# Air Quality Assessment Sensitivities

## Zurich Airport Case Study

## Contents

# 1. Introduction

## 1.1. Airport Emission Calculations

In response to legal requirements, obligations under capital development program permits or corporate social responsibility, more and more airports undertake local air quality assessments with calculated emission inventories, modelled pollutant concentrations and measured air quality levels.

A comprehensive guidance manual has been developed by ICAO's Committee on Aviation and Environmental Protection (CAEP) as "Document 9889" [1]. It incorporates best airport business practices and guidance from aircraft and engine manufacturers and aviation organisations. This document provides a systematic approach to local air quality assessments at various levels depending on the purpose of the assessment and the available resources and information. To this end, the manual provides guidance for simple, advanced and sophisticated approaches with each level requiring more complex information. While a simple approach may give reasonable indications on the local air quality emissions, it is recommended to try and use the best possible data and level of sophistication for such assessments.

One of the questions often asked is what the difference in results is between simple methods and more advanced methods and, subsequently, whether efforts are justified to acquire additional data and information for more complex assessments.

The purpose of this study is to demonstrate the sensitivities in air quality assessments at one airport using the different approaches and levels of expertise described in the ICAO guidance manual.

## 1.2. Zurich Airport Case Study

The case study is based on Zurich airport's 2008 traffic unless otherwise stated. The data includes all aircraft operations and aircraft handling activities, as well as the operation and maintenance of the airport infrastructure and all landside road access in the closer vicinity of the airport. It includes all sources as described in ICAO Doc 9889 (Table 1). The substances considered in the study are nitrogen oxides (NOx), hydrocarbons (HC), carbon monoxide (CO), particulate matter (PM) and the greenhouse gas carbon dioxide (CO2). Other substances are of lesser relevance in the context of Zurich airport and are thus not included in this study.

The model used for the study is LASPORT version 2.0 (LASAT for airports) [2]. This model was initially developed in 1999 on behalf of the German Airports Association (ADV) and further developed in 2008-2009 to incorporate the various approaches and calculation guidance as described in ICAO Doc 9889. It is being used for ICAO CAEP policy assessments and simulations alongside other international local air quality models.

The model is able to calculate emissions at various levels of detail, depending on the availability of data (Figure 1 for aircraft engine emissions). The advanced module includes the aircraft performance module ADAECAM (advanced aircraft emission calculation method), which considers actual atmospheric conditions such as wind, temperature, pressure and humidity, and assumptions on the actual take-off mass of aircraft [3]. For a visual impression of the study set-up of Zurich airport in LASPORT, refer to Annexe A.2.

For the purpose of this study, the emission sources "aircraft main engine" and "aircraft APU" are analysed in more detail using the various approaches described in ICAO Doc 9889. The other sources (Table 1) are included in order to put all emission sources in context, but are not calculated with various levels of complexity. The relevant calculation method is described in more detail in each section.

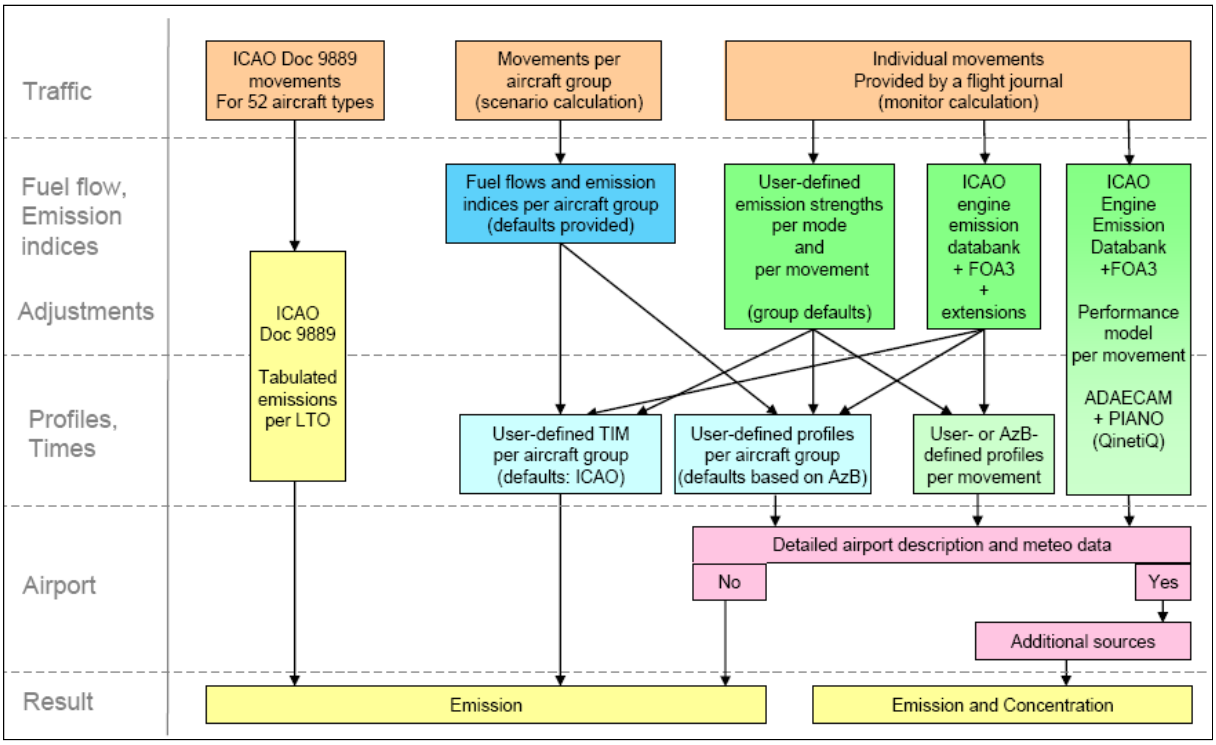



Figure 1 LASPORT aircraft calculation methods

| Source Group | Emission Source | Comments |
|---|---|---|
| Aircraft | Main Engines | Includes engine ignition to idle |
| | Auxiliary Power Units | |
| | Brakes and Tires | PM only |
| Aircraft Handling | Ground Support Equipment | Includes GPU |
| | Aircraft Refuelling | HC only |
| | Aircraft De-Icing | De-icing agents and applying machinery (trucks) |
| | Airside vehicle traffic | |
| Airport Infrastructure | Power plant/boiler house | Includes all furnaces |
| | Emergency power generation | |
| | Airport Maintenance | Building, greenery, surface de-icing |
| | Aircraft Maintenance | Hangars, paint shops, engine run-ups |
| | Fuel stations and fuel farm | HC only |
| | Construction activities | |
| | Fire training | |
| Landside Access | Vehicles | Closer vicinity of airport |
| | Trains | Energy ($CO_2$) only |

Table 1 Zurich Airport Emission Sources

# 2. Zurich Airport

Zurich airport is the largest airport in Switzerland and the main gateway for air travel to the country (Figure 2). It is used as a hub airport by its main carrier, Swiss International Airlines. It is embedded in a densely populated area with downtown Zurich being only approximately 8.5 km distant. While there is little industry in the area, there are several main highways and main roads connecting the city, the airport and the many communities.

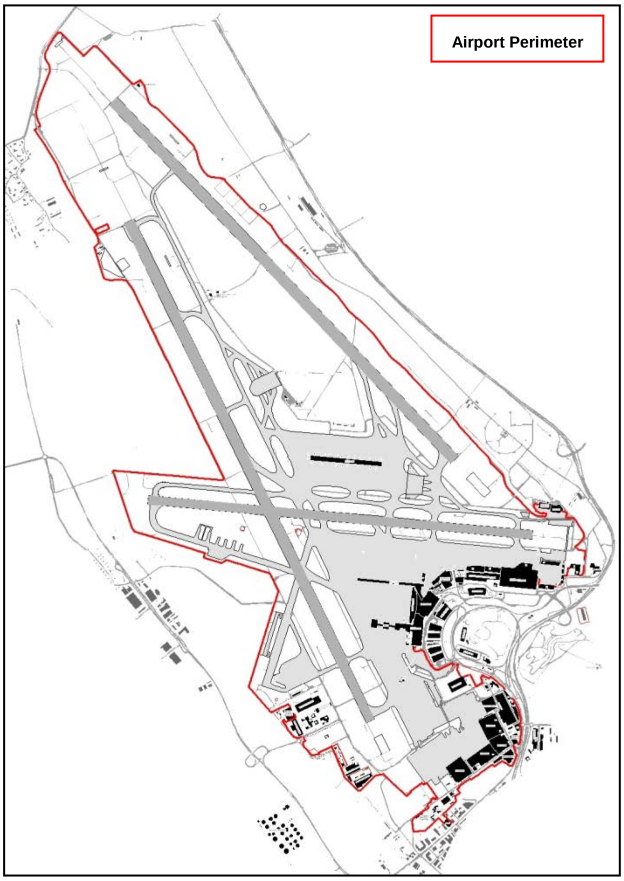



Figure 2 Zurich Airport

| **Traffic** | **2008** |
|---|---|
| Commercial Movements | 231,775 |
| General Aviation Movements | 43,216 |
| Total Movements | 274,991 |
| | |
| Passengers (mio.) | 22.1 |
| Cargo/mail (t) | 419,843 |
| Work Load Units (mio.) | 26.3 |
| Number of Destinations | 174 |
| Number of Airlines | 88 |
| **Infrastructure** | |
| Runways | 3 |
| Aircraft positions | |
| - Pier stands | 90 |
| - Remotes stands | 48 |
| - Long term parking | 6 |
| - General aviation (max.) | 114 |
| Airport perimeter ($km^2$) | 8.8 |

Zurich airport is operated by Flughafen Zürich AG, a private company under a concession of the Federal Department of Energy, Transport, Environment and Communications. A number of tasks are performed by third parties, e.g. aircraft handling and maintenance services, cargo services, fuel services, air navigation services and security.

