Analysis of SO 2 pollution in the South Durban Industrial Basin

Roseanne Diab, Arnold Prause, Hassan Bencherif

Analysis of SO_2 pollution in the South Durban Industrial Basin

Roseanne Diab[a*], Arnold Prause[b] and Hassan Bencherif[c]

THE SOUTH DURBAN INDUSTRIAL BASIN (SDIB) is known for its poor air quality. Sulphur dioxide (SO_2) is a key pollutant and is monitored at four locations within the SDIB. This paper reports geographical variations in SO_2 concentrations over time and discusses the relationship between the pollutant and meteorological variables. Spectral analysis showed that the dominant feature of the data was the diurnal cycle, which was particularly well developed in winter at the two stations closest to the industrial sources. Relatively high SO_2 values occurred in association with low wind speeds, decreasing as wind speed rose to reach a critical threshold ranging between 3.5 and 4.5 m s^{-1}, after which the trend was reversed. The pollution pattern was attributed to stack down-drafting in the presence of strong southwesterly winds. Analysis of high-SO_2 events in conjunction with wind direction revealed that most episodes were linked to sources within the SDIB.

Introduction

The problem of air pollution in the South Durban Industrial Basin (SDIB) has a long history, which has recently been documented.[1] The juxtaposition of heavy processing industry, high traffic transport routes and residential areas, located within a basin characterized by topographic channelling of pollution and poor atmospheric dispersion,[2] has given rise to a severe air quality problem. SO_2 is recognized as a key pollutant in the area and was highlighted as a problem in the Air Sector section of the State of the Environment report for Durban.[3] It also formed a major focus of the Strategic Environmental Assessment for the SDIB,[4] and is one of the few atmospheric pollutants for which there are substantial historical records.[5] A study[6] ranking all South African air pollution monitoring stations, of which there are more than 100 across the country, according to their 5-year SO_2 averages in winter, revealed that five of the 10 stations nationally with the worst pollution records are located in Durban, of which four are in the SDIB.

Various management practices have been introduced to address the poor air quality and are described by Diab and Scott.[1] One of these is the South Durban Sulphur Dioxide Management System (SDSDMS), which aims to manage air pollution in the SDIB such that air quality is maintained at an acceptable level. One of the thrusts of the SDSDMS has been to establish a network of four monitoring stations in the industrial basin. Data from the four stations form the basis of weekly, monthly and annual air pollution reports compiled by the company, Ecoserv, which is responsible for the monitoring and reporting system. Useful insights into the occurrence of exceedences, defined as cases when ambient air pollution levels exceed recognized standards or guideline levels established by regulatory authorities, have been gained by analysis of meteorological conditions and possible industrial conditions at the time of an exceedence.

We report here the key features of SO_2 variations in time and space over the SDIB and discuss, in particular, the role of meteorology in the occurrence of high-SO_2 events.

Data and methods

Averaged hourly SO_2 data from the four monitoring stations (AECI, Athlone, Southern Works and Wentworth), the locations of which are shown in Fig. 1, were analysed for the period 1997–99. The concentrations were measured by an Advanced Pollution Instrument (API) 100A analyser at Wentworth, Monitor Lab analysers at Southern Works and AECI, and a Dasibi 4108 analyser at Athlone. Weekly span and zero checks were performed on all the analysers and each quarter the equipment was calibrated by accredited agents to international standards. A span drift of ±15% was tolerated as well as –10 ppb zero drift (Q. Hurt, Ecoserv, pers. comm., 1998). The Southern Works station moved to a new location about 500 m away in April 1998.[7] For the purposes of this study, however, the data have been treated as a single series.

Data quality checks were performed and all negative readings were eliminated. Some data gaps due to power or instrument failures were present. The percentages of available data were 69, 80, 85 and 88% at AECI, Athlone, Southern Works and Wentworth, respectively. No adjustments or interpolations were made.

Hourly averaged surface meteorological data (wind speed and direction and pressure) for the weather station at Durban International Airport, which is located within the SDIB (Fig. 1), were obtained from the South African Weather Service.

