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WIND TUNNEL EXPERIMENT TO VALIDATE NUMERICAL SIMULATION FOR UNSTEADY GAS DISPERSION IN URBAN AREA

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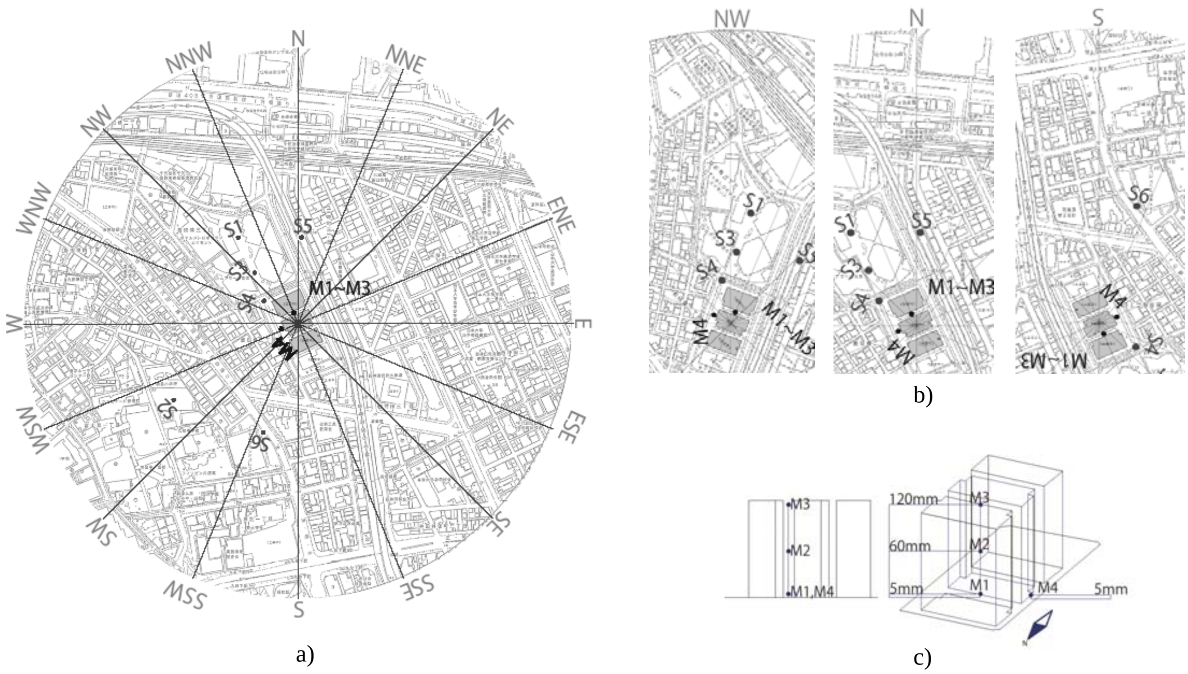
ABSTRACT: This paper shows the time series of concentration under the unsteady discharge condition in a wind tunnel experiment. The aim of this study is collecting data of gas dispersion including concentration fluctuation to validate numerical simulation model of gas diffusion in urban area. This report documents the relation between the time series data and conditions of measurement points. The peak concentration caused by various scale of eddy could exceed the threshold dose for human health. But in Japan, averaged concentration during a long time observation is used for environmental assessment and it does not take the peak concentration into consideration. Therefore, measuring the concentration fluctuations and comprehending the characteristics of fluctuations is critical issue for estimating hazardous nature. In order to take concentration fluctuations into consideration, the stochastic analysis is often used. This report shows the stochastic characteristics, 3rd momentums 'skewness', 4th momentum 'kurtosis' and pdf (probability distritution function) at the each source point.

1 INTRODUCTIONS

Concentration fluctuation is an indispensable element in the study of risk assessment of pollutant dispersion. In many cases, the peak concentration which is caused by varying scales of eddies is much higher than the average concentration. In general, the average concentration as calculated by long-term observation is lower than the ignition limit for flammable gases or an acceptable level for toxic gas. This means that pedestrians could intake a hazardous dose within a split second because of such concentration fluctuations. Therefore, acquiring a database of average concentrations remains inadequate for constructing an assessment of accidental pollutant dispersion. It is necessary to analyze the fluctuation characteristics for each measurement location. This report shows a time series concentration of tracer gas under unsteady discharge conditions in a wind tunnel experiment. We settled the zero time reference upon release at the source point and acquired the time series data at the measurement point. This report documents the relationship between the data characteristics (i.e. how long it takes to arrive at the measurement point and details on the step-up tendency) and the distance from the source point to measurement point. This report also documents the relationship between the characteristics of stochastic analysis and conditions at the measurement point. This data will contribute to validating the numerical simulation of unsteady gas dispersion.

