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Air quality impact of a middle size airport within an urban context through EDMS simulation

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ABSTRACT

The air quality impact of an airport due to both ground sources and air traffic emissions within the troposphere boundary layer is a relevant topic at a local scale, especially where the airport is surrounded by urbanized areas. The work analyses the emissions from the Amerigo Vespucci airport in Florence, Italy. The comparison between the present and the future layout of the airport, which is under project, is addressed, providing a possible tool to guide local air pollution prevention strategies within the framework of the strategic transport infrastructures development.

The emission scenarios of the present and future airport layouts were estimated with EDMS 5.1.3, the software package issued by FAA (Federal Aviation Administration) which is an US-EPA (Environmental Protection Agency) preferred model for airport emissions evaluation. The total yearly emissions of NO_X, CO, SO_X, VOCs and PM_{10} have been assessed, divided into the main phases of the LTO (landing and takeoff) cycle, provided for each aircraft. The results show that the takeoff phase is mainly responsible for NO_X, SO_X and PM_{10} contributions.

The AERMOD dispersion model was run over one year to evaluate the concentrations of those pollutants, modelled as chemically inert. The maximum concentrations occur close to the gate and the ground movement areas. However, the air quality standards ruled by Directive 50/2008/EU are never reached except for NO_X, which shows an overall maximum of the annual average of about 40 μg/m^3, close to the standard for the vegetation health (50 μg/m^3).

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Introduction

Aircraft engines produce pollutants which affect ambient air quality, like all combustion engines. Unlike many other sources, however, aircraft emit pollutants over a range of altitudes. A wide literature exists evaluating the emissions of aircraft during the different phases of flight and ground operations, and some specific studies have been developed to evaluate that fraction of air traffic emissions which affects the air quality at ground level. In general, emissions below the mixing height of the troposphere boundary layer contribute to ground level air pollution, while specific types of emissions have a greater potential impact on climate change when they are emitted above the mixing layer. Especially when the airport is nearby urbanized areas, those emissions can contribute to the background of urban air quality, with respect to air quality

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standards (European Parliament and the Council, 2008). Many authors have studied such impacts through in situ measurements of pollutants concentrations (Schurmann et al., 2007), remote sensing of both the chemical composition of the exhausts of the aircraft engines and the air composition (Schurmann et al., 2007; Wormhoudt et al., 2007; Wayson et al., 2009), numerical simulations of transport, diffusion, deposition and eventually photochemical transformation of the reactive pollutants (Wood et al., 2008).

The Amerigo Vespucci airport emissions impact on the surrounding urbanized area is a challenging case study as a project of a new runway is presently under debate and its foreseen impact on air quality and noise level is carefully considered. Moreover this area is already close to the air quality standards (European Parliament and the Council, 2008). Thus, the foreseen development of transport efficiency, due to the better airport layout projected and technological renovation of the aircraft fleet, shall match the environmental requirements and the social constraints in terms of standards of comfort for citizens.

In the present work a preliminary analysis of the impact of the future airport on air quality, with respect of some primary pollutants, has been developed. The evaluation methodology is based on the emission scenario assessment from air traffic and on the numerical simulation of the dispersion in the atmosphere of the pollutants, performed after the sectorial guidelines (EEA, 2011).

Methodology

The main elements for the assessment of air quality impact of an airport and its relevance with respect to the air quality standards, through a numerical simulation, are the following:

- layout of the airport and related infrastructures;
- emissions scenarios of selected pollutants;
- selection and settings of the simulation model.

First of all, the present airport layout and one of the projected future ones have been considered, to perform a comparison of the two. The emissions scenarios selected include the aircraft engines exhaust and the other sources within the airport layout. The future development of industrial activities and residential centers in the area surrounding the airport, together with the foreseen improvement of the roadways and urban railways, have not been considered. Their contribution to air pollution should be accounted for following the submission of the ultimate design of the new airport layout to the governmental authority.

The selected pollutants are: NO_X, CO, SO_X, VOCs and PM_{10}, treated as inert substances. These are the main pollutants emitted by aircraft engine exhaust and by other airport-related sources which contribute to air pollution. The current data about particulate formation and composition from aircraft engines are still inadequate, thus the primary PM_{10} emissions have been considered only. In the present paper, the $PM_{2.5}$ emissions and their air quality impact, whose standards are entering into force in Italy at 1st January 2015, are taken as equal, thereby considering the most restrictive conditions. The role of aircraft emissions to secondary particulate is under scientific debate (Miracolo et al., 2011), showing their potential in formation of secondary organic aerosol and secondary sulfates. A further analysis should include these processes which are not investigated in the present study, based only on inert pollutants impact.

The emission scenarios have been developed and estimated by means of EDMS 5.1.3, a software package issued by FAA (Federal Aviation Administration), using its internal database of aircraft, aircraft-engines combinations and performances, and ICAO (International Civil Aviation Organization) engine exhaust emission factors and fuel flow.

The emissions inventory built using EDMS is interfaced with the AERMOD dispersion code, a bi-gaussian stationary plume model (Venkatram, 1980; Venkatram, 1983) recommended by US-EPA for stationary source impact assessments (USEPA, 2004a; USEPA, 2004b; USEPA, 2004c; USEPA, 2005). This code has been elected to be appropriate for both point, area or volume stationary ground sources and aircraft emission sources. These later categories, which are mainly moving sources, are modelled and simulated by AERMOD as area sources, even when elevated.

Emissions from aircraft, GAV (Ground Access Vehicles), GSE (Ground Support Equipments), stationary sources and private vehicles contribute to the total air pollution burden associated with airport operations. Aircraft tend to dominate airport emissions; however, GSE and are significant contributors to the overall emissions, especially in case of the ground power unit (GPU) which substitutes the APU when the aircraft is at the passenger stands. Thus, the emissions from aircraft, from APUs and these GSEs will be considered only. Among the aircraft operating at a civil airport, two main categories are operating at the Amerigo Vespucci: air carriers, also known as commercial aviation, which own and operate at least one aircraft that seats at least 60 passengers, and general aviation, which consists of small planes that are usually privately owned or belong to corporations. The other categories, air taxis and military aircraft, are not present.