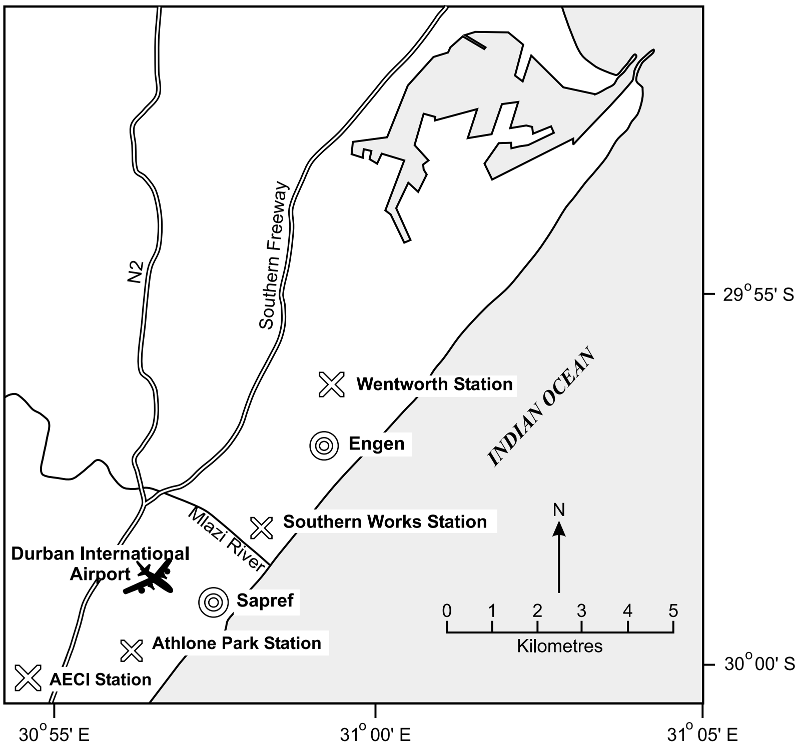

Fig. 1. Map of the South Durban Industrial Basin, showing the location of the four SO_2 monitoring stations.

[a]School of Life and Environmental Sciences, University of Natal, Durban 4041, South Africa.
[b]School of Pure and Applied Physics, University of Natal, Durban.
[c]Department of Physics, University of Réunion, Réunion.
*Author for correspondence. E-mail: diab@nu.ac.za

