Institution: University of East Anglia

Unit of Assessment: 7 – Earth Systems and Environmental Sciences

a. Overview

The School of Environmental Sciences is one of the longest established and largest multi-disciplinary departments of environmental sciences in Europe. We have a holistic approach to research, integrating physical, chemical, biological, and social sciences into the study of natural and human environments. In the 2001 Research Assessment Exercise (RAE) the School received the highest possible research ranking, a performance that was maintained as the highest ranking large interdisciplinary department in the 2008 RAE. Note the vast majority of staff in this UOA 7 submission are from the School of Environmental Sciences.

The School has been recognised for producing influential science as quantified via citation metrics that have recently placed it as the *5th institute in the world for Geosciences – the 3rd ranked university* (Thomson Reuters 2009-2010); *6th in the world for Oceanography – the top research institution in the UK* (Thomson Reuters Essential Science Indicators, 2000-2010) and *3rd in the world for environmental and ecological economics* (Ecological Economics, 2012).

Over this REF evaluation period we have published over 2000 peer-reviewed publications, involving hundreds of external co-authorships from over 100 different countries. This includes more than 60 publications in *Science, Nature, Nature Geoscience* and *Nature Climate Change*. We have been awarded over £42M for research activities during the REF period, including over £27M from the Research Councils, the Royal Society and charities. The School has consistently produced interdisciplinary research which meets the needs of policy makers at all levels of governance. One notable example is our high level of involvement in all five Intergovernmental Panel on Climate Change (IPCC) Assessments, including the highest number of IPCC authors in 2007 and four Convening or Lead Authors in 2013.

The School covers a wide range of disciplines and has, since its inception, taken an interdisciplinary approach to environmental problems. The School is large, returning 66 members of staff (63 FTE) to this REF and currently supporting around 90 contract research staff and more than 150 PhD students. The School is part of the Faculty of Science which leads development of Science-wide research strategy through its Dean, Associate Dean for Research and its Executive and Research Committees. School research strategy is developed by the School's Executive Committee led by the Head of School (currently Andrews). The School's Director of Research (Renfrew) is a member of the School's Executive, the Science Faculty Research Committee and is Chair of the School's Research Committee which takes responsibility for implementing strategic decisions and managing the internal peer review of research grant applications.

To ensure cohesion and enable management, the School facilitates **research groups** through dedicated work-space, co-location of faculty, research fellows, officers & associates, PhD students and technical staff, whilst also encouraging inter-group communications via School-wide conferences, inter-group seminars, newsletters, internet and intranet pages and a new central coffee area to promote informal discussion. Although our research centres and groups are important, we would emphasise that a great deal of research activity goes on *across groups* as well as within them. In RAE 2008 the school operated nine research groups. Strategic decisions reflecting national and international research priorities and changes in the funding landscape have led to some re-organisation over the last few years into seven larger research groups, namely:

(1) Ocean and Atmospheric Sciences;
(2) the Climatic Research Unit (CRU);
(3) the Tyndall Centre;
(4) the Environmental Biology Group;
(5) the Centre for Social and Economic Research on the Global Environment (CSERGE);
(6) the Science, Society and Sustainability (3S) Group;
(7) the Geoscience Group

REF1 notes the research group membership of our staff. In the next section our research activities are described via these research groups. However we also identify ***three cross-cutting research***

themes that underpin our research strategy, with activity from each research group typically contributing to more than one of these cross-cutting themes.

b. Research strategy

Research strategy for the School develops principally within three overarching themes of international importance where we have built a critical mass of expertise. These are

(i) Climate, Ocean and Atmospheric Sciences
(ii) Resources, Sustainability and Governance
(iii) Geosciences and Natural Hazards.

In addition, we communicate and place into context our science under **policy and governance** which is implicit, and occurs, in all of the themes. We outline below some of the major activities that fall under these themes and demonstrate how our **seven research groups** contribute to them. However it is worth noting that research group members often contribute to more than one theme; so our research groups should *not* be thought of as subsets of the themes. Furthermore much research activity cuts across the groups, reflecting our philosophy of interdisciplinary working. Hence the themes cut across and provide links between our groups.

(i) Climate, Ocean and Atmospheric Sciences *This theme has been, and remains, a key research area for the School: we study climate and paleo-climate records, components of the climate system, interactions between these components and climate predictions. We are well-known for our research on biogeochemical cycles, particularly nutrient and carbon flows and biogenic and greenhouse gases; atmosphere/ocean circulation especially in the polar regions; and options for geo-engineering future climate. We are also well-known for integrating the study of the climate system from fundamental studies of physical processes, to climate modelling, and into climate impacts, adaptation and policy.*

(1) The Ocean and Atmospheric Sciences Group is distinctive in its breadth: arguably what sets it apart from other groups in the UK (and more widely) is its encompassing of physical, chemical and biological oceanography along with the physics and chemistry of the atmosphere. This broad portfolio has enabled world-leading research both within each discipline and also across disciplines and at the interface. For example a long-running strength has been atmosphere-ocean interactions (both physical and chemical) and coupled atmosphere-ocean dynamics. Our research focuses on both global and regional topics in marine and atmospheric chemistry, as well as in global and regional (e.g. polar and maritime continent) oceanography and meteorology. This group also contributes to the *Natural Hazards* theme via studies of storms, flooding and droughts.

(2) The Climatic Research Unit's ground-breaking research on natural and anthropogenic climate change at multiple spatial scales has provided the basic science that underpins international and national climate policies. CRU specialises in climate science to increase knowledge of the timing, magnitudes, geographical details and likely impacts of future climate changes, while striving for a realistic assessment of their associated uncertainties. CRU's unique global data sets are ubiquitous in climate science and have been continuously supported by the US Dept. of Energy since 1977.

