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Comparative Study of Gaussian and Non-Gaussian Models in Evaluation of Pollutant Dispersion

Fawzia Mubarak[1] and Khaled S. M. Essa[2]
[1]*RadiationProtection Department, Nuclear Research Center, Atomic Energy Authority, Cairo, Egypt*
[2]*Mathematics and Theoretical Physics Department, Nuclear Research Center, Atomic Energy Authority, Cairo, Egypt*

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Different degrees of accuracy for Gaussian and non-Gaussian models were analyzed for the evaluation of dispersion processes with homogeneous or spatial dependent dispersion coefficients that were described by different sigma schemes. The aim of this study is to present and investigate a comparison between Gaussian and non-Gaussian models for simulation of pollutant dispersion in the Planetary Boundary Layer (PBL), considering the effect of meteorological parameters. Downwind concentrations of I-131 were measured through five experiments at different meteorological conditions. Observed data were compared with that predicted using Gaussian and non-Gaussian calculations. Models performances were evaluated using different sigma schemes estimation. The results show that non-Gaussian calculations perform much better than Gaussian as Gaussian models have shown to be unreliable at closer range, i.e. at few hundred meters away from the source. At high wind speed, all approaches in case of non-Gaussian calculations perform much better than Gaussian. Power law function methods show reasonable estimates within factors of 1.2 to 2.4 in case of Gaussian and 0.25 to 0.86 in non-Gaussian application. In a moderate wind speed, Brigg's formula (in non-Gaussian) provides reasonable estimates of downwind concentration and has been shown to be accurate to within factors of 0.24 to 1.76 when compared observed data. Although Gaussian models works reasonably not good during weak and variable wind conditions, split sigma shows equitable estimates within factors of 0.5 to 1.08 in low wind speed with Gaussian application. In general, uncertainty increases as going downwind far from the source and decreases with increasing atmospheric stability.

Keywords: Pollutant concentration, Gaussian model, Non- Gaussian model, power low function, Brigg's formula

Introduction

Air pollution has a wide range of hazards to human and environment. These environmental problems are complex and have bad effects on many natural processes and affect the ecological balance. For this reason, it is important to develop our understanding of dispersion process of pollutants in the atmosphere and its impact on human and environment [1]. For this purpose, comparison between different models, (Gaussian and non-Gaussian models), were investigated. The precise evaluation of pollutant distributions is very important but it is complex, especially in the urban environment with low wind speed and calm conditions. Meteorology and topography of the study area can strongly affect plume behavior. Difficulties come from the uncontrollable nature and variation of wind and weather conditions. In practice, Gaussian plume model is the most common model, which assumes the constant wind speed and turbulent eddies with height [2, 3]. It is relatively simple, fast and easy-to-use, at the

Corresponding author: fawziamubarak@yahoo.com
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expense of limited applicability and less accurate estimates [4, 5]. It also, works reasonably well during most meteorological regimes, except for weak and variable wind conditions; it does not require complex meteorological inputs [6]. For these reasons, these models are still widely used by the environmental agencies all over the world for regulatory applications. It depends on the methods used to determine dispersion parameters [7]. Although the existing Gaussian models perform reasonably well in predicting the spatial distribution of the gas concentration at larger distance from the source, they have shown to be unreliable at closer range [8]. The possibility of replacing these models at the near-range by a more accurate non-Gaussian model must represented [9] and the comparison is therefore being investigated. Among a non-Gaussian model, in which wind speed and turbulence are not constant with height and depending on a general performance for solving the advection-diffusion equation a comparison were hold [10, 11]. For both models, the solution is forced to represent real situations by means of empirical parameters, referred to as "sigmas". The various versions of Gaussian models and non-Gaussian models fundamentally differ in the methods utilized to evaluate the sigmas as a function of atmospheric stability and the downwind distance [12].

The main objective of this study is to analyze different degrees of accuracy for Gaussian and non-Gaussian models for the evaluation of dispersion processes with homogeneous or spatial dependent dispersion coefficients that were described by different sigma schemes. Power low function, Brigg's formulae, standard and split-sigma methods were used in this comparison.

Model simulations and analyses

Model simulation results were used according to Gaussian and non-Gaussian.

Gaussian model

In the Gaussian Plume model horizontal and vertical growth of the plumes were predicted to estimate the air pollutant concentration. They are expressed in terms of standard deviations of concentrations in lateral (y) and vertical (z) directions i.e., σ_y and σ_z respectively and characterize the dispersion according to atmospheric turbulence [8]. Gaussian model equation of air pollution can be expressed as:

$$C=\frac{Q}{[2\pi\sigma_y\sigma_z+C_w A]U}\left[\begin{array}{l}\exp(-\lambda x/U)\left[\exp\int_0^x \frac{dx}{\sigma_z\exp\frac{H^2}{2\sigma_z^2}}\right]\left\{-\left(\frac{2}{\pi}\right)^{1/2}\right\}V_d/U\,\exp\left(\frac{-y^2}{2\sigma_y^2}\right)\\ \left[\exp\left(\frac{-(z-H)^2}{2\sigma_z^2}\right)+\exp\left(\frac{-(z+H)^2}{2\sigma_z^2}\right)\right]\end{array}\right] \quad (1)$$

Where the parameters are defined by the following descriptions:

C (Bq m^{-3}) = Concentration of air pollutant;

(Bq s^{-1}) = Continuous point source strength;

(m s^{-1}) = Wind speed at height H;

(m) = Lateral dispersion parameter;

σ_z (m) = Vertical dispersion parameter;

x (m) = Horizontal distance in the direction of downwind.

y (m) = Lateral distance from plume centerline,

z (m) = Height above ground;

A: is the cross-sectional area of the building normal to the wind and

C_w: "shape factor" to represent the fraction of "A" over which the plume is dispersed; C = 0.5 is a conservative value which is commonly used.

exp(-λx/U) term is due to radioactive decay,

V_d is the deposition velocity (m/s).