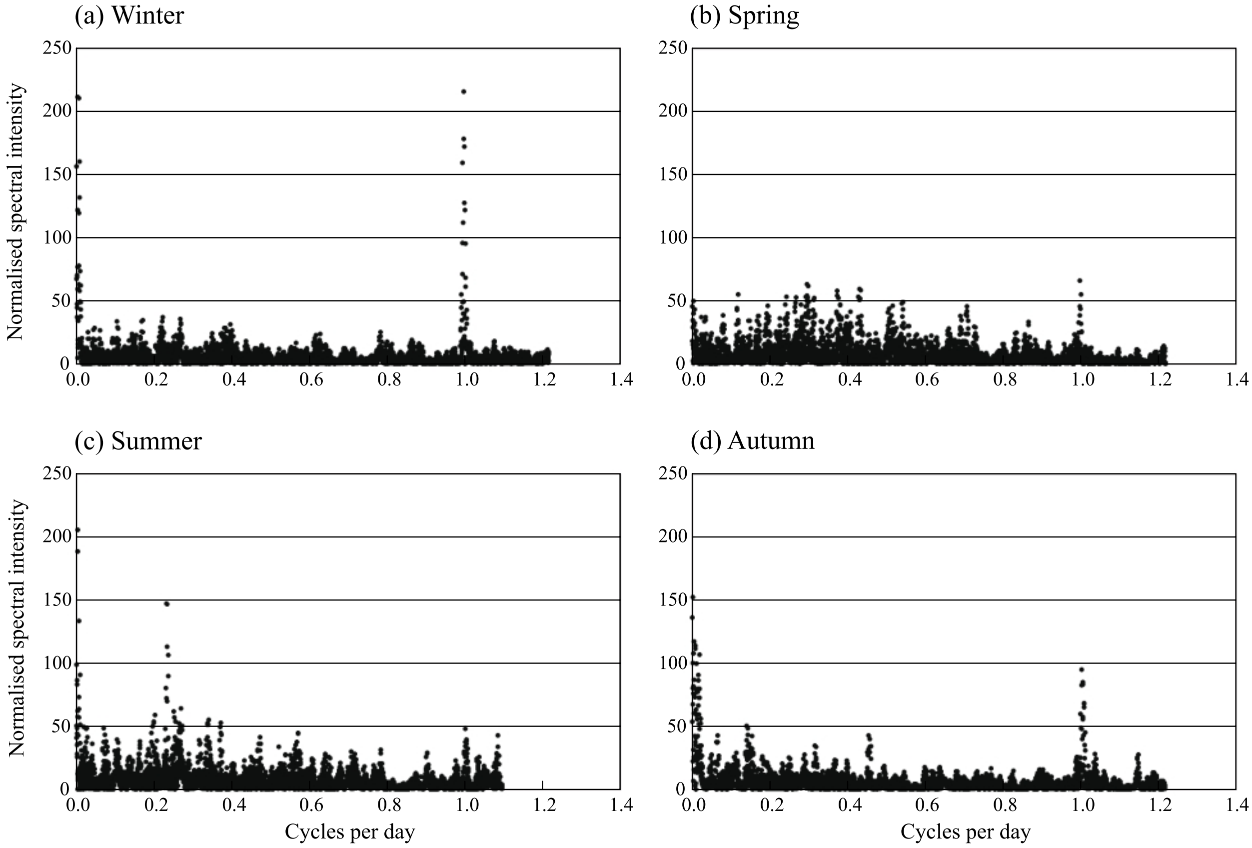

Fig. 2. Results of the seasonal spectral analyses at Wentworth. Winter is defined as June–August, spring as September–November, summer as December–February, and autumn as March–May.

Spectral analysis was performed using Lomb's periodogram method, which is based on the fitting of sine and cosine curves to a given data set, and has an advantage over Fourier analysis in that it is suited to time series where there are data gaps. Details of the method are given by Press *et al.*[8] Spectral analyses were conducted for each station for the entire 3-year period and also as a function of season; in total, 20 spectra were obtained. Only periods greater than 24 hours were considered in the analysis.

Results

Spectral analysis

Spectral analysis for the four stations over the 3-year study period revealed that the dominant and the only significant feature was the diurnal cycle, which was present at three of the stations, but only very weakly developed at Athlone. The diurnal cycle in SO_2 was particularly strong in winter and autumn at Wentworth (Fig. 2), in winter at Southern Works and in winter, autumn and spring at AECI (latter two stations not shown). Clearly, the marked diurnal change in atmospheric stability that characterizes the winter and autumn seasons accounted for the corresponding peak in the SO_2 spectral analysis.

There was another peak at 0.26 (equivalent to 3.9 days) at Wentworth, which was most clearly evident in the summer months (Fig. 2). This peak is possibly representative of synoptic scale forcing as it corresponds fairly closely to the periods detected by Preston-Whyte and Tyson[9] in their analysis of pressure oscillations along the South African coast. They observed periods of 3 and 6 days. The peak was also evident to a lesser extent at Athlone, AECI and Southern Works in summer (not shown).

At Athlone, the most prominent peak for the period as a whole was 0.14 (equivalent to 7.1 days), which was not present at the other stations. It was conspicuous in both summer and winter and dominated the diurnal cycle. The possibility that this peak was related to the weekly industrial cycle is not excluded, although in the absence of further investigation this supposition is speculative.

The scatter evident in the spring and summer periodograms for Wentworth (Fig. 2) is typical of all stations, although stronger at Southern Works than elsewhere. During autumn and winter there were extended periods of anticyclonic circulation that produced fine, settled weather, in contrast to spring, when the anticyclonic circulation was disrupted by the frequent passage of mid-latitude cyclones.

There is no evidence of an annual cycle, although it is possible that one might be detected with a longer data series. In the light of these results, further discussion of the SO_2 patterns will focus on the diurnal characteristics.

Diurnal variations in SO_2

The plots of hourly averages by season and for the mean annual conditions at two of the stations (Fig. 3) confirmed the varying significance of the diurnal cycle. At AECI (also at Athlone, not shown) there was little diurnal variation. The SO_2 values varied about the 5 ppbv level (10 ppbv at Athlone, not shown). In winter, the SO_2 values were slightly higher than the consistent levels recorded in the other seasons and also exhibited a diurnal cycle in which relatively higher SO_2 concentrations were recorded at 11:00. At Wentworth (and Southern Works, not shown) the diurnal curves had an amplitude of ~10 ppbv and did not differ substantially from season to season except in winter, when a marked diurnal variation was apparent. Distinctive peaks with mean values greater than 50 ppbv occurred at 08:00 and 10:00 at Wentworth and Southern Works, respectively. These morning phenomena are suggestive of fumigation peaks, which arose after the post-sunrise decay of the surface temperature inversion, which occurs with a higher frequency and intensity in winter (80% in winter compared with 30% in summer[10]). However, the possibility of a relationship to a traffic peak or the industrial cycle cannot be ignored. Minimum values occurred in the mid- to late afternoons.