2 EXPERIMENTAL SETUP

The experiment was conducted in the environmental wind tunnel at the Institute of Industrial Science within the University of Tokyo. The cross-section of the wind tunnel is 2,200 mm wide and 1,800 mm high with a working section 16,470 mm long. We used the equipment as an open-circuit wind tunnel to prevent the tracer gas from accumulating in the chamber. The turntable has a diameter of 2,000 mm and can be rotated through 360 degrees. The wind velocity can be adjusted from 0.2 m/s to 2.0 m/s. The model is based on the Idabashi district in Tokyo, Japan, at a scale of 1:500. The area is primarily comprised of mid-sized and high-rise office buildings and small accommodation units. The source points were sited in a district of mid- to high-rise office buildings (S1 S3 S4), on a trunk road (S2), on a highway (S5), and in a school ground (S6), as shown in Figure 1-a). The inner diameter of the ejection hole was 6 mm. Above the ejection hole, we placed a baffle plate in order to discharge the tracer gas as a passive scalar. The measurement points were placed alongside the next office building, which is located in the center of the model (Figure 1-b), 1-c)). The height of measurement point M1 is 5 mm (equivalent to 2.5 m at full scale), M2 is 60 mm (30 m at full scale), and M3 is 120 mm (60 m at full scale).Measurement point M4 was placed in front of the entrance to the office building at a height of 5 mm(2.5 m at full scale). We monitored the concentrations at both the measurement points and source points, and the temporal sequences for these two data readings are synchronized. Each sampling last for 1 minute. During this minute, we started and stopped the gas ejection, so the data shows a tendency to step up after ejection and then step down. From the data at source points, we identified when ejection started and stopped. A fast Flame Ionization Detector (FID) (THC-2A: TECHNICA) was used to measure the concentration fluctuation, while a hot-wire anemometer (CTA: DANTEC) was used to measure the approach flow velocity.



a) c)

Figure. 1 Geometry of the Wind Tunnel Model and Details

3 *APPROACH FLOW PROFILE*

Preliminary measurements were carried out to establish the boundary layer in the working section. The atmospheric stability was set neutral. The velocity at a height of 1,000 mm at the center of the turntable was settled at 2 m/s. The CTA was used for velocity measurements, while the response frequency was 1,000 Hz. As shown in Figure. 2, the measurement points were positioned at the center of the turntable (center); 1,400 mm upwind of the center (X–1400); 1,100 mm downwind of the center (X+1100); 550 mm right of the center as viewed

