H14-309

A SCREENING METHOD FOR OZONE IMPACTS OF NEW SOURCES BASED ON HIGH-ORDER SENSITIVITY ANALYSIS OF CAMX SIMULATIONS FOR SYDNEY

Greg Yarwood[1], Yvonne Scorgie[2], Nick Agapides[3], Edward Tai[1], Prakash Karamchandani[1], Claire Holman[3], Nick Agapides[4], Kelsey Bawden[4], Jason Spencer[4], Toan Trieu[4]

[1]ENVIRON, 773 San Marin Drive, Suite 2115, Novato, CA 94998, USA
[2]ENVIRON Australia, 100 Pacific Highway, North Sydney NSW 2060, Australia
[3]ENVIRON UK, Box House, Box, Wiltshire SN13 8AA, UK
[4]New South Wales Office of Environment & Heritage, 59-69 Goulburn St, Sydney NSW 2000, Australia

Abstract:An efficient screening methodology is developed to evaluate ozone impacts of proposed new emission sources in the New South Wales Greater Metropolitan Region (GMR) which includes greater Sydney, Newcastle and Wollongong. Photochemical grid models, such as the Comprehensive Air quality Model with extensions (CAMx), are used to evaluate ozone impacts because they account for non-linear ozone chemistry and other important processes (transport, dispersion, etc.) However, applying CAMx for every proposed new source would impose an unnecessary burden that can be avoided by using an ozone screening method (OSM) to determine when more detailed evaluation is needed. We developed an OSM based on high-order sensitivity analysis of CAMx simulations for the GMR. CAMx simulations were performed for four summer months from 2003--2005. Prototypical new sources were introduced at five locations within the GMR and ozone impacts were analyzed within the plume downwind of each new source. Ozone sensitivity to new emissions of NOX and VOCs was computed at first and second-order by using the high-order decoupled direct method (HDDM) in CAMx. Ozone sensitivity coefficients were implemented in the screening tool (a spreadsheet) to calculate the incremental increase in ozone concentration that results from adding a new emission source in one of five sub-regions of the GMR. Thus, the OSM accounts for non-linear interaction between NOX and VOC emitted by the new source, differences in the reactivity of VOCs emitted by the new source, and sub-regional variation in ozone sensitivity to VOC and NOX within the GMR airshed. New sources that are estimated to cause ozone increases exceeding a screening threshold become candidates for more detailed evaluation using a model such as CAMx.

Key words: *Ozone, emission source impacts, VOC, NO_X, screening tool, decoupled direct method, HDDM, CAMx.*

INTRODUCTION

Ambient ozone in Australia is regulated under the National Environment Protection (Ambient Air Quality) Measure (Air NEPM) standards. The level of the 1-hour standard is 100 ppb and the 4-hour standard is set at 80 ppb. Ozone concentrations in the Sydney region have exceeded either or both of the Air NEPM ozone standards every year since 1994 (DECCW, 2010). The number of days when the 1-hour standard was exceeded in Sydney ranged from none in 1995 to 19 in 2001. Concentrations in the Sydney airshed can be as high as double the Air NEPM standards. Ozone exceedances are less frequent in the Illawarra, near the town of Wollongong to the south of Sydney, occurring on up to 7 days a year. The lower Hunter region, near the town of Newcastle to the north of Sydney, has recorded only two exceedances of the 1-hour standard since 1999. When new stationary sources of ozone precursor emissions are proposed within the Sydney Greater Metropolitan Region (GMR), there should be a robust methodology for ozone impact assessment that accounts for existing local air quality and the magnitude of the new source emissions.

