THE NASHVILLE DAILY AIR POLLUTION FORECAST

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ABSTRACT

During the period of the Nashville Community Air Pollution Study, the Weather Bureau at Nashville, Tenn., forecasted air pollution to be one of three levels for the following day. The forecast method was most reliable during the winter season when pollution ranges were high. Discrimination of air pollution levels can undoubtedly be improved through experience and further studies, and the method is general enough to be used at other locales.

1. INTRODUCTION

An air pollution forecast was provided daily for the City of Nashville, Tenn., from January 23, 1959 to August 1, 1959. The forecasts, which were issued by the U.S. Weather Bureau at Nashville, were for high, low, and little or practically no pollution for the following day. The forecast method was intentionally made simple so that specialized experience would not be required by the forecasters and also took into account the type of routine forecasts which could be made. The criteria selected were to some extent based on past studies and experience of meteorologists at the Weather Bureau Research Station, Cincinnati, Ohio. This was probably the first time that a Weather Bureau Office made daily quantitative forecasts of air pollution levels.

2. METHOD

The forecast pollution level (i.e., high, low, little or none) was objectively determined from forecast values of a stability index and surface wind speed. Meteorologists at Berry Field, approximately 8 miles southeast of Nashville proper, could make these forecasts without prior knowledge or experience of air pollution meteorology. The low-level stability index was obtained by algebraically subtracting the forecast surface temperature for 0600 CST tomorrow from the forecast 900-mb. temperature for the same time. This index value, together with the forecast of weather the 0600 CST surface wind speed would be greater or less than 7 kt., was used to forecast the intensity of the air pollution as follows:

Forecast stability index (SI) and surface wind speed (WS) for 0600 CST	*Forecast air pollution level*
SI>0 and WS<7 kt.	High pollution
SI<0 and WS<7 kt. or SI>0 and WS>7 kt.	Low pollution
SI<0 and WS>7 kt.	Little or no pollution

The forecast was made at approximately 1500 CST and was valid for the next morning. Wind speeds were forecast using prognostic positions of pressure systems and prognostic pressure gradient. The 900-mb. temperature forecast was based on 850-mb. up-wind radiosonde observation information, and wind patterns and temperature advection as indicated on the 850-mb. chart. The latter was adjusted to the 900-mb. level, keeping in mind lifting or subsidence, as indicated. Surface temperatures were forecast using the 850-mb. temperature forecast and adjusting it to the surface with due allowance for forecast cloud cover or the lack of it, as an indication of radiational cooling and with allowance for wind speed as an indication of vertical mixing at low levels.

3. RESULTS

For each day, the air pollution at Nashville is described by each of the following:

A. Forecast Pollution Level, FPL:—The level of pollution forecast by the Weather Bureau at Nashville using the previously described method.

B. Pollution Level From the Observed Meteorological Criteria, PL(OC):—The stability index and wind speed which actually occurred determined this level in the same way that the forecast elements determined the FPL. In other words, the PL(OC) and the FPL would be identical if the meteorological elements were correctly forecast.

C. Measured Pollution Level, MPL:—In conjunction with the Nashville Community Air Pollution Study, there were 32 sampling stations uniformly spaced over the city from which continuous measurements of sulfur dioxide (pphm) and soiling index (Coh/1000 linear ft.) were available. Coh values determine by filter paper method, are an approximation of the soiling properties of the atmosphere. At seven of these stations, which were also uniformly spaced, more extensive sampling was done, and continuous 24-hour total particulate concentrations

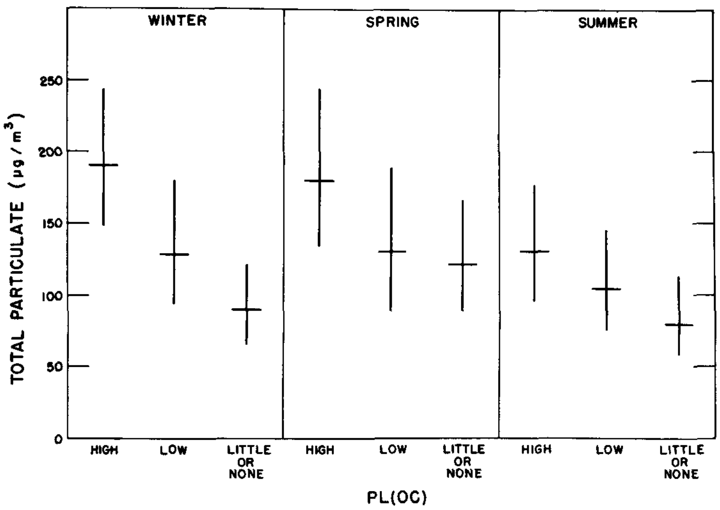

FIGURE 1.—Total particulate compared to pollution level indicated by observed meteorological criteria, PL(OC), separated by seasons and air quality group. Horizontal line is geometric mean, vertical line gives limits of one standard deviation.