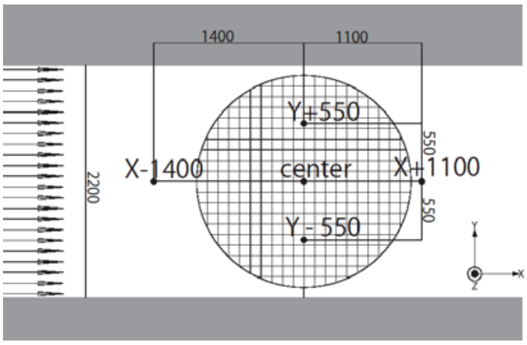


Figure. 2 Measurement points for approach flow velocity

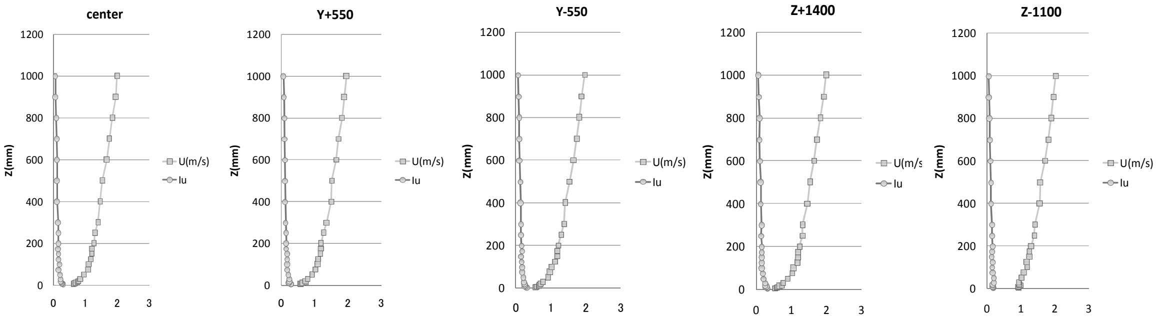


Figure. 3 Detail of approach flow

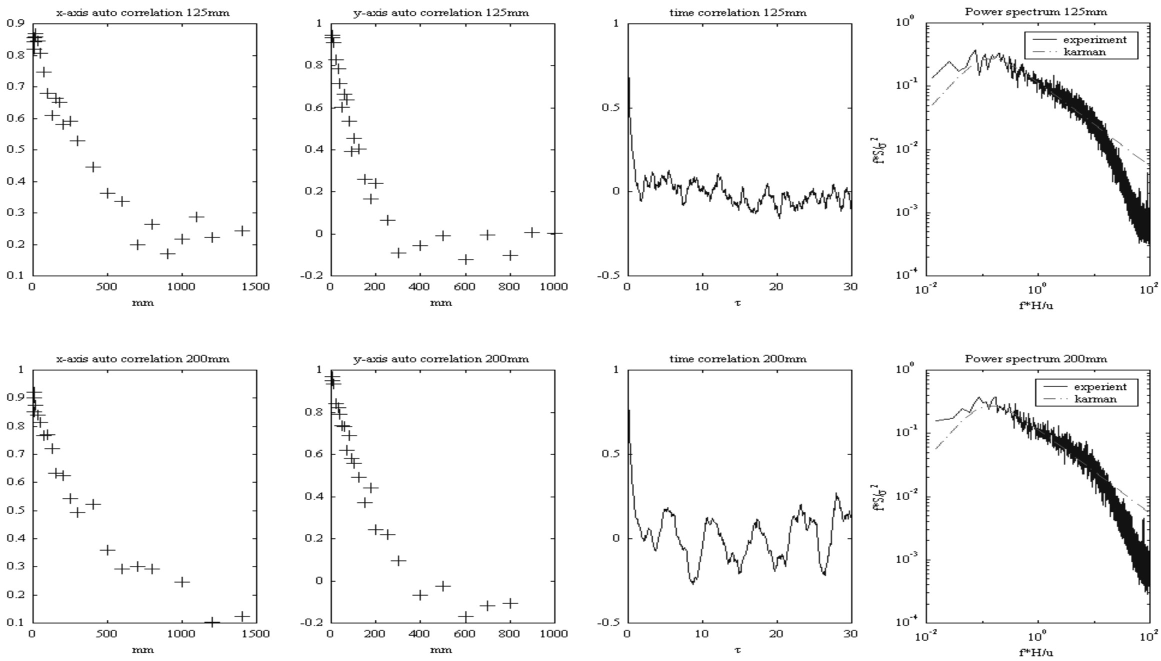


Figure. 4 Auto-correlation coefficients and Power spectra

from downwind (Y+550); and 550 mm left of the center as viewed from downwind (Y-550). Measurements were taken each minute. Figure 3 shows the velocity and turbulent intensity. The roughness was settled to realize the power law ($U \propto Z^{\alpha}$ where α is 0.25, U is the velocity, and Z is the height).Figure 4 shows the auto-correlation coefficient and powers pectrum. The measurement heights were 125 mm and 200 mm. X-axis auto-correlation coefficient and Y-axis auto-correlation coefficient was measured. The X-axis auto-correlation still took a value of more than zero 1,400 mm downstream in both the 125-mm and 200-mm high cases. (The maximum range of traverse movement was 1,400 mm downstream.) According to this measurement, the turbulence length scale was 509 mm at a height of 125 mm, and 497 mm at a height of 200 mm. The Y-axis auto-correlation was zero in the measurement distance. The

Y-axis turbulence length scale was 100 mm at height 125 mm, and 134 mm at height 200 mm. The turbulent time scale was 0.35 s at height 125 mm and 0.47 s at height 200 mm. The rightmost chart in Figure 4 shows the power spectrum of the approach flow. Compared to the Karman spectrum, there is attenuation in the high frequency domain, but the peak frequency tendency of the experiment corresponds to that of the Karman spectrum.

