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Analysis of background ozone in the Sydney basin

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Abstract: It has been known that the "background ozone" level in urban cities is changing over the years. What is the background ozone and why this is changing is not entirely clear. This paper looks at one definition of background ozone level and using this definition to derive the background level of ozone using ambient quality data measured at the monitoring stations. From the derived background ozone level, it is possible to determine the change of background level from the early 1990 to the present day. The change or trend in background level at different monitoring stations will be accessed using the Long Range Dependent method and the results are shown to be not the same at different stations. This shows that the local conditions at each station are important in determining whether a quality management plan to reduce ozone below exceedance level is effective (or achievable) or not.

Keywords: *Background ozone; Sydney basin; ozone trend*

1. INTRODUCTION

Background ozone level, in the context of photochemical smog process, is referred to ozone level that is formed from natural processes free from anthropogenic influences. The concept is easily grasped and formulated but the problem is to define and distinguish what is natural and anthropogenic effects. A “clean” environment before anthropogenic changes, in practice is hard to find and determine when man already changes the settings. What is part of the natural world or an anthropogenic world is not clear and has to be considered to be able to apply in practice. And the “clean environment” is also changed with time as the natural processes or events occurring over time. In the Sydney basin, we don’t know what past clean unpolluted air before settlement and pre-industrial period is and since then vegetation and land use pattern had changed overtime. It is unrealistic to determine clean background ozone level in Sydney basin.

Clean pristine sites in the rural or bushland areas have been cited as good sites to measure the background ozone. The background ozone level is mostly from tropospheric natural sources but also has possibly stratospheric origin transported down to the surface. We can also define a local background ozone level or a global background level in which the ozone formation process is determined on the global scale at some pristine measuring sites around the globe. The background level can therefore has the temporal and spatial scale depending on the place and period we consider.

Olmans et al (2008) measured ozone levels, which they indicate and use as background ozone, at some remote sites in California (such as Trinidad) where the airflow patterns almost come from the Pacific free of contamination from continental North American continent. Their measurement shows that the monthly background ozone fluctuates around 35 ppb for the six years period (2002-2007) with maximum about 50 ppb and minimum about 25 ppb.

Monks (2003) reviewed the ozone trend in Europe and conclude that there is strong evidence for increasing background ozone concentration in western and northern Europe.

Background ozone level is important as it sets the reference level against which anthropogenic effect can be ascertained by the measured ozone level at an area and the basis for human health risk assessment estimates. It also determine whether policy expectations on the levels to which hourly average ozone concentrations can be lowered as a result of emission reduction requirements is realistic or not. Background level is important in risk estimates associated with ozone concentrations in excess of background concentrations. The risk can be estimated by extrapolation of exposure-response relationships down to background levels even there is uncertainty about the concentration-response relationship at lower concentrations and whether there is evidence for the existence of population response threshold. Epidemiological studies indicate so far that there is no threshold of ozone level for premature mortality and other morbidity health effects (eg. exacerbation of asthma) below which there is no population response (US EPA, 2006).

2. DEFINTION OF BACKGROUND OZONE

2.1 Policy Relevant Background (PRB)

The US EPA has defined Policy-Relevant Background (PRB) as background ozone concentrations used for purposes of informing decisions about NAAQS are referred to as Policy Relevant Background (PRB) ozone concentrations (US EPA, 2006)

“Policy Relevant Background concentrations are those concentrations that would occur in the United States in the absence of anthropogenic emissions in continental North America (defined here as the United States, Canada, and Mexico). Policy Relevant Background concentrations include contributions from natural sources everywhere in the world and from anthropogenic sources outside these three countries. Background levels so defined facilitate separation of pollution levels that can be controlled by U.S. regulations (or through international agreements with neighboring countries) from levels that are generally uncontrollable by the United States. EPA assesses risks to human health and environmental effects from ozone levels in excess of PRB concentrations.

