Institution: University of Bristol

Unit of Assessment: Chemistry UoA 8

Title of case study:
CH2: Climate Change and Air Quality: Interdisciplinary Research that is Transforming the Teaching of Chemistry across the World

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

Bristol ChemLabS (part of the School of Chemistry) has used School of Chemistry research on the atmosphere (air quality, atmospheric chemistry and the history of greenhouse gases on Earth) to enhance dramatically the quality and uptake of chemistry education in the UK and approximately 20 other nations. This radical advance has been achieved through ChemLabS' outreach activity, which has involved running more than 1,200 events for over 250,000 students over the past six years (and over 1,000 events since 2008). ChemLabS' atmospheric chemistry education packages are now being delivered in other countries, its textbooks/articles have been taken up across Europe, and it has trained more than 500 teachers directly. As a result of its activities, which are grounded in rigorous research, Bristol ChemLabS has been able to document increased interest in science and higher uptake at post-16 level.

2. Underpinning research (indicative maximum 500 words)

Pancost (Professor of biogeochemistry, 2000-present; Organic Geochemistry Unit, OGU) and **Shallcross** (Professor of atmospheric chemistry, 1999-present; Atmospheric Chemistry Research Group, ACRG) have spent the past 15 years studying human impacts on the atmosphere and the corresponding effects of carbon dioxide, methane and trace gases on the Earth's climate. This work has been conducted as a central part of the Bristol Global Change Research Theme, incorporating collaborations with other chemists [**Evershed**, **O'Doherty**, **Rigby**, **Simmonds** (UoB Senior Research Fellow)]. Collectively, OGU and ACRG atmosphere and trace gas work is represented by over 200 highly cited publications, of which a selection led by **Pancost** and **Shallcross** are listed below. Its larger relevance is reflected in its policy impact; the air quality research has been used by the UK Home Office and Ministry of Defence to update their emergency-response models, and the palaeoclimate research will be cited in the forthcoming Intergovernmental Panel on Climate Change report.

One aspect of this research is the development of geochemical tools for the reconstruction of past pCO_2 levels and temperatures, which is at the centre of assessing how carbon dioxide and other greenhouse gases affect climate (**1-3**). The work illustrates that throughout geological history, climate sensitivity (especially in polar regions) is either at the high end of, or greater than, that assumed for most climate models. For example, the Bristol researchers showed that the Pliocene, widely considered an ideal analogue for anticipating future warming (including by the IPCC), was characterised by pCO_2 levels similar to those we had already achieved in 2000 but also by global temperatures that were 3ºC warmer than those of today (**1**). Such work will be included in the next IPCC report, an achievement facilitated by **Pancost** co-hosting international workshops on pCO_2 reconstruction at Bristol Zoo in 2010 and a Royal Society (RS)-funded Kavli Meeting in 2011.

Related research has been led by **Shallcross** and is focussed on air quality and pollutant dispersion and transformation (DAPPLE project, 2002-09) (**4-6**). Novel inert gas-phase tracers have been developed that allow the characterisation of air flow and dispersion of pollutants within the urban environment. These experiments have shown that robust, simple models can be used for emergency-response planning, that pollution from moving sources penetrates much further into the urban environment than that from stationary sources and that outdoor pollution enters the indoor environment in greater quantities than first thought and remains there for longer than predicted. These findings, together with extensive chemical modelling, have allowed us to build a more complete picture of the complex urban environment and the chemical and physical transformations that take place therein.

These are just two examples of the extensive research conducted on how greenhouse gases (GHGs) are produced, behave in the atmosphere and affect the Earth's climate, and how pollutants move and are transformed in the urban environment. Additional research areas include investigating the methane cycle in modern and ancient soils, wetlands and marine sediments, quantifying trace GHGs in the atmosphere and understanding and characterising pollutant transformation in the urban environment (**5**).

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

Publications

(1) Alkenone and boron-based Pliocene pCO_2 records, O. Seki, G. Foster, D. N. Schmidt, A. Mackensen, K. Kawamura and R. D. Pancost, *EPSL*, 2010, **292**, 201-211. Listed in REF 2.*

(2) Increased terrestrial methane cycling at the Palaeocene–Eocene thermal maximum, R. D. Pancost, *et al*., *Nature*, 2007, **449**, 332-335. doi:10.1038/nature06012.*

(3) Large terrestrial and marine carbon and hydrogen isotope excursions in a new Paleocene/Eocene boundary section from Tanzania, L. Handley, P. N. Pearson, P. R. Bown and R. D. Pancost, *EPSL* 2008*,* **275**, 17-25, doi:10.1016/j.epsl.2008.07.030.

(4) Introduction to the DAPPLE Air Pollution Project, D. Shallcross *et al*., *Sci. Tot. Env*. 2004, **332**, 139-153, doi:10.1016/j.scitotenv.2004.04.020.

