GPM for SIBYL manual

Version: July-2022

Gaussian plume model for SIBYL

SATOH Daiki
Japan Atomic Energy Agency
satoh.daiki@jaea.go.jp

References:

D. Satoh, H. Nakayama, T. Furuta, T. Yoshihiro, K. Sakamoto, "Simulation code for estimating external gamma-ray doses from a radioactive plume and contaminated ground using a local-scale atmospheric dispersion model", PLOS ONE, 2021.
https://doi.org/10.1371/journal.pone.0245932

1. Gaussian Plume Model

The Gaussian Plume Model (GPM) describes a radioactive gas release from a ventilation shaft under steady atmospheric conditions. **Figure 1** shows the dispersion of radioactive gas in the GPM; which can be expressed as follows:

$$C(x,y,z)=\frac{Q}{2\pi\sigma_y(x)\sigma_z(x)U}\cdot\exp\left(-\frac{y^2}{2\sigma_y(x)^2}\right)\cdot\left[\exp\left(-\frac{(z-H)^2}{2\sigma_z(x)^2}\right)+\exp\left(-\frac{(z+H)^2}{2\sigma_z(x)^2}\right)\right],$$

where $C(x,y,z)$ (Bq/m^3) is the activity concentration on the *x*, *y*, and *z* (m) Cartesian coordinates that specify the downwind distance from a release point, the crosswind distance from the emission plume centerline, and the vertical direction above the ground, respectively. *Q* (Bq/s) represents the emission rate of the radioactive material, and *U* (m/s) shows the mean wind speed along the plume centerline. $\sigma_y(x)$ and $\sigma_z(x)$ (m) are the parameters that depend on the *x* coordinate and represent the standard deviations of the centerline of the Gaussian distributions in the y and z directions, respectively. *H* (m) is the height of the emission plume centerline above the ground. The $\sigma_y(x)$ and $\sigma_z(x)$ values were taken from the Pasquill-Gifford curves given for stability classes (A, B, C, D, E, F, and G); class A is the most unstable and class G indicates a calm and steady atmospheric condition. The approximate equation of the Pasquill-Gifford curves can be expressed as follows:

$$\sigma_y(x)=\gamma_y\cdot x^{\alpha_y},$$
$$\sigma_z(x)=\gamma_z\cdot x^{\alpha_z},$$

where α_y, γ_y, α_z, and γ_z are the coefficients depending on *x* and the Pasquill-Gifford stability class. The numerical values of those parameters are summarized in **Tables 1** and **2** for $\sigma_y(x)$ and $\sigma_z(x)$, respectively.

Table 1: Coefficients for $\sigma_y(x)$ in the approximate equation of the Pasquill-Gifford curves.

Class	$\boldsymbol{\alpha_y}$	$\boldsymbol{\gamma_y}$	**Range of *x* (m)**
A	0.901	0.426	0 ~ 1,000
	0.851	0.602	1,000 ~
B	0.914	0.282	0 ~ 1,000
	0.865	0.396	1,000 ~
C	0.924	0.1772	0 ~ 1,000
	0.885	0.232	1,000 ~
D	0.929	0.1107	0 ~ 1,000
	0.889	0.1467	1,000 ~

E	0.921	0.0864	0 ~ 1,000
	0.897	0.1019	1,000 ~
F	0.929	0.0554	0 ~ 1,000
	0.889	0.0733	1,000 ~
G	0.921	0.0380	0 ~ 1,000
	0.896	0.0452	1,000 ~

Table 2: Coefficients for $\sigma_z(x)$ in the approximate equation of the Pasquill-Gifford curves.

Class	$\boldsymbol{\alpha_z}$	$\boldsymbol{\gamma_z}$	**Range of *x* (m)**
A	1.122	0.0800	0 ~ 300
	1.514	0.00855	300 ~ 500
	2.109	0.000212	500 ~
B	0.964	0.1272	0 ~ 500
	1.094	0.0570	500 ~
C	0.918	0.1068	0 ~
D	0.826	0.1046	0 ~ 1,000
	0.632	0.400	1,000 ~ 10,000
	0.555	0.811	1,0000 ~
E	0.788	0.0928	0 ~ 1,000
	0.565	0.433	1,000 ~ 10,000
	0.415	1.732	10,000 ~
F	0.784	0.0621	0 ~ 1,000
	0.526	0.370	1,000 ~ 10,000
	0.323	2.41	10,000 ~
G	0.794	0.0373	0 ~ 1,000
	0.637	0.1105	1,000 ~ 2,000
	0.431	0.529	2,000 ~ 10,000
	0.222	3.62	10,000 ~

