ON THE RELATIONSHIPS OF RANGE TO STANDARD DEVIATION OF WIND FLUCTUATIONS

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[Manuscript received May 31, 1962; revised November 16, 1962]

ABSTRACT

The relationships of ranges to their respective standard deviations for wind direction and speed fluctuations are found for two urban locations at a height of 33 ft. above ground level. The standard deviations are computed from 1-, 5-, 10-, and 15-sec. average and 5-, 10-, and 15-sec. instantaneous chart readings. The sampling intervals for which the standard deviations and ranges are computed are 15, 30, and 60 min.

The findings indicate: (1) the wind-direction range shows promise for standard use as an indicator of the standard deviation of wind direction fluctuations; (2) the wind-speed range relationships to standard deviation of wind speed are not consistent. Also, the wind direction results are found to compare favorably with results from other investigations.

1. INTRODUCTION

One of the practical objectives of meteorological research in the field of urban air pollution is finding relatively easily measurable meteorological parameters that indicate the diffusion of pollutants in the boundary layer. There are several lines of attack to this problem. Some of these involve the use of wind speed, vertical wind gradient, vertical temperature gradient, standard deviation of wind fluctuations, and various combinations of these parameters.

Hay and Pasquill [1] and Cramer, Record, and Vaughan [2] have shown that the standard deviation of fluctuations in horizontal wind direction is a good indicator of the lateral dispersion from individual point sources of air pollution over short travel distances. Whether this parameter can be used as an indicator with the complex multiple sources existing in urban areas or with longer travel distances is not known. The standard deviation of fluctuations in wind speed is another indicator of the dispersion of pollutants. Therefore, there is much interest in whether either or both of these parameters can be useful tools in the calculation of urban air pollution dispersion.

Few of the wind instruments used in urban air pollution surveys have components that compute standard deviations of fluctuations. Many continuous chart records are available, however, from which the extreme ranges of wind direction and wind speed can be obtained. Therefore, if the ranges of wind direction and speed were found to be good predictors of their respective standard deviations, these ranges could be used to approximate standard deviations and could then be tested as indicators of air pollutant dispersion in urban areas. The purpose of this study is to determine whether the ranges can be used to obtain reasonably close approximations of the standard deviations in urban areas and, if they can, to find the relationships.

2. PROCEDURE

Beckman and Whitley K100A wind systems were selected for use in this study because their sensitivity at low wind speeds and the balance between sensor motion and

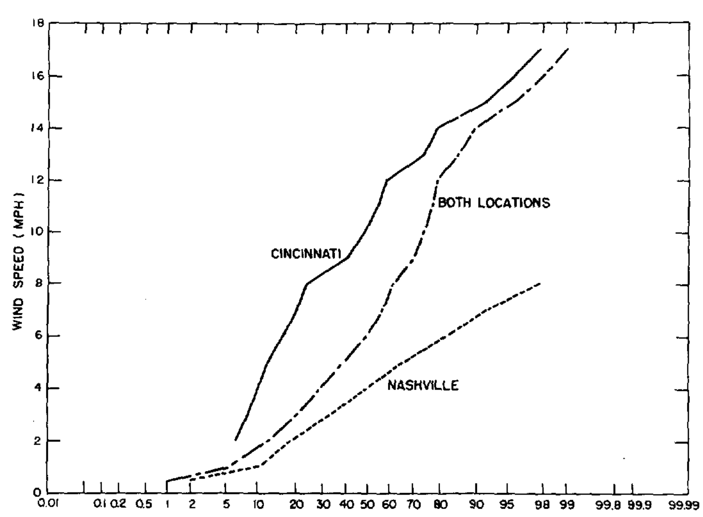

Figure 1.—Distributions of 15-min. mean wind speeds.

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[2] This research has been partially supported by the U. S. Public Health Service.

