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Airport Local Air Quality Studies - ALAQS

Derivation of smooth & shift parameters to account for source dynamics in ALAQS-AV emission grids

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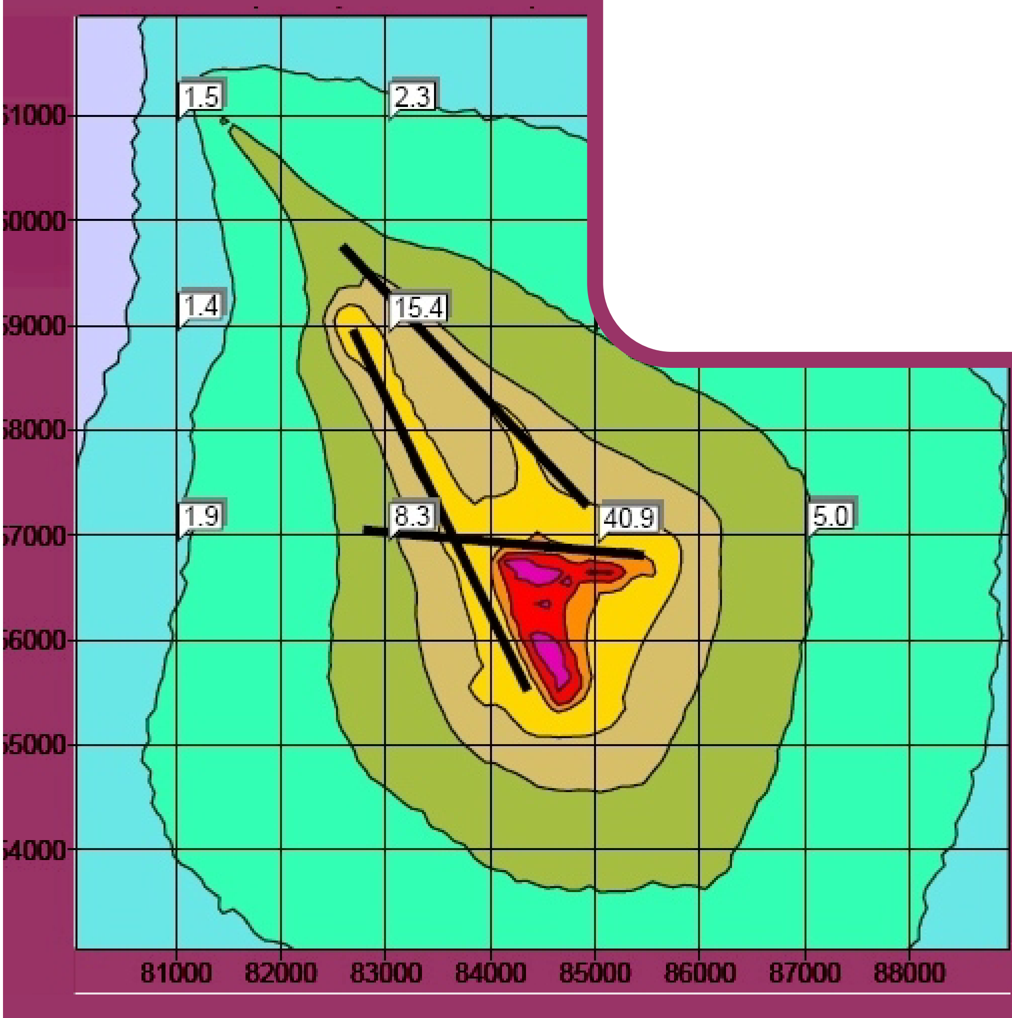

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Derivation of smooth & shift parameters to account for source dynamics in ALAQS-AV emission grids

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EXECUTIVE SUMMARY

The modelling system ALAQS-AV calculates the three-dimensional emission distributions for source groups that are connected to an airport, for example aircraft, auxiliary power units, and motor vehicles. To apply this output to dispersion models, it is necessary to account for source dynamics like turbulence and momentum of the exhaust from aircraft engines or thermal plume rise.

Different dispersion models have different abilities and means to include source dynamics. In addition, they incorporate different auxiliary models, for example to calculate the thermal rise of a buoyant plume from a given heat flux.

To provide an emission output that is handled – at least in principle – by all dispersion models of interest in the same way, one can include the effects of source dynamics already in the spatial emission distribution. In general, source dynamics causes enhanced mixing in the atmosphere and a spatial shift of the emitted exhaust gas, for example due to directed exit momentum or plume rise. Therefore, its effects can be accounted for in an approximate form by smoothing and shifting the initial source extent (smooth & shift approach).

In this study, the required smooth & shift parameters for the different source groups associated with an airport are derived on general grounds from the modelling concepts and default parameter settings that are applied in the modelling system LASPORT Version 1.6. LASPORT utilizes the Lagrange particle model LASAT and explicitly accounts for source dynamics.

The parameters are tested by comparisons with the results from dispersion calculations carried out with LASPORT, both for simple test cases and for a more complex example (Zürich Airport).

The tests show that the near ground concentrations obtained with the smooth & shift approach are in close agreement with the ones obtained by explicitly accounting for source dynamics.

Only in the vicinity of the runway and apron areas, up to distances of a few hundred metres, the smooth & shift approach leads to an underestimation of the concentrations near ground.

With the set of smooth & shift parameters at hand, the smoothed & shifted emission grids created by ALAQS-AV can be used in form of grid sources in dispersion calculations with the Lagrange particle model LASAT.

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Abstract:
An approach is developed in which source dynamics are accounted for by smoothing and shifting the initial source volume. The approach can be used in the ALAQS-AV toolset to provide a generic emission interface in form of passive grid sources that can be handled by any type of dispersion model. The smooth & shift parameters were derived from comparisons with results from the airport dispersion modelling system LASPORT.

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ABBREVIATIONS

AUSTAL2000	Official reference model of the UBA for licensing procedures in Germany
ADV	German Airports Association (Arbeitsgemeinschaft Deutscher Verkehrsflughäfen)
ALAQS	Airport Local Air Quality Studies
APU	Auxiliary Power Unit
EU	European Union
GPU	Ground Power Unit
GSE	Ground Support Equipment
ICAO	International Civil Aviation Organization
LASAT	Lagrange Simulation of Aerosol Transport
LASPORT	LASAT for Airports
LTO	Landing-Takeoff Cycle
TA Luft	German Technical Instruction on Air Quality Control (Technische Anleitung zur Reinhaltung der Luft)
UBA	German Federal Environmental Agency (Umweltbundesamt)
VDI	Association of German Engineers (Verein Deutscher Ingenieure)

1 INTRODUCTION

The Airport Local Air Quality modelling system ALAQS-AV determines the spatial distribution of emissions from various source groups associated to an airport such as aircraft, auxiliary power units (APU), ground power units (GPU), ground support equipment (GSE), and motor traffic. Additional models and data manipulations are required in order to apply this emission information in a dispersion calculation.

An important issue is the treatment of source dynamics. For example, the exhaust from aircraft engines is not passively emitted into the atmosphere. It is emitted with a large momentum, turbulence and temperature difference with respect to the ambient air: The directed momentum shifts the emitted trace material away from the emission origin; the hot exhaust gas is subject to buoyancy which shifts the exhaust plume upwards; the initial turbulence leads to enhanced dispersion in the atmosphere. Hence, although source dynamics have no impact on the derivation of the emissions, they must be included in a subsequent dispersion calculation.[1]

Different dispersion models have different abilities and means to include source dynamics. In addition, they may have different specifications and limitations, for example with respect to the number of sources they can handle, or the way time-dependent emissions are accounted for. Thus, it is necessary, in general, to apply in between the emission model and the dispersion model a separate model, in the following referred to as source model, which incorporates the necessary model assumptions, adjustments, and transformations.

One of the aims of ALAQS-AV is to apply the derived emissions to different dispersion models (for example Gauss plume models, Lagrange particle models, or Euler models) and to compare the resulting concentration distributions. The fact that a source model must be invoked complicates such a comparison as differences in the results may origin both from the source model and the dispersion model itself. Another aspect is that different dispersion models may incorporate different auxiliary models, for example to calculate the thermal rise of a buoyant plume from a given heat flux. Here, again, it can happen that differences in the results are not due to the dispersion model itself but due to an incorporated auxiliary model (which could be easily exchanged).

As an alternative approach, the emission model can provide a simplified output that, in principle, can be directly applied by any dispersion model – without the need of a source model or other auxiliary models. A conceptually simple emission output is a three-dimensional, passive emission grid: For each grid cell, the amount of trace material is specified that is passively emitted in a given time interval. Here, any source dynamics are already included in the distribution of the emissions over the grid.

For aircraft applications, source dynamics typically decay on a time scale of a few minutes. Within this time it leads to a shift and enhanced dispersion of the emitted plume. As one is usually interested in concentration means on an hourly basis (assessment values according to EU directives are based on hourly, daily, and yearly concentration means), the effects of source dynamics can thus be accounted for in an approximate way by smoothing and shifting the initial source extent (smooth & shift approach).

In the vicinity of a source – more precisely: in the region where the emitted plume is transported by the mean wind during the decay time of the initial source dynamics – the smooth & shift

[1] ALAQS-AV produces an inventory of airport emissions, where the different source types are merged in a single relational database structure. The structure (DEC05 version) retains all the essential characteristics of the emission source including time courses, geometry, direction of motion, and dynamics. In addition, the smooth and shift approach is used to associate each source to a number of three-dimensional grid cells to account for initial dispersion characteristics and to facilitate the integration with most dispersion models. For dispersion modelling, either the active sources or the smoothed and shifted passive sources can be extracted from an ALAQS-AV inventory database.

approach can cause an underestimation of the concentration near ground. Further away from the source (typically some hundred meters), it gives results that are comparable to the ones obtained by explicitly modelling the source dynamics.

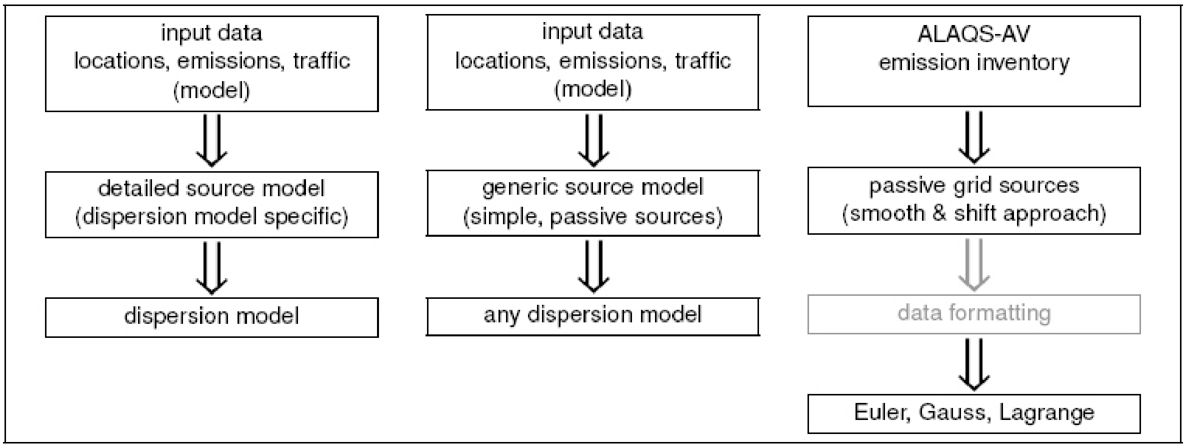


Figure 1: Different model chains for dispersion calculations.

EUROCONTROL decided to pursue the smooth & shift approach and to extend ALAQS-AV such that it can provide a passive emission grid as output. The smooth & shift parameters, which are required to create such a grid, were derived by comparisons with the airport dispersion modelling system LASPORT which incorporates the Lagrange dispersion model LASAT. LASPORT allows both to account for the source dynamics explicitly as well as to apply passive, smoothed & shifted sources. Hence it was straightforward to derive and validate the smooth & shift parameters that correspond to the LASPORT default settings for the source dynamics of the various source groups.

The Lagrange particle model LASAT was extended to read and process a three-dimensional, passive emission grid (grid sources). A simple text format with optional data compression was chosen for the storage of the – in general time dependent – grid source data.

The derivation of the smooth & shift parameters is given in Section 2. Section 3 contains an example application using LASPORT for Zürich Airport followed by an outlook in Section 4. Appendix A gives a description of the LASAT grid sources and the required file formats. Appendix B lists the LASAT input files that were used for the test calculations of Section 1.

2 SMOOTH & SHIFT PARAMETERS

The smooth & shift parameters were derived on the basis of the default parameterization that is applied in LASPORT 1.6[2] for handling source dynamics of aircraft, APU, GPU, start emissions, GSE, and motor traffic.

It was intended to derive the smooth & shift parameters on a general and transparent basis so that they can be easily adjusted to modified parameter settings, or extended to other model concepts in the future.

2.1 Aircraft

Aircraft exhaust is characterized by a directed exit momentum, velocity fluctuations, and a thermal heat flux, all of which depend on the type of aircraft, the type of aircraft engine, and the thrust setting of the engine.