Layout of the airport and related infrastructures

The present layout refers to the 05–23 runway (Fig. 1), 1717 m long 30 m wide, and classified as category 3C under ICAO standards. The actual usage of the runway is limited, due to the adverse wind conditions, to only 90.2% of the scheduled time available, compared to the minimum of the ICAO requirements of 95%. Close to the runway two service areas are located: at the eastern side, there is a 35,000 m^2 area available for commercial aviation, containing up to seven large aircraft (Airbus

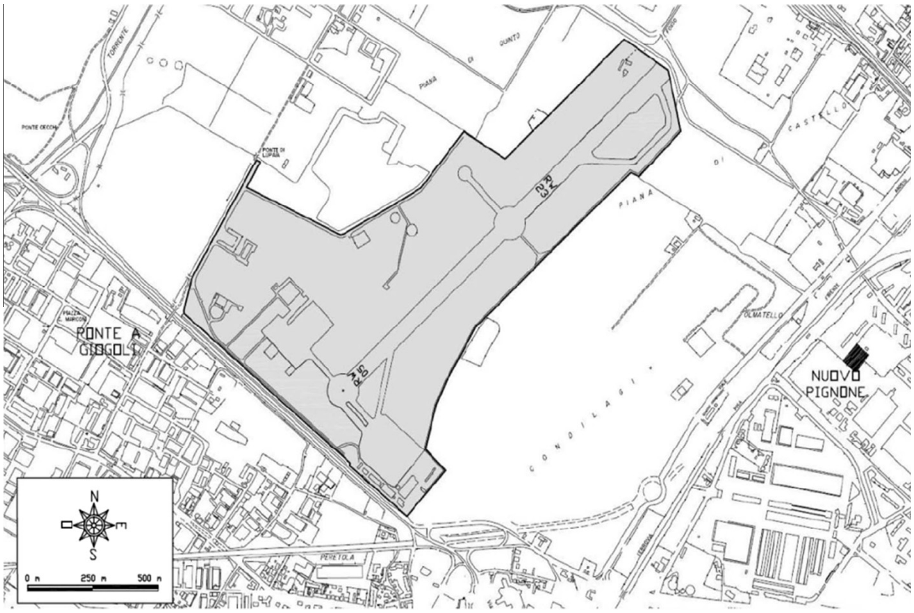

Fig. 1. Present layout of the Amerigo Vespucci airport. The nearby urbanized areas are shown in the South western sector. For example the Duomo of Florence is ≈ 6 km far in the South eastern direction.

A319 or Boeing 737 for example); at the western side there is a 20,000 m^2 area available for general aviation. The future layout considered is the most probable among the projects under discussion, after ENAC (National Civil Aviation Organization) forecasts. It will have a 12–30 runway (Fig. 2) of 2000 m length and a number of connections among the runway and the gates for the taxi operations. The edge of the runway will serve as an idle area. The new layout will probably allow for an availability of up to 95% of the scheduled time, as required for a 4D category airport after the ICAO standards.

Takeoff and landing trajectories

The takeoff and landing runway and flight trajectories within the civil airports in Italy are selected by ENAV,[1] based on the destination and origin of the flight, on the weather conditions and on the operating procedures scheduled for noise prevention.

In the present layout 90% of takeoff is on the RW 23 and 90% of landing on RW 05. The actual flight trajectories have been processed for our study from the radar observations (Fig. 3) during summer 2008.

In the future layout 100% of takeoffs from RW 23 and 100% of landings on RW 12 have been considered, independent of wind direction. In fact, only a minor percentage of different takeoff and landing directions are foreseen, as the windrose has a minimum of wind frequency within the North eastern and South western sectors, parallel to the airport runways. The flight trajectories have been designed from the ENAC hypothesis about the feasible takeoff-landing procedures (Fig. 3).

Emissions scenarios of selected pollutants

The emissions scenario due to air traffic on a selected time resolution must be based on the airport layout, the aircraft fleet and the number of flights per unit time of each aircraft of the fleet. In the present study the following scenarios have been considered:

- Scenario A: present values for airport layout RW 05-23, aircraft fleet and number of flights.
- Scenario B: projected airport layout RW 12-30 and possible future fleet, including new aircraft, and number of flights, increasing up to 40% of the present.

Aircraft emit pollutants while operating on the ground and during their flight in the atmosphere and, due to mixing within the boundary layer of the atmosphere, some of these emissions affect ground level pollutant concentrations. The aircraft operations of interest within the mixing zone are defined as those in the LTO (landing and takeoff) cycle. The standard LTO cycle begins when the aircraft enters the mixing zone as it approaches the airport on its descent from cruising altitude, lands and taxis to the gate. The cycle continues as the aircraft taxis back out to the runway, takes off, and climbs out

[1] This is a limited company which provides utilities about the air traffic management. It is under the direction of the Economy and Finance Ministry and audited by ENAC.

