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ON THE VARIABILITY OF THE WIND SPEED EXPONENT IN URBAN AIR POLLUTION MODELS

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Abstract—Following analyses by Benarie of air quality data obtained in Rouen and Strasbourg, France, the paper quantifies the seasonal variability in the exponent of wind speed for an air pollution model developed for TSP, CO and β-scattering in Canberra, Australia.

Key word index: Particulates, carbon monoxide, β-scattering, box model, seasonal variability, wind speed.

INTRODUCTION

Benarie (1978, 1980a, b) has provided experimental evidence based on regression analysis that the assumption of simple inverse proportionality between pollutant concentration and wind speed u is not always valid for urban areas. In particular, Benarie (1980b) used a generalized box model of the form

$$\chi = CQ\, u^b \qquad (1)$$

to investigate seasonal variations in the wind speed exponent b for 24-h SO_2 and black smoke (reflectivity) data. For both pollutants, he used data sets recorded over 3 yr at three sites from Rouen and recorded over 2 yr at five sites in Strasbourg, France. In both cities the spatial average of the exponent for SO_2 in summer was not significantly different from zero whereas during the winter heating season the spatial average of the exponent was -0.25. For black smoke the summer exponent was near -0.2 and in winter it varied from -0.3 to -0.5. The model described by Equation (1) is commonly employed assuming an exponent of -1 (e.g. Hanna, 1971).

It is argued by Benarie (1980b) that in real urban situations the exponent will be between 0 and -1. The value of the exponent is considered to depend on the extent of the urban area, the siting of the air quality monitors within it and the intensity of vertical mixing relative to advection. The argument is based on consideration of idealized situations. At one extreme, an infinite, relatively sourceless plane requires the wind speed exponent to be -1 as in the usual box model. At the other extreme, a constant ground concentration from uniform emissions over a sufficiently extended plane will not be strongly affected by wind speed so that the exponent tends towards zero.

In this paper we investigate the seasonal variability in the wind speed exponent of model (1) for 24-h average total suspended particulates (TSP), β-scattering and CO data collected in Canberra, Australia.

THE DATA SET AND AIRSHED CHARACTERISTICS

TSP data have been collected in Canberra since 1980. The monitoring sites are in the major town centres of Civic and Woden, and, since 1981, in Belconnen and Kambah. TSP concentrations are recorded at each site and are based on 24-h samples collected every 6 days. β-Scattering and CO measurements are also taken but are available at present only for the year 1982. β-Scattering and CO concentrations as 1-h averages are measured at the Civic site only.

Meteorological data are collected at two monitoring sites; one near the Civic site and the other at the airport. Wind speed measurements at the sites differ greatly but the Civic site is considered to be more representative of the wind speeds affecting the level of air pollution concentrations.

Sources of particulate matter in ACT can broadly be divided into two categories: anthropogenic and natural. As Canberra has only light industry, the two most significant sources of airborne emissions are motor vehicles and wood-fire burning both for heating and cooking. The major natural source of particles is non-C matter. For C matter from wood fires and non-C matter, seasonal variation is significant. Traffic levels and hence the associated C matter emissions vary little seasonally. Taylor *et al.* (1987) estimate that wood fires contribute nearly 50% of the non-background particulate pollution in Canberra's commercial areas and about 80% in suburban areas during the winter months. In the summer months a much higher non-C and organic matter component will be contributed because of the drier conditions.

The next section will attempt to quantify the broad influence of wind speed on TSP, β-scattering and CO as well as the C and non-C components of TSP. The variability of the influence of wind speed between seasons is significant. The winter season is taken to cover the months from April to September inclusive and the summer season the remaining months.

METHOD AND RESULTS

Time-wise regressions were applied first to the logarithmic form of the model (1), viz.

$$\ln \chi = a + b \ln u, \qquad (2)$$

where a denotes the natural logarithm of the atmospheric stability term C times the emission strength Q. These were performed for the annual summer and winter periods at individual sites. For TSP, the data were also amalgamated to obtain both a seasonal spatial average across the four monitoring sites in each year and a seasonal time average over the years at each site.

