) where a drag force is applied according to Aumond et al., 2013 and Bergot et al., 2016.

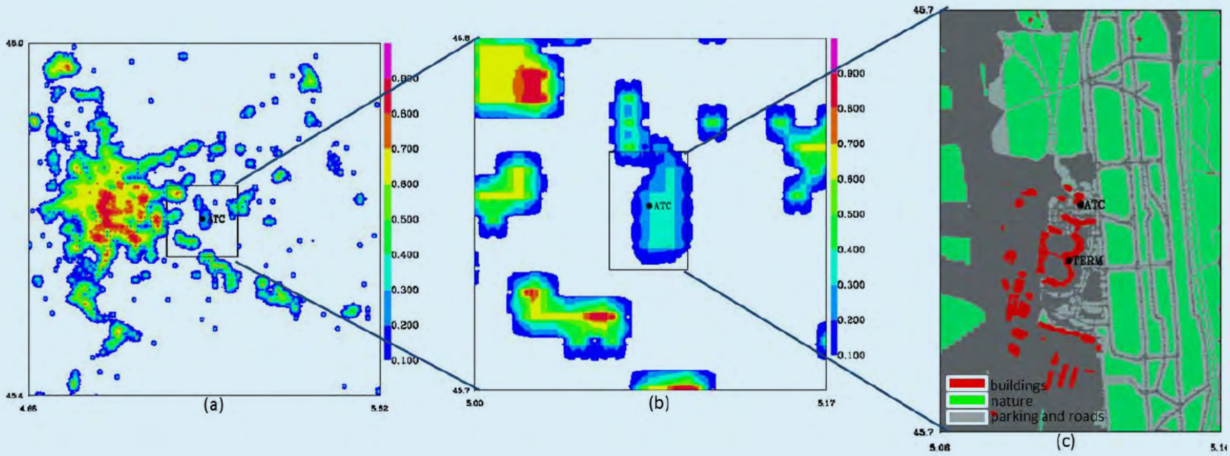


Figure 2: 3 domains of simulation in grid-nesting two ways: (a) 250 m resolution, width=67.5×67.5 km; (b) 50 m resolution, width=13.5×13.5 km; (c) 10 m resolution, width=3×4.5 km

RESULTS

Dynamic situation

The simulation starts at 6:00 UTC on September 10th and runs for 1000 seconds only, because of a very high CPU consumption. In fact, the simulation is run on a supercomputer using 240 multi-core processors. This period represents the maximum of aircraft traffic.

For this day, the weather conditions are good, with high radiation, and increasing temperatures. The wind is low less than 2 m/s from north-west, as shown in Figure 3, in good agreement with the observations (not shown here).

The Turbulent Kinetic Energy (TKE) as well as temperature and wind are impacted by the surface land cover. In fact, buildings have a strong impact: they increase TKE and temperature, the decrease upstream wind, thanks to the drag force applied. The local boundary layer and the vertical mixing are consequently enhanced near the buildings.