Provisions in the airport's operating manual require the airport to annually report $NO_x$ emissions from aircraft, handling and infrastructure to the federal and cantonal authorities. If an implied threshold of 2,400 t of $NO_x$/a is exceeded, the airport is required to conduct an additional analysis (emissions and concentrations) and develop a new mitigation plan to be endorsed by the federal authorities.

# 3. Airport Emission Inventory

## 3.1. Aircraft Emissions Sensitivities

As described in ICAO Doc 9889, aircraft emissions include emissions from the main engines, the APU (auxiliary power units), main engine start-up and the particulate matter emissions from brake and tyre wear. In this section, emissions from the aircraft main engines and the APU are calculated using different method approaches and variations in performance affecting parameters.

### 3.1.1. Aircraft Main Engines

Emission inventories of aircraft in the vicinity of airports are traditionally calculated using ICAO engine exhaust emission data and the ICAO reference LTO cycle, the latter sometimes adapted to airport specific taxi times. Initially intended for certification purposes, the LTO cycle cannot sufficiently account for operational issues (flex-rated take-off, climb profiles). Consequently, an operational aircraft LTO cycle has also been defined as the basis for performance based modelling (Table 2).

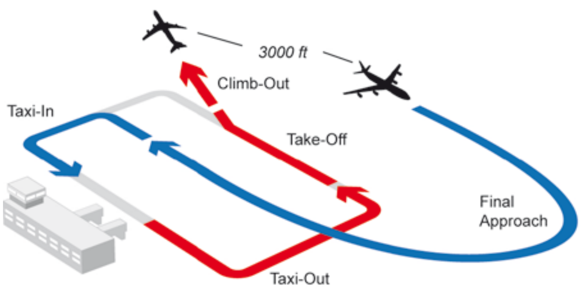
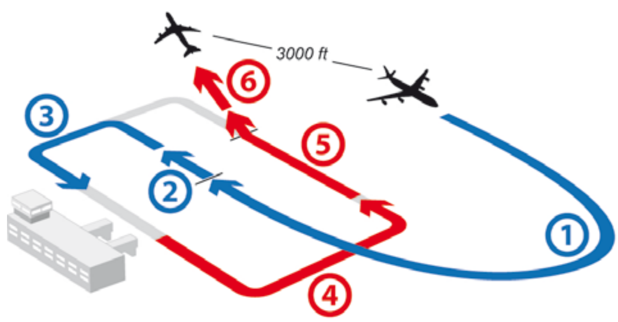
| ICAO Certification Reference LTO-Cycle | Operational Aircraft LTO-Cycle |
|---|---|
|  |  |
| 4 phases with defined thrust and time in mode. | 6 phases with climb out being split into (5) initial climb (lift off to main throttle back) and (6) final climb (throttle back to 3000 ft) and approach split into (1) approach to touch down and (2) touch down to end of rollout. (3) Taxi-in and (4) taxi-out stay the same. |

Table 2 ICAO reference and operational aircraft LTO Cycle

In a first set of sensitivity calculations, the approaches as listed in Doc 9889 are applied, ranging from a very simple approach (publicly available look-up table) to a very advanced approach (sets of publicly available information, with some data under license agreements). Specifically the following approaches have been used (Table 3; for more detailed information refer to Annexe 4):

| Scenario | Fleet and engines | Emission calculation |
|---|---|---|
| A | Number of cycles for a given set of aircraft (Simple Method) | UNFCCC look up table (Simple A) |
| B | Aircraft types with default/representative engine (Advanced) | ICAO certification reference LTO-cycle and EEDB (Simple B) |
| C | Actual aircraft engine combinations (by UID) (Sophisticated) | |
| D | | ICAO certification reference LTO-cycle with actual aircraft taxi times (Simple B and Advanced A) |
| E | | Performance based modelling with operational LTO-cycle (cf table 2) (Advanced B): Meteorological parameters: daily 06-22 hours average |

Table 3 Calculation Scenarios

The results of the first set of sensitivity calculations (Scenarios A through E) are listed in Table 4 for the various substances. For more detailed results (emissions per individual LTO-mode), refer to the tables in Annexe 4.

| Substance | | Approach A (UNFCCC Table) | Approach B (Repres. fleet, ICAO certification LTO) | Approach C (Detailed fleet, ICAO certification LTO-cycle | Approach D Detailed fleet, actual taxi times | Approach E (Detailed fleet, performance based) |
|---|---|---|---|---|---|---|
| **$NO_x$** | **(t/a)** | 1'078 | 1'273 | 1'242 | 1'179 | 912 |
| **HC** | **(t/a)** | 110 | 136 | 207 | 141 | 215 |
| **CO** | **(t/a)** | 1'099 | 1'214 | 1'686 | 1'146 | 1'354 |
| **PM** | **(t/a)** | - | 13 | 13 | 11 | 10 |
| **$CO_2$** | **(t/a)** | 268'096 | 330'351 | 333'820 | 281'828 | 248'691 |

Table 4 Aircraft Engine Emission summary results

The results from Scenarios A to E reflect the increase in calculation complexity for the same set of traffic data. The differences in results between Scenarios B and C are only due to the more refined fleet identification by using the detailed fleet (Sophisticated Method with each aircraft with its actual engine identification) versus the representative fleet (Advanced Method with each aircraft with a typical representative engine).

The differences between Scenarios C and D result from the variation in the taxi-time of aircraft by using the actual taxi-time for each individual movement, as opposed to using the ICAO certification time in mode of 26.0 minutes for each aircraft cycle.

The results in Scenario E finally reflect the most advanced modelling methodology that uses the integrated performance model, ADAECAM (advanced aircraft emission calculation model). As would be expected from previous studies [e.g. 4, 5], the actual fuel burn (resulting in $CO_2$) as well as $NO_x$ and PM emissions are considerably lower than when using traditional calculation approaches. Conversely, the emissions from HC and CO are higher, due to the inverse relationship between fuel burn and emission indices for those substances.

The results of Scenario A seem to give fairly good results compared to Scenario E. However, there are various factors that influence the end results: variety of aircraft models, actual engine considered, taxi time and other times in mode. While for Zurich airport, the factors overestimating and underestimating the results seem to balance out, this could be very different for other airports. As such, it cannot generally be concluded that the Scenario A is "almost" as good as the Scenario E.

Zurich Airport has calculated aircraft engines emissions since 1991, using the Scenario D method. With the availability of the more advanced model LASPORT 2.0, Zurich Airport changed the aircraft engine calculation method to the Scenario E method in 2008.

A second set of sensitivity calculations has been performed focussing on the sensitivity of ambient conditions. Specifically, the meteorological parameters have been changed, using varying assumptions for temperature, pressure and humidity [6]. The results are listed in the following Table 5 (aircraft engine emissions up to 3,000 ft, without start-up, in metric tonnes) for the aircraft movement data for the year 2007.

| **Case name** | **Description** | **Fuel burn** | | **$NO_x$** | | **HC** | |
|---|---|---|---|---|---|---|---|
| ICAO-LTO | Certification (ICAO) fuel flows, emission indices, and times-in-mode | 100,372 | 100% | 1172 | 100% | 198 | 100% |
| ICAO-LSP | Certification (ICAO) fuel flows and emission indices, individual LASPORT default profiles | 84,192 | 84% | 1072 | 91% | 141 | 71% |
| ADC-ISA | ADAECAM emissions and profiles, ISA conditions (15.0C, 1013.25 hPa, 60%) | 74,363 | 74% | 834 | 71% | 181 | 91% |
| ADC-TY | ADAECAM emissions and profiles, ISA conditions but plain annual average temperature (10.3C) | 74,363 | 74% | 751 | 64% | 217 | 110% |
| ADC-TPRY | ADAECAM emissions and profiles, annual averages for temperature, pressure, humidity (10.3C, 967.48 hPa, 77%) | 74,363 | 74% | 806 | 69% | 186 | 94% |
| ADC-TPRD | ADAECAM emissions and profiles, time series of temperature, pressure, humidity in form of daily means (average between 6:00 and 22:00) | 74,363 | 74% | 858 | 73% | 203 | 103% |
| ADC-TPRH | ADAECAM emissions and profiles, time series of temperature, pressure, humidity in form of hourly means | 743,63 | 74% | 864 | 74% | 208 | 105% |

Table 5 Aircraft engine emission results for varying atmospheric conditions (t/a)

Temperature has the strongest effect on the emission indices. On average, the $NO_x$ emissions increase by about 2% with an increase of ambient temperature by 1°C. Sensitivity to pressure and relative humidity is smaller, but not negligible. HC (and CO) emissions are more sensitive to ambient changes than $NO_x$ emissions.

