

Institution: University of East Anglia

Unit of Assessment: UoA7 Earth Systems and Environmental Sciences

1. Unit context and structure, research and impact strategy

1.1 CONTEXT AND STRUCTURE OF THE UNIT

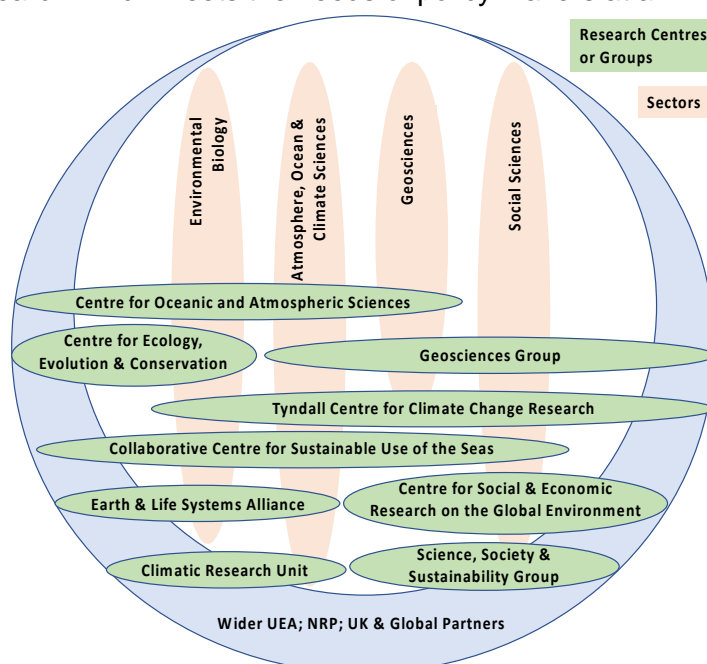
Our UoA7 return comprises the research and impact of 70 staff working within earth systems and environmental sciences at the University of East Anglia (UEA). Of these, 68 are within the **School of Environmental Sciences** and 2 in Mathematics. The School is in the Faculty of Science and enjoys excellent collaborations across the Science Schools, particularly with Mathematics, Biological Sciences and Chemistry, as well as with the Schools of International Development, Psychology, Medicine; and the other Institutes of the Norwich Research Park (NRP). The School was established in 1967, at the awakening of environmental sciences as an academic discipline, and with an interdisciplinary ethos at its heart. It is one of the most comprehensive University departments of its kind in the world; particularly renowned for integrating physical, chemical, biological and social sciences to understand the Earth, its life, its people and their interactions.

Our sustained contribution was recognised in 2017, when the School was awarded a **Queen's Anniversary Prize** for Higher and Further Education in recognition of "*Combined natural, social and environmental sciences to advance understanding and protection of the environment*".



We are a large unit, returning 65.4 FTE (up from 63 in 2014). During the REF period we have published over 1600 peer-reviewed publications, involving hundreds of external co-authorships from more than a hundred different countries. This includes more than 80 publications in *Science* (14), *PNAS* (12), *Nature* (14), *Nature Climate Change* (31), *Nature Geoscience* (6), and other *Nature Subject* journals. In the **QS World Rankings for 2020**, UEA is 1st for Earth and Marine Sciences and 3rd for Geography for citations per paper globally. Four of our researchers (**Jones, Le Quéré, Nicholls, Peres**) were in the world's top 1% most cited scientists in 2020. During the REF period we have been awarded £67M (up from £42M in REF2014) for 487 research projects, including £34M from UKRI and £17M from the EU. The School has consistently produced interdisciplinary research which meets the needs of policy makers at all levels of governance, contributing to our number one ranking for research impact in REF2014.

Our research is organised into centres of research excellence and research groups, many of which are interdisciplinary, and some extend to other Schools or research partners. Researchers commonly belong to multiple centres. Note the School also has four disciplinary sectors which are used to organise and manage teaching. Here we briefly describe our research centres and groups:



The **Climatic Research Unit** (established 1972) improves understanding of the climate system and its interactions with society, through creating observational datasets that are used extensively for monitoring climate change and evaluating models. It also provides information for climate services and develops decision support tools.



The **Centre for Ocean and Atmospheric Sciences** brings together scientists researching the physics and biogeochemistry of the atmosphere and oceans, and critical interactions between them. We host staff from the National Centre for Atmospheric Science (NCAS) in both CRU and COAS.



In the 50th year of UEA's affiliation with the **Centre for Environment, Fisheries and Aquaculture Science (Cefas)** in 2015, the School established the **Collaborative Centre for Sustainable Use of the Seas** which uses innovative science and practical expertise to achieve sustainable use of the seas.



The UEA-led **Tyndall Centre for Climate Change Research** (established 2000) is a partnership of universities bringing together researchers from social, natural and engineering sciences to spearhead interdisciplinary research on how society should cope with climate change.



The **Science, Society and Sustainability Research Group** pioneers new approaches for understanding and transforming relations between science, innovation and society in addressing the sustainability challenges of energy, climate change and emerging technologies.



The **Centre for Social and Economic Research on the Global Environment** focuses on sustainable development and decision making, including economics, politics and other social sciences.



The **Centre for Ecology, Evolution and Conservation** is one of the largest groups of ecologists and evolutionary biologists in Europe, bringing together researchers from the Schools of Environmental and Biological Sciences.



The **Earth and Life Systems Alliance** is a strategic cornerstone of the NRP with researchers investigating the effects of global change on biodiversity, elemental cycles and food security from the molecular level through to the ecosystem level.



The **Geosciences Group** investigates geohazards, geophysics, sedimentology, hydrogeology and hydrology, volcanology, geochemistry and palaeoclimatology and, where relevant, links to societal responses, for example, through risk from volcanic hazards in the STREVA project.



1.2 RESEARCH STRATEGY AND PROGRESS AGAINST REF2014 PLANS

Our research and impact strategy is refreshed periodically, aided most recently by away-days and a University-wide strategic review led by the Pro-Vice Chancellor (PVC) for Research & Innovation in 2015.

This led to our **2015-2030 Research Vision** to pursue:

“cutting-edge interdisciplinary environmental science research that directly addresses the grand environmental challenges of the 21st century”,

and our overall **Mission Statement** to:

“achieve breakthrough advances in society’s understanding of the causes, consequences and societal implications of major challenges such as climate change, ecosystem loss and energy security”.

Our strategy is to appoint staff to areas of research priority and where we see funding opportunities, then let them drive their research agenda. We aim for a culture of solution-oriented research, creating forums for interdisciplinary discussions, forging external partnerships, and providing international leadership. This culture generates world-leading impact from our research activities through direct engagement with policy makers, governments, government agencies, businesses and the public.

The School’s research and innovation strategy is developed by the Executive Group led by the Head of School (HoS) (**Hiscock**) and the Directors of Research (**Reeves**) and Innovation (Dorling, returned to UoA6; formerly **Reid**). Hiscock is on the Faculty’s Executive, and Reeves and Dorling are on the Faculty’s Research and Innovation Executives respectively. Reeves chairs the School’s Research and Innovation Committee. Strategy at the Faculty level is led by the PVC for Science, the Associate Dean for Research (**Renfrew**) and the Associate Dean for Innovation (**Reid**) – both in UoA7.

To ensure cohesion and sustainability, the School facilitates and funds research centres and groups through dedicated workspace; co-location of staff and PhD students; a social area; daily School Bulletins; monthly Research Newsletters; a comprehensive programme of seminars across all our centres with a wide range of external and internal speakers; and our regular Zuckerman symposium show-casing our interdisciplinary research.

1.2.1 Research Strategy Successes

Evidence for the success of our strategy is presented in **Box1**. Here the **research centres** of the authors are noted. It is implicit that our researchers had collaborators.

Box1: Selected research highlights

Authors in COAS and CRU

Bakker demonstrated, using the UEA-led SOCAT CO₂ dataset, that the Southern Ocean carbon sink strengthened for over a decade (2015, *Science*, 10.1126/science.aab2620), and has reframed the carbon cycle of the subpolar Southern Ocean (2019, *Science Advances*, 10.1126/sciadv.aav6410).

Suntharalingam carried out the first comprehensive quantification of global nitrous oxide sources and sinks (2020, *Nature*, 10.1038/s41586-020-2780-0).

Heywood documented multidecadal warming of Antarctic waters linked to increased ice shelf melt (2014, *Science*, 10.1126/science.1256117) and the role of eddy transport in ocean circulation there (2014, *Nature Geoscience*, 10.1038/ngeo2289)

Renfrew found decreasing intensity in open-ocean convection in the Greenland and Iceland Seas, due to changes in sea-ice extent and differential warming (2015, *Nature Climate Change*, 10.1038/nclimate2688).