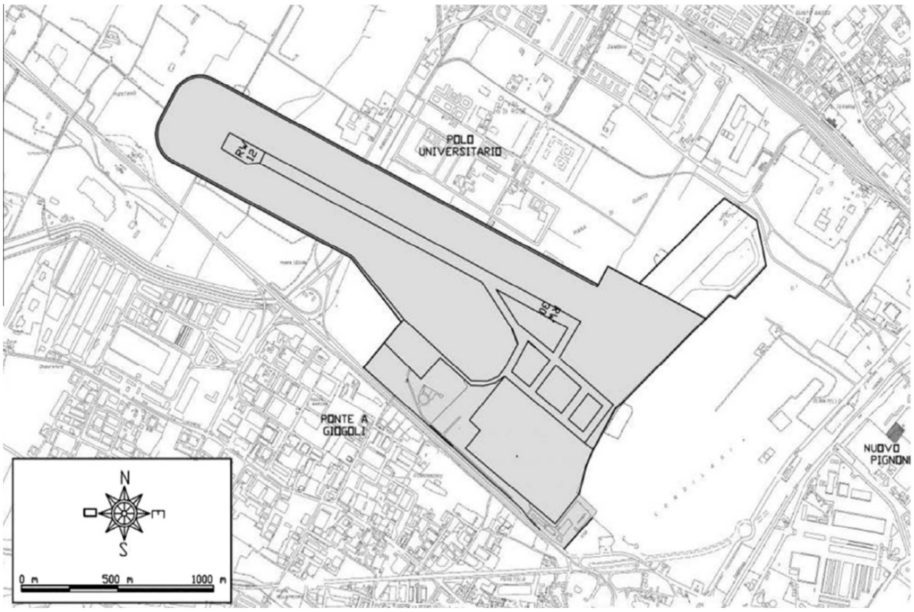

Fig. 2. Future layout of the Amerigo Vespucci airport. The direction of the runway is approximately orthogonal to the present one, allowing for different flight trajectories.

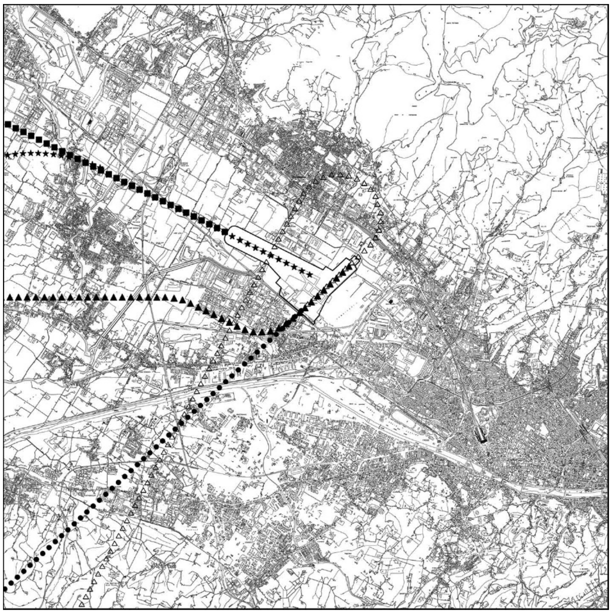

Fig. 3. Aircraft flight trajectories. Present layout: black circle = landing RW 05; black triangle = takeoff RW 23 (empty triangle = takeoff RW 05). Future layout: black square = takeoff RW 30; black star = landing RW 12.

up to cruising altitude of about 900 m. The five specific operating modes in a standard LTO are: approach, taxi/idle-in, taxi/idle-out, takeoff, and climbout.

The EDMS method of calculating the air traffic emissions involves multiplying emission factors (in mass of pollutant emitted per thousand mass of fuel burned) by the fuel flow rate (mass of fuel per unit time) by the time spent in each phase of the LTO cycle. The fuel flow rate depends on the thrust setting in each operative phase. For the reference ICAO LTO cycle it corresponds to: 30% thrust during the approach phase, 7% thrust during all the movements on the ground, 100% during takeoff and 85% thrust during climbout. Since several models of aircraft engines can power the same aircraft body, the assignment of engines to specific aircraft bodies has been defined based on the BACK database (BACK Aviation Solutions, 2005), and therefore the emission factors. In the inventory processed in this study, the emission factors for each aircraft owned by an airline have been computed as a weighted average of the combination of aircraft-engine models owned by that airline and the corresponding emission factors from the internal database of EDMS. LTO data for airline–aircraft combinations were then used to complete the inventory.

The emissions from APU and GSE equipment have been computed for each LTO cycle, assuming that APUs are employed for 13 min and GSE, including GPUs and passengers stands, for 50 min and 5 min respectively. Moreover, the GSE are assumed to work with commercial airlines only.

Scenario A: number of flights, aircraft fleet and traffic profiles

In the case of Scenario A, the present number of flights and aircraft fleet have been considered based on the real air traffic of recent years.

The commercial aviation is scheduled; thus, the fleet and the air traffic of the Scenario A (Table 1) have been collected from the airport timetable of 2011 supplied by AdF (Florence Airport Ltd.) for a total of 25,588 flights. Among the aircraft, only 10 types have been recorded as contributing more than 2% of total traffic. All aircarft accounting less than 2% of the total number of flights have been considered as flights of the most similar aircraft among the 10 reported. The general aviation is not scheduled; thus, the aircrew and the air traffic of the Scenario A (Table 2) have been collected from the actual flights performed during recent years (2007 and 2008), supplied by AdF with an average total of 7645 flights. As shown in Table 2, only 17 types of aircraft have been recorded as contributing more than 2% to the total traffic. Here again, less frequent aircraft were treated by similarity rules. The APUs of both commercial and general aviation aircraft have been attributed to each aircraft according with AdF instructions. In Table 2 only the main propulsion engines are recorded.

About traffic time profiles, the hourly averages of the Scenario A were computed as a mean of the air traffic of 3 years, 2008–2011. First of all, the monthly profile was developed from the actual air traffic of each month during these reference years. From Fig. 4 it is evident that the traffic peak of commercial aviation always occurs during summertime in July and August, and the lowest values in December and February. The general aviation has a similar monthly trend, except for August, a month during which the traffic is as low as during winter time (Fig. 4). The weekly profiles were the computed. The commercial aviation movement data have a constant profile during the week, based on the timetable of 2011. The general aviation was investigated on a sample of real schedule during six weeks (in spring, fall and winter during 2007 and 2008), from which a regular trend resulted with two low peaks on Wednesdays and Thursdays. Finally, the daily profile was built. For commercial aviation, based on the 15-min data of the timetable of 2011, both the takeoff and landing hourly counts were processed for each aircraft simulated. For the general aviation the same sample during six weeks was used to compute the takeoff and landing hourly counts for the whole aircraft category.