4 CHARACTERISTICS OF CONCENTRATION RESPONSE

Table 1 shows the concentration measurement cases. In the cases under the column ‘1 MINUTE’, concentrations were measured for one minute during continuous discharge, and the average concentration was no more than 30 ppm. In the cases under the column ‘32 ENSEMBLE’, the one-minute measurements were carried out 32 times. In this one minute, ejection of the tracer gas was started and stopped, so step-up and step-down characteristics are contained in the data at the same instant. In this document, the notation “S1-NNW-M4” indicates that “the source point was S1, the wind direction was NNW and the measurement point was M4”. Figure 5 shows the experimental details. We used two probes and measured the concentrations at both the source and measurement points. These two data readings were input to the same logger. Thus, their time series were synchronized. The FID detector tube was 40-cm long and its response frequency was 50 Hz. Figure 1-c) shows location details for the source and measurement points. Ethylene was used as the tracer gas, and a valve system (Scanivalve Corp.) was used to allow step-up ejection. A mass flow controller was used to ensure a fixed flow rate of 1 cc/s. For this data, the step-up and step-down time series was extracted and averaged for 32 data readings. In the data, noise was observed at about 18 Hz, so we cut off frequencies exceeding 12.5 Hz by Fourier transform. A zero time reference was set at the point that exceeded the value 6σ of the fluctuation at the source point before initiating the discharge. In terms of the step-down tendency, the data does not appear to reflect the step-down characteristics. Accordingly, this report only documents the step-up discharge characteristics.

Table 1: Measurement case

1MINUTE

source point	wind direction	measurement pont
S1	NNW	M4
	NW	M2
	NW	M3
	NW	M4
S2	WSW	M4
	SW	M3
S3	NNW	M1
	NNW	M2
	WNW	M3
	W	M3
S5	NNE	M3
	N	M3
	NNW	M3
	NNW	M4
S6	SSW	M1

32ENSEMBLE

source point	wind direction	measurement pont
S2	SW	M1
	SW	M2
	SW	M4
S3	NNW	M4
	NW	M1
	NW	M2
	NW	M3
	NW	M4
S4	NNW	M4
	NW	M1
	NW	M2
	NW	M3
	NW	M4
	WNW	M1
	WNW	M2
	WNW	M4
	W	M1

32ENSEMBLE

source point	wind direction	measurement pont
S4	W	M2
	W	M4
	WSW	M1
S5	NNE	M1
	NNE	M2
	NNE	M4
	N	M1
	N	M2
	N	M4
	NNW	M1
	NNW	M2
S6	SSW	M4
	S	M1
	S	M2
	S	M3
	S	M4

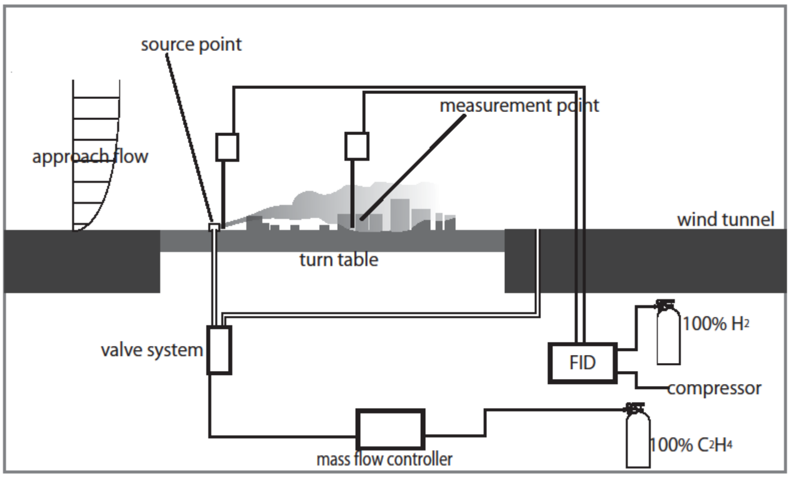


Figure. 5 Details of experiment

5 DISCUSSIONS

5.1 Discussion about wind direction

In this report, the concentration is described as:

$$C^* = CuL^2/(Q \times 1000000) \tag{1}$$

The time is described as:

$$t^* = tu/L \tag{2}$$

where L is the reference height of the building beside the measurement point (12.5 [cm]), u is the reference velocity at the reference height (112 [cm/s]), and Q is the flow rate of the tracer gas ([1 cc/s]). This report shows C^* as a scaled concentration. The wind velocity at a height of 1 m at the center was 2 m/s, the same condition as ***3.***

