

Institution: University of Edinburgh (UoE)

Unit of Assessment: UOA 7

1. Unit context and structure, research and impact strategy

1a. Context and structure

Understanding the Earth and its unique environment is now inextricably linked with questions of human agency. Our Unit of Assessment (UoA) rises to this challenge by researching fundamental challenges spanning the physical sciences, social sciences, and humanities. We engage directly with social, political and geographical aspects of our Earth systems and their impacts, and actively work with diverse stakeholders to address real world problems.

Led by the School of Geosciences (SoG), we are one of the largest multi- and inter-disciplinary groupings of geoscientists and geographers in the UK, comprising 132 academic staff (FTE 123.3), including four environmental archaeologists based in the School of History, Classics and Archaeology (HCA), 103 research associates, and 470 postgraduates, half of whom are on taught Masters courses. Our scale allows both depth and breadth of approach, and **our diversity – a critical and enduring strength – generates a thriving culture of interdisciplinarity.**

Our research is organised into three broad thematic areas, *Dynamic Earth Systems (DES)*, *Accountable Geographies (AG)* and *Environment and Society (E&S)* (Fig. 1). Each theme encompasses fundamental disciplinary, interdisciplinary and applied research, including translation into solutions. This diversity has enabled us to address the major research challenges of our times – from analysing the impacts of climate change on natural and human systems, to developing sustainable communities and seeking solutions to environmental problems.

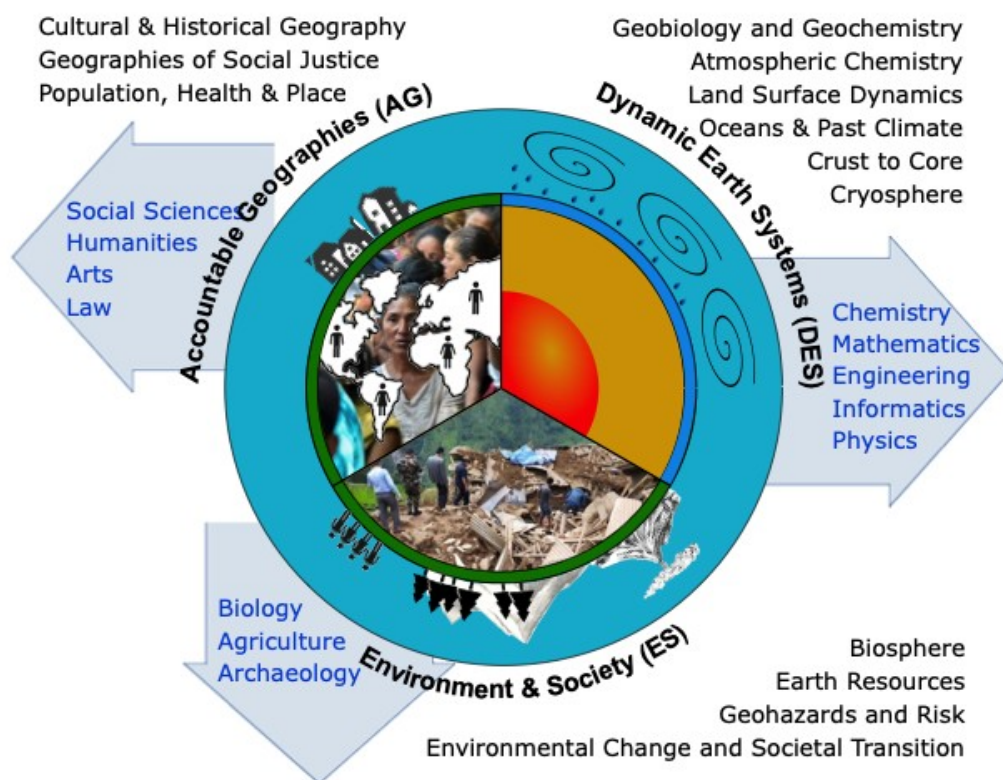


Fig. 1 Three research themes, with component research strands and outward-looking disciplinary collaborations (blue text).