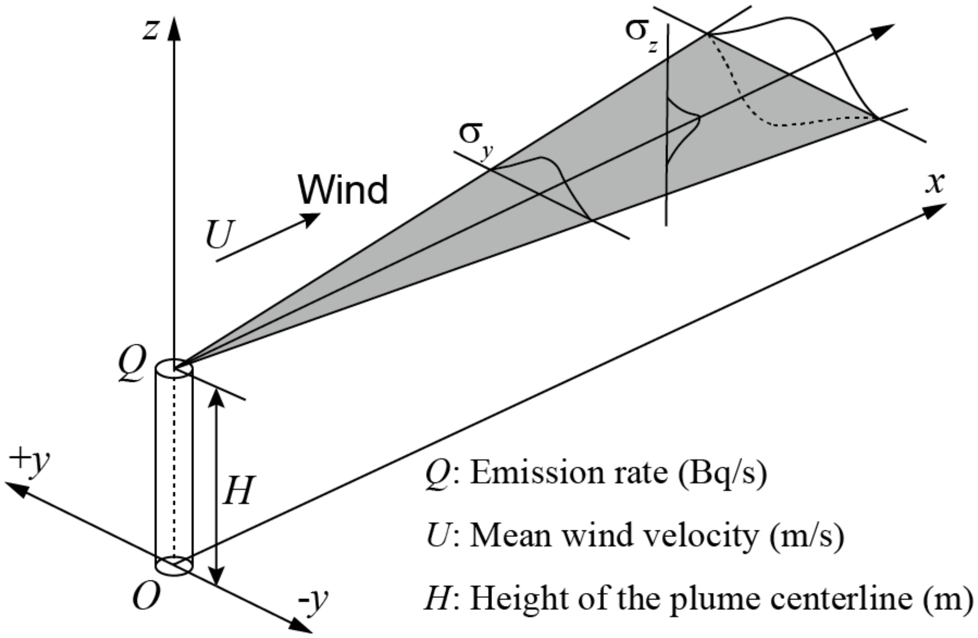


Figure 1: Schematic of a steady-state radioactive gas release in GPM.

2. Directory-and-file structure

The GPM for SIBYL is a part of the SIBYL-distribution package. The directory-and-file structure is shown in **Figure 2** with red dashed line enclosing the programs and files regarding GPM. “GPM_for_SIBYL-manual.pdf” indicates this document. In the following sections, the detail of the files under “GPM” is described.