The results of the annual analyses are shown in Table 1 for TSP and in Table 2 for the C and non-C components of TSP, for β-scattering and CO. They largely corroborate the findings of Benarie. The wind speed exponent in Table 1, for example, varies from -0.16 to -0.63 in winter, depending on the site and the year. In summer, the associated t-values indicate that the exponent is not estimated as being negative with any reasonable statistical significance. Indeed, the exponent generally seems to be positive in summer. Histograms of concentration against wind speed categories of 1 m s^{-1} width confirm the strength of the inverse relationship in winter and the weakness of it in summer. Figures 1–4 for the Civic site in 1984 and 1981 are typical results. Indeed, the inverse relationship holds for all sites and all years in winter. The associated t-values corroborate this, as do the associated plots (not shown here) which are of similar behaviour to those of Figs 1 and 3. Conversely, for summer the t-values and the corresponding plots confirm that no inverse relationship can be assumed.

The estimate of the exponent b is reasonably constant from year to year in winter at individual sites. Except for the one odd result at Woden in 1982, at individual sites the variation in the mean value of the exponent in a given year is within 1 SEM in any other year.

Observation of Fig. 2 and the corresponding plots for the other sites suggests that the TSP concentration in summer does not decrease and perhaps increases with wind speed. For β-scattering and CO the seasonal variation is similar but the estimated exponent remains negative in summer, as shown in Table 2. This is a situation we might expect since summer is a much drier season and in the case of TSP, wind may import dust as well as re-entrain it. Also, TSP is a measure of total particle mass. As wind speed increases, larger particles may be suspended in the atmosphere. A few large particles would have a significant effect on TSP concentrations.

It can be shown also that both the C and non-C components exhibit an inverse relationship with wind speed in winter but not in summer. Taylor *et al.* (1987) have undertaken an elemental analysis of all TSP samples from the Civic site in 1981. Figures 5 and 6 show the contribution to TSP from C sources with

Table 1. Estimated wind speed exponent b and k $(= CQ)$ values, and average $\bar{\chi}$ of measured values ($\mu g\ m^{-3}$) for Canberra TSP

Site	Season	1981 b	1981 k	1981 $\bar{\chi}$	1982 b	1982 k	1982 $\bar{\chi}$	1983 b	1983 k	1983 $\bar{\chi}$	1984 b	1984 k	1984 $\bar{\chi}$	1981–1984 b	1981–1984 k	1981–1984 $\bar{\chi}$
Civic	Winter	−0.44	99.48	92	−0.31	90.92	87	−0.40	66.69	70	−0.47	73.70	68	−0.37	79.04	78
	Summer	0.19	62.80	77	0.08	67.35	78	0.33	68.03	100	0.00	41.26	53	0.18	57.97	78
Woden	Winter	−0.37	55.70	51	−0.16	68.72	72	−0.24	62.80	65	−0.26	70.11	68	−0.28	64.72	64
	Summer	0.17	39.65	50	0.20	43.82	56	0.36	57.40	81	0.25	33.45	50	0.23	43.38	60
Belconnen	Winter	—	—	—	−0.41	38.47	37	−0.37	31.50	32	−0.63	33.12	32	−0.48	33.78	33
	Summer	—	—	—	0.19	36.23	49	0.51	38.47	67	0.06	21.12	29	0.25	30.27	49
Kambah	Winter	—	—	—	−0.34	41.68	42	−0.40	31.19	35	−0.58	35.87	40	−0.40	36.97	40
	Summer	—	—	—	0.27	33.78	46	0.38	31.82	54	−0.01	19.30	26	0.30	26.84	42
Spatial average	Winter	−0.37	70.81	70	−0.28	55.15	59	−0.31	47.47	53	−0.44	50.40	53	−0.32	49.90	57
	Summer	0.19	50.91	64	0.17	45.15	58	0.42	46.53	76	0.08	27.39	40	0.25	40.04	60

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