Institution: University of York

Unit of Assessment: 8, Chemistry

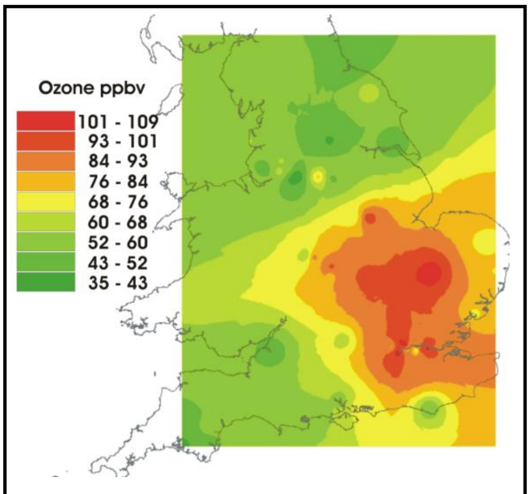
Title of case study: Natural organic emissions and summertime UK air quality

1. Summary of the impact

Research performed at York during 2003-6 revealed the unexpectedly high level of organic emissions by trees in the UK during the hottest periods, catalysing the formation of smog. This research on causes of summertime air pollution informed UK government policy reports in 2008/9. It also resulted in on-going changes in modelling of biogenic emissions by DEFRA (Department for Environment Food and Rural Affairs), embedding the knowledge into all future government policy evaluations of air pollution. The Met Office and others have now improved their air quality forecasts provided to the public by adding the effect of natural emissions. The beneficiaries of the York research include government and those people at health risk from low air quality. The impact spans public policy, environmental policy and health.

2. Underpinning research

Ozone in the troposphere is an air pollutant and a greenhouse gas. Moreover, it has been known for 40 years that the action of light on volatile organic compounds (VOCs) in the atmosphere generates ozone at ground level, resulting in “photochemical smog”. It is a challenge to determine how much ozone will form at a given time, since each VOC has a different ozone-forming potential. We need therefore to know what types of VOCs are present in air, and in what quantities. In 2003, NERC supported a major experimental project[1] led by Lewis (also including Carpenter, Hamilton and Lee from York) to take state-of-the-art measurement into the field in the UK to establish which organic compounds were drivers of ozone formation. Other contributing universities were Leeds, UEA, Manchester, Bristol and Imperial. The York team led the consortium and made the measurements of organic emissions, while the other universities provided supporting data. York led the data analysis.



Ozone levels during 2003 heat wave

Observations of all major VOC classes and other compounds were made during summer 2003 as part of a large collaborative field experiment during the most significant heat-wave for more than a decade. Ozone in SE England exceeded 240 μg m^{-3} on some days, levels reminiscent of the 1970s and early 1980s before the widespread use of catalytic converters in vehicles. This was a highly unexpected level of air pollution since European policy on emissions targets had been assumed to have mitigated against very high ozone episodes. Using data from this field study, the York group published papers in which they determined that during the hottest periods, organic emissions (especially isoprene) from plants rose dramatically leading to a natural contribution to the overall atmospheric VOC loading, in turn generating additional smog which was not accounted for in predictive forecasting models.[2,3] This was an unexpected finding since the UK was considered to have negligible isoprene emissions from its plant stock. These publications highlighted for the first time the potential direct impacts of a warmer climate on air quality in the UK and consequent impacts on quality of life. The research models demonstrated the inadequacy of accounting procedures for emissions used by UK government since their methods did not include these natural organic emissions in a representative way.

Key researchers

Alistair C. Lewis: Started 01/05/03 as Reader. Chair since 01/10/06

Lucy J. Carpenter: Started 01/09/2000 as Lecturer A, Chair since 01/10/09

James D. Lee: Started: 01/09/03 as Research Fellow Grade II, Promotion to Grade 8 01/10/11

Jacqueline F. Hamilton: Started 20/08/03 as Post-doc. Appointment to Lecturer from 01/02/08

3. References to the research

This research exceeds the quality threshold as is evident from journal quality, number of citations (data from Scopus, November 2013) and recognition in Lewis's Leverhulme Prize and RSC John Jeyes Award.[4]

Research funding to determine atmospheric chemistry of organic compounds in the UK.