Exit momentum and velocity fluctuations decay on a time scale of a few minutes, effects of buoyancy on a larger time scale of some minutes to some 10 minutes. Buoyant plume rise depends on the local wind speed and the atmospheric stratification, both of which are a function of time.

From comparisons with time-resolved LIDAR measurements of exhaust plumes from individual (large) aircraft at takeoff (carried out at Düsseldorf Airport), published studies, and test calculations with the advanced plume rise model PLURIS, the following set of model parameters was selected to describe aircraft source dynamics:

`ExitVel`	Directed exit velocity opposite to the direction of aircraft motion.
`SigLon`	Velocity fluctuations along the direction of aircraft motion.
`SigHor`	Horizontal velocity fluctuations across the direction of aircraft motion.
`SigVer`	Velocity fluctuations perpendicular to the directions of `SigLon` and `SigHor`.
`SigTime`	Decay time for the exit velocity and the velocity fluctuations.
`Width`	Horizontal width of the line sources which represent the aircraft emissions.
`Height`	Vertical width of the line sources which represent the aircraft emissions.
`Shift`	Vertical shift of the aircraft emissions due to the influence of wing tip vortices.

The parameter values are a function of the thrust setting which is categorized by the standard ICAO modes Idle, Approach, ClimbOut, and TakeOff. The experimental data did not allow for a derivation of individual parameter settings for each aircraft type or aircraft group, hence the same parameter values are applied to all aircraft. Thermal plume rise is accounted for in a conservative way by an initial vertical extent of the line source (`Height`).[3] The default values applied in LASPORT 1.6 are listed in Table 1.

[2] For further information on LASPORT see the Internet at www.janicke.de.
[3] This already is a smooth & shift approach.

Table 1: Default parameter settings applied in LASPORT 1.6 to account for the source dynamics of aircraft.

Parameter	Unit	Idle	Approach	ClimbOut	TakeOff
`ExitVel`	m/s	0.00	0.00	9.00	9.00
`SigHor`	m/s	0.79	1.64	2.77	3.00
`SigLon`	m/s	0.79	1.64	2.77	3.00
`SigVer`	m/s	0.48	0.99	1.66	1.80
`SigTime`	s	80.00	80.00	80.00	80.00
`Width`	m	50.00	50.00	50.00	50.00
`Height`	m	25.00	25.00	25.00	25.00
`Shift`	m	0.00	-100.00	-100.00	0.00

Assuming that velocity fluctuations have already decayed but dispersion due to atmospheric turbulence is still negligible, the vertical concentration distribution at idle and takeoff can be approximated by a Gaussian distribution of the form

$$c(z) = c_0\, e^{-z^2/(2\sigma_z^2)} \tag{2.1}$$

where the variance σ_z^2 is the sum of the initial variance (determined by h_0, parameter Height) and the variance due to vertical velocity fluctuations (determined by T, parameter `SigTime`, and σ_W, parameter `SigVer`),

$$\sigma_Z^2 = \tfrac{1}{12} h_0^2 + (\sigma_w T)^2 \tag{2.2}$$

If the source is characterized instead by an initial vertical extent h only (smooth & shift approach),[4]

$$\tilde{c} = \tilde{c}_0\, \Theta(h - z)\,, \tag{2.3}$$

the smooth & shift parameter h can be determined from the conditions that the vertical concentration integral is the same in both approaches,

$$\int_0^\infty c(z)dz \overset{!}{=} \int_0^\infty \tilde{c}(z)dz \;\rightarrow \sqrt{\tfrac{\pi}{2}}\sigma_z \overset{!}{=} \tilde{c}_0 h\,, \tag{2.4}$$

and that the concentration at ground is the same in both approaches,

$$c(0) \overset{!}{=} \tilde{c}(0) \;\rightarrow\; c_0 \overset{!}{=} \tilde{c}_0\,. \tag{2.5}$$

This yields

$$h \;=\; \sqrt{\tfrac{\pi}{2}}\sigma_z \;=\; \sqrt{\tfrac{\pi}{2}}\sqrt{\tfrac{1}{12}h_0^2 + (\sigma_w T)^2}\quad. \tag{2.6}$$

(SigVer x SigTime)^2

[4] The step function $\Theta(x)$ is unity for positive and zero for negative x.

For TakeOff, h_0 = 25 m, σ_w = 1.8 m/s, and T = 80 s, which yields h = 181 m. For Idle, h_0 = 25 m, σ_w = 0.48 m/s, and T = 80 s, which yields h = 49 m. The vertical extent for Approach and ClimbOut and the horizontal widths are analogously derived.

For the vertical extent at ClimbOut and Approach, it must be taken into account that the plume axis is elevated from the ground, therefore not only the vertical extent needs to be adjusted for the smoothed & shifted sources but as well the lower source edge in order to preserve the vertical centre of symmetry of the plume. This can be achieved by lowering the emissions by the amount $(h-h_0)/2$, where again h is the vertical extent of the smoothed & shifted source and h_0 is the vertical extent of the original LASPORT source.

The effect of the directed exit velocity v_e (parameter `ExitVel`) on the concentration distribution depends on the wind direction. For cross wind, the concentration distribution is shifted by a larger amount than for parallel alignment of wind direction and exit direction. The wind direction changes with time but the smooth & shift parameters are defined as stationary ones at this stage. Therefore, an approximation yielding reasonable results is to apply a horizontal source shift of half the one produced by the exit velocity, that is $v_e T/2$ = 360 m.

Table 2 lists the LASPORT settings that implement the smooth & shift approach based on the values given in Table 2.1.

Table 2: Smooth & shift parameters for aircraft. The values correspond to the LASPORT default settings given in Table 2.1

Parameter	Unit	Idle	Approach	ClimbOut	TakeOff
`ExitVel`	m/s	0	0	0	0
`SigHor`	m/s	0	0	0	0
`SigLon`	m/s	0	0	0	0
`SigVer`	m/s	0	0	0	0
`SigTime`	s	0	0	0	0
`Width`	m	81.0	165.0	278.0	301.0
`Height`	m	49.0	100.0	167.0	181.0
`Shift`	m	0.0	-137.5	-171.0	0.0
Horizontal shift	m	0.0	0.0	360.0	360.0

Example TakeOff:
An aircraft starts to accelerate from zero velocity at x = 450 m in negative x-direction. Acceleration is constant until take off at $x = -1350$ m. In a LASPORT scenario calculation, the take off distance is modelled by two line segments which are travelled in equal times. The line parameters defining the geometry are (in metres)

Segment	Start	End	Horizontal width	Lower edge	Upper edge
`lsp1`	450	0	50	0	25
`lsp2`	0	-1350	50	0	25

For the according smoothed & shifted lines, the geometric parameters – the only parameters – read

Segment	Start	End	Horizontal width	Lower edge	Upper edge
sas1	810	360	301	0	181
sas2	360	-990	301	0	181

Example Approach:
An aircraft approaches a runway in negative x-direction at an angle of 3 degree until touch down at x = 0 m followed by constant deceleration until roll off at x = −1000 m. In a LASPORT scenario calculation, the emission touches ground already at x = 1900 m because of the downward shift of the exhaust plume by 100 m; like for take off, the distance between touch down and roll off is modelled by two line segments which are travelled in equal times. The line parameters defining the geometry are (in metres)

Segment	Start	End	Horizontal width	Start point lower edge	Start point upper edge
lsp1	3900	1900	50	105	130
lsp2	1900	0	50	0	25
lsp3	0	-750	50	0	25
lsp4	-750	-1000	50	0	25

For the according smoothed & shifted lines, the geometric parameters – the only parameters – read

Segment	Start	End	Horizontal width	Start point lower edge	Start point upper edge
sas1	3900	2616	165	67.5	167.5
sas2	2616	0	165	0	100
sas3	0	-750	165	0	100
sas4	-750	-1000	165	0	100

Figure 2 to Figure 4 show the results of LASAT dispersion calculations with the aircraft line sources described in the preceding examples TakeOff and Approach, and according calculations for the aircraft idle movements. The LASAT input files used for the comparisons are listed in Appendix B.

Each of the figures shows a colour-coded isoline plot of the concentration distribution near ground for an isotropic wind rose[5] as calculated:

- with the source parameters of Table 1 (explicit modelling of the source dynamics),
- with the smooth & shift parameters of Table 2,
- without source dynamics (geometric parameters of Table 1).

At a distance of some hundred metres away from the source location, the passive, smoothed & shifted sources yield concentration distributions that are very similar to the ones obtained for the original, active sources. For TakeOff, the shift of the smoothed & shifted distribution eastwards is a bit to small; for Approach and Idle, the smoothed & shifted concentrations are slightly too high, differences being of the order of 10% to 20%.

In a more realistic application presented in the next section, which involves a variety of aircraft paths and other source groups, the differences between the original LASPORT concentration

[5] Average over 36 subsequent hourly concentration distributions for a wind direction changing from one hour to the next by 10 degree. The atmospheric stratification was slightly stable (Monin-Obukhov length 300 m), the surface roughness length was 0.3 m.

distribution and the one obtained from the smoothed & shifted sources are even smaller and range below 10% further away from the runways.

Figure 2 to Figure 4 also clearly demonstrate that neglecting source dynamics leads to a strong overestimation of the aircraft-induced concentrations near ground.

2.2 APU (and thermal plume rise in general)

Like the aircrafts' main engines, APU are turbines. However, their cross section and volume flow is much smaller and the main effect of source dynamics can be attributed to thermal plume rise.

Thermal plume rise depends on the meteorological conditions, in particular on the wind speed. It is calculated by means of a plume rise model which determines either the rise as a function of source distance or the maximum rise only.

In the context of the smooth & shift approach, thermal plume rise can be accounted for by calculating the plume rise via a suitable plume rise model and adding the maximum rise to the original source height (effective source height).

At this stage, the smooth & shift parameters are not a function of time, hence an average or conservative meteorological condition needs to be applied for the plume rise calculation. This simplification seems justified for APU which, in comparison to aircraft and motor traffic, contribute only little to the overall concentrations.

In LASPORT, thermal rise of APU is parameterized by a heat current, which depends on the aircraft group, and calculated by means of the plume rise formula of the German guideline VDI 3782 Part 3. Typical heat currents range between 0.05 MW and 0.5 MW.[6] For such small heat currents Q, maximum plume rise Δ_h is calculated according to VDI 3782 part 3 as

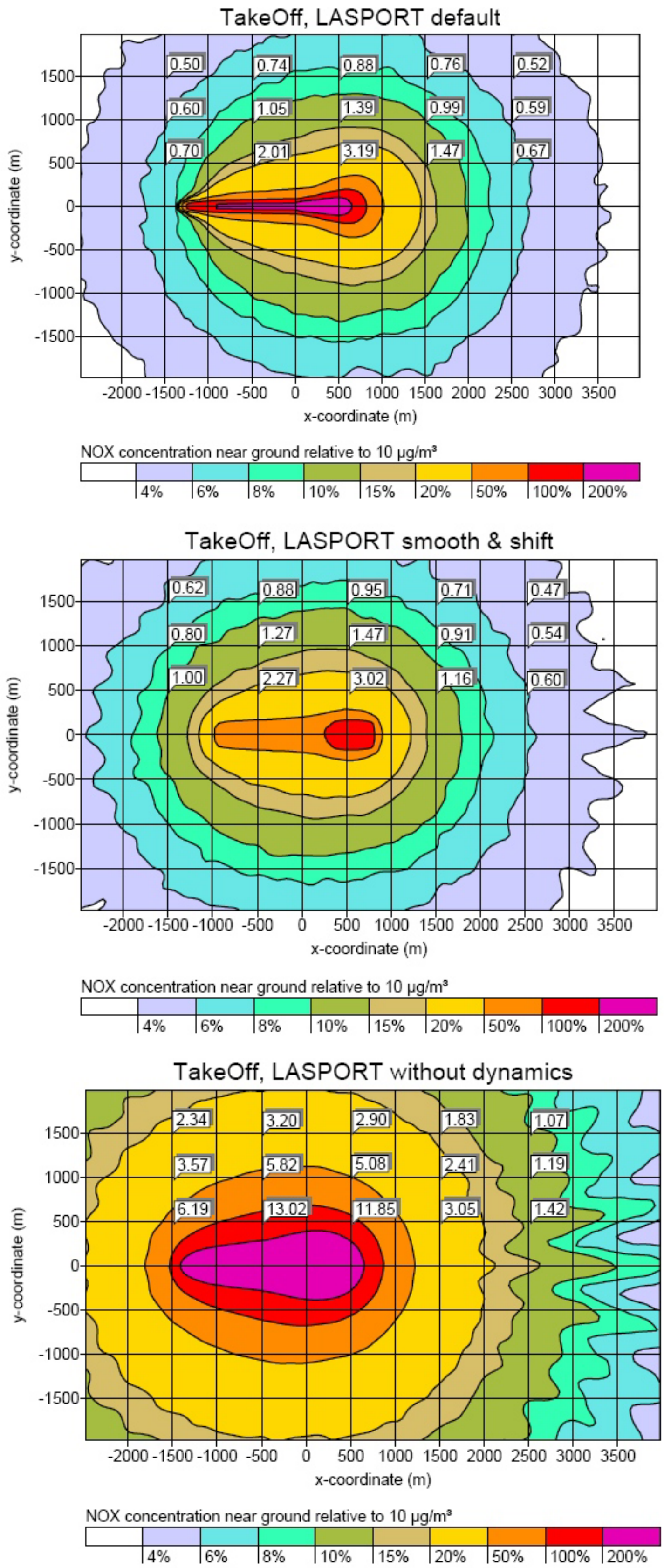
$$\Delta h = h_0 \frac{84\sqrt{Q/Q_0}}{u/u_0} \quad \text{for } Q < 1.4 \text{ MW} \qquad (2.7)$$

with the wind velocity at source height, u, and the scaling parameters h_0 = 1 m, Q_0 = 1MW, and u_0 = 1 m/s. For wind velocities between 1 m/s and 3 m/s and heat currents between 0.05 MW and 0.5 MW, plume rise ranges between 6 m and 60 m.