(5) Dispersion Experiments in Central London: The 2007 DAPPLE project, D. E. Shallcross *et al*., *Bull. Amer. Meteor. Soc.* 2009, **90**, 955-969. http://dx.doi.org/10.1175/2009BAMS2638.1.*

(6) Use of Reactive Tracers To Determine Ambient OH Radical Concentrations: Application within the Indoor Environment, I. R. White, D. Martin, M. P. Muñoz, F. K. Petersson, S. J. Henshaw, G. Nickless, G. C. Lloyd-Jones, K. C. Clemitshaw and D. E. Shallcross, *Env. Sci. Tech.* 2010, **44**, 6269-6274. DOI: 10.1021/es901699a.

Grants (examples only):

(a) Pancost (2006-2008) *An integrated study of the Middle Miocene*, NERC, £110k.

(b) Pancost and Seki (2006-2007) *Fellowship*, Japan Society for Promotion of Science, ~£100k.

(c) Pancost (2010-2013) *Timing, causes and consequences of the decline in Pliocene* pCO_2*,* NERC, £490k.

(d) Pancost (2012-2015) *Terrestrial methane cycling during the Paleogene*, NERC, £900k.

(e) Simmonds and Shallcross (1999-2002) *URGENT Programme,* NERC, £274k.

(f) Shallcross (2002-2006) *DAPPLE*, EPSRC, £157k.

(g) Shallcross (2006-2009) *DAPPLE2*, Home Office, £266k.

(h) Shallcross (2010-2011) PFC tracer development, DSTL, £56k.

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

Pancost and **Shallcross** recognised that through Bristol ChemLabS, this research could serve as a powerful mechanism for engaging students with chemistry as it: (i) highlights the importance of chemistry in addressing some of the greatest societal challenges and (ii) inspires a passion for all science through the innate interdisciplinarity of the work. Thus, research has driven one of the world's most ambitious school engagement efforts, co-ordinated by **Shallcross** and **Harrison** (School of Chemistry Director of Outreach). ChemLabS has therefore leveraged the quality, societal relevance and unique interdisciplinary aspects of climate change research to inspire and motivate students to become better engaged with their environment and pursue further education and careers in science. The specific research components that inform ChemLabS' outreach are the use of state-of-the-art analytical chemistry to make sensitive measurements of gases in the atmosphere, the application of physical and chemical principles to the modelling of atmospheric chemistry, the chemistry underpinning air pollution and catalytic cycles, and the use of paleoclimatic archives to determine the sensitivity of global temperatures to pCO_2. This research is presented by a combination of: (i) research presentations/events by **Shallcross**, **Pancost** and members of their research groups and (ii) the '*Pollutant's Tale*', lecture demonstration which

incorporates research results from **Pancost** and **Shallcross**.

ChemLabS activity that has derived primarily from this research during the impact period of 2008-2013 is oulined below.

- **Pancost** and **Shallcross** and members of their research groups, working with the Director of Outreach, **Harrison**, have delivered more than 1,000 presentations to over 400 schools in the UK, reached over 250,000 students and thousands of teachers, delivered outreach in 15 countries (including Australia, China, New Zealand, Singapore and South Africa), and run activities ranging from lectures to research conducted with students and resulting in co-authored papers (**a**).
- Bristol ChemLabS has delivered over 100 public lectures, engagement activities at many UK festivals, including the Bristol Festival of Nature (which draws more than 20,000 attendees and for which **Pancost** served as a Steering Group member), the 2008 RS Summer Science Exhibition, numerous regional and national science festivals (*eg* Cheltenham), the RS Warm Climates of the Past discussion meeting in 2011, regular presentations at international science festivals (*eg* National Science Weeks in South Africa, 2008-2012; Namibia, 2011; Jersey, 2008 and 2010; Malta 2011/12) and at international science centres (*eg* Sci-Bono, Johannesburg).

Crucially, to facilitate the continued teaching of such material, ChemLabS has conducted extensive follow-up activity, including writing articles, contributing to textbooks and training teachers. The team: (i) organises the annual Festival of Contemporary Science that always features climate change and atmospheric chemistry research and has been attended by more than 200 school teachers, (ii) has run a Teachers' Master's Course since 2005 that features climate change research as an example of How Science Works, established the RCUK course for teachers on Climate Change, a course that continued to be delivered through the UK Science Learning Centre Network (145 times with approximately 1,200 attendees), and regularly updates CHeMneT members (Bristol ChemLabS' teacher network), (iii) trains overseas colleagues and postgraduates to present this work across the world, with lecture demonstrations in South Africa to nearly 1,000 students per month at four centres and (iv) has written 15 publications directed at school teachers or students [*eg* Science in Schools, Chemistry Review, Education in Chemistry, Physics Education, School Science Review (**b**)]. See www.chemlabs.bris.ac.uk/outreach/recent_events.html for full reports of ChemLabS's outreach events.