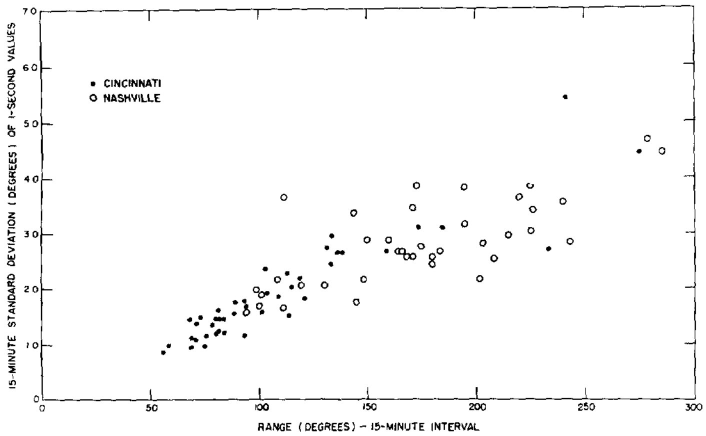

FIGURE 2.—Scatter diagram of range vs. standard deviation for wind direction (15-min. sampling interval).

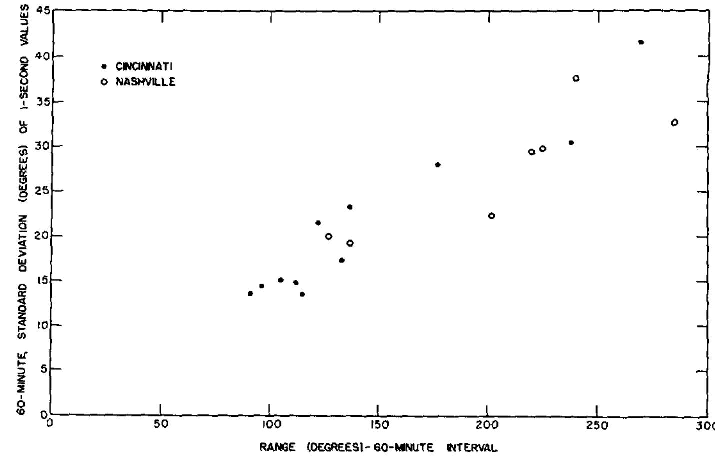

FIGURE 4.—Scatter diagram of range vs. standard deviation for wind direction (60-min. sampling interval).

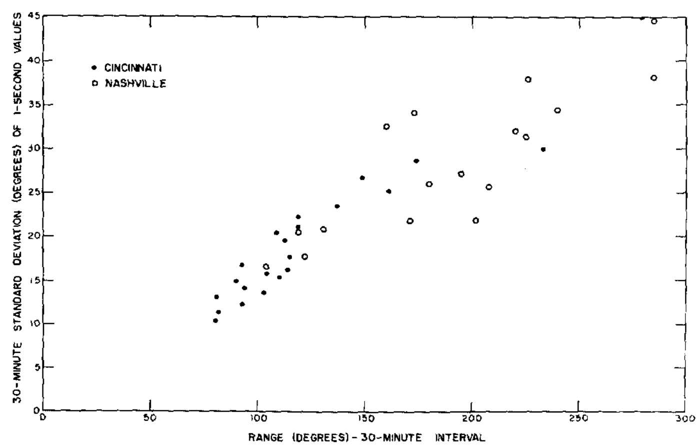

FIGURE 3.—Scatter diagram of range vs. standard deviation for wind direction (30-min. sampling interval).

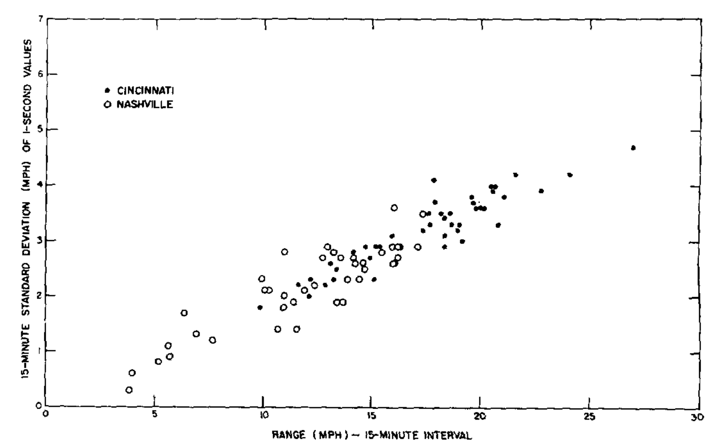

FIGURE 5.—Scatter diagram of range vs. standard deviation for wind speed (15-min. sampling interval).

recording system provides a reasonably accurate description of actual air motions. Two systems were used, in Cincinnati and in Nashville, both installed at a height of 33 ft. above ground level. The Cincinnati site is in a relatively open area with buildings over 300 ft. away to the south and hills to the west. The Nashville site is on a grassy plot with 20-ft. trees nearby and 25-ft. buildings about 100 ft. to the south.