### 3.1.2. Aircraft APU

Aircraft APU are used on the ground to provide electricity and air conditioning to the aircraft. However, air conditioning is only needed for temperatures typically outside the range of 0°C-18°C or during long periods on the ground. In addition, APU are used for the main engine start-up. At Zurich airport, all pier stands are equipped with fixed ground power and pre-conditioned air, and the use is mandated by the airport operating manual [7]. At open stands, mobile GPU are available for electricity, but there are insufficient mobile air conditioning units for all stands. As such, the actual operating time of APU has to be independently modelled by considering the aircraft ground time, the aircraft stand allocation and the ambient conditions (temperature).

To demonstrate the sensitivity of the APU emissions, various scenarios are calculated using two approaches for both the Simple and Advanced Methods (Table 6). In Approach A, it is assumed that there is no fixed ground power or GPU available and in Approach B, the fixed ground power is used to its fullest extent. The Simple and Advanced Methods differ in the availability of information on APU types and assignments, and the APU operating times. APU emission factors (Simple and Advanced) and generic operating times (Simple) are found in the ICAO Doc 9889.

| | **Simple Approach (A)** | **Advanced Approach (A)** | **Simple Approach (B)** | **Advanced Approach (B)** |
|---|---|---|---|---|
| Fleet definition and emission indices. | Aircraft fleet in 2 categories (short and long haul), each with generic APU | Aircraft individually assigned with one of seven generic APU- types | Aircraft fleet in 2 categories (short and long haul), each with generic APU | Aircraft individually assigned with one of seven generic APU- types |
| APU Operating times | 45 min short haul (SH or narrow body)<br>75 min long haul (LH or wide body)) | Modelled actual time (assuming no fixed ground power, local regulation applied (limited max. APU operating times)) | Generic estimate, depending on gate electrification:<br>15' NB/WB with<br>52' NB without<br>75' WB without | Modelled actual time (dependent on aircraft stand, ground time and ambient temperatures) |
| **Substance** | | | | |
| NOx (t/a) | 107.0 | 111.7 | 63.2 | 19.5 |
| HC (t/a) | 5.3 | 13.9 | 2.9 | 7.5 |
| CO (t/a) | 36.9 | 65.0 | 25.3 | 22.2 |
| PM (t/a) | 3.3 | 12.9 | 2.1 | 2.6 |
| $CO_2$ (t/a) | 39,521 | 42,190 | 23,022 | 8,978 |

Table 6 APU emission using various methodologies

Approach A shows little differences for fuel burn (or $CO_2$) and $NO_x$ between the Simple and Advanced Methods. While some differences can occur from the assumptions in operating times, the largest part of the difference occurs by applying more detailed emission factors (seven generic APU models instead of two) for HC, CO and PM. Approach B, describing a scenario as applied at Zurich airport (fixed ground power and PCA available on most stands), shows larger differences in $NO_x$ and $CO_2$ with lower emissions from the Advanced

Method. This is driven by both the more detailed emission factors and the refined modelling of the APU operating times. For simplicity reasons, the (small) effects on the GPU emissions have not been taken into account.

### 3.1.3. Other Aircraft Emissions

Other aircraft emissions include engine start-up to idle (HC emissions) and brake and tyre wear. Both types of emissions are not considered in the Simple Method, but are accounted for in the Advanced Method. Engine start-up to idle emission calculation follows the ICAO Doc 9889 guidance. Aircraft brake and tyre PM emission factors are based on work done for the Heathrow Project for Sustainable Development (HPSD).

## 3.2. Other Airport Emissions

Emissions from airport operation further include aircraft handling, airport infrastructure and landside access. They are calculated using various methods as pre-processors to the LASPORT system. They are briefly described in the following section, while the emission calculation results are summarised in Table 7. There is no separate modelling with simple and advanced methods, as only advanced methods have been developed for Zurich airport.

### 3.2.1. Aircraft Handling

- Ground Support Equipment: In this bottom up approach, each type of GSE is identified for the service of an aircraft and its operating time estimated depending on aircraft size (large, medium, small, regional, business, turboprop), type of operation (arrival or departure) and stand usage (pier or remote stand). Emission indices from industry sources are used and average handling emission loads per operation calculated [8].
- Aircraft refuelling: HC emissions from refuelling activities, dependant on the aircraft stand (fuel pit available or fuelling by trucks).
- Aircraft de-icing: Emissions from the application of de-icing agents with the agent itself and the emissions of the machinery (de-icing trucks).
- Airside vehicle traffic: Emissions from vehicles circulating on the airside area of the airport. All airside roads are identified and vehicle counts of cars, vans and trucks conducted. For each road segment, an average traffic pattern (speed) is determined and the specific emission indices applied as suggested by the Federal authorities [9].

### 3.2.2. Airport Infrastructure

- Power plant/boiler house and emergency power stations: Specific operational parameters (operating hours, fuel consumption, load factor, installed capacity) and fuel and emission indices are used for all power and heat producing plants, including stand alone furnaces and emergency power stations.
- Airport maintenance: This includes cleaning agents, building maintenance and repairs as well as maintenance of the greeneries. Surface de-icing is also included with emissions from de-icing agents and from the machinery. Emission factors are used as suggested by the industry.
- Aircraft maintenance: This includes aircraft hangars with cleaning and paint shops (emission factors from the industry) and all engine test runs and run-ups, using detailed statistics on engine type, run-up operation and ICAO engine emission factors.
- Fuel stations and fuel farm: Operational information on fuel stored and dispensed with emission indices from industry.
- Construction activities: A specific model has been developed using emission factors for construction equipment and airport specific construction activities (e.g. apron resurfacing), thus generating emission loads per unit of typical tasks.

- Fire training: Amount and specific emission factors are used for various typical training agents for the airport fire service (e.g. butane, kerosene, wood).

#### 3.2.3. Landside Access

- Road access: The methodology applied is the same for the airside vehicle traffic. It also includes turn-off, start-up and evaporation emissions from vehicles. The system boundary is where vehicles would turn off from the regional road system into the dedicated airport road system. This is on average a distance of approximately 3 km from the central terminal area (see illustration in A.2).
- Trains: $CO_2$-emissions only are calculated using factors provided by the Swiss Federal Railway and passengers counts at the airport. The study area covers the train lines from the airport to both the city of Zurich (South, 5 km) and Winterthur (Northeast, 8 km).

## 3.3. Total Airport Emissions

The total airport emissions including all four source groups are listed in Table 7. For the aircraft emissions, only results for one simple and one advanced method for the aircraft are listed (aircraft: Scenarios B and E; APU: Approach B). The results of the methods as discussed in Section 3.1 are thus set in context with all other airport related emissions.

| **Source** | **$NO_x$ (t)** | | **HC (t)** | | **CO (t)** | | **PM (t)** | | **$CO_2$ (1,000 t)** | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Simple | Adv. | Simple | Adv. | Simple | Adv | Simple | Adv | Simple | Adv |
| Aircraft | 1,336 | 932 | 178 | 263 | 1,239 | 1,376 | 19 | 16 | 353.4 | 257.7 |
| Aircraft Handling | 75 | 75 | 22 | 22 | 29 | 29 | 4 | 4 | 6.3 | 6.3 |
| Infrastructure | 58 | 58 | 82 | 82 | 33 | 33 | 2 | 2 | 40.4 | 40.4 |
| Landside Traffic | 26 | 26 | 11 | 11 | 135 | 135 | 1 | 1 | 11.5 | 11.5 |
| **Total** | **1,495** | **1,091** | **293** | **378** | **1,436** | **1,573** | **26** | **23** | **411.6** | **315.9** |
| Difference | | -27% | | +29% | | +10% | | -12% | | -23% |

Table 7 Total airport emission sources in a simple and advanced method

The results demonstrate the general prediction that the gain in accuracy when increasing the level of calculation and modelling sophistication leads to lower emissions in $CO_2$, $NO_x$ and PM and higher emissions in HC and CO. Depending on the governing requirements for emission inventory calculations, extra efforts are justified to better reflect the emissions from the airport activities.

The aircraft share of the total airport emissions is demonstrated for the chosen assumptions of the boundaries for both the aircraft and the landside traffic. In addition, the results do not give any indication for the concentrations or the impacts in the airport area.

## 3.4. Global Emissions

Although Zurich Airport is unable to influence global emissions from aircraft and their impacts on the climate, it is actively committed to supporting international efforts to reduce emission levels. EUROCONTROL – the European Organisation for the Safety of Air Navigation – has estimated that the volume of overall emissions resulting from all IFR flights from Zurich Airport in 2008 includes approximately 13,220 tonnes of nitrogen oxides ($NO_x$) and 2.97 million tonnes of carbon dioxide ($CO_2$). This has been calculated using the model AEM (advanced emissions model) and EUROCONTROL's own flight database and includes the LTO cycle [10]. In order to avoid potential double counting, only one way (departing flights) are calculated with the LTO cycle applied fully to Zurich airport.

