An investigation of high ozone episodes in the City of Johannesburg

Yerdashin R. Padayachi*[1], Tirusha Thambiran[1], Mogesh Naidoo[2], Rebecca M.Garland[2], Nelvia Phala[2]

[1] CSIR, Natural Resources and the Environment Unit, Climate Studies, Modelling and Environmental Health Research Group, P O Box 17001, Congella, 4103, South Africa
[2] CSIR, Natural Resources and the Environment Unit, Climate Studies, Modelling and Environmental Health Research Group, PO Box 395, Pretoria 0001, South Africa

A study of ozone monitoring data in Johannesburg highlighted that the city is frequently affected by high ozone episodes. There is limited knowledge about the chemical and meteorological drivers of these high ozone episodes in Johannesburg. In this paper, a case study of the Delta Park air quality monitoring station is used to describe the process used to identify ozone episodes and the drivers thereof in the city. In 2005 alone, it was found that there were 483 exceedances of the 8-hourly South African National Ambient Air Quality Standard for ozone at Delta Park. The bulk of these episodes occurred in the summer (DJF) and spring (SON) months. Examples of the pollution events during these seasons occurring on 3 February 2005 and 16 September 2005, as well as an event on 31 July 2005 occurring during winter (JJA) are presented. Concentrations of ozone precursor gases at the station were not high for days prior to and on the day of the three ozone episodes. It was unlikely that local sources of pollution contributed to the high ozone concentrations measured at Delta Park station. To determine the origin of the air masses which were transported over Delta Park for the 3 episodes, the Hybrid Single Particle Lagrangian Integrated Trajectory Model (HYSPLIT) model was used. The results of the case study are used to make recommendations for air quality improvements in the city.

Keywords: Ozone, Pollution episode, Meteorological condition, Trajectory model, HYSPLIT.

1. Introduction

Near-surface ozone can have deleterious health effects. There has been a dearth of research in recent years that has indicated that climate change may have implications for the photochemical production of near-surface ozone (Bell et al., 2007; Hogrefe et al., 2004). Since the inception of the National Environmental Management: Air Quality Act (Act No.39 of 2004) (the AQA) in South Africa there has been a greater emphasis on the need for appropriate data to support the implementation of the AQA. As such there has been an increase in the number of air quality and meteorological monitoring stations around the country, with the data being freely available for research purposes from the South African Air Quality Information System (SAAQIS). The aim of this study was to access and use the ambient air quality monitoring data from the SAAQIS to identify possible high ozone episodes in the City of Johannesburg and to identify the key drivers of these episodes. The results of the episodic analysis presented are used to provide recommendations for future research that is needed to support air pollution abatement in the city in the context of a changing climate.

2. An analysis of air pollution episodes in City of Johannesburg

The City of Johannesburg has four air quality monitoring stations that measure ozone levels namely, Delta Park, Buccleuch, Alexandra and the Newtown station. In this study, the monitored data for ozone and its precursor gases for these stations were obtained from the SAAQIS. A data cleaning procedure was used to create usable datasets of ozone for the period of 2004 - 2011. Data quality issues and the lack of precursor data recorded at these sites limited the availability of suitable data necessitating a focus on identifying pollution episodes for further investigation.

A set of selection criteria were applied to the ozone datasets for these stations to identify potential episodes that would have sufficient data for further investigation and that would also represent a pollution event. These criteria included:

1. Exceedances of the 8-hour running average of the National Ambient Air Quality Standard for ozone (61 ppb) (South African Department of Environmental Affairs, 2009)
2. Concentrations within the upper percentiles (95^{th} , 75^{th}, 50^{th}) of the 8-hour concentrations within each annual dataset
3. Exclusion of episodes occurring at one station
4. Minimum of 70% data coverage for days before and after the episode event

The fourth criterion was also applied to the datasets of the ozone precursor gases, namely, nitrogen dioxide (NO_2); nitrogen oxide (NO) and oxides of nitrogen (NO_x).

Based on the application of these criteria it was found that the Delta Park station had anomalously high ozone concentrations compared to other stations (Figure not shown here). Additional analysis using back trajectories were performed for this station. Specifically, the HYSPLIT model was used to determine the path of air masses that may have transported precursor pollutants to the Delta Park air quality monitoring station. The trajectories were calculated using meteorological data from the Global Data Assimilation System (GDAS) at 500 m above ground level, every 72 hours over the period of the episode. The vertical motion was calculated using the model vertical velocity similar to (Gangoiti et al. 2006).

