

Chapter 3

Papers

This chapter outlines the main findings in each scientific paper published as part of this thesis. These publications addressed the research questions framed in Sect. ?? and are found in Chaps. ??–??.

3.1 Paper I: A comparison of chemical mechanisms using tagged ozone production potential (TOPP) analysis

Published: J. Coates and T. M. Butler. A comparison of chemical mechanisms using tagged ozone production potential (TOPP) analysis. *Atmospheric Chemistry and Physics*, 15(15):8795–8808, 2015.

The first paper presents a box modelling study where the effects on ozone production from VOC degradation chemistry in reduced chemical mechanisms (Table ??) was compared to the detailed MCM chemical mechanisms. Other chemical mechanism comparison studies noted differences in ozone levels between chemical mechanisms, however these studies did not deduce the root causes for these differences. This chemical mechanism comparison used the tagging approach described in Sect. ?? to give insights into how the simplified representation of VOC degradation by chemical mechanisms influenced ozone production.

The ozone production from the degradation of VOCs typical of urban environments were compared between the different chemical mechanisms. The box model simulated maximum ozone production (VOC-and-NO_x-sensitive) regime by

emitting the amount of NO required to balance the source of radicals at each time step. As described in Sect. ??, the tagging approach used the production of O_x as a proxy for ozone production.

The simulated ozone mixing ratios using reduced chemical mechanisms were generally lower than the ozone mixing ratios using the reference MCM chemical mechanisms on the first two days of simulations. Only the CRI v2 and RADM2 produced higher ozone mixing ratios than the MCM chemical mechanisms. Higher ozone mixing ratios using CRI v2 than the MCM were obtained during the development of the CRI v2. In RADM2, a lower yield of ketones from the degradation of HC3 (representing less-reactive VOC such as alkanes and alcohols) compared to the MCM led to higher ozone mixing ratios with RADM2.

The VOC degradation described in CRI v2, a lumped-intermediate chemical mechanism, produced the most similar amounts of O_x to the MCM v3.2 for each VOC. On the other hand, the degradation of VOC in all other reduced chemical mechanisms led to differences in O_x production with the largest differences occurring after the first day of simulations. The degradation of aromatic VOC in the reduced chemical mechanisms led to the largest differences in O_x production from the MCM v3.2.

Many VOC are broken down into smaller-sized degradation products faster on the first day in reduced chemical mechanisms than the MCM v3.2. The faster breakdown of VOC leads to lower amounts of larger-sized degradation products that can further degrade and produce O_x in the reduced chemical mechanisms. Thus, many VOC in reduced chemical mechanisms produce a lower maximum of O_x than the MCM v3.2 resulting in lower O_3 mixing ratios from the reduced chemical mechanisms compared to the MCM v3.2.

Reactive VOC, such as alkenes and aromatic VOC, produce maximum O_x on the first day of the simulations. Alkenes produce similar amounts of O_x on the first day between chemical mechanisms; differences in O_x production arise when mechanism species are used to represent individual VOC. Large inter-mechanism differences in O_x production result from the degradation of aromatic VOC on the first day due to the faster break down of the mechanism species representing aromatic VOC in reduced chemical mechanisms. The less-reactive alkanes produce maximum O_x on the second day of simulations and this maximum is lower in each reduced chemical mechanism than the MCM v3.2 due to the faster break down of alkanes into smaller sized degradation products on the first day.

3.2 Paper II: Variation of the NMVOC Speciation in the Solvent Sector and the Sensitivity of Modelled Tropospheric Ozone

Published: E. von Schneidemesser, J. Coates, A. J. H. Visschedijk, H. A. C. Denier van der Gon, and T. M. Butler. Variation of the NMVOC speciation in the solvent sector and the sensitivity of modelled tropospheric ozone. *Atmospheric Environment*, Submitted for Publication, 2016.

The second publication compared the ozone levels produced when using different emission inventories of NMVOC emissions for the solvent sector within a box model. Different chemical mechanisms (MCM v3.2, MOZART-4 and RADM2) were used to ascertain whether the representation of tropospheric chemistry affected the differences in ozone production when using the different emission inventories.

Emission inventories (EIs) are a critical model input but also a major source of uncertainty in modelling studies. For example, the speciations of EIs in many locations are not reflected by ambient measurements, EIs may not adequately reflect the temporal nature of emissions and many EIs may be outdated. Before taking upon the huge task of updating EIs addressing these issues, a scoping study looking at the sensitivity of ozone production when changing the model input from was performed in this study.

The experimental setup considered emissions from the solvent sector as this sector has the largest contribution to NMVOC. Model simulations used NO_x conditions simulating VOC-and- NO_x -sensitive conditions thus looking at the differences in maximum ozone production when using the emission inventories for the solvent sector in Table ???. Furthermore, simulations were performed using different chemical mechanisms (MCM v3.2, MOZART-4 and RADM2) comparing the differences with different representations of VOC degradation chemistry. Simulations using the tagging chemical mechanisms in Sect. 3.1 were performed allowing allocation of O_x production to the emitted NMVOC specified by each EI.