Major Achievements during this REF period include:

- **Sustained growth** from 76FTE in RAE2008 and 104FTE in REF2014, to **123.3FTE** submitted to REF2021, with 35 new academic staff appointed in this REF period, ensuring a vibrant and embedded research programme well beyond REF2021.
- Securing **£138.6M** in research grants and contracts over the REF period, or **1.12M per FTE**, improving average annual income per FTE from £128K in REF2014 to **£160K**.
- Securing **£29.6M since 2016** of ODA-compatible GCRF/Newton Fund grant awards. We lead and host the **GCRF Urban Disaster Risk Hub (£20.1M)**, lead the **GCRF Multi-hazards and risk initiative (Ixchel) (£3.19M)**, and are key partners in two of the other seven GCRF Hubs (**One Ocean** and **South Asia Nitrogen**).
- Securing two consecutive **NERC Doctoral Training Partnership** awards (value **£16.0M**), and leading the **SENSE Centre for Doctoral Training** (value **£2.2M**).
- Competitively renewing/upgrading our world-leading analytical facilities, notably the **NERC Ion Microprobe Facility** (50% NERC-funded, **£1.49M** in 2018-20) with a new **7f-Geo SIMS instrument (£2.90M** in 2017) for high precision/high throughput measurements in geological and material sciences.
- Leading the UoE **Space and Satellites data-driven innovation** theme of the **£1.3B** Edinburgh Region City Deal (UoE received **£237M** from UK and Scottish Governments and leveraged partner investments to achieve **£661M** 2018).
- Generating **£25.3M** for industry-sponsored research projects, business development and innovation activity, ~18% of our total research and innovation income.
- External recognition of our researchers as leaders of their fields: five staff elected **Fellows of National Academies**; four awarded European Research Council Fellowships; five awarded Independent Research Fellowships.

1b. Research strategy

Our **vision** is to address the challenge of **creating an holistic understanding of the Earth and its environmental systems with human agency**.

Building on our three thematic research areas Dynamic Earth Systems (DES), Accountable Geographies (AG), and Environment and Society (E&S) which represent communities of practice (Fig. 1), we collectively **aim** to address the major environmental and social research challenges (RC) of our times:

RC1. Understanding, modelling and forecasting the global Earth and Climate system (DES)

RC2. Reducing Disaster Risk through a more integrated understanding of physical processes and the drivers of human vulnerabilities (AG, E&S, DES)

RC3. Understanding the environmental, social, cultural and political dimensions of human geography, including questions of inequality, justice, and health (AG, E&S)

RC4. Developing low carbon solutions for energy and climate change mitigation (E&S)

RC5. Promoting sustainable use of resources, including agriculture, forests, landscapes and infrastructure (E&S, AG)

RC6. Exploiting the potential of Earth Observation in the era of big data using drone and satellite observations (E&S, DES)

RC7. Improving our understanding and hence management of marine ecosystems (DES, E&S)

Our **Values** focus effort on:

- staff development and renewal, by setting and supporting high standards of research excellence to address contemporary research challenges (sections 2a, b, d)
- unequivocal commitment to equality and diversity (section 2c)
- hosting and developing a suite of world-class analytical facilities to study diverse systems (section 3b)
- maintaining the vibrancy of core disciplines across our diverse portfolio (section 1c), while
- integrating diverse disciplinary approaches to a common goal (section 1e(ii)), and
- ensuring impact arises from relevant research, with early engagement of stakeholders (section 1d)

Research Strategy: Since 2014 we have maintained a healthy disciplinary base, while successfully growing multi- and inter-disciplinary research strengths. Intellectual diversity and disciplinary interaction have proven to be key assets when tackling contemporary research challenges. In line with our vision, we have made several strategic investments since 2014 to meet these challenges, with new staff appointments highlighted below.

In *Disaster Risk Reduction* (addressing research challenge RC2) we developed a critical mass of staff across the natural sciences, social sciences and humanities committed to co-producing transdisciplinary research with a range of stakeholders in the global South. We built on strong existing capability but broadened the remit to include interdisciplinary analysis of risk and resilience (**Crowley, Gioli, McCloskey**). This strategic growth enabled the success in 2019 of the **£20.1M** GCRF *Urban Disaster Risk Hub* where we lead a consortium of 11 UK universities, international investigators and partners. In addition, the recent 2020 award of our **£3.19M** GCRF Multi-hazards and risk - *Ixchel* project (**Calder, Cupples**), resulted from disciplinary appointments in natural hazards and critical geography during the REF2014 period.