All of the data were collected between 0730 and 1915 LST under clear to scattered cloud conditions. A wide range of wind-speed conditions (fig. 1) was included in the data. Fast chart speed (6 in./min.) runs were made of the continuous recordings of wind direction and speed, and these chart records were reduced to 1-sec.-average chart readings. Standard deviations were computed from every reading, and from every 5th, 10th and 15th reading. These will hereinafter be referred to as 1-sec. average and 5-, and 10- and 15-sec. instantaneous readings, respectively. Also, standard deviations were computed from these 1-sec. readings averaged end-to-end over periods of 5, 10, and 15 sec. The sampling intervals for the computation of the standard deviations were 15, 30, and 60 min.

Scatter diagrams of range versus standard deviation were plotted (figs. 2–7). Since these plots appeared to show a linear relationship, simple linear regression and correlation analyses were performed to determine the relationships between the computed standard deviations and their respective ranges. Analyses were made for each location separately (tables 1 and 2) and for both locations combined (table 3). The regression equations between locations were then tested to determine whether the relationships were the same. The data from both locations were also divided into two groups, development data and test data, so that the regression equations could be developed and tested for generality of application with the 1-sec. standard deviation data as an example (table 4). The data were separated as evenly as possible into the two groups. All of the data from a given day were kept in

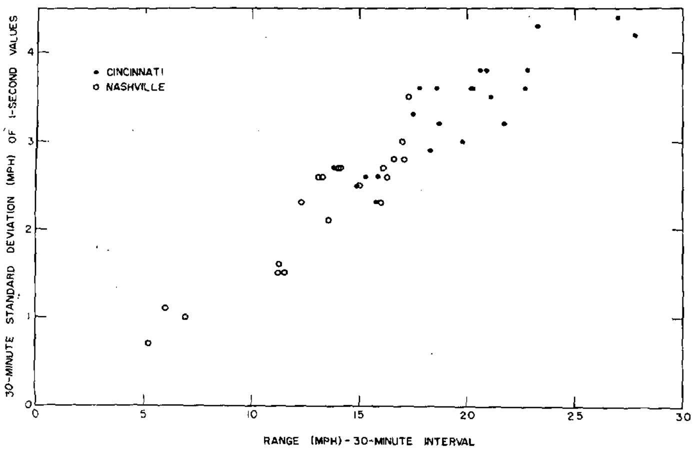

FIGURE 6.—Scatter diagram of range vs. standard deviation for wind speed (30-min. sampling interval).

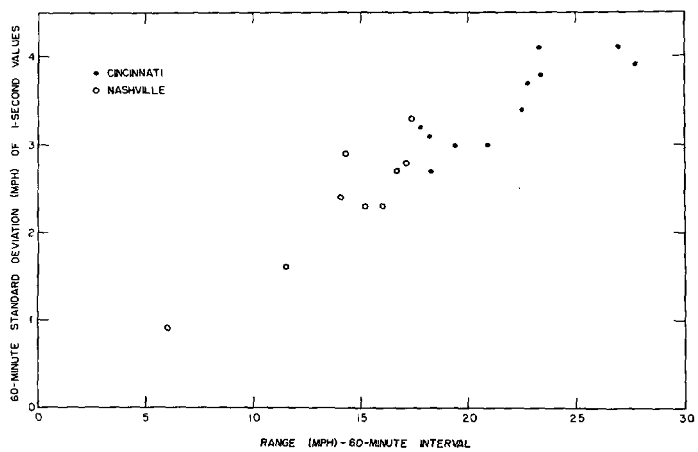

FIGURE 7.—Scatter diagram of range vs. standard deviation for wind speed (60-min. sampling interval).

one of the groups so that these groups would be as independent of each other as possible.