1. NERC consortium project 2002-2006, part of the Polluted Troposphere Research Programme: Tropospheric Organic Chemistry Experiment (TORCH), NER/2002/00498. Principal Investigator A.C Lewis (at University of York), with 15 co-investigators from five UK HEIs. Total grant £975K.

Peer-reviewed papers with research outcomes used later as evidence for policy change:

2. **J. D. Lee, A. C Lewis**, P. S. Monks, M. Jacob, **J. F. Hamilton**, **L. J. Carpenter**, *et al*. "Ozone Photochemistry And Elevated Isoprene During The U.K. Heat Wave Of August 2003". *Atmos. Environ*. 2006, **40**, 7598-7613. DOI: 10.1016/j.atmosenv.2006.06.057. *43 citations*.

3. S. Utembe, M. E. Jenkin, **A. C. Lewis**, J. R. Hopkins and **J. F. Hamilton**. "Modelling The Ambient Distribution of Organic Compounds During The August 2003 Ozone Episode In The Southern U.K". *Faraday Discuss.* 2005, **130**, 311-326. DOI: 10.1039/b417403h. *29 citations.*

Other evidence of quality: Awards to A.C. Lewis

4. Philip Leverhulme prize in 'Ocean, Earth and Atmospheric Science' (2004) – citation: "Alastair Lewis has used his talent for chemical analysis to open a new area of atmospheric chemistry, devising innovative techniques to measure complex hydrocarbon volatiles both in the unpolluted atmosphere and in urban air. ... They can play an important role in the chemistry of the atmosphere and are involved in the generation of ozone, which is a potential health hazard when it occurs in the lower atmosphere at high concentration. His measurements have helped to show that recent exceptional summer temperatures in the UK have been accompanied by large emissions of carbon volatiles from vegetation, resulting in high ozone levels across the country."

RSC John Jeyes Award 2012 citation: "For his significant contributions to our understanding of the atmospheric chemistry, transport and impacts of organic compounds, enabled by his development of novel methods of chemical analysis".

4. Details of the impact

The research directly resulted in changes in UK government policy and improved forecasts of air quality made available to the public. In the UK, air pollutants reduce lifespan on average by 8-14 months, and by up to 9 years for the most vulnerable groupings, inducing respiratory and pulmonary diseases that affect disproportionately the elderly and children. Health costs are estimated to be £10.7 billion per annum[5] and are comparable to those of alcohol and drug misuse. Vulnerable people are advised to consult air quality forecasts, as illustrated by the Met Office and Asthma Society:[6] "*If you find pollution triggers your asthma, keep well informed about air quality. Ozone can be a problem for some people. Levels are likely to be higher on hot summer days."* Air pollution also causes ecological damage and reduces crop yields. The connection between heat-waves and air pollution and their impacts on the population reached wide attention during summer 2003, a period that led to several thousand additional deaths throughout Europe attributable to ozone and fine particulates.[7] The event catalysed public debate on the effects of air pollution, the possible impacts of a warmer climate and the effectiveness of Government policy for pollution control. In response, DEFRA collaborated with the York team to improve their capability for prediction of air quality. This collaboration began in 2003 and continues, most recently during the heat-wave of July 2013.

The government has benefited from clear scientific evidence for the causes of continuing peak summertime ozone pollution, and an enhanced appreciation of the limitations of EU control policies in periods of high temperatures. The inclusion of biogenic species in predictive models has provided government with an improved capability to forecast air quality in the short term,[8] and provided advice to the public (for example through DEFRA and Met Office air quality forecasts). It has also improved estimates of future changes in air pollution of natural origin and those arising through policy change. There is now a better appreciation of the balance between the effects of natural and man-made emissions on air quality. Since controlling anthropogenic emissions is a costly activity, the benefits of improved prediction are felt in both health and financial domains.