Figure 6 shows the ensemble-averaged data for the S5 case. S5 is located on a highway and the ejection hole was set at a height of 2.5 cm above the ground. The difference between each line is the direction. In each wind direction case, M3 recorded values of less than 30 ppm, so no unsteady gas dispersion measurements were conducted. The highest concentration was measured in the N direction. In terms of the step-up tendency, the tracer gas arrived at the measurement point faster in the case of the NNW direction compared to other cases. This is because the main wind direction corresponded to the direction of the highway road and the tracer gas drifted along the road without hindrance. On the other hand, FID detected a lower concentration in this case. This is because the void at the measurement point was perpendicular to the wind direction. In the N and NNE cases, the concentrations around each measurement point are quite different from each other, but in the NNW case, there is little difference around the two cases.

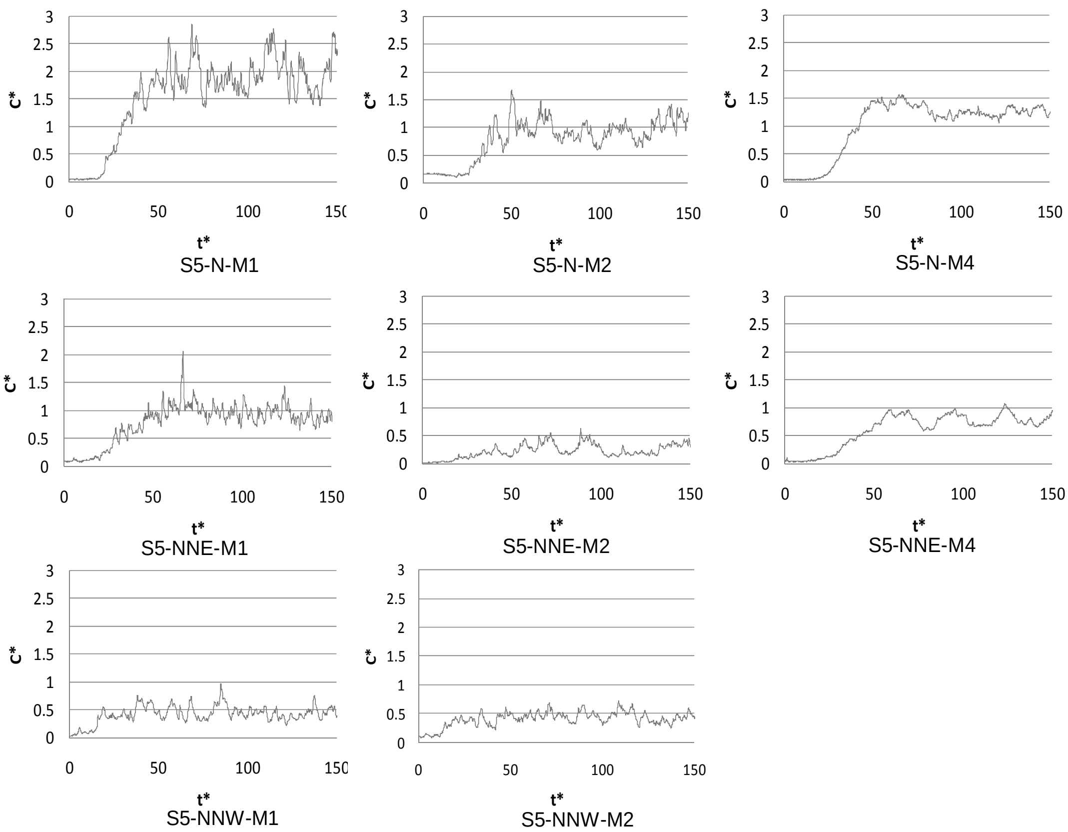


Figure. 6 S5 case data

5.2 Discussion about distance between source and measurement points

Figure 7 shows the time series response of each source point. Table 2 shows the average concentration, standard deviation, maximum concentration, skewness, kurtosis, the values at 97% (which corresponds to the value at 2σ if the pdf has a normal distribution) and 84% (corresponding to σ if the pdf has a normal distribution), 2σ, and σ in each case. S4 is the nearest point, followed by S3, S5, S1, S6 and S2. The direction was chosen in which the concentration at M1~M3 recorded the largest value for each source point. In the S1 case, no points measured concentrations of more than 30 ppm. Around S1, there is a high-rise building and it can be assumed that the tracer gas was dispersed before reaching the measurement point. The nearer the source point selected (S3, S4), the higher the concentration recorded at M1 and M2 compared to M3. The greater the distance, the smaller the difference in arrival times and difference of concentrations at each source point. In the S3 and S4 cases, the arrival times at M1, M2 and M4 were faster than at M3. The average concentration and standard deviation were highest in the S4-NW case, the nearest source point to a measurement point. The distance