(3) The UEA-led Tyndall Centre for Climate Change Research spearheads interdisciplinary research on how society should cope with climate change; distilling climate science into policy-relevant information. The group make explicit, and raise awareness of, the risks, trade-offs and opportunities arising from climate change and related environmental, energy and economic concerns, and exerts an important influence on the design and implementation of UK, EU and international climate-related policies and actions. The Tyndall Centre comprises eight UK nodes plus a new Fudan Tyndall Centre in Shanghai, China. The Tyndall group also contribute significantly to the *Resources, Sustainability and Governance theme*.

Key Achievements in this theme

The release of a new global temperature series (HadCRUT4) – already being widely used and cited; the first study to examine *when* specific temperature thresholds might be crossed under climate change; establishing the first UK office of the *Global Carbon Project* in 2012 – leading the annual publication of global CO_2 emissions & sinks used by policy makers and researchers worldwide; creating the narrative *'mitigate for two degrees but adapt for four'*; obtaining the first

year-long time series of oxygen-based productivity at a UK coastal site; carrying out the first assessment of radiative forcing potential of geo-engineering proposals; contributing to adaptation and resilience theory in the UK's Foresight Report on environmental migration; launching a new peer-review journal *WIREs Climate Change*; obtaining the first observations of previously unknown greenhouse and ozone-depleting gases; leading the Surface Ocean CO_2 Atlas (SOCAT); obtaining the first observations of jets around Greenland (windiest place in the world ocean); becoming the first UK university with a fleet of underwater gliders capable of physical and biogeochemical observations and undertaking successful missions in the North Atlantic, North Sea, Indian Ocean and Ross Sea, Antarctica.

Theme Strategic Plans

COAS: To reflect our strengths and create a strong outward facing identity, in August 2013 the Science Faculty initiated a new **Centre for Ocean and Atmospheric Sciences (COAS)**. COAS will encompass the Ocean and Atmospheric Sciences group and will also affiliate relevant researchers throughout the School and beyond. The aims of this new Centre are to strengthen our UK and international reputation; provide more internal structure for this relatively large (~30 faculty) research group and build on existing strategic partnerships with e.g. the *British Antarctic Survey (BAS), Plymouth Marine Laboratory (PML),* the *Centre for Environment, Fisheries & Aquaculture Science (Cefas), the Met Office* and the *National Centre of Atmospheric Sciences (NCAS).* We envisage COAS playing a coordinating and leading role in a number of new and planned research activities, such as the NERC-funded *Ocean2Ice* project (£1.1M over 2013-2017, Lead PI Karen Heywood), and the European Research Council-funded *Arctic sea ice, biogeochemistry and impacts on the atmosphere: Past, present, future* (£2M over 2014-19, Lead PI COAS Director Roland von Glasow).

IPCC: Following our major contribution in 2007 (23 authors of various types), the School has actively promoted continued participation in the IPCC process – we have several Lead Authors for the Fifth Assessment Report and many more contributing authors. We have run workshops on using the 'CMIP5 database', on which many primary studies are based, and indeed contributed to this database via our role in the CMIP5 contribution of HiGEM model output.

The **Tyndall Centre** has received over £20M in Research Council funding since its founding and UEA has continued to lead its development both nationally and internationally. During the REF period we have invested in five Tyndall faculty positions at UEA, opened a new Tyndall Centre in Fudan University, Shanghai, and one in the School of Psychology, Cardiff, thus expanding our capacity both internationally and across disciplines. The Fudan Tyndall Centre is funded with a 15 year commitment by the Chinese central government, and is co-directed by UEA's pro Vice-Chancellor Trevor Davies, who spends 30% of his time in China. Collaborations between the UK and China through twelve initial projects provide unique strength into how climate change interacts with human health, food and water security, and further support our efforts to propose and communicate effective solutions for carbon emissions reductions worldwide. The Tyndall Centre's Director (Le Quéré) has recently been elected onto the first Science Committee of *Future Earth* - a ten-year international interdisciplinary UN-sponsored programme.

(ii) Resources, Sustainability and Governance *This theme is strongly linked to the international priorities of biodiversity loss, ecosystem services and sustainable consumption. Research into policy development and implementation relevant to the environment are also key aspects – as delivered by the following groups and the Tyndall Centre.*

(4) The Environmental Biology Group works across a range of ecological scales from entire biomes to genes, integrating theoretical population, community and landscape ecology to management applications of international scope. The main foci are: biodiversity and evolutionary responses to land-use change (including toxicity); ecological and physiological consequences of climate change; population responses to natural resource exploitation and genomics. Two long-term research programmes in the Neotropics and Paleotropics address mechanisms of biodiversity erosion resulting from anthropogenic habitat change; including deforestation, habitat fragmentation and wildfires. Climate change research focuses on the constraints imposed by life-history and landscape structure on dispersal in reassembling novel biological communities. Research in environmental microbiology focuses on the ecophysiology, genomics and metagenomics of microbes involved in biogeochemical cycles and cycling of atmospheric trace gases using both

cultivation-dependent and cultivation-independent technologies.