Section 2 presented the finding from York that biogenic volatile organic compounds are released in large quantities from vegetation in the UK on hot summer days, promoting rapid photochemical formation of ozone. The natural emissions offset some of the benefits from policies to reduce man-made VOCs from sources such as combustion and solvent usage. York scientists calculated the impacts of biogenics on air quality using their unique measurements and supporting data from other HEIs.

The research data collected by York were shared within months with the evidence team at DEFRA, the Government department responsible for ensuring UK compliance with European legislation, and specifically the air quality Directive 2008/50/EC. At the same time there was substantial media reporting and debate about the research.[9] Peer-reviewed publications from York followed in 2005 and 2006.[2,3] These academic publications were then used by DEFRA as a key part of the evidence base that guided the terms of reference for two Government reports. It is through these reports published in 2008 and 2009, and on-going policy recommendations and practice changes, that the impacts of the research in this assessment period are seen.

The first DEFRA expert report on the impacts of climate change on air pollution appeared in 2008[10] and a second reporting on ozone in the UK appeared in 2009.[11] In addition, DEFRA called an expert meeting in 2009.[12] Both reports made substantial reference to the original underpinning research, highlighting the impacts that this new understanding of natural emissions may have on air quality, and how climate change may exacerbate this process. *"The drought conditions accompanying the episode (summer 2003) decreased deposition of ozone to vegetation, while the high temperatures led to increased emissions of isoprene, a highly reactive volatile organic compound that is emitted from vegetation, and is an ozone precursor. Both of these effects further contributed to the high ozone concentrations."*[10] Both Government reports made reference to the need to improve the representation of biogenic species in UK emissions models in the light of the York research. In 2010, DEFRA tendered for an update of the reporting of natural VOC emissions for the UK, and the models used for national policy development continue to be updated to include this source. This key change to represent natural VOC emissions in the models used by Government for future scenario testing has embedded the original research in all future policy formulations. Specific direct consequences are: (a) DEFRA contracted the consultancy Ricardo-AEA (http://www.ricardo-aea.com) to include natural emissions in future air quality predictions, work that is on-going; (b) the Met Office is including natural emissions in the models used for their air-quality forecasts for the public (http://www.metoffice.gov.uk/guide/weather/air-quality).

Activities supporting DEFRA air-quality evidence and policy requirements continue to the present. Lewis is a current member of the Government Expert Committee, the Air Quality Expert Group. DEFRA continues to support a range of air pollution and emissions research projects at York Chemistry with Lewis, Lee and Hamilton. In 2012, DEFRA and York created a new permanent staff position split between Whitehall and York to accelerate the translation of NERC air quality science outcomes into government departments (Dr Sarah Moller).

Quotations: Dr Tim Murrells, Technical Director, National Atmospheric Emissions Inventory, Ricardo-AEA (05/04/13) "*The research project TORCH, led by Prof. Lewis at University of York, provided a very detailed chemical analysis of processes occurring in the UK during very high temperature conditions. The research, and later DEFRA expert publications, highlighted that natural organic emissions of isoprene could elevate UK ozone during very warm weather. In response, there is now a programme of work, commissioned by DEFRA and led by Ricardo-AEA, to provide recommendations on approaches for estimating biogenic emissions inventories and their use in models to support air pollution prediction and forecasting. Ricardo-AEA includes biogenic inventories in its Ozone Source Receptor Model which is used to predict future ozone concentrations in the UK and to inform DEFRA's policies on ozone air quality by predicting the impacts of future changes in precursor emissions. Ricardo-AEA also uses this information in models used for DEFRA's daily forecasts and public alert systems on air pollution for the protection of human health.*"[13]