H (m) = effective height of plume above ground; H=h+Δh; where h is the stack height and Δh is the plume rise equals 3(wD/u); D is the internal stack diameter and w is the exit velocity of the pollutants [13].

The best empirical estimations of deposition velocities are 0.01 m/s for elemental iodine, 0.0001 m/s for organic iodine and 0.001 m/s for aerosols. The wet deposition process has been ignored, as the annual average precipitation of the study area is very little (40-80mm) as measured by meteorological tower. The magnitude of cross-sectional area completely overwhelms small values of σ_y and σ_z leading to unrealistically large diffusion. Therefore, this effect was limited to no more than one-third of the diffusion expected without the building for short-term centerline calculations [14].

Non-Gaussian model

The concentration from a continuous point source of strength Q with interference from the ground at a mean wind speed U using non-Gaussian plume formula can be calculated as follows[15]:-

$$\bar{C}_n(x,y,z,t)=\left\{\frac{1}{U\pi^2 x\,t}-\frac{h_s\sqrt{t}}{\sqrt{K_n\pi}}+\frac{1}{2\sqrt{K_n\,\pi t}}\left(\exp\left(\frac{(z-2h+h_s)}{(z+h_s)}\right)\right)\right\}Q\exp(-\lambda x/U)\frac{\exp\left(-y^2/2\sigma_y^2\right)}{\sigma_y\sqrt{2\pi}} \quad (2)$$

Where:
C is the mean concentration of the effluent at a point (x, y, z), (Bq m^{-3}).
Q is the source strength (Bq).
U is the mean wind speed (m s^{-1}).
x,y,z are downwind, crosswind and vertical coordinate system at the center of the moving cloud.
Σ_i(i=x,y,z) are the plume dispersion coefficients in the x,y and z directions respectively (m),
Exp (-x λ /U) is the radioactive decay for the specified nuclide,
H is the effective stack height {h_s (stack height) +Δ h (plume rise)} (m) [15].
By substituting in equation (3) to obtain the eddy diffusivities in vertical turbulent transport K_n,

$$\sqrt{2tK_n}=\sigma_z \quad (3)$$

$$K_n=\frac{\sigma_z^2 u}{2x} \quad (4)$$

Meteorological parameterization and field data

Stability classifications

Dispersion parameters schemes

Different methods were proposed to estimate the standard deviations of the lateral and vertical downwind concentration distribution of pollutant σy and σz. In this study, power law, Briggs, standard method and split sigma methods for calculating σ_y and σ_z were used to characterize the most accurate one in dispersion calculations [16], as follows:

Power –law functions methods

In this method, σ_y and σ_z can be calculated from the following relations:

$$\sigma_y = c\,x^m \quad (5)$$

$$\sigma_z = d\,x^n \quad (6)$$

Where c, d, m, n values [17] differ according to stability classes, as shown in Table (1).

Briggs Method

In this method, σ_y and σ_z can be calculated according to [18] as shown in Table (2).

Standard method

This method is based on a single atmospheric stability determined by vertical temperature gradient, Δ*T*/Δ*Z* (Table 3). Analytical expressions based on (*P* –*G*) curves used for the dispersion estimates have the form:

$$\boldsymbol{\sigma_y}=\frac{rx}{\left(s+\frac{x}{a}\right)^p} \quad (7)$$

$$\boldsymbol{\sigma_z}=\frac{sx}{\left(s+\frac{x}{a}\right)^q} \quad (8)$$

Where *r*, *s*, *a*, *p* and *q* are constants depending on the atmospheric stability (Table 3) [19].

Table (3) represents a correspondence between vertical temperature gradient, **Δ*T*/Δ*Z*,** and standard deviations of wind direction in lateral directions, $\boldsymbol{\sigma_\theta}$**,** for different stability classes.

'Split Sigma' method

In this method, $\Delta T/\Delta Z$ values were used to characterize vertical turbulence, σ_z as in Equation (8) and σ_θ to characterize the lateral turbulence, σ_y, (equations 9 & 10 and Table 3).The basic concept of this method is that $\Delta T/\Delta Z$ corresponds to thermal turbulence effects only and that σ_θ characterizes mechanical turbulence [17], then the following forms were used according to stability conditions.

$$\sigma_y = 0.15\,\sigma_\theta\, x^{0.71} \quad \text{(In stable conditions)} \quad (9)$$

$$\sigma_y = 0.0.045\,\sigma_\theta\, x^{0.86} \quad \text{(In unstable conditions)} \quad (10)$$

In our study, the stack height of the emitting source is 27 m; the surrounding buildings' height is 21.5 m and building width = 18.5 m [20]. Table (4) shows the source strength (Bq) and decay constants for studied fission radionuclides for different experiments. Meteorological data was provided by meteorological station located very near to the study area. The height of the meteorological tower is 15 m. Vertical temperature gradient ($\Delta T/\Delta Z$) was determined by measuring the temperature at 10 and 60 m levels [17]. Horizontal and vertical stability classes were estimated as shown in Table (5).

