Institution: University of Reading

Unit of Assessment: 7 Earth Systems and Environmental Sciences

a. Context

Research at UoR covers a great many aspects of environmental and Earth system science, centred on core expertise in meteorology, hydrology and biogeochemistry - but covering areas as diverse as volcanism, climate science, paleoclimatology, storm hazards, boundary layer dynamics, groundwater systems, soil and aquatic ecology and chemistry, glaciology, radiative processes, urban meteorology, airborne dispersal, sea level rise, space weather, atmospheric chemistry, sea ice, atmospheric electricity, security of food, energy and water supply, and many more. The research includes monitoring (from the ground and from space), targeted observations, numerical modelling (often using top-end high-performance computing), understanding processes, and algorithm development and testing. In all areas, some of our research is aimed at defining and solving specific problems whilst other parts are fundamental science. Much multi-disciplinary research is carried out with other groups in UoR and other institutes.

The impact of the Unit's research is achieved via a variety of products including provision of evidence, advice, data, model predictions and codes, algorithms, scenario tests, equipment and forecasting procedures. These underpin environmental management, policy-making, and sound economic practice in a wide range of end-user organisations. **Major beneficiaries** include:

(a) The Met Office and corresponding organisations in many other nations and the multi-national European Centre for Medium-Range Weather Forecasts (ECMWF).

(b) Government Departments and Agencies, in the UK and around the world (particularly in developing nations) responsible for the monitoring of, mitigation of, and adaptation to, environmental issues (such as climate change, hazardous weather, soil and water quality, water supply, airborne pollution, food security and energy security). The UK agencies include the Environment Agency, Defra, Countryside Council for Wales, Natural England, COBRA, DfID, Greater London Authority, the Scottish Government. International agencies include the United Nations Environment Programme (UNEP), Intergovernmental Panel on Climate Change (IPCC), World Health Organisation (WHO), World Meteorological Organization (WMO), European Organization for the Safety of Air Navigation (EuroControl), Teagasc (Irish Agriculture and Food Development Authority), European Space Agency, the EU Joint Research Centre.

(c) Charities concerned with aid, the environment and health

(d) Industries strongly influenced by environmental factors, such as insurance/re-insurance, construction, agriculture, food distribution, aviation, road transport, waste, water supply, power generation and distribution, marine, satellite construction and spacecraft operations.

b. Approach to impact

Some of our research is very long-term in its vision and so could be classed as "pure" whereas other projects are designed to address a specific problem and so are more "applied" in nature. However, the largest category is best characterised as "strategic" or "translational" in that it is targeted at applications but is broad in its scope. Our approach is to proactively seek engagement with potential users to both plan our research and to advertise our capabilities. Historically, the Department of Meteorology at UoR grew because of the close proximity of, and strong working relationship with, the **Met Office** and later **ECMWF**. The legacy of this history is that the application of world-class research into weather and climate has always been at the heart of our work. Those relationships have continued following the move of the Met Office to Exeter and UoR is now one of four Universities in a formal research partnership with them. In particular, the Unit brings a unique expertise in dynamical meteorology to this partnership and the relationship is cemented with the largest number of collaborative projects and posts funded by the Met. Office within the Unit, in addition to the MetOffice@Reading group embedded within the Unit. Collaboration with ECMWF is based on working relationships between individual scientists and via jointly funded grants (for example from the European Commission, EC). These operational agencies are just two of many pathways by which research done in the Unit is applied. Knowledge exchange (KE) and delivery of impact is under-taken through project-based partnerships with the

end-user national and government organisations (some of which listed in section a) and with private sector organisations, international agencies and charities. Collaboration is encouraged using resources from UoR's Walker Institute and UoR's Research and Enterprise Development Unit and new partnerships have been forged to draw together the Unit's expertise to meet emerging science evidence and prediction requirements.