Dr Chris Jones, Head, Earth System and Mitigation Science, Met Office Hadley Centre (22/04/13): *"In part due to NERC-funded TORCH campaign, the Met Office has developed global and regional chemistry climate models which include detailed process-based representations of the dependence of isoprene emissions on temperature and light levels. This emissions scheme will shortly be included in our air quality forecast model which provides daily forecasts of ozone and other pollutants for the UK and has been demonstrated to improve the ability of the model to represent ozone levels during period of elevated pollution. The work carried out during the TORCH campaign both improved our understanding of the role of isoprene in European and UK ozone episodes and also provided a driver to ensure that these processes are fully considered by Air Quality models for the UK. The campaign was therefore a very valuable contribution to improving our understanding of air pollution and in furthering our ability to model future air pollution events."*[13]

Stephen Elderkin, Deputy Director Analysis and Evidence, DEFRA (1/10/13). *"Summer 2003 resulted in a period of poor air quality with impacts on health across Southern England and in many other parts of Europe. Understanding the causes of poor air quality events such as this is of great importance to Defra. The NERC TORCH project has been a particularly useful scientific resource in understanding the detailed chemistry occurring during very high temperature conditions in the UK.....The improvements to model chemistry resulting from the findings of the TORCH campaign on the significance of natural organic emissions have led to an improved ability to forecast high ozone events and therefore provide appropriate guidance and warnings to the public. It has also led to an improvement in our ability to project future concentrations of ozone reducing uncertainty in evidence to support decisions on the scale and nature of measures required to tackle air pollution."* [13]

5. Sources to corroborate the impact

5. *www.publications.parliament.uk/pa/cm200910/cmselect/cmenvaud/229/22906.htm#a11*

6. *www.asthma.org.uk/knowledge-bank-pollutants*

www.metoffice.gov.uk/guide/weather/air-quality#Air-quality-index

7. J. R. Stedman *et al.* "The predicted number of air pollution related deaths in the UK during the August 2003 heatwave." *Atmos. Env.* 2004, **38**, 1087. DOI: 10.1016/j.atmosenv.2003.11.011

8. N. H. Savage *et al.* "Air quality modelling using the Met Office Unified Model (AQUM OS24-26): model description and initial evaluation", *Geosci. Model Dev.*, 2013, **6**, 353. DOI: 10.5194/gmd-6-353-2013

9. *References to public debate (not exhaustive) prior to Government reports and prior to 2008*

The Observer. 9/5/04. Front-page story 'Summer heat to spark killer fog of ozone'.

The Daily Telegraph. 10/5/04. Page 3 "Heatwave Britain – when trees turn toxic".

BBC 1 TV News (1pm, 10pm).10/05/04. 'Summer ozone'

10. Government reports and meetings referencing research (within REF impact period). *http://archive.defra.gov.uk/environment/quality/air/airquality/publications/airqual-climatechange/documents/summary.pdf* . DEFRA, - '*Air Quality and Climate Change – A UK perspective*', Published 2008, ISBN 0-85521-172-5 See for example Section 3 in executive summary (page 3), or chapter 4 on VOCs. (pages 102-150) DEFRA, - *Air Quality and Climate Change policymakers' summary'*, see pages 18-20, Air Quality and Climate Change'

11. *http://archive.defra.gov.uk/environment/quality/air/airquality/publications/airqual-climatechange/documents/contents-execsumm.pdf* DEFRA, - '*Ozone in the United Kingdom'*. Published 2009. ISBN 978-0-85521-184-4. See for example DEFRA recommendations relating to reporting of biogenic VOCs in Annex 1 and Annex 2. Policy recommendation specifically associated with biogenic VOCs with reference to this research, also in Executive Summary.

12. DEFRA, - Expert meeting to consider biogenic emissions and air quality, 2009, see *http://uk-air.defra.gov.uk/reports/cat11/0903231041_Ozone_in_the_United_Kingdom_-_Agenda.pdf*, and then subsequent links to presentations including from National Atmospheric Emissions Inventory on updating biogenic inventory.

13. *Confirmatory Letters:* from AEA-Ricardo, Met Office and DEFRA are available from University of York.