Field data

Table (1): Dispersion parameters for different Pasquill stability classes

σ_θ(degrees)	R_{iB}	Stability	(σ_y) c	m	(σ_z) d	n
>24^0	<-0.01	Very unstable	1.46	0.71	0.01	1.54
18^o-22^o	<-0.01	Unstable	1.52	0.69	0.04	1.17
15^0-20^0	-0.01	Neutral	1.36	0.67	0.09	0.95
8^0-13^0	>0.1	Stable	0.79	0.70	0.40	0.67

Table (2): Briggs and McElroys' formulas(1973) for σ_y(x) and σ_z (x) for urban conditions

Stability classes	σ_y (m)	σ_z (m)
A	$0.32x\ (1+0.0004x)^{-1/2}$	$0.24x\ (1+0.001x\ )^{1/2}$
B	$0.32x\ (1+0.0004x)^{-1/2}$	$0.24x\ (1+0.001x)^{1/2}$
C	$0.32x\ (1+0.0004x)^{-1/2}$	$0.20x$
D	$0.16x\ (1+0.0004x)^{-1/2}$	$0.14x\ (1+0.0003x)^{-1/2}$
E	$0.11x\ (1+0.0004x)^{-1/2}$	$0.08x\ (1+0.00015x)^{-1/2}$
F	$0.11x\ (1+0.0004x)^{-1/2}$	$0.08x(1+0.00015x)^{-1//2}$

Table (3): Dispersion parameters in corresponding to Pasquill stability classes

Stability classes	A	B	C	D	E	F
$\Delta T/\Delta Z$ (K/100 m)	<−1.9	−1.9 to −1.7	−1.7 to −1.5	−1.5 to −0.5	−0.5 to 1.5	>1.5
σ_θ (degree)	25	20	15	10	5	2.5
σ_φ (degree)	10	8	6.5	5.5	2.5	1
a (km)	0.927	0.370	0.283	0.707	1.07	1.17
s (m/km)	102.0	96.2	72.2	47.5	33.5	22.0
q	−1.918	−0.101	0.102	0.465	0.624	0.70
r(m/km)	250	202	134	78.7	56.6	37.0
p	0.189	0.162	0.134	0.135	0.137	0.134

Table (4): Source strength (Bq) and decay constants for studied fission radionuclides

Experiment	I-131
1	11347091
2	11347091
3	26636
4	21309
5	143836
λ	$9.95x10^{-7}$

Table (5): Meteorological data (wind speed 'u', vertical temperature gradient, mechanical lateral turbulence, stability classes and plume spread (°))

Experiment	U (m/s)	σ_θ (degree)	$\Delta T/\Delta z$ (°c/100m)	Stability Classes horizontal	vertical	Plume spread (°)
1	4.8	21.7	-0.52	B	D	315
2	3.1	13	-0.35	D	E	315
3	2.8	17.8	-0.36	C	E	337.5
4	3.3	27.5	-0.425	A	E	315
5	1.9	24	-0.12	B	E	292.5

Results and Discussion

Tables (6-10) show comparisons between activity concentrations of I-131in different experiments as evaluated by Gaussian and non-Gaussian models using different sigma schemes. Tables (11-15) show the comparisons among predicted concentrations by different sigma schemes divided by observed concentrations. It can be concluded that, non-Gaussian application gave satisfactory results much better than Gaussian.

Tables (16-19) show observed / predicted concentrations by different methods for different experiments. It can be concluded that, at high wind speed, all approaches in case of non-Gaussian calculations perform much better than Gaussian (experiment 1). While in moderate wind speed (experiments 2-4), Brigg's formula (in non-Gaussian) provides reasonable estimates of downwind concentration and has been shown to be accurate within factors of 0.24 to 1.76 when compared with measured concentrations. Although Gaussian models works reasonably not good during weak and variable wind conditions, split sigma provides reasonable estimates within factors of 0.5 to 1.08 in low wind speed (experiment 5) with Gaussian application.

Figures 1 and 2 show that all approaches in case of non-Gaussian calculations perform much better than Gaussian as Gaussian models have shown to be unreliable at closer range, i.e. at few hundred meters away from the source [8].

Conclusions

The main aim of this study was to present and discuss the difference between Gaussian and non-Gaussian models for simulation of pollutant dispersion in the PBL, considering the effect of meteorological parameters. Models performances were evaluated using different sigma schemes estimation. Results show that both models present comparable results and, in this preliminary evaluation, their performance was with different degree of accuracy. Generally, non-Gaussian calculations perform much better than Gaussian as Gaussian models have shown to be unreliable at closer range, i.e. at few hundred meters away from the source. At high wind speed, all approaches in case of non-Gaussian calculations perform much better than Gaussian (experiment 1). Power law function methods show realistic estimates within factors of 1.2 to 2.4 in case of Gaussian and 0.25 to 0.86 in non-Gaussian application (Table 11). In moderate wind speed (experiments 2-4), (Tables 12-14), Brigg's formula (in non-Gaussian) provides reasonable estimates of downwind concentration and has been shown to be accurate within factors of 0.24 to 1.76 when compared with measured concentrations. Although Gaussian models works reasonably not good during weak and variable wind conditions, split sigma provides reasonable estimates within factors of 0.5 to 1.08 in low wind speed (experiment 5) with Gaussian application as shown in Table (15). In general, uncertainty increases with downwind distance and decreases as the atmosphere becomes more stable for both models.