(5) The Centre for Social and Economic Research on the Global Environment (CSERGE) focuses on relationships between the natural environment and human wellbeing: examining environmental decision making, environmental governance, and the relationships between the environment and human health. CSERGE has pioneered work on the *'Ecosystem Services'* approach. Our highly interdisciplinary work fuses natural sciences with economics and social sciences to examine how the natural environment contributes to wellbeing and how sustainable development can be delivered through improved decision-making. Key applications include the linkage between land use change and policy, market forces and technology and integrated analyses of sustainable production of renewable energy. CSERGE has a long record of work on environmental governance, recent foci being the integration of environmental concerns into government fiscal cycles and multi-level and collaborative EU/UK environmental governance.

(6) Our new Science, Society, and Sustainability Group (3S), emerged from a recent strategic review of social sciences research. It aims to better understand, and transform, relations between science, policy and society in responding to sustainability challenges. It is inherently interdisciplinary, building expertise at the interface of science and technology, human geography, political science and environmental psychology. 3S research is based around several interrelated strands. Research on sustainable consumption has developed around grassroots innovations for sustainability, community-led complementary currencies and energy innovations. Work on participation and engagement has pioneered a new reflective research programme, for example initiating and analysing new forms of science-society interaction on emerging technologies, radioactive waste management and catchment management. The group probes underlying causes, governance challenges and potential policy solutions to sustainability issues, including examining environmental science advisory processes (e.g. the IPCC) and developing new option ranges for adaptation and mitigation strategies within the EU.

Key Achievements in this theme

Leading the economics team for the *UK National Ecosystem Assessment* which strongly informed the *UK Natural Environment White Paper 2011*; roles in Defra Science Advisory Committee; produced influential policy reports for Defra, BIS, Sciencewise, and the European Commission; contributed to the design of the Amazon Region Protected Areas program - which accounted for 37% of the decrease in deforestation in Brazil, ensuring protection of ~70 million hectares of tropical forest and its associated biodiversity and carbon stock; contributed to a new Biodiversity Audit methodology challenging the basis for conservation in Europe; developed a new theory of immune gene evolution explaining why deleterious mutations have accumulated in the immune genes of vertebrates; co-developed a Climate Change Impacts Report Card for Terrestrial Biodiversity in the UK; developed a 'template' for the management of catchment water resources, now adopted in part as a requirement of Defra*'s Pilot Catchments Programme*; evaluated how on-farm mitigation measures reduce the impacts of water pollution through the Defra-funded *Wensum Demonstration Test Catchment* Project.

In 2008, the **Earth and Life Systems Alliance (ELSA)** was launched – a major strategic collaboration (previewed in RAE2008) – with ~£2.5M in pump-priming funds from UEA and the *John Innes Centre (JIC)*. ELSA is a multidisciplinary alliance that integrates research in biological, environmental and social sciences to tackle the challenges posed by a changing climate. The three priority themes are: *Biodiversity and adaptation in the face of global environment change*; *Elemental cycles that sustain life and the planet*; and *Agricultural transitions under climate change*. Following the appointment of a Director in 2012 (Murrell) and new faculty (van Oosterhout in 2011) ELSA has funded ten PhD studentships. One of these PhD students has recently led a publication in *Nature Climate Change* showing a previously unrecognized but critical role in resource allocation and marine phytoplankton stoichiometry, with implications for biochemical cycles.

Theme Strategic Plans

NRP: In March 2011 the Treasury announced a £26M investment for the *Norwich Research Park (NRP)*. The NRP is a partnership between UEA, the Norfolk and Norwich University Hospital and four independent research institutes – JIC, the Institute of Food Research and the Genome Analysis Centre (all funded by the BBSRC) and The Sainsbury Laboratory. ELSA is a key component of the NRP's research and impact strategy. We aim to further grow activities in this

area over the next 5 years; e.g. Colin Murrell has just been awarded a grant of $1.25m from the Gordon & Betty Moore Foundation to develop a suite of cutting-edge techniques in microbial molecular ecology to investigate the role of methylotrophic bacteria in marine microbial food webs.

CSERGE: Ian Bateman is a member of both the Defra Science Advisory Council and the H.M. Treasury Natural Capital Committee, providing the School with excellent access to and impact upon Government policy in these areas. He is also PI of the NERC *Valuing Nature Network,* which brings together nearly 1200 institutions, agencies, government departments, businesses and individuals in 43 countries to link decision-making to research into the sustainable use of natural capital and ecosystem services. CSERGE has played a key role in developing this network and the research it disseminates. To exploit our prominence in this area, during the REF period the School has invested in two new junior faculty appointments who will allow us to move into frontier areas of research over the next decade: specific targets are the macroeconomics of natural capital and "green growth"; behavioural response and dynamics generated by environmental change; and the application of economic game theory to the provision of ecosystem services. In September 2013, the School bid to ESRC for £7.3M for a *Centre for Natural Capital Decision Research* – nine faculty were involved and the proposed research (e.g. on how natural capital contributes to human wellbeing and how it should be best managed) will be a key component in our future activities.

(iii) Geosciences and Natural Hazards Theme: *This theme includes our earth science research on sedimentary processes, paleoceanography and hydrogeology & hydrology; we have a focus on improving our understanding of and resilience to natural hazards, in particular volcanoes and earthquakes, but also in storms and flooding through activity in the Ocean and Atmospheric Sciences, CRU and Tyndall Groups.*

(7) The Geoscience Group includes study of the fundamental understanding and quantification of natural hazards. This ranges from broad themes such as elucidating the source processes of earthquakes, through to the mapping of earthquake clusters, ground deformation and topographic measurements of active lava domes to help quantify volcanic hazards. Geohazards researchers work closely with stakeholders to predict, analyse and map hazards and improve risk management strategies – often collaborating with 3S group researchers. Other activity is directed at understanding the evolution of sedimentary basins and associated fluid flow including through faults, in rivers and during flooding. These activities are directly linked to human wellbeing through water and hydrocarbon resource management and exploitation. The group also contributes to the *Climate, Ocean and Atmospheric Sciences theme* as we probe earth system events on centennial to millennial timescales. Our approach here is mainly sedimentological and geochemical and is based on both terrestrial and marine records, with significant activity on the understanding of palaeo-oceanographic and palaeo-climatological events that have relevance to society through, e.g. future sea-level change.