LASPORT assumes as default a vertical extend of the APU emissions between 3 m and 8 m above ground – reflecting the uncertainty in the APU location as a function of aircraft type — and an APU heat current of 0.1 MW for large and medium jets and 0.05 MW for small and regional jets, see Table 3.[7] Applying the smaller value for a more conservative estimate of the concentrations near ground, the resulting plume rise for a mean wind speed of 1.5 m/s is Δh = 12 m, yielding the smooth & shift parameters given in Table 4.

Figure 5 shows as an example the results of dispersion calculations for APU emissions, modelled in form of an area source. The figures show the concentration average over 100 days of a realistic meteorological time series, calculated with explicitly modelling the plume rise for a heat current of 0.1 MW (top), with a passive source shifted 18 m – according to Equation (2.7) – upwards (middle), and without accounting for plume rise (bottom). The LASAT input file used for the comparison is listed in Appendix B.

[6] The heat current can be roughly estimated from the APU engine power and the efficiency factor.
[7] These heat currents are relatively small, yielding a more conservative estimate of the concentration near ground.

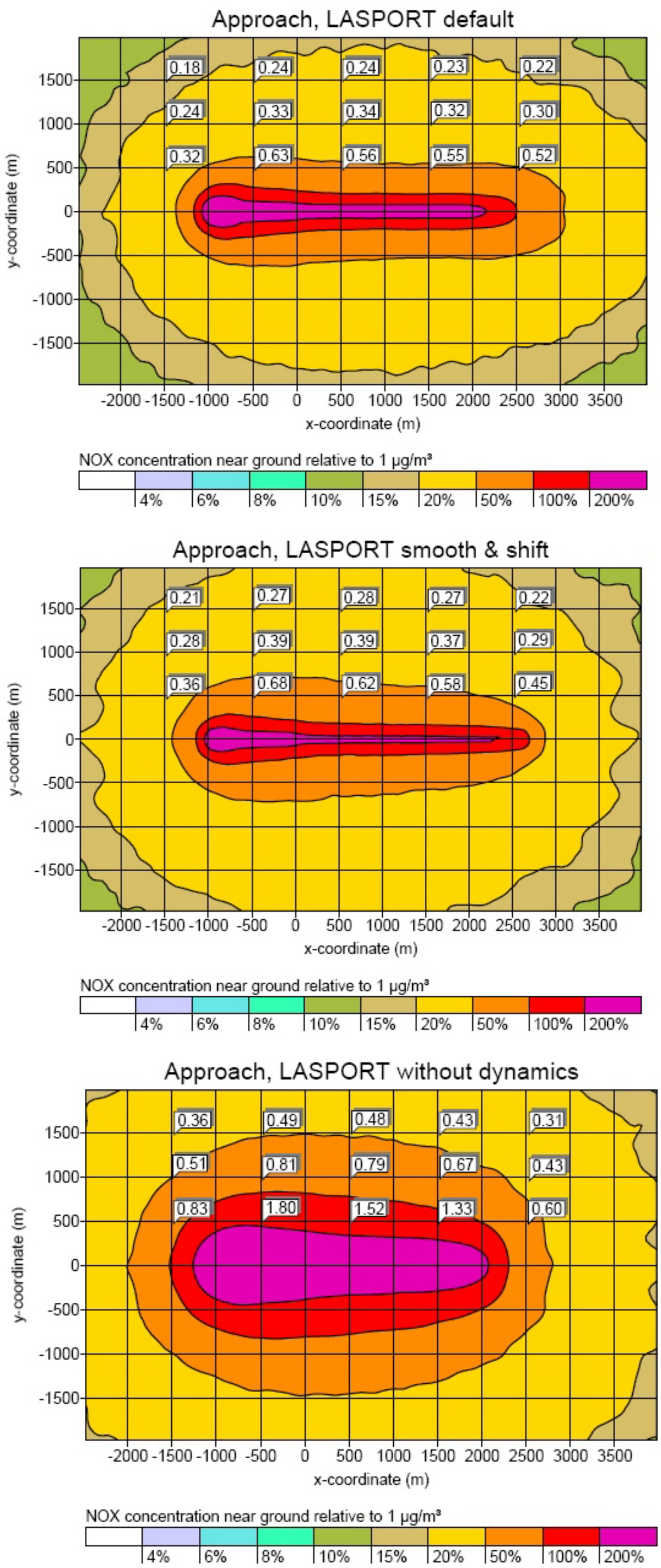


Top: LASPORT default source dynamics.

Middle: Passive, smoothed & shifted sources.

Bottom: Without source dynamics.

Figure 2: Concentration distribution near ground resulting from aircraft takeoffs (example TakeOff in Section 2.1; LASAT calculation for an isotropic wind rose).

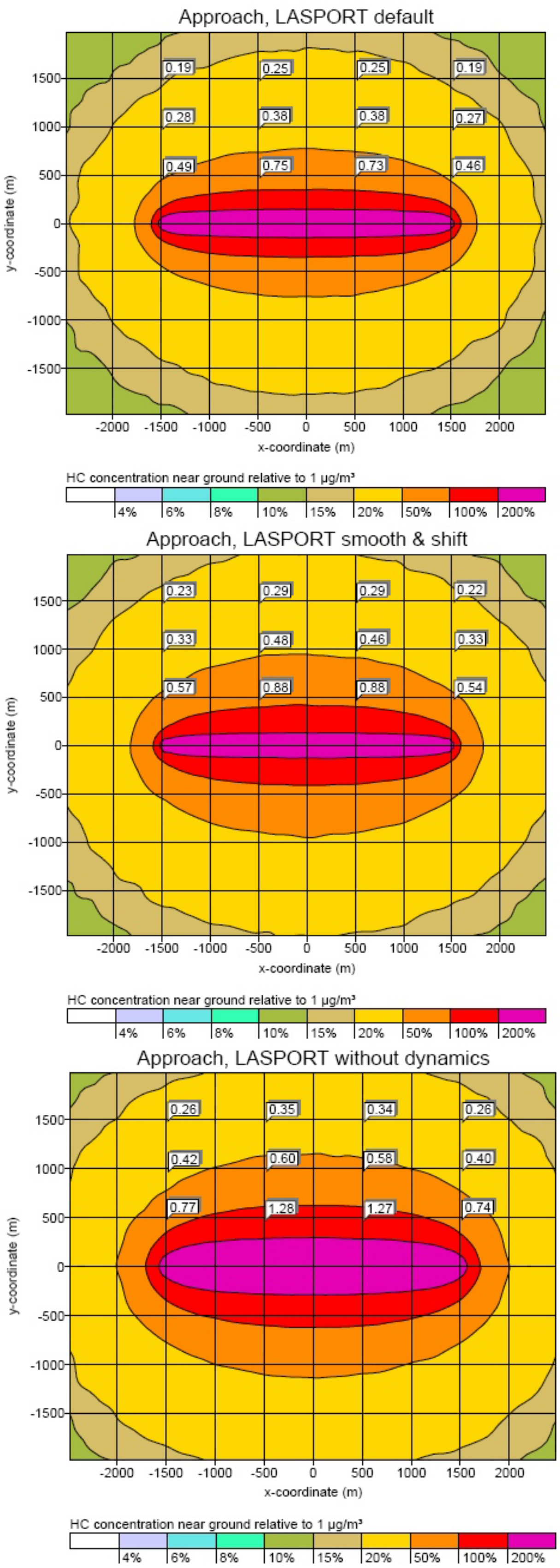


Top: LASPORT default source dynamics.

Middle: Passive, smoothed & shifted sources.

Bottom: Without source dynamics.

Figure 3: Concentration distribution near ground resulting from aircraft approaches (example Approach in Section 2.1; LASAT calculation for an isotropic wind rose).



Top: LASPORT default source dynamics.

Middle: Passive, smoothed & shifted sources.

Bottom: Without source dynamics.

Figure 4: Concentration distribution near ground resulting from aircraft idle movements (LASAT calculation for an isotropic wind rose).

The same line of arguments can be used to derive the smooth & shift parameters – the vertical shift in this case – for other sources that are subject to plume rise. Here it might be necessary to invoke a more sophisticated plume rise model like PLURIS (JANICKE & JANICKE, 2001).

Table 3: Default parameter settings applied in LASPORT 1.6 for APU

Parameter	LASPORT name	Unit	Value
APU, lower edge	`APUZmin`	m	3.0
APU, upper edge	`APUZmax`	m	8.0
APU, heat current	`APU-Q`	MW	0.1, 0.05

Table 4: Smooth & shift parameters for APU. The values correspond to the LASPORT default settings given in Table 3

Parameter	LASPORT name	Unit	Value
APU, lower edge	`APUZmin`	m	15.0
APU, upper edge	`APUZmax`	m	20.0
APU, heat current	`APU-Q`	MW	0.0

2.3 GPU, GSE, start emissions, motor vehicles

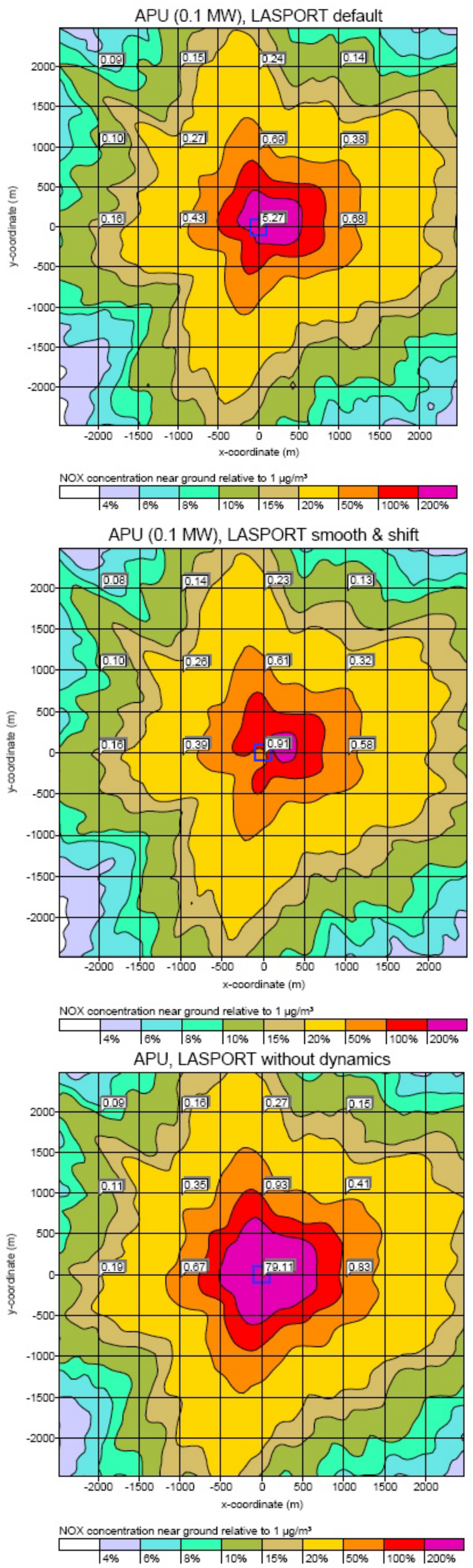
For GPU, GSE, start emissions,[8] and motor vehicles, LASPORT by default does not explicitly model the source dynamics but applies a vertical source extent which either accounts for the uncertainties in the actual source height (GPU, GSE) or the effects of enhanced turbulent mixing (start emissions, motor vehicles). The default settings, which are listed in Table 5, can be directly applied as smooth & shift parameters.[9]

Table 5: LASPORT default values for the vertical source extent of other source groups. The values can be directly applied as smooth & shift parameters.

Parameter	LASPORT name	Unit	Value
GPU, lower edge	`GPUZmin`	m	0.0
GPU, upper edge	`GPUZmax`	m	5.0
GSE, lower edge	`HndZmin`	m	0.0
GSE, upper edge	`HndZmax`	m	5.0
Start emissions lower edge		m	0.0
Start emissions, upper edge	`Height[Idle]`	m	25.0
Motor vehicles, lower edge		m	0.0
Motor vehicles, upper edge	`StreetDepth`	m	2.0

[8] Hydrocarbon emissions from aircraft engines before ignition

[9] LASPORT allows to include thermal plume rise for GPU by the specification of a heat current (parameter GPU-Q); the default value, however, is zero. In addition, LASPORT allows to explicitly account for vehicle induced turbulence as an alternative to the vertical extent listed in Table 5



Top: With explicit modelling of plume rise (heat current 0.1 MW)..

