Stack height according to TA Luft
(Technical Instructions on Air Quality Control)

BESMAX

Program documentation of Version 1.3.0

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General remarks

Proper use of the program requires expertise in the context of the TA Luft (German Regulation *Technische Anleitung zur Reinhaltung der Luft*, Technical Instruction on Air Quality Control, which regulates uniform federal principles in Germany for the determination of air pollutants for installations requiring approval). The program and data are provided free of charge under the GNU Public License. No guarantee is given for their accuracy or suitability for a particular purpose. The entire risk associated with their use lies with the user.

The program is available on the website of the German Federal Environment Agency. Updates and information on problems are also posted here as needed. Questions regarding the program can be sent to the email address info@austal.de.

> *Note:* *Only the original version of* `Besmax.jar` *as provided by the German Federal Environment Agency should be used. Version 1.3.0 has the CRC32 checksum 697B0495. Version number and checksum are displayed in the header of the program window and in all text output.*

Contents

Update information

1.3.0 (697B0495)

- The program has been internationalised; German (identifier `de`) and English (`en`) are implemented by default. For details, see Section 3.
- For output (user interface, result file, screen output), a comma is used as decimal separator for German and a point for all other languages.
- The CRC32 checksum of the program (file `Besmax.jar`) is displayed.
- The effective source height is consistently denoted by `heff` (previously also `he`).
- In batch mode under Windows with file `Besmax.exe`, the JAVA VM option `-XX:TieredStopAtLevel=1` is used, which prevents sporadic program aborts when using multiple threads under Windows 11 (this effect has so far not been observed under Windows 10 and Linux).

1 Program

1.1 Background

TA Luft (2021) specifies in Section 5.5.2.1, Paragraph 5, that in the case of multiple stacks, compliance with the S-value must be checked by superimposing the concentration plumes. The program Besmax (*Bestimmung der maximalen Konzentration*, determination of the maximum concentration) performs this superposition and displays the maximum concentration value near the ground, which can be compared with the S-value.

The specifications in Section 5.5 of the TA Luft alone already enable a programmatically implementation of the prescribed calculation method. With Besmax, the German Federal Environment Agency provides a public reference solution. It can be used both for practical applications and for checking other programs that claim to implement the calculation method according to Section 5.5 of the TA Luft.

The copyright for the program Besmax is held by the German Federal Environment Agency, 06844 Dessau-Roßlau, Germany, and Janicke Consulting, 88662 Überlingen, Germany. Program and source code are provided free of charge and are subject to the GNU Public License (GPL). Source code and GPL are contained in the JAR file (archive file).

1.2 Files

The calculation of the maximum ground-level concentration is based on a library of individual plumes that have been calculated in accordance with Annex 2, Section 14 of the TA Luft. The directory containing the individual plumes is named `plumes` and has a size of approximately 1 gigabyte (GiB)[1]. The program checks whether the content corresponds to the original, so no changes must be made to the files.

The program Besmax is a JAVA program and requires a Java Runtime Environment (JRE) including JavaFX. The program has been tested under JAVA 21. For Windows 64-bit and Linux 64-bit, Besmax comes with a local JRE tailored to Besmax (subdirectory `jre`), which is based on OpenJDK 21 Temurin (adoptium.net) and OpenJFX 21 Gluon (gluonhq.com). The JAVA program itself is named `Besmax.jar` and is located in subdirectory `jar`. The JAVA program also expects the directory `plumes` with the plume library to be located in the same directory as itself.

The directory above `jar` contains the program `Besmax.exe` for Windows 64-bit (and the program `Besmax` for Linux 64-bit), which starts `Besmax.jar` with the supplied local JRE.

[1] The plume library is provided as a set of 3 archive files, which must be downloaded and unpacked before using the program.

It can be started with a double-click and executes the following command[2]:

```
jre\bin\javaw -jar jar\Besmax.jar
```

Besmax applies the program PLURIS according to the standard VDI 3782-3 (2022), *Determination of plume rise*, for the calculation of plume rise. It is integrated in the program Besmax (IBJpluris).

