Institution: University of Cambridge

Unit of Assessment: 8

Title of case study: Impact on International Measures to Control Ozone-Depleting Substances and their Replacements.

1. Summary of the impact (indicative maximum 100 words)

Atmospheric science research in the Department of Chemistry, University of Cambridge has played a leading role in demonstrating the depletion of the ozone layer following anthropogenic emissions of halogenated compounds and other Ozone Depleting Substances (ODS). This research has been a key input into the series of assessment reports that have made the case to policy makers for the strengthening of the Montreal Protocol. The research underpinning these reports has made a vital contribution to a number of changes to the Protocol that have ensured a more rapid phase-out of a wider range of ODS and their replacements, leading to significant global health and climate benefits during the REF period. Researchers at Cambridge have helped to raise global awareness of these benefits, helping to maintain support for the Protocol among policy makers and the public, and supported European legislation to limit the environmental impact of ODS and their replacements.

2. Underpinning research (indicative maximum 500 words)

The Centre for Atmospheric Science, established in 1993, is a joint venture within the University of Cambridge between the University Departments of Chemistry, Applied Mathematics and Theoretical Physics and Geography. Co-directed by Professor John Pyle (1920 Professor of Physical Chemistry, University of Cambridge, in Cambridge since 1985), the centre has since its inception been among the world leaders in stratospheric ozone science. Pyle played a leading role in the development of state-of-the-art chemistry/climate models for the stratosphere. The physical and chemical processes in his numerical models have been evaluated successfully against atmospheric observations and so can be used to explain the role of ozone depleting substances in past changes in atmospheric composition and can be used to project future changes. Dr Neil Harris (Dept of Chemistry since 1990, NERC Advanced Fellow since 2010) has been a pioneer in the analysis of existing atmospheric ozone data to understand long-term changes in ozone, and in conducting field experiments in the Arctic to quantify the detailed chemical processes leading to ozone loss each winter. He has been making atmospheric measurements of ozone-depleting halocarbons including chlorofluorocarbons (CFCs) and shorter-lived compounds since the mid-1990s.[1]

Together these researchers have made substantial contributions to the understanding of global ozone loss and to the contribution of ozone depleting substances. Examples of relevant underpinning research performed between 1993 and 2013 are listed below:
A) Model calculations performed by the Pyle group have demonstrated that CFCs and other halogenated compounds have led to depletion of ozone in the Arctic; they confirmed that severe Arctic ozone loss occurs in some winters, following the same chemical mechanism as found in Antarctica, [2] in agreement with observational analyses that the Pyle group helped to develop.[3]
B) Harris has explained the observed decadal changes in ozone in middle latitudes, showing that both chemical and dynamical processes play a role in the observed ozone changes.[4]
C) Pyle's calculations project the future evolution of ozone, explaining how atmospheric ozone concentrations should respond to regulation, with slow 'recovery' this century,[5] and how these chemistry-climate model projections show that, had the Montreal Protocol not been enacted, ozone depletion would have been even more severe and that consequently large changes in surface temperature and UV radiation would have occurred.[6]
D) The Pyle group has shown that the scientific framework for regulation of short-lived ozone depleting substances is different to that of the longer-lived gases, like the CFCs. For short-lived gases, the Ozone Depletion Potential (ODP), a concept enshrined in legislation, varies with region and season of emission, whereas for long-lived gases the ODP is a constant.[7]

Key researchers in Cambridge that contributed to the research include: Dr Martyn Chipperfield (PDRA and Temporary Assistant Lecturer 1993-1999, now Professor at the University of Leeds)

and Dr Peter Braesicke (Senior Researcher, Centre for Atmospheric Science, Cambridge, 1999-2013, Professor at the Karlsruhe Institute of Technology, Germany since August 2013).