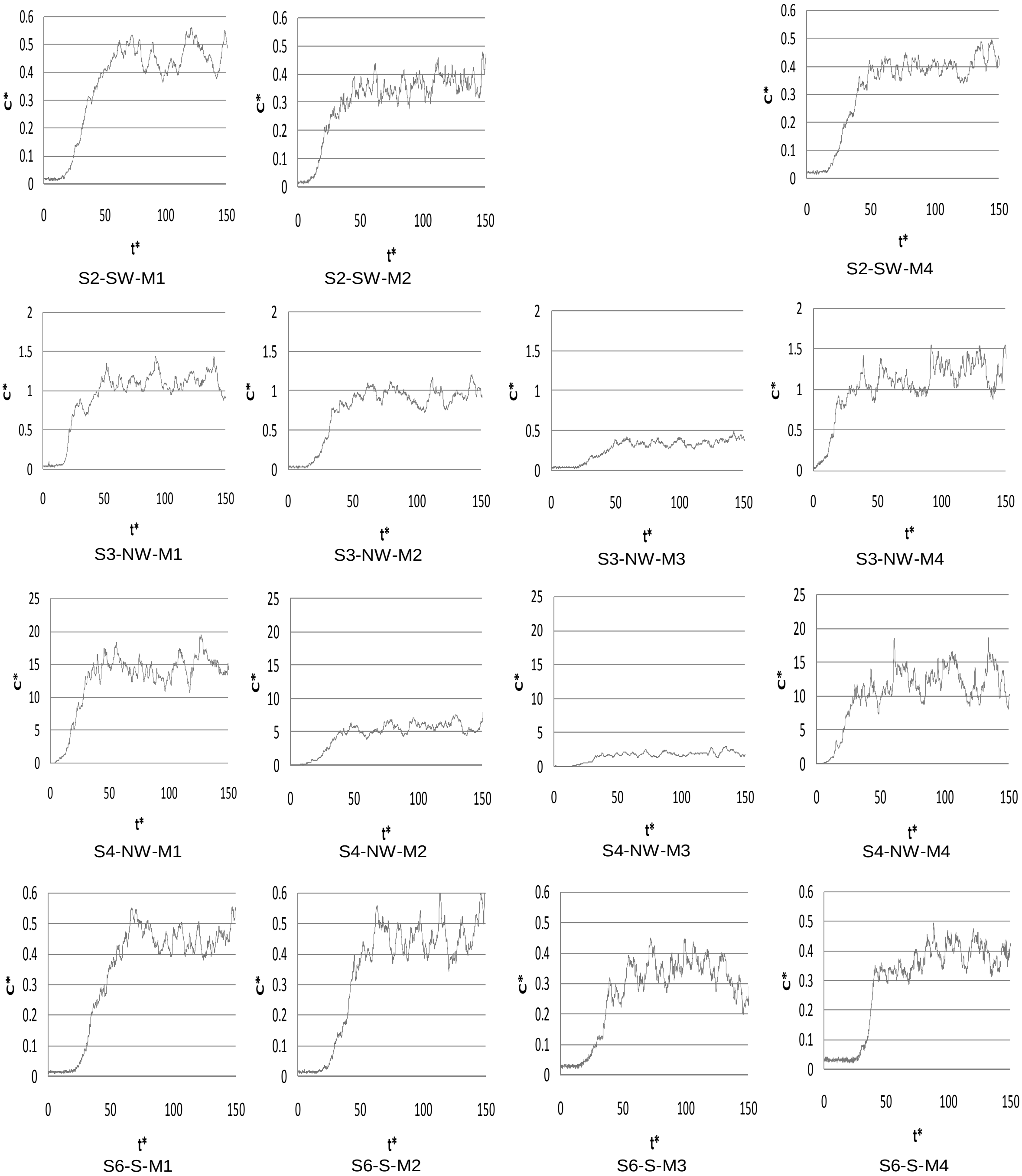


Figure. 7 Time-series response of each source point

from the source point to measurement point is furthest in the S2-SW and S6-S cases and the standard deviation for these cases were significantly lower than other cases. In the S3 case, the tracer gas was attenuated before reaching the measurement point. In general, as distance increases, so the standard deviation is reduced (as shown in Table 2). This reflects the characteristics of dispersion. In the nearer case (S4-NW), the concentration shows a large fluctuation. But with increased distance, the gas dispersed so sufficiently that the difference in concentration at the measurement point became low and uniform and became independently of flow field feature (S2-SW and S6-S cases).