Key Achievements in this theme

Playing a leading role in a paradigm shift in the way that natural hazard science can be used to improve the resilience of affected communities, e.g. as outlined in contributions to *'Future Prediction for Geo-Physical Hazards'* and the *UK Government Office Foresight Project: Improving Future Disaster Anticipation and Resilience;* first database of earthquake source models obtained using InSAR data; developing operational ensemble forecasting systems for river basins in the UK and China; playing leading roles in NERC's *Storm Risk Mitigation Programme* and in NERC's *Flood Risk from Extreme Events Programme.*

Theme Strategic Plans

STREVA: We are leading a multi-million pound project on *'Strengthening Resilience to Volcanic Hazards (STREVA)'* funded as part of a NERC/ESRC directed-research programme. This places an emphasis on improved analysis of volcanic risk, while accounting for the complexities and uncertainties in eruption forecasting as well as the vulnerability of exposed populations and the role that politics, society and culture play in creating and eroding resilience to eruptive activity. The need for this evidence-based approach to analysing risk has been highlighted in the latest *BIS Foresight Review on Reducing Risk to Natural Disasters*. We intend to strengthen present expertise in this area over the next five years with appointments to support development into other natural hazard domains and to enhance our ability to quantify and analyse natural hazards.

c. People, including:

i. Staffing strategy and staff development

In a large School there are opportunities for realigning research priorities when staff leave or when new recruitment occurs. The responsibility for strategic staffing rests with the Head of School and the School's Executive (around a dozen senior staff) who aim to realign research priorities to develop or pursue new directions or respond to new research initiatives and funding opportunities. New faculty are only hired if they are judged to be producing research that is internationally-leading in quality. Since 2008 eighteen faculty have left the School: of these, eight retired, although three continue to play active research roles as Emeritus Professors (Brimblecombe, Leeder, Vincent); one was seconded for several years to be Director of the *'Living with Environmental Change'* programme (Watkinson); and six have taken chairs elsewhere. The School has recruited twenty six new staff, fifteen to their first faculty position. We have used these appointments strategically to bolster priority research areas, in particular: *ocean modelling* (Zhai, Hall, Johnson joint with Cefas), in *ELSA* (Murrell, Van Oosterhout), *environmental economics* (Binner, Anger-Kraavi), *energy* (Wilson, Hargreaves) and *natural hazards* (He); although all our research groups have benefitted.

The School is proactive in promoting research activity and the effectiveness of its staff through workshops on, for example: knowledge exchange and impact; writing and publishing world-class science; funding opportunities for research; and promoting interdisciplinary approaches. We make strategic decisions to focus research direction and help prospective Principal Investigators (PIs) prioritise and manage grant applications. To illustrate: lead PIs for major collaborative projects have been relieved of School duties at crucial periods in the grant preparation cycle; and PIs are encouraged and funded to attend 'town hall' meetings. We steer the phasing of responsive mode grant submissions and implement a rigorous internal review of all responsive mode grant applications which strongly supports and nurtures less experienced PIs. The School has a discretionary strategic investment fund (typically around £120K per annum) with which to fund the above and many other pump-priming research activities.

Early Career Researchers (ECR)

All incoming ECR are mentored by senior staff. Staff appraisal is annual for ECR, and annual or biennial for more established staff. All Lecturer appointments are required to pass the Certificate in Higher Educational Practise (run by UEA's Centre for Staff and Educational Development), which includes material on research development and encourages research-led teaching. To assist with individual research planning an online research management IT-system is in place. The School's Promotion committee contributes to the University's confirmation of appointment and the promotion of academic staff – which requires assessment of performance across the four areas of research, teaching, enterprise and engagement – as well as overseeing study leave applications.

The School has a large (typically ~90 FTE) and diverse population of **Research Associates** (RAs). There is a Researchers Affairs Forum run by, and for, RA's with the goal of championing ECR & RA issues. These activities and recommendations are linked to the School's Research Executive by a Research Staff Co-ordinator (Joshi). There are RAs on all of the School's major committees. To support the implementation of the *Concordat to Support the Career Development of Researchers*, the University has established a Research Staff Working Group which steers the University's strategy for career development and monitors implementation of activities. Part of the School's Research Staff Co-ordinator role is to ensure the School engages fully with the Concordat.

In September 2012 UEA was awarded the *HR Excellence in Research Award from the European Commission*. This award recognises UEA's commitment to support the personal, professional and career development of research staff, particularly through alignment with the principles of the European Charter for Researchers, Code of Conduct for Recruitment and the UK Concordat. During the REF period, *Roberts funding* (as allocated via RCUK) has supported the career development of RAs and PhD students with the goal of increasing employability through enhanced personal, professional and career management skills. All staff members are encouraged to attend development courses covering a range of research, technical and management topics.