Laube, Oram, Reeves and **Sturges**, discovered new ozone-depleting substances in the atmosphere, feeding through to our policy impact activities via the Montreal Protocol (2014, *Nature Geosciences*, 10.1038/ngeo2109).

Nowack and **Joshi** presented evidence that the representation of stratospheric ozone in climate models can impact estimates of effective climate sensitivity (2014, *Nature Climate Change*, 10.1038/nclimate2451).

Authors in the Tyndall Centre, 3S group, CSERGE, CRU and CEEC

Wilson developed a low energy demand scenario for meeting the 1.5 °C target and sustainable development goals without negative emission technologies (2018, *Nature Energy*, 10.1038/s41560-018-0172-6) and showed that a diverse set of measures targeting buyers is necessary to drive widespread adoption of clean technologies (2018, *Nature Energy*, 10.1038/s41560-018-0195-z).

Chilvers, Pallett and Hargreaves developed a conceptual framework for understanding participation in socio-technical change with reference to energy systems and highlighted the challenges of building just transitions (2018, *Energy Research and Social Science*, 10.1016/j.erss.2018.03.020).

Lake, Osborn, Peres and Warren showed how future climate change could amplify the incidence and spread of dengue fever in Latin America and that significant impacts can be avoided by constraining global warming to 1.5 °C (2018, *PNAS*, 10.1038/s41558-019-0419-7).

Le Quéré, Wilson and Jordan showed that decreasing CO₂ emissions in 18 countries were driven by decreases in energy use and shifts to renewable energy (2019, *Nature Climate Change*, 10.1038/s41558-019-0419-7); while **Le Quéré** led a quantification of the temporary reduction in daily global CO₂ emissions during the COVID-19 lockdown (2020, *Nature Climate Change*, 10.1038/s41558-020-0797-x).

Warren and Price projected that the number of insect species losing more than half their geographic range by 2100 can be reduced by two-thirds if warming is limited to 1.5 °C (2018, *Science*, 10.1126/science.aar3646).

Authors in ELSA, CEEC and COAS

Murrell described the mechanism by which a methanotroph assimilates methane, a key greenhouse gas (2014, *Nature*, 10.1038/nature13192) and further discovered a protein that enables methanotrophs to store copper for methane oxidation (2015, *Nature*, 10.1038/nature14854).

Peres revealed how overhunting in Amazonian forests has limited seed dispersal inducing widespread erosion of forest carbon stocks and biomass collapse (2015, *PNAS*, 10.1073/pnas.1516525113), and moreover that fragmentation of forests has had a global impact on forest vertebrates (2017, *Nature*, 10.1038/nature24457).

Franco and Gilroy have enabled better predictions of the effect of global change on the resilience and diversity of European birds (2016, *Ecology Letters*, 10.1111/ele.125697); and have provided strategies for better agricultural practice and preservation of biodiversity (2014, *Nature Climate Change*, 10.1038/nclimate2200).

Van Oosterhout provided new insights into the structure, function and evolution of an archetypal supergene in *Primula vulgaris* (2016, *Nature Plants*, 10.1038/nplants.2016.188), and with **Mock** presented insights into the evolutionary genomics of a cold-adapted diatom in the Southern Ocean, *Fragilariopsis cylindrus* (2017, *Nature*, 10.1038/nature20803).

Authors in Geosciences

Cooper and Hiscock demonstrated that hydrogeological conditions can be used to develop refined regional-scale emission factor estimates required for accurate greenhouse gas inventories (2017, *Environmental Science and Technology*, 10.1021/acs.est.7b02135).

Alexander proposed that discharge variability is a more reliable basis for classifying alluvial rock records, recasting a paradigm (2018, *Sedimentary Geology*, 10.1016/j.sedgeo.2017.12.022).

Barclay demonstrated that preserving livelihoods was critical to protecting life during volcanic crises (2019, *Frontiers in Earth Science*, 10.3389/feart.2019.00205).

1.2.2 Reviewing our REF2014 Research Plans

In REF2014, we set out a number of specific strategic objectives which are reviewed here:

(i) Develop the Centre for Ocean and Atmospheric Sciences

COAS was established in 2013, so our aim has been to facilitate its science and grow its reputation. Evidence for success includes:

Responding to national priorities in 2017-2019, by securing three of the five projects within NERC's *Role of the Southern Ocean in the Earth System* directed research programme.

Our links with the **British Antarctic Survey (BAS)**, **Plymouth Marine Laboratory (PML)** and **National Oceanographic Centre (NOC)** have strengthened to become extensive and significant during the REF period. Our collaborative projects and our PhD co-supervisions include: 11 projects (£3M) and 14 students with BAS; 20 projects (£6M) and 6 students with PML; 18 projects (£6.7M) and 3 students with NOC. Together these partners have 15 honorary positions in the School.

The new **CCSUS** has cemented our relationship with **Cefas**. We have a co-funded (50:50) post in Marine Ecosystems (**M. Johnson**; then **Nolte**) and 20 Cefas staff have honorary positions. Cefas have funded research and consultancy worth £706k and co-supervised 14 PhD students.

Links with the **Met Office** have strengthened. UEA is in the top five UK universities for joint publications (increasing to 94 in the last five years). The Met Office have funded five research projects (£947k), three consultancy projects (£366k), been Industrial CASE partners for four PhDs and project partners >10 times.

Links with **NCAS** have grown to include the co-development of the CRU climate datasets. We have a co-funded research fellow (**Oram**) and host two NCAS staff (**Forster** and **Harris**).

(ii) Lead the development of the Tyndall Centre both nationally and internationally

During the REF period our aim was to sustain and enhance Tyndall's research activities, including with international partners. Evidence for our success includes:

Steering its flagship **global carbon budget annual publication** (e.g., **Le Quéré, Box1**), bringing together >70 scientists from 50 organisations and 10 countries. We also hosted the European Office (2015-2017) for *Future Earth*.

Leading on reducing CO₂ emissions from academic flying, with its Tyndall Travel Strategy, highly praised in the Editorial of *Nature* (March 2015), and inspiring similar strategies worldwide.

Developing a partnership with the University of Cape Town, through a Newton Fund exchange programme, for 20-PhDs on climate change; and sustaining the Fudan Tyndall Centre with its focus on air quality.

Investigating the potential of innovation, behaviour and policy in the field of energy and climate change mitigation, as evidenced by publications (**Box1**) and an ERC Starting grant to **Wilson** (2015).

Appointing a new Director (**Nicholls**), bringing expertise on coastal systems and climate change, with former Director **Le Quéré** remaining in the School. Both are "highly cited" (top 1%) researchers.

(iii) Sustain our impressive participation in the Intergovernmental Panel on Climate Change (IPCC)

We have continued our participation as authors and reviewers of the *AR5 WGII report* (2014) (**Warren, Vaughan, Peres**), and the *IPCC Special Reports on Global Warming of 1.5°C* (2018) (**Warren**) and *Ocean and Cryosphere* (2019) (**Nicholls, Webber**).

(iv) Grow our activities across the NRP

The NRP includes UEA and four world-class biological and plant science research institutes – the John Innes Centre, Sainsbury Laboratory, Quadram Institute and Earlham Institute. Our aim was to increase our NRP collaborations and exploit this concentration of world-leading scientists – ten were in the top 1% for citations in 2020, including four from our School.

We have grown our activities primarily via ELSA under its Director (**Murrell**) and Deputy Director (**van Oosterhout**). ELSA leads multidisciplinary research between partner institutions across the NRP, with over 140 publications since 2014. It promotes joint funding and co-supervision of PhD students (8 since 2014). Genome sequencing, in collaboration with the Earlham Institute, has been critical to some of our research highlights (**Box1**).

(v) Sustain our natural capital decision research

Our aim has been to sustain CSERGE under its Director (**Turner**), supported by **Ferrini, Bark** and **Lovett**, as it re-focuses following staff changes.

Since 2014, CSERGE has expanded beyond the School to include partners in the Earlham Institute, Cefas and the School of Economics. It is leading a UKRI project *ADVENT* on valuing natural capital in low carbon energy pathways and is part of the GCRF-funded GROW Columbia project.

(vi) Support development in natural hazards

Our aim has been to grow our vibrant natural hazards and volcanology groups and their interdisciplinary approach to volcanic risk reduction.

The landmark *Strengthening Resilience to Volcanic Hazards (STREVA)* project (2012-2019) led by **Barclay**, demonstrated the value of an interdisciplinary approach to volcanic risk reduction (**Box1**). Subsequent partnerships have led to six GCRF projects (£1.1M), including city-leadership within the £18M *Urban Disaster Risk Hub*. Wide-ranging developments across the humanities, social and natural sciences illustrate our strategic support of interdisciplinary research.

