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A CLIMATOLOGY OF PHOTOCHEMICAL SMOG EPISODES IN SYDNEY AUSTRALIA

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1. INTRODUCTION

Concentrations of ozone often exceed Australian air quality goals in Sydney during summer. The meteorological conditions associated with photochemical smog in the Sydney region and surrounds are complex. Photochemical smog episodes are generally confined to the months October to March, inclusive. Sydney is located on the eastern coast of Australia at latitude -33.8ºS (Figure 1), and experiences a temperate climate with warm to hot summers and cool to cold winters (BoM, 1991). The main urban areas are located within a basin bound by elevated terrain to the north, west and south (Figure 2). The weather in the region is affected by relatively complex topography with overnight cold-air drainage flows, particularly during cooler months and frequent sea breezes during the warmer months.

Modified from :http:// www.ga.gov.au/map/

Figure 1 Location map of Sydney, (-33.8º S)

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In 1998, the Australian National Environment Protection Council (NEPC) produced a National Environment Protection Measure for Air Quality (the Air NEPM) (NEPC, 1998). The Air NEPM provided for the first time in Australia a set of national ambient air quality standards. The Air NEPM standards for ozone are 100 ppb for a 1-hour average concentration and 80 ppb for a 4-hour average, with an allowable exceedance of 1 day per year. Furthermore the New South Wales (NSW) state environmental regulatory body the Department of Environment and Conservation (DEC) has set long-term goals for NSW based on The World Health Organization (WHO) ozone goals of 80 ppb (1-hour average) and 60 ppb (4-hour average). Figure 3 presents a graph showing the number of days in which the Air NEPM ozone goal of 100 ppb was exceeded over the 10-year period 1992 to 2001. Days in which the exceedance can be attributed to bushfires within Sydney and surrounding regions are presented in purple.

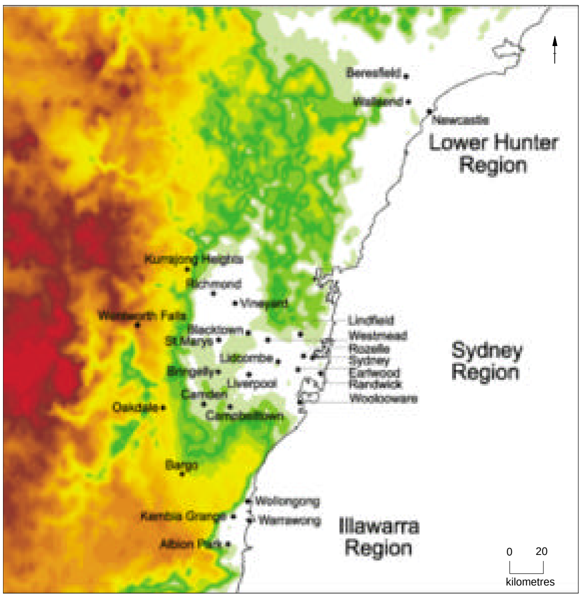

Figure 2 Topography of Sydney and surrounding region and location of NSW DEC air monitoring siteS