Table (6): Observed and predicted concentrations of I-131 for different methods (experiment 1)

istance (n	bserved (B /m^3) [17]	Gaussian Predicted conc. (Bq / m^3)				Non-Gaussian Predicted conc. (Bq / m^3)			
		Power law method	Briggs Method	Standard method	Split-sigma	Power law method	Briggs Method	Standard method	plit-sigma
100	4.1	4.9	5.9	0.5	2.05	4.764	6.149	5.010	5.116
110	3.8	5.3	6.5	0.45	1.85	4.483	5.763	4.904	4.926
120	3.8	6.9	7.3	0.35	1.65	4.240	5.432	4.808	4.759
130	3.7	6.7	7.4	0.34	1.55	4.029	5.145	4.722	4.611
140	3.4	6.2	7.6	0.31	1.35	3.843	4.893	4.644	4.477
150	3.2	5.5	7.7	0.29	1.1	3.677	4.669	4.572	4.357
160	3.1	5.3	8.4	0.26	0.9	3.528	4.470	4.506	4.247
170	3	5.1	8.9	0.24	0.6	3.394	4.290	4.445	4.146
180	2.9	4.8	8.3	0.22	0.45	3.272	4.127	4.388	4.053
190	2.7	4.2	7.7	0.2	0.4	3.161	3.979	4.334	3.968
200	2.4	3.4	6.4	0.15	0.35	3.059	3.844	4.284	3.888
300	1.4	2.1	4.4	0.1	0.2	2.360	2.928	3.910	3.312
400	0.5	1.2	2.1	0.05	0.1	1.964	2.418	3.665	2.956

Table (7): Observed and predicted concentrations of I-131 for different methods (experiment 2)

istance (n	Observed (Bq /m^3) [17]	Gaussian Predicted conc. (Bq / m^3)				Non-Gaussian Predicted conc. (Bq / m^3)			
		Power law method	Briggs Method	Standard method	Split-sigma	Power law method	Briggs Method	Standard method	lit-sigma
100	4.4	10.4	16.9	0.7	0.5	6.306	5.333	4.121	2.930
110	4.5	10.7	17.1	0.6	0.45	5.944	4.998	3.910	2.774
120	4.6	11.1	17.3	0.6	0.41	5.632	4.711	3.726	2.640
130	4.7	11.4	17.5	0.6	0.37	5.360	4.462	3.565	2.521
140	4.8	11.7	17.6	0.5	0.34	5.119	4.243	3.422	2.417
150	5.1	12.0	17.6	0.5	0.31	4.905	4.049	3.294	2.323
160	5.1	12.3	17.7	0.5	0.29	4.712	3.876	3.179	2.239
170	4.8	12.5	17.6	0.4	0.26	4.539	3.721	3.074	2.162
180	4.6	12.7	17.6	0.4	0.25	4.381	3.580	2.978	2.093
190	4.2	12.8	17.5	0.3	0.23	4.236	3.451	2.891	2.029
200	4.1	12.9	17.4	0.3	0.22	4.104	3.334	2.810	1.970
300	2.4	12.2	14.5	0.2	0.12	3.192	2.539	2.246	1.562
400	1.6	10.0	12.0	0.10	0.10	2.670	2.097	1.915	1.324

Table (8): Observed and predicted concentrations of I-131 for different methods (experiment 3)

Distance (m)	Observed (Bq /m^3) [17]	Gaussian Predicted conc. (Bq / m^3)				Non-Gaussian Predicted conc. (Bq / m^3)			
		Power law method	Briggs Method	Standard method	Split-sigma	Power law method	Briggs Method	Standard method	Split-sigma
100	0.051	0.033	0.0544	0.007	0.009	0.034	0.030	0.016	0.007
110	0.049	0.034	0.055	0.005	0.007	0.032	0.029	0.016	0.007
120	0.047	0.036	0.0554	0.004	0.006	0.030	0.027	0.015	0.006
130	0.042	0.037	0.0558	0.004	0.005	0.029	0.026	0.014	0.006
140	0.04	0.038	0.0561	0.003	0.004	0.027	0.024	0.014	0.006
150	0.037	0.039	0.0562	0.002	0.003	0.026	0.023	0.013	0.005
160	0.033	0.039	0.0563	0.002	0.002	0.025	0.022	0.013	0.005
170	0.03	0.039	0.056	0.001	0.001	0.024	0.021	0.012	0.005
180	0.027	0.039	0.0561	0.001	0.001	0.023	0.021	0.012	0.005
190	0.023	0.039	0.0559	0.001	0.001	0.023	0.020	0.012	0.005
200	0.02	0.038	0.0557	0.0008	0.0009	0.022	0.019	0.011	0.005
300	0.018	0.029	0.0506	0.0006	0.0008	0.017	0.015	0.009	0.004
400	0.014	0.02	0.044	0.0004	0.0006	0.014	0.012	0.008	0.003