Personal Research Fellowships

During 2008-2013 two *Advanced NERC Fellowships* have been won by existing School

researchers: Rachel Warren (2008-2013; now a Reader) and Johannes Laube (2011-2016; following his NERC Fellowship), plus one *NERC Knowledge Exchange Fellowship by* Tobias Krueger (2011-2013). We have also hosted two competitive *ESRC Fellows*: Angela Cassidy (2010-2011) and Tom Hargreaves (2009-2012; now a Lecturer). In addition, Gill Malin and Andrew Manning progressed from *Advanced and Quest NERC Fellowships* (respectively) to Readerships in 2009 & 2011, and David Oram holds an *NCAS Fellowship* (2008-ongoing). The School has also hosted four *Marie Curie Postdoctoral Fellows* during the assessment period.

In 2008 the School had nine *RCUK fellows* and since then seven have progressed to become faculty in the School, five as Readers (Baker, Osborn, Reeves, Mock and Suntharalingham), one as Senior Lecturer (Seyfang) and one as Lecturer (Pedentchouk). Of the other two: Rogers-Hayden left academia, while de Boer took an Associate Professorship in Stockholm. This successful progression reflects both the quality of recruits, and our nurturing of talent; talent that is now shaping our future research direction. The School encourages its staff to apply for competitive fellowships and several have been successful with the *Leverhulme Trust* and the *Royal Society* during the REF period (see REF5e).

International Appointments Incoming: Rob Hall (from USA): Xiaoming Zhai (from Canada and Germany); Helen He (from China); William Cheung (from Canada)

International Appointments Outgoing: Nathan Gillett (to Canada); Agatha de Boer (to Sweden); Matt Cashmore (to Denmark); William Cheung (to Canada).

Visiting Scholars
We welcome visiting scholars at all levels and have hosted over 200 from the UK, over 50 from the EU and over 40 from elsewhere, for substantial periods of time since 2008. We also encourage outgoing visiting scholars. These have included at least 13 substantial visits abroad of our faculty, as well as numerous shorter visits by RAs and PhD students.

Seminars
We host and fund six subject-specific seminar series, in addition to occasional School-wide seminars and symposia.

Equality and Diversity
Our commitment to equality and diversity is demonstrable at all levels. The Head of School between 2007 and 2010 was female; we have female research group leadership, healthy female representation on our School Executive and all other committees with representation occurring at all levels (RA's to Professors). Of our new appointments, 11 from 26 have been female, as have around 50% of our progressing fellows. The School has faculty members from a diverse range of ethnic backgrounds and from a variety of countries. Some have disabilities, and these are supported by extra administrative support where required. The School Equality and Diversity Co-ordinator (Franco) is responsible for co-ordinating between the School and the University on these issues. The University runs a contact, support and information network *(RESNET)* for female research staff from across the NRP, which runs events to promote career development and raise awareness about equal opportunities. The University's staff and student profile has changed greatly in recent years and now has the same range of diversity as found in more 'urban' universities. UEA's *Single Equality Action Plan* identifies policies on equality and diversity issues which are proactively delivered by the Equality and Diversity Committee. Information on staff and student populations helps to raise awareness and inform decisions from an equality perspective. In 2012, UEA was awarded a *Bronze Award from Athena SWAN*, recognising the University's solid foundation for eliminating gender bias and development of an inclusive culture that values all staff. The School is now working towards its *Bronze Athena SWAN Award.*

ii. Research students

Postgraduate research (PGR) students play a vital role in the School. In total, 174 doctorates were awarded (from 08/09 to 12/13 – see REF4). The School typically has more than 150 PGR students enrolled, of which ~80% are home/EU and ~20% are overseas. Important funders are: NERC (~35%, with around 35% of NERC students holding CASE awards with industrial partners); the other research councils (~15%, especially ESRC); and the University, Faculty of Science or NRP (~20%). The remainder are funded through a wide variety of charities, businesses, research institutes and governments or self-funded. Between 2008/9 to 2012/13 all of our faculty have been

primary PhD supervisors and on average have been primary supervisor for 2.85 students at any one time. Our PhD completion rates are generally high. For example for students starting in 2005/6 & 2006/7: 90% of NERC- or UEA-funded students have completed and we have never failed to meet the completion threshold stipulated by NERC.

The School led a successful UEA bid, for a **NERC Doctoral Training Partnership (DTP)**, named **Environment East (EnvEast)** and working with twelve strategic partners, including the Met Office, Cefas, BAS, PML, Centre for Ecology and Hydrology, Marine Biological Association and the Universities of Essex and Kent, plus 10 other contributing partners including RSPB, NCAS and Tyndall Fudan. The EnvEast DTP is one of just 15 successful NERC-funded DTPs nationally (announced November 2013). EnvEast has secured 12 studentships per annum for 5 years (2014-2019), with the School expecting lead supervision on ~8 of these studentships per annum. The rationale for partnership is science-led, building on existing interdisciplinary collaborations, including at the NERC-BBSRC and NERC-ESRC interfaces, where we already have a track record of research and postgraduate researcher training success. EnvEast's mission is to train future scientists capable of making outstanding contributions to their discipline with the ability to apply their knowledge to the challenges facing the global environment.

The School attracts high-quality PGR students, with the vast majority of competitively-awarded PhD studentships going to students with a first class degree and/or excellent MSc. The School actively encourages its own academically gifted undergraduate students into research, if they wish, both at UEA and elsewhere; e.g. we have been running *NERC's Research Experience Placement* scheme since 2009, which places talented undergraduate students within the School for a summer project – giving them a taste of PGR life. The PGR recruitment process is rigorous, with potential students identified initially by application to advertised projects, then interviewed by at least two academics, with admissions decisions made by a Studentship Panel. Academic ability is paramount, but funding is also used strategically to encourage research students to areas that are perceived as harder to recruit into, to support new faculty or to address a particular requirement.