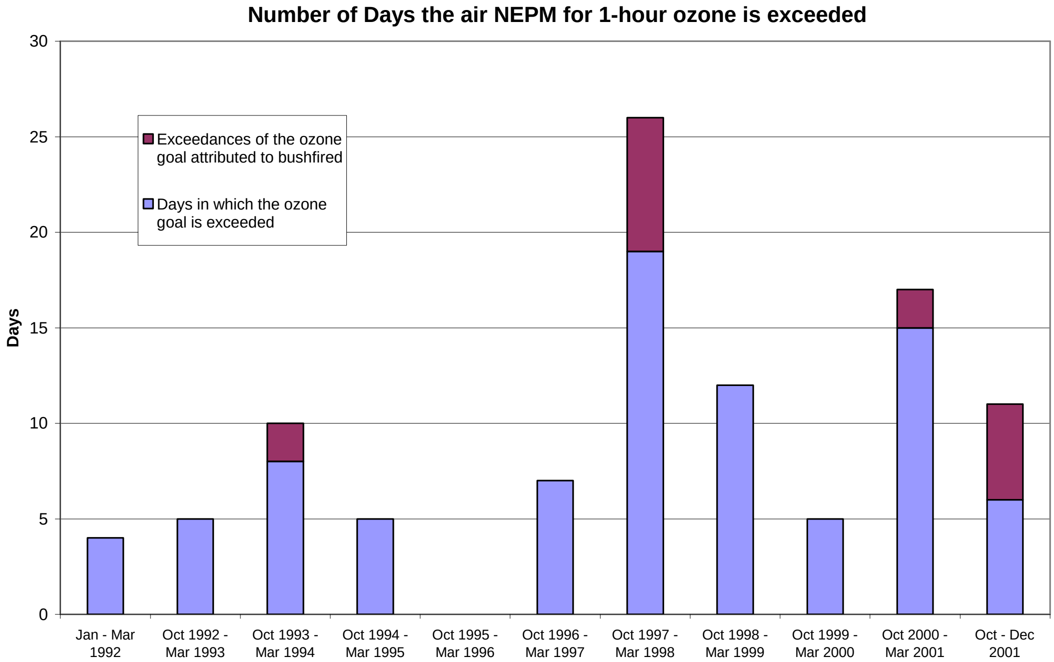

Figure 3 Number of days in which the Air NEPM ozone goal of 100 ppb was exceeded

Previous studies of photochemical smog formation in Sydney are often episode-based and there remain features in the occurrence of photochemical smog that are yet to be fully explained (Hyde, *et al.* 1995). A study by Leighton and Spark (1995) produced a manual classification of mean sea level synoptic maps to ascertain the relationship between synoptic climatology and pollution events in Sydney. They identified the main synoptic situations covering the eastern Australian region for winter and summer associated with moderate to high pollution events. The amount of time an anticyclone remained in the region was also related to number of pollution days. They found summertime pollution events to be associated with a light west to northwesterly gradient wind.

Meso-scale conditions have a large influence on the formation of photochemical smog in the Sydney basin. High ozone peaks, particularly in the central and western regions of Sydney, are most commonly associated with an afternoon sea breeze that transports precursor emissions across the Sydney basin.

In order to gain a better understanding of the synoptic signatures behind photochemical smog processes, this paper presents an objective synoptic climatology of photochemical smog episodes in Sydney. This climatology has been produced using multivariate statistical techniques including principal component analysis and cluster analysis in order to assign days into meteorologically homogeneous synoptic categories. Meteorological inputs to these statistical procedures include both surface and upper air observations, for warm months (October to March) over a ten year period (1992 – 2001).

Days in which Sydney's air quality may have been affected by bushfires were removed from analyses. Systematic records of bushfire activity in Sydney are scarce. The most comprehensive data came from the National Parks and Wildlife Service (NPWS) wildfire database, which covers wildfire activity from 1995 to the present. Using this database, days in which there was significant bushfire activity in the Sydney region were isolated and daily maximum observations of ozone and PM_{10} were then compared for both bushfire days and non-bushfire days. Days in which there were bushfires in the Sydney region generally showed a marked increase in particulate concentrations compared to non-bushfire days. From this analysis, days in which daily maximum values of ozone exceeded 80 ppb and PM_{10} exceed 110 $\mu g/m^3$ were deemed days in which air quality in Sydney was probably being affected by bushfires. A threshold of 80 ppb ozone was chosen as it corresponds to the NSW DEC long-term 1-hour ozone goal. Twenty-seven days were identified between 1992-2001 using these criteria; these days were removed from the analyses.

On a number of days in which there were bushfires in the Sydney region ozone and particulate concentrations were below the criteria described above. However, on some occasions synoptic, regional and meso-scale winds may have transported some residual bushfire air into the Sydney Basin; however the resultant impact on subsequent ozone concentrations was low. Therefore, these days were not excluded from the synoptic classification.

2. SYNOPTIC CLIMATOLOGY METHODS

A synoptic climatology of photochemical smog episodes in Sydney was undertaken. This analysis involved using multivariate statistical techniques including principal component analysis and a two-stage cluster analysis to classify days into meteorologically homogenous synoptic categories. These synoptic categories were then related to ground level ozone concentrations. The method of synoptic classification used in this research is the *circulation-to-environment* approach, in which the classification is produced first and is then related to the environmental variable in question (Yarnal 1993). This method is becoming more frequent in air pollution climatology studies, particularly in the study of photochemical smog (e.g. Cheng, *et al.* 1992; Eder, *et al.* 1994; Davis, *et al.* 1998; Greene, *et al.* 1999; Schreiber, 2000).

The multivariate statistical techniques were used to group suites of meteorological variables into synoptic categories found to be representative of the air mass characteristics at that time. Principal Component Analysis (PCA) was used as a data reduction technique. Data reduction is achieved by finding linear combinations (principal components) of the original variables, which account for as much of the total variance in the original variables as possible (Statheropoulos, *et al.* 1998). The components are ordered such that the first component explains the greatest proportion of the variance and the second accounts for as much of the residual variance as possible while remaining orthogonal (i.e. completely independent) to the first in data-space. Remaining components explain less variance than the proceeding components. By retaining only a proportion of the principal components, a large amount of the original variance can be explained whilst substantially reducing the size of the data matrix.

Each principal component comprises a series of loadings that represent the correlation between the principal component and the meteorological parameter. The larger the component loading the more important the meteorological parameter is in the interpretation of that principal component. Once the principal components and their respective loadings are established it is necessary to ascertain the relationships between the original raw variables for each day and the principal components. This is achieved through the calculation of component scores for each day, which are values for each day's weather observations based on the principal components (PC). Thus, days with similar meteorology conditions will exhibit proximate principal component scores (Shahgedanova, *et al.* 1998).

To generate synoptic categories PCA was used in conjunction with cluster analysis. Clustering procedures were used to group days with similar component scores and to assign each day into a meteorologically homogeneous subset of the data (Kalkstein and Corrigan, 1986; Shahgedanova, *et al.* 1998; Greene, *et al*. 1999). The component scores matrix (number of days times the retained PCs) obtained from PCA served as the input matrix for cluster analysis. The reduced size and the absence of co-linearity make it ideal data for clustering (Davis, *et al.* 1998).