Table (9): Observed and predicted concentrations of I-131 for different methods (experiment 4)

Distance (m)	Observed (Bq /m^3) [17]	Gaussian Predicted conc. (Bq / m^3)				Non-Gaussian Predicted conc. (Bq / m^3)			
		Power law method	Briggs Method	Standard method	Split-sigma	Power law method	Briggs Method	Standard method	Split-sigma
100	0.058	0.029	0.0369	0.0011	0.0003	0.037	0.033	0.0086	0.0029
110	0.054	0.03	0.0373	0.001	0.0003	0.034	0.031	0.0081	0.0027
120	0.051	0.031	0.0376	0.0009	0.0003	0.032	0.029	0.0077	0.0026
130	0.046	0.032	0.0379	0.0009	0.0003	0.031	0.027	0.0074	0.0024
140	0.041	0.031	0.0381	0.0008	0.0002	0.029	0.026	0.0071	0.0023
150	0.037	0.031	0.0382	0.0007	0.0002	0.028	0.025	0.0068	0.0022
160	0.033	0.03	0.0382	0.0007	0.0002	0.027	0.024	0.0066	0.0021
170	0.029	0.028	0.0382	0.0006	0.0002	0.026	0.023	0.0063	0.0020
180	0.023	0.027	0.0381	0.0006	0.0002	0.025	0.022	0.0061	0.0019
190	0.018	0.025	0.038	0.0005	0.0002	0.024	0.021	0.0060	0.0019
200	0.015	0.023	0.0378	0.0005	0.0002	0.023	0.020	0.0058	0.0018
300	0.007	0.018	0.0343	0.0003	0.0001	0.018	0.015	0.0046	0.0013
400	0.003	0.0061	0.03	0.0002	0.0001	0.015	0.013	0.0039	0.0011

Table (10): Observed and predicted concentrations of I-131 for different methods (experiment 5)

Distance (m)	Observed (Bq/ m^3) [17]	Gaussian Predicted conc. (Bq / m^3)				Non-Gaussian Predicted conc. (Bq / m^3)			
		Power law method	Briggs Method	Standard method	Split-sigma	Power law method	Briggs Method	Standard method	Split-sigma
100	0.25	1.59	3.32	1.14	0.27	0.025	0.197	0.106	0.068
110	0.26	1.71	3.37	1.12	0.27	0.024	0.185	0.101	0.064
120	0.28	1.83	3.41	1.11	0.26	0.022	0.174	0.096	0.060
130	0.28	2.49	3.44	1.1	0.25	0.021	0.165	0.092	0.056
140	0.27	2.01	3.46	1.09	0.21	0.020	0.157	0.088	0.054
150	0.26	2.08	3.48	1.08	0.19	0.019	0.150	0.085	0.051
160	0.25	2.11	3.48	1.08	0.17	0.019	0.143	0.082	0.049
170	0.21	2.13	3.47	1.07	0.13	0.018	0.137	0.079	0.047
180	0.19	2.12	3.46	1.06	0.12	0.017	0.132	0.077	0.045
190	0.16	2.1	3.45	1.06	0.11	0.017	0.128	0.074	0.043
200	0.11	2.06	3.4	1.05	0.09	0.016	0.123	0.072	0.041
300	0.04	1.31	3.0	0.4	0.02	0.012	0.094	0.058	0.031
400	0.01	0.62	2.51	0.1	0.0097	0.010	0.077	0.049	0.025

Table (11): Observed / predicted concentrations of I-131 (experiment 1)

Distance (m)	Observed / predicted (Gaussian)				Observed / predicted (Non-Gaussian)			
	Power law method	Briggs Method	Standard method	Split-sigma	Power law method	Briggs Method	Standard method	Split-sigma
100	1.20	1.44	0.12	0.50	0.86	0.67	0.82	0.80
110	1.39	1.71	0.12	0.49	0.85	0.66	0.77	0.77
120	1.82	1.92	0.09	0.43	0.90	0.70	0.79	0.80
130	1.81	2.00	0.09	0.42	0.92	0.72	0.78	0.80
140	1.82	2.24	0.09	0.40	0.88	0.69	0.73	0.76
150	1.77	2.48	0.09	0.35	0.87	0.69	0.70	0.73
160	1.77	2.80	0.09	0.30	0.88	0.69	0.69	0.73
170	1.76	3.07	0.08	0.21	0.88	0.70	0.67	0.72
180	1.78	3.07	0.08	0.17	0.89	0.70	0.66	0.72
190	1.75	3.21	0.08	0.17	0.85	0.68	0.62	0.68
200	1.42	2.67	0.06	0.15	0.78	0.62	0.56	0.62
300	1.50	3.14	0.07	0.14	0.59	0.48	0.36	0.42
400	2.40	4.20	0.10	0.20	0.25	0.21	0.14	0.17

Table (12): Observed / predicted concentrations of I-131 (experiment 2)

