

Research Excellence Framework: Impact pilot exercise

Example case studies from Earth Systems and Environmental Sciences

November 2010

Introduction

1. This document provides some examples of case studies submitted to the impact pilot exercise that the Earth Systems and Environmental Sciences panel scored highly, and that indicate good practice in terms of the pilot submissions.
2. They are presented here in a revised format to that in which they were submitted. The original template required the impact arising to be described first, followed by the underpinning research and ending with evidence for both previous sections¹.
3. The expert panels recommended that the sections in the template should be reversed, starting with a clear description of the research and justification that it is of high quality, followed by an explanation of how it led to the impact and what that impact was. It was also recommended that the references to the research should be separated from references to 'user contacts' and external sources of corroboration.
4. For the purposes of publishing these examples, therefore, we invited participating institutions to revise the case studies that had been identified as suitable for publication². A revised template and guidance were provided to ensure clear presentation of the evidence for publication. Further refinements to the template and guidance for the full REF will be made subsequently.
5. The examples published were selected from among the highest-scoring case studies submitted to the pilot, to show a range of types of impacts that were submitted, and to provide examples of good practice from among the pilot submissions.
6. The examples do not represent model case studies that should be replicated in REF submissions. As the range of published examples is intended to show, there are many and diverse ways in which impacts arise and can be described for assessment in the REF.

¹ This template can be viewed in the 'Guidance on submissions for institutions participating in the pilot' available at www.ref.ac.uk under Impact pilot exercise.

² For this we provided further guidance, 'REF impact pilot: revised case study template and guidance' (July 2010), available at www.ref.ac.uk under Impact pilot exercise.

Establishing methods to detect irradiated foods (University of Glasgow)

1. Short summary of the case study

This University of Glasgow study was the first to develop methods and equipment for screening foodstuffs for irradiation. Professor Sanderson's research has led to new UK and European standards providing protection and reassurance to consumers.

Between January 2005 and December 2009 every consumer in the UK and Europe has benefited from the added protection provided by the work of Professor Sanderson and his team in relation to food labelling and screening.

2. Underpinning research

In the 1980s, it was believed that irradiated food could not be detected. The UK Advisory Committee for Irradiated and Novel Foods reported in 1986 that "There are as yet no generally applicable chemical or physical tests which would be adequate for the enforcement of legal and commercial requirements, or for investigation purposes, for determining whether a food or a food ingredient has been irradiated" (ACINF, 1986).

Professor David Sanderson had been working with luminescence research based on single photon counting for several years and was convinced it would be suitable for detection methods for foodstuffs. Having learned of the problem of detection of irradiated food from media coverage of the UK Policy review, he actively pursued this line of research, writing to various consumer bodies, government departments and the food industry, and eventually receiving the first of a series of research contracts from the Ministry of Agriculture in 1987 to explore luminescence methods.

The underlying processes, when minerals and other dielectric media store energy from ionising radiation by charge trapping at defect centres, leading to luminescence emission under stimulation, were known from solid-state physics research. Thermoluminescence dating of ceramics and thermoluminescence dosimetry using natural and synthetic materials applies such principles and Professor Sanderson had been involved in development and application of these phenomena using single photon counting methods beforehand. The application to bioinorganic systems and to mixed organic/inorganic materials, however, was new, in particular in terms of the recognition that photostimulated luminescence might be capable of detecting food irradiation using Anti-Stokes wavelength shifts in new luminescence instruments.

The research was led by Professor Sanderson, with input from Mrs Christine Slater, Dr Lorna Carmichael, Simon Murphy, Dr Saffron Fisk, Lorna Carmichael and Simon Murphy (all of University of Glasgow at that time) and also had collaborative links with many international laboratories.

By 1996, Professor Sanderson, by now Senior Lecturer and Head of Physics at the Scottish Universities Environmental Research Centre (SUERC), had developed two international standard methods based on luminescence. EN1788 describes the application of thermoluminescence to silicates extracted from a wide variety of foods using techniques first developed at his laboratory in 1986. EN13751 describes the use of pulsed photostimulated luminescence for rapid instrumental screening.

The development and validation of these methods has been the result of a series of externally funded research projects supported by the UK Ministry of Agriculture, Fisheries and Food; the Food Standards Agency; and European Commission sources.

3. References to the research

Details of Professor Sanderson's publications in this area are listed below:

1. Sanderson D.C.W., Carmichael L.A., Ni Riain S., Naylor J.D., Spencer J.Q., 1994, Luminescence Studies To Identify Irradiated Food, Food Science And Technology Today, 8(2), 93-96
2. Sanderson D.C.W. Carmichael L.A. Naylor J.D., 1995, Photostimulated Luminescence And Thermoluminescence Techniques For The Detection Of Irradiated Food, Food Science And Technology Today, 9(3), 150-154
3. Sanderson D.C.W. Carmichael L.A., Fisk, S., 1998, Establishing Luminescence Methods To Detect Irradiated Foods, Food Science And Technology Today, 12, (2), 97-102
4. Sanderson D.C.W. and Carmichael L.A., 2000, Using Luminescence Methods to Detect Irradiated Foods, Proceedings of International Symposium on Luminescence and its Applications, The MS University of Baroda Press, India, Volume II p 216-230
5. Sanderson D.C.W, Carmichael L.A., Fisk S., 2003, [Thermoluminescence Detection of Irradiated Fruits and Vegetables : An International Collaborative Trial](#), Journal of AOAC International 85(6) 971-975 – **Peer-reviewed**
6. Sanderson D.C.W, Carmichael L.A., Fisk S., 2003, [Thermoluminescence Detection of Irradiated Shellfish : An International Collaborative Trial](#), Journal of AOAC International 85(6) 976-982 – **Peer-reviewed**
7. Sanderson D.C.W, Carmichael L.A., Fisk S., 2003, [Photostimulated Luminescence Detection of Irradiated Shellfish : An International Collaborative Trial](#) , JAOAC International 85(6) 983-989 – **Peer-reviewed**
8. Sanderson D.C.W, Carmichael L.A., Fisk S., 2003, [Photostimulated Luminescence Detection of Irradiated Herbs, Spices and Seasonings : An International Collaborative Trial](#) AOAC International 85(6) 990-997 – **Peer-reviewed**

Relevant grants and contracts:

1987-89 - £103,000 from MAFF to investigate luminescence techniques for identifying irradiated foods (ref N384)

1990-92 - £128,000 from MAFF for development of luminescence tests to identify irradiated fruits and vegetables (ref N1701)

1991 - £14,800 from BCR (EC) for conducting an international interlaboratory study of luminescence identification of irradiated herbs and spices

1992-94 - £117,000 from MAFF for development of luminescence tests to identify irradiated shellfish (ref N2635)

1994-96 - £110,196 from MAFF for establishing luminescence detection methods for fruits and vegetables and shellfish, by means of international interlaboratory trials (ref 1B073)

1996-97 - £40,578 from MAFF to extend international validation studies to the PSL method (ref 1B073)

1996 - £51,477 from MAFF for Detection of irradiated food for a MAFF surveillance exercise (ref

AN1132)

1997-98 - £38,308 from MAFF for development of validated luminescence methods for detecting irradiated foods (ref FS1921).