The Unit has established, developed, and made extensive use of a number of centres and collaborations to act as pathways to impact of our research. Much of our impact is achieved via these groupings. The aim in each case is two-way Knowledge Exchange (KE): partnerships with stakeholders and partners are pro-actively sought and developed (preferably with leveraged resources as that increases the quality of the engagement) as a way of both informing the Unit's researchers and planners of requirements and of supplying information, solutions and techniques relevant to those requirements. Fruitful collaborations have been forged with many companies, for example BMT, Willis-Re, BP, National Grid who have funded Professors and KE fellows within the Unit, as well as research. Some mechanisms that have been developed to promote KE are:

The **Walker Institute** for Climate System Research was set up in 2006 to coordinate and develop research across the University into climate change and its consequences, and to engage closely with research users and stakeholders. It advertises the Unit's capabilities, informs Unit scientists of emerging needs and promotes interdisciplinary research to address problems. It delivers CPD and awareness raising, advice to government departments and agencies on climate change scenarios for the UK and advice and research to assess the implications for a number of sectors, including water, agriculture, soils and construction. It also organises stakeholder engagement events to help initiate the flow of information in both directions and to stimulate the co-production of knowledge. A few of a great many examples, which have been the subject of specific case studies, include working in partnership with the insurance industry, the water industry, Deloitte, the agri/food sector and energy sectors and in the public sector with research councils, DECC and DfID. There has also been a strong collaboration on Africa with the Rockefeller Foundation.

The **Weather and Climate Hazards Laboratory** (WCHL) was established during this REF period to address the fundamental research challenges concerned with understanding and quantifying the drivers of variability and change in weather and climate hazards, and with the applications of that knowledge. This is a collaborative venture between the Walker Institute, NCAS, University of Exeter, and relevant parts of the Willis Re-insurance Research Network. The foundations of WCHL are in national and international collaborative programmes in high-resolution climate modelling and assessment, enabled by a long-term NERC-Met Office collaboration (Joint Weather and Climate Research Programme), and the aim is to quantify how varying and changing weather and climate-related risks impinge upon decision-making in both the public and commercial sectors. For example, industry analysts estimate that WCHL could generate a reduction in average insured losses due to storm damage that considerably exceeds 5%, but even this would be worth between £62-130million per annum to the UK insurance industry.

The **Aquatic Environments Research Centre** (AERC) was founded in 1995 to undertake interdisciplinary research on the structure, function, problems and management of a range of different aquatic environments. It provides monitoring and model-based assessments of the cycling of the macronutrients (carbon, nitrogen and phosphorus) and a range of contaminants in relation to environmental change, including the disruption to ecosystem health in waters throughout Europe and North America. The research is in partnership with a wide range of Government and non-Government agencies with responsibility for the management of the chemical, hydrological and ecological status of waters, including: Defra, the Environment Agency, UK Water Industry Research, all the major UK water companies, Natural England, CCW (now Natural Resources Wales), The Rivers Trust, Game and Wildlife Conservation Trust, RSPB, the National Trust.

The **Soil Research Centre** (SRC) was formed from existing UoR groups in 2010 and carries out research with impact in agricultural production, biodiversity, carbon sequestration, contamination and remediation, waste management and the effects of climate change. KE is delivered via most of the agencies involved with AERC plus others such as Syngenta, the Royal Horticultural Society, the waste sector, EarthEnergy Ltd. and the Institution of Occupational Medicine.