1.2.3 Research Strategy for the next Five Years

Our research strategy evolves from recent successes (as above) and new strategic aims within the framework of our research vision. Here we outline several specific aims:

(i) Lead and develop ClimateUEA

The School has driven a major institutional development: the *ClimateUEA* initiative (established 2019). This UEA-wide initiative aims to expand on the successes of CRU, Tyndall and COAS to develop multi-disciplinary climate research and climate solutions across UEA with the School providing research impetus and leadership, e.g., developing collaborations with our world-renowned Creative Writing experts. The School co-leads four of the six challenges; each has specific objectives which will need research funding to be met. So far, we have won major funding (£1.35M) for a **Leverhulme Doctoral Training Centre** on the *Critical Decade for Climate Change* recruiting its first cohort during 2021. Our future aims are to win further research funding and spearhead *ClimateUEA* nationally and internationally.

(ii) Push our aspirations for a global NetZero recovery from COVID-19

We have provided key advice to the UK government on setting its 2050 *Net Zero* target for greenhouse gas emissions (see **Box2**). Solutions are now needed to achieve this target. We will pursue research to deliver solutions for *Net Zero* from understanding carbon sequestration on land and in the ocean, the possibilities and impacts of planned greenhouse gas removal to offset residual emissions, and the potential of disruptive innovations in the energy and land sectors. We will also pursue research on verification of emissions with Earth System data, namely through the development and analysis of atmospheric trace gases and carbon balance.

(iii) Increase the scientific basis for climate action with our leadership of the Tyndall Centre and CAST

We have been the lead institute for the Tyndall Centre for more than 20 years quantifying the risks that climate change poses and identifying the potential for adaptation and mitigation. We are playing a key role in the new ESRC *Centre for Climate Change and Social Transformations* (CAST; 2019-2024, £1M to UEA, with potential for up to 15 years funding), led by Tyndall-Cardiff, focusing on the social transformations needed to produce a low-carbon and sustainable society. We also want to increase the scientific basis for the support of adaptation to climate change in coastal areas, develop the science for sustainable use of land, and strengthen Tyndall-CRU collaborations. Prestigious new ERC awards to **Wilson** (Consolidator) and **Jordan** (Advanced) will enable analysis on digitalisation impacts on climate and the political challenges with delivering *Net Zero*.

(iv) Grow our Science, Society and Sustainability Research Group

We will build on the successful development of our 3S Group as a centre for internationally leading research on the social dimensions of science, technology and sustainability. Specifically, through our leadership of the UK Energy Research Centre Phase 4 in 2019-2024 (Co-Directed by **Chilvers**, £0.65M to UEA), including the new Observatory for Societal Engagement with Energy (led by **Chilvers** with **Pallett** and **Hargreaves**).

(v) Develop Data Science for environmental research and sustainable geoscience

The School is exceptionally active in the delivery of widely used environmental datasets, such as the CRU climate records. We now aim to develop our data science research for environmental sciences. This will build on recent methodology developed to uncover changes in CO₂ emissions during the COVID-19 pandemic and our use of machine learning to assess recent Southern Ocean CO₂ changes (**Box1**). We plan to forge new collaborations with colleagues in the School of Computing, build on our current expertise and support our recently appointed lecturers in data science and atmospheric chemistry (**Nowack**), and data science and geohazards (**Bie**). This is part of our strategy for strengthening and deepening our interests in **sustainable geoscience** via the understanding of the genesis and evolution of geohazards, geo-resources (including water), and marginal (biodiverse) landscapes. It will advance understanding by combining novel instrumentation and data mining.

(vi) Expand our pole-to-pole exploration of the physical environment

We have research programmes funded to deploy observing platforms under the ice in Antarctica (**Heywood**), in clouds over the Arctic and Antarctica (**Renfrew**), around Indonesia (**Matthews**), and along the length of the Atlantic Ocean (**Manning**). We want to ensure that the COVID-19 pandemic restrictions do not have long-lasting impact on these critical programmes and are organising for a strong return to the field as soon as possible.

(vii) Develop our partnerships with businesses and government agencies

UEA provides academic leadership to the East of England and the School has a strategic role which complements our generally global research portfolio, e.g., through our collaborations with Anglian Water and County Councils. We aim to sustain such research via 'place' orientated funding, such as *EIRA (Enabling Innovation: Research to Application)*, launched in 2019) which is co-led by UEA.

1.3 IMPACT: STRATEGIC GOALS, MECHANISMS AND ACHIEVEMENTS

Impact is embedded in the School's 2015-2030 strategy:

"building strong partnerships with governments, businesses and civil society to identify societal solutions that put society firmly on a path to sustainability in the 21st century".

The School's longstanding approach to translating research into impact is to tailor research to the needs of stakeholders. Our researchers are supported to engage with senior policy makers, civil society organisations, government agencies, businesses and the public. We aim to engender the mutual trust and respect that is critical for effective knowledge exchange, co-production and collaboration, so that impact flourishes. In REF2014, 77% of our impact was assessed to be 4*. We have sustained this level of impact via a range of mechanisms:

- Our Directors of Innovation and Research engage with an **Annual Review of Impact**, supported by our Research and Innovation Services and overseen by the relevant Associate Deans. Assessments from this review act as a gateway to internal funding.
- We have had several **Impact Workshops** covering impact generation; the sharing of ideas for impact activities; peer review of embryonic Impact Case Studies (ICS).
- We have supported impact through **institutional funding** (more than 50 awards, totalling over £830k in the REF period; see Section 3) and **staff mechanisms** (see Section 2).
- During the REF period, we have nurtured and supported a **strong and diverse portfolio of impact activities, including 23 potential ICS with 6 submitted (Box2)**:

Box2: Our REF2021 Impact Case Studies

ICS1: Impacting international policy on biodiversity through valuing ecosystem services and natural capital

ICS2: Global temperature research and data products underpin international climate negotiations

ICS3: Global carbon budgets influence the design and implementation of Net-Zero emissions targets

ICS4: Protecting the ozone layer and climate - halocarbon research underpins the Montreal Protocol

ICS5: Informing policy for a greener Brexit

ICS6: More accurate weather and climate models from an improvement in surface exchange over sea ice

Our Approach:

- **Knowledge Exchange** with intergovernmental agencies is critical to our policy-relevant impact, such as with the *IPCC (ICS2, ICS3)*; the *United Nations Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (ICS1)*; and the *Montreal Protocol Scientific Assessment of Ozone Depletion (ICS4)*). This has been aided by workload adjustments to participate in these bodies (e.g., **Jones, Osborn**).
- **Co-production** is critical to realising some of our impact through:
 - Stakeholder funding, e.g., Defra's UK *National Ecosystem Assessment Follow-On (ICS1)* and a *BEIS* consultancy project (**ICS3**);
 - Membership of influential or statutory bodies, e.g., **Le Quéré's** membership of the UK *Climate Change Committee*; and her appointment as Chair of the French *Haut Conseil pour le Climat (ICS3)*;
 - Advice to government committees, e.g., **Jordan** for the *Environmental Audit Committee* in the House of Commons (**ICS5**).
- **Direct collaborations**, for example with the Met Office, have enabled the production of the highly used HadCRUT dataset (**ICS2**) and the implementation and evaluation of parameterizations in their weather and climate models (**ICS6**).
- All six submitted ICS have received UEA funding, including support for research staff in CRU and the Tyndall Centre that have been critical for **ICS2** and **ICS3**.

1.4 OUR APPROACH TO INTERDISCIPLINARY RESEARCH

An interdisciplinary approach to research has been at the heart of the School since its founding in 1967 and was highlighted in the Queen's Anniversary Prize in 2017. This ethos has been sustained over many decades by our approach to research challenges. Over 20% of our submitted outputs are classed as interdisciplinary. Some highlights are in **Box1** (outputs from **Lake, Barclay, & Gilroy**). Our ethos has been aided by, for example, School-wide dissemination of seminars, our regular interdisciplinary Zuckerman Symposia and regular School discussion meetings. Further evidence includes two 50:50 staff members – **Matthews** with Mathematics and **Gilroy** with Biology – and membership from other Schools in many of our research centres.

1.5 OPEN RESEARCH

Our strategy for open research is to **maximise access to our publications and data**. For example, all accepted manuscripts are uploaded to the Pure research information system and become externally accessible in compliance with REF open access requirements. The University also administers UKRI and charity funds to pay for open access publication in accordance with funders' requirements. In addition, the School selectively funds gold open access when institutional funds are not available.