Middle: Passive source shifted by 18m upwards

Bottom: Without accounting for plume rise.

Figure 5: Concentration distribution near ground resulting from APU emissions, modelled as an area source (blue outlines).

3 EXAMPLE - ZÜRICH AIRPORT

As an application of the smooth & shift approach to a ”real world” example, LASPORT dispersion calculations were carried out for Zürich Airport for the period of half a year.[10] Aircraft, APU, GPU, GSE, start emissions, and airside motor traffic were considered. In order to give an estimate of the relevance with respect to the resulting concentrations, Table 6 lists the overall emissions of the various source groups.

Table 6: Overall NOx emissions (emission period 6 months) of the various source groups applied in the example calculations for Zürich Airport (Section 3).

Aircraft emissions are listed up to 1000 ft (305 m) above ground.

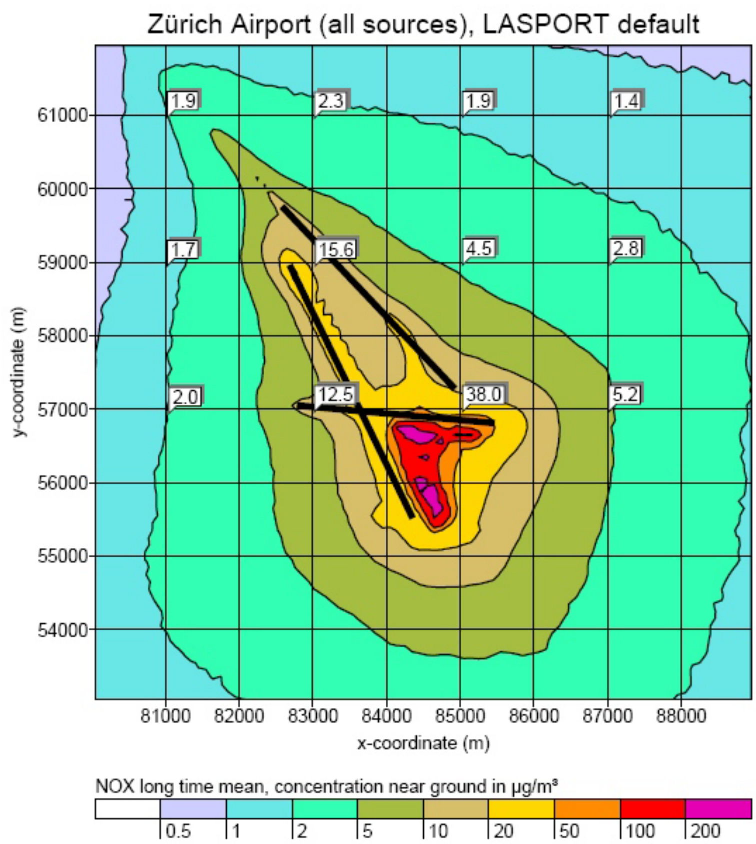
Source group	NOx emission (t)	Fraction
Aircraft, Idle	48	
Aircraft, Approach	74	
Aircraft, ClimbOut	84	
Aircraft, TakeOff	198	
Aircraft, total	404	84%
APU	22	5%
GPU	7	1%
GSE	9	2%
Airside motor traffic	37	8%
Total	479	100%

Figure 6 depicts the 6-month average concentration for NO_x near ground; the plot at the top shows the original LASPORT calculation, the bottom one the LASPORT calculation with the smooth & shift parameters of Section 2. The NO_x concentration distributions resulting from aircraft emissions only are shown in Figure 7. Figure 8 shows the 6-month average concentrations for HC emitted from aircraft only (58 t up to 1000 ft, emitted to 90% on the taxiways). Finally, Figure 9 depicts the distributions of the EU short time assessment value for NO_2 (hourly mean that is exceeded 18 times), resulting from emissions of all source groups.

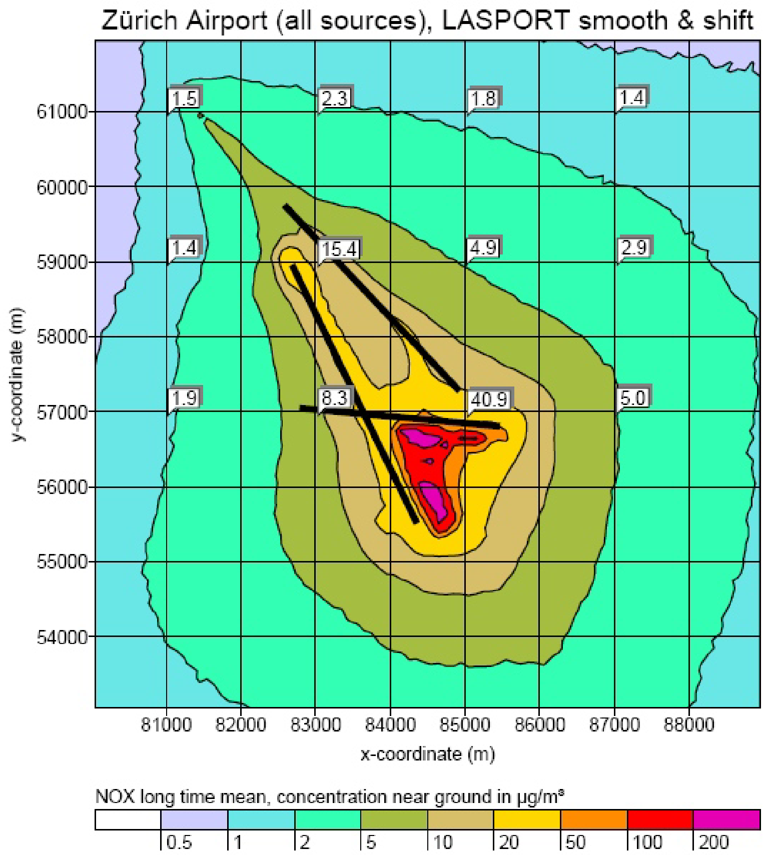
The figures show that for both the long-term and short-term means the near ground concentrations obtained with LASPORT and the smooth & shift parameters from the precious section are very similar to the ones obtained with the default LASPORT settings, in particular outside the direct runway and apron areas.

The comparisons indicate that, in the context of the LASPORT modelling concept, the simplifications connected with the smooth & shift approach have no significant impact on the resulting concentration distributions if one is not interested in the direct runway or apron areas. Observed concentration differences with respect to an explicit modelling of source dynamics range mostly below 10%.

[10] The data were kindly provided by Emanuel Fleuti and Peter Hofmann from Unique, Zürich.

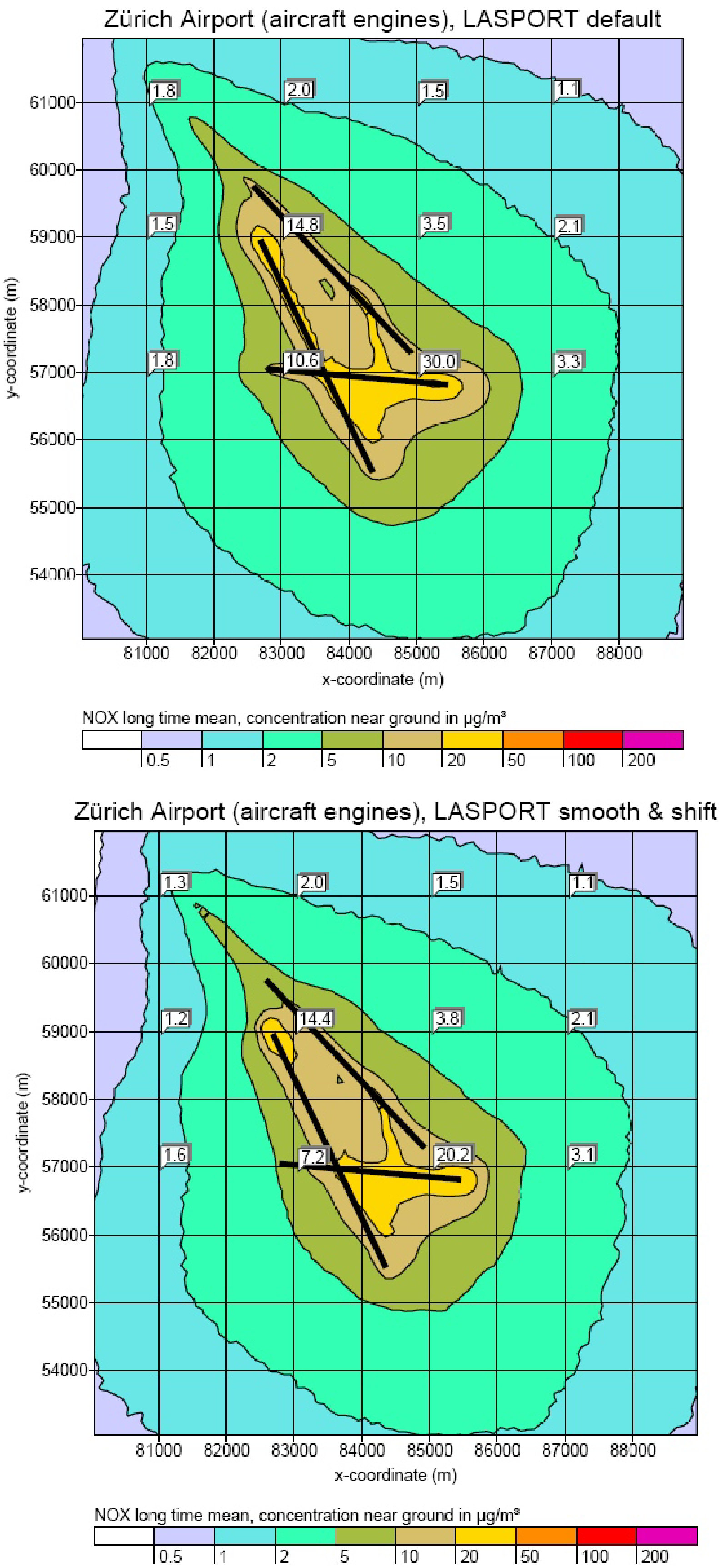


Top: LASPORT calculation with default source dynamics.



Bottom: LASPORT calculation with smoothed & shifted sources.

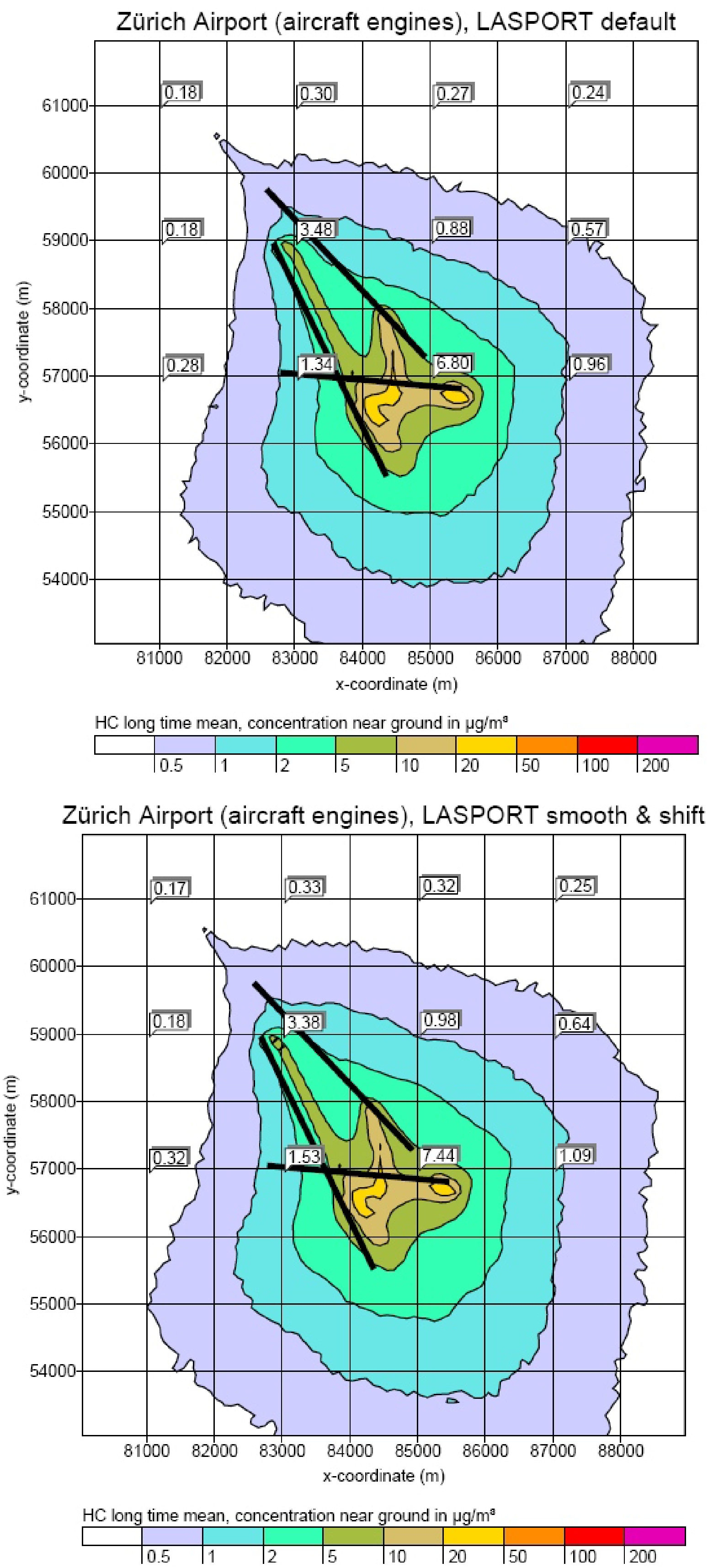
Figure 6: Long-time mean (6 months) for NOx near ground (example Zürich Airport, all source groups)



Top: LASPORT calculation with default source dynamics.