Distance (m)	Observed / predicted (Gaussian)				Observed / predicted (Non-Gaussian)			
	Power law method	Briggs Method	Standard method	Split-sigma	Power law method	Briggs Method	Standard method	Split-sigma
100	2.36	3.84	0.16	0.11	0.70	0.77	0.99	1.40
110	2.38	3.80	0.13	0.10	0.76	0.76	0.97	1.37
120	2.41	3.76	0.13	0.09	0.82	0.81	1.02	1.44
130	2.43	3.72	0.13	0.08	0.88	0.83	1.04	1.47
140	2.44	3.67	0.10	0.07	0.94	0.80	0.99	1.41
150	2.35	3.45	0.10	0.06	1.04	0.79	0.97	1.38
160	2.41	3.47	0.10	0.06	1.08	0.80	0.98	1.38
170	2.60	3.67	0.08	0.05	1.06	0.81	0.98	1.39
180	2.76	3.83	0.09	0.05	1.05	0.81	0.97	1.39
190	3.05	4.17	0.07	0.05	0.99	0.78	0.93	1.33
200	3.15	4.24	0.07	0.05	1.00	0.72	0.85	1.22
300	5.08	6.04	0.08	0.05	0.75	0.55	0.62	0.90
400	6.25	7.50	0.06	0.06	0.60	0.24	0.26	0.38

Table (13): Observed / predicted concentrations of I-131 (experiment 3)

Distance (m)	Observed / predicted (Gaussian)				Observed / predicted (Non-Gaussian)			
	Power law method	Briggs Method	Standard method	Split-sigma	Power law method	Briggs Method	Standard method	Split-sigma
100	0.44	0.83	0.159	0.222	1.51	1.68	3.12	7.36
110	0.48	0.88	0.167	0.200	1.54	1.72	3.15	7.47
120	0.55	0.96	0.143	0.179	1.56	1.75	3.17	7.53
130	0.65	1.07	0.137	0.176	1.46	1.64	2.95	7.05
140	0.69	1.12	0.102	0.143	1.46	1.64	2.93	7.00
150	0.77	1.18	0.085	0.128	1.41	1.59	2.81	6.74
160	0.88	1.33	0.095	0.119	1.31	1.48	2.59	6.24
170	0.95	1.40	0.075	0.100	1.24	1.40	2.43	5.87
180	1.05	1.52	0.054	0.081	1.15	1.31	2.26	5.46
190	1.18	1.71	0.061	0.061	1.01	1.16	1.98	4.80
200	1.30	1.87	0.033	0.033	0.91	1.04	1.77	4.30
300	1.44	2.08	0.037	0.037	1.05	1.22	1.98	4.88
400	1.70	2.43	0.043	0.043	0.98	1.14	1.79	4.47

Table (14): Observed / predicted concentrations of I-131 (experiment 4)

Distance (m)	Observed / predicted (Gaussian)				Observed / predicted (Non-Gaussian)			
	Power law method	Briggs Method	Standard method	Split-sigma	Power law method	Briggs Method	Standard method	Split-sigma
100	0.50	0.64	0.019	0.005	1.59	1.76	6.74	19.71
110	0.56	0.69	0.019	0.006	1.57	1.76	6.63	19.66
120	0.61	0.74	0.018	0.006	1.58	1.76	6.58	19.77
130	0.70	0.82	0.020	0.007	1.50	1.68	6.22	18.90
140	0.76	0.93	0.020	0.005	1.40	1.58	5.78	17.77
150	0.84	1.03	0.019	0.005	1.32	1.50	5.43	16.86
160	0.91	1.16	0.021	0.006	1.23	1.39	5.02	15.75
170	0.97	1.32	0.021	0.007	1.13	1.28	4.57	14.46
180	1.17	1.66	0.026	0.009	0.93	1.06	3.75	11.95
190	1.39	2.11	0.028	0.011	0.75	0.86	3.02	9.73
200	1.53	2.52	0.033	0.013	0.65	0.74	2.60	8.41
300	2.57	4.90	0.043	0.014	0.40	0.46	1.53	5.26
400	2.03	10.00	0.067	0.033	0.21	0.24	0.77	2.78

Table (15): Observed / predicted concentrations of I-131 (experiment 5)

Distance (m)	Observed / predicted (Gaussian)				Observed / predicted (Non-Gaussian)			
	Power law method	Briggs Method	Standard method	Split-sigma	Power law method	Briggs Method	Standard method	Split-sigma
100	6.36	13.28	4.56	1.08	9.96	1.27	2.35	3.66
110	6.58	12.96	4.31	1.04	11.00	1.41	2.58	4.08
120	6.54	12.18	3.96	0.93	12.53	1.61	2.92	4.68
130	8.89	12.29	3.93	0.89	13.19	1.70	3.05	4.96
140	7.44	12.81	4.04	0.78	13.33	1.72	3.06	5.04
150	8.00	13.38	4.15	0.73	13.42	1.74	3.06	5.10
160	8.44	13.92	4.32	0.68	13.45	1.75	3.05	5.14
170	10.14	16.52	5.10	0.62	11.74	1.53	2.65	4.51
180	11.16	18.21	5.58	0.63	11.02	1.44	2.48	4.26
190	13.13	21.56	6.63	0.69	9.61	1.25	2.15	3.73
200	18.73	30.91	9.55	0.82	6.83	0.89	1.52	2.66
300	32.75	75.00	10.00	0.50	3.22	0.43	0.69	1.30
400	62.00	251.00	10.00	0.97	0.97	0.13	0.20	0.40