3. RESULTS AND DISCUSSION

The significant results are as follows:

A. Wind-Direction Relationships.—(1) The correlation decreases with increasing averaging period. (2) The correlation increases and the standard errors of estimating the standard deviation for both stations combined decrease with increasing sampling time. (3) The correlations are higher for Cincinnati data than for Nashville data. The regression constants were not found to be significantly different between the two sets of data, however. (4) The regression equations computed from the development data were found to be equally applicable to the test data, as is indicated by the consistently high correlation indices found for the test data applied to the regression equations of the development data.

B. Wind-Speed Relationships.—(1) The correlation generally decreases with increasing averaging period. (2) The correlation is essentially constant for all sampling intervals, and the standard error of estimating the standard deviation for both stations combined increases slightly with increasing sampling interval. (3) The correlations are slightly lower for Cincinnati data than for Nashville data; a possible exception is the 15-min. sampling period. The regression constants were found to be significantly different between locations, especially for the 30- and 60-min. sampling intervals. (4) The correlation index of test data decreases with increasing sampling interval.

For each wind parameter the results of the two different methods of testing the regression equations (i.e., by statistically testing the difference in regression constants for significance and by application of test data to regression

TABLE 1.—*Relationships between standard deviation and range for wind direction. (r is the correlation coefficient; a and b are the intercept and slope, respectively, of regression equation $\sigma=a-bR$; σ_{E1A} is the standard error of predicting $\sigma_{1\,avg.}$ from range; n is the number of observations.)*

Location	Reading Interval (sec.)	Sampling Time								
		15 minutes			30 minutes			60 minutes		
		r	*a*	*b*	*r*	*a*	*b*	*r*	*a*	*b*
Cincinnati	5 inst	0.89	−0.8	0.18	0.96	0.2	0.16	0.96	0.2	0.14
	10 inst	.89	−1.0	.19	.95	.0	.16	.96	−.1	.15
	15 inst	.85	−.4	.18	.96	−.3	.16	.97	−.4	.15
	1 avg	.90	−.6	.18	.95	.6	.15	.96	.6	.14
	5 avg	.90	−1.4	.18	.95	−.2	.15	.96	−.3	.14
	10 avg	.89	−2.2	.18	.95	−.9	.15	.96	−1.1	.14
	15 avg	.89	−2.8	.18	.95	−1.6	.16	.96	−1.8	.15
		$\sigma_{E1A}=\pm3.6°$ $n=44$			$\sigma_{E1A}=\pm2.3°$ $n=22$			$\sigma_{E1A}=\pm2.4°$ $n=11$		
Nashville	5 inst	0.67	5.8	0.13	0.81	2.2	0.14	0.89	−1.1	0.14
	10 inst	.64	6.9	.12	.80	2.5	.14	.89	−1.4	.14
	15 inst	.66	6.0	.13	.82	2.0	.14	.89	−1.3	.14
	1 avg	.68	6.8	.13	.79	4.3	.13	.87	1.0	.13
	5 avg	.64	4.3	.13	.77	0.7	.13	.86	−3.7	.14
	10 avg	.62	2.3	.13	.76	−1.7	.14	.86	−6.1	.14
	15 avg	.60	0.9	.13	.75	−3.3	.14	.86	−8.0	.15
		$\sigma_{E1A}=\pm6.7°$ $n=38$			$\sigma_{E1A}=\pm5.2°$ $n=18$			$\sigma_{E1A}=\pm4.2°$ $n=8$		

TABLE 2.—*Relationships between standard deviation and range for wind speed. (r is correlation coefficient; a and b are the intercept and slope, respectively, of regression equation $\sigma=a+bR$; n is the number of observations.)*

Location	Reading Interval (sec.)	Sampling Time								
		15 minutes			30 minutes			60 minutes		
		r	*a*	*b*	*r*	*a*	*b*	*r*	*a*	*b*
Cincinnati	5 inst	0.92	0.18	0.17	0.89	0.70	0.13	0.86	0.81	0.12
	10 inst	.93	.08	.18	.88	.53	.14	.86	.79	.12
	15 inst	.90	.13	.18	.83	.69	.14	.83	.68	.13
	1 avg	.93	.19	.17	.87	.57	.14	.85	.79	.12
	5 avg	.92	.12	.17	.87	.53	.14	.85	.82	.11
	10 avg	.90	.12	.16	.86	.60	.12	.85	.84	.10
	15 avg	.88	.13	.15	.85	.60	.12	.82	1.02	.09
		$n=44$			$n=22$			$n=11$		
Nashville	5 inst	0.89	0.0	0.18	0.93	−0.26	0.19	0.92	−0.25	0.18
	10 inst	.89	−.03	.18	.92	−.33	.20	.89	−.32	.19
	15 inst	.88	.06	.18	.92	−.17	.18	.92	−.29	.19
	1 avg	.89	−.01	.18	.92	−.26	.19	.91	−.26	.18
	5 avg	.88	.05	.17	.91	−.18	.17	.90	−.16	.17
	10 avg	.86	.05	.16	.89	−.08	.16	.91	−.16	.16
	15 avg	.84	.08	.15	.88	−.07	.15	.88	−.05	.15
		$n=41$			$n=20$			$n=9$		