A new University-level initiative will extend open access to underpinning datasets. Our data are already made available following funder data policies, e.g., via NERC data centres. The School has gone beyond these requirements, for example:

- CRU global climate datasets are among the most frequently used datasets in geosciences (e.g., the world-renowned HadCRUT global temperature, Morice *et al.* 2012, has 1370 citations) and are disseminated via the CRU website, CRU-developed Google Earth layers and external data centres.
- In collaborations with NRP colleagues, we have developed open-source software for whole genome datasets (*HybridCheck*); and population genetics (*Micro-Checker*; Van Oosterhout *et al.* 2004 has > 10,000 citations).

1.6 RESEARCH INTEGRITY AND ETHICS

Our approach to Research Integrity is guided by our Ethics Officer (**Pallett**) and is in line with University and national policy. During the REF period, the addition of environmental considerations to such policies has meant an increase in scrutiny and resourcing. All PGR students in the School are taught about research ethics. For research projects we receive support from the Research and Innovation Services, while approval comes from the Science Faculty Research Ethics Committee. The School has led elements of University practice, e.g., in 2014 **Pallett** joined the University Research Ethics Committee to advise on issues related to environmental impact and wrote university-wide guidance.

2. People

2.1 STAFFING STRATEGY AND STAFF DEVELOPMENT

Our **staffing strategy** aims to create a **sustainable and thriving research environment** to facilitate the career development of existing research staff, and to recruit outstanding new staff in open competition. We aim to provide the highest standards of equality, diversity and inclusion to attract, develop and retain high-achieving research staff and students. We are returning 70 staff (45M:25F); 62 are 'Academic Teaching & Research' faculty on indefinite contracts and 8 are independent researchers of whom only 3 (2M:1F) are on fixed-term contracts. We support part-time working and have 12 (5M:7F) such staff. On average we have had 63 Research Associates (RAs) and fellows employed each year of the REF period.

2.1.1 Staff Development Strategy

To implement our staff development strategy, we deploy a suite of mechanisms at University, Faculty and School levels:

- All staff undertake **Annual Appraisals**. The approach is supportive and reflective: celebrating achievements, considering what has helped or hindered progress, planning short- and long-term objectives, identifying support required, and raising issues for the attention of the HoS. It is also a chance to discuss career progression, including promotion. Appraisers of RAs are not normally their line manager, allowing them to discuss their progress with an independent person. Staff can request a different appraiser.
- The School operates an annual **Research Activity Planning** exercise for all ATR faculty (optional for RAs) to encourage self-reflection and strategic planning of research activities. Data on outputs, grants, PhD supervision and research impact for the last few years underpin the reflection and discussions in a meeting with a senior researcher. We have found these meetings encourage staff to plan more carefully, for example, which grant calls to target. They also provide an opportunity for constructive feedback on future aspirations.
- These meetings inform an **Annual Research Review** which is led by the Director of Research and HoS, supported by a research services manager, and overseen by the Associate Dean for Research in Science and the PVC-Research.
- Staff have access to over 200 on-site **Training Courses**. Several are compulsory and must be renewed regularly (e.g., *Diversity in the Workplace*, *GDPR*); others are required for certain activities (e.g., recruitment, appraisal). Funding is available for specialised training requirements, such as, fieldwork first aid and female-focused senior leadership (e.g., **Bark, Pallett, Reeves**).
- The School's **Promotions Committee** considers cases for confirmation of appointment and promotion of academic and contract research staff as part of UEA's procedures. Staff are offered support in their applications by mentors or line managers. Guidance notes are available from our Athena SWAN committee and feedback is provided by the Committee chair (the HoS). In the REF period 12 staff (6M:6F) have had their appointments confirmed; 10 (6M:4F) have been promoted to Senior Lecturer, eight (3M:5F) to Associate Professor; and 17 (13M:4F) to Professor. In addition, eight RAs (5M:3F) have been promoted.
- **New faculty** are provided with a **mentor**, who guides them through UEA processes and supports them during their probation. They are required to pass the *Certificate in Higher Education Practice*, which encourages research-led teaching and includes research objectives as part of a Personal Development Plan. Early career lecturers are given a **reduced teaching and admin workload** – 50% in their first two years, rising to a full load by year four – and receive a research development fund of £30k. They are also eligible for the Faculty early-career PhD studentship competition, beneficiaries include **Nowack**.
- During the REF period, eight staff held **fellowships** supported by various funders (EPSRC, NERC, EU, Royal Society, Leverhulme Trust and British Academy).
- UEA has a Code of Practice for the Management of Research Staff which is informed by the *Concordat to Support the Career Development of Researchers*. The School's Research Staff Co-ordinator (**Webber**) is the point-of-contact for RAs, who are offered mentors and have access to staff training.
- The School has been pro-active in **improving career progression for RAs**. The Director of Research and Researcher Affairs Forum Chair have been instrumental in the implementation of the 2019 Concordat at University level: meeting with the PVC-Research; contributing to a

new Research Staff Promotions Handbook; and working with Human Resources to implement new merit-based promotion criteria that now apply across the University. The University **funds any financial shortfall** resulting from RA promotion.

- **Technical staff** play a key role in underpinning and facilitating our research. UEA promotes opportunities for technical staff to gain professional recognition through the Science Council's Professional Registers, demonstrating transferability skills across academia and industry, and provides a framework to support career development and promotion.

2.1.2 Staff Recruitment Strategy

Staffing policy is the responsibility of the School's Executive Group and is guided by the School Strategy. During the REF period, 22 members of faculty have left: eight retired with seven taking on Emeritus positions; 13 moved elsewhere and one passed away. We have **recruited 17 new indefinite contract staff** and increased our independent researcher numbers, so overall our staff numbers are marginally higher than in 2014. Our general approach is to recruit at early career stage (all but three have been lectureships) and provide a research environment for them to succeed. This approach helps balance our demographic profile. New faculty are only hired if judged to be producing internationally excellent research. We foster career progression in our own research staff: eight have transitioned from fellowships or RA posts into faculty positions (**Bakker, Cooper, Gilroy, Harwood, Laube, Pallet, Price, Webber**); while four have transitioned from fellowships elsewhere (**Bark, Mahony, Nowack, Ebbensgaard**). Three new appointments came from overseas institutes (**J. Johnson, Bennett, Nolte**); and two from UK institutes (**Nicholls, Rose**).

- These 17 new faculty appointments have been aimed at sustaining our research activities across the whole School: five in COAS, one in CRU, two in Tyndall, three in Geosciences, two in CEEC, four in 3S, and one in CSERGE.
- When **independent fellows** take on lectureships, we arrange for them to complete their fellowships enabling them to focus on their research, while becoming familiar with the School.
- The University has always offered relocation expenses to academic staff, and from 2019 this was extended to research staff.
- All our new appointments have passed probation at the appropriate stage.

2.1.3 Support for Staff at the beginning of their Research Careers

On starting at UEA, our staff have a University and **School Induction Programme**, led by our local administrative support team and their line manager. They are given a welcome pack and guidance on processes at UEA. In addition, RA's have specialised support, including:

- RA representatives sit on all relevant School committees, voicing RA views and supporting their professional development.
- RA's are invited to organise seminar series – giving them the opportunity to invite speakers and host discussions.
- We have a lively School **Researchers Affairs' Forum** chaired by an RA and attended by the Research Staff Co-ordinator (occasionally the HoS) that discusses promotion, professional development, etc.
- We use indicative job descriptions to ensure that RA jobs are costed at the correct level on grant applications and appointed on an appropriate salary grade.
- We encourage RAs to become members of the supervisory teams of PhD students where appropriate.
- Our researchers are encouraged to take part in the **University-wide Annual Researcher Summit** (featuring "Special Merit in Research" Awards – the 2020 recipient being in the School).

2.1.4 Study Leave and Exchanges

The School encourages study leave with staff eligible for six months every six semesters. Study leave has enabled people to:

- Prepare major grant proposals, e.g., **Matthews** (*TerraMaris* £3M consortium)
- Participate in major field campaigns (e.g., **Matthews, Hall** and **Heywood BoBBle**)
- Visit overseas institutes to develop research collaborations (e.g., **Reid**, Chinese Academy of Sciences; **Malin**, Ocean University China; **Zhai**, University of Hamburg; **Peres**, State University of Sao Paulo; and **Sturges**, University of Colorado)
- Develop impact, and interact with stakeholders (e.g., **Lovett**, Anglian Water; **Warren** and **Osborn**, *IPCC*)

2.1.5 Recognition and Reward for Research and Impact Activities

Research and impact effort are recognised in our **Workload Allocation Model** which includes time for core research (30%), investigator time on funded grants, PhD supervision and impact activities (Section 2.3).

Staff are rewarded via promotion and discretionary payments. Staff successes are celebrated via the School Research Newsletter which highlights research and impact achievements (e.g., grants won, papers published, awards received).