Postgraduate Supervision and Training

PGR students have a supervisory team comprising at least two research active members of faculty. All supervisors must undertake a training course on PhD supervision, covering best practice and PhD regulations. This also provides a forum for discussion of the role of the supervisor. In addition mentoring is provided for all staff new to PGR supervision.

The School places great importance on the training and development of PGR students. This is pursued with a view to training the brightest and the best scientists for the future whilst also providing them with opportunities for personal development that will equip them for a variety of careers. Within the School there is a PGR Admissions Director (von Glasow) whose role is to oversee the recruitment of students, and a PGR Progress Director (Lake) whose role is to monitor progress, welfare and ensure timely completion. Student progress is monitored closely via a series of three standard progress reports each year; intervention occurs at the first indication of limited progress. If these reports highlight generic issues (e.g. lab resource constraints), these are investigated further, as are issues of general concern that arise from the School's bi-monthly *Graduate Affairs Committee* and the bi-annual *Graduate Affairs Forum.* Our PGR student training is organised via a Faculty-wide *Science Graduate School,* which ensures that all research students receive the highest quality of supervision, training and career development opportunities. The Science Graduate School was set up in 2009, under the leadership of the Associate Dean for PGR (Brimblecombe from this School), and has been very successful in bringing together all elements of science PGR training.

In addition to the research skills that a student gains directly from their project, research training is delivered by a *Personal and Professional Development* programme. Founded on the *RCUK Researcher Development Statement*: generic and technical elements are delivered by external trainers, the Science Faculty PGR Skills Training Coordinator and faculty members from all Science Schools. This programme continually evolves in response to student feedback and requests from students, staff and funding agencies. In 2011-12 more than 140 courses were offered. In addition to this comprehensive UEA programme, funding is also available for specialised summer schools or workshops, which are incorporated into the student's individual programme via 'reflective reports'. The School has also hosted specialised PGR events: e.g. a

Mass Independent Fractionation summer school for 24 international PhD students – an Initial Training Network for Marie Curie fellows; and a Tyndall Centre PhD student-led conference for 100 on *"Knowledge Gaps in Climate Change Research: How are you tackling it?"*

The School facilitates a lively and ambitious research environment for its PGR students. For example, a team of PGR students won *NERC's Environment Young Entrepreneurs Scheme* in 2011/12; and PGR students host a weekly 'happy hour' social event every Friday evening in the main social space or beside the lake in fine weather. The School actively encourages PGR students to write up their research for publication; one material incentive has been the frequent release of "writing up" funds to provide living expenses for students beyond their stipend period.

d. Income, infrastructure and facilities

External recognition of research excellence across the School is evidenced by research income of over £42M (for financial years 2008-9 to 2012-13), including almost £25M from RCUK and the Royal Society, over £8M from the EU, almost £4M from central government and over £2M from charities (see REF4b for details). *On average we have won new research awards totalling £9.3M per year during the REF period.* The School has also had over 120 separate consultancy contracts for research activities – totalling an additional £1.7M – including £1.0M from UK Government, £0.2M from the EU, and almost £0.2M from Industry. We aim to enhance this track record by continuing to diversify our income streams from a wide variety of indirect and direct government research-awarding bodies.

As befitting a large School, our infrastructure and facilities are considerable. We have 1866 m^2 of research laboratory space (31% of total School space), plus dedicated teaching laboratories, seminar rooms and meeting areas. Between 2001 and 2005, several major building and laboratory refurbishment projects took place within the School partly funded by JIF and SRIF awards. These included the *Laboratory for Global Marine & Atmospheric Chemistry* specialised laboratories, and the award winning low-energy *'ZICER'* building which houses a "Virtual Reality" suite. These investments enhanced our already-existing world-class facilities which include: a 10-m recirculating marine/freshwater flume and a 6-m density tank, as well as the environmental analyses laboratories described below. In the current REF period, the School has been successful with several bids to the **Faculty of Science's Capital fund** (see below) as well as securing £1M for new teaching laboratories. All of these investments are complete, including:

(i) Integrated Environmental Analysis Laboratories - £1M investment
We have consolidated our major instruments under one organisational umbrella to provide a service that is available across the Norwich Research Park (NRP) and to external users. New funding has been spent on laboratory refurbishment (£310K) to bring together our stable isotope, scanning electron microscope, X-ray fluorescence & diffraction spectrometers, ICP-MS (Inductively Coupled Plasma Mass Spectrometry), ion chromatography and elemental analysis into one integrated suite. These facilities are managed and run by a lab manager and six full time technical staff: two research officers develop research programmes, instrumentation and collaborations, e.g. supporting our palaeoclimatological science, volcanology and isotope geochemistry. In addition to these refurbishments, three new isotope mass spectrometers have been funded, one unique instrument designed and built by our research officer specifically to analyse clumped isotopes for palaeotemperature reconstruction. Since increasing access to the analytical facilities we have been involved in a number of projects across the NRP, in research collaborations worldwide, and also in a number of commercial contracts.