Contributions to PRB ozone include photochemical actions involving natural emissions of VOCs, NOx, and CO as well as the long-range transport of ozone and its precursors from outside North America and the stratospheric-tropospheric exchange (STE) of ozone. Natural sources of ozone precursors include biogenic emissions, wildfires, and lightning."

The definition of PRB implies that, unless all the sources within North America were shut down or traced to, the measurement obtained at various background "pristine" sites cannot be used to determine the PRB level and only Chemical Transport Model (CTM) can be used to estimate the range of PRB values. The US EPA uses the global model GEOS-CHEM to estimate the background ozone level. The estimated PRB ozone concentrations are shown to be depending on season, altitude and total surface ozone concentration with the estimated range of 0.03 to 0.05 ppm for typical summertime background levels. In the 1996 ozone review, the EPA used 4 pphm as the 8-hour daily maximum background ozone level in its health risk assessment evaluations and judged that it is appropriate to estimate risks within the range of air quality concentrations down to estimated policy-relevant background level.

We can define a similar PRB level in the Australian context as the background level in which there are no anthropogenic emission sources in continental Australia. A pristine site, which is not affected by emission sources, could be found to measure the background ozone. Currently there is no plan in all of the state or federal environment authorities to establish such a site for ozone measurement. With regard to the modeling approach, our experience in air quality modeling in the Sydney region indicates that the modeling approach is still having a degree of uncertainty especially at the background level in which there is no anthropogenic emission source in the region. A measurement approach combined with analytical methods using some assumptions on the background level provides alternative way to find the ozone "background" level.

2.2 "Non-policy" background ozone

Altshuller et al (1) have used criteria that are enumerated and discussed for determining whether ozone concentrations at a given site can be considered to be "background" ozone. Using several techniques, the current ozone background at inland sites in the United States and Canada for the daylight 7-h (0900-1559h) seasonal (April-October) average concentrations usually occurred within the range of 35±10 ppb. For coastal sites, the corresponding ozone concentrations are somewhat lower, occurring within the range of 25±10 ppb for locations in the northern hemisphere, but with most ozone concentrations at the coastal sites in the range of 30±5 ppb. These ranges suggest that the background ozone is somewhat dependent on a number of conditions such as the nature of upwind flow, lack of pollution sources, and terrain conditions including deposition with respect to forest or agricultural areas.

In this paper, a "non-policy" background ozone level is considered: non-photochemical condition background ozone. This allow us to use ambient measurements to define it and have the flexibility in taking into account local site conditions.

Non-photochemical background ozone level at a site in Sydney is defined as the average of measured nighttime and early morning hourly values (ie. from 19 hour to 08 hour next morning).

This definition of background ozone excludes the photochemical process that would occur during daytime if only natural sources (excluding anthropogenic sources) presented. There are a number of estimated background ozone levels of interest (1-hour daily maximum, 8-hour daily maximum and daily average) using the hourly measured data at the stations and mostly with summer as the period of interest. A better definition of background level is to include the daytime photochemical process when only natural sources presented. But as discussed before, this defined background ozone can only be estimated by using the modeling method or by using observation at remote clean sites.

2.2.1 Estimated daily non-photochemical background ozone

From the above definition of non-photochemical condition background ozone, a summary statistics on the level of background ozone at different sites can be found. Table 1 shows the results for a number of monitoring sites in the Sydney region. The stations ae mostly urban sites (except Vineyard and Richmond in the North West are located in the semi-rural or suburban area).