In addition, a great many **collaborative projects** have been established to transfer up-to-date scientific understanding in a specific area to industry and to national and local governments and to collaborate with them to develop facilities and capabilities. Several of these have been via NCEO who specialise in the areas of data assimilation and the testing of models using the global coverage that space data enables. The Unit has a world-leading reputation and a unique track record of partnering with space and non-space companies to deliver innovative environmental products and services. Its expertise extends into visualisation and e-Science. Two EC-FP7 funded projects, CHARMe and IS-ENES2, are good examples. UoR (through NCEO), RAL Space, Astrium, and Logica have partnered with the large European data producers and providers (MO, DWD, KNMI, ECMWF) in the CHARMe collaboration which will provide a means to ensure products and core services from ESA's GMES (Global Monitoring for Environmental Security) are used in a wide variety of climate services. Similarly, UoR are making large leadership and other contributions to IS-ENES2 (infrastructure project of the European Network for Earth System Modelling, ENES) and to ENES in general. Both will have a lasting legacy, not only in the data handling and in modeling, but also in the way that future funding calls by the EC are constructed so as to build on the capacity achieved in the projects themselves. New markets have been developed by collaborations between various groupings within the Unit; for example, precision agriculture working with the Centre for Food Security, the use of urban meteorology by the construction and retail (supermarket) sectors and by city authorities, the use of water quality modelling for scenario testing by the water industry, the application of weather and climate data to energy saving in the aviation industry and to the renewable energy sector, the use of storm tracking in the marine sector.

The Unit's scientists also make important contributions to a large number of international organisations aimed at informing **policy on environmental issues**, such as WMO, IPCC, UNEP (particularly its Foresight Panel on Emerging Issues for c.21st), United Nations (UN) Framework Convention on Climate Change, UN Economic Commission for Europe, International Convention on Long Range Transboundary Air Pollution, EC Directorate-General Environment, EuroControl, the WMO/UNEP Scientific Assessments of Stratospheric Ozone Depletion and ESF's European Nitrogen Assessment. In all these cases, work by the Unit has been fed through into the development of viable mitigation and adaptation policies.

c. Strategy and plans

Because the Unit has, over several decades, established a large activity in, and infrastructure for, impact-related activities (see previous section), our approach is, in many ways, evolutionary rather than revolutionary. Nevertheless, we aim to expand and develop our KE activities whilst maintaining the same proportion of underpinning basic research. A key and increasing requirement is to work across traditional academic disciplines to meet recognised "grand challenges". UoR has made this aim viable by investing in 50 new academic posts across the university in climate-related areas, particularly regarding food, water and energy security. Target sectors include space, energy, food, construction, water, finance and insurance.

Our strategy for future KE and realisation of impact is twofold. (1). We aim to expand and fully exploit the procedures, practices and networks already in place (see section b). To support this we now have three NERC KE fellows (working with the insurance and marine sectors, African governments and Met agencies, and with agriculture) and one funded by Willis-Re on insurance. We are planning to expand and diversify with more, some funded as EC Marie Curie fellows. We aim to increase the number of KTP projects, building on successful examples with Willis, BP and National Grid. We also already have several KE placements with UK Government agencies and departments for PDRA staff to promote KE and provide a better understanding of the nature of the science knowledge, evidence and uncertainties and ways this feeds into the development of environmental management and policy. (2). We aim to develop the following major new initiatives.

Space@Reading. Space-based Earth observation data is vital for understanding global-scale phenomena. It also has many uses from resources exploration to disaster monitoring. UoR is a founder member of the TSB's Space Catapult, a not-for-profit company which is a partnership of public and private sector organisation (formerly known as ISIC). As part of this, UoR is forming a major new activity to bring together the space-related expertise to work with the UK space industry. The Unit was very prominent in the development of the CEMS (Climate and Environmental

Modelling from Space) facility which has already demonstrated the potential of the Catapult.

Environmental Virtual Observatory. New techniques for the visualisation and manipulation of environmental data are being developed in a proof-of-concept portal currently under development through a NERC-funded programme involving a wide range of academic and end-user partner organisations and bringing in new partners (e.g. Google, Microsoft, TSB). Allied to other new initiatives such as cloud-computing facilitated data access, these techniques will make possible a new generation of environment-related KE activities by supplying science evidence that is timely, comprehensive and optimally adapted to the user's need.