> *Note: When the program is started, the plume library is checked for integrity. This may delay the start slightly.*

The current program versions are Besmax 1.3.0 and IBJpluris 3.2.0. The library folder `plumes` contains 1508 text files in 29 directories and is located in the subdirectory `jar`. The delivered program `Besmax.jar` has the CRC32 checksum 697B0495.

1.3 Memory requirements and multi-threading

Besmax is memory-intensive. It is recommended to run the program exclusively on a 64-bit system with at least 8 GiB of RAM.

With the standard call listed above, the program uses a maximum of 4 GiB RAM under Windows 10 and 16 GiB under Windows 11. This memory must not only be physically but also practically available as free memory (programs running in parallel with Besmax may already use several GiB of RAM).

In addition, the programs `Besmax`*S* (*S*=8, 24, 56) are provided in subdirectory `add`, which request a maximum of *S* GiB RAM and are typically suitable for systems with 16, 32, or 64 GiB of physical RAM. To use these programs, they must be copied to the next higher directory level.

The maximum amount of memory provided can also be specified explicitly in batch mode with the call

`Besmax .`*S*

or

`jre\bin\java -Xmx=`*S*`g -jar jar\Besmax.jar`

where *S* is the amount of RAM in GiB.

> *Note: If the formally allocated maximum memory cannot be accessed by JAVA (e.g., if 8 GiB are requested but only 6 GiB are actually available), the program may terminate without a detailed error message.*

[2] In addition, option `-XX:+AlwaysPreTouch`, not listed below, is used, which has been observed to result in slightly shorter calculation times for complex calculations. Option `-XX:TieredStopAtLevel=1` is also used, which prevents sporadic program aborts under Windows 11.

Besmax supports multi-threading for the calculation of the concentration distributions. Each thread requires a certain amount of memory. Therefore, the memory requirements of Besmax also depend on the number of threads used. The default number is the total number available on the computer system minus 1. The number of threads can be explicitly specified by the user. To do this, Besmax must be started in batch mode in a console (DOS window/command prompt under Windows, console under Linux) or via a batch procedure:

`Besmax --num-threads=`N

or

`jre\bin\java -jar jar\Besmax.jar --num-threads=`N

where N is the number of threads. The program checks internally whether the available memory is sufficient for the desired number of threads in the specific application and, if necessary, automatically reduces the number with a corresponding message.

> *Note: Combinations of very high and very low effective source heights can lead to high memory requirements, because in this case the plumes must be mapped over a very large area (due to the high sources) with a very fine resolution (due to the low sources).*

Both options can be combined.

1.4 Command-line arguments

In addition to the two command-line arguments listed above, there are others. If arguments are specified, the program runs in batch mode without a graphical user interface by default. The graphical user interface is forced by argument `--interactive`. The sources to be processed can also be specified. The argument (`--source`) is explained below. Finally, argument `--help` (or `-h` or `-?`) can be used to display a short help text.

The program call with all possible call options is:

`Besmax .`S `--num-threads=`N `--interactive --help --source=...`

or

`jre\bin\java -Xmx`N`g -jar jar\Besmax.jar --num-threads=`S `--interactive --help --source=...`

2 Method

The program Besmax calculates the maximum hourly ground-level concentration (average value over the lowest 3 metres) of an emitted substance for one or more neighbouring point sources. This is done using the results of dispersion calculations that have been performed for each of the meteorological situations to be considered[3] and a spectrum of emission heights for a passive point source in flat terrain, without the influence of buildings and without deposition.

The calculation is performed in three steps:

1. The effective source height h_{eff} is calculated for each source and each meteorological situation using the program PLURIS.
2. The ground-level concentration distribution is determined for each source and each meteorological situation by interpolating the pre-calculated fields to the current effective source height.
3. For each meteorological situation and each wind direction (varying in increments of 5 degrees), the concentration fields of the individual sources are superimposed and summed up, and the maximum concentration value is determined.

2.1 Work flow

The work flow is as follows:

1. For the first source, enter the required data in the designated input fields (replace the default example values): Name of the source, emission mass flow, position, stack height[4], inner diameter, exit temperature, exit velocity, water content[5,6]. As an alternative to exit velocity and water content, norm volume flow (wet) and norm volume flow (dry) can be specified, both at operating conditions.