(ii) Marine Sciences - over £1M investment
Over £500K was used to refurbish two laboratories to Containment Level 2 standards for environmental marine microbiology studies; a further £158K was provided for 3 new cavity ringdown spectrometers, for accurate and precise measurements of marine trace gases (e.g. CO_2, oceanic N_2O and CH_4). An investment of £465K in 2009 purchased four autonomous underwater vehicles, ***Seagliders***, these are state-of-the-art platforms for interdisciplinary oceanographic research. As the first UK university to own and operate a Seaglider fleet, we are pro-active in their deployment worldwide, particularly for process studies where there are pressing scientific challenges to address. For example, the Indian and Southern Ocean's have been a focus and in 2014 we will make the first glider observations in the Amundsen Sea to assess the ocean heat

transport towards Pine Island Glacier. Closer to home, our collaboration with Cefas includes plans for their further deployment in UK shelf seas.

(iii) Norwich Energy Materials Laboratory - £1M investment
This new laboratory has received significant Faculty of Science funding benefiting researchers from several Science Schools, including Environmental Sciences, during the REF period**.** These labs make UEA well-placed for UK sustainable energy research for hydrogen production and storage, and solar energy utilisation.

In addition to the above major investments we have also established extensive field infrastructure in support of the Defra **Wensum Demonstration Test Catchment Project** during the assessment period. This Defra investment (so far £745K on equipment) will be maintained by us until 2017 at least. The infrastructure is already supporting additional research students and we fully expect to build on this research platform with new catchment science projects.

As well as laboratory-based research, our researchers undertake many **field campaigns across the world**, whether on ocean-going research vessels to the Southern Ocean, atmospheric measurements on research aircraft in the Arctic, or land-based activities in extreme environmental conditions in the Amazon. Many of these activities require either bespoke instrumentation or modifications to existing instruments to operate in such environments. Specialised scientific engineering support is available to undertake development and modifications of field and lab instruments. A recent development has been to amalgamate the School's electronics workshop with the Science Faculty's mechanical workshops into one facility. The new service provides a single point-of-use for all projects. The workshops are operated by 4 full time specialist technical engineers and the service is available across the NRP.

The School owns and operates **Weybourne Atmospheric Observatory**, on the north Norfolk coast, with support from NCAS. It houses a variety of chemistry, aerosol and meteorological instruments and is regularly used for national and international field campaigns. **Trace gas measurements** are a fundamental part of our research activities. There has been no facility or commercial company in the UK that can supply calibration and working standards for CO_2 and other important greenhouse gases and tracers. As part of Andrew Manning's research fellowship NERC funded the creation of a *Cylinder Filling Facility*. This is now in operation and is managed by the School. As well as providing standards for our own research, the Facility is available to collaborators and other research institutions worldwide.

The University supports a suite of state-of-the-art **High Performance Computing** (HPC) facilities for the use of all research staff. We are amongst the highest users of these facilities, e.g. through climate, ocean and atmospheric modelling. The university has invested over £3.5M in HPC facilities during the assessment period. In 2008 the *ESCluster* was installed (109 nodes), with this upgraded between 2010-2013 to the *Grace cluster* comprising 302 nodes (4148 cores) and a theoretical peak performance of 65 TFlops. The HPC services are supported by a team of specialist technicians who can install and optimise the running of new software, as well as plan our future upgrades. The **University library**, extended in 2005 and refurbished in 2010, subscribes to over 7000 journals and operates a public digital repository with >25,000 UEA-authored articles.

To manage, operate and develop our world-class facilities the School has four **Research Officers** and 28 **Technical & Administrative staff** supporting all areas of research and teaching through dedicated expertise for specific laboratories, field campaigns and analytic work. The School runs an annual **competitive equipment fund** (typically >£100K p.a.), which provides vital resources for new researchers, new strategic investment, and seed-corn funds.

The NRP Equipment Pool, Professional Services and Consultancy
The University and its Norwich Research Park partners have started a coordinated equipment pool to allow easy and cost-effective use of local resources. There is a simple web-based booking system for the complete suite of instrumentation and facilities, including all necessary specialist technical support. The pool will encourage efficient, effective and cost-saving equipment sharing across the NRP, to the benefit to all participants and with the bonus of increased collaboration between previously unconnected research groups.

One of the largest components of the NRP equipment pool is the School's new integrated

Environmental Analysis Facilities. We have been making use of the on-line booking and management system to identify spare capacity and offer that via consultancy or as a service. Here we are creating links across the NRP and with institutions and industry across the UK, as well as bringing in additional income. Recent clients include Jeyes, Lotus Cars, Intelligent Fingerprinting, the Environment Agency and Cefas.

Many members of staff undertake a variety of **consultancy roles** for a wide range of activities from laboratory services (e.g. the Environmental Analysis Facilities), to specific research projects and advice for government. During the REF period, this has brought in additional income of £1.7M.

e. Collaboration or contribution to the discipline or research base

Researchers within the School collaborate widely with other academics, with industrial partners, with NGOs and with Government. These collaborations are actively encouraged by the School's positive approach to winning and carrying out research awards, by our strategic decisions and our internal management processes. During the assessment period, we have published with researchers in over a hundred countries, within numerous UK Universities and locally with researchers in other Schools at UEA or institutes within the Norwich Research Park. Some specific examples where the School has played a *leading role* are detailed below:

Major (>£1million or >20 publications) International & National Collaborations

- The Greenland Flow Distortion Experiment (PI Renfrew, funder NERC)
- Synoptic Antarctic Shelf-Slope Interactions Study (PI Heywood, previewed in RAE2008)
- ADAM: Adaptation and Mitigation Strategies (PI Hulme, funder EU)
- Defra Demonstration Test Catchments: the Wensum (PIs Hiscock & Lovett, funder Defra)