UEA celebrates achievements through its annual **Impact and Innovation Awards**. The School encourages nominations and has had winners:

- Outstanding Impact in Policy and Practice (**Jordan** and **Rayner** – 2018)
- Consultancy Project of the Year (**Warren** and **Le Quéré** – 2019).

2.2 POSTGRADUATE RESEARCH STUDENTS

2.2.1 Overview

Postgraduate research (PGR) students are key to the intellectual vitality and research activity of the School and, for example, we have PGR co-authors on 20% of our returned outputs. On average we have had 147 PGR students (142 on PhDs; 13 part-time) registered each academic year of the REF period.

Governance and training of all our PGR students is overseen by the Science Graduate School which is a part of the UEA Doctoral College. The School's Director of PGR (**Manning**) is on the Science Faculty's PGR Committee, which is led by the Associate Dean for PGR. There is **very high overall satisfaction** amongst our PGR students: 92% compared to the sector average of 82% in the PGR Experience Survey (2019).

2.2.2 Funding and Recruiting our PGR Students

The School leads **first and second round NERC Doctoral Training Partnerships** – EnvEast (2014-2022) and ARIES (2019–2027) – with the Director (**Sturges**) and several other role-holders in the School. Our students can be 'associated' with a DTP and so benefit from their cohort training, and almost all take up this opportunity – the School has paid for 42 associations (>£20k).



Our NERC DTPs have been at the **forefront of a student-centred approach to training** and pioneered a number of innovations which have been emulated across UEA and some of our partner universities. These innovations led to EnvEast being the only DTP to have “green” (excellent) scores in all components of the mid-term review of round 1 NERC DTPs.

UEA has played a key role in the **Next-Generation Unmanned System Science (NEXUSS) Centre for Doctoral Training**, funded by NERC and EPSRC and led by the University of Southampton. **Hall** is on the Steering Committee. Out of a total of 44 available studentships, the School has hosted 10 studentships, and co-supervised several more with the School of Computing.

The remainder of our students (~50%) are funded from a range of sources including NERC Industrial CASE, the *South East Network for Social Sciences* DTP, EPSRC, the Faculty of Science, the China Scholarship Council, and Southern University of Science and Technology, Shenzhen. We have been working to **broaden funding routes** for PhD studentships, firstly from additional external funding such as the *Leverhulme DTC* starting in 2021; and secondly by lobbying for additional investment into PhDs by the Faculty of Science who have agreed and increased annual investment since 2019.

Our Approach to Recruitment

The recruitment of PGR students adheres to UEA's policies on recruitment and Equality & Diversity. Recruitment is via open calls followed by a formal selection process involving the proposed supervisory team and independent interviewers. In all cases, we aim to widen participation, enhance diversity and support well-being, for example:

- All DTP interview panellists must have unconscious bias training and DTP panels must exhibit gender diversity. Tracking through the recruitment cycle shows near equal gender balance.
- Since 2018, the DTPs have provided an additional three months' stipend to "convert" students from highly numerate disciplines to environmental sciences – awarded to four of our students.

2.2.3 Supervision, Monitoring and Representation

All PGR students have a supervisory team, with at least two supervisors. Where the primary supervisor is an early career researcher, the secondary supervisor must be experienced. All PGR supervisors are required to undertake training in *Best Practice in Research Supervision* every three years.

Formal review meetings with the supervisory team occur three times a year, with progress reports reviewed by the School's PGR Director and action taken as needed. In practice, supervisors typically meet students weekly and meetings are regularly recorded. PGR students undergo a formal probationary review in their first year – all passed during 2016-19.

The School's Graduate Affairs Committee is co-chaired by the Director of PGR and a PGR student. We have PGR Representatives on the Health & Safety Committee, Equality & Diversity Committee and School Board.

2.2.4 Skills Training and Career Preparation

All PGR students engage in a Training Pathway. The *UEA Code of Practice* commits to skills and employability training, taking into account national standards. When students start, they complete a Training Needs Analysis, identifying their strengths and weaknesses. They update this as a Personal Development Plan annually, in consultation with their supervisors and with feedback from our Training Coordinators.

We provide an extensive and high-quality training programme open to all students. It includes advanced skills training (e.g., *Environmental Genomics*), broader academic skills (e.g., writing research papers) and life skills (e.g., mental health first aid). Our programme is evidence-based, academic-led and delivered by highly qualified staff.

Most of our students are in (or are associated with) our NERC DTPs and these run four weeks of mandatory multidisciplinary **cohort residential training**, which is generally rated as 'excellent'

or 'very good'. All multi-day training events include a component on well-being such as work-life balance, or mindfulness. In addition:

- We have funded several internship schemes subsidising the placement of students into relevant business for up to three months, e.g., into *WeatherQuest* and *Benthic Solutions*.
- All ARIES multi-day cohort training events feature former PGRs talking about their career experiences.
- We fund a student club for promoting enterprise, innovation and employability activities.
- NEXUSS specifically trains their students in the development and application of smart and autonomous observation systems, e.g., ocean gliders. Student cohort training events have included designing and carrying out a survey using robotic techniques.
- We have run **three 5-day NERC Advanced Training Short Courses on ocean gliders**. These included hands-on experience using UEA's unique glider calibration tank and expert tuition on ocean science and using gliders. Each course had 21-24 participants from across the UK (occasionally overseas), most being PGR students.

UEA has two careers advisers dedicated to supporting research students in skills development and preparation for their future career. External businesses are involved, contributing to sessions e.g., *Preparing for Non-academic Interviews*.

2.3 EQUALITY AND DIVERSITY (E&D)

The School is fully supportive of UEA's strategy and policies on E&D. In line with these, all staff undergo appropriately tailored training, such as *Diversity in the Workplace* (refreshed every two years). Through a mix of formal and informal approaches, we strive for a professional, supportive and inclusive research environment for all.

E&D considerations informed a new fully transparent **Workload Model**, developed and implemented by the Faculty of Science in 2019 to bring consistency across its Schools. The chair and deputy chair of our School's E&D Committee were on the Faculty's Workload Model working group. The new model allocates 30% of staff time to core research activities – proposal writing, research, output writing and impact development – as well as protecting funding success by accounting for Investigator time. Time-consuming one-off activities can also be accounted for, e.g., ICS development.

2.3.1 Equality and Diversity (Athena SWAN) Activity

The School's Equality and Diversity (Athena SWAN) Committee comprises the Chair (**Lorenzoni**), HoS, School Manager, members of faculty, including the Care Leave Champion, along with RA, Local Support and HR Representatives. The Chair is on the School's Executive and Promotions Committees, as well as the Faculty's EDI Steering Group and participates in the UEA Athena SWAN Central Operational Group. Also, **Malin** is on the *UEA Equality Frameworks Central Steering Group*. The Faculty has two Athena SWAN and E&D Coordinators who assist the School in implementing its activities. Females are well represented on the School's Executive: six of ten School Directors are women, including the Director of Research (**Reeves**) who is also Deputy HoS.

The School obtained the Bronze (2014) and then Silver (2017) Athena SWAN Awards demonstrating great progress across a range of E&D issues during the REF period.



When the School achieved Silver, the Panel commended the guidance for promotion applications, recruitment materials, our care leave champion, and non-PI appraisers for RAs. Progressing through our Action Plan we have relaunched our mentoring scheme, held a grant application workshop, addressed issues with the workload model and supported RAs applying for promotion. In addition:

- We have added positive action statements on E&D to our recruiting materials. A revised version is now used Faculty-wide.
- There has been a shift in our gender balance with 41% of newly recruited faculty being female compared with 23% of those leaving.
- To enable staff to accommodate personal needs, core hours (10am to 4pm) have been established.
- We support **part-time working** and have 12 (5M:7F) such staff. Part-time arrangements are considered in applications for **study leave and promotion**.
- The School has supported several instances of **shared parental leave**.
- Periods of parental leave or caring leave are considered in the promotion process.
- Since 2015, the Faculty has allocated a fund of £10k p.a. for **Transition back to Work** following a period of absence such as parental leave. In 2019 this was extended to become a **Return to Work/Family Support Fund** that now covers PGR students. A total of £5.6k has been awarded to our staff, e.g., for laptops and travel for accompanying persons to provide infant care during fieldwork.
- Following the School's Athena SWAN action, the Faculty established a **Bridging Fund** to cover gaps of up to three months for RAs between contracts; so far one RA in our School has benefitted. While previously, in 2015, another RA had bridging funding of £25k from the PVC-Science.
- The School has supported one staff member and several PGR students with scribes to allow them to work productively.
- We promote well-being events (e.g., Time to Talk Day) via our daily newsletter.
- We host seminars to enhance inclusivity both locally and nationally, e.g., **Barclay** hosted a series of Black Lives Matter panels for the VMSG group of the *Geological Society of London* in 2020.