## 3.5. Special Reporting on $CO_2$

Based on the available data and the modelling of the respective emissions, the $CO_2$-emission foot print of the airport can be derived. For this purpose the GHG Protocol [11], in combination with the ACI Guidance Manual on Airport GHG Emissions Management [12] has been applied and the results listed in Table 8.

| Scope | t $CO_2$ | Comments |
|---|---|---|
| Scope 1 | 30,788 | Includes all Flughafen Zürich AG owned or operated sources: Power plant, furnaces, emergency power generators, company vehicles and machinery. |
| Scope 2 | 2,639 | Purchased electricity for own consumption |
| Scope 3A | 112,260 | Scope 3 emissions that the airport operator can influence to some degree: aircraft taxiing, APU, GPU, road access traffic on airport premises, construction on behalf of the airport operator, fire training. Aircraft taxiing is approximately 90,000 t. |
| Scope 3B | 2,899,331 | Scope 3 emissions that the airport operator cannot significantly influence: Aircraft LTO and global emissions (excl. taxiing), GSE, third party furnaces, aircraft maintenance (engine run-ups), rail access traffic. Of this total, 2,720,000 t of $CO_2$ are contributed by the global en-route aircraft emissions[1] and 160,000 t by the LTO cycle (excl. taxiing). |

Table 8 $CO_2$-Emissions Zurich Airport in 2008

The results confirm the general finding at airports that the aircraft contributes the largest proportion of $CO_2$-emissions. Scope 1 and 2 emissions at Zurich airport constitute approximately 10% of airport emissions in the closer vicinity (LTO cycle, road traffic) and approximately 1% of the global airport induced $CO_2$ emissions. These results may differ slightly from data as calculated by using the model LASPORT. This is due to the modelling approach in LASPORT, where emissions have to be spatially and temporally resolved, thus requiring more complex modelling, while a simple inventory can rely on total fuel masses only.

## 3.6. Airport Emissions in the Context of Regional Emissions

While an airport constitutes an entity in itself, it is often set in context with other activities in the local geographic area with the goal of attributing a proportion of the total local emissions to the airport. This is possible only if the proper data is available. For the interpretation of the results, there are two main aspects to be carefully considered:

- The system boundaries within which the emissions are counted. The smaller an area is, the larger the airport's proportional share will be, although the airport itself may have a small emissions load.
- The activities that take place in the regional system. The less activities take place, the higher the airport's emissions contribution would be in the total context.

[1] From the AEM total global emissions, the ADAECAM LTO-cycle emissions are subtracted, even though the ADAECAM LTO-cylce is modelled differently from the AEM LTO-cycle and yields different results.

Consequently, putting an airport’s emissions into a regional context will always be very site specific, so generalised conclusions and comparisons with other regions cannot be easily made.

For Zurich airport, the regional context is usually the Canton of Zurich, thus a political geographical system (Figure 3). The Canton of Zurich covers an area of approximately 35 by 50 km (maximum of 42 x 59 km) or 1,730 $km^2$ (Zurich airport: 9 $km^2$). While Zurich airport is surrounded by several major motorways (four- to six-lane divided highways), there are few industrial activities close by with significant contributions to local air quality levels.

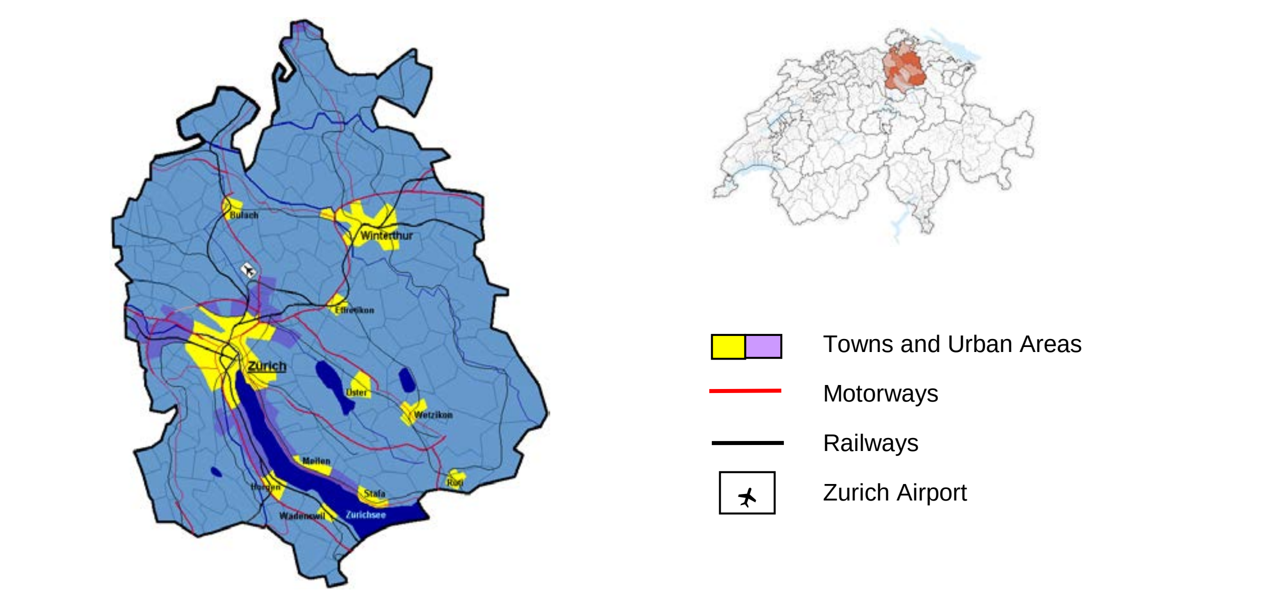



Figure 3 Canton of Zurich within Switzerland

The cantonal authorities publish emission inventories at regular intervals, covering all activities in the canton including the airport. For this purpose, the airport usually submits a detailed emission inventory that is added to the cantonal inventory. The latest figures have been modelled for the year 2005, based on baseline data of the year 2000 (except for the airport data that were actual data for 2005, but still using the former calculation methodologies) [13]. The data is listed in Table 9 and also shows the contribution of the aircraft emissions to the total emissions. It has to be recognised that the emission masses do not reflect the impact contribution.

| Source Group | Unit | $NO_x$ | VOC | PM10 |
|---|---|---|---|---|
| Road and rail traffic | t/a | 6,827 | 2,752 | 785 |
| Furnaces and heatings | t/a | 2,677 | 590 | 391 |
| Industry | t/a | 1,902 | 9,254 | 457 |
| Agriculture | t/a | 844 | 1,701 | 334 |
| Aircraft (certification LTO, modified taxi time) | t/a | 1,266 | 363 | 45[2] |
| **Total** | **t/a** | **13,415** | **14,660** | **2,012** |
| Contribution of aircraft | % | 9.4% | 2.5% | 2.2% |

Table 9 Canton of Zurich emissions by source groups in 2005.

The results show an aircraft $NO_x$ contribution of 9.4% which is the second smallest source group. For PM and VOC emissions (2.2-2.5%), the aircraft contributes the least.

## 3.7. Effect of Emissions on Regional Concentrations

Emissions are often used as a surrogate for the effective air pollution level, because the modelling of concentration is fairly complex. This approach may be correct for emissions exhausted lower than 300 m above ground. Emissions that are emitted above this elevation don't contribute directly to the ground concentrations, because they are rapidly spread in a wider area, diluted and transformed. All emission sources on the ground like road traffic, industry or agriculture are automatically within this height limit. Aircraft, however, reach rapidly after take-off a height of 300 m and more, which means that it is not appropriate to use the emissions of the whole LTO cycle to determine concentrations, but only the part up to 300 m above ground [15].

Several studies showed that emissions above 300 m have hardly any effect on the concentrations [16, 17]. Emissions in the height band between 300 and 915 m do not contribute measurably to the concentration and system borders can be adjusted accordingly.

### 3.7.1. Suggestion for Adjustments

Zurich Airport made an analysis which contains the factors mentioned above, based on the data of all operations at Zurich airport in 2010.

| Aircraft emissions in LTO cycle | Unit | 2010 | 2010 | 2010 |
|---|---|---|---|---|
| **1. Bases of calculation** | | | | |
| LTO cycle | | ICAO | Operational | Operational |
| Calculation tool | | LASPORT 2.0 | LASPORT 2.0 | LASPORT 2.0 |
| Height limit | m | 914.4 | 914.4 | 300 |
| **$NO_x$** | | | | |
| Total | t | 1'168.90 | 851.57 | 498.19 |
| Difference to ICAO-approach | % | | -27.1% | -57.4% |

[2] Including non-combustion effects

| | | | | |
|---|---|---|---|---|
| **Particulate matter (PM10)** | | | | |
| Total | t | 11.94 | 9.53 | 6.01 |
| Difference to ICAO-approach | % | | -20.2% | -49.7% |

Based on the analyses, there is suggested to adjust the engine emissions of scheduled and charter operations at airports, calculated with the reference LTO cycle, like the following, in order to reflex the effects of emissions on concentrations:

Nitrogen oxides ($NO_x$): -55% (Scheduled and charter operations at international airports in Switzerland)
Particulate matter (PM10): -50% (likewise)

With this adjustment, the application of emissions as an indicator for concentrations is reasonable.