Region	Site	Period	1st Quartile (ppb)	Median (ppb)	3rd Quartile (ppb)	Average (ppb)
Sydney East	Woolooware	1/1/1998 to 30/8/2004	2.7	11.9	19.9	12.4
	Rozelle	1/7/1998 to 17/11/2005	2.1	6.5	14.8	9.1
	Randwick	1/1/1998 to 18/11/2005	2.6	12.5	21.1	13.0
	Earlwood	1/2/1998 to 17/11/2005	1.6	4.4	13.4	8.0
	Lindfield	1/1/1998 to 11/02/2005	1.3	6.6	11.3	9.6
North West	Vineyard	1/1/1998 to 18/11/2005	2.9	9.8	18.4	11.7
	Richmond	1/1/1998 to 17/11/2005	1.6	7.0	16.5	10.0
South West	Bringelly	1/1/1998 to 18/11/2005	1.1	5.1	15.4	9.0
	Liverpool	1/1/998 to 17/11/2005	1.1	3.1	10	6.5
Sydney West	Westmead	1/1/1998 to 6/8/2004	1.1	2.8	10.3	6.5
	St Marys	1/1/1998 to 18/11/2005	0.6	2.9	12.0	7.0
	Lidcombe	1/1/1998 to 1/5/2002	1.3	3.5	10.9	6.7
	Blacktown	1/7/1998 to 3/6/2004	1.8	5.0	12.8	8.1

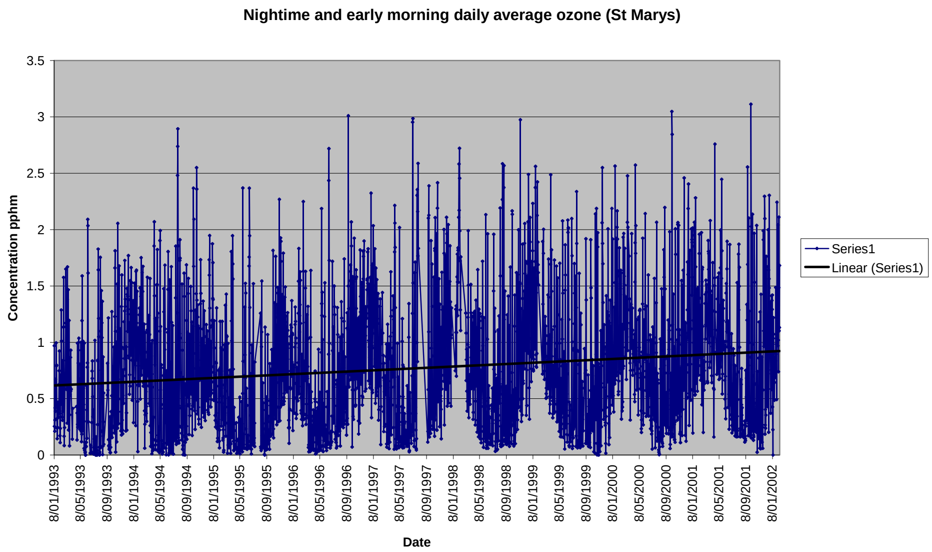
Table 1 – Summary statistics of non-photochemical background ozone at monitoring sites in the Sydney region.

From Table 1, there is difference in the background ozone levels between region, with the East and North West of Sydney having higher background ozone level than the West and South West of Sydney.

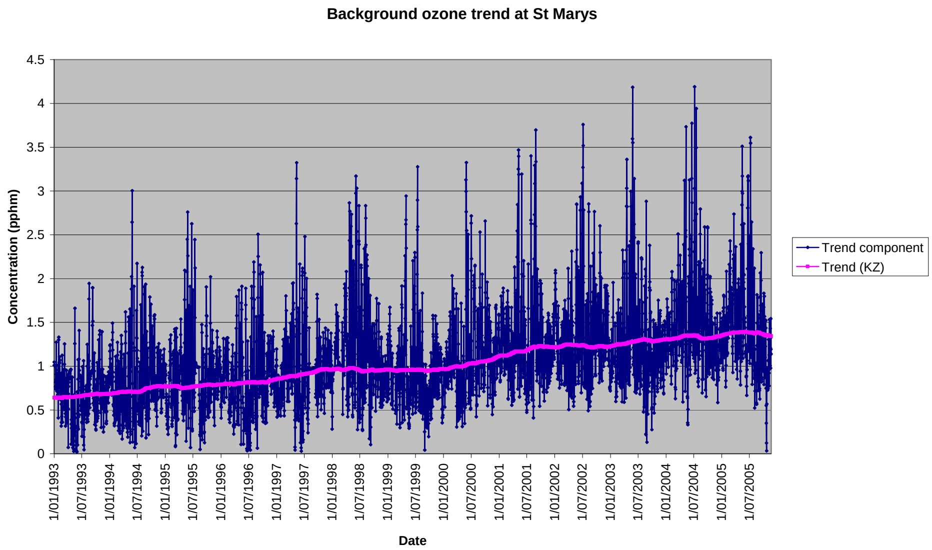
2.2.2 Trend of non-photochemical background ozone in Sydney