UEA has supported **ResNet**, a network promoting gender equality and fairness, for over 20 years. ResNet organises events to promote career development; provide inspiration, information and support; and raise awareness of E&D issues. It is run by a committee from across the NRP including two members of the School: **Malin** (Chair) and **Barclay** who between them have led about 20% of the >75 events delivered during 2014-20.



2.3.2 Equality and Diversity in the REF Submission

This submission was constructed to present the quality of our research and impact, in compliance with **UEA's agreed REF2021 Code of Practice**, and recognising the need to maintain fairness and eliminate potential unconscious bias (all decision-makers received Unconscious Bias training and the UoA Coordinator received advice from the School's E&D Committee).

Output selection followed the UEA REF Code of Practice. Colleagues self-scored their outputs, which were then graded by at least two independent senior assessors (22M:7F). Assessors were briefed with advice on avoiding unconscious bias. A selection of outputs were also sent for external assessment. Anonymised assessment scores were returned to staff, giving them the opportunity to reflect on and challenge them if desired. A subset of assessors reviewed all scores and, when necessary, undertook additional assessments. Using the final scores, outputs were ranked and attributed to authors to allow selection of our highest ranked outputs, while adhering to the REF rules and our Code of Practice. The gender profile of attributed authors' outputs (29%F) reflects that of the Unit as a whole (35%F), given fewer senior staff and more part-time staff are female.

ICS selection was based on our Annual Impact Review meetings, conducted by the School Directors, the Faculty Associate Deans, and the Faculty Managers of Research and Innovation, overseen by the PVC-Research (3M:4F). Constructive feedback was returned to ICS authors at each stage.

3. Income, infrastructure and facilities

3.1 INCOME FOR RESEARCH AND IMPACT

The School has been awarded £67M for 487 research projects during the REF period (up from £42M in REF2014). £48M is from UK sources, £17M from the EU and £2M international. £34M is from UKRI (including £27M from NERC), £5M is from Government, £4M from charities, £2M from NIHR and £1M from industry. Examples of **major grants and prestigious awards** include:

- In 2016 and 2017, **Murrell** and **Heywood** won prestigious *ERC Advanced Grants* worth €2M and €3.5M respectively. Murrell has shown that the phyllosphere of an isoprene-emitting tree contains a diverse isoprene-degrading population (*PNAS*, 10.1073/pnas.1812668115). Heywood is developing the capability to make autonomous, climate-relevant ocean measurements to better understand air-sea-ice interaction, dense water formation and ice shelf melting.
- In 2016, **Wilson** and **Laube** each won *ERC Starting Grants* worth €1.6M and €1.5M respectively. Wilson has been investigating how social influences and disruptive innovations can reduce carbon emissions (**Box1**). Building on research during a NERC Fellowship in the REF period, Laube has used innovative technologies to explore halocarbon chemistry and circulation of the stratosphere (**Box1**).
- In 2019, **Le Quéré** won a prestigious *Royal Society Research Professorship* (£1.53M) to develop a high-complexity model to investigate carbon variability in the ocean.
- The £2.20M *Wensum Demonstration Test Catchment* project funded by Defra was extended with a further £1M to **Lovett, Hiscock** and **Cooper**. Working with collaborators and stakeholders they have demonstrated the nitrogen and phosphorus response to farming practices in arable catchments (**Box1**).
- **Lake** and Hunter (Medicine) have received joint awards totalling £2.1M from the NIHR that has led to interdisciplinary research on topics such as the spread of dengue fever in a warming climate (**Box1**).
- A major programme on Asian houbara conservation led by **Dolman** has been extended with a further £1.14M from *Birdlife International*.
- A £1.14M award from the *European Centre for Medium-range Weather Forecasts* enabled **Goodness** and **Jones** to advance climate services for the renewable energy sector through capacity building and user engagement.



3.2 STRATEGY AND SUPPORT FOR GENERATING RESEARCH AND IMPACT INCOME

We have an internal grant-reviewing system in place for all UKRI research councils to review proposals for their responsive rounds, aiming to improve their quality and support PIs. Our average success rate with NERC (our largest funder) is comparatively high at 28%. Indeed, in every year of the REF period our NERC success rate has been **higher than the sector average**; and since July 2016 we have been **above their demand management threshold**. In 2020 we rolled out a voluntary mentoring scheme for proposals to any funding scheme.

The School **regularly hosts workshops with research councils** in conjunction with the Associate Dean for Research. For example, we hosted an EPSRC theme day in 2018 with a programme leader giving a keynote talk, several presentations on ‘tips to winning funding’, a Q&A panel and a networking poster-event. Similar NERC theme days in 2016 and 2019 included keynote talks by NERC Directors. These funder-focused events are used to develop a positive research culture, facilitate networking and encourage grant proposal planning.

The School supports **fellowship** applicants via mentoring, proposal reviewing, interview preparation and facilitating advice from professional and technical staff. We advertise fellowship

opportunities via our Fellowships webpages, social media, and internally via emails and our research newsletter. UEA's *Science Fellowship Champion (Murrell)* leads a popular (~50 attendees) annual workshop on applying for fellowships. Fellowship schemes that require a significant financial contribution from the University, such as the *Leverhulme Early Career Fellowships* and *UKRI's Future Leaders Fellowships*, have an internal sift process to ensure high quality applications. During the REF period, the School has supported 70 fellowship applications and been successful with 10. Long-term (five year) fellows are offered a permanent contract if probation conditions are passed (e.g., **Laube**).

Support for Generating Impact

Impact from our research, and potential REF ICS, are supported by UEA and the School. The School's Director of Innovation (**Dorling**, formerly **Reid**) has sustained our culture of impact through School meetings, advice on converting research into impact, help with securing funding, and workshops to share best practices; all supported by UEA's Impact Team and Relationship Managers (see Section 1.3). We have a strong and diverse portfolio of impact activities, with 23 potential ICS and 6 submitted (**Box2**).

Our **Annual Impact Review** involves School- and Faculty-level review and scoring with Impact Team support and PVC-Research oversight. This review provides a gateway to access institutional impact funding. We have received more than **50 awards, totalling over £828k in the REF period**. Sources include: UEA's HEIF allocation (£165k), ESRC Impact Accelerator Fund (£65k), PVC Strategic Funds (£60k), Associate Dean Funds (£14k), UEA Proof of Concept Fund (£18k), Innovation Development Funding (£79k), UEA's GCRF Fund (£71k), the NRP Translational Fund (£86k), and the EIRA Fund (£75k).

This impact funding has been spent on a range of activities including: developing animal tracking devices; establishing the *Marine Knowledge Exchange Network*;



developing safer agrochemicals to reduce the environmental impact of pesticides; evidencing the potential for paper crumble to re-carbonise soil and improve soil quality; visiting stakeholders in Brazil and producing and distributing Brazilian fisheries management brochures; holding a two-day summit with leaders from government, business and civil society organisations; creating experiential films, mobile exhibits and a website about volcanic risk in the Caribbean; producing a systematic review to inform EU referendum debates and establishing the Brexit & Environment think tank (**ICS5**); meeting with officials from government departments (**ICS1**); working on the CRU datasets (**ICS2**); the development and piloting of the *ScienceBrief* platform which has supported journalism for the *IPCC*, etc. (**ICS3**); knowledge exchange activities (**ICS4**); parameterization testing in the Met Office weather and climate model (**ICS6**).

3.3 INFRASTRUCTURE SUPPORTING RESEARCH AND IMPACT

The School is supported by UEA's Research and Innovation Service. Two Project Officers support research grants from proposal development to final reporting. The Impact team oversees impact portfolio development/review processes, delivers impact training, coordinates workshops, and assists staff with evidence gathering. A Relationship Manager dedicated to Marine, Agricultural and Environmental Sciences helps broker interactions with a variety of companies and organisations.

3.3.1 Institutional Facilities

The Science Faculty is supported by 91 technical staff (15 in the School), dedicated laboratories and modern scientific instrumentation. During 2017/18 a review of centrally managed Science Analytical Facilities and of Technical Services took place. This led to a re-arrangement of the facilities into seven **Faculty of Science Instrument Platforms**: *Bio-Imaging, Structural Imaging, X-Ray, NMR, Mass Spectrometry, Elemental Analysis and Stable Isotopes*. Six have users in the

School: ranging from rock analysis within the *X-Ray* and *Structural Imaging Platforms*; metaldehyde and iodine analysis from soil & water within the *Mass Spectrometry Platform*; gas (**Dennis**, *Geology*, 10.1130/G39291.1), feather and soil analysis within the *Stable Isotope Platform*; and seawater (**Bakker**, **Box1**), agricultural runoff (**Hiscock**, **Box1**) and soil analysis within the *Elemental Analysis Platform*. Each platform has an academic lead to spearhead platform development, and School provides these for the *Elemental Analysis* (**Malin**) and *Stable Isotope* (**Dennis**) *Platforms*.