Scenario B: number of flights, fleet composition and traffic profiles

In the Scenario B, the new runway would allow overcoming some of the worst performances of the present airport: frequent diversions towards other airports; delays of the departures due to temporary adverse weather conditions or waiting for the runway to be available from the previous takeoff; reduced maximum size of aircraft admitted. Consequently, the improvement of the size of the runway and the management of the air traffic would probably lead to extend the offer of connections towards Europe and the whole Mediterranean area (IRPET, 2010). The combination of the general increase of air traffic expected in the next decade (EUROCONTROL, 2010; IRPET, 2010) and the new airport layout was evaluated as a potential increase of 40% of the number of flights, both in the commercial and in the general aviation. Then, a total number of 35,822 flights for the commercial aviation and 10,703 in the case of general aviation was used to assess Scenario B emissions. Within the fleet (Table 1), it was assumed that Avro RJ 85 and RJ 100, which represent about 33% of the present total traffic of commercial aviation, would be substituted. In fact these aircraft have not been manufactured since 2001 and their current widespread usage is due to their high manageability even in such short runways as those of the present Florence airport. Consequently, it is foreseen to introduce some new larger aircraft that are nowadays present in other airports and are in the fleets of the airlines working at the Amerigo Vespucci: Airbus A320, new Boeing 737, Bombardier CRJ 900 and Bombardier CRJ 1000. These aircraft will probably represent up to 37% of the whole air traffic. On the contrary, the fleet of the general aviation was left unchanged. The engine and the APU was attributed to each aircraft as in the A scenario.

The monthly and daily profiles for Scenario B were set equal to those of A for the common aircraft while the hourly profile of the new 4 aircraft of commercial aviation was built assuming that they would cover the less crowded hours.

Selection and settings of the simulation model for pollutant dispersion

The numerical simulations of dispersion of pollutants in the atmosphere have a wide field of applications and have been carefully reviewed in the scientific literature and a crowd of numerical codes are nowadays available and tested (ETC-ACC, 2010). The complex mechanisms of transport, diffusion, deposition, chemical and photochemical transformation and decay at different dynamical scales make it unfeasible to be solved by an universal model. Moreover, the whole set of these phenomena depends on the boundary and initial condition, deterministically or chaotically. Thus, the simulations of air quality impact of emission sources is largely affected by uncertainties, due to the intrinsic approximations of the models and to the meteorological and emissions input data, which should be known at a spatial and time resolution scale consistent with the dynamic scale of the models. The estimate of the uncertainties is necessary to assess the reliability of the results (Borrego

Table 1
Fleets and air traffic (total number and percentage) of the commercial aviation in the A and B scenarios.

Aircraft	Engine	Annual flights of A and B scenarios			
		A		B	
Airbus A319-100	CFM56-5A3	7676	30%	10747	30%
Avro RJ85	LF507-1F, −1H	6397	25%	–	–
Avro RJ100	LF507-1F, −1H	2047	8%	–	–
ATR 72-200	PW127F	1791	7%	1791	5%
Boeing 737-700	CFM56-7B18	512	2%	716	2%
Bombardier D.-8-Q400	PW150A	1535	6%	1433	4%
Embrarer ERJ 190	CFM56-7B20/2	3838	15%	5373	15%
Fokker 70	TAY MK620-15	768	3%	1075	3%
Fokker 100	SPEY Mk555 T.lpy	512	2%	716	2%
SAAB 2000	PW127-A	512	2%	716	2%
Airbus A320-100	CFM56-5-A1	–		3582	10%
Boeing 737 next gen	CFM56-3C-1	–		2507	7%
Bombardier CRJ-900	CF34-8C5 LEC	–		3582	10%
Bombardier CRJ-1000	CF34-8C5 LEC	–		3582	10%
Annual flights		25588	100%	35820	100%

Table 2
Fleets and air traffic (total number and percentage) of the general aviation in the A and B scenarios.

Aircraft	Engine	Annual flights of A and B scenarios			
		A		B	
Socata TB-9 Tamp.	IO-320-D1AD	1315	17%	1841	17%
Cessna 172	O-320	1140	15%	1596	15%
Raytheon Hawk. 800	TF E731-3	912	12%	1277	12%
Cessna 525 CIT. JET	JT15D-1 series	526	7%	736	7%
Cessna CIT. excel	JT15D-4 series	386	5%	540	5%
Cessna 550 CIT. II	JT15D-5, −5A, −5B	421	6%	589	6%
Dassault Falcon 2000	PW308C Annular	386	5%	540	5%
Gulfstream V	BR7007-710A1-10	333	4%	466	4%
Hawker Beech. 400	JT15D-5, −5A, −5B	228	3%	319	3%
Dassault Falcon 900	TFE731-3	351	5%	491	5%
Pilatus PC-12	PT6A-67B	298	4%	417	4%
Gulfstream IV	TAY 611-8C T.lpy IIJ	175	2%	245	2%
Cirrus SR22	TIO-540-J2B2	245	3%	344	3%
Dassault Falcon 20	CF700-2D	193	3%	344	3%
Socata TBM-700	PT6A-60	1933	3%	270	3%
Cessna 750 CIT. X	AE3007C Type 2	298	4%	417	4%
Bombardier Chall.601	CF34-3A LEC II	245	3%	344	3%
Annual flights		7645	100%	10703	100%

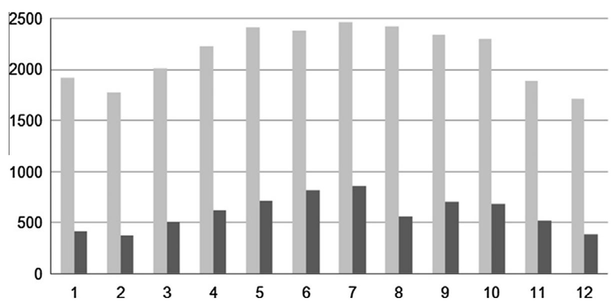

Fig. 4. Number of movements per month for commercial (pale gray) and general (black) aviation on average during 2008–2011. Months are labelled by numbers from January (1) to December (12).

et al., 2008). Thus, the choice of the appropriate numerical tool must match the modelling of the phenomena investigated and the approximation level required.