In theory, excluding all anthropogenic sources in the region and Australia wide, the background ozone level in Sydney should be stable and constant with respect to time. However, it is possible that global emission outside Australia or other mechanism such as climate-induced changes could influence the level of background ozone over time. It is therefore beneficial to study the change of background ozone as derived from ozone measurements in the temporal domain.

Using hourly ozone monitoring data from the period of 1993 to 2005 at various stations in the Sydney basin and applying the Long Range Dependence (LRD) method (Anh et al. (1997)) and the regression method, the long term trend of the non-photochemical background ozone can be found. Figure 1 shows the results at St Marys site.using the two methods mentioned above for daily average ozone data



(a)



(b)

Figure 1 – Trend using regression (a) and using LRD method (b). The data are daily average ozone averaged over night-time and early morning hourly data ("background" ozone).

Figure 1 shows that there is an increase of daily average background level at St Marys over the period of 1993 to 2005. For all other sites in the Sydney basin, except at Lidcombe, the same trend is found.

Analysing all hourly ozone data instead of daily average ozone shows similar result as shown in figure 2 using regression method.

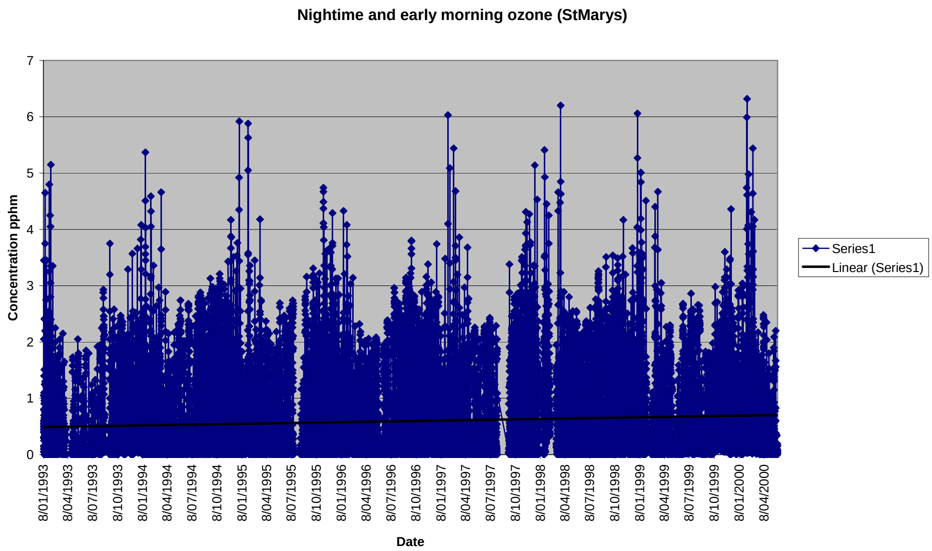


Figure 2 – Trend using regression on night-time and early morning hourly data.

Rather than considering whole yearly ozone data for each year, we can focus only on the summer ozone data when photochemistry is most active. In this case only summer data will be used to find the change in background level during the summer period over the years. But the analysis results show that there is not much difference in the trend lines between only summer data and all yearly data.