1998 - £27,092 from MAFF for a preliminary investigation of the impact of blending on luminescence detection of irradiated herbs and spices, ref CSA 4790

1999-2002 - £158,894 from MAFF/Food Standards Agency for Investigation of statistical and imaging methods for luminescence detection of irradiated ingredients in blended foods, ref CSA 5240

2001-2002 - £33,500 from the Food Standards Agency, for conducting analytical surveillance of unlabelled irradiated foods in the UK.

2003 - £17500 from the Food Standards Agency to conduct a short investigation of the luminescence properties of talc

2004-2007 - £154,157 from the Food Standards Agency – Development of Proficiency Testing for Detection of Irradiated Foods, ref E01068

2008 - £51,000 from Food Standards Agency - Optimisation of Photostimulated luminescence methods for detecting irradiated dietary supplements

4. The contribution, impact or benefit

Food irradiation is the use of high energy ionising radiation to extend shelf life by reducing the bacterial loads associated with natural foods. Until the 1990s, however, enforcement was hampered by the absence of reliable and efficient detection methods.

Professor Sanderson and his team began exploring the possibility of using luminescence tests to solve this problem. His research led to the development of two international standard methods based on luminescence. Firstly, EN1788 (first introduced in 1992) “Detection of Irradiated Foods containing silicates using thermoluminescence”. This method implements almost all of the TL procedures developed at SURRC between 1987 and 1992. Secondly, EN13751:PSL (first introduced in 2001) “Detection of Irradiated Foods using Photostimulated Luminescence”, a method based on the SURRC pulsed PSL instrumental system. Today, these standards are the most widely used methods to detect irradiated foods and remain unchanged since their introduction.

Between January 2005 and December 2009 every consumer in the UK and Europe has benefitted from the added protection provided by the work of Professor Sanderson and his team in relation to food labelling and screening. Authenticity and traceability of foodstuffs are important to consumers, regulators and the food industry. The work carried out in Glasgow has provided consumers with substantially enhanced protection from unlabelled irradiated food, which can be used as a substitute for good sanitary practices in food production. In compliance with EC legislation, the UK Food Labelling Regulations 1996 and the Food Irradiation Provision Regulation 2000 require all foods, or listed ingredients of food, which have been irradiated, to be labelled with the words 'irradiated' or 'treated with ionising radiation'.

The standards are employed successfully by governments across Europe. There have been several cases where companies have been found to be supplying irradiated products not in compliance with food law, leading to costly recalls (often sanction enough) and other enforcement action including at least one UK prosecution. Food retailers and suppliers also use Sanderson's

methods for screening ingredients, thus managing their regulatory risk. In 2001 Professor Sanderson's tests found a high proportion (42 percent) of food supplements that were sampled in the UK were irradiated and not in compliance with the law. Subsequent testing in other countries found this to be a widespread problem and the information was brought to the attention of the public at large.

Professor Sanderson's laboratory is recognised as the leading laboratory in the field of irradiation detection in foods. As well as setting new standards for testing, it is the only establishment to develop, design and sell Photostimulated Luminescence (PSL) systems to detect irradiated food. Since 2005, the team has supplied over 200 laboratories worldwide with their own systems to ensure the ingredients they are using are non-irradiated. Each of these instruments is capable of making many tens of thousands of measurements per annum across the world.

5. References to corroborate the contribution, impact or benefit

European Standards:

BSEN1788, 1996; 2001; Detection of Irradiated Foods containing silicates using thermoluminescence. European standard developed by the CEN Technical Committee 275 Working Group 8, and published in two revisions following international consultation and voting procedures. The method implements almost all of the TL procedures developed at SURRC between 1987 and 1992.

BSEN13751, 2002; Detection of Irradiated Foods using Photostimulated Luminescence. European standard developed by the CEN Technical Committee 275 Working Group 8, and published following international consultation and voting procedures. The method is based on the SURRC pulsed PSL instrumental system.

Testimonial from named Food Irradiation Specialist:

"My previous work in the UK involved both the policy / enforcement of food irradiation legislation and dealing with enquiries and correspondence from a broad section of people on matters related to food irradiation.

EN1788 and EN13751 are the most widely used methods to detect irradiated foods. In a regulatory sense, EN1788 and EN13751 are necessary to ensure that food can be tested for compliance with the law. Both tests used together are a powerful tool in ensuring compliance with food irradiation regulations and also labelling regulations [to ensure that food is correctly labelled as irradiated].

Authenticity and traceability are important to consumers, regulators and the food industry. Consumer confidence in the food they buy and eat is fundamental to trade in food. However, confidence in food is difficult to measure accurately. Tests EN1788 and EN13751 are used predominantly in the UK and much of Europe.

In a practical sense, EN1788 and EN13751 have been employed to great effect. Some companies have been found to be supplying products not in compliance with the law on food irradiation. It has cost them a great deal to remove the items from sale and this is usually sanction enough (but there has been at least one successful prosecution).

The use of these tests by regulators has ensured that food businesses (especially those who deal in food supplements) take action to check their products for irradiation on a routine basis. The availability of these tests for use by the food industry has also helped to settle disputes between

companies. The tests are also available to be used by consumer groups and others who would like to test the authenticity of food.

Prof. Sanderson's laboratory is recognized as the foremost in the use of and development of luminescence techniques to detect irradiated food."

Contact details for an individual at the International Atomic Energy Agency were included for corroboration purposes.

Details of Government and European reports:

1. Sanderson D.C.W, Slater C., Cairns, K.J.,1989, Development Of Luminescence Tests To Identify Irradiated Foods, Progress Report 2, MAFF Project N384, 142p Ministry of Agriculture Fisheries and Food, London
2. Sanderson D.C.W., Schreiber G.A., Carmichael L.A.,1991, A European Interlaboratory Trial Of TL Detection Of Irradiated Herbs And Spices. SURRC Report To BCR (European Commission) 46p
3. Sanderson D.C.W., Carmichael L.A., Clark P.A., Clark R.J.,1992, Development Of Luminescence Tests To Identify Irradiated Foods. Final Report N1701 : Identification Of Irradiated Fruits And Vegetables, MAFF N1701, 104 p, Ministry of Agriculture Fisheries and Food, London
4. Sanderson D.C.W., 1992, Thermoluminescence Detection Of Irradiated Herbs And Spices, MAFF Validated Methods, V 27, MAFF, Norwich
5. Sanderson D.C.W. Carmichael L.A. Ni-Riain S. 1993, Photostimulated Luminescence And Thermoluminescence Techniques For Detecting Irradiated Foods. Detection Of Irradiated Shellfish, Maff N2635, Report March 1993, 41 p. Ministry of Agriculture Fisheries and Food, London
6. Sanderson D.C.W. Carmichael L.A. Naylor J.D., 1995, Establishing Luminescence Detection Methods For Irradiated Fruits, Vegetables And Shellfish, Results From The 1995 MAFF Trial On TL Detection Of Irradiated Shellfish, MAFF 1B0873, 15 p
7. Sanderson D.C.W. Carmichael L.A. Naylor J.D., 1996, Establishing Luminescence Detection Methods For Irradiated Fruits, Vegetables And Shellfish, Results From The 1995 MAFF Trial On TL Detection Of Irradiated Fruits And Vegetables, MAFF 1B0873, 16 p
8. Sanderson D.C.W., McLeod J.J. (1999). A preliminary investigation of the impact of blending on luminescence detection of irradiated herbs and spices, Final Report Project CSA 4790 , 50 p
9. Sanderson, D.C.W., Carmichael, L.A., Murphy, S.D., Whitley, V.H. , Scott, E.M., Cresswell A.J., 2004, Statistical And Imaging Methods For Luminescence Detection Of Irradiated Ingredients. Food Standards Agency Research Report, Reference CSA 5240, 40 p
10. D.C.W. Sanderson, L.A. Carmichael, S. Fisk, P. Key, E.M. Scott And M. Thompson, 2007, Final Report: Development Of Proficiency Testing For Detection Of Irradiated Food Project E01068, Volume I: Project Summary And Results Of First Round PSL Trials September 2005, 87 p, (Food Standards Agency, London); Volume II Results Of Second Round PSL and TL Trials September 2006, 129p, (Food Standards Agency, London); Volume III :Results Of Third Round PSL and TL Trials June 2007, 165 p , (Food Standards Agency, London)

Patent information:

Sanderson D.C.W., 1993, Detection Of Irradiated Foods, Patent GB877 940425, 17p, UK Patent Office

European Member State Official Testing Reports since 2005

[OJ 2007/C122/3-21](#)

[OJ 2008/C 282/3-19](#)

The Turbidites Research Group Industry-funded consortium: knowledge into use via provision of applied research, expert review of the field and focused consultancy (University of Leeds)

1. Short summary of the case study (Maximum 150 words)

This case study provides three examples of impact delivered via direct consultancy to the oil business by the Turbidites Research Group (TRG). Work of the TRG has been applied to improve geological models used by the oil industry in decision making. The decision-making process in the oil business is very closely tied to estimates of the reliability of the geological models used to underpin reservoir flow simulation models, and hence economic models. TRG inputs have brought about better constraint of their geological models improving their economic advantage.

2. Underpinning research (Maximum 500 words)

Provide information about the research and the specific insights that underpin the impact or benefit claimed in this case study.

The TRG specialises in deep marine clastic sedimentology.

The three examples of impact provided below are underpinned by the following research. The decision making process in the oil business is very closely tied to estimates of the reliability of the geological models used to underpin reservoir flow simulation models, and hence economic models. The TRG inputs allow better constraint of the geological models – crucially, alongside appraisal of many other factors. Thus it is in the nature of the business that only rarely can a specific input be shown to have had a specific impact.

1. Dr. Simon Barker's PhD (2002-5) and post-doctoral (2005) work, both done under TRG auspices was incorporated into the Britannia oil reservoir re-appraisal. This work was based principally on sedimentological analysis of Britannia core (subsequently published: Barker *et al.*, 2008). A second strand of input involved re-interpretation of debrite prone intervals, leveraging learnings from Joris Eggenhuisen's PhD (e.g., Eggenhuisen, 2009).
2. TRG field work on incisional submarine channel formation, and prediction of internal facies variability was used by the Blake appraisal team in their decision to justify the decision to develop the field (McCaffrey and Kneller 2004; McCaffrey *et al.* 2000). Subsequent work by part-BG – funded TRG PhD student Rufus Brunt (2000-2003; Brunt and McCaffrey, 2007) was incorporated into the field model. Additional consultancy work was focused on building a model to justify extension drilling in the field "Blake Flank" (2005-present).
3. TRG experimental and theoretical modelling work on turbidity current flow (Kneller and McCaffrey, 1999; Brunt *et al.*, 2004; Amy *et al.*, 2004) underpinned interpretations of sheet sand distribution and quality in the Holstein Field, which consists of stacked sandstone reservoirs in a ponded basin on mobile supra-salt substrates.

3. References to the research

Provide references to key research outputs, any key research grants, and evidence of the quality of the research (Maximum of 10 references).

Peer-reviewed literature:

- AMY, L. A., KNELLER, B.C. and **MCCAFFREY, W. D.** (2007). Facies architecture of the Grès de Peïra Cava, SE France: landward stacking patterns in ponded turbiditic basins. *Journal of the Geological Society*, 164, 143-162.
- AMY, L., **MCCAFFREY, W. D.** and B. C. KNELLER, (2004). The influence of a lateral basin slope upon the depositional patterns of natural and experimental turbidites, in P. Joseph and S. Lomas eds., *Tertiary Turbidites Systems of SE France*, Geological Society Special Publication, 221, 311-330.
- BARKER, S.P., HAUGHTON, P.D.W., **MCCAFFREY, W.D.**, ARCHER, S.G. & HAKES, B. (2008) Development of rheological heterogeneity in clay-rich high-density turbidity currents: Aptian Britannia Sandstone Member, U.K. Continental Shelf. *Journal of Sedimentary Research*, 78, 45-68.
- BRUNT, R.L. & **MCCAFFREY, W.D.** (2007) Heterogeneity of fill within an incised channel: the Oligocene Grès du Champsaur, SE France. *Marine and Petroleum Geology*, 24, 529–539.
- BRUNT, R., **MCCAFFREY, W.D.** and KNELLER, B.C. (2004). Experimental modeling of the spatial distribution of grain-size developed in a fill and spill mini-basin setting. *Journal of Sedimentary Research*, 74, 438-446.
- EGGENHUISEN, J.T., (2009). The interaction between substrate evolution and turbidity current development. PhD Thesis, Leeds University.
- KNELLER, B.C and **MCCAFFREY, W.D.** (1999). Depositional effects of flow non uniformity and stratification within turbidity currents approaching a bounding slope: deflection, reflection and facies variation. *Journal of Sedimentary Research*, 69, 980-991.
- MCCAFFREY, W.D.** and KNELLER, B.C. (2004). Scale effects of non-uniformity on deposition from turbidity currents with reference to the Grès d'Annot of SE France, in P. Joseph and S. Lomas eds., *Tertiary Turbidites Systems of SE France*, Geological Society Special Publication, 221, 301-310.
- MCCAFFREY, W.D.**, GUPTA, S. and BRUNT, R. (2002). Repeated cycles of submarine channel incision, infill and transition to sheet sandstone development in the Alpine Foreland Basin, SE France. *Sedimentology*, 49, 623-635.
- MCCAFFREY, W.D.** and KNELLER, B.C. (2004). Scale effects of non-uniformity on deposition from turbidity currents with reference to the Grès d'Annot of SE France, in P. Joseph and S. Lomas eds., *Tertiary Turbidites Systems of SE France*, Geological Society Special Publication, 221, 301-310.