The AERMOD dispersion code coupled with the EDMS emission scenarios is able to provide the preliminary assessment of the projected airport impact on air quality. The space and time resolution and overall extension must allow to compare the pollutants concentrations with air quality standards, taking into account the existing background concentrations. The code also requires orography and meteorological conditions, as input data to the space and time resolution and extension selected. For the dynamical microscale of our study and the purpose of a screening evaluation of impacts, the hypothesis of total transformation of NO_X into NO_2 and SO_X into SO_2 has be imposed, to gain a conservative assessment, and the primary PM_{10} concentrations have been considered only.

Space and time resolution; extension of the simulation

The space and time resolutions of the simulation, determined by the dynamics of the phenomena to be investigated within the troposphere boundary layer, are typical of microscale. Thus, with an horizontal extension of up to a few kilometers and time span of up to 1 h. This time scale also matches the objective of air quality assessment compared with regulatory standards (European Parliament and the Council, 2008), which are often specific percentiles of the distributions of hourly concentration values during one year. With reference to the space resolution, this must match the requirements of the dispersion model and its algorithms depending on the orography. Several studies have investigated how the correct choice of time and spatial resolution and extension affects the results of different dispersion codes. AERMOD has a demonstrated capability of correctly predicting the monthly-averaged pollutant concentrations (Zou et al., 2010), and the model has a low sensitivity to spatial resolution below 250 m (Karppinen et al., 2011). From all these considerations, the simulations have been performed with the time resolution of 1 h and the extension of 1 year, to compute yearly statistical indexes of pollutants concentration, in a square domain 14 km wide (Fig. 5) centered at the south edge of the present runway 05 of the Amerigo Vespucci airport (UTM 676784.00 m E, 4852599.00 m N; Fig. 5). The computational mesh was chosen on a Cartesian grid with a step of 250 m on both the axis. However, the orography input required by AERMOD must be USGS-DEM (Digital Elevation Model) 7.5 min format, with a spatial resolution of 10 m. The terrain is processed by the processor AERMAP to assess the elevation of sources, first, and then to compute the elevation of receptors within the simulation domain. The database available for the present study is the DTM (Digital Terrain Model) of Regione Toscana with a 100 m horizontal step, which was interpolated with a resolution of 10 m.

Meteorological conditions

Within the simulation domain, the meteorological ground conditions are naturally observed by the measurement station located within the airport, property of the Italian Military Air Force and managed by ENAV. This station supplies hourly data of: air temperature, humidity, pressure, visibility, wind speed and direction. These data are representative of the aerodynamical pattern of the flat terrain area centered on the airport and slightly forced by the Monte Morello hill standing NE from the airport.

The AERMOD model requires both hourly surface observations and upper air soundings, or measurement from an instrumented tower, to be processed by the AERMET model. In our study, the ground meteorological data were taken from the airport station and the upper air soundings have been replaced by the dataset LAMA (Limited Area Meteorological Analysis) (Bonafè et al., 2007; Steppeler et al., 2003) supplied by ARPAER (Environmental Protection Agency of Emilia-Romagna). The data extracted from LAMA to be input in AERMET are: (i) air temperature, wind speed and direction for each layer at 60 m, 116 m, 358 m, 618 m and 970 m; (ii) roughness length; (iii) albedo; (iv) latent heat flux; (v) sensible heat flux; (vi) Monin–Obukhov length; (vii) friction velocity; (viii) convective mixing height (Bessagnet et al., 2009); (ix) convective velocity.

From this set of variables, the additional parameters required by AERMET have been computed for the present study: potential temperature gradient above PBL, convective and mechanically driven mixing height, standard deviations of the wind direction and vertical component of the wind.

Results and discussion

The emissions of CO, NO_X, VOCs, SO_X and PM_{10} over one year were computed for the two scenarios and their concentrations were simulated on the mesh of the simulation domain and compared with both the air quality standards and background concentrations.

The yearly emissions of the selected pollutants in the Scenario B show an overall increase compared to the Scenario A, up to 86% for NO_X for example, and a similar trend in the LTO phases apportionment (Tables 3 and 4). In fact, the two phases of approach and taxi/idle are responsible for $\approx$ 80% of CO emissions while the takeoff phase of $\approx$35–55% of the other pollutants emissions. However, some differences between the distributions in the two scenarios can be seen in the taxi/idle phase, which decreases its relative contribution to pollutants emission in the future scenario ($\approx 12\%$ less CO, $\approx 13\%$ less NO_X, $\approx 6\%$ less VOCs, $\approx 17\%$ less SO_X and $\approx 9\%$ less PM_{10}), while the takeoff phase increases dramatically. Those differences in the taxi/idle phases are probably due to different idle times foreseen with respect to the current situation: in the present layout the aircraft just landed must cover all the runway again to reach the gates, and the same is for the departures, when the aircraft must cover the runway in taxi mode to reach the head of RW 23. In the projected layout those operations are not needed any more: the gates area is the end point for RW 12 arrivals and the starting point for RW 30 departures (because these two are the only flight procedures admitted by ENAV and AdF forecasts). Based on these different configurations, EDMS computes the taxi/idle times that differ from the ICAO standard times.