Emissions performance standards for both nitrogen oxides (NO_X) and volatile organic compounds (VOC) are contained in local clean air regulations. However, these performance standards are general and do not relate to the sensitivity of the receiving airshed. The Approved Methods for Modelling do not currently contain a procedure for predicting the impacts associated with ozone precursors. This study was conducted to address the potential need for additional, location-specific stationary source controls, combined with scientifically defensible methods to efficiently determine which sources will have a significant impact on ozone. A tiered approach providing for Level 1 and 2 screening methods was followed to be consistent with modelling approaches applied for other air pollutants. The tiered ozone impact assessment procedure is designed to provide direction about: (1) When an expedited Level 1 assessment will be adequate; (2) When a rigorous Level 2 ozone impact assessment needs to be conducted; (3) How to determine whether an ozone impact assessment is considered to be technically robust; (4) The extent to which additional ozone precursor controls are required at the proposal stage for a new source. Efficient methods for determining these outcomes are required to ensure that the development application process is conducted in a timely, transparent and scientifically rigorous manner.

METHODOLOGY

A literature review was conducted to identify regulatory requirements for new stationary sources in OECD member countries as they apply to ozone precursor emissions. The literature review also looked for precedents on what magnitude of ozone impact is considered permissible for a new stationary source and what modelling methods are used to evaluate ozone impacts of new stationary sources. Photochemical grid models (PGM) were found to be the primary tool for ozone impact assessments. No precedents were found for permissible ozone impacts and so screening thresholds were developed by analogy with levels used for other pollutants. Other regulatory requirements identified by the literature review are discussed in more detail below.

Based on the literature review, the Level 2 assessment uses a PGM to calculate by brute force the ozone increment attributable to emissions from the proposed new source. For the more expedited Level 1 assessment, a screening tool was developed specifically for the Sydney GMR by analysing results of PGM simulations for prototypical new sources added at representative locations within the GMR. Criteria were developed to determine when a Level 1 assessment is adequate or when a Level 2 assessment is needed. These criteria consider the emissions from the new source, the ozone impact of the new source estimated using the Level 1 screening method, and the amount of ozone currently present in the receiving airshed.

Figure 27: The Sydney GMR modelling domain used for CAMx simulations containing the Sydney, Newcastle and Wollongong regions.

REGULATORY APPROACHES IN OTHER COUNTRIES

In the US, regulatory requirements for stationary sources differ between areas that satisfy national ambient air quality standards (NAAQS) for ozone ("attainment areas") compared with those that do not ("non-attainment areas"). Similarly, regulatory requirements differ for existing stationary sources compared with those being newly constructed or modified. The level of control technology required depends on the ambient ozone concentrations within the receiving environment relative to the NAAQS for ozone. Given that there is an emphasis on demonstrating best practice control technologies within the US permitting process, there is not an explicit requirement to model the ozone impact of new sources. In 1988, the US EPA developed an ozone screening method, called the Scheffe point source screening tables, that was based on a trajectory model but this method was found to technically deficient and was retracted (Scheffe, 2006.)

The EU requires that facilities adopt Best Available Techniques (BAT) as prescribed within the EU BAT Reference documents (BREFs). The recent EU Industrial Emissions Directive makes the use of BREFs effectively mandatory. The BREFs provide information on the emissions achievable with BAT, often as a range of emissions, and the Industrial Emissions Directive requires that these should be used to set emission limits in the facility operating permit.

ALLOWABLE OZONE INCREMENT

The literature review did not identify ozone concentration increments for the evaluation of impacts associated with new or modified stationary sources. In the US, concentration increments (i.e. Prevention of Significant Deterioration (PSD) increments) are used for pollutants other than ozone and the relationships between PSD increments and the NAAQS were used as a guide for developing ozone increments. For short-term (i.e. 24-hour or less) averaging periods, the PSD increment for a given pollutant is generally between 1% and 6% of the NAAQS. Applying this relationship to the Air NEPM standards for ozone leads to ozone increments of between 1 and 6 ppb for 1-hour average and between 1 and 5 ppb for 4-hour average ozone.

In this study, an incremental increase of greater than or equal to 1 ppb ozone (expressed as either a 1-hour or 4-hour average) has been selected as the level which represents a significant increase in ground-level ozone. This metric has been selected on the basis of the rationale detailed above, combined with the 1 ppb concentration representing a measurable change using conventional ambient monitoring instrumentation.