3. References to the research (indicative maximum of six references)

1. Gostlow B., A.D. Robinson, N.R.P. Harris, L. O'Brien, D.E. Oram, G.P. Mills, H.M. Newton, S.E. Yong and J.A. Pyle, Micro-DIRAC: An Autonomous Instrument for Halocarbon Measurements, *Atmos. Meas. Tech.*, 3, 507-521, 2010.
2. Large loss of total ozone during the Arctic winter of 1999/2000. B.M. Sinnhuber, M.P. Chipperfield, S. Davies, J.P. Burrows, K.U. Eichmann, M. Weber, P. von der Gathen, M. Guirlet, G.A. Cahill, A.M. Lee, and J.A. Pyle, Geophys. Res. Lett., 27, 3473-3476, 2000. (*****)
3. Chemical depletion of ozone observed in the Arctic Vortex during the 1991/1992 winter. P. von der Gathen, M. Rex, N.R.P. Harris, D. Lucic, B. Knudsen, G.O. Braathen, H. De Backer, R. Fabian, H. Fast, M. Gil, E. Kyro, I.S. Mikkelsen, M. Rummukainen, J. Staehelin and C. Varotsos, *Nature*, 375, 131-134, 1995. (*****)
4. Ozone Trends at northern mid- and high latitudes: a European perspective. N.R.P.Harris, E.Kyrö, J.Staehelin, D.Brunner, S-B.Andersen, S.Godin-Beekmann, S.Dhomse, P.Hadjinicolaou, G.Hansen, I.Isaksen, A.Jrrar, A.Karpetchko, R.Kivi, B.Knudsen, P.Krizan, J.Lastovicka, J.Maeder, Y.Orsolini, J.A.Pyle, M.Rex, *Ann. Geophys*, **26**, 1207-1220, 2008.
5. Decline and recovery of total column ozone using a multimodel time series analysis. J. Austin, J. Scinocca, D. Plummer, L. Oman, D. Waugh, H. Akiyoshi, S. Bekki, P. Braesicke, N. Butchart, M. Chipperfield, D. Cugnet, M. Dameris, S. Dhomse, V. Eyring, S. Frith, R.R. Garcia, H. Garny, A. Gettelman, S.C. Hardiman, D. Kinnison, J.F. Lamarque, E. Mancini, M. Marchand, M. Michou, O. Morgenstern, T. Nakamura, S. Pawson, G. Pitari, J. Pyle, E. Rozanov, T.G. Shepherd, K. Shibata, H. Teyssèdre, R.J. Wilson and Y. Yamashita, *J. Geophys. Res.*, 115, D00M10, doi: 10.1029/2010JD013857, 2010.
6. The world avoided by the Montreal Protocol. O. Morgenstern, P. Braesicke, M.M. Hurwitz, F.M. O'Connor, A.C. Bushell, C.E. Johnson and J.A. Pyle, *Geophys. Res. Lett.*, 35, L16811, doi:10.1029/2008GL034590, 2008.
7. A three-dimensional model calculation of the ozone depletion potential of 1-bromopropane (1-C_3H_7Br). C.H.Bridgeman, J.A.Pyle and D.E.Shallcross, *J. Geophys. Res.*, **105**, 26,493-26,502, 2000. (*****)

(*****) References that best indicate the quality of the research.

Grant Information

- PI: Harris; Grant Title: The Role of Short-lived Species in the Tropical Atmosphere (NERC Advanced Research Fellowship for Dr Neil Harris); Sponsor: NERC; Period of Grant: Jan 2010-Dec 2014; Grant Value: £474,458.
- PI: Pyle; Grant Title: The Lower Stratosphere: Interactions with the Tropospheric Chemistry/Climate System; Sponsor: NERC; Period of Grant: July 2007 – July 2011; Grant Value: £154,026.
- PI: Pyle; Grant Title: Stratosphere-Climate Links with Emphasis on the UTLS (SCOUT); Sponsor: EC; Period of Grant: May 2005 – August 2009; Grant Value: £1,588,101.
- PI: Pyle; Grant Title: Current and Future Stratospheric Ozone Depletion and Implications for Climate Change; Sponsor: Department of the Environment; Period of Grant: Jan 97 - Dec 12; Grant Value: £265,126.

4. Details of the impact (indicative maximum 750 words)

The underpinning research contributed directly to national and international discussions and agreements on the phase-out of ozone depleting gases. A major impact has been via contributions to the Montreal Protocol, EU legislation, advisory roles and dissemination.