We have had significant investment (over £2.5M in the REF period) into the *Instrument Platforms* via applications to Research Council calls, capital equipment funding from UKRI and co-investment from UEA. Our researchers are already making use of these new facilities. **Baker** for iodine analysis in the *Mass Spectrometry Platform's* new ICP-MS (£350k, BBSRC 2017Alert); **Barclay** for the analysis of newly erupted lava in the *Structural Imaging Platform's* new **Scanning Electron Microscope** (£700k, UKRI Capital Award 2019); **Mock** using the *Bio-Imaging Platforms* new **Zeiss confocal microscopes** (£500k, UKRI 2019); and **Andrews** using the *X-Ray platforms* new **Power XRD** (£170k, UKRI 2019). Funding from UKRI, awarded in February 2020, has been allocated to the *Elemental Analysis Platform* (£327k); the *Structural Imaging Platform* (£25k); and the *Bio-Imaging Platform* (£80k).

The Faculty has a 'well-found laboratory' fund, spending on average £292k p.a. on repairing or upgrading equipment. Estates spend on Science infrastructure (e.g., fume cupboard upgrades) has been over £1.5M. UEA has a **PVC Capital Fund** of up to £500k p.a. to co-fund equipment. This has contributed to some of the above Science Faculty equipment, as well as a total of £614k to School equipment.

We make extensive use of UEA's **High Performance Computing** facilities, e.g., for ocean modelling, analysis of DNA sequences, and animal movements (**Box1**). The HPC has had £520K investment p.a. and currently provides 8312 CPU cores. Funding from UKRI, awarded in February 2020, has been allocated for a new GPU farm (£280k) targeted at data science.

3.3.2 School Laboratory and Field Facilities

In addition to hosting some of the Science Faculty Platform equipment, the School has a number of internationally leading research facilities:

We are the only UK university with an **Ocean Glider Facility**, including 11 *Seagliders*, a calibration tank and two dedicated research technicians. **Heywood**, **Hall**, **Kaiser**, **Matthews**, and **Webber** have led over 40 missions in the Indian Ocean, Southern Ocean, North Sea and North Atlantic; and there have been external users. Investments during the REF period total £1.85M including seven *Seagliders* and an ERC-funded *AutoNaut* surface vessel, which is powered by waves and can carry and release a *Seaglider*. These platforms enable us to collect world-leading data in remote environments at a fraction of the cost of ship-based fieldwork (**Box1**).





The **Roland von Glasow (RvG) Air-Sea-Ice Chamber** is a unique, purpose-built facility for investigating the interactions between the ocean, sea-ice and atmosphere. It was originally funded by an *ERC Consolidator Grant* for **von Glasow**, but part way through its construction the grant ended prematurely in 2015 when Roland died. **Kaiser** took over as lead and the Science Faculty provided £220k to complete the facility and a 0.3 FTE research post to support its use (**Crabeck**). The chamber is now part of the Horizon 2020 *EUROCHAMP Infrastructure Activity*

which has facilitated **collaborative projects** with 12 international and four UK groups. One of the first studies used natural and artificial tracers to examine gravity drainage through sea ice and its parameterization (10.1029/2019JC015791). The chamber has also been used with industrial partners, funded by *Innovate UK*, to investigate icing on autonomous vehicles.

The **Weybourne Atmospheric Observatory** is co-funded by UEA and NCAS and coordinated by **Forster**. It is a *WMO Global Atmospheric Watch* site and the UK's only atmospheric station in the *Integrated Carbon Observation System* which is a European Research Infrastructure. The Observatory is part of the *UKRI Infrastructure Roadmap* and encourages external access via the *NCAS Atmospheric Measurement and Observation Facility (AMOF)*. Investment during the REF period has included an FTIR instrument (£99k, NCAS), NO₂ and particle analysers, (£106k, NERC Air Pollution Capital), new masts and a cylinder store (£25k, UEA). Its data feeds into global carbon budget assessments (e.g., **Le Quééré, Box1**).

In 2017 the **Cylinder Filling Facility**, which is a unique facility in the UK providing calibration gases to universities and NERC Centres, was awarded £364k as part of **Manning's** NERC Air Pollution Capital grant of £684k.

The **Stable Isotope Laboratory**, led by **Dennis** and **Marca**, includes the *Stable Isotope Platform* and is part of the *UKRI Infrastructure Roadmap*. It received £251k for a new carbon dioxide laser isotope analyser from the same NERC grant.”

In 2019, **Oram** won funding for a **Time-of-Flight Proton-Transfer Mass Spectrometer** (£440k, NERC Capital award and UEA), which will be accessible via *NCAS-AMOF*, and enhances our halocarbon detection equipment (**Box1**).

3.4 COLLABORATIVE USE OF RESEARCH INFRASTRUCTURE

A number of School's facilities are unique and/or are part of international networks. This encourages collaborations and the School welcomes visitors to UEA, e.g., we have had over 15 visits to use the RvG Chamber.

Our location on the NRP provides access to a number of state-of-the-art life sciences facilities, such as greenhouses at the *John Innes Centre* and BBSRC genomics facilities at the *Earlham Institute* (**van Oosterhout, Box1**).

The School makes extensive use of large NERC platforms such as research vessels, research aircraft, Argo floats, *NCAS-AMOF* equipment and the Argon Isotope Facility. In some projects, **we have led the use of these facilities**: as Principal Scientist on research cruises (e.g., **Heywood**, iSTAR in 2014) or aircraft-based field campaigns (e.g., **Renfrew**, Iceland Greenland Seas Project (IGP) in 2018).

We have also made use of **international research infrastructure**, usually in collaboration, such as with Indian partners to use their Research Vessel *Sindhu Sadhana* in 2016 (*BoBBLE*); or with

US and Norwegian partners to use the NATO Research Vessel *Alliance* in 2018 (IGP); as well as the Monserrat and Hawaiian Volcano Observatories; and the Bauana Field Station in Brazil.

3.6 E&D CONSIDERATIONS IN SUPPORTING FUNDING BIDS OR ACCESS TO INFRASTRUCTURE

Access to internal research and impact funding, infrastructure and equipment in the *Instrument Platforms* is open to all and is based on need and merit. All staff may therefore benefit. Researchers without grant funding can apply for **subsidised access** to the *Faculties Instrument Platforms* to generate 'pilot' data, etc. In line with our overall approach to E&D, we are mindful of avoiding unconscious bias in all decision-making for resource allocation. Our targeted assistance to early career researchers encompasses the whole School and covers grant preparation as well as facilities access.

4. Collaboration and contribution to the research base, economy and society

4.1 RESEARCH COLLABORATIONS, NETWORKS AND PARTNERSHIPS

The multidimensional structure of our School promotes collaborations both within and across disciplines. All our research groups have a distinct web presence which promotes their identity and aids external collaboration. During the REF period, our collaborators on research grants extend to >500 organisations, >350 of which are international (across >50 countries). Fifty-one of our external collaborators have honorary positions in the School. Almost all our papers involve collaborators from other institutes, the majority international. Our leadership of international and national collaborations is exemplified by:

- **Matthews** has been the UK-lead in a major collaboration between the UK and India (BoBBle, £803k to UEA), which has provided new insight into the ocean-atmosphere interactions of the Bay of Bengal (*BAMS*, 10.1175/BAMS-D-16-0230.1). **Matthews** is now leading the NERC-funded (£3M total, £755k to UEA) *TerraMaris* consortium of three UK, three Indonesian institutes and the Met Office, to investigate the Maritime Continent as a driver of global climate. **Matthews's** study leave and our Ocean glider facility have been instrumental.
- **Renfrew** co-leads the Iceland Greenland Seas Project, a collaboration involving >20 institutes with funding from NERC, NSF and Norway (>£3M), which carried out the first coordinated atmosphere-ocean wintertime field campaign in the subpolar seas (*BAMS*, 10.1175/BAMS-D-18-0217.1). UEA hosted the IGP 2019 Workshop.
- **Vaughan** is leading a NERC consortium of four UK universities, on the feasibility of afforestation and biomass energy with carbon capture storage for greenhouse gas removal (£685k to UEA), e.g., pinpointing where carbon storage needs to occur (*Env. Res. Lett.* 10.1088/1748-9326/aaaa02).