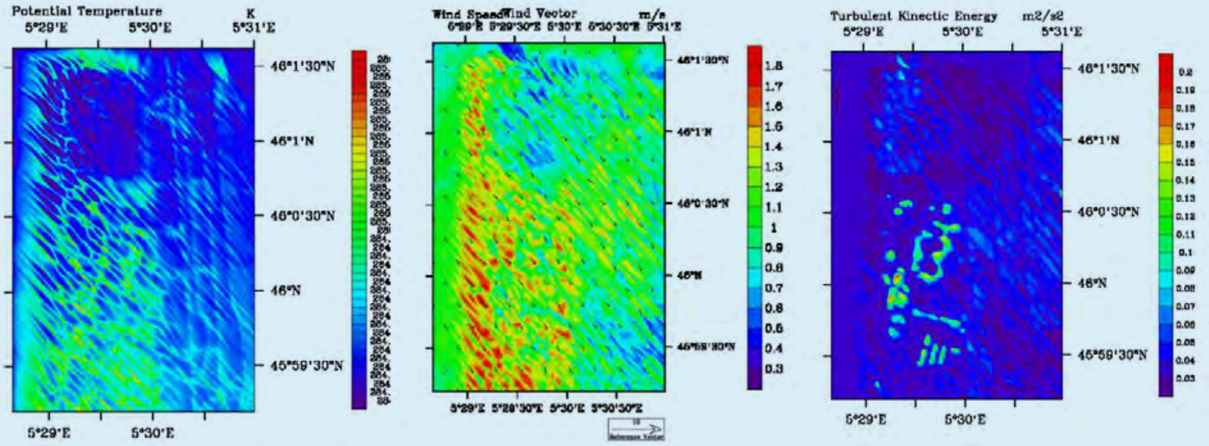
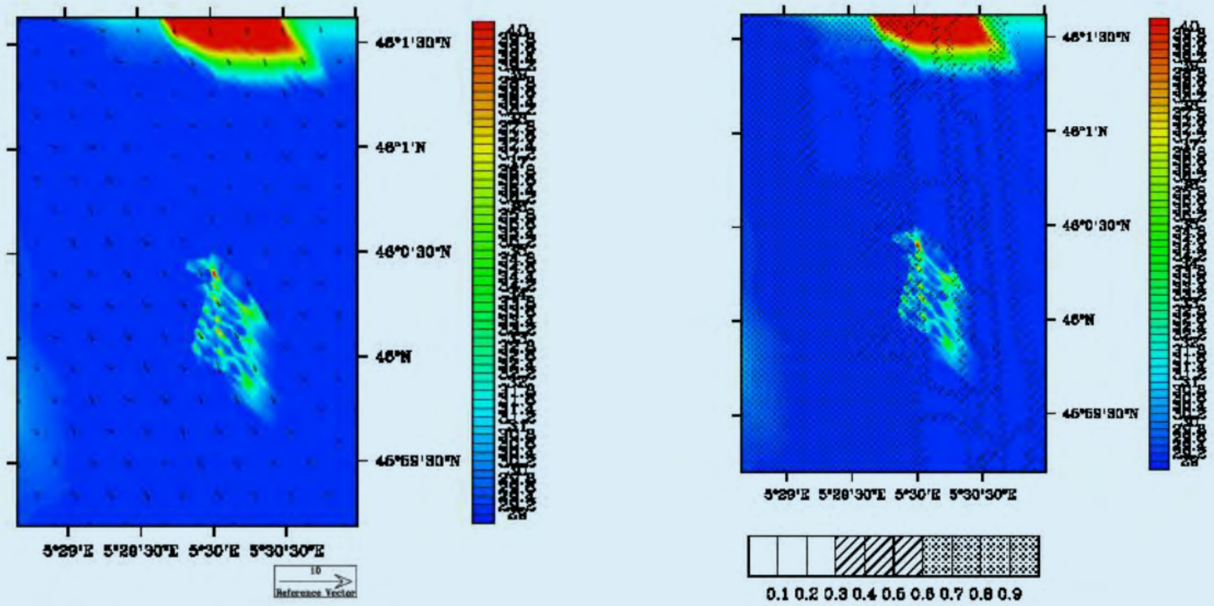


Figure 3: Dynamic situation of the day: (a) Potential Temperature near the ground; (b) Wind module and direction; (c) Turbulent Kinetic Energy

NOx dispersion

As shown in Figure 4, NOx concentrations over the small domain of simulation (10 m resolution) are quite high next to the northern boundary, due to the advection of pollutants from the larger domain and to the road traffic emissions. In fact, the wind from North-North-West, even low, brings a plume with high level of NOx (Figure 4a). The airport itself seems affected by NOx concentration around 50 ppbv, right next to the terminals and parking, where aircraft's engines and APU are operated longer (Figure 4b shows the fraction of buildings, parking or roads together with NOx concentrations)



(a) (b)

Figure 4: NOx concentration (ppbv) at the first level of the model, i.e. 2m height above ground with (a) wind direction and (b) urban fraction cover

CONCLUSION

A real day of air traffic over a regional airport is simulated using the coupling of two state-of-the-art models: IESTA, modeling the aircraft trajectories and engines emissions and Meso-NH, modeling the atmospheric dispersion at 10 m horizontal resolution. In this preliminary study, the NOx are

considered as passive tracers and the simulation lasts only 1000 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 from both terminals' parking and taxiing area. Moreover, the meteorological dynamic (low winds and buildings interactions) provides 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 interaction should be added to simulate more realistic behavior. These improvements need a lot of computing time with supercomputers but will be done in the coming few months.

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