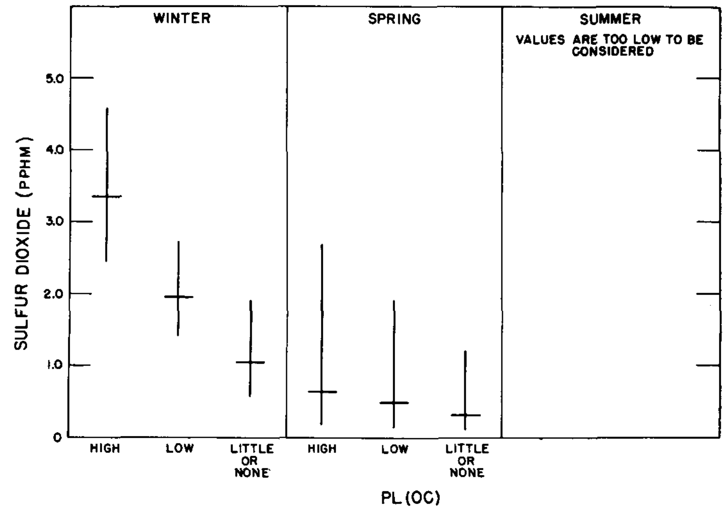

FIGURE 2.—SO_2 measurement compared to PL(OC), separated into seasons and air quality groups.

(μg./m.³) were measured using high-volume air samplers. Daily means for each of the three air quality measurements were computed and used as a basis for determining the MPL's.

Comparisons of the three descriptions of "pollution level" were thus possible. A measure of ability to forecast the meteorological criteria was obtained by a comparison of the FPL and PL(OC) for each day a forecast was made. The effectiveness of the meteorological criteria for indicating pollution level was evaluated by a comparison of the PL(OC) and the MPL for each day. Finally, the FPL and the MPL were compared to determine the merit of the program. The results of the three comparisons are discussed in the following subsections.

EVALUATION OF FORECAST ABILITY: FPL VS. PL(OC)

Table 1, a contingency table of FPL vs. PL(OC), reveals that the forecasts were right more often than wrong with the exception of the "little or none" forecasts. A statistical test (χ^2) indicates that such a distribution has less than 0.1 percent probability of occurring by chance. For the entire period 45 percent of the forecasts were meteorologically correct. If the period is divided into seasons (table 2), then 53 percent of the forecasts were correct in winter, 27 percent in the spring, and 53 percent in the summer. The low springtime figure probably reflects the erratic weather conditions during this season. For the purpose of the study, winter was presumed to be from January 23 to March 15, spring from March 16 to May 15, and summer from May 16 to August 1. These dates were primarily determined from heating degree days although an attempt was made to keep the number of days in each season somewhat equal.

TABLE 1.—*Frequency of forecast air quality level (FPL) classified according to the air quality level from the observed meteorological variables, PL(OC).*

FPL	PL(OC)			
	High	Low	Little or none	Total
High	21	14	2	37
Low	12	24	13	49
Little or none	2	21	7	30
Total	35	59	22	116

Calculated $\chi^2=23.3$
From tables χ^2 (.999) = 18.5

EVALUATION OF EFFECTIVENESS OF METEOROLOGICAL CRITERIA: PL(OC) VS. MPL

Because of differences in range and distribution of air quality data from one season to the next, comparisons were made season by season. Each group of air quality

TABLE 2.—*FPL vs. PL(OC) by seasons*

FPL	PL(OC)			Percent correct
	High	Low	Little or none	
	Winter			
High	10	1	1	82.4
Low	4	3	5	25.0
Little or none	0	3	3	50.0
Total				53.3
	Spring			
High	4	4	1	44.4
Low	5	3	7	20.0
Little or none	2	8	3	23.1
Total				27.0
	Summer			
High	7	9	0	43.8
Low	3	18	1	81.8
Little or none	0	10	1	9.6
Total				53.1