The relevance of the Amerigo Vespucci airport emissions can be evaluated in comparison with another source, close to airport itself, that is the A1 highway (see Fig. 5, the A1 is emphasized with a bold line). The linear extension of $\approx$ 2 km of

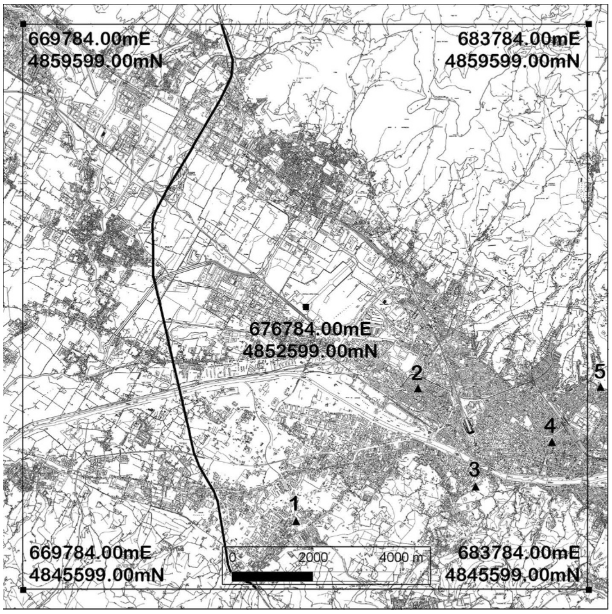

Fig. 5. Simulation domain centered at the south edge of the present runway 05 of the Amerigo Vespucci airport. The black triangles labelled with number 1, 2, 3, 4, 5 are the locations of the monitoring. The A1 highway is emphasized with a bold line on the left.

A1 traffic produce the emissions reported in Table 5 (Regione Toscana, 2008). The CO emissions are quite the same as the airport in the present operating conditions, while there is a significant difference among the other pollutants comparing the total amount of Tables 3 and 5: NO_X emissions at the airport are lower than the highway contribution (64.22 vs. 81.33 Mg/year), SO_X emissions are higher (5.85 vs. 0.39 Mg/year) and PM_{10} are lower (1. vs. 4.65 Mg/year). As for SO_X, its content in ground traffic fuels is significantly less than in aircraft engines fuels; for the difference PM_{10} emissions, it must be mentioned that EDMS computes the emission factors of PM from the Smoke Number of engines, which is missing for about 10–15% of the commercial aviation engines, thus resulting in and underestimate of this pollutant airport emissions. However, it is evident the relevance of A1 emissions, because just 2 km of highway produce a level of emissions equivalent to the contribution of the whole airport.

The concentrations of CO, NO_X, SO_X and PM_{10}, computed with AERMOD on the domain grid with receptors placed at 1.8 m above the ground, provide an estimate of the air quality impact of the airport, to be compared with the air quality standards (European Parliament and the Council, 2008) of CO, NO_2, SO_2 and PM_{10}. VOCs are not included in this comparison, as there is no standards for these substances. Moreover, as the area under study is stressed by other sources, as mentioned above, the background concentrations must also be accounted. Those background concentrations are provided by the regional network of monitoring stations, ruled by Directive 50/2008/EC (European Parliament and the Council, 2008) and property of the local authority (Provincia di Firenze). In the present study the data from urban traffic stations have been selected only (see Fig. 5, those stations are labelled with numbers 1, 3 and 5), referring to 2011, except for SO_2 values referring to 2010 (ARPAT, 2011).

Table 6 represents a comparison of the indicators of concentrations due to the dispersion of the pollutants emitted in the Scenario B with both the corresponding air quality standards (European Parliament and the Council, 2008) and background values.

The dispersion of airport emissions in the atmosphere produces pollutants concentrations below the air quality standards of all the substances, except for NO_X, and contributes marginally to background concentrations, except for NO_X and SO_X.

Table 3
Annual aircraft emissions for each LTO phase and APU and GSE emissions: A scenario (Mg/year).

A scenario	CO	NO_X	VOC	SO_X	PM_{10}
Approach	16.65	8.025	1.56	1.35	0.135
Taxi/idle	24.0	3.20	4.39	0.87	0.075
Takeoff	4.9	33.05	4.68	1.98	0.23
Climbout	5.2	14.75	0.17	1.185	0.11
Total	50.75	59.03	10.8	5.39	0.55
APU	4.2	2.85	0.17	0.39	0.30
GSE	0.6	2.34	0.19	0.07	0.145
Total	55.55	64.22	11.16	5.85	1.00

Table 4
Annual aircraft emissions for each LTO phase and APU and GSE emissions: B scenario (Mg/year).

B scenario	CO	NO_X	VOC	SO_X	PM_{10}
Approach	24.52	16.3	2.21	2.44	0.20
Taxi/idle	30.27	5.17	5.39	1.21	0.095
Takeoff	7.722	63.2	7.82	3.71	0.41
Climbout	7.575	25.2	0.27	1.92	0.17
Total	70.09	109.9	15.7	9.29	0.87
APU	8.22	5.8	0.45	0.82	0.73
GSE	0.74	2.87	0.235	0.01	0.17
Total	79.05	118.6	16.4	10.1	1.77

Table 5
Annual A1 highway traffic emissions (Mg/year) due to 2 km.

CO	NO_X	VOC	SO_X	PM_{10}
52.45	81.33	6.07	0.39	4.65

Table 6
Statistical index, regulatory limit, background and Scenario B concentrations for each pollutant selected.