5.3 Relationship between stochastic factor and measurement point tendencies

Figure 8 shows the concentration fluctuations and pdf. The fluctuation figures present one-time measurement data not including the step-up tendency. All the skewness presented positive value. The kurtosis of S3-NW-M1 presented the higher value, and some strong peaks exceeding the σ value can be observed, but the average concentration was not so high. The peak in this figure was ten times larger than the average concentration and six times larger than the σ value. In contrast, the kurtosis of S4-NW-M1 was not that high, yet this case presented the highest average concentration and standard deviation. The kurtosis of S5-N-M1 had a higher value, with a peak concentration ten times larger than the average, and five times larger than σ. The kurtosis of S2-SW-M1 and S6-S-M1 had a lower value, being four times larger than the average and less than three times larger than σ. The distributions of these two cases were similar to the normal distribution. Compared with S3-NW-M1, the S5-N-M1 case recorded higher concentrations despite being further away than S3. Many pulse-like peaks were observed and vanishingly low value was detected frequently (the concentration in which the probability distribution took the peak value was lower than the average concentration). The pdf was similar to the exponential distribution. In contrast, the case S3-NW-M1 took the value near the average concentration frequently and the pdf was similar to logarithmic normal distribution. The duration time of exceeding the threshold was longer than S5-N-M1. It can be assumed that the risk of sucking in a toxic gas is related not only to the pdf but also to the duration distribution.

Table 2 : Stochastic detail for each wind direction

	ave	std	max	skew	kurt	97.72%	84.13%	ave+2σ	ave+σ
S2-SW-M1	0.472	0.207	1.622	0.749	0.834	0.960	0.673	0.885	0.678
S2-SW-M2	0.375	0.252	3.120	1.293	2.820	1.014	0.619	0.880	0.627
S2-SW-M4	0.422	0.223	1.672	0.948	1.106	0.960	0.655	0.868	0.645
S3-NW-M1	1.179	0.821	11.514	2.497	11.371	3.518	1.795	2.821	2.000
S3-NW-M2	0.916	0.618	6.535	1.971	7.220	2.549	1.427	2.152	1.534
S3-NW-M3	0.401	0.445	3.790	1.940	4.828	1.642	0.817	1.291	0.846
S3-NW-M4	1.206	1.066	14.939	3.789	24.609	4.173	1.813	3.339	2.272
S4-NW-M1	15.540	11.492	99.912	1.433	2.933	45.769	26.384	38.524	27.032
S4-NW-M2	5.940	4.394	39.584	1.466	3.239	17.500	10.051	14.728	10.334
S4-NW-M3	1.967	2.355	18.943	1.951	4.400	8.795	4.128	6.678	4.322
S4-NW-M4	12.445	11.662	134.522	2.036	5.797	45.769	22.256	35.770	24.108
S5-N-M1	1.951	1.736	20.336	2.014	7.200	6.623	3.392	5.422	3.686
S5-N-M2	0.946	1.045	17.118	3.089	19.964	3.751	1.714	3.036	1.991
S5-N-M4	1.319	0.717	7.682	0.980	1.835	3.051	2.046	2.754	2.037
S6-S-M1	0.491	0.264	2.170	0.628	0.969	1.077	0.754	1.019	0.755
S6-S-M2	0.497	0.307	3.474	1.314	3.507	1.265	0.781	1.112	0.804
S6-S-M3	0.374	0.291	2.567	1.378	2.590	1.140	0.655	0.956	0.665
S6-S-M4	0.423	0.313	3.191	1.193	3.319	1.176	0.718	1.050	0.737