Bottom: LASPORT calculation with smoothed & shifted sources.

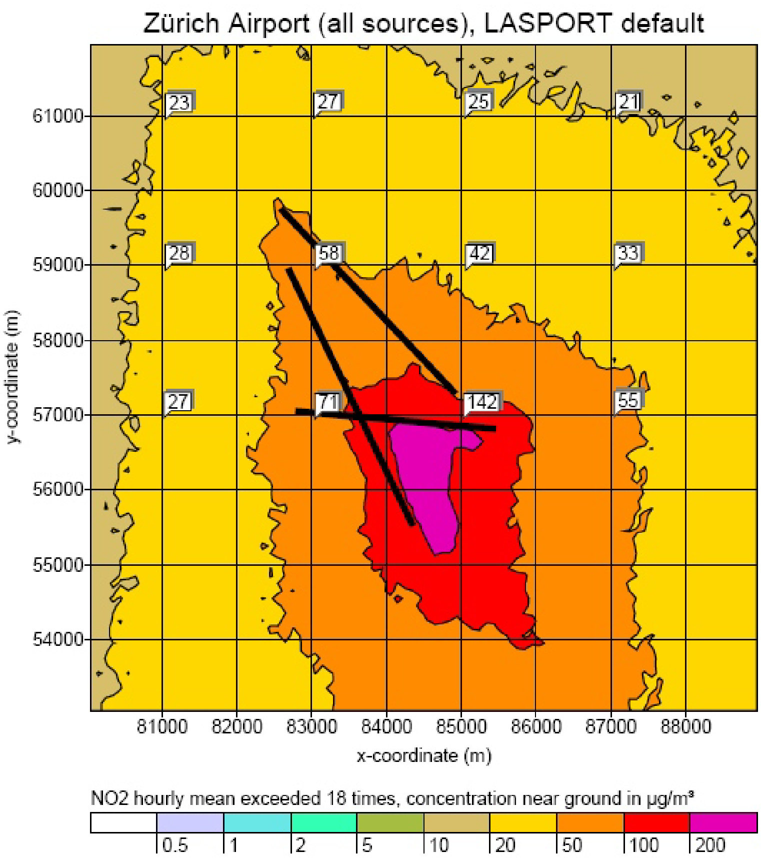
Figure 7: Long-time mean (6 months) for NOx near ground (example Zürich Airport, emissions from aircraft only).



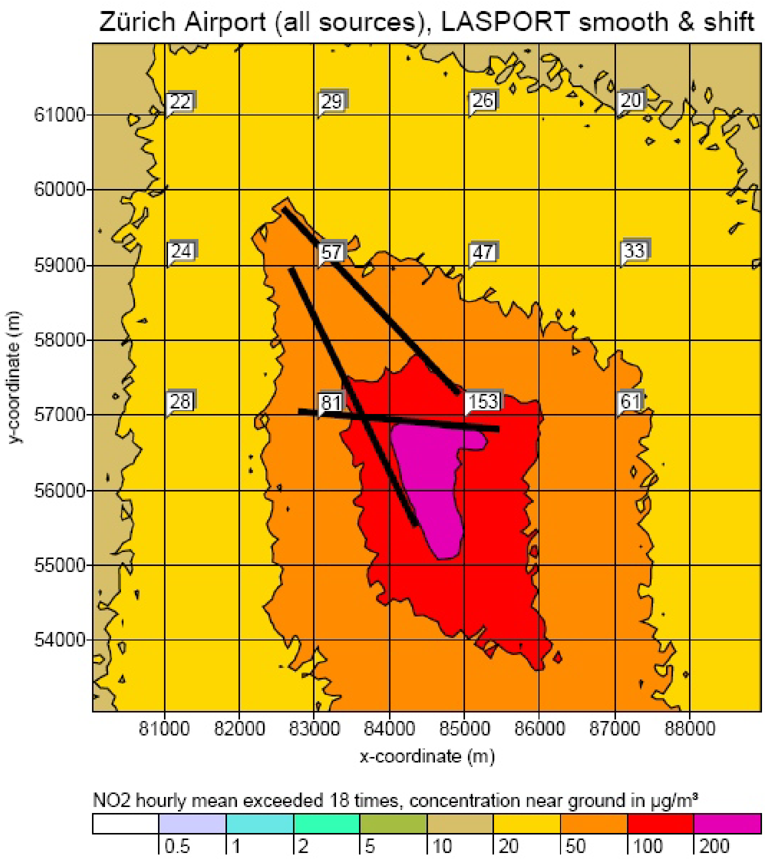
Top: LASPORT calculation with default source dynamics.

Bottom: LASPORT calculation with smoothed & shifted sources.

Figure 8: Long-time mean (6 months) for HC near ground (example Zürich Airport, emissions from aircraft only).



Top: LASPORT calculation with default source dynamics.



Bottom: LASPORT calculation with smoothed & shifted sources.

Figure 9: Short-time mean (hourly mean exceeded 18 times) for NO2 near ground for (example Zürich Airport, all sources).

(intentionally blank)

4 CONCLUSIONS AND OUTLOOK

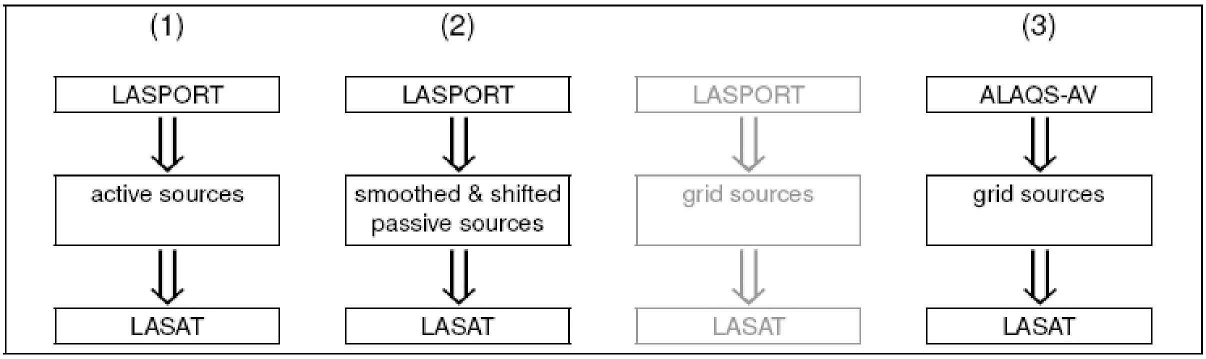


Figure 10: Existing model chains in the context of the smooth & shift approach.

In the preceding sections, the smooth & shift parameters were tested with the program system LASPORT by means of the model chains (1) and (2) in Figure 10.

With LASPORT it is not possible to create grid sources for LASAT (grey model chain in Figure 10). However, the only difference to model chain (2) would be the distribution over finite grid cell volumes, which has only little impact on the results as long as the grid cells are sufficiently small.

The smooth & shift parameters were derived for an application with ALAQS-AV, model chain (3) in Figure 10. A comparison of model chain (2) and model chain (3) will test whether the implementation of the smooth & shift approach in ALAQS-AV and the grid sources in LASAT were carried out in the way intended. For such a comparison, an emission setup must be chosen that is handled by LASPORT and ALAQS-AV in equal ways.[11]

In a next step, comparisons of model chain (1) and model chain (3) can be carried out to further test the sensitivity of the 'smooth and shift' approach.

Finally, it should be noted that model chain (3) involves the application of the program package LASAT, which is presently available only in German. An English version (especially of the reference book) is in preparation and should be available in the first quarter of the year 2006.

[11] For aircraft for example, the same operation times, spatial paths, and emission factors must be applied.

5 REFERENCES

[Ref 1.] **AUSTAL2000** Model in accordance with VDI 3945 Part 3; developed based on LASAT on behalf of the German Federal Environmental Agency; official reference model of the Technical Instruction on Air Quality Control (TA Luft) for licensing procedures; see Internet http://www.austal2000.de (German, including source code and examples; English version envisioned for 2006/2007).

[Ref 2.] **Janicke, U., Janicke, L.** (2001) A three-dimensional plume rise model for dry and wet plumes. Atmospheric Environment 35: 877-890.

[Ref 3.] **LASAT** Model in accordance with VDI 3945 Part 3; commercial software package for calculations according to *TA Luft* an beyond; for further information see http://www.janicke.de (German/English).

[Ref 4.] **LASPORT** Program system based on LASAT for airport air quality assessments; commercial software; for further informations see http://www.janicke.de (German/English).

[Ref 5.] **TA Luft** (2002) Technical Instruction on Air Quality Control (German). See http://www.bmu.de/download/dateien/taluft.pdf.

[Ref 6.] **VDI 3782 Part 3** (1985) Environmental meteorology – Dispersion of air pollutants in the atmosphere – Determination of plume rise. Berlin: Beuth Company (German/English, see http://www.vdi.de).

[Ref 7.] **VDI 3945 Part 3** (2000) Atmospheric dispersion models – Particle model. Berlin: Beuth Company (German/English, see http://www.vdi.de).

Appendix A LASAT grid sources

The preceding LASAT version 2.14 allowed the user to define a 2-dimensional raster source, where the source emissions are distributed over the cells of a regular, 2-dimensional grid. The relative fraction for each grid cell is defined in a separate file in form of a 2-dimensional data table.

In LASAT 2.16 this concept is replaced and extended by 3-dimensional grid sources. The 3-dimensional data table of the grid source is stored in a text file of format DMN. This format has been already applied in the models LASAT, LASPORT, and AUSTAL2000.

Alternatively to text output, the data table can be stored in binary and/or compressed form. Data compression is feasible because the table usually contains a large number of zero values. As compression scheme, the widely used GNU zip utility is applied (file extension `.gz`).

A 3-dimensional emission grid forms a very general representation of spatially varying emissions and it can thus be applied by almost any emission model as an interface to dispersion models like LASAT.

The following sections contain a description of the general file organization, format specifications, and a simple example.

A.1 File organization

The grid source is defined in the LASAT definition file `sources.def`[12] by a source name, a source index, and the horizontal position of the southwest grid corner.[13]

The horizontal mesh width of the grid, the vertical grid intervals, and the 3-dimensional data table with the relative emission for each cell is defined in a separate file, in the following referred to as grid file. The data table should be normalized, i.e. the sum over all entries (cells) should be unity.[14]

A grid file is stored in a subdirectory with a name that is identical to the source name. The file name has the form

`e`*iiii*`.dmna`

where *iiii* is the source index, a 4-digit number with leading zeros. The source index can be marked in the LASAT definition file as time-dependent and specified in form of a time series. This allows to supply a time-dependent relative emission distribution, where the according grid files are provided in the source subdirectory.

Like for ordinary sources, the overall emission of a grid source is defined in the LASAT definition file `emissions.def`[15] either by a constant value or in form of a time series. Hence, there are two features to account for time dependency that can be used either separately or in combined form: a time-dependent overall emission and a time-dependent spatial distribution of the emissions.

A grid file defines the relative emission distribution independent of the trace substance of interest. If the relative emission distribution is the same for all trace substances under investigation, they all can be emitted by the same grid source, optionally with different time-varying emissions. If the

[12] Until the appearance of an English LASAT version this file is called `quellen.def`.

[13] In LASAT, all coordinate specifications must consist of metre values with absolute values smaller 200 000 and they usually refer to a common reference point. Therefore it is feasible to define the absolute position of the grid source in the LASAT definition file and only the relative dimensions (mesh width, vertical spacing) in the grid file.

[14] For security, the data table is normalized as well internally by the program before use.

[15] Until the appearance of an English LASAT version this file is called `staerke.def`.

trace substances show different relative emission distributions, for each trace substance a separate grid source must be defined.

A.2 File format specification

In the LASAT definition files, time-dependent parameters like emissions or source indices are defined in a time series table. The relative emission distribution of a grid source is defined in a DMN file.

The following sections describe the formats of LASAT time series tables and DMN files.

A.2.1 LASAT time series table

Parameters are marked in LASAT definition files as time-dependent by setting the parameter value to a question mark ('`?`'). The time-dependent value is then defined in a time series table.