4. The contribution, impact or benefit (Maximum 750 words)

Describe the impact or benefit and how the research contributed to this

The Turbidites Research Group (TRG) supported by the School of Earth and Environment is an oil industry-funded research consortium, and serves as an example of a model that links research capacity and user need, with impacts recognisable both directly, through documented interventions in specific business assets, and indirectly, through the broader dissemination of group research.

Active since 1992, the TRG specialises in deep marine clastic sedimentology. Total income to date is £3.9M, with up to 14 companies supporting each 3-year phase: some (BP, BG, ConocoPhillips) have been members through each phase. The TRG model entails 4 categories of deliverable:

- research results from a series of stand-alone programmes
- expert overview of the academic literature
- access to bespoke data bases of literature-derived data
- direct consultancy, applied to specific assets

The portfolio approach is designed to maintain broad appeal. The impacts detailed below focus on examples of direct consultancy, as these are most easily quantifiable. Nevertheless, a major thrust of the group and a stated reason for companies to join and rejoin the consortium has been the perception of beneficial impacts to sponsors in each of these categories. The first three categories are delivered to end users directly via a KT-oriented website. This KT approach has been described by sponsors as industry-leading via its impact on key workers.

Note: the decision making process in the oil business is very closely tied to estimates of the reliability of the geological models used to underpin reservoir flow simulation models, and hence economic models. TRG's research has led directly to better constraint of the geological models. However, many other factors are also important in oil field economics. Thus, it is in the nature of the business that only rarely can a specific research input be shown to have had a specific economic impact.

Examples of specific identifiable impact are below:

1. TRG research outputs incorporated into workflows for appraisal and development of the Britannia Field - outer Moray Firth by Britannia Operator Ltd (BOL: jointly owned by ConocoPhillips and Chevron). This asset is now in late field life, but at one point accounted for around 10% of UK daily gas production. Reservoir complexity and potential reservoir variability away from well control remain key issues on Britannia, accounting for significant volumetric uncertainty and representing the primary risk for new drilling opportunities. TRG research outputs played an important role in addressing these issues. Learnings from TRG research have been incorporated into reservoir model updates. The research of Baker led to a new model for the spatial variation of rheology within the particulate sediment gravity flows responsible for depositing the main reservoir interval, which directly impacted predictions of spatial variation in primary rock quality. These anticipated variations were explicitly incorporated into the reservoir model rebuild, providing a more robust depositional framework upon which to base new well prognoses. New well locations have, and are currently, being planned under the guidance of this improved depositional framework. Because infill wells cost upwards of \$20M each, the decision to sanction each new one is significant. Significant new reserves were booked as a result of this programme. To date, subsequent drilling has corroborated the revised depositional framework in the upper reservoir intervals. Eggenhuisen's research work led to a reassessment of the significance of debris flow deposits interleaved with sand beds in the lower Britannia reservoir intervals and a greater appreciation of the potential role of large-scale remobilisation processes. To this end, revisions to the existing correlation scheme were made and incorporated into the subsequent reservoir model updates for the Britannia field. It is believed that these changes represent a significantly improved representation of the field's depositional architecture, aiding its profitability.

2. Research results from the TRG field programme played a key role in the sanction decision and subsequent modelling of the BG-operated Blake Field, inner Moray Firth. Thus company geologists used TRG field data to overcome management scepticism of the geological model. Sanction involves the decision to go forward and develop a discovery for production – an investment of 100s of millions of dollars. The Blake field has subsequently been a production success.
3. Development costs in the deep-water environment of the Gulf of Mexico are very high, with production wells commonly costing in excess of \$100M each – so information that gives operators comfort that their modelling workflows (which yield well locations) are optimised are of great value. TRG experimental and theoretical modelling were extensively applied the BP-operated Holstein Field, Gulf of Mexico, to constrain likely primary variability in the quality of reservoir sands in the geological model, which was used to underpin the sanction decision and development plan

5. References to corroborate the contribution, impact or benefit (Normally maximum of 10 references)

Oil company contacts:

Contact details for individuals at Britannia, Blake and Holstein were provided for corroboration purposes.

Spinout for extensive environmental monitoring (University of Manchester)

1. Short summary of the case study (Maximum 150 words)

Salamander, a “spinout” from the School of Earth, Atmospheric and Environmental Sciences (SEAES) founded in 1996, has developed and marketed a suite of branded products - two for monitoring water quality in distribution (Hydraclam, Chloroclam) and one for monitoring ground gas (Gasclam). Their ability to provide secure, unmanned, stand-alone continuous monitoring in their specific environments makes the products unique. Patents have been applied for and there are no direct competitors. The devices have made significant alterations to “best practicable means” and therefore have major impacts on regulated industries by altering accepted best practice. The greater the investment by the operator the greater the cost benefit and impact but there are clear benefits and impacts even at the initial levels of take up. A major water company has altered the procedure for mains cleaning because of Hydraclam data and also now requires all contractors to use Hydraclam to monitor operations. Also, the presentation of high resolution ground-gas data has begun to be specified as a requirement by the Environment Agency and certain local authorities for site investigation.

2. Underpinning research (Maximum 500 words)

Provide information about the research and the specific insights that underpin the impact or benefit claimed in this case study.

The development of the products has been driven by the limitations of data used in a wide variety of environmental investigations within the Unit (SEAES), and therefore, the underpinning research is very broad and includes contributions from undergraduate, postgraduate and staff activities. Largely, the investigations involved hydrological and hydrochemical monitoring from which the value of more temporally and spatially complete datasets, and the opportunity to improve predictive power by “monitoring more and modelling less” was recognised. In addition to providing the idea, the research also gave the opportunity to develop and test instruments.

Work that can be regarded as relevant began in 1993 at the University with a spinout company being founded in 1996. All the staff of the company were University of Manchester graduates or postgraduates. Dr Stephen Boulton led his research group within the University supervising 3 postdoctoral researchers – 2 industrially funded – 10 PhD students and many MSc and undergraduates whose work was related to development and testing of equipment and methodologies for its use.

The institution enabled the “spinout” activity through Campus Ventures, a University incubator, and the Unit has allowed industrially funded researchers to pay reduced overheads. The company relocated to the University-owned Manchester Science Park in 2006.