# 4. Pollutant Concentrations from Dispersion Modelling

## 4.1. Modelled $NO_2$-Concentration

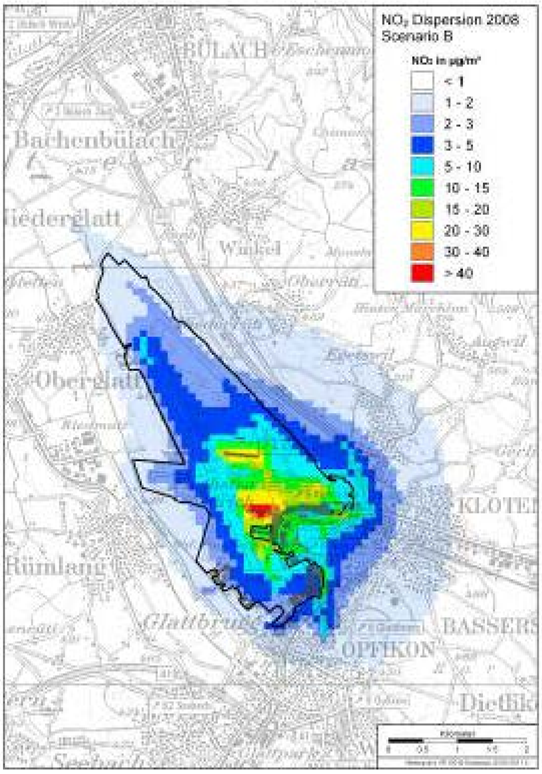
The dispersion calculations in LASPORT are carried out with the Lagrangian particle model LASAT (Lagrange Simulation of Aerosol Transport). The model is setup and verified according to the German guideline VDI 3945 Part 3 and has undergone various validation tests over recent decades. The following physical processes, including time dependencies, can be simulated: transport by the mean wind field, dispersion in the atmosphere, sedimentation of heavy aerosols, deposition on the ground, washout of trace substances by rain and wet deposition, chemical reactions, gamma submersion (cloud radiation). Thermal plume rise is covered parametrically according to the German guideline VDI 3782 Part 3.

The emission sources considered for the concentration modelling are only airport related sources. As such, the concentration maps below only show the additional concentrations by airport sources and not the total concentrations. In consequence, it is not directly possible to state the level of compliance with national standards, as these always apply to total concentrations.

### 4.1.1. $NO_2$-Concentrations of scenarios with variation in emissions

Figure 4 shows the concentrations of all airport sources for the two emission modelling Scenarios B and E (Simple and Advanced emission calculation method). As the meteorological time series is the same in both cases, the difference is caused by the variation in the emission input.

$NO_2$ concentration distribution for Scenario B




$NO_2$ concentration distribution for Scenario E

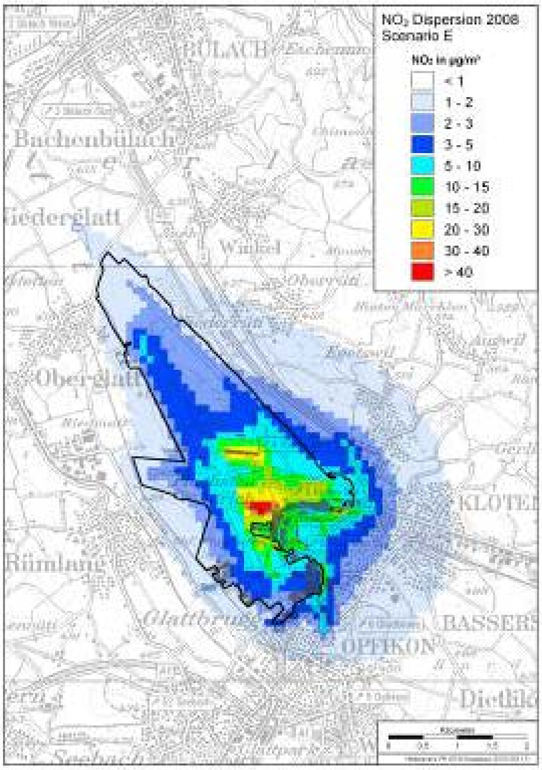



Figure 4 $NO_2$ concentrations $\mu g/m^3$ annual mean for airport emission sources in Scenarios B and E

Both pictures indicate higher concentrations in areas of higher activities (apron, runway threshold, highways). With the given scale, the differences are not apparent. Figure 5 thus shows the difference calculation between Scenario E and Scenario B.

The differences between the scenarios are mainly triggered by the difference in aircraft engine emissions. Those emissions changes are due to more refined emission data information and the application of performance modelling. The results show lower concentrations (-0.2 to -0.8 $\mu g/m^3$ $NO_2$) in the area of runway 28 (cf. Fig. 2-1), the main take-off runway for short and medium range aircraft that often take-off with less than 100% take-off thrust. Higher concentrations (0.2 to 0.8 $\mu g/m^3$ $NO_2$) can be observed at the runway threshold 16, the main take-off runway for long-range aircraft. This could be attributed to the fact that emissions at take-off thrust (in these cases closer to 100% thrust setting) are emitted during a longer period of time (slow aircraft acceleration) than in the certification cycle with linear acceleration along take-off.

**$NO_2$ difference calculations Scenario E - B**

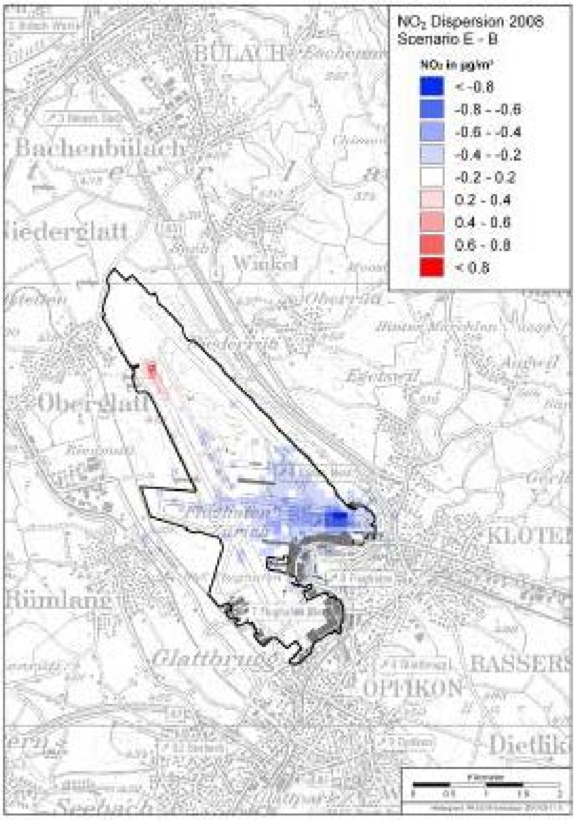



Figure 5 Difference calculations E - B

#### 4.1.2. Aircraft and Airport Sources

An important consideration is setting the aircraft (main) engine emissions in the LTO cycle in context to all other emission sources at the airport (including the aircraft APU emissions). The results for the $NO_2$ concentrations (Scenario E) are displayed in Figure 6 (a & b).

a) $NO_2$ concentration aircraft main engines only

b) $NO_2$ concentration airport sources

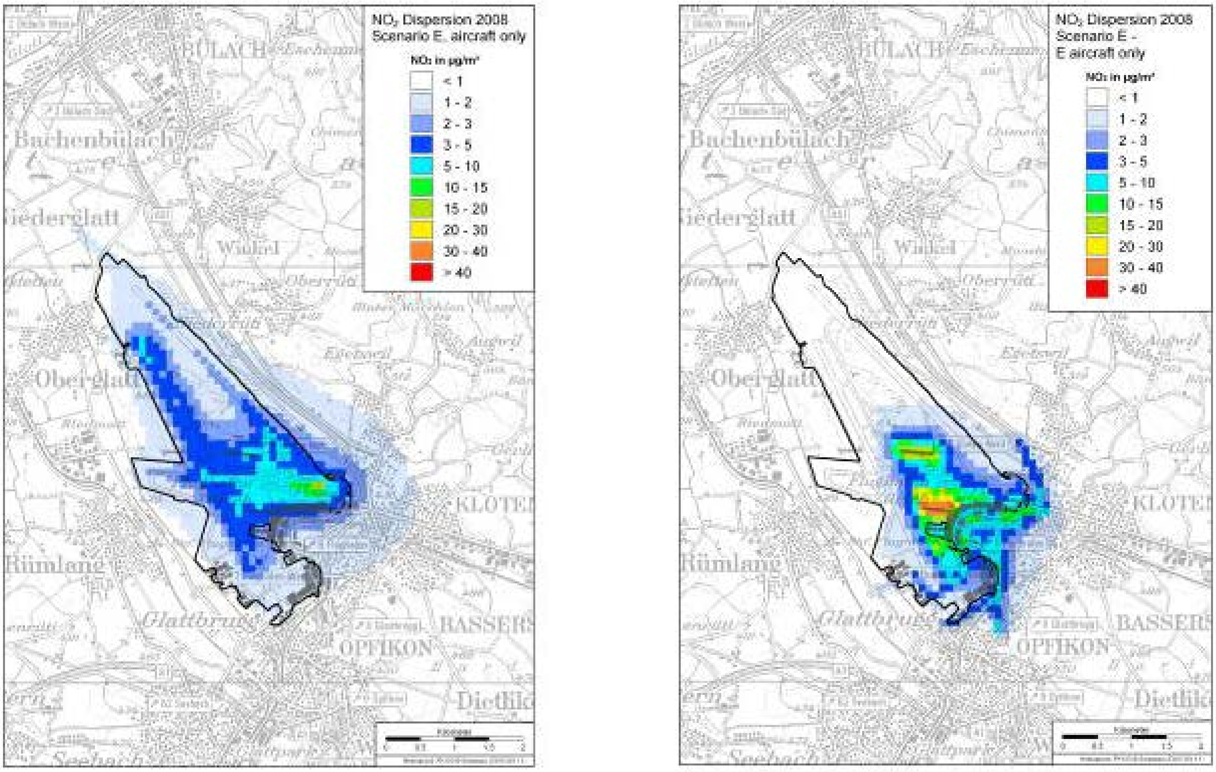



Figure 6 $NO_2$ concentrations µg/m$^3$ annual mean for aircraft and airport emission sources in Scenario E.