A two-stage clustering technique was used. Firstly, average-linkage, a hierarchical, agglomerative method was used to determine the number of clusters and the mean conditions within each cluster. These initial clusters were then used as input in to k-means clustering, a non-hierarchical iterative method.

As each of the clusters exhibits a distinctive air mass and synoptic signature, a characteristic regime of pollution concentration should be associated with each because of the critical impact of weather conditions on the dispersion or accumulation of air pollutants (Cheng, *et al.* 1992).

2.1 Selection of meteorological variables

Surface and upper air meteorological data for warm months (Oct-Mar) over a ten year period (1992 – 2001) were used as input into the statistical analysis. The general goal of any synoptic climatological method is to combine individual weather elements into groups or classes that are representative of the synoptic scale situation at a moment in time. Therefore a coherent combination of meteorological elements is required that is representative of distinct air mass types.

Previous applications of this synoptic climatology technique in air pollution studies have concentrated on surface meteorological variables as inputs to the statistics. For example, (Kalkstein and Corrigan, 1986) recommend the use of surface variables, assuming that the relative meteorological homogeneity of an air mass in its horizontal extent allows inferences concerning vertical processes and associated atmospheric stability. However, some studies have included upper air observations such as twice daily measurements of upper air temperature, dew point temperature, and *u* and *v* wind components (Eder, *et al.* 1994; Davis, *et al*. 1998).

The common meteorological variables used in this type of PCA include: dry bulb temperature, dew point temperature or relative humidity, mean sea level pressure, total cloud cover or global solar radiation and *u* and *v* wind components. Other investigations have included visibility (Kalkstein and Corrigan, 1986), vapour pressure (McGregor and Bamzelis, 1995), total daily solar insolation and morning and afternoon mixing heights (Eder, *et al.* 1994; Davis, *et al.* 1998). Studies by (Eder, *et al.* 1994) and (Davis, *et al.* 1998) on Birmingham, Alabama and Houston, Texas respectively have also included upper air temperature and wind parameters from 850 hPa. Many of the studies mentioned previously are in areas of the United States where ozone concentrations are largely governed by the transport of precursors over a stream of continuous urban and industrial centres. Whilst there are emission sources in the surrounding region, which may transport emission towards Sydney in regional flows, Sydney is relatively isolated from other large urban centres, therefore boundary layer flows tend to be clean and only contain background concentrations of ozone.

Sydney's environment is geographically complex, there are controls on weather patterns from the surrounding topography, and the location of the Sydney basin with topography to three sides and the sea to the east generates a complicated drainage flow, sea breeze circulation. Therefore, it was decided that the inclusion of upper air variables was imperative in gaining a comprehensive understanding of the air mass characteristics behind photochemical smog episodes in Sydney. In order to find the most appropriate suite of meteorological variables for use in the synoptic classification a series of experiments were undertaken using different suites of variables. Table 1 shows all meteorological variables used in the analyses with the variables used for each configuration marked.

Configuration 1 included only surface variables collected from the Australian Bureau of Meteorology's Sydney Airport Automatic Weather Station (AWS), which is a coastal site. Surface variables included:

* 6am and 3pm dry bulb and dew point temperatures (defining the thermal and moisture properties of the air mass)
* 6am and 3pm pressure
* 6am and 3pm total cloud cover (representing incoming solar radiation)
* 6am and 3pm *u* and *v* wind components (indicative of surface flow patterns, and important to the transport and dispersion of pollutants).

Table 1 A summary of the different configurations of meteorological variables used for input to Principal Components Analysis

Meteorological variables used as input to PCA				
Meteorological Variables		Configuration 1	Configuration 2	Configuration 3
Surface Data				
6:00 AM	Temperature (°C)	v	v	v
	Dew point (°C)	v	v	v
	u wind (m/s)	v	v	v
	v wind (m/s)	v	v	v
	MSLP (hPa)	v	v	v
	total cloud cover (oktas)	v	v	v
3:00 PM	Temperature (°C)	v	v	v
	Dew point (°C)	v	v	v
	u wind (m/s)	v	v	v
	v wind (m/s)	v	v	v
	MSLP (hPa)	v	v	v
	total cloud cover (oktas)	v	v	v
Upper Air Data				
6:00 AM	850 hPa temperature (°C) (~1500 m)		v	v
	850 hPa dew point temperature (°C)		v	v
3:00 PM	Mixing height (m)		v	v
	850 hPa temperature (°C)		v	v
	850 hPa dew point temperature (°C)		v	v
	850 hPa u wind (m/s)		v	v
	850 hPa v wind (m/s)		v	v
	975 hPa temperature (°C) (within sea breeze)			v
	925 hPa temperature (°C) (above sea breeze)			v

Configuration 2 included the same surface variables as above, as well as a collection of upper air variables:

* 6am and 3pm 850 hPa dry bulb and dew point temperatures
* 3pm 850hPa u and v wind components
* 3pm mixing height.

Upper air observations were obtained from the Australian Bureau of Meteorology's twice daily radio-sonde ascent at Sydney Airport. Observations from the 850hPa level were chosen as it is a commonly measured level and the air mass at this level is above the planetary boundary layer.