The company has received about £600k of private investment TSB funding and has benefitted directly through the University from Research Council Funding (as detailed below); the contribution to impact of the Unit.

Initially the research contributed to the design and development of a datalogging system for environmental applications, including a wide range of sensors. As these products matured into the specific Clams, research contributed to development of telemetry systems. The company was a partner in several TSB projects concerned with wireless sensor networks – DTI Envisense programme GLACSWEB, SECOAS, DTI PIPES, and ran a similar NERC SBRI project, which employed a CASE PhD student in the Unit. The company worked with the School of Computer Science at the University on an EPSRC WINES DIAS project with a PhD student in the Unit. A TSB project was built around Gasclam and devoted to the development and dissemination of a new ground gas monitoring methodology. This funded a PDRA in the Unit and was extended using funding from other interested industry partners.

3. References to the research

Provide references to key research outputs, any key research grants, and evidence of the quality of the research (Maximum of 10 references).

Examples of peer reviewed Journal articles that underpin the impact:

Gaffney, J.W., K.N. White, and S. Boulton (2008) Oxidation state and size of Fe controlled by organic matter in natural waters. *Environmental Science & Technology* 42 3575-3581.

Hand, V.L., et al. (2008) Experimental studies of the influence of grain size, oxygen availability and organic carbon availability on bioclogging in porous media. *Environmental Science & Technology* 42 1485-1491.

Marshall, I.W., et al. (2007) Multi-sensor cross correlation for alarm generation in a deployed sensor network. *Smart Sensing and Context, Proceedings*. 4793 286-299.

Roadknight, C., et al. (2005) An intelligent sensor network for oceanographic data acquisition. *Ad-Hoc, Mobile, and Wireless Networks, Proceedings*. 3738 235-243.

Boulton, S., et al. (2001) Evidence that polysaccharide and humic and fulvic acids are co-extracted during analysis but have different roles in the chemistry of natural waters. *Applied Geochemistry* 16 1261-1267.

Boulton, S. and J. Rebeck (1999) The effects of eight years aeration and isolation from polluting discharges on sewage- and metal-contaminated sediments. *Hydrological Processes* 13 531-547.

Boulton, S., N. Johnson, and C. Curtis (1997) Recognition of a biofilm at the sediment-water interface of an acid mine drainage-contaminated stream, and its role in controlling iron flux. *Hydrological Processes* 11 391-399.

Peer reviewed grants that underpinned research:

Awarded to SEAES

Dr S Boulton "A general model for prediction of changes in fluxes to and from contaminated sediments in response to changes in water quality" NERC, April 1999-May 2002 (£105,246),

Prof DJ Vaughan "Quantifying the effects of biofilm growth on hydraulic properties and on sorption equilibria: micro to macro measurements" NERC, June 2000-Nov 2002 (£143,970)

Dr AAA Fernandes "Design, Implementation and Adaptation of Sensor Networks through Multi-dimensional Co-design" EPSRC Oct 2005-Sept 2008 (£237,401)

Awarded to the company

Consortium headed by British Telecom (Ian Marshall lead), Salamander, University of Southampton "Glacial Sensor Web Pervasive Computing in the Glacial Environment" DTI June 2003- June 2005 (£25k to Salamander, 50% of cost)

Consortium headed by British Telecom (Ian Marshall lead), University College London, Salamander, University of East Anglia “Self-organizing collegiate sensor networks (SECOaS)” DTI Sept 2003 – Sept 2005 (£52k to Salamander, 50% of cost)

Consortium headed by British Telecom (Jane Tateson lead), Imperial College, Cambridge University, Salamander “Personalised Information from Prioritised Environmental Sensing (PIPES)” Technology Strategy Board April 2006- Dec 2009 (£26k to Salamander, 50% of cost), Salamander Small Business Research Investment Grant NERC 2005-2007 (£125,000)
Co-award to Salamander, University of Manchester & Urban Vision Partnership DTI 2007 (£233,000)

4. The contribution, impact or benefit (Maximum 750 words)

Describe the impact or benefit and how the research contributed to this

Ground-gas monitoring methodology, and therefore risk prediction and greenhouse gas auditing, was known to be flawed because of the mismatch between sampling frequency and concentration variability. Gasclam, initially developed 2001, final version 2006, was designed to overcome this and has changed “best practice” in ground-gas monitoring. Through publications [2, 3], workshops, conference presentations, via CL:AIRE (Contaminated Land: Applications in Real Environments) and marketing activities, funded by TSB and industry, all regulators (local authority and Environment Agency) and most practitioners are aware of the potential for a revised methodology using gas concentration data with high time resolution. TSB funded a project to develop and disseminate a new methodology, the project was reviewed and accepted by the CL:AIRE Technology and Research Group, and an expert advisory group consisting of several of the authors of present guidance was constituted (and now involved in reviewing the new methodology). The use of Gasclam has begun to be recommended by regulators. Gasclam is licensed globally to lonscience Ltd and 250 units have been ordered to date.

Hydraclam and Chloroclam meet the needs of “proactive network management” by providing high-resolution information about the system, and have, therefore, begun to bring about changes in asset management practices. Dissemination has proceeded via CIWEM, PIG, KTN etc. seminars. The Hydraclam is already in use by all major UK water service providers as an investigative tool and United Utilities, Bristol Water and Yorkshire Water Services have deployed networks of telemetered devices (ClamNet) for long-term condition monitoring. Full market penetration will result in deployment of both Hydraclam and Chloroclam in every district metering area in the UK. Licenses for the products have been granted to Siemens (Hydraclam UK license 2005 to be updated to global in 2010, Chloroclam global license 2010) conditions of the license being minimum sales of 35,000 Chloroclams (@ royalty £600 per unit) worldwide 2010-2015. As the projected UK income from Hydraclam of £60 million 2008-2016 is solely royalty payments, it can be regarded as Gross Value Added (GVA - the difference between output and intermediate consumption for any given sector/industry) and if half this income was assumed to be reinvested the Office of National Statistics 2004 Input-Output Framework multiplier of 2.21 for a “Research & Development” company could be applied, thereby giving a GVA of £96 million [1]. Whilst the impact of other investors including Research Councils reduces the impact share of SEAES to 25% this GVA is a fraction of the total, as it is calculated only from UK sales of Hydraclam.

5. References to corroborate the contribution, impact or benefit (Normally maximum of 10 references)

Corroborating information:

1. NERC Impact Case Study 2010 – Monitoring Water Quality in the UK (DTZ, Richard Cook)
2. The Land Remediation Yearbook 2008 – Environmental Industries Commission p. 33-36
3. Steve Wilson, Geoff Card and Sarah Haines, *The Local Authority Guide to Ground Gas* (2008), Chartered Institute of Environmental Health, p. 58-60

Contacts:

Contact details of individuals at Siemens, Severn Trent Water, Yorkshire Water Services, CL:AIRE, and Ionscience were provided for corroboration purposes.