[3] Klug/Manier stability classes I to III/2 and wind speeds corresponding to a dispersion class statistics (*Ausbreitungsklassenstatistik*, AKS) of 1 to 12 m/s, a total of 25 situations.

[4] Stack height as defined in Annex 2, Section 14 TA Luft. It corresponds to the stack height according to Section 5.5.2.2 TA Luft without correction according to Section 5.5.2.3 TA Luft. It is not synonymous with the required construction height within the meaning of Section 5.5.2.1 Paragraph 8 TA Luft.

[5] Water content: mass of water vapour and liquid water per mass of dry air.

[6] The values are used as specified by the user and displayed again if necessary. Only in the case of automatic calculations of `nf` and `nt` from `vq` and `zq` and vice versa, fixed decimal places are used for the display (2 for `vq`, 4 for `zq` and 0 for `nf` and `nt`).

The program allows the following value ranges:

Symbol	Short name	Parameter	Unit	Value range
q	`eq`	emission mass flow	kg/h	≥ 0
h	`hq`	stack height	m	$[6; 250]$
d	`dq`	inner diameter	m	$[0; 200]$
T	`tq`	exit temperature	°C	$[10; 600]$
v	`vq`	exit velocity	m/s	$[0; 50]$
x	`zq`	water content	kg/(kg dry)	$[0; 999]$
n_f	`nf`	norm volume flow (wet, at operation)	m^3/h	≥ 0
n_t	`nt`	norm volume flow (dry, at operation)	m^3/h	$\leq n_\mathrm{f}$
l	`lq`	liquid water content (informative only)	kg/kg	$[0; 0.04]$

Sources with zero emission mass flow are ignored in the calculation.

The parameters `dq`, `tq`, `vq`, and `zq` (or `nf` and `nt`) are only required for calculating the plume rise. If the inner diameter `dq` or the exit velocity `vq` is zero, the calculation is performed without plume rise. In this case, stack height and effective source height are identical.

2. To enter additional sources, the button with the plus sign can be pressed, whereupon the program sets up an additional data column for a new source, whose input fields are to be filled in as before. A source (data column) can be deleted by first deleting the name and then pressing *RETURN* (the cursor must still be in the name field).

3. The calculation is started by pressing the button *Calculate maximum concentration*. The button disappears and a coloured bar indicates the calculation progress.

   > *Note: Calculations for combinations of very different effective source heights can take a long time, as in this case plumes have to be superimposed for a very large area with a very fine resolution.*

4. Once the calculation has finished, the result is displayed in the fields further below: the maximum concentration value and its estimated uncertainty, its location and associated meteorological situation (including wind direction)[7] at which it occurs[8].

If the norm volume flows are specified, exit velocity is determined from the norm volume flow (wet) and water content from the difference of the two norm volume flows, assuming that no liquid water is present, see Section 4.1. The values that are not specified by the

[7] For situations in which the wind direction is irrelevant (only one source or only one source relevant to the maximum concentration), the result is shown for a wind direction of 270 deg. If several wind directions yield the same absolute maximum, the result for the smallest of these wind directions is shown.

[8] In some cases, a slightly different meteorological situation is reported as compared to Besmin. This is due to different interpolation methods, which can be noticeable if the maximum concentrations are almost the same for different meteorological situations, but it is not relevant for further assessment.

user, as well as the resulting liquid water content, are calculated immediately during input and updated in the corresponding fields. If the volume flows are specified, the internally calculated values are used in the stack height calculation instead of the displayed rounded values of exit velocity and water content. Further details on the treatment of wet plumes are provided in a separate document in directory `add`.

When entering numerical values, the program checks the input: If the entry cannot be interpreted as a numerical value, the background of the input field turns yellow. If the numerical value is not valid, the background turns red. A calculation can only be performed if no errors are detected.

The results can be saved by pressing the button *Save emission sources and calculated concentration*. The data are saved to the directory `log`, which is located on the same level as the directory `jar` and is created if necessary. The file name is `besmax(`n`).log`, where n is a number used to distinguish between different result files and it is always incremented by 1.

The concentration distribution can be displayed graphically for information (button *Graph*). The display applies the wind system, i.e. the x-axis runs downwind. The emission centre is used as the origin of the coordinate system.