Pollutant	Statistical index on 1 year	Regulatory limit (Directive 2008/50/EC) μg/m^3	Bckgr μg/m^3	Scenario B μg/m^3
CO	Max. daily mean 8 h	10^4	$3 \cdot 10^3$	$0.25 \cdot 10^3$
NO_X as NO_2	Annual mean	40	34	30–40
SO_X as SO_2	Annual mean	20	1	1.5–3
	Max. daily mean	125	-	6–12
PM_{10}	Annual mean	40	29	1.5–2.5

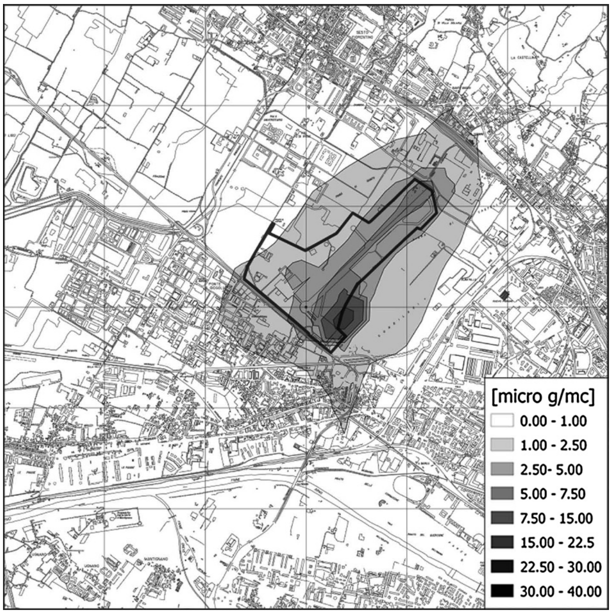

Fig. 6. Distribution of mean annual concentration of NO_X in Scenario A.

With reference to NO_X, the yearly air quality standard of 40 μg/m^3 of NO_2 is potentially reached in the gates area. For SO_X, the maximum levels are well below ($< 10\%$) the yearly and daily limit of SO_2, but the contribution is relevant, scoring up to 50% of the background level in the nearby zones. As for fine particulate matter, primary PM_{10}, the maximum levels are less than 1.5 μg/m^3 (yearly) and 12.5 μg/m^3 (daily, 24-h). These values are well below the regulatory limits (40 and 50 μg/m^3), and

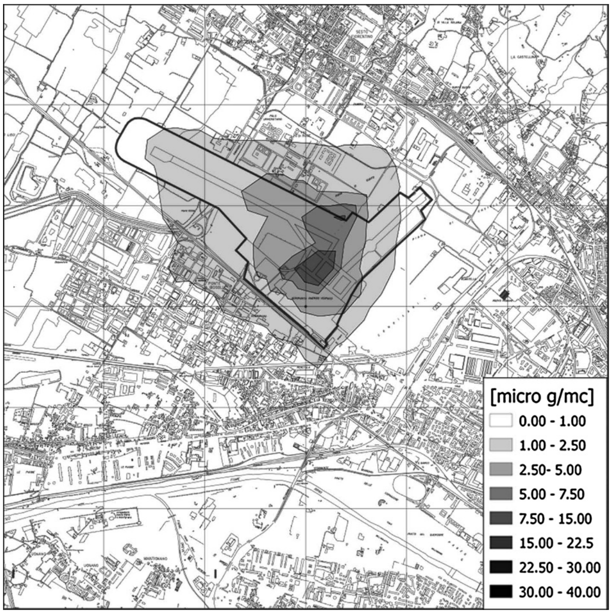

Fig. 7. Distribution of mean annual concentration of NO_X in Scenario B.

must be compared to the background of 29 $\mu g/m^3$ of the annual mean (which is the main relevant indicator, as the daily mean overcomes the threshold for 37 days in 2011, more than the regulatory 35 days permitted). However, the emission factors of PM_{10} are indirectly computed from the Smoke Number of engines, which is not available for the whole aircraft fleet, thus resulting in and underestimate of this pollutant. As most of the PM airport emissions are in the $PM_{2.5}$ class, it can be extrapolated that the maximum yearly average concentrations cannot even reach 50% of the regulatory limit (25 $\mu g/m^3$), even if they are confined within the airport area.

For the comparison of the present and future scenarios, it is suggested to make specific reference to the maps of spatial distribution of the annual mean of NO_X (see Figs. 6 and 7): from these, it is evident that the different runway orientation determines a different pattern, even if the largest concentrations are always encountered in the gates area.

Conclusions

The pollutants emissions from the Amerigo Vespucci Airport in Florence, Italy, and the resulting impact on air quality were calculated. The emissions scenarios due to air traffic were considered in two reference scenarios: case A is representative of the present airport layout RW 23-05, aircraft fleet and number of flights; case B considers the projected airport layout RW 12-30 and the possible near-future fleet, including new aircrafts, and an increased (40%) number of flights. The air traffic conditions were modelled for both commercial and general aviation, applying daily, weekly and monthly emissions profiles.

The emission inventory was developed using the FAA-recommended EDMS 5.1.3 model for CO, NO_X, SO_X, VOCs and PM_{10} based on a detailed database of aircraft, engines and emission factors. The emission factors of PM_{10} were indirectly calculated from the Smoke Number of the aircraft engines, which is not available for the whole aircraft fleet, thus resulting in and underestimate of this pollutant. The emissions of Scenario B are expected to increase in general, clearly due to the increased (40%) air traffic, which is however mitigated by the improved runway orientation and logistics, and by the advancements in the characteristics of the aircraft fleet (larger and more modern aircraft). In both scenarios A and B the total emissions are subdivided among the main phases of the LTO cycle, referring to the single flight/aircraft. The results show that the takeoff phase is mainly responsible of NO_X, SO_X and PM_{10} contributions. However, some differences between the distributions in the two scenarios can be individuated: in case B the takeoff phase increases dramatically while the taxi/idle phase decreases its relative contribution. This results from the fact that the taxi/idle time can be effectively reduced in the future layout, where the gates area is the end point for RW 12 arrivals and the starting point for RW 30 departures.

The relevance of airport emissions in the area, among other pollutants sources, can be considered equivalent to the 2 km of the A1 highway connection.