Mixing height was included because of its importance in the dispersion and dilution of pollutants. Mixing height was derived graphically from upper air temperature traces as the point at which a parcel of air rising dry adiabatically crosses the environmental lapse rate (Holzworth, 1967). Mixing height was derived from the 3pm temperature trace which is important in understanding the depth of the sea breeze. The occurrence and nature of the sea breeze in Sydney during summer has an important influence on ozone concentrations, particularly in western Sydney.

Configuration 3 included the surface and upper air variables above plus an additional two extra upper air variables:

* 3pm 975 hPa temperature
* 3pm 925 hPa temperature

These variables were chosen as the temperature at 975 hPa is often indicative of the temperature within the sea breeze and the 925 hPa temperature is indicative of the conditions just above the sea breeze. These variables were included in order to study the influence of the sea breeze on air mass conditions associated with photochemical smog episodes.

Observations taken at 6am and 3pm were used in the statistical analysis as they are times close to minimum and maximum temperatures and are commonly measured times for the recording of surface meteorological observations. These times also coincide with the twice daily radio-sonde ascents.

Each configuration of variables was analysed using the above mentioned statistical procedures, ozone concentrations within each synoptic category were then analysed. Configurations were compared by evaluating the maximum ozone concentrations observed in each of the synoptic categories.

Nine, ten and eleven synoptic categories were found for configurations 1, 2 and 3, respectively. Table 2 shows the ozone concentrations associated with each of the synoptic categories for each configuration. Configuration 1, containing surface variables only, produced nine warm season synoptic categories for Sydney, one of these categories (cluster 2) contained 55% of all high pollution days (daily maximum ozone greater than 80 ppb), however only 20% of the 414 days falling within this category exceeded this criteria. Configuration 2 improves the isolation of high pollution days with 68% of all high pollution days falling within the synoptic category containing the highest mean maximum daily ozone concentrations; 31% of the 293 days within this category are greater than 80 ppb. Configuration 3 also had 68% of all high pollution days falling within the synoptic category associated with highest ozone concentration. However, with the inclusion of extra upper temperature variables in order to define the upper temperature profile, particularly with regard to processes within and above the sea breeze, some of the low pollution days falling within the high pollution category in Configuration 2 have been reassigned to other synoptic situations in Configuration 3. The daily maximum ozone concentration associated with the high pollution category has been increased in configuration 3 and 48% of all days within this category experienced daily maximum ozone concentrations greater than 80 ppb. This has confirmed that the suite of meteorological variables used in configuration 3 were the best at isolating the air mass characteristics behind photochemical smog episodes for Sydney.

3. SYNOPTIC CLIMATOLOGY RESULTS USING METEOROLOGICAL VARIABLES SPECIFIED IN CONFIGURATION 3

Eleven synoptic categories were found in Sydney during the warm season. Meteorological inputs from both surface and upper air observations from Sydney airport were used in the development of the synoptic climatology and ozone concentrations associated with each of the synoptic categories have been investigated. One synoptic category was found to be associated with high pollution concentrations. Of the days in the high ozone cluster, 48% were found to exceed the New South Wales proposed 1-hour ozone goal (80 ppb), a further 32% were found to experience ozone concentrations between 60 to 80 ppb, while the remaining 20% of days recorded concentrations less than 60 ppb ozone. On the basis of an examination of surface synoptic charts, enhanced ozone concentrations were found to be associated with a high pressure system located in the middle to eastern Tasman Sea producing light north westerly gradient winds, high afternoon temperatures, the presence of an afternoon sea breeze, a shallow mixing height and warming aloft. Table 3 presents the mean meteorological conditions associated with the synoptic category associated with highest ozone concentrations.

To further understand the meteorological processes operating during Sydney’s pollution episodes, a selection of days falling in this high pollution synoptic category were analysed in greater detail, particularly the meteorological differences between days with similar synoptic conditions, yet quite different ozone concentrations. The ozone season from October 2000 to March 2001 was chosen to analyse in greater detail. This season was chosen as it represented a relatively severe ozone season with seventeen exceedances of the current ozone goal being recorded; in addition the season experienced relatively small influences from bushfire activity, with only two of the exceedances being attributed to bushfires.

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Table 2 Ozone concentration associated with each configuration