LEVEL 1 OZONE SCREENING PROCEDURE

The Level 1 screening procedure was developed from simulations using the Comprehensive Air quality Model with extensions (CAMx; ENVIRON, 2010) for the Sydney GMR performed for two ozone seasons (i.e. December and January; 2003/4 and 2004/5) with and without new sources added. Representative emissions for each prototypical new source, based on an average of existing sources, were set at 0.611 tonnes/day of NO_X and 0.759 tonnes/day of VOC. Five source locations were analysed, namely West Sydney, Central Sydney, East Sydney, Newcastle and Wollongong. For each source location, several (4-5) days were selected for screening purposes that had enhanced ozone in the GMR, acceptable CAMx model performance, and ozone impacts from the new source that were predominantly over land. The selected days were then used for CAMx simulations with the high-order Decoupled Direct Method (HDDM; Cohan et al., 2010) used to calculate sensitivity coefficients of ozone to the additional NO_X and VOC emissions from a new source. The sensitivity coefficients were calculated at first and second-order (i.e., $\partial O_3/\partial NO_X$, $\partial O_3/\partial VOC$, $\partial^2 O_3/\partial NO_X^2$, $\partial^2 O_3/\partial VOC^2$, $\partial^2 O_3/\partial NO_X \cdot \partial VOC$) to account for non-linearity in the relationship between ozone formation and emissions. These ozone sensitivity coefficients enable ozone impacts to be calculated for a new source with different emissions than the prototypical new source described above.

The ozone screening tool is implemented as a spreadsheet. Emissions of NO_X, VOC and CO are input and the ozone increment is calculated for 300 grid cells downwind of the source (Figure 1). VOC emissions can be specified either as total VOC or with source-specific VOC composition. Supplying source-specific VOC composition is the preferred method because it avoids having to assume that the source emits a default mixture of VOCs. Ozone impacts are adjusted for VOC composition using reactivity factors calculated specifically for each source location using HDDM in CAMx.

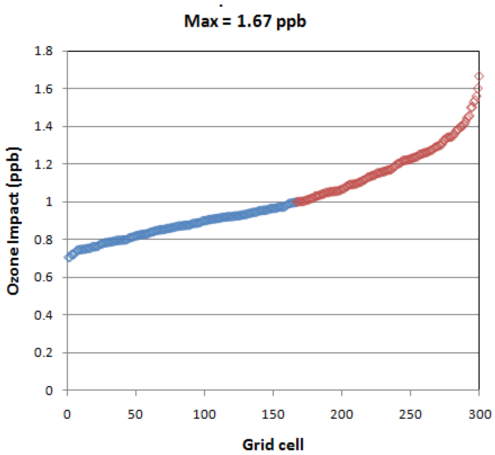

Figure 1. 1-hour ozone increments for 300 grid cells downwind of a new source in Newcastle emitting 2 tonnes/day of NO_X and 5 tonnes/day of VOC calculated using the Level 1 screening tool. The maximum impact (1.67 ppb) exceeds the maximum allowable increment of 1 ppb for nonattainment areas.

The accuracy of the screening tool methodology was evaluated by comparison with the results of additional CAMx simulations for sources with NO_X and/or VOC emissions between zero and 25 times the emissions that were used to develop the screening tool. The screening tool method was found to be accurate and had small bias as illustrated by Figure 2. This analysis also provides a comparison between the Level 1 and Level 2 screening methods (because the Level 2 method uses brute force simulations) and shows that the methods are consistent. However, use of the Level 1 screening tool should be restricted to sources with emissions within an applicable range.