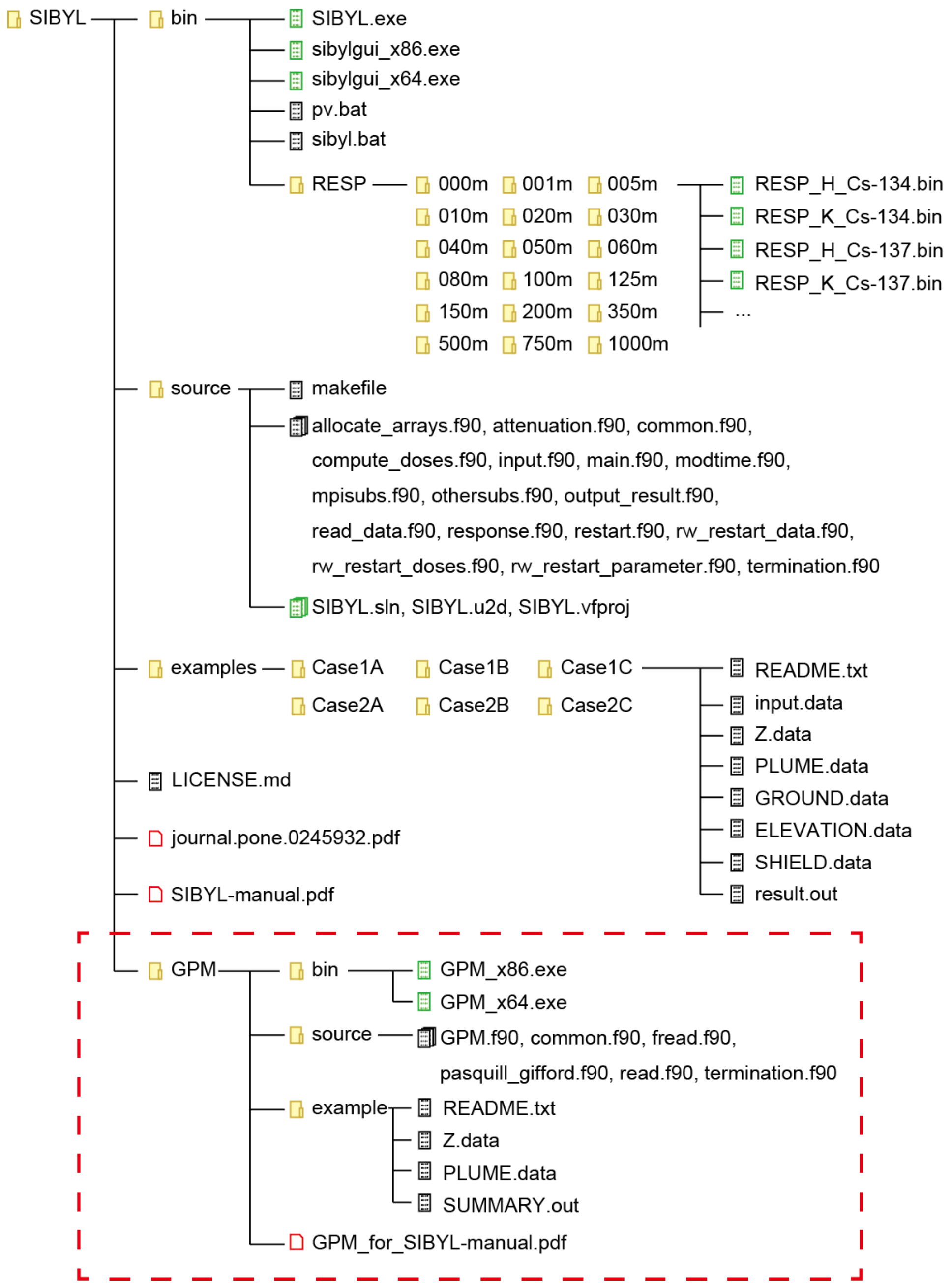


Figure 2: Directory-and-file structure of GPM for SIBYL

2.1. "bin" directory

The "bin" directory contains executable files of the GPM for SIBYL. "GPM_x86.exe" and "GPM_x64.exe" were compiled under x86 and x86-64 environments, respectively, on Windows 10.

2.2. "source" directory

The "source" directory maintains the Fortran-95 source files. Note that they are designed for sequential computation, not for concurrent computation.

2.3. "example" directory

This directory contains an example of the GPM calculation used in the SIBYL's original paper as Case 1A (https://doi.org/10.1371/journal.pone.0245932).