The SO_2 levels remained elevated (close to 40 ppbv) throughout the night at Wentworth (Fig. 3), which was not the case at Southern Works. The Wentworth diurnal curve in winter thus had a double SO_2 maximum, peaking at 08:00 and 24:00. The absence of this feature at Southern Works implies that Wentworth is exposed to a nocturnal source of pollution not evident at Southern Works. Investigation of night-time (20:00–04:00) SO_2 peaks revealed that most occurred in conjunction with offshore westerly to northwesterly winds. We conclude that the well-developed mountain–plain circulation, which plays an important role in the regional transport of pollution from the interior of KwaZulu-Natal to the coast,[11] is responsible for the higher SO_2 values at Wentworth. The monitoring station at Wentworth is more elevated (~60 m above sea level) than the Southern Works station (which is at sea level) and is therefore more exposed to the offshore air flow. The transport of pollution from outside the boundaries of the SDIB is thus believed to raise the pollution levels by ~15 ppbv at night.

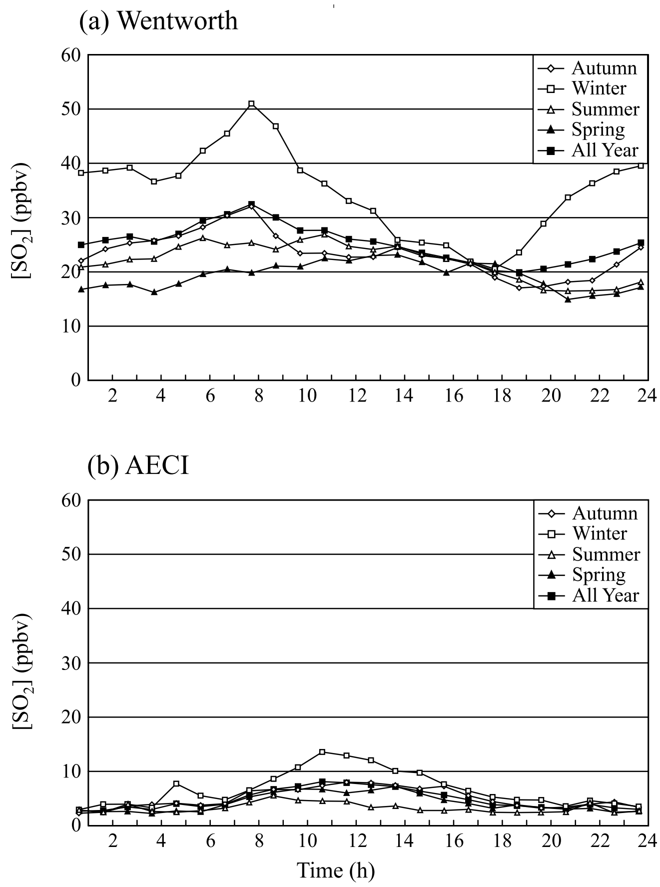

Fig. 3. Mean seasonal and mean annual diurnal variations in SO_2 concentration (ppbv) at Wentworth and AECI monitoring stations. To convert from ppbv to μg m^3, multiply by 0.382.

Relationship between SO_2 and meteorological variables

The dependence of SO_2 concentration on wind speed followed two different patterns according to station (Fig. 4). At AECI and Athlone, there was virtually no dependence of SO_2 level on wind speed. Slighter higher SO_2 readings were observed at low wind speeds, more evident at Athlone than at AECI, but then a fairly constant SO_2 level of ~10 ppbv at Athlone and ~5 ppbv at AECI was reached. At Wentworth and Southern Works, however, a distinctly different pattern was observed. High SO_2 values, reaching 40 ppbv at Southern Works, were recorded under low wind conditions. A minimum was reached at ~3.5 m s^{-1} and then there was a steady rise in concentration as wind speed increased. The reason for the different patterns is most likely the location of the monitoring stations in relation to the SO_2 sources. The former pattern (Athlone and AECI) reflected the background SO_2 concentration in the area and was not greatly influenced by changes in wind speed or by local SO_2 sources. This is substantiated by the relatively consistent seasonal and mean annual diurnal cycles shown in Fig. 3. The pattern at the other two stations conformed to expectations — SO_2 concentrations were high and then declined as wind speed increased and gave rise to greater dilution. This behaviour implies that these stations are located close to SO_2 sources. A critical wind speed of ~3.5 m s^{-1} (4.5 m s^{-1} at Wentworth) was reached, after which the trend was reversed. The reason for this unexpected behaviour could be stack down-drafting in strong winds, giving rise to high SO_2 concentrations at ground level. This further suggests that the SO_2 originated from an elevated source such as industrial stacks and that they were responsible for increasing ambient SO_2 concentrations by ~ 30–40 ppbv above background levels.