The pictures show the different effects of ground based emissions (b) and the both ground and air based emissions from the aircraft (a). Ground based airport emissions tend to produce high concentrations, but are spatially rather contained within the airport and along the access roads while the ground/air based aircraft emissions are spread over a larger area, but with generally lower emissions. This is also due to the fact that only emissions up to a height of approximately 300m above ground contribute significantly to the concentrations on the ground. Emissions above this height contribute to the overall concentration picture only marginally and such concentrations may even be within the statistical uncertainty of the model.

A comparison between the Scenarios B and E for the aircraft-induced emission concentration only shows a very similar pattern as displayed in Figure 5.

### 4.1.3. $NO_2$-Concentrations of Scenarios with Variation in Meteorological Data

For the dispersion calculation, a meteorological time series with values of wind speed and wind direction at a specified height above ground and the Monin-Obukhov length (or stability class) as a metric of the atmospheric stability are required. Wind directions and speeds are applied exactly as provided; the time series can consist of intervals of arbitrary length (typically one hour). For Zurich airport, data from the airport meteorological station has been used for wind speed and direction, pressure, temperature and humidity. The atmospheric stability has been derived from data obtained by an ultrasound anemometer in 10-minute-intervals (Figure 7).

Sometimes, only wind speed and direction are available and no additional information on the atmospheric stability. For Zurich airport, it has been attempted to derive a time series based on publicly available 10-year average data [18]. Using only the most prominent wind direction with an average wind speed or the most prominent wind direction with most prominent wind speeds have yielded unrealistic concentrations and cannot be used. The next step was to evaluate all wind direction/speed combinations and to create a one week time series with 10 minutes values according to the percentage distribution of the various combinations. These time series has been randomly distributed over the year. Also the stability classes have been assumed equally present and distributed randomly over the year (Figure 8).

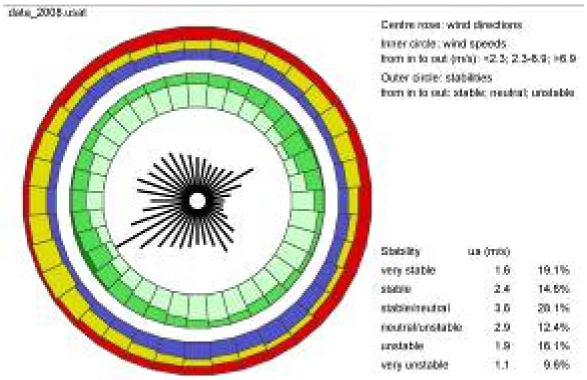



Figure 7 Actual meteorological information for Zurich airport in 2008

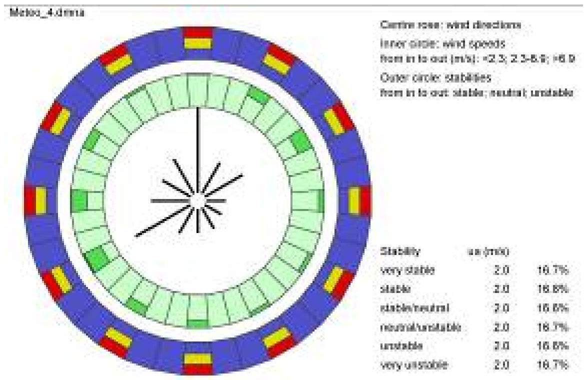



Figure 8 Modelled simple meteorological information for Zurich airport

For Scenario B, this simple meteorological time series has been applied and the concentration modelled (Figure 9). The difference to the concentration distribution with the actual meteorological data is shown in Figure 10.

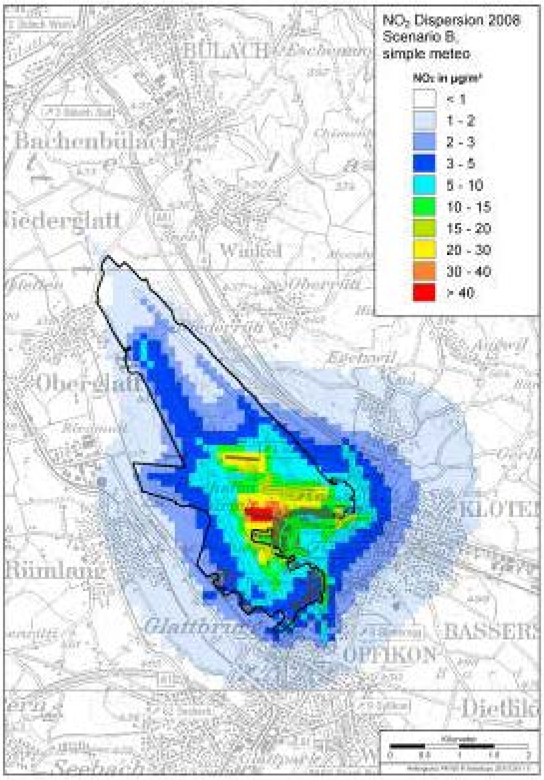



Figure 9 Scenario B concentration distribution using a modelled simple meteorology.

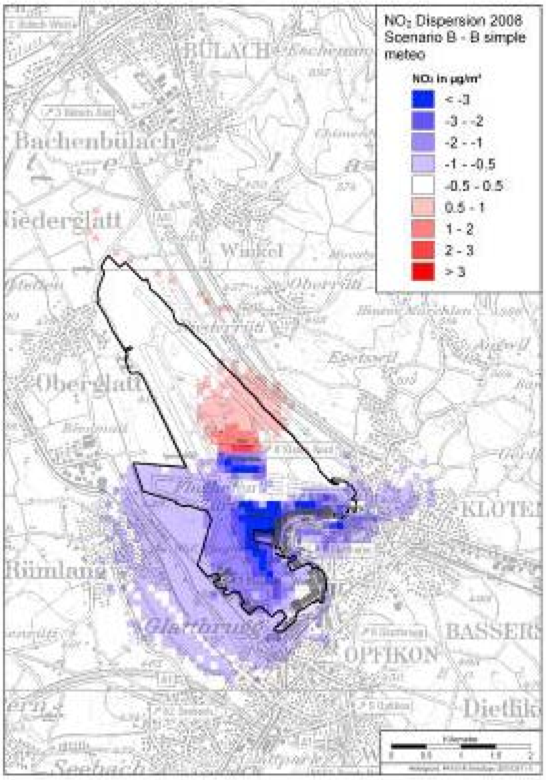



Figure 10 Difference between the simple modelled and actual meteorology for Scenario B.

The modelled simple meteorology shows basically the same dispersion pattern as with actual meteorology. The differences show that with the modelled simple meteorology, the concentrations are mostly overestimated. This result depends on the details of how the simplified meteorology has been set up and it cannot be generalised. However, it is generally true that the detail and quality of the meteorological input has a strong impact on the resulting concentration distribution.

#### 4.1.4. $NO_2$-Concentrations of Scenarios with Variation in Emissions and Meteo

The previous sections have presented the different effects of changing the methodologies for emission input or for meteorological data. In many cases an application may suffer from both lack of information of emission sources and required meteorological data. A final analysis is presented demonstrating the difference between Scenario B with a simple modelled meteorology and Scenario E with actual required meteorological information (Figure 11).

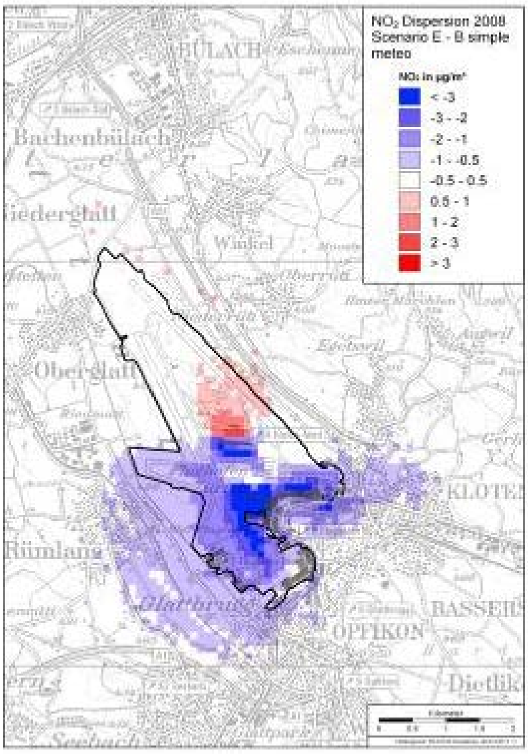
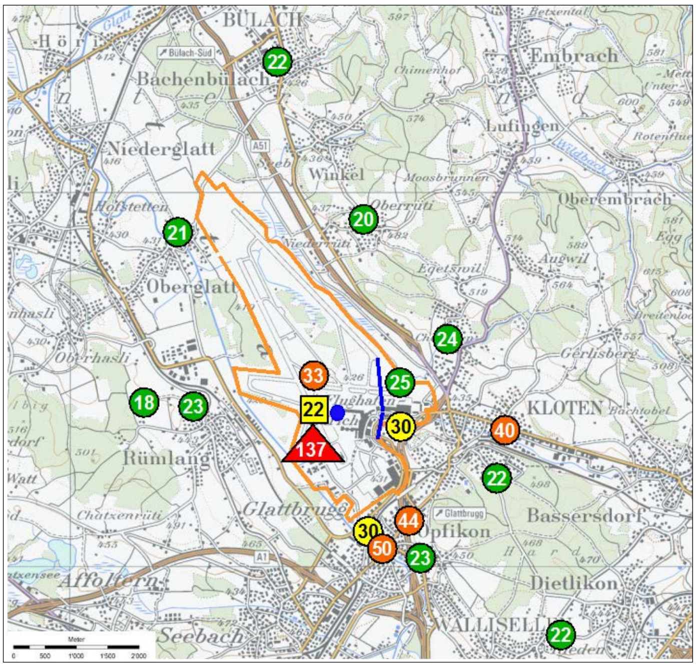