The School has a number of **strategic collaborations or partnerships** internationally and nationally, for example, with

- Ocean University of China, with Alliance Co-Director and Honorary Professor (**Mock**) and Visiting Professor (**Malin**) – we have co-organised workshops at UEA and in China;
- Southern University of Science and Technology, China, we are part of a split-site PhD program with four current students at UEA;
- Our leadership of the Tyndall Centre over the last 20 years;
- Cefas, the BAS, the PML, NOC and NCAS (Section 1.2.2).

4.2 DEVELOPING RELATIONSHIPS WITH RESEARCH USERS, BENEFICIARIES AND AUDIENCES

Our relationships with stakeholders and research users are wide-ranging and impactful. They often involve the co-production of knowledge or the participation by our researchers in

government committees or advisory boards or engaging with business. Here we illustrate some relationships **highlighting the bodies** gaining from our research and impact:

- Lorenzoni has worked with the **IPCC** to improve climate science communication (10.1038/nclimate3162).
- Goodess has improved access to country-specific climate information through a **World Health Organisation** project and has incorporated a weather generator into the **Caribbean Community Climate Change Center** toolkit.
- Peres has empowered local people to adopt **community-based fisheries management in the Amazon (Box1)**.
- Dolman has advocated sustainable hunting of the houbara which has been adopted in Pakistan, Uzbekistan and the United Arab Emirates and developed a biodiversity audit that has shaped conservation practice of a wide range of practitioners, including **Natural England, the Wildlife Trusts, PlantLife, RSPB, Forestry Commission, MoD, Environment Agency and National Trust**.
- Barclay has worked with **local communities and government agencies** in the Caribbean, Colombia and Ecuador to integrate community perspectives with scientific knowledge to reduce volcanic disaster risk (**Box1**).
- Chilvers, Hargreaves, Lorenzoni, Mahony, Pallett and Seyfang have worked on transforming societal engagement in innovation and sustainability in collaboration with government, business, civil society organisations such as **BEIS, Scottish Government, Involve / Sciencewise, Forum for the Future, Anglian Water, Adnams, Norfolk County Council, Liftshare**, and the **Green Alliance**.
- Reid is collaborating with **Certis Europe** and **Anglian Water** to produce safer agrochemicals with improved capacity for biodegradation, and with **Greenworld** to evidence the potential for paper crumple to improve soil quality.
- Hiscock, Lovett, and Cooper collaborate with industry partners in the agritech and water sectors and with landowners, farming and environmental organisations and government agencies through the **Wensum Alliance** and **Water Resources East** to protect catchment water resources and reduce the impact of agricultural pollution.

Such relationships also **enrich the School's research environment**, for example:

- Our partnership with **Anglian Water**, coordinated through the **Anglian Centre for Water Studies** brings together industry and academia and has led to research projects (e.g., **Reid**) and PhD studentships.
- We collaborate with **WeatherQuest Ltd**, a weather services company, and the **World Energy and Meteorology Council**, which links weather knowledge with risk management for the energy industry, both located at UEA. This has led to internships and subsequent employment for several PhD students.
- In the DTPs and CDT, 80% of our studentships have had co-supervision from a partner organisation.
- Our DTPs have collaborated with other DTPs, e.g., to lead the "**envEXPO**" event, that brings PGRs and academics together with representatives from industry and government.

4.3 ENGAGEMENT WITH DIVERSE COMMUNITIES

The School works hard to engage all members of society in the results and implications of its research findings. Every year our press office issues on average, 24 press releases leading to 4,119 media reports of our research. One recent highlight was the stories related to the impacts of COVID-19 on carbon emissions (**Box1**), which was *Carbon Brief's* most mentioned article using *Altmetric* data.

The School contributes internationally, nationally and regionally to engagement including:

- Participating in documentaries for national broadcasters, *L'Aventure Météo* (**Renfrew**), *Climategate: Science of a Scandal* (**Jones, Osborn**)
- Running public exhibitions, *The London Volcano* (**Barclay**)
- Creating games, *Volcanoes Top Trumps* (**Barclay**) with >38,000 packs sold, and the proceeds dispersed to communities impacted by volcanic hazards
- Giving lectures and running exhibits for the annual *Norwich Science Festival* (**J. Johnson, Barclay, Robinson, Wilson**) and UEA's *Christmas Lectures for Children* (**Barclay, Herd, Reid, Renfrew, Ryan** (PGR))



UEA celebrates achievements with its annual **Engagement Awards**. The School encourages nominations and has had several winners:

- Outstanding Achievement in Engagement (**Barclay** 2014)
- Engagement Champion Award (**Chilvers** 2015)
- Engagement Project Award (**M. Johnson** 2015; **J. Johnson** 2016; **Price** 2019; Ryan (PGR) 2019)

4.4 SUSTAINING THE DISCIPLINE IN RESPONSE TO NATIONAL AND INTERNATIONAL AGENDAS

Responding to National Priorities

We have provided expert advice to **Defra** as members of their **Scientific Advisory Council** (Jickells), **Air Quality Expert Group** (Reeves), **Social Science Expert Group** (Jordan); and to **BEIS** and **Innovate UK** as co-leads of a working group on Citizen-Centred Low-carbon Transition (Chilvers).

We have provided support through advisory committees for: **Natural England** (Dolman); the **Met Office** (Renfrew); the **Hadley Centre** (Le Quéré), and the **National Farmers Union Water for Food Group** (Hiscock).

We have provided **extensive support to NERC** including: *Marine Facilities Advisory Board* (Robinson (chair)); *HPC Steering Committee* (Stevens (chair), Joshi); *NCAS Executive Committee* (Reeves); *NCAS-AMOF Board* (Manning); *Training Advisory Group* (von Glasow, Laube).

Responding to International Priorities

We make numerous contributions to international bodies including: **Future Earth's IMBeR Integrated Marine Biosphere Research** (Robinson is Chair of the Scientific Steering Committee); the **UN Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection** (Baker); the **World Meteorological Organisation's WCRP Grand Challenge on Regional Sea-level Change and Coastal Impacts** (Nicholls co-leads) and **WWRP Polar Prediction Project** (Renfrew); **Future Earth and WCRP's Surface Ocean - Lower Atmosphere Study** (Suntharalingam); and the **International Society for Microbial Ecology** (Murrell).

We also have members of **international Advisory Boards** including the *Max Planck Institute for Terrestrial Microbiology* (Murrell) and *Helmholtz Institute for Climate Science* (Warren) in Germany.

4.5 CONTRIBUTIONS TO THE RESEARCH BASE**Journal Editorship** includes:

Atmospheric Chemistry and Physics (Sturges, Kaiser, Reeves), *Wiley Interdisciplinary Reviews: Climate Change* (Lorenzoni), *Environmental Microbiology* (Murrell), *Environmental Impact Assessment Review* (Bond), *Energy Research and Social Science* (Hargreaves), *Global Biogeochemical Cycles* (Suntharalingam), and *Philosophical Transactions of the Royal Society A* (Joshi).

Participation in Grant Committees includes:

NERC Discovery (numerous); *NERC Fellowships* (Heywood (chair)); *NERC Large Grants* (Joshi); *NERC CDT* (Lake); *NERC Capital Call* (Manning); *ESRC* (Chilvers); *UKRI Clean Air* (Reeves); *UKRI Fellowships* (Barclay); *GCRF* (Barclay); *Royal Society Newton International Fellowships* (Heywood);

and **internationally** includes *ERC Consolidator* (Robinson (deputy chair)); *Academy of Finland* (Hiscock, Kaiser); *Swedish Research Council* (Lake (panel chair)); *Psychological Society of America* (Malin); *DFG, Germany* (Renfrew).

Prizes and Fellowships include

- The School as a whole was recognised for advancing understanding and protection of the environment with the award of a **Queen's Anniversary Prize** for Higher and Further Education in 2017.
- **Jickells** received the **Order of the British Empire** in 2018 for his services to marine and atmospheric sciences and **Le Quéré** became a **Commander of the British Empire** for her services to climate change science in 2019.
- **Le Quéré** was also elected as a **Fellow of the Royal Society** (2016), received the prestigious **Grande Médaille Albert 1^{er} de Monaco** (2015), the **Heineken Prize for Environmental Sciences** (2020), and was made a **Chevalier of the French Legion of Honour** (2019).
- **Jickells** (2016) and **Heywood** (2019) were elected as a **Fellows of the American Geophysical Union**.
- **Heywood** received the **Challenger Society Medal** for her outstanding contribution to the field of oceanography in 2016.
- **Renfrew** received the **Adrian Gill Prize from the Royal Meteorological Society** recognising significant multi-disciplinary meteorological research achievements in 2018.
- **Barclay** received the **Volcanic and Magmatic Studies Group Award** from the *Geological Society of London* in 2015.
- **Zhai** received a **Challenger Society Fellowship Award** in 2018.