The numbers shown in the graph are the concentration values occurring in the evaluation grid as percentage of the specified reference value `Cref`. With `Tick`, the spacing of the axis labels can be selected. The sources are marked with their names at the specified position. The default settings are:

Kl, Ua:	meteorological situation for which the maximum occurs
Ra:	wind direction for which the maximum occurs
Tick:	10 times the mesh size of the evaluation grid
Cref:	maximum concentration value

The graph can be saved as SVG file by pressing the mouse button on the graph while holding down the control key (`CTRL`).

2.2 Batch mode

In batch mode, the source parameters are passed by command-line arguments. Here, either 9 parameters must be specified (backward compatibility with Version 1.0)

`Besmax --source=`n,x_q,y_q,h,d,v,T,x,q

or

`jre\bin\java -jar jar\Besmax.jar --source=`n,x_q,y_q,h,d,v,T,x,q

or 11 parameters must be specified (parameters and their order correspond to the user interface)

`Besmax --source=`n,q,x_q,y_q,h,d,T,v,x,n_f,n_t

or

`jre\bin\java -jar jar\Besmax.jar --source=`n,q,x_q,y_q,h,d,T,v,x,n_f,n_t

where the values must be separated by commas and a decimal point must be used for floating point numbers.

The parameters are:

n	source name
q	emission mass flow (kg/h)
x_q	x-coordinate (m)
y_q	y-coordinate (m)
h	stack height (m)
d	inner diameter (m)
T	exit temperature (°C)
v	exit velocity (m/s)
x	water content (kg/(kg dry))
n_f	norm volume flow (wet) (m^3/h)
n_t	norm volume flow (dry) (m^3/h)

> *Note: If 11 parameters are specified, the values of n_f and n_t must be set to a negative value (e.g., -1) when v and x are specified, and vice versa. If n_f and n_t are specified, the program checks whether the resulting liquid water content is zero and, if not, terminates with an error message.*

If the option `--interactive` is also specified, these source parameters are entered into the table of the graphical user interface of Besmax and the calculation can be performed interactively.

In batch calculation, control outputs and the parameters of the maximum concentration are listed on the screen:

...	origin of the coordinate system
...	source list
`cm`	concentration value
`dm`	statistical uncertainty
`xp`	x-coordinate
`yp`	y-coordinate
`k`	stability class
`ua`	wind speed
`ra`	wind direction

With the additional option `-i`, only the calculation of the exhaust gas parameters is performed (n_f and n_t from v and x, or v and x from n_f and n_t) and the values are written to the log file.

Source specifications and program calls can be combined or archived in a batch file. This allows for example to repeat the calculation at a later time or in a modified form without additional effort.

Example of a batch file:

```
jre\bin\java -jar jar\Besmax.jar ^
--interactive ^
--source=" A, 100.0,  0.0,  0.0, 100.0, 0.0, 10.0,  0.0,  0.0, -1, -1" ^
--source=" B, 200.0, 50.0, 50.0,  40.0, 2.0, 40.0, 12.0, 0.03, -1, -1"
```

3 Internationalisation

The program supports multiple languages (Native Language Support) and is delivered with German (code `de`) and English (code `en`) as default languages.

The language to be used is specified in the settings file `.besmax` (XML format) in subdirectory `jar`. It can be changed with a text editor if necessary. This file is read when the program starts. In addition, the language can be specified with the command-line argument

`--language=`*ln*

where *ln* is the 2-letter language code. The argument overrides the settings file, but does not change it.

Example:

```
jre\bin\java -jar jar\Besmax.jar --language=en
```

In the graphical user interface, the contents of the settings file can be changed using a pop-up menu that appears by a right-click on the title at the top of the window. Changes will only take effect the next time the program is started and the settings file is read again.