Further data on key meteorological factors (solar radiation and rainfall) and vertical velocity were also used in this study. Solar radiation is a key factor in the photochemical production of ozone (Mittal et al. 2007). For these episodes solar radiation for the Delta Park station was not available and thus modeled information was used. The CCAM (Conformal Cubic Atmospheric Model) was forced by the NCEP Final Reanalysis dataset and run at a resolution of 15 km x 15 km over southern Africa. A subset grid was extracted and values for the point closest to the Delta Park coordinates were taken.

The vertical temperature profile is useful in identifying temperature inversions. The only vertical temperature profile measurements available for this region are from the daily Irene balloon soundings. While these data could be useful in identifying the regionally stable layers, the data cannot be used to show a diurnal profile. Thus vertical temperature data from the CCAM were used in this study

3. High ozone events at the Delta Park monitoring station

In 2005 alone, it was found that there were 483 exceedances of the 8-hourly South African National Ambient Air Quality Standard (NAAQS) for ozone at Delta Park. The bulk of these episodes occurred in the summer (DJF) and spring (SON) months (Figure 1). Examples of the pollution events occurring during these seasons included, 3 February 2005 and 16 September 2005, as well as an event on 31 July 2005 occurring during winter (JJA).

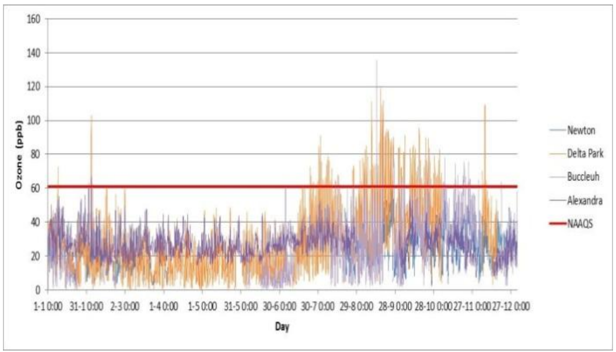

Figure 1: Time series of 8-hourly ozone monitored at Delta Park in 2005.

The episodes on 16 September and 3 February were chosen because the summer (i.e. 3 February 2005) episode did not occur in a typical ozone season i.e. spring. Additionally, the spring episode (i.e. 16 September 2005) was chosen because it had the highest exceedance as compared to other days with exceedances in spring.

These two high readings are further isolated considering the two days before and after the occurrence of the episodes. There are also a high numbers of exceedances observed during the spring season as compared to the summer. Additionally, ozone peaks occurred at different times when considering the two days on either side of the occurrence, with the 3 February and the 16 September showing peaks late in the day around 16:00 and 17:00, respectively (Figures not shown here).

Furthermore, during the 3 February and 16 September 2005 there were neither clouds nor rain recorded according to the historical from OR Tambo and (Figures not shown here**)** the vertical profile of modelled temperature shows no inversions on the days of these episode.

For the 16 September the predominant wind directions for strong winds was both north westerly and north easterly and on the 3 February the dominant wind direction was south east with less strong winds according to the historical data from OR Tambo.

During the occurrence of the two episodes, meteorological conditions were similar with no clouds, no modelled rainfall or inversions. Even though there was elevated ozone levels on these days, precursor concentrations (particularly for 3rd Feb) investigated above does not indicate localized ozone formation.

The episode occurring during the period during 28 July to 2 August, which shows the highest peak in 8 hour ozone as shown in Figure 2 below on 31 August. The peak occurs on a Sunday as opposed to those occurring peaks on 3 February 2005 and 16 September 2005 (weekdays). The ozone peak of Sunday, 31 July 2005 was found to be at 111 ppb whereas the week day average was around 70 ppb for the same time of day.

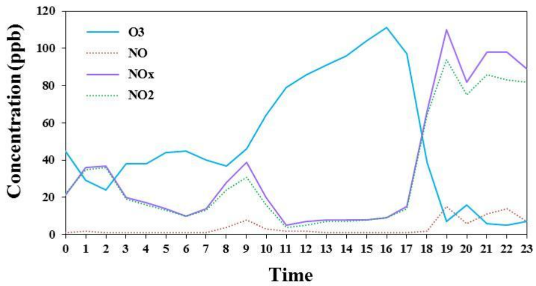

Figure 2: Diurnal ozone profile for the 31 July 2005 at Delta Park station.