The time series of the time-dependent parameters can be placed all in one table, thereby using the same sequence of successive time intervals, or in separate tables, each with its own sequence of time intervals.[16]

A time series table consists of a one-line table header followed by the table rows, one for each time interval. The entries of a line are separated by one or more blanks or a tabulator.

The line with the table header must start with an exclamation mark as first character followed by the column names. The columns with the start and end time of the time intervals are named `T1` and `T2`, respectively.

The column name for a time-dependent parameter depends on the type of parameter. For the source index, the column name is `Iq.`*Source*, where *Source* is the name of the grid source.[17]

Time-dependent emissions can be accounted for in different ways:

- The time-dependent emission of an individual source and a particular trace substance is defined in a column with name `Eq.`*Source*.*Tracer*.
- If the time course of emissions is the same for all trace substances of a source, the source can be placed in a source group and an overall factor is specified with which all emissions of all sources of that group are multiplied. This factor and the according column header have the name `Fq.`*Srcgroup*, where *Srcgroup* is the name of the source group.
- If all emissions of all sources have the same time course, an overall factor can be used with which all emissions are multiplied. This factor and the according column header have the name `Emisfac`.

After the table header follows the data part with the table rows. A table row must start with the character `Z` followed by the values for all table columns. Time specifications for `T1` and `T2` are made relative to an absolute date (e.g. 2005-11-30) in the form *d*.*hh*:*mm*:*ss*. For data entries, a point must be used as decimal separator.

The following shows an example for a LASAT time series table over two days with the time-dependent overall factor `Emisfac` specified in form of successive means over 4 hours.

```
!   T1             T2             Emisfac
Z   000.00:00:00   000.04:00:00   0.00
Z   000.04:00:00   000.08:00:00   0.05
Z   000.08:00:00   000.12:00:00   0.40
Z   000.12:00:00   000.16:00:00   0.25
```

[16] Time-dependent meteorological parameters are always stored in a single, separate time series table.
[17] If a source with name *Name* is placed in a source group with name *Srcgroup*, the complete source name that has to be used has the form *Srcgroup*.*Name*. The same applies to trace substances that are placed in a trace substance group

```
Z    000.16:00:00    000.20:00:00    0.20
Z    000.20:00:00    001.00:00:00    0.10
Z    001.00:00:00    001.04:00:00    0.00
Z    001.04:00:00    001.08:00:00    0.05
Z    001.08:00:00    001.12:00:00    0.40
Z    001.12:00:00    001.16:00:00    0.25
Z    001.16:00:00    001.20:00:00    0.20
Z    001.20:00:00    002.00:00:00    0.10
```

A.2.2 DMN format

Files with extension `.dmna` are plain text files with a file header followed by a data part. The file header contains information about the type, size, and structure of the data part. The elements of the data part, in the following referred to as records, are either single objects (a number or a string) or a sequence of objects. The data part can have a dimension between 1 and 5, the records being addressed by the according indices *i* to *m*.

The data part is stored in text format either directly after the header part or in a separate file with the same name but extension `.dmnt`.

Alternatively to text format, the data part can be stored in binary format in a separate file with the same name but extension `.dmnb`. In a binary file, the data records are written in their internal order (*i* is the slowest running index, *j* the next one and so on), consecutively and without control characters.

If the data part is placed in a separate file, it can be stored also in compressed format (GNU zip), where the file extensions are `.dmnt.gz` and `.dmnb.gz`, respectively.

In the file header, each line defines one parameter. The name of a parameter appears at the beginning of the line followed by one or several values. Allowed separators between name and values are a blank, a tabulator, or a semicolon. The line is terminated by LF or CR+LF. The order in which the parameter lines appear is arbitrary.

Header lines starting with a dash ('`-`') as first character are ignored (comment lines).

At the right side of the parameter name, the type (string, integer, float) and number of values are indicated. An underlined parameter name indicates that this parameter must be specified, otherwise it can be omitted in which case its default setting is used.

`cmpr` integer (1)
Compression level (GNU zip) of the data part (between 0 and 9, default is 0). For 0, the data part is uncompressed. For values larger 0, the data part is stored in a separate file with the same name but extension `.dmnt.gz` (text output) or `.dmnb.gz` (binary output).

`data` string(1)
Name of the file with the actual data table. If data is not specified or if it has the value "*", the data table is written in case of formatted (text) output to the same file as the file header. For unformatted (binary) output, the file name of the header is used but with the extension `.dmnb` instead of `.dmna`. If data contains a path specification, it is interpreted as relative to the directory that contains the file header.

`dims` integer (1)
Number of dimensions (maximum 5).

`fact` float(1)
Factor with which all data elements of type float or double are multiplied before formatted output (default is 1). When reading in formatted data, the elements are divided by fact. The factor acts only on those data elements for which no factor is specified in the format string (see `form`).

`file` string(1)

Name of the file (for documentation in case the file name is changed at later times).

`form` string(1)

Format used to save data elements in formatted output. If the elements of the data table are records that consist of several data elements, a format must be specified for each element and form is the sum of all formats.

Format = $\text{Format}_1\text{Format}_2$...

Format_i = *Name*%(**Factor*)*Length*.*PrecisionSpecifier*

Where:

Name	name of the data element (optional)
Factor	scaling factor (optional including brackets)
Length	length of the data field
Precision	number of decimal positions (for floating point numbers)
Specifier	type specifier

The scaling factor *Factor* is handled like the parameter `fact`. The specification *Length* is the minimum length of the data field and may be exceeded if necessary for the display of the data field. The numbers are separated by at least one separator character.

The following type specifiers are recognised:

Spec.	Type	Byte length	Description
`c`	character	1	single character
`d`	integer	4	decimal number
`x`	integer	4	hexadecimal number
`f`	float	4	floating point number (without exponent)
`e`	float	4	floating point number (with exponent)
`t`	integer	4	time specification (without date)

The specifiers `f` and `e` may be preceded by a `l` (double of length 8 bytes). The specifiers `d` and `x` may be proceeded by a `h` (short integer of length 2 bytes).

Time format for binary output: The time specification without date is the number of passed seconds. If the specifier `t` is proceeded by a `l`, the number (double of length 8 bytes) is interpreted as time specification with date: The positions to the left side of the decimal separator represent the number of days passed since 1899-12-30.00:00:00 plus 10^6, the decimal positions represent the fraction of seconds passed at the specified day. Time format for text output: The time is specified in the form *dd.hh*:*mm*:*ss* or *hh*:*mm*:*ss*, with `lt` in the form *yyyy-MM-dd.hh*:*mm*:*ss*.

Similar format specifications can be merged:

`vx%5.2fvy%5.2fvz%5.2f` is equivalent to `vx%[3]5.2f`.[18]

[18] For merged formats, the specified *Name* applies to the first element only. For the following elements, the last character of *Name* is increased by one alphabetical position.

`hghb` integer (dims)
Upper bound for the data indices in the order *i*, *j*, …

`locl` string(1)
Representation of floating point numbers: With `C` (default setting), a decimal point is applied. With `german`, a comma is applied as decimal separator. If a file contains a comma as decimal separator, `locl` must be specified.

`lowb` integer (dims)
Lower bound for the data indices in the order *i*, *j*, ..

`lsbf` integer (1)
Least significant byte first (0 or 1, default is 1). Specifies the byte order for binary output.

`mode` string(1)
Output mode: binary or text (default is text).

`sequ` string(1)
Index sequence for the data output (default is `i+,j+`,...). Usually, the fastest index is the one at the far-right side (C convention). For a three-dimensional field A_{ijk}, this corresponds to the specification `i+,j+,k+`. FORTRAN saves data according to `k+,j+,i+`.

A minus sign instead of a plus sign denotes an index running backwards.

For a formatted two-dimensional data table with values oriented north wise (north at the top, west at the left side), `sequ` has the value `j-,i+`.

It is possible to select sub-ranges, for example `j=10..1/1,i=5..25/1,k=1`. The optional setting `/n` specifies the starting value of the corresponding index. If a sub-range is selected with `sequ`, the index boundaries `lowb` and `hghb` still refer to the original index definitions.

`size` integer (1)
Record size of the data in bytes. For formatted output the sum of record sizes resulting from the format specification must be equal to size.

If strings contain blanks they must be enclosed in quotation marks, otherwise quotation marks are optional.

Example: A field with floating point numbers $A_{ijk} = 100i + 10j + k$, $i = 1..3$, $j = 2..4$, $k = 0..1$ is saved in form of horizontal layers:

```
form   "%4.1f"
mode   "text"
sequ   "k+,j-,i+"
fact   1.000e-001
dims   3
size   4
lowb   1 2 0
hghb   3 4 1
*

14.0 24.0 34.0
13.0 23.0 33.0
12.0 22.0 32.0

14.1 24.1 34.1
13.1 23.1 33.1
12.1 22.1 32.1
***
```

A.2.3 DMN format for grid files

The relative emission distribution over the cells of a 3-dimensional grid is provided in form of a DMN file with a 3-dimensional data part. The elements of the data part are addressed by the following indices:

Index	Description	Start value
i	Cell index in x-direction (west to east)	1
j	Cell index in y-direction (south to north)	1
k	Cell index in the vertical direction	1

The following parameters need to be specified in the file header in extension to the system header:

`axes` string(1)
Axes description. It should be set to `xyz` so that post processors like IBJdis are informed about the meaning of the three indices.

`artp` string(1)
Array type description. It should be set to `M` so that post processors programs like IBJdis can correctly construct the graphics legend.

`delt` float(1)
Horizontal mesh width of the emission grid in metre.

`sk` float($k_{max}-k_{min}+1$)
Vertical grid spacing in metres. A setting `0 10 100` for example implies that k = 1 refers to grid cells with a vertical extent from 0 m to 10 m above ground and k = 2 to grid cells with a vertical extent from 10 m to 100 m above ground.

`t1` string(1)
Start of the time interval which the data refer to (default is `-inf`).

`t2` string(1)
End of the time interval which the data refer to (default is `+inf`).

A.3 Other

A.3.1 Simple example

A grid source is defined in the LASAT definition file `sources.def` by the following parameters:

Name	`aircraftnox`
Index	`0001`
Left border	`-200`
Lower border	`-400`

The emission strengths for the different trace substances are defined in the LASAT definition file `emissions.def`, either as constant or in form of a time series.

The grid file `e0001.dmna` with the relative emission distributions for the grid source is stored in subdirectory `aircraftnox` and reads in this example:

```
- grid source aircraftnox
file   e0001.dmna
```

```
delt   100
sk     0    30    60
t1     "-inf"
t2     "+inf"
axes   "xyz"
artp   "M"
mode   "text"
sequ   "k+,j-,i+"
dims   3
form   "%12.4e"
lowb   1 1 1
hghb   6 5 2
*
0.0000e+00 0.0000e+00 0.0000e+00 0.0000e+00 0.0000e+00 0.0000e+00
0.0000e+00 0.0000e+00 0.0000e+00 0.0000e+00 0.0000e+00 0.0000e+00
5.0000e-02 6.0000e-02 7.5000e-02 1.0000e-01 1.5000e-01 0.0000e+00
0.0000e+00 0.0000e+00 0.0000e+00 0.0000e+00 3.5000e-02 0.0000e+00
0.0000e+00 0.0000e+00 1.0000e-02 1.0000e-02 1.0000e-02 0.0000e+00
0.0000e+00 0.0000e+00 0.0000e+00 0.0000e+00 0.0000e+00 0.0000e+00
0.0000e+00 0.0000e+00 0.0000e+00 0.0000e+00 0.0000e+00 0.0000e+00
5.0000e-02 6.0000e-02 7.5000e-02 1.0000e-01 1.5000e-01 0.0000e+00
0.0000e+00 0.0000e+00 0.0000e+00 0.0000e+00 3.5000e-02 0.0000e+00
0.0000e+00 0.0000e+00 1.0000e-02 1.0000e-02 1.0000e-02 0.0000e+00
***
```

The grid source extends in *x*-direction from -200 m to 400 m (relative to a given reference point), in *y*-direction from -400 m to 100 m (relative to a given reference point), and in *z*-direction from 0 m to 60 m above ground.

The grid cell i = 5, j = 3, k = 1 for example extends in *x*-direction from 200 m to 300 m, in *y*-direction from -200 m to -100 m, and in *z*-direction from 0 m to 30 m above ground. 15% of the emission is homogeneously emitted within this cell.

A.3.2 Data compression

To derive from file `e0001.dmna` of the preceding example a compressed data part one can proceed as follows:

1. Save the data part (lines between the two ”star” lines) to the new file `e0001.dmnt`.
2. Compress `e0001.dmnt` with a freeware GNU zip routine[19] to file `e0001.dmnt.gz`.
3. Delete in `e0001.dmna` the data part and the end line with the three stars.
4. Insert in the header of `e0001.dmna` the parameter `cmpr` with the compression value that was applied.

A program `IBJdata` is provided that allows to read in, write out, and compress DMN files. The program is called on Windows systems in a DOS shell. Help information is provided by calling the program without arguments.