Further analysis of cases of high SO_2 levels in association with strong winds revealed that such events often occurred with a change in wind direction from northeasterly to southwesterly accompanying the passage of a cold front or coastal low. For example, SO_2 values increased sharply from below 20 ppbv on 13 November to 80 ppbv after the wind shifted to southwesterly. Concentrations

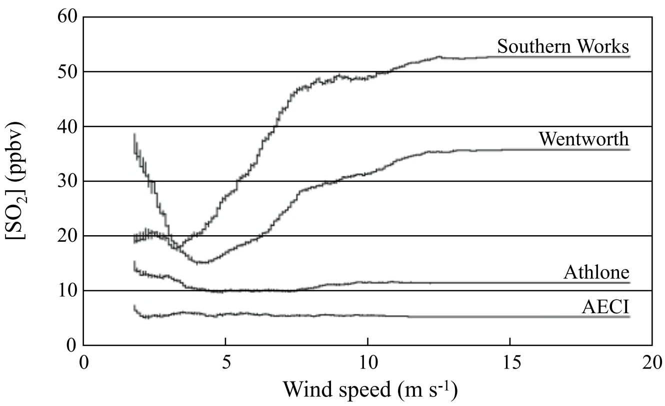

Fig. 4. Relationship between wind speed and SO_2 concentration at each of the four monitoring stations. A 2500-day average was applied to smooth the data.

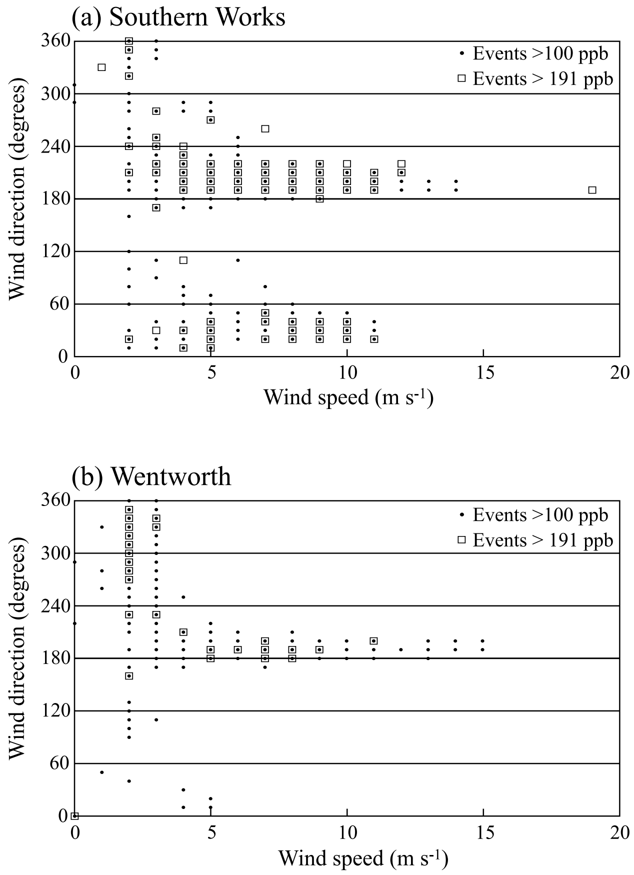

Fig. 5. Occurrence of high-SO_2 events (defined as >100 ppbv and >191 ppbv) as a function of wind speed and wind direction at Southern Works and Wentworth for the period 1997–99.

remained high, reaching above 100 ppbv, for the duration of the strong southwesterly wind.

The contrasts between the stations are further highlighted in the plots of wind speed versus wind direction for high-SO_2 events (defined as >191 ppbv and >100 ppbv) (Fig. 5). The threshold of 191 ppbv was selected as it is equivalent to the mean hourly guideline value recommended by the SDSDMS. The lower criterion of 100 ppbv was arbitrarily chosen in addition to the other to assist in the detection of patterns. At Southern Works, which is centrally located in the SDIB, high-SO_2 events arose in association with strong winds from both prevailing wind directions, the northeast and southwest. At AECI and Athlone (not shown), which are at the southern end of the basin, the association between high-SO_2 events and strong winds was best developed in the presence of northeasterly winds, whereas at Wentworth, situated in the north, it was only evident with southwesterly winds. These differences, when related to the locations of the monitoring stations within the industrial basin, indicate the dominance of the SDIB as a source of pollution. Relatively few high-SO_2 events originated from south of AECI or north of Wentworth.