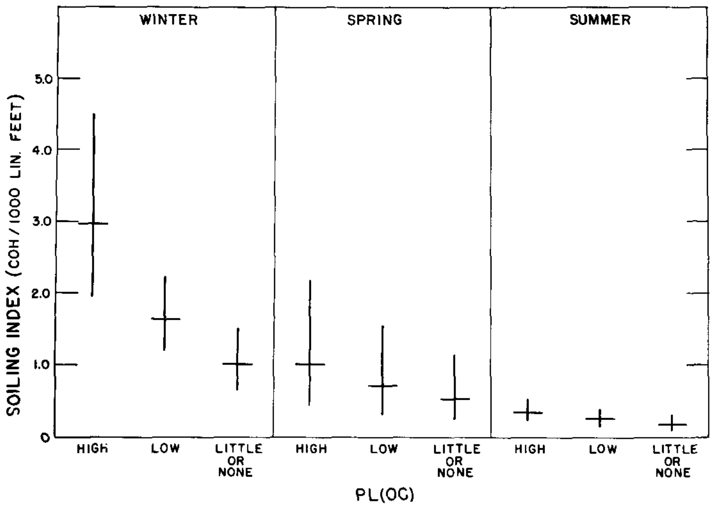

FIGURE 3.—Soiling index values compared to PL(OC), separated into seasons and air quality groups.

data was tested for normality of distribution by season, and it was found that all air quality data for all seasons were distributed in the logarithmic normal. For each season the three types of data, i.e., soiling index, sulfur dioxide, and total particulate, were separated according to the PL(OC), giving three different groups of data for each air quality parameter. The geometric means and standard geometric deviations from the groups thus obtained were plotted on linear graph paper. In figures 1, 2, and 3 the horizontal line is the geometric mean and the vertical line represents one standard geometric deviation on either side of the geometric mean (i.e., approximately 68 percent of the data are between these limits). Each parameter and season should be considered separately, but the one thing that all have in common is that the means are in the proper order. That is, the data selected on the days which were classified as high pollution according to the observed criteria had higher means than those of the low pollution days, and so on. The figures also indicate very definite seasonal differences which vary somewhat according to the type of measurement. Coh and SO_2 values are high with a wide range during the winter months, whereas the summer values are too low to be considered.

A statistical test, the analysis of variance method, was employed to determine if the means differed significantly. The test indicates very significant differences among the means during the winter season for all three air quality parameters. Apparently the method effectively divides the data into three levels during this season. The SO_2 values during the spring and summer seasons are generally too low to be considered. Total particulate as well as soiling index means during the spring season differ significantly, but an inspection of the figures reveals that good discrimination exists between only two levels. For the summer season there are significant differences among the total particulate means, but not as marked as during the winter season. Significant differences among the soiling index means are indicated, but the range of the data is low. To summarize the three figures, it appears that the criteria are valid indicators of three levels of total particulate, soiling index, and sulfur dioxide during the winter season. During the spring season the criteria significantly indicate two levels of total particulate and soiling index, while during the summer season they significantly indicate three levels of total particulate.

A different approach was also used to test the effectiveness of the meteorological criteria. The frequency distributions were divided into thirds, and each day's data were designated as being high, low, or little or none,

TABLE 3.—*PL(OC) vs. MPL by seasons*

PL(OC)	MPL											
	μg./m.³				SO_2				Coh/1000 linear ft.			
	High	Low	Little or none	Percent correct	High	Low	Little or none	Percent correct	High	Low	Little or none	Percent correct
	Winter											
High	14	9	0	60.8	17	6	0	73.9	17	5	1	73.9
Low	3	5	3	45.4	1	7	3	63.6	0	8	3	72.7
Little or none	0	4	14	77 8	0	4	14	77.8	0	5	13	72 2
Total				63.5				73.1				73.1
	Spring											
High	11	6	2	57.9	8	8	3	42.1	9	6	4	47.3
Low	7	6	8	28.6	9	7	5	33.3	7	9	5	42.9
Little or none	2	9	10	47.6	4	7	10	47.6	4	6	11	52.4
Total				44.3				41.0				47.6
	Summer											
High	9	4	3	56.2	Data range too low				Data range too low			
Low	17	20	21	34.8								
Little or none	0	1	2	66.6								
Total				40.3								