`IBJdata` can be used to check files by printing out their contents to the DOS shell, for example

```
IBJdata lasat\test -ie0001.dmna -p
```

or to compress files, for example

```
IBJdata lasat\test -ie0001.dmna -c6 -ums -oe0002
```

A.3.3 Application to ALAQS-AV

The extension of LASAT to grid sources allows to import ALAQS-AV emission results in various ways. In any case, one or more grid files with the relative emission distributions and a time series with the overall emission of a trace substance must be specified.

A brute force method would be to derive from the ALAQS-AV output for every hour of the year and every trace substance a separate emission grid. From this, for each trace substance a LASAT grid source is defined with a time series of 8760 hourly mean emission strengths and a set of 8760 grid files.

It could be the case that only the overall emission and not its relative spatial distribution is a function of time. In this case one could produce just one grid file and according emission time series.

The horizontal mesh width and the vertical intervals that should be used for the emission grid depend on the situation being studied. A first guess would be to use a horizontal mesh width of 100 m. This typically yields 50 to 100 meshes in *x*- and *y*-direction if no extended landside motor traffic is considered.

A default setting for the vertical grid could be for example

```
0 2 4 6 8 10 12 15 20 25 30 35 40 45 50 60 70
80 100 120 150 200 250 300 350 400 450 500 600 800 1000
```

(30 intervals).

[19] See for example www.gzip.org. Note: The file extension of the emission files contains more than 3 characters, therefore the Windows and not the DOS executable must be applied!

Appendix B LASAT input files of the test calculations in Section 2

B.1 TakeOff, input file param.def

```
- general parameter settings ---------------------------------- PARAM.DEF
.
Kennung = "Smooth & Shift, TakeOff" ' title
Intervall = 1:00:00 ' average time interval (1 hour)
Start = 0:00:00 ' start time
Ende = 36:00:00 ' end time
Average = 36 ' write out 36-hour-average
Flags = MAXIMA ' write out EU short time values
---------------------------------------------------------------------------
- definition of the calculation grid -------------------------- GRID.DEF
.
Delta = 50 ' horizontal mesh width
Xmin = -2500 ' left (western) border
Ymin = -2000 ' lower (south) border
Nx = 130 ' number of meshes in x-direction
Ny = 80 ' number of meshes in y-direction
Sk = { 0 3 6 10 15 20 30 40 50 ' vertical spacing
60 70 80 90 100 120 150 200 300 400 600 800 }
---------------------------------------------------------------------------
- definition of line sources (quellen) ----------------------- QUELLEN.DEF
- X1/X2 x-coordinate of the first/second point
- Y1/Y2 y-coordinate of the first/second point
- H1/H2 upper (for line sources only!) border of the first/second point
- Bq horizontal extent
- Tq vertical extent
- Fr model parameter controling reflection at ground (should be set to -1)
- Fq exit angle with respect to z-direction
- Gq exit angle with respect to north clockwise
- Ts time scale on which SH, Sk, Sv, Vq decay
- Sl longitudinal velocity fluctuations
- Sh transversal, horizontal velocity fluctuations
- Sv transversal, vertical velocity fluctuations
- Vq exit velocity
-
.
!  Name  |  X1   Y1 H1     X2     Y2  H2     Bq  Tq  Fr  Fq  Gq  Ts  Sh    Sl    Sv    Vq
---------+-------------------------------------------------------------------------------------
Q  lsp1  |  450  0  25.0   0      0   25.0   50  25  -1  90  90  80  3.00  0.00  1.80  9.00
Q  lsp2  |  0    0  25.0   -1350  0   25.0   50  25  -1  90  90  80  3.00  0.00  1.80  9.00
Q  sas1  |  810  0  181.0  360    0   181.0  301 181 -1  0   0   0   0     0     0     0
Q  sas2  |  360  0  181.0  -990   0   181.0  301 181 -1  0   0   0   0     0     0     0
Q  nod1  |  450  0  25.0   0      0   25.0   50  25  -1  0   0   0   0     0     0     0
Q  nod2  |  0    0  25.0   -1350  0   25.0   50  25  -1  0   0   0   0     0     0     0
-----------------------------------------------------------------------------------------------
---------------------------------------------------------------------------
- definition of the trace substances ------------------------- STOFFE.DEF
        .
        Einheit = ug              ' mass unit
        Vsed = 0.0               ' settling velocity
        Rate = 200                ' particle emission rate
-
- Vdep deposition velocity
- RefC reference value for the graphical display with IBJdis
! Name | Vdep RefC
-----------+-------------
K NOX_lsp | 0.000 10 ' emitted by source lsp (LASPORT)
K NOX_sas | 0.000 10 ' emitted by source sas (s&s)
K NOX_nod | 0.000 10 ' emitted by source nod (no dynamics)
--------------------------
---------------------------------------------------------------------------

- definition of emission strengths -------------------------- STAERKE.DEF
.
- example:     10 small aircraft per hour with ff=2.347 kg/s, ei=22.82 g/kg
-              takeoff distance 1800m with average vel 45 m/s, partitioned
-              in two segments crossed in equal times (20s)
-              -> 1071 g NOX per aircraft and segment
-              -> hourly emission rate 10710/3600 g/s = 3.0e6 ug/s
```

```
-
! Quelle | NOX_lsp NOX_sas NOX_nod
---------+---------------------------
E lsp1   | 3.0e6 0 0
E lsp2   | 3.0e6 0 0
E sas1   | 0 3.0e6 0
E sas2   | 0 3.0e6 0
E nod1   | 0 0 3.0e6
E nod2   | 0 0 3.0e6
----------------------------------------
---------------------------------------------------------------------------
- defintion of meteorology ------------------------------------ WETTER.DEF
. Version = 2.1      ' version of the met. pre-processor
        Z0 = 0.3     ' roughness length (m)
        D0 = 1.8     ' displacement height (m)
        Ha = 12      ' anemometer height (m)
        Ua = 3       ' wind speed (m/s)
        Ra = ?       ' wind direction (against north clockwise), time-dependent
        Lm = 300     ' Monin-Obukhov length (slightly stable stratification)
- meteorological time series ---------------------------------- WETTER.ZTR
-
!       T1                    T2              Ra
        (ddd.hh:mm:ss)     (ddd.hh:mm:ss)     (grad)
Z       0.00:00:00         0.01:00:00 10
Z       0.01:00:00         0.02:00:00 20
Z       0.02:00:00         0.03:00:00 30
Z       0.03:00:00         0.04:00:00 40
Z       0.04:00:00         0.05:00:00 50
Z       0.05:00:00         0.06:00:00 60
Z       0.06:00:00         0.07:00:00 70
Z       0.07:00:00         0.08:00:00 80
Z       0.08:00:00         0.09:00:00 90
Z       0.09:00:00         0.10:00:00 100
Z       0.10:00:00         0.11:00:00 110
Z       0.11:00:00         0.12:00:00 120
Z       0.12:00:00         0.13:00:00 130
Z       0.13:00:00         0.14:00:00 140
Z       0.14:00:00         0.15:00:00 150
Z       0.15:00:00         0.16:00:00 160
Z       0.16:00:00         0.17:00:00 170
Z       0.17:00:00         0.18:00:00 180
Z       0.18:00:00         0.19:00:00 190
Z       0.19:00:00         0.20:00:00 200
Z       0.20:00:00         0.21:00:00 210
Z       0.21:00:00         0.22:00:00 220
Z       0.22:00:00         0.23:00:00 230
Z       0.23:00:00         0.24:00:00 240
Z       0.24:00:00         0.25:00:00 250
Z       0.25:00:00         0.26:00:00 260
Z       0.26:00:00         0.27:00:00 270
Z       0.27:00:00         0.28:00:00 280
Z       0.28:00:00         0.29:00:00 290
Z       0.29:00:00         0.30:00:00 300
Z       0.30:00:00         0.31:00:00 310
Z       0.31:00:00         0.32:00:00 320
Z       0.32:00:00         0.33:00:00 330
Z       0.33:00:00         0.34:00:00 340
Z       0.34:00:00         0.35:00:00 350
Z       0.35:00:00         0.36:00:00 360
```

B.2 Approach, input file param.def

```
- general parameter settings ----------------------------------- PARAM.DEF
.
    Kennung = "Smooth & Shift, Approach"         ' title
    Intervall = 1:00:00                          ' average time interval (1 hour)
    Start = 0:00:00                              ' start time
    Ende = 36:00:00                              ' end time
    Average = 36                                 ' write out 36-hour-average
    Flags = MAXIMA                               ' write out EU short time values
--------------------------------------------------------------------------
- definition of the calculation grid --------------------------- GRID.DEF
.
        Delta = 50                   ' horizontal mesh width
        Xmin = -2500                 ' left (western) border
        Ymin = -2000                 ' lower (south) border
        Nx = 130                     ' number of meshes in x-direction
        Ny = 80                      ' number of meshes in y-direction
        Sk = { 0 3 6 10 15 20 30 40 50 ' vertical spacing
               60 70 80 90 100 120 150 200 300 400 600 800 }
Nzd = 1
--------------------------------------------------------------------------
- definition of line sources (quellen) ---------------------- QUELLEN.DEF
- X1/X2 x-coordinate of the first/second point
- Y1/Y2 y-coordinate of the first/second point
- H1/H2 upper (for line sources!) border of the first/second point
- Bq horizontal extent
- Tq vertical extent
- Fr model parameter controling reflection at ground (should be set to -1)
- Fq exit angle with respect to z-direction
- Gq exit angle with respect to north clockwise
- Ts time scale on which SH, Sk, Sv, Vq decay
- Sl longitudinal velocity fluctuations
- Sh transversal, horizontal velocity fluctuations
- Sv transversal, vertical velocity fluctuations
- Vq exit velocity
-
.
!  Name   |  X1    Y1 H1      X2      Y2   H2      Bq   Tq   Fr   Fq   Gq   Ts   Sh    Sl    Sv    Vq
---------+-----------------------------------------------------------------------------------------------
Q  lsp1   |  3900  0  130.0   1900    0    25.0    50   25   -1   87   90   80   1.64  1.64  0.99  0.0
Q  lsp2   |  1900  0  25.0    0       0    25.0    50   25   -1   90   90   80   1.64  1.64  0.99  0.0
Q  lsp3   |  0     0  25.0    -750    0    25.0    50   25   -1   90   90   80   1.64  1.64  0.99  0.0
Q  lsp4   |  -750  0  25.0    -1000   0    25.0    165  25   -1   90   90   80   1.64  1.64  0.99  0.0
Q  sas1   |  3900  0  167.5   2616    0    100.0   165  100  -1   0    0    0    0     0     0     0
Q  sas2   |  2616  0  100.0   0       0    100.0   165  100  -1   0    0    0    0     0     0     0
Q  sas3   |  0     0  100.0   -750    0    100.0   165  100  -1   0    0    0    0     0     0     0
Q  sas4   |  -750  0  100.0   -1000   0    100.0   165  100  -1   0    0    0    0     0     0     0
Q  nod1   |  3900  0  130.0   1900    0    25.0    50   25   -1   0    0    0    0     0     0     0
Q  nod2   |  1900  0  25.0    0       0    25.0    50   25   -1   0    0    0    0     0     0     0
Q  nod3   |  0     0  25.0    -750    0    25.0    50   25   -1   0    0    0    0     0     0     0
Q  nod4   |  -750  0  25.0    -1000   0    25.0    165  25   -1   0    0    0    0     0     0     0
------------------------------------------------------------------------------------
--------------------------------------------------------------------------
- definition of the trace substances ------------------------ STOFFE.DEF
.
        Einheit = ug                 ' mass unit
        Vsed = 0.0                   ' settling velocity
        Rate = 200                   ' particle emission rate
-
- Vdep deposition velocity
- RefC reference value for the graphical display with IBJdis
! Name       | Vdep RefC
-----------+-------------
K NOX_lsp  | 0.000 10 ' emitted by source lsp (LASPORT)
K NOX_sas  | 0.000 10 ' emitted by source sas (s&s)
K NOX_nod  | 0.000 10 ' emitted by source nod (no dynamics)
--------------------------
--------------------------------------------------------------------------

- definition of emission strengths -------------------------- STAERKE.DEF
- example: 10 small aircraft per hour with ff=0.673 kg/s, ei=8.6 g/kg (5.8 g/s).
-       Approach over 3900m until touch down of the aircraft with 3 deg and
-       67 m/s. Because plume down-shift by 100m, the plume touches ground 1900
-       before the touch-down point of the aircraft. This gives two segments.
-       After touch-down point constant deceleration
```

```
-       until rest over 1000m in two segments crossed in equal times (15s)
-       -> 1. segment: 30 sec / 174 g NOX per aircraft
-       -> 2. segment: 28 sec / 162 g NOX per aircraft
-       -> 3. and 4. segment: 15 sec / 87 g NOX per aircraft
-
      ! Quelle  |  NOX_lsp     NOX_sas       NOX_nod
      -----------+--------------------------
      E lsp1    |  4.8e5  0   0
      E lsp2    |  4.5e5  0   0
      E lsp3    |  2.4e5  0   0
      E lsp4    |  2.4e5  0   0
      E sas1   |  0       3.1e5      0
      E sas2   |  0       6.2e5      0
      E nod1   |  0       0   4.8e5
      E nod2   |  0       0   4.5e5
      E nod3   |  0       0   2.4e5
      E nod4   |  0       0   2.4e5
---------------------------------------------------------------------------
- defintion of meteorology ----------------------------------- WETTER.DEF
        . Version = 2.1     ' version of the met. pre-processor
        Z0 = 0.3            ' roughness length (m)
        D0 = 1.8            ' displacement height (m)
        Ha = 12             ' anemometer height (m)
        Ua = 3              ' wind speed (m/s)
        Ra = ?              ' wind direction (against north clockwise), time-dependent
        Lm = 300            ' Monin-Obukhov length (slightly stable stratification)
- meteorological time series --------------------------------- WETTER.ZTR
-
!       T1                  T2                  Ra
        (ddd.hh:mm:ss)      (ddd.hh:mm:ss)     (grad)
Z       0.00:00:00          0.01:00:00 10
Z       0.01:00:00          0.02:00:00 20
Z       0.02:00:00          0.03:00:00 30
Z       0.03:00:00          0.04:00:00 40
Z       0.04:00:00          0.05:00:00 50
Z       0.05:00:00          0.06:00:00 60
Z       0.06:00:00          0.07:00:00 70
Z       0.07:00:00          0.08:00:00 80
Z       0.08:00:00          0.09:00:00 90
Z       0.09:00:00          0.10:00:00 100
Z       0.10:00:00          0.11:00:00 110
Z       0.11:00:00          0.12:00:00 120
Z       0.12:00:00          0.13:00:00 130
Z       0.13:00:00          0.14:00:00 140
Z       0.14:00:00          0.15:00:00 150
Z       0.15:00:00          0.16:00:00 160
Z       0.16:00:00          0.17:00:00 170
Z       0.17:00:00          0.18:00:00 180
Z       0.18:00:00          0.19:00:00 190
Z       0.19:00:00          0.20:00:00 200
Z       0.20:00:00          0.21:00:00 210
Z       0.21:00:00          0.22:00:00 220
Z       0.22:00:00          0.23:00:00 230
Z       0.23:00:00          0.24:00:00 240
Z       0.24:00:00          0.25:00:00 250
Z       0.25:00:00          0.26:00:00 260
Z       0.26:00:00          0.27:00:00 270
Z       0.27:00:00          0.28:00:00 280
Z       0.28:00:00          0.29:00:00 290
Z       0.29:00:00          0.30:00:00 300
Z       0.30:00:00          0.31:00:00 310
Z       0.31:00:00          0.32:00:00 320
Z       0.32:00:00          0.33:00:00 330
Z       0.33:00:00          0.34:00:00 340
Z       0.34:00:00          0.35:00:00 350
Z       0.35:00:00          0.36:00:00 360
---------------------------------------------------------------------------
```