4 Technical details

4.1 Calculation of source parameters

The norm volume flows (standard conditions at 273.15 K and 101300 Pa according to Section 2.4 of the TA Luft) are calculated from the given values of diameter d, exit temperature T (in degrees Celsius), exit velocity v, and water content x as

$$n_\mathrm{f} = \frac{\pi}{4} d^2 v \frac{T_0}{T_0 + T} \tag{1}$$

$$n_\mathrm{t} = \frac{n_\mathrm{f}}{1 + x(R_\mathrm{v}/R_\mathrm{d})} \tag{2}$$

with $T_0 = 273.15\,\mathrm{K}$, gas constant $R_\mathrm{d} = 287.05\,\mathrm{J/(kg\,K)}$, and $R_\mathrm{v} = 461.52\,\mathrm{J/(kg\,K)}$.

The calculation of exit velocity and water content from the specified norm volume flows is accordingly

$$v = \frac{4}{\pi} \frac{n_\mathrm{f}(T_0 + T)}{T_0 d^2} \tag{3}$$

$$x = \frac{n_\mathrm{f} - n_\mathrm{t}}{n_\mathrm{t}(R_\mathrm{v}/R_\mathrm{d})} \tag{4}$$

with $v = 0$ and $x = 0$ in case $d = 0$.

These conversions are only correct if there is no liquid water. Where Besmax shows a calculated numerical value for x, the calculation has been performed according to Equation (4), regardless of whether the result implies a liquid water content or not.

4.2 Plume super-positioning

Besmax applies data from dispersion calculations that were carried out for passive, point-like sources with the emission rate 1 g/s and heights h_l with

$$h_0 = 10\,\mathrm{m} \tag{5}$$

$$h_l = h_0 \cdot 2^{l/4}, \quad l = 0..26 \tag{6}$$

and in addition the heights 6 m and 8 m. This covers the height range 6 m to 905 m. The highest effective source height reported by PLURIS is 800 m. From the calculated concentration fields, only the values of the lowest layer ($0 \leq z \leq 3$ m) are used: Concentration $c_{i,j;l,m}$ for grid cell (i,j), source height h_l and meteorological situation

m, together with the associated statistical uncertainty $d_{i,j;l,m}$. The calculation grids G_l have the following extent:

$$\text{number of meshes in } x\text{-direction } n_\mathrm{x} = 220 \tag{7}$$
$$\text{number of meshes in } y\text{-direction } n_\mathrm{y} = 200 \tag{8}$$
$$\text{mesh width } \Delta_l = h_l/2 \tag{9}$$
$$\text{left border } x_{\mathrm{min},l} = -20\Delta_l \tag{10}$$
$$\text{lower border } y_{\mathrm{min},l} = -100\Delta_l \tag{11}$$

The index ranges are $i = 1..n_\mathrm{x}$ and $j = 1..n_\mathrm{y}$. For a displaced grid $G^*_l(\delta_\mathrm{x}, \delta_\mathrm{y})$, the source is not at the origin but at $(\delta_\mathrm{x}, \delta_\mathrm{y})$. In the displaced grid, the concentration c^* at location (x,y) is given by[9]

$$c^*_{l,m}(x,y) = c_{i^*,j^*;l,m} \tag{12}$$
$$i^* = 1 + \lfloor (x - \delta_\mathrm{x} - x_\mathrm{min})/\Delta_l \rfloor \tag{13}$$
$$j^* = 1 + \lfloor (y - \delta_\mathrm{y} - y_\mathrm{min})/\Delta_l \rfloor \tag{14}$$

The dispersion calculation applied the wind direction $r_\mathrm{a} = 270\,\mathrm{deg}$, the plume is thus oriented mainly in x-direction.

The user specifies n_q emission sources with parameters P_n, which include the following values ($n = 1..n_\mathrm{q}$):

$e_{\mathrm{q},n}$	emission rate
$x_{\mathrm{q},n}$	x-coordinate
$y_{\mathrm{q},n}$	y-coordinate
$h_{\mathrm{q},n}$	stack height

The emission centre $(\bar{x}, \bar{y})$ is

$$\bar{x} = \sum_n e_{\mathrm{q},n} x_{\mathrm{q},n} / \sum_n e_{\mathrm{q},n} \tag{15}$$
$$\bar{y} = \sum_n e_{\mathrm{q},n} y_{\mathrm{q},n} / \sum_n e_{\mathrm{q},n} \tag{16}$$

The coordinates of the emission sources relative to the emission centre are

$$\tilde{x}_{\mathrm{q},n} = x_{\mathrm{q},n} - \bar{x} \tag{17}$$
$$\tilde{y}_{\mathrm{q},n} = y_{\mathrm{q},n} - \bar{y} \tag{18}$$

A graphical representation is always such that the emission centre is the coordinate origin.