TABLE 3.—*Relationships between standard deviation and range for wind direction and speed at both locations. (r is the correlation coefficient; a and b are the intercept and slope, respectively, of regression equation* $\pi = a + bR$*; n is the number of observations;* σ_E *is the standard error of prediction.)*

Parameter	Reading Interval (sec.)	Sampling Time											
		15 minutes				30 minutes				60 minutes			
		r	a	b	σ_E	r	a	b	σ_E	r	a	b	σ_E
Direction	5 inst	0.87	2.7	0.14		0.91	1.8	0.14		0.94	1.1	0.13	
	10 inst	.85	2.9	.14		.90	1.8	.14		.93	.9	.13	
	15 inst	.86	2.4	.15		.92	1.1	.15		.95	.2	.14	
	1 avg	.88	2.5	.15	±4.6°	.91	2.0	.14	±4.0°	.94	1.4	.13	±3.4°
	5 avg	.84	2.4	.14	±5.1°	.88	1.6	.14	±4.5°	.91	.7	.13	±4.1°
	10 avg	.81	2.0	.13	±5.4°	.85	1.1	.13	±4.9°	.89	.1	.13	±4.5°
	15 avg	.79	1.7	.13	±5.6°	.83	.7	.13	±5.2°	.88	.4	.12	±4.7°
		$n=82$				$n=40$				$n=19$			
Speed	5 inst	0.94	0.02	0.181		0.94	0.08	0.165		0.94	0.27	0.145	
	10 inst	.94	−.01	.182		.94	.02	.168		.92	.30	.143	
	15 inst	.93	.02	.181		.93	.10	.165		.93	.23	.148	
	1 avg	.94	.02	.181	±1.5	.94	.03	.168	±1.7	.93	.26	.146	±1.8
	5 avg	.93	.0	.171		.94	.03	.159		.93	.29	.136	
	10 avg	.92	.01	.163		.93	.01	.149		.94	.27	.131	
	15 avg	.91	.01	.157		.92	.09	.144		.93	.29	.125	
		$n=85$				$n=42$				$n=20$			

equations computed from development data) were consistent. The conclusions which can be drawn from these tests are that the wind-direction relationships are consistent while the wind-speed results are not.

Also, wind speed is suggested to have an influence on the accuracy of the predicted standard deviations of wind direction from the range. This is indicated by the higher correlations found when using the Cincinnati data, which generally represent higher wind speeds, as compared with the Nashville results, which represent lower wind speeds (fig. 1).

TABLE 4.—*Relationships between standard deviation and range-development data. (r is the correlation coefficient; a and b are the intercept and slope, respectively, of regression equation* $\pi = a + bR$*; n is the number of observations; 1A is correlation index of test data applied to regression equations from development data for* σ_{1A}*.)*