Major and/or Long-term Local Collaborations

The School plays a leading role in environmental research for the East of England. In addition to fruitful collaborations with other Schools inside UEA, we also have long-term collaborations with a number of key institutes in the region: with the JIC and the Genome Analysis Centre; a strategic alliance (from 2003) with the BAS, based in Cambridge, and a strategic alliance (from 2008) with Cefas, based in Lowestoft. Specific examples:

- Joint faculty appointments with BAS (Le Quéré until 2010) and Cefas (Cheung until 2010, Johnson from 2012)
- Honorary lectureships or professorships with BAS (2) and Cefas (11) at present
- Over 20 (15) PhDs jointly supervised with BAS (Cefas) during the assessment period

Major Interdisciplinary Collaborations

The School is renowned for its pioneering interdisciplinary research. During the REF period this can be exemplified as follows:

- between natural and social scientists on several government reports and leading to the award of a £3M grant from NERC/ESRC's *Increasing Resilience to Natural Hazards in Earthquake-prone & Volcanic Regions programme* in 2012 (Lead PI Barclay).
- between environmental scientists, biologists, and agriculturalists via the Earth and Life Systems Alliance (ELSA), which has invested £2.5M of NRP funding.

Collaborations with Industry, Government and Other Research Users

The School takes a highly proactive approach to its collaborations with research users, for example, involving scientists from the Met Office, Defra and DECC, at both the project planning stage and the analysis and results stages of our research. Thus the School can shape aspects of its research agenda to tackle questions posed by users (e.g. via directed calls from Defra or NERC). This often leads to joint publications. For example, during the current assessment period we have produced at least 23 publications with Met Office scientists. A few examples of research collaborations that have a significant user contribution are listed below:

- *ACCACIA (Aerosol-Cloud Coupling and Climate Interactions in the Arctic*, PI Renfrew, Funder: NERC, Partner: the Met Office, Contribution: >10 person-months); just one of 18 grants in the assessment period with Met Office partnership.
- *Wensum Demonstration Test Catchment*: funding from Defra of over £2.5M

- *SEER – Social, Economic and Environmental Research:* funding from ESRC of £2.2M

The School also collaborates actively with **ADAPT Commercial**, a UEA-owned subsidiary company, that focuses on helping organisations reduce and manage their carbon emissions; and with **WeatherQuest**, a UEA-hosted independent weather services provider.

Leadership in the Academic Community

The School's researchers often play important international and national leadership roles. For the sake of brevity only a few examples from the REF period are given below [note SSG is Scientific Steering Group]:

International and National Boards; Panel Membership

- Scientific advisory board, *Alfred Wegener Institute, Germany* – Karen Heywood
- Scientific advisory board, *Bert Bolin Climate Centre, University of Stockholm* – Phil Jones
- International Review Panels, *Max Planck Institute of Terrestrial Ecology, Germany;* and *Darwin Center for Biogeosciences, Utrecht, The Netherlands* – Colin Murrell
- Co-Chair SSG Joint Weather and Climate Research Programme (Met Office & NERC); SSG of World Meteorological Organisation's *Polar Predictability Panel* – Ian Renfrew
- SSG of *Surface Ocean Lower Atmosphere (SOLAS)* – Roland von Glasow
- Science Committee of *Future Earth* – Corinne Le Quéré
- SSG Joint Group of Experts on Scientific Aspects of Marine Env. Protection – Alex Baker
- RAE2008 and REF2014 Earth & Environment panel member – Tim Jickells
- DECC review panel for the Hadley Centre – Tim Jickells

Leadership in Research Councils

- NERC Theme Leader for Earth System Science – Tim Jickells
- NERC Chair of Isotope Geosciences Steering Committee – Julian Andrews
- ESRC Strategic Research Board – Jacquie Burgess
- NERC/ESRC Increasing Resilience to Natural Hazards Advisory Group – Jenni Barclay

Leadership in Government, Industry and Professional Bodies

- Chief Scientific Advisor to Defra (until 2012) – Sir Bob Watson
- Head of the UK National Ecosystem Assessment Economics Team and Senior Adviser & author to a UK Foresight programme – Ian Bateman
- Scientific Advisor to the Foreign and Commonwealth Office – Jenni Barclay
- Defra Advisory Group on Sustainable Production and Consumption – Kerry Turner
- Chair of the Broads Authority – Kerry Turner
- President of the Challenger Society for Marine Science (2008-10) – Carol Robinson

Election to Learned Societies and Other Honours, Awards or Prizes

- Sir Bob Watson received the Blue Planet prize in 2010, was elected Fellow of the Royal Society in 2011 and was knighted in 2012
- Peter Liss was elected Fellow of the Royal Society and awarded a CBE in 2008
- Ian Bateman was awarded a Wolfson Research Merit award in 2011 and an OBE in 2013
- Peter Brimblecombe received the Europa Nostra Grand Prix in 2009
- Karen Heywood won the Georg Wüst prize for Oceanography and a Leverhulme Fellowship in 2009
- Kevin Hiscock was awarded the Whitaker Medal of the Geological Society in 2011
- Andy Jordan was elected to the Academy of Social Sciences in 2008 and won a Leverhulme Trust Major Research Fellowship in 2010
- Phil Jones was elected a Fellow of the American Geophysical Union in 2009

Chief Editorship of Journals

- Joint Chief Editor of *Environmental and Resource Economics* – Ian Bateman
- Executive Editor and co-founder of *Atmospheric Chemistry and Physics* – Bill Sturges
- Managing Editor, *Environment and Planning C* – Andy Jordan
- Joint Chief Editor, *Environmental and Resource Economics* – Kerry Turner
- plus over 20 other journal editorships amongst our researchers.