This is the inverse of what should be expected since traffic tends to on average peak during the weekdays.

The HSYPLIT back trajectories were used to investigate if this peak could have been influenced by the transport of pollution air masses to the region (Figure 3).

Looking at the back trajectories (Figure 3), most days follow a similar circulation pattern, that being the anti-cyclonic flow over the Highveld, which is characteristic for this season (Balashov et al. 2014). The peak ozone days i.e. 30th (light blue trajectory) and 31st (green trajectory), exhibit similar horizontal transport to the Delta Park station, from the west closest to the station. However this is also similar to days 29 July and 2 August which show lower ozone concentrations.

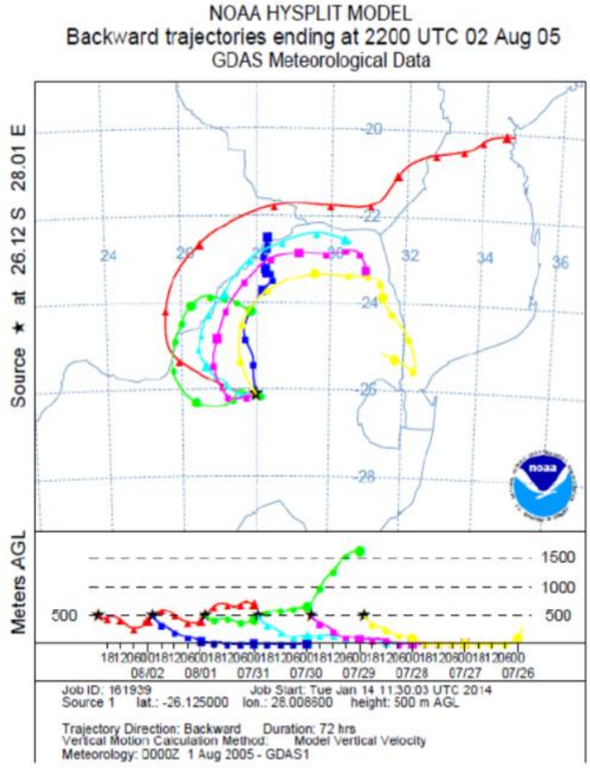

Figure 3: Back trajectories to Delta Park for 28 July to 2 August 2005.

The vertical transport as shown in Figure 3 does show an important difference with the 31 July receiving air masses from higher altitudes. This could indicate both precursor and ozone transport from further afield. The anti-cyclonic circulation is often produced by a persistent high pressure cell located over the Highveld region, which may lead to semi-permanent stable layers. Such stability may be noted when looking at the vertical temperature profile.

However, further research is needed to investigate the possibility of the weekend effect. This will involve developing an improved understanding of whether:

- A reduction in NO_x emissions on weekends reduces the titration of ozone
- A weekend change in the timing of NO_x emissions allows for more efficient production of ozone
- Less precursors or pollution allows for more sunlight and thus more efficient photochemical production of ozone.

The influence of long-range transport and the 'weekend effect' on near-surface ozone levels has important implications for the City of Johannesburg. Other cities, internationally, have demonstrated that although efforts have been made to remediate near-surface ozone issues, there is evidence that while local emissions of ozone have been successfully reduced, there has no drastic decline of near-surface ozone levels over the past 10 years (Huryn and Gough 2014).

4. Conclusion

The high ozone events at the Delta Park station is of interest for further study as this station is an urban background air quality monitoring station and was specifically situated in an area where there are no obvious localised air pollution emission sources. However, this station often exceeds the 8-hourly NAAQS for ozone. Furthermore, these exceedances are a major concern since ozone is detrimental to human health as well as the environment. There is relatively little knowledge about the mechanisms of chemical transformation and transportation of ozone and its precursor gases in the urban areas of Johannesburg.

There is a possibility that the peaks observed during the high episodes in spring and summer presented above, were formed as a result of transported reacted precursors {NO and oxidated volatile organic compounds (VOCs)}. Future research on the characterisation of the NO_x/VOC's relationship is needed to understand the 'weekend effect' noted during the winter episode discussed. Measurement of VOC and oxidation products around Delta Park will aid immensely in this characterization and allow for effective air quality management and allow the city to be better prepared for the potential impacts of climate change on the levels of pollution experienced.

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