The World Meteorological Organisation and the Montreal Protocol The World Meteorological Organisation (WMO) has published 7 *Scientific Assessment of Ozone Depletion* reports since 1987. The most recent in 2010 (published spring 2011), contains over 35 citations to underpinning research performed in the Department of Chemistry.[1] On the evidence of their ongoing research contributions, the group led by Pyle was asked to contribute scientific evidence to all the WMO assessments. Pyle was a lead author on the 1985, 1991, 1998 and 2002 assessments and

contributing author and Assessment Co-Chair of the 2010 report. The earlier reports all feed into the on-going Montreal Protocol regulation process. In addition, Harris contributed to all reports and was a lead author on the1994 report as well as the report currently being prepared for publication in 2014. On the basis of their expert knowledge and research contribution, the Cambridge team were also selected to contribute to the shaping of the reports' accompanying executive summaries, which include information for policymakers, most recently in 2010.[LC1]

Pyle was also a lead author in the special report for the UNEP/WMO Intergovernmental Panel on Climate Change (IPCC) on "Safeguarding the Ozone layer and the Global Climate System" in 2005.[2] This report had a major impact on the direction of subsequent research on the climate impact of CFC replacements, which is now starting to be reflected in international regulation and which is a major topic in the current WMO Scientific Assessment where Harris is a lead author of the chapter on 'Scenarios, Information and Options for Policymakers'. The WMO assessment reports (most recent 2010, published in 2011), and in particular their summaries, have also been used internationally to monitor the success of the Montreal Protocol in protecting the ozone layer and climate, for example, by comparing the rate of halocarbon reduction with that observed, and to inform the wider public about the process.

The Montreal Protocol on Substances that Deplete the Ozone Layer came into force in 1987, in response to the scientific evidence that human-induced depletion of the ozone layer was indeed occurring. The Protocol mandates that the measures it introduced must be regularly assessed (now every 4 years) on the basis of available scientific, environmental, technical, and economic information. In particular, it specifies a scientific assessment process by which panels of experts are required to prepare reports to guide policymakers in their decisions regarding the protocol. The original Montreal Protocol in 1987 called for modest regulation on the emission of CFCs and allowed for on-going revision based on scientific evidence. The 10 subsequent amendments and adjustments to the Protocol, based on the Scientific Assessments, brought about more rapid phase-out of the CFCs and also added new controls for many more ozone-depleting compounds. The most recent adjustments were made in 2007, were enacted in the following years and remain current (see below for on-going EU legislation). The impact of these amendments and adjustments (reduced ozone depletion) will be felt for many decades. Pyle and Harris have worked to ensure their research has been widely reported in the media since 2008, thereby contributing both to the public understanding of the importance of climate change and the role of environmental policy. [3,4,5,6,7&8]

On the basis of his significant research contribution, since 2008 Professor Pyle has been one of four international Co-Chairs of the Science Assessment Panel (SAP), who provide direct advice to the Meetings of the Parties to the Montreal Protocol[1]. By undertaking these roles, it has been possible to ensure that the group's research findings are effectively communicated to the policymakers. The Chief Officer, Multilateral Fund for the Implementation of the Montreal Protocol Secretariat, provided the following statement about the role of the SAP: *"The SAP plays an invaluable role in analysing, interpreting, and presenting atmospheric trends. The clarity of this work has enabled global political/regulatory decisions that have resulted in a continuing improvement of stratospheric ozone levels since the inception of the Montreal Protocol in 1987, as well as aiding the many amendments to accelerate the Protocol's progress. I would like to thank Professor Pyle and his team for their continued dedicated efforts to provide a sound scientific basis for our work in protecting the environment".*[LC2]

Pyle's involvement in the Montreal Protocol has been funded since 2007 by DEFRA, to whom he provides ad hoc advice.

Impacts on Health The Montreal Protocol has had a major impact in avoiding ozone depletion, in avoiding climate change thanks to the phase out of those ozone-depleting substances which are also greenhouse gases, and in preventing UV-related health issues. A recent paper, using model calculations by the Pyle group, indicates that, by 2030, the Protocol will have prevented two million cases of skin cancer annually, and further reinforces the case for the Montreal Protocol.[9] Ensuring that the Protocol is adjusted and amended according to the latest scientific developments is essential to their continuing impact.