Conservation of Bumblebees (University of Stirling)

1. Short summary of the case study (Maximum 150 words)

The Bumblebee Conservation Trust (BBCT), a conservation charity, was founded by researchers led by Professor Goulson in the School of Biological and Environmental Sciences at Stirling specifically to bridge the gap between their research findings and conservation practice. The aim of the trust is to conserve bumblebees by: raising public awareness of bumblebee conservation issues; involving the public in practical conservation and in recording schemes; promoting wildlife-friendly gardening; influencing policy relating to agri-environment schemes; joining with other NGOs to create habitat for bumblebees. The BBCT now has 7,000 members, over 2,000 of whom actively participate in bumblebee recording or conservation. Other impacts include awareness raising through extensive media coverage for bumblebee conservation, an education pack for primary schools, joint initiatives with a nationwide Garden Centre chain (Wyevale) and a supermarket (Morrisons), the establishment of the first bumblebee nature reserve and other land management projects, direct engagement with farmers in agri-conservation practices, and political lobbying and influencing.

2. Underpinning research (Maximum 500 words)

Provide information about the research and the specific insights that underpin the impact or benefit claimed in this case study.

Goulson's research group has spent the past 16 years conducting research on the ecology and conservation of bumblebees, and has produced >160 peer-reviewed publications in this time. Over time the group's research became increasingly focused on explaining why many species are declining, and in developing techniques to conserve them. They discovered much about the basic ecology, foraging range and dietary requirements of both rare and common bumblebees. Some of this work has developed island populations in the Hebrides as a model system in which to understand the population biology of bumblebees; islands have the advantage that the size and isolation of populations are more easily defined. The Hebrides also support significant populations of endangered bumblebees. Knowledge gleaned from this work has then been applied to understanding how best to conserve small, declining populations of bumblebees in habitat fragments on the mainland (e.g. Somerset levels, Salisbury Plain) and in Europe. Molecular studies by the group have revealed the impacts of inbreeding on bumblebees and allowed estimation of minimum viable population sizes. Parallel studies have sought to understand how lowland farm management and agri-environment schemes affect population size and pollination service provision by common bumblebee species. The group have also become involved in understanding the impacts that bees can have on biodiversity when released outside their native range.

In combination with other studies of bumblebees conducted by other research groups elsewhere, we now have a clear idea how to conserve bumblebees; they simply need enough of the right flowers, at the right times of year, provided in patches distributed at an appropriate spatial scale. For some species, action is urgently needed as current populations are too small to persist in the long term; unless population size is increased they will probably go extinct. This action needs to

be integrated with farming practices to produce a sustainable system whereby pollination services for crops and wildflowers are secured. However, farmers, nature reserve wardens and politicians do not read scientific journals. Much of the research that goes on into how best to conserve declining species is never translated into action.

This body of work began when Goulson was at Southampton University in 1995, and moved with him to Stirling in 2006. The key researchers were/are all PhD students and postdocs within this group. Dr Ben Darvill deserves particular mention; he was an undergraduate at Southampton and went on to do his PhD (Southampton) and a postdoc (Stirling) with Goulson before helping found BBCT, for which he now works full time.

3. References to the research

Provide references to key research outputs, any key research grants, and evidence of the quality of the research (Maximum of 10 references).

Selected peer-reviewed publications by Goulson et al. on bumblebee ecology / conservation

- 2009 Lye GC, Park K, Osborne JL, Holland J and Goulson D. Assessing the value of Rural Stewardship schemes for providing foraging resources and nesting habitat for bumblebee queens (Hymenoptera: Apidae). *BIOLOGICAL CONSERVATION* 142: 2023-2032
- 2009 Whitehorn, P., Tinsley, M., Brown, M.J.F, Darvill, B. & Goulson, D. Impacts of inbreeding on bumblebee colony fitness under field conditions. *BMC EVOLUTIONARY BIOLOGY* 9:152
- 2008 **Goulson, D, Lye, GC, Darvill, B. Decline and conservation of bumblebees. *ANNUAL REVIEW OF ENTOMOLOGY* 53: 191-208**
- 2006 Carvell, C., Roy, D.B., Smart, S.M., Pywell, R.F., Preston, C.D. and Goulson, D. 2006 Declines in forage availability for bumblebees at a national scale. *BIOLOGICAL CONSERVATION* 132, 481-489
- 2006 Ellis, J.S., Knight M.E., Darvill, B., & Goulson, D. Extremely low effective population sizes, genetic structuring and reduced genetic diversity in a threatened bumblebee species, *Bombus sylvarum* (Hymenoptera: Apidae). *MOLECULAR ECOLOGY* 15: 4375-4386
- 2005 Knight, M.E., Martin, A.P., Bishop, S., Osborne, J.L., Hale, R.J., Sanderson, R.A. & Goulson, D. An interspecific comparison of foraging range and nest density of four bumblebee (*Bombus*) species. *MOLECULAR ECOLOGY* 14: 1811-1820
- 2005 Goulson, D. Hanley, M.E. Darvill, B., Ellis, J.S. and Knight, M.E. Causes of rarity in bumblebees. *BIOLOGICAL CONSERVATION* 122: 1-8
- 2003 Kells, A.R. & Goulson, D. Preferred nesting sites of bumblebee queens (Hymenoptera: Apidae) in agroecosystems. *BIOLOGICAL CONSERVATION* 109: 164-174

Key grants:

- BBSRC, 2001, Landscape-scale factors affecting bumblebee populations in agroecosystems, £135k
- Leverhulme, 2001, The Hebrides as a model system for studying population structure of rare bumblebees, £40k
- Leverhulme, 2004, The Hebrides as a model system for studying population structure of rare bumblebees (follow up grant), £133k
- BBSRC, 2006, Effects of mass-flowering crops on bumblebee populations in arable farmland, £263k
- Leverhulme, 2007, Use of a sniffer dog to detect bumblebee nests, £116k
- Natural England, 2009, Reintroduction of the extinct short-haired bumblebee to the UK, £115k

Evidence of the quality of the research: Goulson's research has been cited >2,400 times in the last 15 years. It has attracted much media interest, with articles in national newspapers, radio and television.

4. The contribution, impact or benefit (Maximum 750 words)

Describe the impact or benefit and how the research contributed to this

SBES staff (Goulson, Darvill) founded the Bumblebee Conservation Trust (BBCT) in 2006. BBCT is a charity devoted to translating what we have learned about bumblebee biology into practical measures to conserve this declining group of pollinators. The research outputs feeding into these measures include detailed knowledge of bumblebee foraging and nesting needs, understanding of their distributions, population density and dispersal abilities, and knowledge on the scale at which habitat manipulations are required to influence bumblebee population size.