The impact of this activity has been profound and is demonstrated by the following:

- Publications which have been widely accessed; the climate change and atmospheric chemistry articles in Science in School alone have been downloaded over 250,000 times.
- The translation of articles into nine languages, most commonly Spanish.
- The impact on student training in the UK, which is demonstrated by funding from industry to deliver these activities in their communities, including: (i) EDF Energy who have funded ChemLabS to develop the company's long-term interests in Somerset by '*building up enthusiasm for science in order to up skill the local communities in STEM subjects*' (**c**) supported by six atmospheric and climate change chemistry lectures; and (ii) the AstraZeneca Science Teaching Trust (AZSTT), which has engaged ChemLabS to deliver demonstrations on climate change across the UK.
- The impact on international student training, illustrated by the uptake of our material by South African institutions, including: (i) the Chemistry Department at Rhodes University, and (ii) The Sci-Bono Science Centre, Johannesburg, which has had its demonstrators trained by ChemLabS to deliver '*A Pollutant's Tale*', during Earth Science Week in 2011 and the National Science Week in 2012.
- The use of our articles by a UK examination board within Post 16 examinations 2012/13.
- The recognition of ChemLabS' outreach work through many awards to **Shallcross** and **Harrison** and the outreach team, including more than 10 national and international awards from the RS, the RSC, the Royal Meteorological Society (both Outreach and research) and The Bank of America (**d**).

In addition, the quality and range of the impact of this research is documented by hundreds of collected testimonials from teachers and research at Master's level (**e**). Bristol ChemLabS has quantified the impact with respect to: (i) uptake of this research in course curricula and teaching, (ii) its effect on students' cognition, (iii) how it has changed students' educational choices and (iv) cultural changes in developing countries. With respect to (i), ChemLabS' teaching has now been incorporated into UK national exam boards' coursework. Moreover, in one- to two-year follow-up studies with 60 of the teachers who attended ChemLabS' 2010 national teacher training day (the Festival of Contemporary Science), 100% declared it either 'very good' or 'good' in terms of usefulness to their teaching practice (**f**). With respect to (ii), Bristol ChemLabS has studied the impact of its engagement activity on UK school's understanding atmospheric chemistry (**g**). In terms of (iii), via repeated visits and interactions with some schools, ChemLabS has been able to study how its outreach activity has transformed students' educational choices, *eg* the team has been visiting the Crypt School in Gloucestershire for five years resulting in an increase from 5 to 60 students opting to study chemistry at A-Level, (**h**). Finally, in terms of (iv), papers on the use of these climate-based educational resources in the South African context are being published (**i**).

Overall, the impact of outreach on students, teachers and participating postgraduates has been the subject of 15 papers published (**j**), forming the basis of three postgraduate master's level theses where Bristol ChemLabS has demonstrated that students' understanding of the science underpinning climate change has been improved, that teachers' confidence in teaching these topics has been increased and that student aspirations have been raised.

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

(a) Smoke is in the air: How fireworks affect air quality. *Science in School*, 2011, **21**, 47-51. http://www.scienceinschool.org/2011/issue21/fireworks

(b) *Eg* Climate Change modelling in the classroom, *Science in School* 2008, **9**, 28-33, and Climate Change: Outreaching to School Students and Teachers in *Handbook of Climate Change Mitigation*, Springer 2012, D.E. Shallcross and T. G. Harrison.

(c) Letter from EDF available on request.

(d) List of awards for ChemLabS outreach (or co-ordinators): (i) 2010 Times Higher Education Outstanding ICT Initiative of the Year Award, (ii) 2010 Royal Society's Hauksbee Award, (iii) 2009 Highly Commended BITC Education Award, (iv) 2009 Big Tick Education Award, (v) 2009 Royal Met. Soc. Michael Hunt Award, (vi) 2008 RSC Tertiary Education Award, (vii) 2006 SCI Science Education Award, (viii) 2005 RSC Higher Education Award, (ix) 2005 RSC Schools Education Award, (x) HEA National Teaching Fellowship.

(e) Testimonials archived at: http://www.chemlabs.bris.ac.uk/outreach/Outreach%20Feedback.pdf

(f) Feedback from teachers who have adopted our materials in courses or who have attended Festival of Contemporary Science, RCUK courses, MSURE course and CHeMneT are available [see also testimonials under (**e**)].

(g) S. R. Glover first year transfer report research in Chemistry Outreach for PhD thesis 2011.

(h) Letters from Head of Crypt School and Cheltenham Ladies College, available on request.

(i) An impact assessment of atmospheric chemistry demonstrations in Western Cape schools, S. N. Sunassee, *et al*., *Acta Didactica Naponcensia* 2012, **5**(4) http://dppd.ubbcluj.ro/adn/article_5_4_5.pdf.

Publications on the benefits of engagement:

The advantages perceived by schoolteachers in engaging their students in university-based chemistry outreach activities, J. Tuah, T. G. Harrison and D. E. Shallcross, *Acta Didactica Napocensia* 2009, **2**, 31-44, and a review of the use of demonstration lectures in the promotion of positive attitudes towards, and the learning of science with reference to a '*A Pollutant's Tale*', a demonstration lecture on air quality and climate change, J. Tuah, T. G. Harrison and D. E. Shallcross, *Romanian Journal of Education* 2010, **1**, 93-102.