A maximum difference in ozone mixing ratios ranging between 11 ppb and 15 ppbv when using the different EIs was obtained from the box model simulations using each chemical mechanism. When using the same EI speciation, a maximum difference of 6.7 ppbv in ozone mixing ratios was determined between simulations with different chemical mechanisms. Thus both the choice of chemical mechanism and EI influenced the amount of ozone produced.

Further simulations using emissions from all other non-solvent sectors while varying the emissions from the solvent sector produced a lower maximum difference in ozone mixing ratio (6–9 ppbv) for each chemical mechanism. When further including emissions from biogenic sources reduced the maximum differences in ozone mixing ratios even further (5–8 ppbv) with each chemical mechanism.

Reactive VOC, such as alkenes and aromatic VOC, had the highest contribution to O_x production on the first day. While less-reactive VOC, such as alkanes and oxygenated VOC, contributed the most to the cumulative O_x production after seven days.

EIs specifying more emissions of alkanes produced more O_x than EIs specifying larger emissions from oxygenated NMVOC. A positive correlation between O_x production and the specification of alkane species by the EIs was determined while a negative correlation was determined between cumulative O_x production and specification of oxygenated species by the EIs. No correlation was found between the specification of aromatic species by EIs and O_x production and not all EIs specify alkene emissions thus no correlation was made between alkene emissions and O_x production.

3.3 Paper III: The Influence of Temperature on Ozone Production under varying NO_x Conditions – a modelling study

Published: J. Coates, K. A. Mar, and T. M. Butler. The influence of temperature on ozone production under varying NO_x conditions – a modelling study. *Atmospheric Chemistry and Physics Discussions*, In preparation, 2016.

The final study of this thesis looked at the ozone-temperature relationship with different NO_x conditions simulated by a box model. A non-linear relationship between ozone production with temperature and NO_x conditions has been noted using an analytical model constrained to observational measurements but not yet reproduced in a modelling study. Temperature increases ozone production through increasing NMVOC emissions from biogenic sources and by increasing the rates of chemical reactions. Modelling studies have as yet not quantified which of these effects is more important for ozone production. The study aimed to determine whether temperature-dependent increases in reaction rates or isoprene emissions were more important for ozone production on the urban scale and whether the non-linear

relationship of ozone with temperature and NO_x was reproduced using different chemical mechanisms.

Box model simulations were performed using NMVOC emissions representative of central Europe, first using a temperature-independent source of isoprene emissions followed by simulations using the temperature-dependent source of isoprene emissions described using the MEGAN2.1 algorithm. The choice of chemical mechanism may also influence the relationship of ozone on temperature, thus all simulations were repeated using the MCM v3.2, CRI v2, MOZART-4, RADM2 and CB05 chemical mechanisms. Model simulations included vertical mixing to the free troposphere and were performed by systematically varying the temperature and NO emissions at each temperature (Sect. ??). The tagged chemical mechanisms could not be used in this study as the NO_x conditions gave rise to simulations with NO_x -saturated conditions where using O_x production as a proxy for ozone production is not valid (Sect. ??).

A non-linear relationship of ozone with temperature and NO_x emissions was produced using each chemical mechanism. This non-linear relationship was similar to that previously reported from observational studies. In each chemical mechanism, the absolute increase in ozone with temperature was greater for temperature-dependent chemistry than the increase ozone with temperature due to isoprene emissions. The largest increases in ozone mixing ratios were obtained in High- NO_x conditions and the lowest increase in ozone mixing ratios was achieved using Low- NO_x conditions.

The net increase in the production of O_x normalised by the loss rate of emitted VOCs with temperature was caused by the decrease in ozone deposition with temperature. Furthermore, the O_x production was constant with temperature showing that the production of O_x with temperature was controlled by the loss rate of VOCs. The increased loss rate of VOCs with temperature was mainly due to the increase of OH with temperature. The increase in OH with temperature is coupled to the increase of ozone with temperature showing the strong coupling of ozone with OH.

The box model results were also compared to observational data and output from the 3-D model WRF-Chem. The rate of increase of ozone with temperature from the box model was about half the rate of increase of ozone with temperature using observational and WRF-Chem output. Observational data and the output of 3-D models such as WRF-Chem include additional effects of temperature on ozone, such as stagnant conditions, where low wind speeds lead to the accumulation of oxidants promoting ozone production.

Model simulations were performed without mixing to approximate stagnant conditions and in these model simulations the increase in ozone with temperature was faster than the model simulations including mixing. The differences in the rate of increase of ozone with temperature between mixing simulations and chemical mechanisms indicated a higher sensitivity to mixing than the choice of chemical mechanism.