Figure 11 Difference between simple and advanced methods for both emissions and meteorological data

A comparison between Figure 9 and Figure 10 shows few differences. This confirms other findings at Zurich airport that the variations in emissions have generally smaller effects than variations in meteorological conditions. This was first observed in 2001 after the September and October events (9/11 and Swissair grounding) when emissions dropped by 20% but showed virtually no effects on the $NO_2$ values that were measured at the airport's measurement station. It has to be noted that these findings hold true for Zurich airport, but may not necessarily be generalised.

## 4.2. Measured Ambient Air Quality

Zurich airport has conducted ambient air quality measurements at the airport since 1996 and in the airport region since 2001. The station locations were determined in cooperation with the cantonal authorities who also perform the measurements (data management and station maintenance). While the stations on the airport premises are automatic continuous measurement stations for NO, $NO_2$, $O_3$, $SO_2$ and PM10, the stations outside the airport are $NO_2$ passive sampling tubes [14].




**Pollutants:**
○ $NO_2$ (annual mean)
□ PM10 (annual mean)
△ Ozone (98-percentile)

**Colours:**
Green: meets national standard
Yellow: +/-10% of national standard
Red: exceeds national standard

**Stations:**
Blue dot/line: airport stations

Values in $\mu g/m^3$

Figure 12 Airport air pollution measurement stations for different pollutants and 2008 concentrations

The results for $NO_2$ show legal compliance for most locations, but exceeded values at locations mainly dominated by road traffic and also in the middle of the airport premises (Figure 10). Ozone and PM10 are still showing exceeded values similar to those in many areas throughout Switzerland. $SO_2$ concentrations (not illustrated) are very low and of no significance.

## 4.3. Airport Specific $NO_2$-Impacts on Local Air Quality

In the context of local or regional studies it is often of interest to determine the impacts of airport related emissions in relation to the total impacts. As has been discussed, the emission masses are not a representative metric, because these results depend on the chosen system boundary. When using pollutant concentrations instead, at locations distant from the airport, the contribution of airport related emission sources can become insignificant. However, this can only be determined by modelling and not by measuring.

Consequently, the most appropriate approach to modelling should be to generate a regional model with all sources (airport and non-airport related) and then to identify the contributions of individual sources. This has been done for Zurich airport for a Scenario B calculation in 2004 [18]. In lieu of an actual regional modelling, the measurement station network for $NO_2$ in the airport region has been used to determine the modelled share from airport related sources to the total measured concentrations for 2008 (Figure 13).

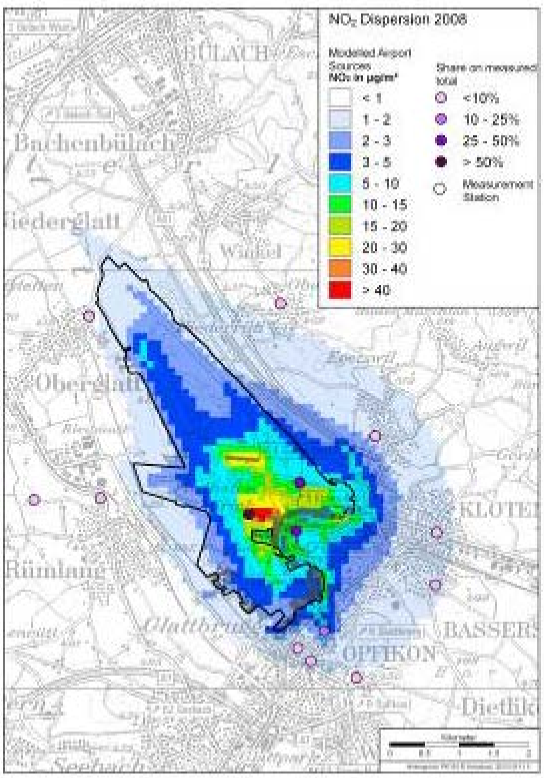



Figure 13 Share of modelled airport sources on measured total concentrations.

The results for Zurich airport in 2008 show significant shares of airport impacts within the airport perimeter and areas of high activities (>25%). With increasing distance away from the airport, the share decreases rapidly and becomes less than 10% within 1 kilometre distance from the airport boundary. Other emission sources become thus predominant at locations removed from the airport.

# 5. Conclusions

The sensitivity analysis for Zurich airport emission and concentration dispersion modelling for 2008 has shown the following results:

- An increase in emission calculation complexity and accuracy reduces the calculated emission masses for $NO_x$, PM and $CO_2$ significantly, and increases the emissions from HC and CO at the same time.
- The variation of calculated emissions from the aircraft's main engines has the largest impact on the total emission mass.
- The emission mass is not a suitable metric to describe the significance of airports in the context or regional air quality, as aircraft emissions are often counted up to 914 m above the airport level, whilst other sources are at ground level only.
- Regional assessments require too many local assumptions to allow comparisons between different regions.
- Aircraft pollutants spread over a larger area outside the airport perimeter than airport ground sources.
- As close as 1 km from an airport boundary, the contribution to pollutant concentration levels from airport sources can be 10% or less.
- The distribution of $NO_x$ concentration tends to be more dependent on meteorological conditions than on the variation in emissions. Therefore, when modelling dispersion, the accuracy of the meteorological data can be more important than the level of sophistication of the emissions calculations.

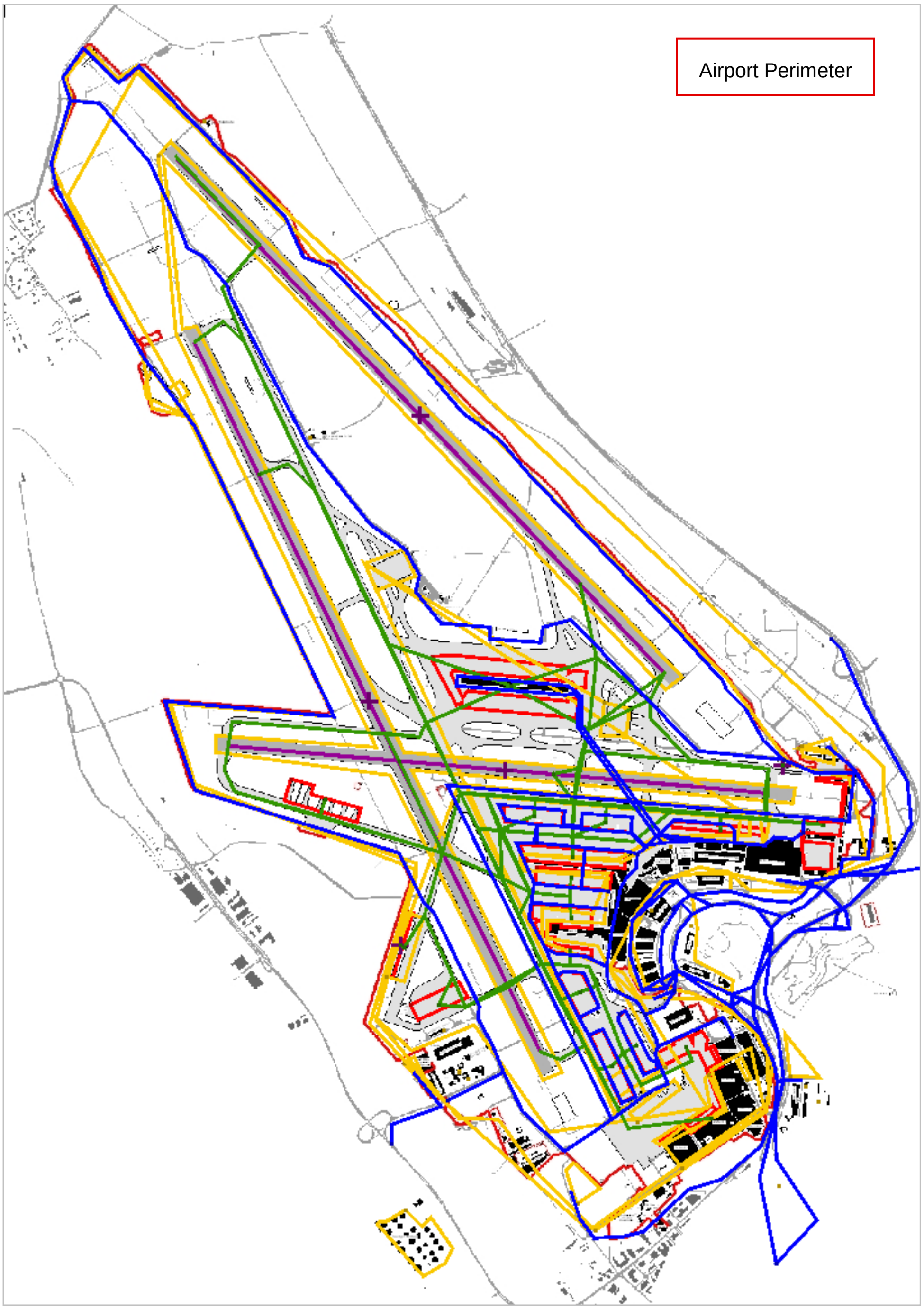
Depending on the specific requirements set forward by authorities or by stakeholder interests it is important to define the necessary level of complexity for emission calculation and concentration modelling. As specified in ICAO Doc 9889, the application of simple approaches may be sufficient. However, where a lower level of uncertainty in the modelling is required, more complex approaches have to be adopted. This increases the range and quality of the data required and the necessary data processing and modelling expertise. For Zurich airport, the application of advanced or sophisticated approaches in combination with a suitable dispersion model is important in the stakeholder dialogue.