Jaff and Ray (2007) has reported ozone trend at 11 remote rural sites in north and western US (including Alaska), in which 7 sites show statistically significant increase in ozone with mean trend of 0.26 ppb per year. These sites are considered as 'pristine' background ozone sites. Temperature changes can explain only a fraction of the trend and the authors suggested that possible explanations for these trends, including increasing regional emissions, change in the distribution of emissions, increasing biomass burning or increasing global background ozone. They strongly suggested that the increase trend is probably due to rapid growth in emissions within North Asia.

Simmonds et al. (2004) shows an increasing trend of background ozone observations at Mace Head on the west coast of Ireland since 1987 through 2003 with a trend of 0.49±0.19 ppb per year. They conclude that there has been at least one major perturbation of the ozone trend during the 1998-1999 timeframe associated with global biomass burning coupled to an intense El Nino event of 1997.

3. DISCUSSION

With regard to ozone background trend, there is a clear upward trend as indicated at nearly all monitoring sites in Sydney. This upward trend is also in line with results in US as reported by Jaff and Ray (2007) and Europe by Simmonds et al. (2004). The increasing trend is suggested as due to increasing global emission especially in North Asia. There is important implication of this background trend for regulatory authorities in many countries in setting the ozone goal and target for emission reduction, as it may be not possible to act independently in the regional context without coordinated action on the global scale.

Currently the ozone goal for 1 hourly and 4-hourly in Australia are 10pphm and 8 pphm respectively. In Sydney, there are several exceedances above the 1 hourly goal each year. There are efforts to reduce the number of exceedances through emission control of motor vehicles, domestic and commercial sources of NOx and Volatile Organic Compounds (VOC) albeit with the increasing population and the number of vehicle fleet. A lower goal was also considered but with the increasing level of background ozone in the Sydney region the efforts and policy measures to reduce the number of exceedances are less effective and in fact are more difficult or impossible to achieve. In Sydney, most exceedances of ozone occured in the West, North West and South West and the relative high background ozone in Sydney North West compared to other parts of Sydney will make this region increasingly difficult to achieve the target of reducing the number of exceedances above the ozone standard.

REFERENCES

Altshuller, A. P., Lefohn, A. S. (1996) Background ozone in the planetary boundary layer over the United States. *J. Air Waste Management Assoc.* 46:134-141.

Anh, V., Duc, H., Azzi, M. (1997), Modelling anthropogenic trends in air quality data, *Journal of Air & Waste Management*, Vol. 47, Jan. 1997, pp 66-71

Jaffe, D., Ray, J. (2007), Increase in surface ozone at rural sites in the western US, *Atmospheric Environment*, 41, 2007, pp. 5452-5463.

Monks, P. (2003), TROTREP Tropospheric ozone and precursors, Trends, Budgets and Policy, Synthesis and Integration Report, Report to the EU FPV Energy, Environment and Sustainable Development Program, European Union, 2003. http://atmos.chem.le.ac.uk/trotrep

Simmonds, P., Derwent, R., Manning, A., Spain, G., Significant growth in surface ozone at Mace Head, Ireland, 1987–2003, *Atmospheric Environment*, 38 (2004), pp. 4769-4778.

Oltmans, S., Lefohn, A., Harris, J., Shadwick D., Background ozone levels of air entering the west coast of the US and assessment of long-term changes, *Atmospheric Environment*, 42 (2008), pp. 6020-6038.

U.S. Environmental Protection Agency (2006) Air Quality Criteria for Ozone and Related Photochemical Oxidants (final). *Research Triangle Park, NC: Office of Research and Development*; EPA/600/R-05/004af. February, http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=149923

U.S. Environmental Protection Agency (2007) Review of the National Ambient Air Quality Standards for Ozone: Policy Assessment of Scientific and Technical Information OAQPS Staff Paper. *Research Triangle Park, NC: Office of Air Quality and Planning and Standards*, EPA-452/R-07-003. January. http://www.epa.gov/ttn/naaqs/standards/ozone/data/2007_01_ozone_staff_paper.pdf