Comparison of maximum ozone concentrations for different synoptic categories- configuration 1,2 and 3											
Configuration 1 Cluster Number (n)	1 (283)	2 (414)	3 (192)	4 (158)	5 (70)	6 (80)	7 (34)	8 (38)	9 (372)		
Number of clusters 9											
Mean daily ozone concentration (ppb) for cluster	**30**	**60**	**59**	**29**	**47**	**35**	**28**	**31**	**53**		
Number of days maximum 60 ppb = O_3 < 80 ppb	0	90	47	0	9	0	0	0	82		
Percentage of days maximum 60 ppb = O_3 < 80 ppb	0%	22%	24%	0%	13%	0%	0%	0%	22%		
Number of days maximum O_3 = 80 ppb	0	81	35	0	3	0	0	0	28		
Percentage of days maximum O3 = 80 ppb	0%	20%	18%	0%	4%	0%	0%	0%	8%		
Percentage of all high pollution days (O_3 =80 ppb) falling in cluster	0%	55%	24%	0%	2%	0%	0%	0%	19%		
Configuration 2 Cluster Number (n)	1 (252)	2 (293)	3 (167)	4 (38)	5 (44)	6 (247)	7 (198)	8 (29)	9 (149)	10 (5)	
Number of clusters 10											
Mean daily ozone concentration (ppb) for cluster	**31**	**74**	**45**	**50**	**30**	**38**	**52**	**48**	**58**	**31**	
Number of days maximum 60 ppb = O_3 < 80 ppb	5	88	20	6	0.0	24	40	4	34	0	
Percentage of days maximum 60 ppb = O_3 < 80 ppb	2%	30%	12%	16%	0%	10%	20%	14%	23%	0%	
Number of days maximum O_3 = 80 ppb	0	92	3	1	0.0	5	9	0	26	0	
Percentage of days maximum O3 = 80 ppb	0%	31%	2%	3%	0%	2%	5%	0%	17%	0%	
Percentage of all high pollution days (O_3 =80 ppb) falling in cluster	0%	68%	2%	0%	0%	4%	7%	0%	19%	0%	
Configuration 3 Cluster Number (n)	1 (283)	2 (193)	3 (241)	4 (200)	5 (26)	6 (28)	7 (46)	8 (149)	9 (5)	10 (95)	11 (156)
Number of clusters 11											
Mean daily ozone concentration (ppb) for cluster	**38**	**87**	**61**	**30**	**49**	**47**	**30**	**44**	**31**	**52**	**44**
Number of days maximum 60 ppb = O_3 < 80 ppb	26	61	83	1	4	3	1	14	0	20	9
Percentage of days maximum 60 ppb = O_3 < 80 ppb	9%	32%	34%	0%	15%	11%	2%	9%	0%	21%	6%
Number of days maximum O_3 = 80 ppb	5	92	30	0	1	0	0	1	0	6	1
Percentage of days maximum O3 = 80 ppb	2%	48%	12%	0%	4%	0%	0%	1%	0%	6%	1%
Percentage of all high pollution days (O_3 =80 ppb) falling in cluster	4%	68%	22%	0%	0%	0%	0%	0%	0%	4%	0%

Table 3 Mean meteorological conditions associated with the high pollution category

Meteorological Variables			Cluster Number (number of days in cluster)										
			1 (283)	2 (193)	3 (241)	4 (200)	5 (26)	6 (28)	7 (46)	8 (149)	9 (5)	10 (95)	11 (156)
6am	Surface	Temperature (°C)	20.3	21.2	17.8	17.3	19.5	18.6	15.1	17.0	19.8	20.4	13.3
		Dew Point (°C)	17.8	18.5	14.8	13.1	15.8	11.8	7.7	13.2	6.7	17.2	8.1
		u Wind (m/s)	-2.5	1.0	0.5	-3.9	1.9	1.5	0.9	0.9	3.4	1.2	-0.8
		v Wind (m/s)	0.9	-0.1	-0.7	0.9	-0.6	-1.4	-2.9	-0.4	-4.7	-0.4	-2.3
		Pressure (hPa)	1015	1012	1018	1020	1008	1008	1007	1015	995	1008	1019
		Cloud Cover (oktas)	6.3	3.5	2.4	6.0	5.5	2.2	3.7	5.3	5.4	5.9	2.7
	Upper Air	850hPa Temperature (°C)	12.4	18.1	12.2	6.8	15.9	14.1	7.2	9.6	10.7	15.9	5.3
		850hPa Dew Point (°C)	8.6	4.9	0.2	4.3	4.4	-2.6	-0.7	3.4	0.3	6.2	-2.5
3pm	Surface	Temperature (°C)	23.2	29.2	25.6	20.4	31.9	32.1	23.1	22.6	24.5	25.5	19.8
		Dew Point (°C)	17.4	18.2	14.4	12.7	11.8	3.6	3.0	13.6	4.3	17.2	9.1
		u Wind (m/s)	-2.6	4.3	3.2	-3.9	3.4	2.5	-0.9	4.0	1.6	2.1	-1.5
		v Wind (m/s)	3.3	4.8	5.0	3.3	-5.4	-6.2	-6.7	4.5	-12.3	2.0	4.3
		Pressure (hPa)	1015	1010	1016	1020	1004	1004	1006	1012	996	1006	1018
		Cloud Cover (oktas)	6.1	2.9	1.9	5.9	5.2	2.4	3.5	5.1	6.2	6.0	2.7
	Upper Air	Mixing Height (m)	551	331	646	878	1680	2698	1977	562	1709	290	800
		850hPa Temperature (°C)	12.6	20.0	14.7	7.5	16.9	16.5	8.1	11.9	10.5	16.3	7.6
		850hPa Dew Point (°C)	8.2	5.8	-0.9	3.9	6.4	0.0	-1.8	4.2	0.1	7.3	-3.6
		850hPa *u* Wind (m/s)	-0.8	1.1	-0.3	-2.2	3.4	2.9	-0.6	3.5	5.7	4.1	-1.1
		850hPa *v* Wind (m/s)	-0.6	-4.8	-2.9	0.4	-10.7	-9.3	-10.8	-6.0	-23.9	-10.5	-5.1
Daily Maximum Ozone (ppb)			**38**	**87**	**61**	**30**	**49**	**47**	**30**	**44**	**31**	**52**	**44**