It is evident from Fig. 5 that low-speed (<1.5 m s^{-1}), northwesterly (270–360°) offshore winds did account for some, albeit relatively few, of the high-SO_2 events observed at Wentworth as stated above. These winds would have been responsible for importing pollution into the SDIB from sources further inland. They were also evident to a lesser extent at Southern Works and Athlone.

Conclusion

Spectral analysis of data at four stations in the SDIB showed that the principal period in the data was that of the diurnal cycle. It was best developed in winter and autumn. These findings were endorsed by the averaged hourly data, which depicted strong diurnal cycles in winter at Wentworth and Southern Works, the two stations closest to the pollution sources. The morning peaks (at 08:00 and 10:00 at Wentworth and Southern Works, respectively) are thought to be due to post-sunrise decay of the surface temperature inversion. A secondary SO_2 maximum was observed at 24:00 at Wentworth and is ascribed to the transport of pollution from outside the boundaries of the industrial basin, which is believed to raise the pollution levels by ~15 ppbv at night.

SO_2 values at AECI and Athlone showed virtually no dependence on wind speed and hence we conclude that the SO_2 levels at these two stations reflect background concentrations, as these sites are fairly distant from SO_2 sources. At the other two stations (Wentworth and Southern Works), however, a distinctly different relationship to wind speed was observed. Relatively high SO_2 values were recorded at low wind speeds, with decreasing levels as wind speed rose, but then a critical wind speed was reached after which the trend was reversed. We suggest that stack down-drafting in the presence of strong winds gave rise to these high SO_2 concentrations at ground level.

Analysis of high-SO_2 events revealed that such occasions were associated with northeasterly winds at AECI and Athlone, with both prevailing wind directions at Southern Works, and with only southwesterly winds at Wentworth. These differences, related to the locations of the monitoring stations, clearly indicate the dominance of the SDIB as a polluting area.

We thank Ecoserv for the provision of SO_2 data. Funding for this research was provided by the National Research Foundation and the University of Natal. We thank Frank Sokolic also for his assistance with the preparation of figures.

1. Diab R.D. and Scott D. (1999). Urban air pollution and quality of life: case study of a community struggle in Durban, South Africa. Paper presented at *19th Annual Meeting of the International Association for Impact Assessment*, Glasgow, 15–19 June 1999.
2. Diab R.D. and Preston-Whyte R.A. (1980). Local weather and air pollution potential: the case of Durban. *Environ. Conserv.* **7**(3), 241–244.
3. Diab R.D. and Preston-Whyte R.A. (1995). State of the Environment Report for the Durban Metropolitan Area: Air Sector Report. Physical Environment Department, Durban.
4 van Himbergen M., O'Beirne S. and Raghubir S. (1999). Air quality impacts of the proposed petrochemical cluster in South Durban. ENV-P-C 98021, CSIR, Pretoria.
5. Matooane L. and Diab R.D. (2001). Air pollution carrying capacity in the South Durban Industrial Basin. *S. Afr. J. Sci.* **97**, 450–452.
6. Bissett R. (1995). Ambient sulphur dioxide and smoke monitoring report. Report for the Steering Committee of the South Durban Sulphur Dioxide Management System for the period 1 April 1995 to 30 September 1995. Durban Water and Waste, Durban.
7. Ecoserv (1998). South Durban Sulphur Dioxide Management System Monthly Report, April 1998. Ecoserv (Pty) Ltd, Durban.
8. Press W.H., Flannery B.P., Teukolsky S.A. and Vetterling W.T. (1992). *Numerical Recipes,* 2nd edn. Cambridge University Press, Cambridge.
9. Preston-Whyte R.A. and Tyson P.D. (1973). Note on pressure oscillations over South Africa. *Mon. Weath. Rev.* **101** (8), 650–653.
10. Tyson P.D., Preston-Whyte R.A. and Diab R.D. (1976).Towards an inversion climatology of southern Africa: Part I, Surface inversions. *S. Afr. Geog. J.* **58**, 151–163.
11. Tyson P.D. and Preston-Whyte R.A. (1972). Observations of regional topographically-induced wind systems in Natal. *J. Appl. Met.* **11**, 643–650.