Table (16): Observed / predicted concentrations by power law function for different experiments

Distance (m)	O / P (Gaussian) Power law method					O / P (Non-Gaussian) Power law method				
	Exp.1	Exp. 2	Exp. 3	Exp. 4	Exp. 5	Exp.1	Exp. 2	Exp. 3	Exp. 4	Exp. 5
100	1.20	2.36	0.44	0.50	6.36	0.86	0.70	1.51	1.59	9.96
110	1.39	2.38	0.48	0.56	6.58	0.85	0.76	1.54	1.57	11.00
120	1.82	2.41	0.55	0.61	6.54	0.90	0.82	1.56	1.58	12.53
130	1.81	2.43	0.65	0.70	8.89	0.92	0.88	1.46	1.50	13.19
140	1.82	2.44	0.69	0.76	7.44	0.88	0.94	1.46	1.40	13.33
150	1.77	2.35	0.77	0.84	8.00	0.87	1.04	1.41	1.32	13.42
160	1.77	2.41	0.88	0.91	8.44	0.88	1.08	1.31	1.23	13.45
170	1.76	2.60	0.95	0.97	10.14	0.88	1.06	1.24	1.13	11.74
180	1.78	2.76	1.05	1.17	11.16	0.89	1.05	1.15	0.93	11.02
190	1.75	3.05	1.18	1.39	13.13	0.85	0.99	1.01	0.75	9.61
200	1.42	3.15	1.30	1.53	18.73	0.78	1.00	0.91	0.65	6.83
300	1.50	5.08	1.44	2.57	32.75	0.59	0.75	1.05	0.40	3.22
400	2.40	6.25	1.70	2.03	62.00	0.25	0.60	0.98	0.21	0.97

Table (17): Observed / predicted concentrations by Brigg’s formula for different experiments

Distance (m)	O / P (Gaussian) Briggs method					O / P (Non-Gaussian) Briggs method				
	Exp.1	Exp. 2	Exp. 3	Exp. 4	Exp. 5	Exp.1	Exp. 2	Exp. 3	Exp. 4	Exp. 5
100	1.44	3.84	0.83	0.64	13.28	0.67	0.77	1.68	1.76	1.27
110	1.71	3.80	0.88	0.69	12.96	0.66	0.76	1.72	1.76	1.41
120	1.92	3.76	0.96	0.74	12.18	0.70	0.81	1.75	1.76	1.61
130	2.00	3.72	1.07	0.82	12.29	0.72	0.83	1.64	1.68	1.70
140	2.24	3.67	1.12	0.93	12.81	0.69	0.80	1.64	1.58	1.72
150	2.48	3.45	1.18	1.03	13.38	0.69	0.79	1.59	1.50	1.74
160	2.80	3.47	1.33	1.16	13.92	0.69	0.80	1.48	1.39	1.75
170	3.07	3.67	1.40	1.32	16.52	0.70	0.81	1.40	1.28	1.53
180	3.07	3.83	1.52	1.66	18.21	0.70	0.81	1.31	1.06	1.44
190	3.21	4.17	1.71	2.11	21.56	0.68	0.78	1.16	0.86	1.25
200	2.67	4.24	1.87	2.52	30.91	0.62	0.72	1.04	0.74	0.89
300	3.14	6.04	2.08	4.90	75.00	0.48	0.55	1.22	0.46	0.43
400	4.20	7.50	2.43	10.00	251.00	0.21	0.24	1.14	0.24	0.13

Table (18): Observed / predicted concentrations by standard method for different experiments

Distance (m)	O / P (Gaussian) Standard method					O / P (Non-Gaussian) Standard method				
	Exp.1	Exp. 2	Exp. 3	Exp. 4	Exp. 5	Exp.1	Exp. 2	Exp. 3	Exp. 4	Exp. 5
100	0.12	0.16	0.159	0.019	4.56	0.82	0.99	3.12	6.74	2.35
110	0.12	0.13	0.167	0.019	4.31	0.77	0.97	3.15	6.63	2.58
120	0.09	0.13	0.143	0.018	3.96	0.79	1.02	3.17	6.58	2.92
130	0.09	0.13	0.137	0.020	3.93	0.78	1.04	2.95	6.22	3.05
140	0.09	0.10	0.102	0.020	4.04	0.73	0.99	2.93	5.78	3.06
150	0.09	0.10	0.085	0.019	4.15	0.70	0.97	2.81	5.43	3.06
160	0.09	0.10	0.095	0.021	4.32	0.69	0.98	2.59	5.02	3.05
170	0.08	0.08	0.075	0.021	5.10	0.67	0.98	2.43	4.57	2.65
180	0.08	0.09	0.054	0.026	5.58	0.66	0.97	2.26	3.75	2.48
190	0.08	0.07	0.061	0.028	6.63	0.62	0.93	1.98	3.02	2.15
200	0.06	0.07	0.033	0.033	9.55	0.56	0.85	1.77	2.60	1.52
300	0.07	0.08	0.037	0.043	10.00	0.36	0.62	1.98	1.53	0.69
400	0.10	0.06	0.043	0.067	10.00	0.14	0.26	1.79	0.77	0.20

Table (19): Observed / predicted concentrations by split-sigma method for different experiments