The charity has grown from a starting point of no paid staff, no members and no funds in June 2006 to have 7,000 members and provide employment for 6 full-time staff (Aug 2010). All members receive wildflower seeds, an identification poster and a quarterly newsletter. They are strongly encouraged to get involved in trust activities which include bumblebee identification training days and three different bumblebee recording schemes. Between them these schemes have so far generated >100,000 individual bee records sent in by >3,500 recorders. Over 2,000 members now actively participating in either bumblebee recording or conservation.

Other impacts:

- Awareness: We persuaded the *Independent* to feature the launch of BBCT on their front 3 pages in June 2006. Since then we have had much media coverage, including substantial articles about bumblebees and their decline in *The Sunday Times*, *The Guardian*, *the Telegraph*, *The Daily Mail*, television coverage on BBC "The One Show" and BBC Breakfast News, and a 30 minute programme "The Plight of the Bumblebee" on Radio 4. This media coverage has substantially raised awareness of bumblebee declines and how they may be reversed in the public consciousness.
- Wildlife gardening: In 2009 we teamed up with Wyevalde Garden Centres to run an "Insect Weekend" with displays illustrating the best plants for bumblebees in 122 garden centres across the country. The trust has distributed >15,000 packs of wildflower seeds.

- We have a mission to raise awareness in children (the land managers of tomorrow), and to this end we obtained funding from Scottish Natural Heritage to develop an education pack for primary schools. This had input from educational specialists and was trialled in several primary schools; it has since been requested and sent out to over 200 schools. Trust staff have visited many schools to talk about bumblebees and advise on creating school wildlife gardens.
- Through an initiative with Morrisons supermarkets, 200,000 packets of wildflower seed and information on bumblebees were given away with bouquets of flowers in 2010.
- Practical Conservation: The Trust set up the first “Bumblebee nature reserve”, a 20 acre grassland restoration project at RSPB Vane Farm, Loch Leven. We recently obtained funding for a major (200 acre) grassland restoration project in Carmarthenshire with the Grasslands Trust. With funding from Natural England and working with various partners including RSPB, we are midway through a project to reintroduce the extinct short-haired bumblebee to the UK. More than 500 acres of suitable bumblebee habitat have been created in SE Kent in advance of the reintroduction attempt. Working with FWAG and NFU, each spring and summer our two conservation officers organise numerous “farmer’s days”, on-farm social gatherings at which farmers meet to discuss bumblebee conservation and how best to manage bumblebee-friendly agri-environment prescriptions. Farmers very readily grasp the importance of bumblebees as pollinators of crops and wildflowers, and we have found that this grass-roots approach to conservation is paying great dividends in terms of delivering bee-friendly farming. Many more projects are in the pipeline.
- Lobbying: Our activities have led to a number of invitations to meet with politicians, including members of the Scottish and European Parliaments, Ministers and even a visit to No.10.

Evidence of the range of impacts the trust has had can be obtained from simply typing *bumblebee conservation* into Google – the first >100 webpages that come up all refer to the work of the trust, and include diverse sources from the BBC to local government to sock manufacturers. Goulson was Science Communicator of the Year runner up in 2006 (Biosciences Federation), was BBSRC’s “Social Innovator of the Year” in 2010, and was also given the PraxisUnico Impact Award for Environmental Research in 2010.

5. References to corroborate the contribution, impact or benefit (Normally maximum of 10 references)

Details of BBCT’s activities can be found on their website <http://www.bumblebeeconservation.org/>

The Charities Commission hold details of the financial organisation and aims of the trust.

The following organisations can provide corroboration of the claims made in the case study:

Morrisons supermarket

Wyevale garden Centre

National Farmers Union

The Grasslands Trust

British Trust for Ornithology

[Names and contact details were provided]

Compilation of the CRU Global and Hemisphere Land Area Temperature Record and Future Climate Scenario Analysis (University of East Anglia)

1. Short summary of the case study (Maximum 150 words)

During the late 1980s, CRU undertook seminal research to develop regional climate change scenarios – initially using arbitrary changes and temporal analogues - and was also one of the pioneer groups using global climate model output for this purpose during the 1990s. More recently, CRU research has exploited regional climate models and developed statistical downscaling techniques to provide information at higher spatial scales demanded by users and decision makers.

CRU, together with the Met Office Hadley Centre (MOHC), produces one of the three surface temperature datasets (HadCRUT3) for the world. CRU produces the land component and MOHC the marine of HadCRUT3. Agreement with the two US datasets is excellent, as illustrated in numerous publications, including the IPCC's Fourth Assessment Report (AR4) in 2007. These temperature series are widely used as the cornerstone to all discussions about climate change.

2. Underpinning research (Maximum 500 words)

Provide information about the research and the specific insights that underpin the impact or benefit claimed in this case study.

Past Climate

The scientific community's effort to reconstruct Northern Hemisphere temperatures, in which CRU has played a key role, underpins important policy-relevant questions: *Can we explain the causes of climate change over the last millennium? How unusual is the recent warming in the context of natural climate variability?* Some applications are specifically linked to climate models and predictions of future climate. For example, CRU has shown, rather wide uncertainties, that climate model simulations of past temperatures are consistent with the evidence provided by the proxy-based reconstructions, while this is not so if only natural forcings are considered. This provides some confidence in the future climate projections made using these models, and re-affirms the importance of anthropogenic greenhouse gas emissions in explaining climate changes over the instrumental and historical period. These temperature reconstructions have also provided another constraint on estimating the sensitivity of the climate system to changes in radiative forcing. Via the IPCC assessments, CRU's research has contributed to decision-makers' acknowledgement of the urgent need to address anthropogenic climate change.

CRU's research began in the 1970s under Hubert Lamb, exploring evidence for climate change during historical time recorded in natural and documentary proxy records. Recent work in this area has focussed on the use of high-resolution climate proxies, prominent among them being the analysis and interpretation of tree-ring data. CRU has been responsible for widely adopted methodological advances in this field and has produced multiple spatially-detailed and regional-average reconstructions, of various climate parameters. CRU is well known for its reconstruction of mean summer temperature changes, extending over centuries to millennia in different regions of the world; CRU researchers have produced or contributed to widely cited and utilised reconstructions of average Northern Hemisphere temperature changes 1-2,000 years *BP* some based solely on tree-ring data and others based on compendia of multi-proxy sources. This work

has made a particular contribution to 2001 and 2007 IPCC Working Group 1 assessments. The papers on which these IPCC assessments in 2001 and 2007 cover the period 1995 to 2010.

3. References to the research

Provide references to key research outputs, any key research grants, and evidence of the quality of the research (Maximum of 10 references).

Brohan, P., Kennedy, J., Harris, I., Tett, S.F.B. and Jones, P.D., 2006: Uncertainty estimates in regional and global observed temperature changes: a new dataset from 1850. *J. Geophys. Res.* **111**, D12106.