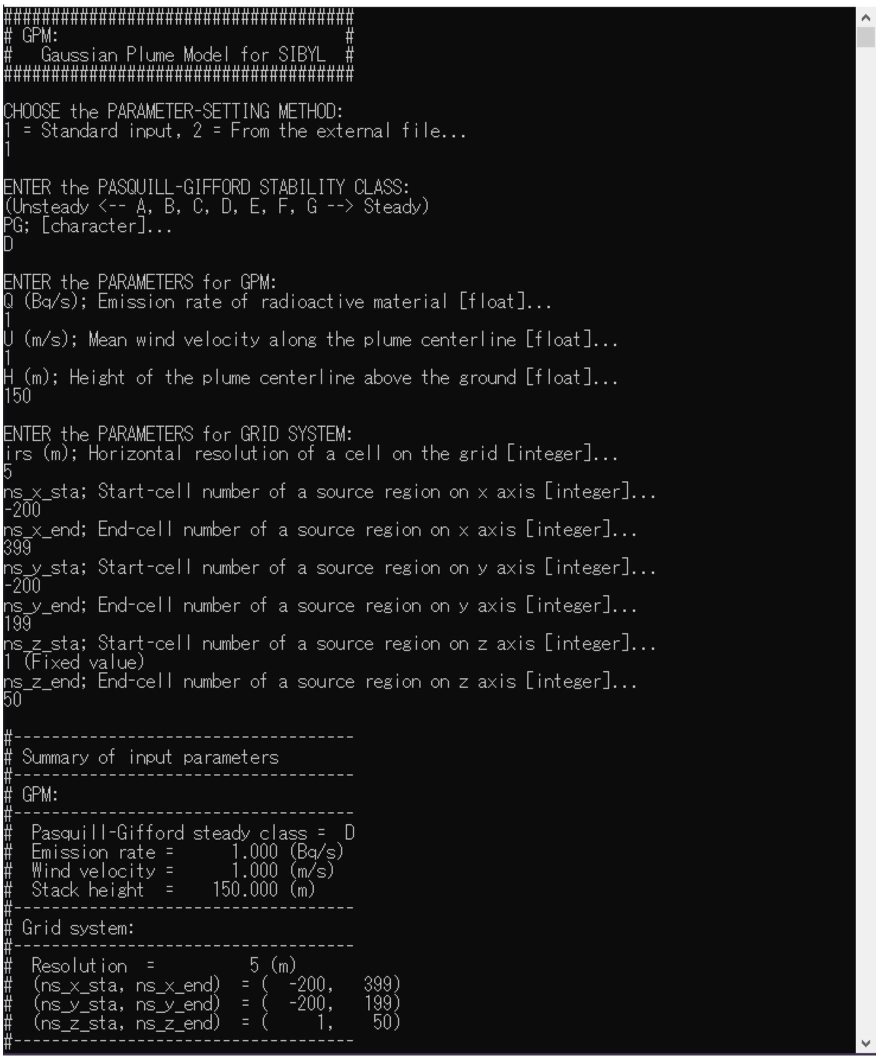
3. Input parameter setting

Table 3 lists the input parameters for calculations of GPM for SIBYL. First of all, the code asks whether those parameters are read from standard input or an external file. If the users enter "1", the code takes values of the parameters step by step from standard input on a terminal as depicted in **Figure 3**. If the value of "2" is chosen, the parameters are read from "SUMMARY.out" which was generated in previous calculations setting the parameters manually.

Table 3: Input parameters for GPM calculations

Variable name	**Example**	**Explanation**
PG	D	(character) Pasquill-Gifford stability class chosen from A, B, C, D, E, F, and G.
Q	1	(float) Emission rate of radioactive material (Bq/s).
U	1	(float) Mean wind velocity along the Gaussian plume centerline (m/s)
H	150	(float) Height of the Gaussian plume centerline above the ground (m).
irs	5	(integer) Horizontal resolution of one cell on the grid (m).
ns_x_sta	-200	(integer) Start-cell number of a source region on x axis.

ns_y_sta	399	(integer) End-cell number of a source region on x axis.
ns_y_sta	-200	(integer) Start-cell number of a source region on y axis.
ns_y_end	199	(integer) End-cell number of a source region on y axis.
ns_z_sta	1	(integer) Start-cell number of a source region on z axis. The value is fixed to 1. Note that the vertical resolution along z axis is read from an external file named “Z.data”.
ns_z_end	50	(integer) End-cell number of a source region on z axis.



```
######################################
# GPM:                               #
#   Gaussian Plume Model for SIBYL   #
######################################

CHOOSE the PARAMETER-SETTING METHOD:
1 = Standard input, 2 = From the external file...
1

ENTER the PASQUILL-GIFFORD STABILITY CLASS:
(Unsteady <-- A, B, C, D, E, F, G --> Steady)
PG; [character]...
D

ENTER the PARAMETERS for GPM:
Q (Bq/s); Emission rate of radioactive material [float]...
1
U (m/s); Mean wind velocity along the plume centerline [float]...
1
H (m); Height of the plume centerline above the ground [float]...
150

ENTER the PARAMETERS for GRID SYSTEM:
irs (m); Horizontal resolution of a cell on the grid [integer]...
5
ns_x_sta; Start-cell number of a source region on x axis [integer]...
-200
ns_x_end; End-cell number of a source region on x axis [integer]...
399
ns_y_sta; Start-cell number of a source region on y axis [integer]...
-200
ns_y_end; End-cell number of a source region on y axis [integer]...
199
ns_z_sta; Start-cell number of a source region on z axis [integer]...
1 (Fixed value)
ns_z_end; End-cell number of a source region on z axis [integer]...
50

#-----------------------------------
# Summary of input parameters
#-----------------------------------
# GPM:
#-----------------------------------
#  Pasquill-Gifford steady class =  D
#  Emission rate =      1.000 (Bq/s)
#  Wind velocity =      1.000 (m/s)
#  Stack height  =    150.000 (m)
#-----------------------------------
# Grid system:
#-----------------------------------
#  Resolution  =          5 (m)
#  (ns_x_sta, ns_x_end)  = (  -200,   399)
#  (ns_y_sta, ns_y_end)  = (  -200,   199)
#  (ns_z_sta, ns_z_end)  = (     1,    50)
#-----------------------------------
```