[9] $\lfloor x \rfloor$ is the largest integer number that does not exceed x.

For each meteorological situation m, the following steps are carried out:

1. For each source n, the following steps are carried out:

   a) PLURIS is used to calculate the effective source height $h_{\mathsf{e},n}$.

   b) The calculation height h_{l_n} is selected that lies immediately below the effective source height, i.e.

   $$h_{l_n} \leq h_{\mathsf{e},n} < h_{l_n+1} \tag{19}$$

   c) The concentration values of the source n are later determined by linear interpolation from the concentration values of the grids G_{l_n} and G_{l_n+1}. For this purpose, the two interpolation weights $w_{0,n}$ and $w_{1,n}$ are defined:

   $$w_{0,n} = \frac{h_{l_n+1} - h_{\mathsf{e},n}}{h_{l_n+1} - h_{l_n}} \tag{20}$$

   $$w_{1,n} = 1 - w_{0,n} \tag{21}$$

   d) The two grids are shifted to the location of the source, hence the grids $G^*_{l_n}(\tilde{x}_{\mathrm{q},n}, \tilde{y}_{\mathrm{q},n})$ and $G^*_{l_n+1}(\tilde{x}_{\mathrm{q},n}, \tilde{y}_{\mathrm{q},n})$ are applied.

2. An evaluation grid G_{res} is defined, whose mesh size Δ_{res} is equal to the smallest mesh size that occurs,

   $$\Delta_{\mathrm{res}} = \min_n \{\Delta_{l_n}\} \tag{22}$$

   and which covers all grids $G^*_{l_n+1}$.

3. The concentration $c_{\mathrm{res},i,j}$ in the evaluation grid is calculated from the sum of contributions of the individual source grids:

   $$c_{\mathrm{res},i,j;m} = \sum_n \left[w_{0,n} c^*_{l_n,m}(x_i,y_j) + w_{1,n} c^*_{l_n+1,m}(x_i,y_j) \right] \tag{23}$$

   $$(x_i,y_j) = \text{centre of cell } (i,j) \text{ in the evaluation grid } G_{\mathrm{res}} \tag{24}$$

   The statistical uncertainty $d_{\mathrm{res},i,j;m}$ is calculated accordingly by adding the variances.

4. The maximum ground-level concentration for the meteorological situation m and the standard wind direction $r = 0$ is

   $$c_{\max,m,0} = \max_{i,j} \{c_{\mathrm{res},i,j;m}\} \tag{25}$$

5. Steps 1 to 4 are repeated for all other wind directions as necessary, changing the wind direction in increments of 5 degrees. Technically, this is achieved by rotating the group of sources around the emission centre in the opposite direction. This preserves the alignment of the grids with the coordinate axes of the evaluation grid. The maximum concentration for the meteorological situation m is

   $$c_{\max,m} = \max_r \{c_{\max,m,r}\} \tag{26}$$

The value $c_{\max}$ reported by Besmax as the maximum concentration is the maximum across all meteorological situations:

$$c_{\max} = \max_m \{c_{\max,m}\} \tag{27}$$

4.3 Internationalisation

Language-dependent text strings are located in the files `Besmax_`*ln*`.properties` (UTF-8) in the subdirectory `de/janicke/tal` within the JAR archive `Besmax.jar`.

If an additional language is to be added to the program, a properties file with the appropriate content and language identifier must be created and copied into this location in the JAR archive.

The new language can then be specified in the settings file `.besmax` or by the command-line argument `--language`. If the new language is also to appear in the pop-up menu of the user interface, the entry `bundles` must be expanded accordingly in all properties files.

Changing the contents of file `Besmax.jar` changes its CRC32 checksum.

4.4 Further information

Further technical details can be found in the *Report on Environmental Physics No. 9* (1st edition)[10].

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[10] The report is available as a PDF file from the German National Library (www.dnb.de) (urn:nbn:de:101:1-201709132627) and on the website of Janicke Consulting (www.janicke.de).