3.1 A case study of two days falling within the high pollution category

The 2000-2001 photochemical smog season has been examined in greater detail in order to examine the synoptic and meso-scale features leading to high pollution events in Sydney. To illustrate the complexity of both synoptic and meso-scale wind flows, and the vertical temperature structure, on days predicted to be high photochemical smog in Sydney, two days falling within the high pollution category were examined in more detail:

* **21 December 2000** - experienced a maximum hourly average ozone concentration of 158 ppb;
* **22 December 2000** – fell within the high pollution category, however maximum hourly average ozone concentrations in Sydney reached only 62 ppb.

A selection of the available meteorological data for each day is shown in
Figure **4** and Figure 5 respectively. For each event the following data are presented:

* The surface synoptic chart at 10am and 10pm Eastern Standard Time (EST)
* Half-hourly surface winds at Sydney Airport (Mascot) at the coast
* The 6am, 10am, 3pm and 10pm (EST) radio-sonde ascents made at Sydney Airport
* Wind profiles at Sydney Airport for 6am and 10am (EST).

On each day the overall surface synoptic situations were characteristic of features observed during most ozone events in Sydney (Hyde, *et al.* 1995), with a region of high pressure in the Tasman Sea and a ridge extending north east across northern New South Wales (NSW) and Queensland (QLD). On both days low-level 6am vertical temperature profiles show a shallow mixed layer at the surface and a sharp capping inversion above. However, on the 21st of December the surface winds in the morning were southeasterly, whereas on 22nd of December the surface winds were north-northeast to northerly. Below we discuss features of the surface winds, and upper wind and temperature structures that probably resulted in these two events having quite different maximum hourly average ozone concentrations in Sydney.