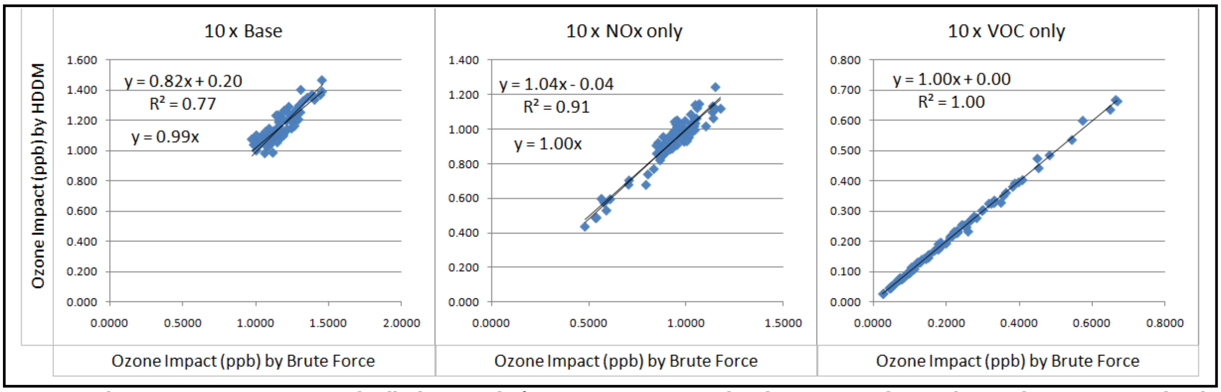

Figure 2. 1-hour ozone increments in grid cells downwind of a new source in Central Sydney computed using the Level 1 screening tool and by brute force CAMx simulations. The VOC and/or NO_X emissions were 10 times larger than used to develop the screening tool.

The Level 1 screening tool is applicable for assessing the impact of sources with emissions of up to 5,500 tonnes/annum of NO_X and/or 7,000 tonnes/annum of VOC (25 times larger than used to develop the screening tool.) If source emissions exceed this upper bound, a Level 2 refined procedure may be required. If the ozone impact estimated by the Level 1 screen tool exceeds the maximum allowable increment (1 ppb for ozone nonattainment areas), a Level 2 refined procedure may be required.

LEVEL 2 OZONE SCREENING PROCEDURE

The Level 2 refined procedure uses the model inputs developed for the Level 1 screening procedure. Two CAMx runs are performed, with and without the new source emissions, to directly determine the ozone impact of the new source by brute force. The Level 2 refined procedure is closely related to the Level 1 screening procedure to provide consistent evaluations of new source ozone impacts. The intent of directly modelling the source using the Level 2 refined procedure is to eliminate any uncertainties attributable to the parameterisation of model results using the Level 1 screening procedure tool. The same criteria should be used to evaluate the significance of new source ozone impacts for the Level 1 and Level 2 procedures.

CONCLUSIONS

An easy to use screening procedure has been developed to evaluate ozone impacts of new stationary sources proposed for the Sydney GMR. This Level 1 procedure is based on high order sensitivity analysis of CAMx simulations for prototypical new sources located at representative locations within the GMR. The procedure is implemented in a spreadsheet.

The Level 1 screening procedure tool has been tested by comparison with brute force CAMx simulations in which different size sources have been added at the Central Sydney location. The Level 1 screening procedure tool provided accurate results over a wide range of source sizes with NO_Xemission rates varying from zero to 5,578 tonnes/annum and VOC rates varying from zero to 6,921 tonnes/annum. The upper ends of these emission ranges are 25 times larger than the source emissions used to develop the tool. The accurate performance of the tool over wide variations in NO_X and VOC emission inputs derives from including second-order sensitivity coefficients to account for non-linearity in ozone formation.

The following recommendations are given for use of the Level 1 screening procedure tool: (1) Source-specific VOC emissions and speciation is required when applying the Level 1 screening procedure tool to meet OEH ozone impact assessment requirements. Documentation should be provided describing the basis for the VOC emissions and speciation and why it is appropriate for the type of source. (2) The Level 1 screening procedure tool is applicable for the assessment of sources with emissions up to 5,500 tonnes/annum of NO_X and 7,000 tonnes/annum of VOC. In the event that source emissions exceed the upper bound emission rates of the tool, a Level 2 refined procedure should be conducted.

In this study, an incremental increase of greater than or equal to 1 ppb ozone (expressed as either a 1-hour or 4-hour average) was selected as the level which represents a significant increase in ground-level ozone. This metric was selected by analogy with screening levels used for other air pollutants, combined with the 1 ppb concentration representing a measurable change using conventional ambient monitoring instrumentation.

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