EU Legislation The various assessments, informed by Cambridge research and that of the

international community, led to a strengthening of the regulations covering production and emission of ozone depleting substances. EU legislation was introduced in 2008 to speed up the phase out of the HCFC family of halocarbons, replacements for the CFCs.[10] Hydrofluorocarbons (HFCs), another family of halocarbons, are replacement gases for the ODS which have the attractive property that they do not lead to any ozone depletion. They are, however, strong greenhouse gases and so there are very good reasons to limit their future growth. Based on the halocarbon research, Dr Harris gave evidence to the European Parliament in June 2011 during a special session of the ENV committee on 'Reduction of non-CO2 Emissions'. This session was part of the process which led to a resolution passed by the European Parliament and, in 2013, to the introduction of EU legislation on Fluorinated Greenhouse Gases limiting future HFC usage.[11]

The Senior Administrator for the European Parliament, Committee for Environment, Public Health and Food Safety writes*: "since 2008 I have appreciated the impact of its pioneering research and assessment influence in the regulatory process of the Environment, Public Health and Food Safety Committee of the European Parliament…Overall, research by the Cambridge group made a significant impact to both policy actions and environmental protection.*[LC3]

Working with Industry Pyle continues to provide informal, independent advice to industries producing and using halocarbons (e.g. 3M).

5. Sources to corroborate the impact (indicative maximum of 10 references)

Letters of corroboration available for audit

LC1 Senior Scientific Officer at World Meteorological Organization, Switzerland.
LC2 Chief Officer, Multilateral Fund for the Implementation of the Montreal Protocol Secretariat, Canada.
LC3 Senior Administrator, European Parliament, Committee for Environment, Public Health and Food Safety, Belgium.

References in the public domain

1. WMO (World Meteorological Organization), *Scientific Assessment of Ozone Depletion: 2010,* Global Ozone Research and Monitoring Project–Report No. 52, 516 pp., Geneva, Switzerland, 2011. http://ozone.unep.org/Assessment_Panels/SAP/Scientific_Assessment_2010/index.shtml Earlier reports, to which Pyle and Harris contributed, are available via ozone.unep.org
2. UNEP/WMO Intergovernmental Panel on Climate Change (IPCC) "Safeguarding the Ozone layer and the Global Climate System" (2005). http://www.ipcc.ch/pdf/special-reports/sroc/sroc_full.pdf
3. Relating to Cambridge research on the world avoided by the Montreal Protocol: SBS Australia: http://www.sbs.com.au/news/article/1693247/Ozone-layer-agreement-saved-human-lives
4. Special Issue of "The Conversation" (Australian online science magazine links) http://theconversation.edu.au/saving-the-ozone-layer-saved-human-lives-9494
5. Naked Scientist:http://www.thenakedscientists.com/HTML/content/interviews/interview/1569/
6. Sunday Times http://www.thesundaytimes.co.uk/sto/news/uk_news/Environment/article1127288.ece
7. Chemistry World http://www.rsc.org/chemistryworld/2012/07/storm-horizon-ozone-levels
8. Newsweek Magazine: A Climate Cure's Dark Side by Sharon Begley http://www.thedailybeast.com/newsweek/2011/01/30/a-climate-cure-s-dark-side.html
9. Skin cancer risks avoided by the Montreal protocol – worldwide modelling integrating coupled chemistry-climate models with a risk model for UV. A Van Dijk, H Slaper, PN den Outer, O Morgenstern, P Braesicke, JA Pyle, H Garny, A Stenke, M Dameris, A Kazantzidis, K Tourpali, AF Bais. *Photochemistry and Photobiology*, 89, 234-246, 2013.
10. EU legislation from 2008 on more rapid phase-out of HCFCs: http://europa.eu/legislation_summaries/other/l28064_en.htm
11. The European Parliament HFC proposals can be found at: http://www.europarl.europa.eu/oeil/popups/ficheprocedure.do?reference=2012/0305(COD)&l=en