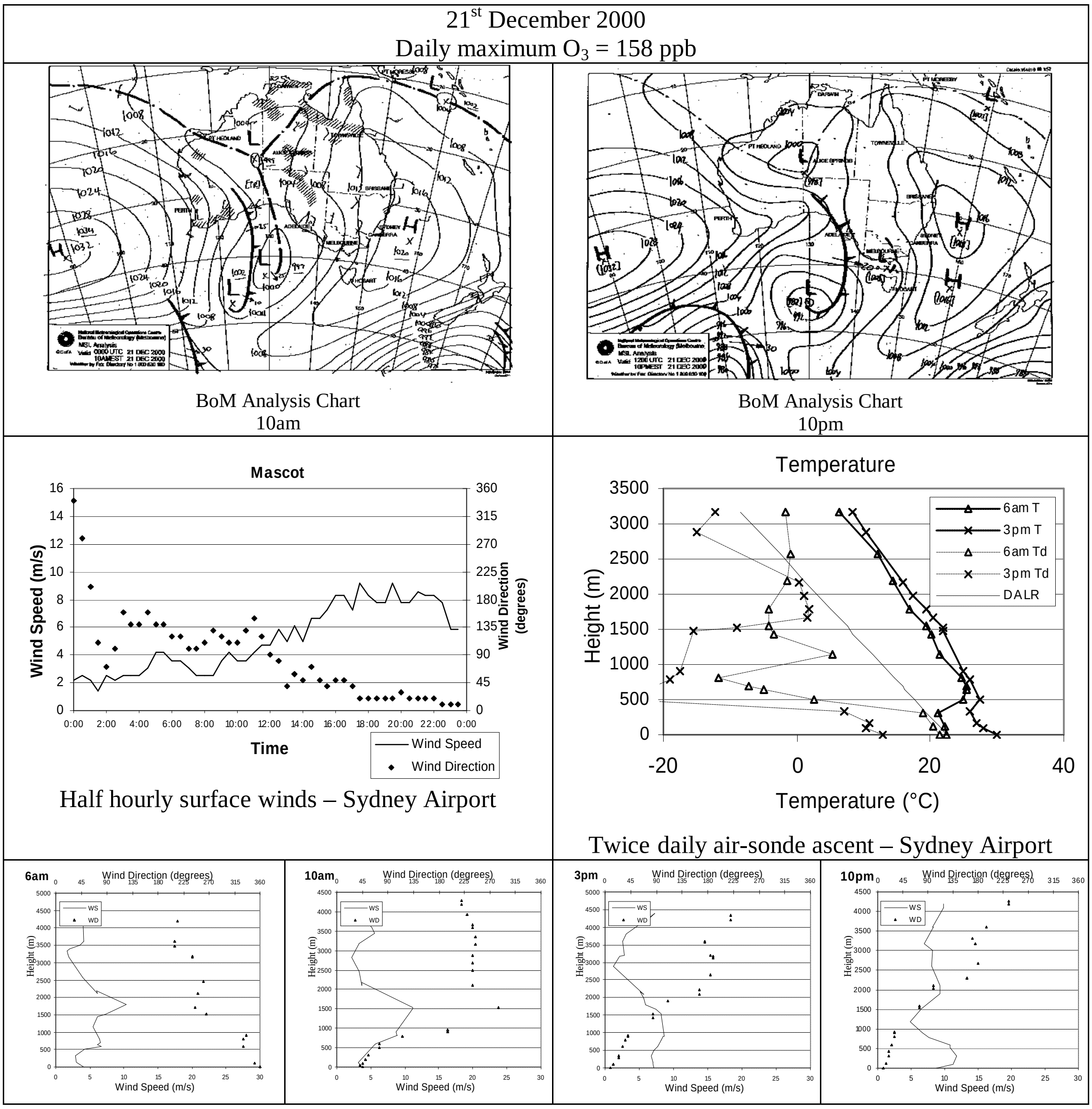

Figure 4 Meteorological conditions associated with a high ozone day, 21st December, 2000

3.1.1 High ozone event – 21st December 2000

On the basis of the synoptic chart presented in Figure 4, surface winds at Sydney on the morning of the 21st December should be north to north-easterly. However, the surface winds at Sydney Airport show a moderate (4-5 m/s) south to south-easterly during the morning gradually backing late morning and early afternoon to become an east to northeast sea breeze; the wind then turns north-northeasterly in the late afternoon and evening. The 6am radio-sonde profile presented in Figure 4 illustrates that this southeasterly flow is quite shallow and at around 300m is capped by an inversion with slightly stable warmer west-southwesterly flow above.

The shallow southerly flow present at Sydney Airport during the early hours of the morning is characteristic of some generic ozone events in Sydney (Hawke, *et al.* 1978). During these events these shallow flows move into the Sydney Basin late the precious evening or early morning. If this shallow flow, capped by an inversion, is still present after sunrise then morning precursors of photochemical smog are trapped and transported across the Sydney Basin potentially forming high concentrations downwind. In addition, the presence of a shallow east to north east sea breeze, as occurred on this day, continues to trap and transport precursor emissions across the Basin contributing to ongoing high concentrations of ozone.

3.1.2 Low ozone event – 22nd December 2000

The day after the event discussed above shows a very similar surface synoptic chart, with a high in the eastern Tasman Sea and a ridge of high pressure extending northwest over northern NSW and Qld. However, in contrast to the previous day, where surface winds were initially south to south-easterly, surface winds on the 22nd December are north-northeasterly alongshore winds throughout the night, turning northerly at 6am and continuing in this direction until the onset of a northeasterly sea breeze at around 3pm.The morning radio-sonde profile shows a characteristic temperature profile of this type of day with a very shallow layer within the north-northeasterly alongshore flow capped by a deep inversion to around 800 metres and an adiabatic layer to approximately 1800 metres.

The 6am wind profile presented in Figure 5 is consistent with the overall synoptic situation, with moderate northwesterly gradient winds above the surface. The afternoon profile shows a northeasterly sea breeze capped by a shallow inversion and a deep layer of west-northwesterly winds above. However, the main difference between this day and other occasions with similar synoptic situations and north east to north westerly winds, is the strong winds observed after 9am at Sydney Airport. There was also a rapid increase in surface temperatures at the coast on this day which would have rapidly eroded the inversion observed in the 6am radio-sonde ascent. Consequently, following the breakdown of the inversion, moderate to strong northerly winds would have mixed down to the surface and precursor emissions in the Sydney Basin would have rapidly diluted and dispersed, with the well mixed layer extending to 1800m.

4. DISCUSSION AND PLANS FOR FUTURE RESEARCH

Meteorological conditions associated with photochemical smog episodes in Sydney are complex and include both synoptic and meso-scale processes. The synoptic climatology produced in this research includes meteorological variables that encompass processes from both these scales. The synoptic climatology has isolated one synoptic situation associated with high pollution episodes. By studying the synoptic and associated meso-scale processes experienced within this category it has been possible to ascertain some of the determining factors required to produce a high pollution day in Sydney.

The two days examined in detail, both having almost identical synoptic charts, illustrate the difficulty in predicting high ozone events in Sydney. While on each day the temperature profiles at 6am show a shallow well-mixed layer capped by an inversion, winds within this surface layer are associated with quite different meso-scale flows. For example, on the 21st December there were overnight and morning south to south-easterly winds, while on the morning of the 22nd December winds were alongshore north-northeasterly before the breakdown of the surface layer and onset of a moderate to strong northerly synoptic flow.

On the 21st of December the north to north-west synoptic flow, combined within onshore north-east sea breeze, could be expected to govern ozone concentrations in Sydney. However, as discussed above it was a south-easterly meso-scale flow that most probably produced such high concentrations in Sydney.

In contrast, the following day, where synoptic conditions were almost identical and concentrations of ozone were predicted to be high, the rapid breakdown of the surface inversion morning and subsequent mixing down of moderate to strong northerly gradient winds resulted in quite low concentrations of ozone.

The examples above illustrate the complexity and difficulty of predicting some high ozone events in Sydney, and in particular the influence of different meso-scale flows, therefore a more detailed analysis of the relative influence of the current parameters used in the statistic analyses is necessary to determine the relative importance of individual factors on individual days.