Briffa, K. R., F. H. Schweingruber, P. D. Jones, T. J. Osborn, S. G. Shiyatov, and E. A. Vaganov. 1998a. Reduced sensitivity of recent tree-growth to temperature at high northern latitudes. *Nature* **391**:678-682.

Briffa, K. R., F. H. Schweingruber, P. D. Jones, T. J. Osborn, I. C. Harris, S. G. Shiyatov, E. A. Vaganov, and H. Grudd, 1998b. Trees tell of past climates: but are they speaking less clearly today? *Philosophical Transactions of the Royal Society of London Series B – Biological Sciences* **353**, 65-73.

Briffa, K.R., Osborn, T.J., Schweingruber, F.H., Harris, I.C., Jones, P.D., Shiyatov, S.G. and Vaganov, E.A., 2001: Low-frequency temperature variations from a northern tree-ring density network. *J. Geophys. Res.* **106**, 2929-2941.

Briffa, K. R., V. V. Shishov, T. M. Melvin, E. A. Vaganov, H. Grudd, R. M. Hantemirov, M. Eronen, and M. M. Naurzbaev. 2008. Trends in recent temperature and radial tree growth spanning 2000 years across northwest Eurasia. *Philosophical Transactions of the Royal Society B-Biological Sciences* **363**, 2271-2284.

Jones, P.D. and Moberg, A., 2003: Hemispheric and large-scale surface air temperature variations: An extensive revision and an update to 2001. *J. Climate* **16**, 206-223.

Jones, P.D., Groisman, P.Ya., Coughlan, M., Plummer, N., Wang, W-C. and Karl, T.R., 1990: Assessment of urbanization effects in time series of surface air temperature over land. *Nature* **347**, 169-172.

Jones, P.D., Lister, D.H. and Li, Q., 2008: Urbanization effects in large-scale temperature records, with an emphasis on China. *Journal of Geophysical Research*, **113**, D16122.

Mitchell, T.D. and Jones, P.D., 2005: An improved method of constructing a database of monthly climate observations and associated high-resolution grids. *Int. J. Climatol.* **25**, 693-712.

4. The contribution, impact or benefit (Maximum 750 words)

Describe the impact or benefit and how the research contributed to this

Present Climate

CRU's non-temperature datasets are open to other scientists via its web site, with citation rates in papers of >700 in 1999, 2000 and 2005, for example. CRU datasets are used in many Detection

and Attribution (D&A) studies, attempting to relate warming to the changing composition of the atmosphere. The AR4's conclusion that 'Most of the observed increase in global average temperatures since the mid-20th century is with a 90% probability due to the observed increase in anthropogenic greenhouse gas emissions' draws on papers by Jones dating back to 1993.

The Intergovernmental Panel on Climate Change (IPCC)

The IPCC Assessment Reports, to which CRU scientists have contributed since 1990, form the knowledge basis on climate change underpinning international negotiations led by the United Nations. Professors Tom Wigley, Phil Jones and Andrew Watson contributed to the First Assessment in 1990; they were joined by Professors Peter Liss, Kerry Turner, and Neil Adger in the Second Assessment (1995). Professor Bob Watson, now Professor in ENV and DEFRA's Chief Scientific Advisor, chaired Working Group II of the Second Assessment, and the complete Third Assessment (2001). In total, 25 members of ENV contributed to the 4th assessment for which the IPCC was awarded the 2007 Nobel Peace Prize, jointly with Al Gore.

CRU has played a leading scientific, co-ordination and communication role in a series of EU projects on the development and application of regional scenarios: the FP5 MICE, PRUDENCE and STARDEX projects and the FP6 ENSEMBLES project. The importance of these projects is reflected in the IPCC AR4 and the current drafting of the IPCC Special Report on Extremes. CRU provided expert guidance on regional scenarios for the PESETA project – maps from which are presented in the 2007 Green Paper on adaptation. Both ENSEMBLES and PESETA are identified as major projects underlying the impact assessment report accompanying the 2009 White Paper on *Adapting to Climate Change: Towards a European Framework for Action* (http://ec.europa.eu/environment/climat/adaptation/index_en.htm).

Future Climate Projections

Recommendations from these EU projects have influenced policy-makers' choice of a multi-model approach to achieve a better representation of modelling uncertainty. The 2009 UK Climate Projections (UKCP09) represent the state-of-art globally in their detailed assessment of uncertainty. A probabilistic approach is taken; the UKCP09 science report cites a 2007 paper led by CM Goodess in justifying this approach. Goodess was a member of the UKCP09 science steering committee and was one of the five international reviewers of the probabilistic projections appointed by DEFRA.

CRU, together with the University of Newcastle, developed the weather generator (Wgen) which is freely accessible from the UKCP09 user interface, allowing users to produce their own daily data from the projections for local scale analysis, particularly of extreme events. Much of the development work on the CRU Wgen (led by Professor Jones) was undertaken in a series of EPSRC funded projects on climate change and the built environment, as well as for the Environment Agency. The *EarWig* tool developed for the Agency is used on an operational basis.

Ongoing work, largely funded by the EPSRC, is further tailoring the Wgen for specific applications and decision-making tools, focusing on urban planning and the urban heat island. This work involves many regional stakeholders, as well as national bodies such as the CABE and the TCPA. The GLA has recently incorporated policy on controlling the urban heat island in the London Plan. This work is also feeding into development of new national building design data by the Chartered Institute of Building Service Engineers.

CRU have developed the global patterns of possible future climate change used within the DECC/DEFRA-funded AVOID programme. This programme provided key advice to the UK Government during the December 2009 Copenhagen Conference, focussing on the range of climate change impacts that could be avoided by adopting policies to limit emission of greenhouse gases.

5. References to corroborate the contribution, impact or benefit (Normally maximum of 10 references)

ENSEMBLES and PESETA are identified as major projects underlying the impact assessment report accompanying the 2009 White Paper on *Adapting to Climate Change: Towards a European Framework for Action* http://ec.europa.eu/environment/climat/adaptation/index_en.htm).

Jenkins, G.J., Murphy, J.M., Sexton, D.S., Lowe, J.A., Jones, P.D. and Kilsby, C.G.: UK Climate Projections: Briefing report, Met Office Hadley Centre, Exeter, UK. 2009.

Jones, P.D., Kilsby, C.G., Harpham, C., Glenis, V., and Burton, A.: UK Climate Projections science report: Projections of future daily climate for the UK from the Weather Generator, University of Newcastle, UK. 2009.

2001 and 2007 IPCC Working Group 1 assessments.

IPCC, 2007: *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 996 pp.

IPCC, 2001: *Climate Change 2001: The Scientific Basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change* [Houghton, J.T., Y. Ding, D.J. Griggs, M. Noguer, P.J. van der Linden, X. Dai, K. Maskell, and C.A. Johnson (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 881pp.

Contact details of individuals at IPCC, DEFRA, UKCIP and Met Office were included for corroboration purposes.