Parameter	Reading Interval (sec.)	Sampling Time								
		15 minutes			30 minutes			60 minutes		
		r	a	b	r	a	b	r	a	b
Direction	5 inst	0.86	2.5	0.15	0.90	1.9	0.15	0.94	1.9	0.13
	10 inst	.85	2.5	.14	.89	1.8	.15	.93	1.5	.13
	15 inst	.83	2.8	.15	.90	1.6	.15	.94	1.4	.14
	1 avg	.87	2.5	.15	.90	2.5	.14	.93	2.6	.13
	5 avg	.85	1.3	.15	.88	1.0	.14	.92	.9	.13
	10 avg	.83	.6	.15	.87	.0	.14	.90	.0	.13
	15 avg	.81	−.1	.15	.85	−.8	.14	.89	−.8	.13
		$1A=0.90$ $n=54$			$1A=0.93$ $n=26$			$1A=0.94$ $n=12$		
Speed	5 inst	0.94	0.06	0.182	0.96	−0.03	0.171	0.95	0.09	0.154
	10 inst	.94	−.01	.183	.95	−.10	.175	.95	.07	.154
	15 inst	.93	−.03	.186	.94	−.03	.172	.95	−.01	.161
	1 avg	.94	.01	.182	.95	−.06	.172	.95	.05	.156
	5 avg	.93	.02	.171	.94	−.03	.162	.94	.13	.144
	10 avg	.92	.02	.164	.93	.05	.151	.95	.15	.137
	15 avg	.91	.02	.157	.93	.05	.145	.94	.15	.133
		$1A=0.91$ $n=57$			$1A=0.84$ $n=28$			$1A=0.76$ $n=13$		

4. COMPARISON OF THE RESULTS WITH THOSE FROM OTHER INVESTIGATIONS

Several pilot studies have been made to describe the relationships between range and standard deviation [3, 4, 5, 6]. The results are summarized (table 5) so that these findings can be compared with the results of this more comprehensive treatment of the subject discussed herein (i.e., Cincinnati and Nashville). Most of the other investigations obtained the relationships by using a different method, which consisted of computing the mean and standard deviation of the ratio of the range to the standard deviation of wind-direction fluctuations. To facilitate a comparison of the other findings with the findings from Cincinnati and Nashville, the means and standard deviation of R/σ were computed for averaging intervals of 1 and 15 sec.

All of the mean R/σ values seem to compare favorably among the stations except for the Middletown data. The results from Oak Ridge, Shippingport, and Idaho Falls are in extremely good agreement. The average ratios for the Cincinnati and Nashville data were lower when 1-sec. average readings were used and higher when 15-sec. averages were used. These average ratios for different time-averaged chart readings represent the extreme range of mean R/σ values that were encountered in the study. Generally these ratios are of the same magnitude as those from the other three locations that agreed so closely.

5. SUMMARY AND CONCLUSIONS

The wind-direction range shows promise for standard use as a representation of the standard deviation of wind-

TABLE 5.—*Summary of results of various investigations of relationships between standard deviation and range for wind direction. (Sampling times: Oak Ridge, Middletown, Shippingport, Cincinnati, and Nashville—15 min.; Idaho Falls—5 to 24 min.)*

Location	Instrument and Height	Chart Reading Interval	(R/σ)	Standard Deviation of R/σ	Number of Observations
Oak Ridge, Tenn. [3]	Instruments Corp. Anemographs at 18, 54, and 154 ft. levels.	10-sec. instantaneous	6.8	±1.50	14
Middletown, Conn. [4]	Bendix-Friez Aerovane at 200 ft. level	10-sec. instantaneous	5.0	±0.15	42
Shippingport, Pa. [5]	Instruments Corp. Anemographs at 40 and 400 ft. levels	5-sec. instantaneous	6.6	±1.48	14
Idaho Falls, Idaho [6]	Bendix-Friez Aerovanes at 20 and 250 ft. levels	7½ sec.-instantaneous	6.6	±1.51	31
Cincinnati, Ohio	Beckman & Whitley K100A Wind system at 33 ft. level	1-sec. average	5.9	±0.95	44
		15-sec. average	6.9	±1.53	44
Nashville, Tenn	Beckman & Whitley K100A Wind system at 33 ft. level	1-sec. average	6.3	±1.17	38
		15-sec. average	8.6	±2.09	38

direction fluctuations. The analysis shows that the standard errors for all sampling intervals and averaging times are less than 6°. The longer the sampling interval (up to 1 hr.), the shorter the averaging time, and the higher the wind speed, the more reliable is the range as a predictor of the standard deviations.

Wind-speed range is not a good predictor of the standard deviation of wind speed. The independent data do not verify the development data results, the relationships are not comparable between the two locations, and there do not seem to be any readily explainable systematic variations in the relationships.

These conclusions should be applicable to many wind systems, but when the response characteristics of other wind systems differ significantly from those of the Beckman and Whitley wind system, an empirical determination of the regression constants may be required.

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