22nd December 2000
Daily maximum O_3 = 62 ppb

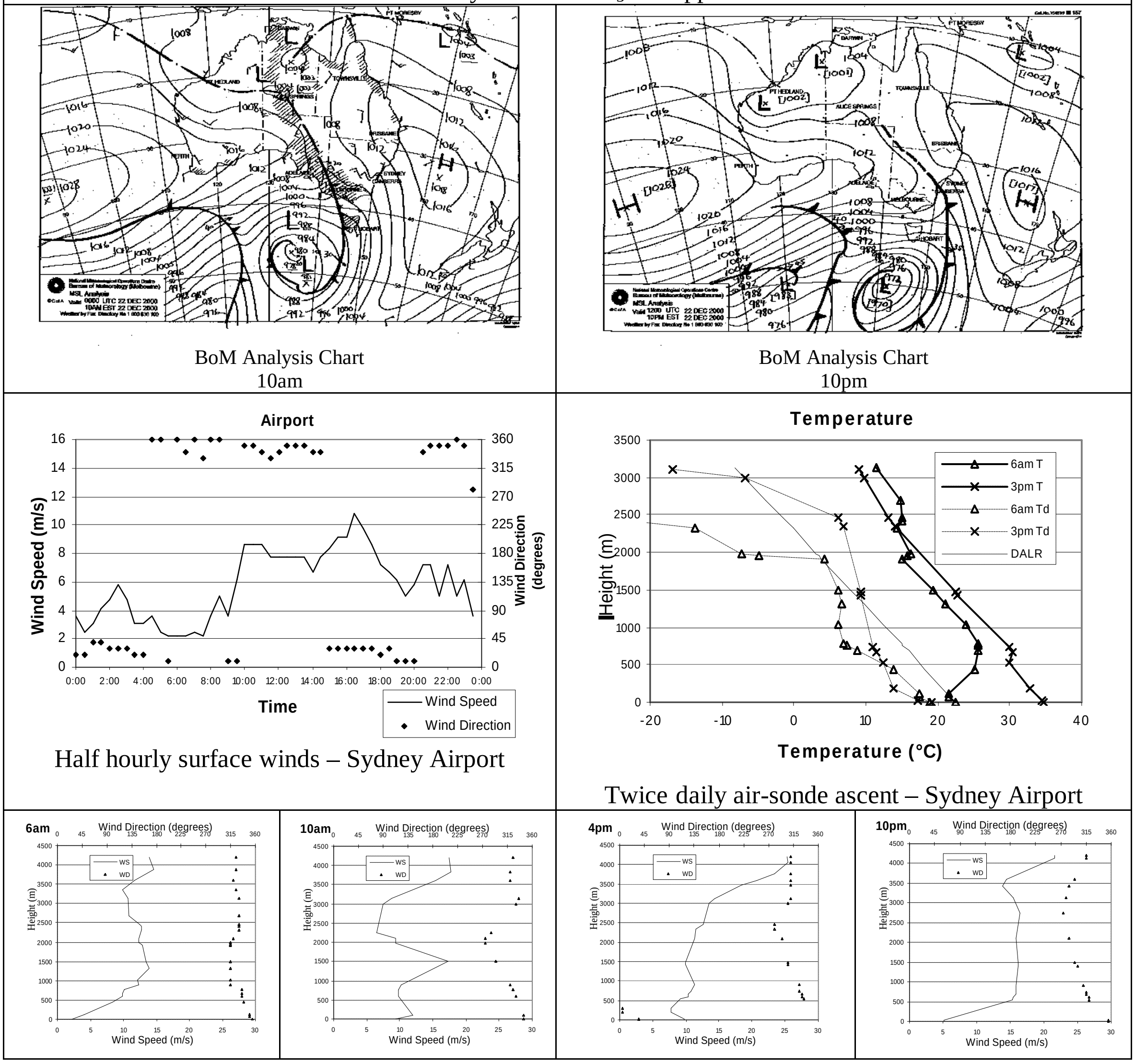

Figure 5 Meteorological conditions associated with a medium ozone day, 22nd December, 2000

In future research it is hoped to refine this climatology even further by assessing the importance of current and additional variables to the statistical analyses. A selection of the additional variables currently being considered includes maximum temperatures experienced at Richmond, in western Sydney, as well as solar radiation measured at some DEC monitoring stations in Sydney. The temperature difference between the coast and mainland in conjunction with data on solar radiation is expected to improve the understanding of meso-scale flows and the occurrence of photochemical smog in Sydney. It is also thought that the inclusion of more frequent upper wind observations from the 6am and 10am wind accents may help in the understanding of synoptic movements throughout the morning.

This analysis is also to be expanded through use of the Australian Commonwealth Scientific and Industrial Research Organisation's (CSIRO) 3D wind field-based model for air pollution studies (TAPM). It is expected that TAPM simulations will be useful for increasing the understanding of atmospheric processes associated within this synoptic category.

Future research is to also involve investigating the atmospheric processes behind the 30 days, 12% of 241 days within the category, associated with high pollution occurring in synoptic category 3.

It is envisaged that results from this research will be useful to Australian regulatory bodies from both a forecast point of view and for the planning of future sources in Sydney and surrounding regions.

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