Figure 3: An example of terminal window when standard input is chosen.

4. Outputs

The GPM code generates "PLUME.out" and "SUMMARY.out" as output files. "SUMMARY.out" is the summary file of input parameters at that problem. This summary file can be re-used as input data for the next GPM calculation. "PLUME.data" contains the data of activity concentrations of a Gaussian plume calculated by GPM. The data are used as a SIBYL input, and can be visualized using the ParaView software (https://www.paraview.org/) through the GUI software of SIBYL as demonstrated in **Figure 4**.

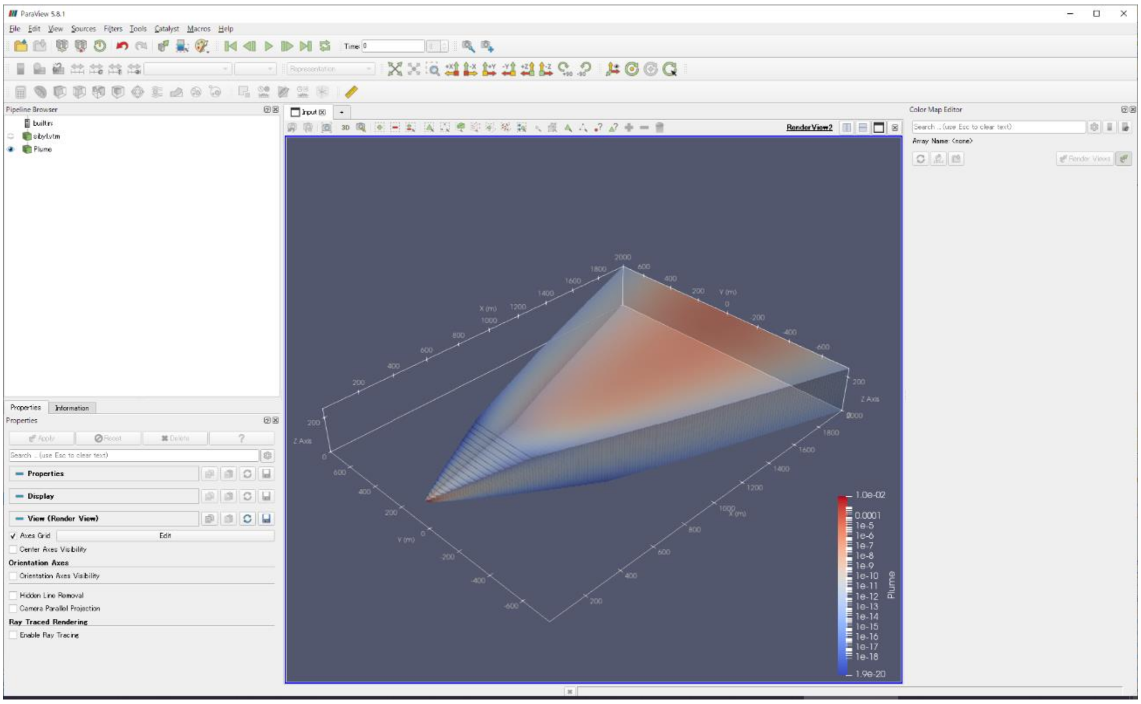


Figure 4: An example of visualization on ParaView for the data in "PLUME.data" calculated by GPM.

5. Execution of GPM

The GPM code requires "Z.data", which describes heights of z-cells, for the code execution. The data structure of "Z.data" is found in the SIBYL's manual. The execution file in "bin" directory or compiled by the users should be moved to a directory of the current problem including "Z.data". Then, the code runs by double-clicking the executable file on GUI, or entering filename on a command line at that directory.