6 CONCLUSIONS

This report showed the step-up tendencies under the unsteady discharge condition and documented the characteristics of concentration fluctuations. In the experiment, the geography of the City's actual conditions is reproduced and the data contains influences of building and other infrastructures. In the case near the source point, the hindrance was directly influential to the tendency of the arrival time and the standard deviation at each measurement point and the tendency differed at each source point. As the distance from source and measurement point increase, the gas dispersed so sufficiently that the difference in concentration at the measurements became uniform and independently of flow field feature. The concentration fluctuation tendency was analyzed by the pdf. It could be assumed that the fluctuation tendency such as duration time of peak is related to the pdf. As the next issue, the relation between the time interval of peak and probability distribution function would be researched

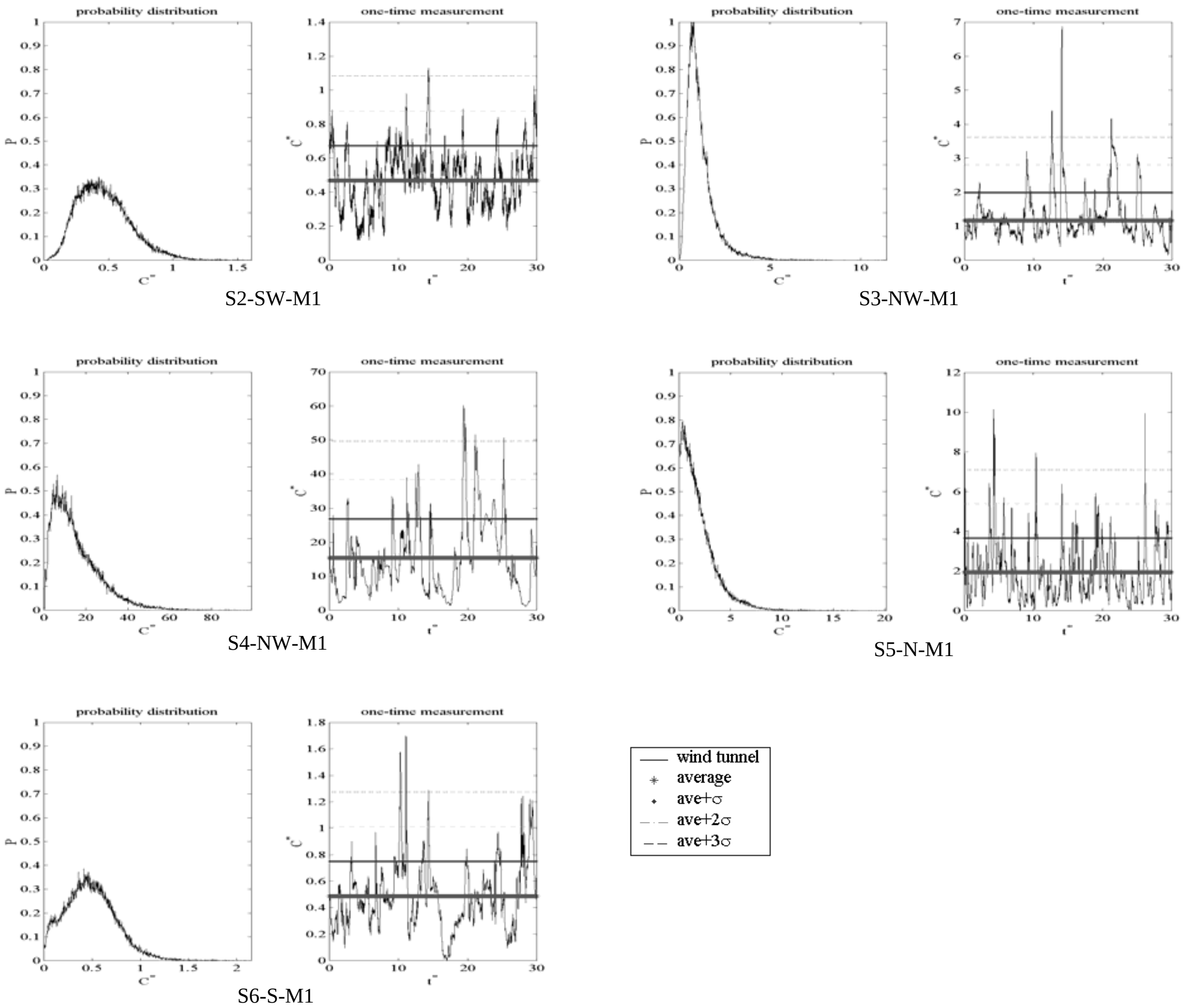


Figure. 8 Fluctuation data for one-time measurements

7 ACKNOWLEDGEMENTS

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