B.3 Idle, input file param.def

```
- general parameter settings ---------------------------------- PARAM.DEF
.
   Kennung = "Smooth & Shift, Idle"         ' title
   Intervall = 1:00:00                      ' average time interval (1 hour)
   Start = 0:00:00                          ' start time
   Ende = 36:00:00                          ' end time
   Average = 36                             ' write out 36-hour-average
   Flags = MAXIMA                           ' write out EU short time values
--------------------------------------------------------------------------
- definition of the calculation grid -------------------------- GRID.DEF
.
   Delta = 50                               ' horizontal mesh width
   Xmin = -2500                             ' left (western) border
   Ymin = -2000                             ' lower (south) border
   Nx = 100                                 ' number of meshes in x-direction
   Ny = 80                                  ' number of meshes in y-direction
   Sk = { 0 3 6 10 15 20 30 40 50           ' vertical spacing
   60 70 80 90 100 120 150 200 300 400 600 800 }
--------------------------------------------------------------------------
- definition of line sources (quellen) ----------------------- QUELLEN.DEF
        - X1/X2 x-coordinate of the first/second point
        - Y1/Y2 y-coordinate of the first/second point
        - H1/H2 upper (!) border of the first/second point
        - Bq horizontal extent
        - Tq vertical extent
        - Fr model parameter controling reflection at ground (should be set to -1)
        - Fq exit angle with respect to z-direction
        - Gq exit angle with respect to north clockwise
        - Ts time scale on which SH, Sk, Sv, Vq decay
        - Sl longitudinal velocity fluctuations
        - Sh transversal, horizontal velocity fluctuations
        - Sv transversal, vertical velocity fluctuations
        - Vq exit velocity
        -

! Name  |   X1    Y1 H1      X2      Y2   H2      Bq   Tq   Fr   Fq   Gq   Ts   Sh    Sl    Sv    Vq
--------+-------------------------------------------------------------------------------------------
Q lsp   |-1500    0  25.0    1500    0    25.0    50   25   -1   90   90   80   0.79  0.79  0.48  0.00
Q sas   |-1500    0  49.0    1500    0    49.0    81   49   -1   0    0    0    0     0     0     0
Q nod   |-1500    0  25.0    1500    0    25.0    50   25   -1   0    0    0    0     0     0     0
----------------------------------------------------------------------------------------------------
- definition of the trace substances ------------------------- STOFFE.DEF
.
   Einheit = ug                             ' mass unit
   Vsed = 0.0                               ' settling velocity
   Rate = 200                               ' particle emission rate
-
- Vdep deposition velocity
- RefC reference value for the graphical display with IBJdis
! Name        | Vdep         RefC
--------------+---------------
K HC_lsp     | 0.000          10        ' emitted by source lsp (LASPORT)
K HC_sas    | 0.000           10        ' emitted by source sas (s&s)
K HC_nod    | 0.000           10        ' emitted by source nod (no dynamics)
--------------------------
--------------------------------------------------------------------------
- definition of emission strengths -------------------------- STAERKE.DEF
.
- example:     10 small aircraft per hour with ff=0.2417 kg/s, ei=3.02 g/kg
-              distance 3000 m, velocity 30 km/h
-              -> 263 g HC per aircraft
-              -> hourly emission rate 2630/3600 g/s = 7.3e5 ug/s
-
! Quelle     |HC_lsp   HCsas      HC_nod
----------+---------------------------------------------
E lsp   |    7.3e5      0          0
E sas   |    0          7.3e5      0
E nod   |    0           0        7.3e5
-------------------------------------
--------------------------------------------------------------------------
- defintion of meteorology --------------------------------- WETTER.DEF
      .Version = 2.1      ' version of the met. pre-processor
      Z0 = 0.3            ' roughness length (m)
      D0 = 1.8             ' displacement height (m)
```

```
      Ha = 12              ’ anemometer height (m)
      Ua = 3              ’ wind speed (m/s)
      Ra = ?               ’ wind direction (against north clockwise), time-dependent
      Lm = 300            ’ Monin-Obukhov length
- meteorological time series ---------------------------------- WETTER.ZTR
-
!      T1                  T2                  Ra
       (ddd.hh:mm:ss)      (ddd.hh:mm:ss)     (grad)
Z      0.00:00:00          0.01:00:00 10
Z      0.01:00:00          0.02:00:00 20
Z      0.02:00:00          0.03:00:00 30
Z      0.03:00:00          0.04:00:00 40
Z      0.04:00:00          0.05:00:00 50
Z      0.05:00:00          0.06:00:00 60
Z      0.06:00:00          0.07:00:00 70
Z      0.07:00:00          0.08:00:00 80
Z      0.08:00:00          0.09:00:00 90
Z      0.09:00:00          0.10:00:00 100
Z      0.10:00:00          0.11:00:00 110
Z      0.11:00:00          0.12:00:00 120
Z      0.12:00:00          0.13:00:00 130
Z      0.13:00:00          0.14:00:00 140
Z      0.14:00:00          0.15:00:00 150
Z      0.15:00:00          0.16:00:00 160
Z      0.16:00:00          0.17:00:00 170
Z      0.17:00:00          0.18:00:00 180
Z      0.18:00:00          0.19:00:00 190
Z      0.19:00:00          0.20:00:00 200
Z      0.20:00:00          0.21:00:00 210
Z      0.21:00:00          0.22:00:00 220
Z      0.22:00:00          0.23:00:00 230
Z      0.23:00:00          0.24:00:00 240
Z      0.24:00:00          0.25:00:00 250
Z      0.25:00:00          0.26:00:00 260
Z      0.26:00:00          0.27:00:00 270
Z      0.27:00:00          0.28:00:00 280
Z      0.28:00:00          0.29:00:00 290
Z      0.29:00:00          0.30:00:00 300
Z      0.30:00:00          0.31:00:00 310
Z      0.31:00:00          0.32:00:00 320
Z      0.32:00:00          0.33:00:00 330
Z      0.33:00:00          0.34:00:00 340
Z      0.34:00:00          0.35:00:00 350
Z      0.35:00:00          0.36:00:00 360
--------------------------------------------------------------------------
```

B.4 APU, input file param.def

The meteorological time series over 100 days is specified in the separate file `wetter.def` which is not listed here.

```
- general parameter settings ----------------------------------- PARAM.DEF
.
      Kennung = "Smooth & Shift, APU" ' title
      Intervall = 1:00:00            ' average time interval (1 hour)
      Start = 0:00:00                ' start time
      Ende =100.00:00:00             ' end time
      Average = 2400                 ' write out 36-hour-average
      Flags = MAXIMA                 ' write out EU short time values
--------------------------------------------------------------------------
- definition of the calculation grid -------------------------- GRID.DEF
.
      Delta = 50                                  ' horizontal mesh width
      Xmin = -2500                                ' left (western) border
      Ymin = -2500                                ' lower (south) border
      Nx = 100                                    ' number of meshes in x-direction
      Ny = 100                                    ' number of meshes in y-direction
      Sk = { 0 3 6 10 15 20 30 40 50              ' vertical spacing
            60 70 80 90 100 120 150 200 300 400 600 800 }
      Nzd = 1                                     ' save the lowest layer only
--------------------------------------------------------------------------
- definition of square sources (quellen) --------------------- QUELLEN.DEF
- Xq x-coordinate of the lower left corner before rotation
- Yq y-coordinate of the lower left corner before rotation
- Aq extension in x-direction before rotation
- Bq extension in y-direction before rotation
- Cq vertical extend
- Wq rotation angle clockwise
- Qq heat current in MW to derive thermal plume rise
-
- final plume rise dh estimate with VDI 3782/3 which for Qq < 1.4 MW reads
- dh = 84*sqrt(Qq)/u
- u varies with height and time, but a typical value for u between 3m and
- 8m above ground (default LASPORT vertical extend for APU) is 1.5m/s. This
- yields dh=(40 25 18 12) m for Qq=(0.5 0.2 0.1 0.05) MW
-
.
!  Name  |    Xq      Yq      Aq      Bq     Cq     Hq    Wq    Qq
--------------+------------------------------------------------------------------------------------
-------------
Q  lsp05 |  -100    -100     200     200     5      3    0.0   0.50
Q  lsp02 |  -100    -100     200     200     5      3    0.0   0.20
Q  lsp01 |  -100    -100     200     200     5      3    0.0   0.05
Q  sas05 |  -100    -100     200     200     5     43    0.0   0.00
Q  sas02 |  -100    -100     200     200     5     28    0.0   0.00
Q  sas01 |  -100    -100     200     200     5     21    0.0   0.00
Q  nod   |  -100    -100     200     200     5      3    0.0   0.00
------------------------------------------------------------------
--------------------------------------------------------------------------
- definition of the trace substances ------------------------- STOFFE.DEF
.
      Einheit = ug                                ' mass unit
      Vsed = 0.0                                  ' settling velocity
      Rate = 1                                    ' particle emission rate
-
- Vdep deposition velocity
- RefC reference value for the graphical display with IBJdis
!  Name           |          Vdep         RefC
------------------------------+-------------------------------------------
K  NOX_lsp05      |        0.000          10
K  NOX_lsp02      |        0.000          10
K  NOX_lsp01      |        0.000          10
K  NOX_sas05      |        0.000          10
K  NOX_sas02      |        0.000          10
K  NOX_sas01      |        0.000          10
K  NOX_nod        |        0.000          10
--------------------------------------------------------------------------
- definition of emission strengths -------------------------- STAERKE.DEF
. EmisFac = 0.51e6
-         example: 10 small aircraft per hour with APU ff=81 kg/h, ei=6.8 g/kg
-         and operation time before start 20 min
```

```
-         -> 550.8 g NOX per aircraft APU
-         -> hourly emission rate 1836/3600 g/s = 0.51e6 ug/s
-         -> applied in this example as EmisFac. The source strengths
-         below (1) are multiplied with this factor.
-
! Quelle  |          NOX_lsp05    NOX_lsp02   NOX_lsp01  NOX_sas05   NOX_sas02    NOX_sas01
   NOX_nod
---------------+-------------------------------------------------------------------------------------
--------------------------------------------------------------
E  lsp05 |       1          0          0          0         0          0          0
E  lsp02 |       0          1          0          0         0          0          0
E  lsp01 |       0          0          1          0         0          0          0
E  sas05 |       0          0          0          1         0          0          0
E  sas02 |       0          0          0          0         1          0          0
E  sas01 |       0          0          0          0         0          1          0
E  nod   |       0          0          0          0         0          0          1
```

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