Based on the detailed EDMS emissions inventory, a complete year-long (2011) simulation using AERMOD was performed over the domain surrounding the airport with a grid resolution of 250 m and receptors placed at a height of 1.8 m over complex terrain. The statistical indexes of concentrations of CO, NO_X, SO_X and PM_{10}, were compared both with the corresponding air quality standards and with the background values of CO, NO_2, SO_2 and PM_{10}. As a result of the future scenario,

NO_X potentially reaches both the yearly air quality standard of 40 $\mu g/m^3$ of NO_2 in the gates area and the present background level. SO_X records maximum levels well below the yearly and daily limit of SO_2, however, its concentration is relevant, scoring up to 50% of the background level in the nearby zones.

In the comparison between Scenario A and Scenario B, the impact of the future scenario results in larger concentration levels of all the pollutant; moreover the different runway orientation determines a different pattern of pollutants impact, even if the largest concentrations are always encountered in the gates area.

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References

ARPAT, 2011. Relazione annuale sullo stato della qualità dell'aria nella Regione Toscana, Anno 2011, Rete Regionale di Rilevamento della Qualità dell'Aria, Area Vasta Costa.

BACK Aviation Solutions, 2005. Aviation Link: FLEET. Users Guide. Edition 16. June 2005.

Bessagnet, B., Menut, L., Curci, G., Hodzic, A., Guillaume, B., Liousse, C., Moukhtar, S., Pun, B., Seigneur, C., Schulz, M., 2009. Regional modeling of carbonaceous aerosols over Europe – focus on secondary organic aerosols. J. Atmos. Chem. 61, 175–202.

Bonafè, G., Deserti, M., Jongen, S., Minguzzi, E., Stortini, M., 2007. Validation of meteorological input for air quality simulations in Northern Italy. Dev. Environ. Sci. 6, 768–770, ISSN: 1474-8177/DOI:10.1016/S1474-8177(07)06820-9.

Borrego, C., Monteiro, A., Ferreira, J., Miranda, A., Costa, A.M., Carvalho, A., Lopes, M., 2008. Procedures for estimation of modelling uncertainty in air quality assessment. Environ. Int. 4, 613–620.

European Parliament and the Council, 2008. Directive 2008/50/EC of the European Parliament and of the Council of 21 May 2008 on Ambient Air Quality and Cleaner Air for Europe.

EEA Technical Report No 102011. The Application of Models Under the European Union's Air Quality Directive. A Technical Reference Guide.

ETC-ACC, 2010. Guidance on the Use of Models for the European Air Quality Directive, A Working Document of the Forum for Air Quality Modeling in Europe, FAIRMODE, ETC-ACC Report Version 6.2, 99 pp.

EUROCONTROL, 2010. Long-Term Forecast, Fligth Movements 2010-2030, STATFOR, EUROCONTROL.

IRPET, 2010. Lo viluppo dellaeroporto di Firenze, Istituto Regionale Programmazione Economica Toscana, ISBN 978-88-6517-016-8, 99 pp.

Karppinen A., Kangas, L., Soares, J., Riikonen, K., Denby, B., Kukkonen, J., 2011. Effect of spatial and temporal resolution on exposure modeling. In: Proceedings to the 14th Conference on Harmonization within Atmospheric Dispersions Modelling for Regulatory Purposes.

Miracolo, M.A., Hennigan, C.J., Ranjan, M., Nguyen, N.T., Gordon, T.D., Lipsky, E.M., Presto, A.A., Donahue, N.M., Robinson, A.L., 2011. Secondary aerosol formation from photochemical aging of aircraft exhaust in a smog chamber. Atmos. Chem. Phys. 11, 4135–4147.

Regione Toscana, 2008. Inventario Regionale delle Sorgenti di Emissione in aria ambiente. Aggiornamento allanno 2007. Firenze, Italy.

Schurmann, G., Schafer, K., Jahn, C., Hoffmann, H., Bauerfeind, M., Fleuti, E., Rappengluck, B., 2007. The impact of NO_X, CO and VOC emissions on the air quality of Zurich airport. Atmos. Environ. 41, 103–118.

Steppeler, J., Doms, G., Schttler, U., Bitzer, H.W., Gassmann, A., Damrath, U., Gregoric, G., 2003. Meso-gamma scale forecasts using the nonhydrostatic model LM. Meteorol. Atmos. Phys. 82, 75–96.

USEPA, 2004. Guideline on Air Quality Models. 40 CRF Ch. I, Appendix W to Part 51, U.S. Environment Protection Agency.

USEPA, 2004. Aermod: Description of Model Formulation, U.S. Environmental Protection Agency Report-454-R-03-004, 99 pp.

USEPA, 2004. Addendum: Aermod, Model Formulation Document, U.S. Environment Protection Agency.

USEPA, 2005. Guideline on Air Quality Models. 40 CRF Ch. I, Appendix W to Part 51, U.S. Environmental Protection Agency, 92 pp.

Venkatram, A., 1980. Dispersion in the stable boundary layer. In: Venkatram, A., Wyngaard, J.C. (Eds.), Lectures on Air Pollution Modeling. American Meteorological Society, Boston, p. 390.

Venkatram, A., 1983. On dispersion in the convective boundary layer. Atmos. Environ. 16, 245–248.

Wayson, R.L., Fleming, G.G., Iovinelli, R., 2009. Methodology to estimate particulate matter emissions from certified commercial aircraft engines. J. Air Waste Manage. Assoc. 59, 91–100.

Wood, E.C., Herndon, S.C., Timko, M., Yelvington, P.E., Miake-Lye, R.C., 2008. Speciation and chemical evolution of nitrogen oxides in aircraft exhaust near airports. Environ. Sci. Technol. 42, 1884–1891.

Wormhoudt, J., Herndon, S.C., Yelvington, P., Miake-Lye, R.C., 2007. Nitrogen oxide ($NO/NO_2/HONO$) emissions measurements in aircraft exhausts. J. Propul. Power 23, 906–911.

Zou, B., Zhan, B., Wildson, J., Zeng, Y., 2010. Performance of AERMOD at different time scales. Simul. Model. Pract. Theory 18, 612–623.