# Annexes

## A.1. Abbreviations

| | |
|---|---|
| ACI | Airport Council International, Geneva, Switzerland |
| ADAECAM | Advanced Aircraft Emission Calculation Method |
| AIP | Aeronautical Information Publication |
| CAEP | Committee in Aviation and Environmental Protection (ICAO) |
| CO | Carbon Monoxide |
| $CO_2$ | Carbon Dioxide |
| FOCA | Federal Office for Civil Aviation, Bern, Switzerland |
| FOEN | Federal Office for the Environment, Bern, Switzerland |
| GHG | Greenhousegas Protocol (www.ghgprotocol.org) |
| HC | Hydrocarbons |
| IATA | International Air Transport Association, Geneva |
| ICAO | International Civil Aviation Organisation, Montreal |
| LASAT | Langrangian Simulation of Aerosol Transport |
| LASPORT | LASAT for Airports |
| LTO | Landing and Take-off Cycle |
| NOx | Oxides of Nitrogen |
| PM | Particulate Matter |
| RWY | Runway |
| TWY | Taxiway |
| VOC | Volatile Organic Compounds |

## A.2. LASPORT Zurich Airport Study Setup

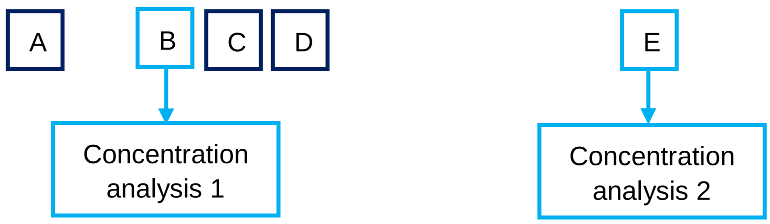



**Color Scheme:**

| | |
|---|---|
| Purple: | Runways |
| Green: | Taxiways |
| Red: | Aircraft Stands |
| Blue: | Roads (airside and landside) |
| Yellow: | Other sources (infrastructure, fuelling, parking, …) |
| Not displayed: | Departure routes |

## A.3. Aircraft Emission Calculation and Concentration Modelling Approaches

| Key Parameters | Simple Approach | | Advanced Approach | | Sophisticated Approach |
|---|---|---|---|---|---|
| Fleet (aircraft/engine combinations) | Identification of aircraft group types (e.g. all B737 or all A319/320/321) | | Identification of aircraft with a representative engine type. | | Actual aircraft type/subtype and engine combinations (by tail number and engine UID or similar) |
| Movements | Number of aircraft movements by aircraft type (according to look-up table), as defined in "Fleet" | | Number of aircraft movements by aircraft-engine combinations as defined in "Fleet" | | Number of aircraft movements by aircraft tail number |
| Emissions Calculation | Option A<br>UNFCC Look-up table (no calculation) | Option B<br>Spreadsheet calculation | Performance based calculation, potentially reflecting additional parameters like forward speed, altitude, ambient conditions (model dependent). | | Performance based with actual engine data (P3/T3) and including ambient conditions |
| Thrust Levels | Option A<br>N/A | Option B<br>rated thrust | Option A<br>Average airport and/or aircraft group specific reduced thrust rate | Option B<br>Performance model calculated rated reduced thrust | Actual air carrier provided thrust |
| Time in Mode | | Option B<br>ICAO Certification LTO | Option A<br>Modified times in mode (airport specific average or actual for one or several modes) | Option B<br>Performance model calculated time in mode. | Movement based actual values for all modes |
| Fuel Flow | | Option B<br>ICAO Certification Databank Values | Option A<br>Derived from ICAO EEDB with thrust to fuel flow conversion model | Option B<br>Derived from ICAO EEDB with performance model | Refined values using actual performance and operational data derived from air carrier |
| Emission Indices | Option A<br>UNFCC LTO Emission Mass by Aircraft Type | Option B<br>ICAO Certification Databank Values | Option A<br>Derived from ICAO EEDB and thrust level | Option B<br>Derived from ICAO EEDB through BFFM2 curve fitting method | Refined values using actual performance and operational data derived from air carrier. |



## A.4. Detailed Aircraft Engine Emissions

The following table shows the detailed results for the various elements in the Landing- and Take-Off cycle (LTO).

| LTO-Cycle Mode | Approach A | Approach B | Approach C | Approach D | Approach E |
|---|---|---|---|---|---|
| | (UNFCCC Table) | (Rep. fleet, ICAO cert. LTO) | (Detailed fleet, ICAO cert. LTO) | (Detailed fleet, modif. ICAO LTO) | (Detailed fleet, performance based) |
| **NOx (t/a)** | | | | | |
| Take-off Ground (TG) | - | 298 | 298 | 298 | 226 |
| Climb Initial (CI) | - | 612 | 600 | 600 | 200 |
| Climb Final (CF) | - | - | - | - | 178 |
| Approach Final (AF) | - | 173 | 168 | 168 | 189 |
| Approach Ground (AG) | - | - | - | - | 5 |
| Idle (ID) | - | 190 | 176 | 113 | 113 |
| **Total Aircraft Engines** | **1'078** | **1'273** | **1'242** | **1'179** | **912** |

| **HC (t/a)** | | | | | |
|---|---|---|---|---|---|
| Take-off Ground (TG) | - | 1 | 1 | 1 | 18 |
| Climb Initial (CI) | - | 2 | 3 | 3 | 16 |
| Climb Final (CF) | - | - | - | - | 16 |
| Approach Final (AF) | - | 4 | 26 | 26 | 30 |
| Approach Ground (AG) | - | - | - | - | 6 |
| Idle (ID) | - | 129 | 177 | 111 | 130 |
| **Total Aircraft Engines** | **110** | **136** | **207** | **141** | **215** |

| **CO (t/a)** | | | | | |
|---|---|---|---|---|---|
| Take-off Ground (TG) | - | 11 | 14 | 14 | 58 |
| Climb Initial (CI) | - | 30 | 51 | 51 | 49 |
| Climb Final (CF) | - | - | - | - | 62 |
| Approach Final (AF) | - | 66 | 186 | 186 | 204 |
| Approach Ground (AG) | - | - | - | - | 43 |
| Idle (ID) | - | 1'107 | 1'435 | 895 | 938 |
| **Total Aircraft Engines** | **1'099** | **1'214** | **1'686** | **1'146** | **1'354** |

| **PM (t/a)** | | | | | |
|---|---|---|---|---|---|
| Take-off Ground (TG) | - | 2 | 2 | 2 | 2 |
| Climb Initial (CI) | - | 5 | 4 | 4 | 1 |
| Climb Final (CF) | - | - | - | - | 1 |
| Approach Final (AF) | - | 2 | 3 | 3 | 3 |
| Approach Ground (AG) | - | - | - | - | 0 |
| Idle (ID) | - | 5 | 4 | 3 | 3 |
| **Total Aircraft Engines** | **-** | **13** | **13** | **11** | **10** |

| **$CO_2$ (t/a)** | | | | | |
|---|---|---|---|---|---|
| Take-off Ground (TG) | - | 35'894 | 36'893 | 36'893 | 33'381 |
| Climb Initial (CI) | - | 92'842 | 95'310 | 95'310 | 28'894 |
| Climb Final (CF) | - | - | - | - | 29'549 |
| Approach Final (AF) | - | 59'135 | 60'603 | 60'603 | 63'626 |
| Approach Ground (AG) | - | - | - | - | 4'083 |
| Idle (ID) | - | 142'481 | 141'014 | 89'023 | 89'158 |
| **Total Aircraft Engines** | **268'096** | **330'351** | **333'820** | **281'828** | **248'691** |

## Figures



## Tables



## Sources


| No. | Document Name |
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| **Version** | **Date** | **Name** | **Modifications** |
|---|---|---|---|
| 1.0 | 12/2009 | SU/ef/sm | (In cooperation with Dr. Ulf Janicke, Janicke Consulting, www.janicke.de) |
| 2.0 | 05/2012 | SU/cr | adapted to Corporate Design, added chapter 3.7 |

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