Distance (m)	O / P (Gaussian) Split-sigma method					O / P (Non-Gaussian) Split-sigma method				
	Exp.1	Exp. 2	Exp. 3	Exp. 4	Exp. 5	Exp.1	Exp. 2	Exp. 3	Exp. 4	Exp. 5
100	0.50	0.11	0.222	0.005	1.08	0.80	1.40	7.36	19.71	3.66
110	0.49	0.10	0.200	0.006	1.04	0.77	1.37	7.47	19.66	4.08
120	0.43	0.09	0.179	0.006	0.93	0.80	1.44	7.53	19.77	4.68
130	0.42	0.08	0.176	0.007	0.89	0.80	1.47	7.05	18.90	4.96
140	0.40	0.07	0.143	0.005	0.78	0.76	1.41	7.00	17.77	5.04
150	0.35	0.06	0.128	0.005	0.73	0.73	1.38	6.74	16.86	5.10
160	0.30	0.06	0.119	0.006	0.68	0.73	1.38	6.24	15.75	5.14
170	0.21	0.05	0.100	0.007	0.62	0.72	1.39	5.87	14.46	4.51
180	0.17	0.05	0.081	0.009	0.63	0.72	1.39	5.46	11.95	4.26
190	0.17	0.05	0.061	0.011	0.69	0.68	1.33	4.80	9.73	3.73
200	0.15	0.05	0.033	0.013	0.82	0.62	1.22	4.30	8.41	2.66
300	0.14	0.05	0.037	0.014	0.50	0.42	0.90	4.88	5.26	1.30
400	0.20	0.06	0.222	0.033	0.97	0.17	0.38	4.47	2.78	0.40

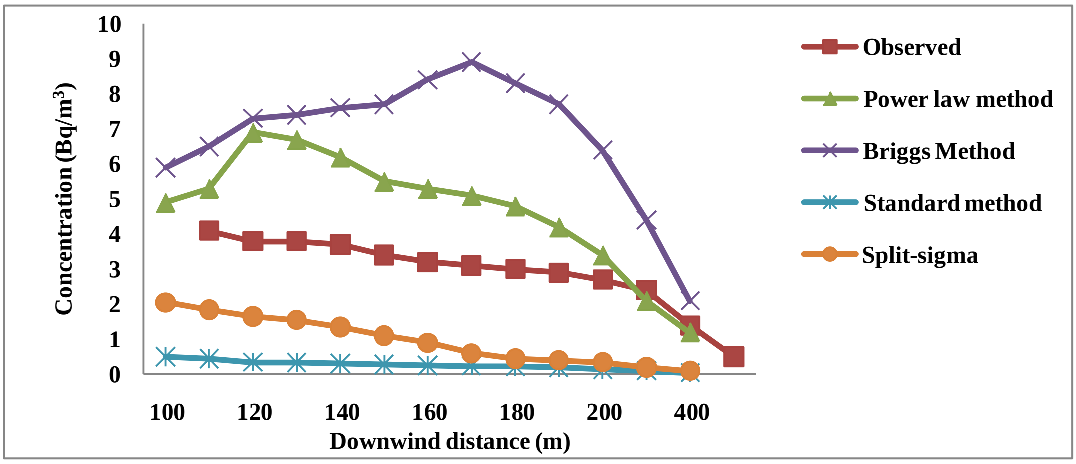

Fig. 1: Variation of observed concentration and Gaussian predicted concentrations via downwind distance in experiment 1

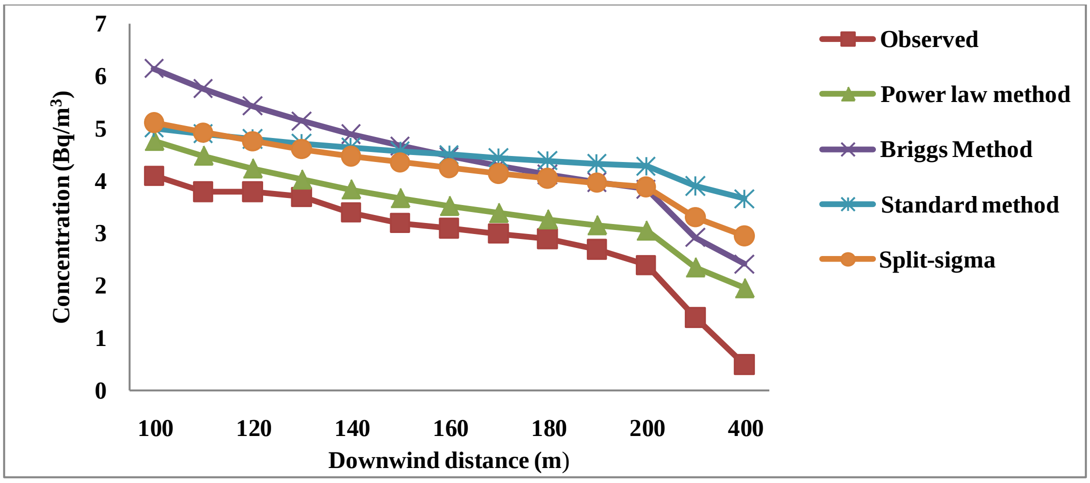

Fig. 2: Variation of observed concentration and non-Gaussian predicted concentrations via downwind distance in experiment 1

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