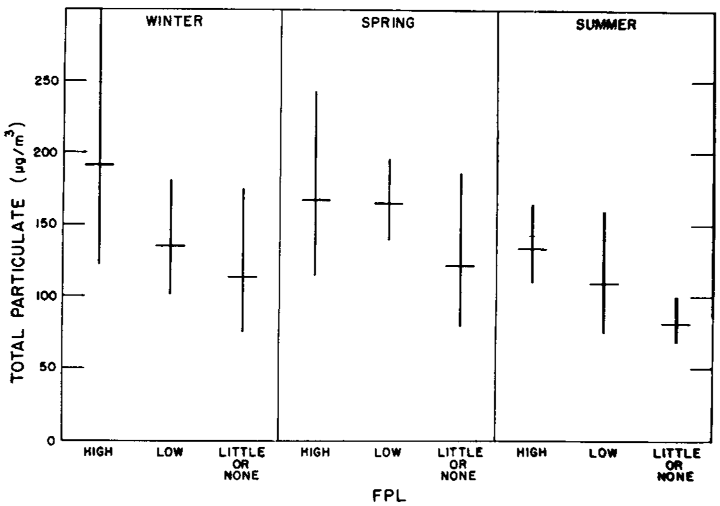

Figure 4.—Total particulate values compared to forecast pollution level (FPL). Horizontal line gives geometric mean and vertical line shows limits of one standard deviation.

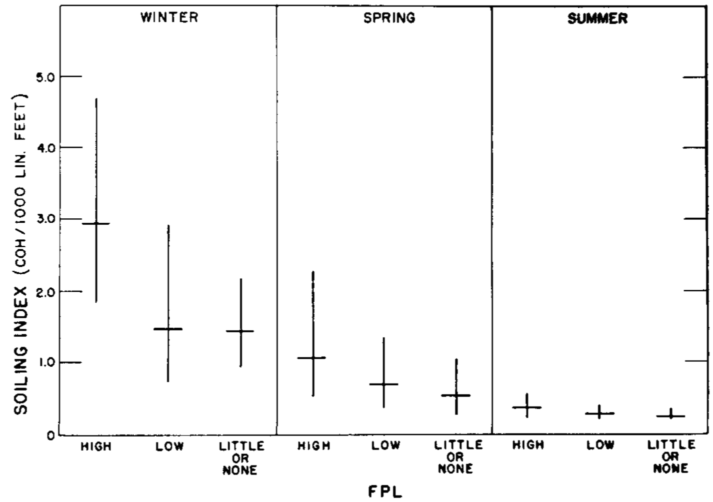

Figure 6.—Soiling index values compared to FPL.

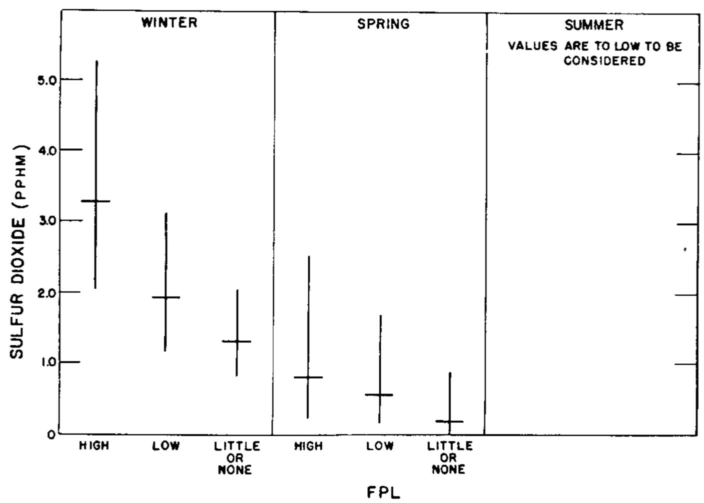

Figure 5.—SO_2 values compared to FPL.

depending whether they fell in the upper, middle, or lower third of the frequency distribution. Contingency tables (table 3) of these values plotted opposite the PL(OC) for each corresponding day were constructed, and percentages of agreement were computed. As expected, these figures are highest during the winter season when weather conditions are sharply defined and pollution ranges are high. With an overall winter average of 70 percent, the PL(OC)'s agree with the air quality level, as determined from the frequency distribution, approximately 7 out of 10 times. The averages during the other two seasons are significantly lower with the highest percentages of agreement for the high pollution and little or no pollution levels. The criteria effectively indicate three levels of pollution during the winter season and only two levels during the spring and summer seasons.