The Climate KIC (Knowledge and Innovation Community). UoR is a member of this EC-funded activity co-ordinated in the UK by Imperial College and the Institute for Sustainability and linked to corresponding centres in France, The Netherlands, Germany and Switzerland. Together this activity is the largest public-private innovation partnership in Europe, aimed at addressing the challenges posed by climate change.

Environmental Technology and Innovation Centre. We are developing plans and proposals for a centre, part funded by HEFCE and involving a partnership with industry, to translate research into environmental applications and services for the public and private sectors.

Afclix is a web-portal of the Africa Climate Exchange Project, led by a KE Fellow in the Unit. It facilitates the exchange of climate science and adaptation knowledge, initially between parties in Sudan, Senegal and the UK. Under Afclix, a number of projects are combined in terms of disseminating results and coordinating activity and opportunities for joint work with aid organisations such as Oxfam are currently being developed. The Unit's work on smart data, model and metadata provision and on visualisation will also be applied in all such projects.

We aim to increase the core staff of groups involved in stakeholder engagement (in business development, administration and technical support) to keep pace with the growth in academic activity. The Walker Institute and WCHL will continue to identify and create new impact opportunities, but we expect many to also grow out of the individual projects and place great store on the KE/Impact plans in the research council grant applications which we ensure are always implemented in full. The investment in academic posts in climate-related areas, integrated management and horizon scanning for environment-related activities (involving the schools of Construction Management & Engineering, Systems Engineering, Biological Sciences, and the Henley Business School, and the departments of Law, Chemistry, Food and Nutritional Sciences, Agriculture, Archaeology, Mathematics and the Centre for Agri-Environmental Research, Law) will allow enhanced engagement with the private sector where there is an increasing need for climate and wider environmental risk assessment, adaptation and mitigation worldwide. We are working towards centralised provision of climate data, model output and metadata for our associates who are increasingly using similar data sets (such as climate scenarios). Considerable duplication of effort would be avoided if these were acquired and maintained centrally, along with the provision of state-of-the-art visualisation tools. At the same time, the ready availability of climate data and the Unit's climate and environmental modelling expertise offers a host of new opportunities for KE/KT.

A measure of the success of our past and future strategies in KE is the number and importance of the case studies that we develop on a routine basis, both to evaluate our effectiveness and to advertise our capabilities. Our reputation with users is best judged by the number of collaborations that are renewed or extended and the steady growth in the number of new collaborators.

d. Relationship to case studies The nine impact case studies submitted have been chosen to reflect both the mix of approaches to impact followed by the Unit and the range of science areas that they are based on. The strong working relationship with the Met Office is exemplified by several of the case studies including those on **sting jet** hazard warnings, **Thames estuary** planning, the effects of **volcanic ash** on the aviation industry and the Unit's input into **climate policy and negotiations**. The **water catchment** management case study shows the impact on policy development of the work of AERC. The Walker Institute and the WCHL both facilitated many aspects of several case studies, in particular for the **storm tracking** and **TAMSAT** applications. Indeed, the initial promise of, and experience gained from, the TAMSAT project contributed to the initial planning of the Walker Institute. Improvement of **greenhouse gas metrics** is an example of research targeted at answering specific questions that we became aware of through our work with

international agencies to formulate advice for policymakers. The **volcano monitoring** case study is one of several examples that grew out of a specific research programme and the KE/KT plans that were always embedded within the grants that initially funded them.

The approach in section (b) led to many more case studies than the 9 which have been submitted, with a total of 30 compiled as part of our monitoring of the overall success of our KE activities. Some significant examples are: the use of our urban meteorology studies in the Mayor's plan for London; emergency service planning and training for toxic cloud release in London; prize-winning citizen science programmes in space weather and climate; the thermal design of supermarkets and other buildings; the application of our composting studies by the waste industry; and our contributions to the development of the Met Office's Unified Model suite. This number will increase still further in the next few years as the effects of the current collaborations with industry and agencies work their way to full exploitation.