Table 4.—*FPL vs. MPL by seasons*

FPL	MPL											
	µ g./m.³				SO_2				Coh/1000 linear ft.			
	High	Low	Little or none	Percent correct	High	Low	Little or none	Percent correct	High	Low	Little or none	Percent correct
WINTER												
High	8	3	1	66.6	10	1	1	83.3	8	3	1	66.6
Low	3	6	3	50.0	3	5	4	41.7	3	3	6	25.0
Little or none	1	1	4	66.6	0	2	4	66.6	0	3	3	50.0
Total				60.0				63.3				46.7
SPRING												
High	6	1	2	66.6	4	4	1	44.4	3	5	1	33.3
Low	6	9	0	60.0	6	5	4	33.3	6	4	5	26.7
Little or none	3	3	7	53.8	2	5	6	46.2	3	3	7	53.8
Total				59.5				40.6				37.8
SUMMER												
High	9	6	1	56.2	Data range too low				Data range too low			
Low	8	8	6	36.3								
Little or none	0	4	7	63.6								
Total				49.0								

EVALUATION OF PROGRAM: FPL vs. MPL

Similar methods were used for the evaluation of the forecasts in terms of the measured pollution level. Here again, the data from the air quality measurements were separated first by season and then according to FPL. The geometric means and standard geometric deviations from the distributions thus obtained were plotted (figs. 4, 5, and 6) and compared. Again it is noticed that the means for all seasons are in the proper order. The forecasts divide the total particulate and sulfur dioxide data into three significantly different levels during the winter season, while the soiling index data are divided into only two distinguishable levels. During the spring season the SO_2 values are again too low to show discrimination and there is only recognizable discrimination between two levels of soiling index and total particulate. Soiling index and SO_2 data are too low to be considered during the summer season. Three significant levels of total particulate are, however, indicated, although the associated large standard deviations indicate that the discrimination is poor.

Table 4 is similar to table 3 except that the FPL is used instead of the PL(OC). The period of highest forecast verification occurred during the winter season with approximately 6 out of 10 forecast pollution levels in agreement with the air quality levels as determined from the frequency distributions. The percentages, however, do indicate that the winter forecasts are more accurate for the highest and lowest levels as compared to the middle level. During the spring and summer seasons approximately half of the forecast levels agree with the associated total particulate levels, and the percentages indicate a greater agreement for the highest and lowest levels during the summer season. SO_2 and soiling index percentages are somewhat lower during the warmer seasons because of the low range of the data. This is a consequence of the increased relative importance of ordinarily random variations of source strength, wind direction, local currents, and other meteorological variables.

4. CONCLUSIONS AND RECOMMENDATIONS

The tested meteorological criteria are shown to be good indicators of three air pollution levels during the winter season, but can discriminate between only two levels during the spring and summer. Of the three methods of measuring air quality, only total particulate maintains high enough values to be considered as a year-round air pollution indicator. Sulfur dioxide and soiling index measurements are very low during the summer season and considered alone imply the absence of community air pollution problems during that season.

While the results are not outstanding, it is believed that forecasting skill would improve with further experience. More elaborate meteorological criteria could have been used which might have given better discrimination among the levels, but such a method would lack the desired forthright manner of the one used. Other straightforward criteria could be devised and tested using the same air quality data and associated meteorological conditions. Among the various weather parameters which could be investigated are average wind speed, wind direction, and the presence or absence of an upper inversion. An additional influential parameter could be the duration of low wind speeds and/or interruption of these low speeds by periods of significant wind speed.

The primary value of this program has been to demonstrate that objective forecast methods can be used by local Weather Bureau offices to forecast daily air pollution levels during those seasons of the year when air pollution concentrations are high and troublesome. The forecast method is general enough that similar methods could be applied to other cities after due consideration of climatology, topography, industrial locations, and the individual needs of the organizations which are using the forecasts.

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