In *Environmental, social, and political impacts on the geography of inequality* (RC3) we lead the *Scottish Longitudinal Studies Centre*, where we expanded the group working on large-scale and long-term administrative and statistical data linkage following the Scottish population (**Dibben**), building on data collected during the work of the **£6.1M** ESRC Administrative Data Research Centre for Scotland, where we also led. We complement quantitative studies by qualitative research examining the social construction of nature, and addressing questions of environmental justice, including a Wellcome Trust award *Remaking One Health* of **£1.45M** (**Srinivasan**).

We launched the planned *Centre for Sustainable Forests and Landscapes* in 2018 (RC5), investing in a new Chair, **Ghazoul**, and three other staff (**Barnes, Hancock, Watmough**), two of whom were interdisciplinary appointments. Its mission is to provide interdisciplinary knowledge critical to delivering sustainable landscape management and policy development, positively impacting carbon budgets (RC1, RC4) with a focus on forested landscape mosaics. This team has already won **£0.9M** in research awards. The Centre leads major initiatives in partnership with governmental, business, NGO, and community stakeholders (RC4) through land-based approaches.

In *Earth Observation* (RC6) we provided critical input to the successful Edinburgh and South-East Scotland Regional City Deal bid, leading specifically on the theme of Space and Satellites (**Collins**), and in *Geo-Data Driven Innovation* more broadly, encompassing themes such as the use of artificial intelligence in geophysical imaging and remote sensing. Independently, the UoE launch of the **£40M** Bayes innovation Hub in 2018 enabled the UoA to attract the analytical wing of *Orbital Microsystems Ltd* to the UK from the USA in 2018, with the mission of providing 'early

awareness' of catastrophic extreme weather events ... through better data for better decision-making'.

We significantly expanded our research capability in *Marine Science and Policy* (RC7) with four key appointments (**Hennige, Henley, Henry, Roberts**) and founded a new *Changing Oceans* Research laboratory, leading to participation in the *One Ocean* GCRF Hub and our leading the €8M H2020 project *iAtlantic* (Integrated Assessment of Atlantic Marine Ecosystems in Space and Time) in 2019.

Our Strategy encourages an agile response to the evolving research agenda. For example, The Scottish Centre for Administrative Data (**Dibben**) provided timely data and analysis for a number of bodies in support of their policy and operational response to the COVID-19 emergency. Specifically, the Centre provided guidance to: Police Scotland on their use of temporary powers feeding into its Independent Advisory Group, local authorities and Scottish government on risk factors that contributed to care home deaths, and to the Scottish government in quantifying the impact of COVID-19 on social inequalities. This work will likely have significant implications for the planning of agile response to the ongoing and future pandemics.

1c. Research Themes and achievements

Our three broad research themes cover a large range of research subjects and approaches (Fig 1). Below we report on key findings.

Dynamic Earth Systems (DES) 56.2 FTE: This theme focuses on understanding fundamental Earth and Planetary processes and their role in complex Earth systems. We work from micron-scale geochemical analysis of seawater and extreme high pressure and temperature experiments on analogues of the deep Earth, to planetary scale geophysical processes of geomagnetic activity, climate dynamics and the composition and dynamics of exoplanet atmospheres. Examples of this work include in:

- *Climate change (RC1)*, we quantified how climate change has already influenced extreme events (**Tett**), the impact of regional aerosol emissions on monsoons (**Bollasina**), and changes in tropospheric ozone (**Stevenson, Doherty**). We predicted decreased lightning under climate change (**Doherty**) and constrained future warming and precipitation change from observations (**Hegerl**). We analysed ways in which Earth's rivers, hillslopes and basins respond to environmental change (**Sinclair**), and predicted its impacts on the nitrogen cycle (**Reay**).
- *Cryosphere (RC1)*, we used ice-penetrating radar to image an area the size of London beneath West Antarctica's Pine Island Glacier, discovering diverse subglacial landscapes that control ice flow (**Bingham**). We used novel space-borne altimetric data to discover ice shelves in the Amundsen Sea Sector melting strongly along narrow sectors, a key constraint for ice shelf and ice sheet stability (**Gourmelen**).
- *Deep Earth*, we demonstrated for the first time that oxygen is not a major impurity in the core by comparing experimental with global seismological results (**Komabayashi**). We developed the first *Interrogation theory* - a general method of evidence-based investigation to infer dynamics of the Earth's subsurface, elicit expert information, and guide autonomous planetary exploration (**Curtis**).
- *Geobiology*, we established for the first time an ocean acidification event coincident with the biggest known mass extinction (**Wood**). We showed through statistical analysis of

fossil records and CT imaging that dinosaurs went extinct abruptly, quickly replaced by placental mammals evolving from small-brained precursors (**Brusatte**).

During the REF period, we strengthened this theme through 13 academic appointments including three Chancellor's Fellows (CF) and five Independent Research Fellows (IRFs). These include a cluster hire in *Marine Science* (4 staff, section 1b), and in: *Geo-Materials and Micro-analysis* **Kelley** (also Head of SoG, Chair), **Pichevin** (Senior Research Scientist); *Solid Earth Systems* **Kalnins** (RSE IRF/Lecturer); *Earth Systems and Resources* **Arnold**, **Molnar** (Lecturers); **Edlmann** (CF); *Earth Observation* **Collins** (CF); *Plant nutrition as Earth System Science* **Street** (NERC IRF /Lecturer), and *Cyrosphere* **Slater** (NERC IRF).

Accountable Geographies (AG) FTE 24.4: This theme produces socially responsible research addressing critical questions about human agency, social justice, cultural meaning and environmental values. Operating in diverse contexts across the world, our work employs distinctive quantitative and qualitative methodologies. It shares a common purpose: we must be accountable for the geographies we produce, and to the communities we collaborate with, while also working to explain and ameliorate geographies of inequality and injustice, holding others to account when and where they persist. Notable areas of strength include in:

- *Disaster Risk Reduction/Critical Geography* (RC2/RC3) in Guatemalan communities impacted by civil war and volcanic disasters, we examine the drivers of risk through human rights and decolonial perspectives and highlight the relationship between community organisation and political skills, and resilience and recovery (**Cupples, Calder**).
- *Geographies of Public Health* (RC3) ground-breaking research has demonstrated the socio-environmental effects of place in producing health inequalities, how the overprovision of alcohol and tobacco outlets in UK neighbourhoods negatively impacts on health outcomes, and how the introduction of pricing controls can work as a mitigating governmental response (**Clemens, Pearce, Shortt, Dibben**).
- *Critical Geography* (RC3) inquiries led by ECRs have addressed the ethics, politics and ecologies of human interactions with more-than-human worlds, examining contemporary meat cultures in India (**Srinivasan**), the cultural-environmental impacts of agri-food systems on Caribbean food security and sovereignty (**Wilson**) and the social problematics of urban gentrification (**Kallin**).
- *Geohumanities* (RC3) our published research has forged scholarly interactions between geography and multiple humanities disciplines. In original studies of cultural landscapes, scientific experimentation and contested environments we have developed influential narrative forms of place-writing and life-writing (**Cresswell, Hunt, Lorimer, MacDonald, Watts, Withers**).

We are committed to supporting the production of research monographs that shape new disciplinary agendas (Smoking Geographies, **Pearce**; Maxwell Street, **Cresswell**; Travels in Print, **Withers**; Shifting Nicaraguan Mediascapes, **Cupples**), and that are of a quality reflected in international awards (Zero Degrees, **Withers**) and nominations for national book prizes (Escape from Earth, **MacDonald**; Energy at the Edge of the World, **Watts**; Zero Degrees (**Withers**).

Since REF2014, we have strengthened this research theme through 12 appointments including one CF and one that was interdisciplinary: in *Geohumanities* **Cresswell** (Ogilvie Chair), **Hunt** (Lecturer); in *Cultural Geography* **Lorimer** (Chair), **Dixon** (Lecturer); in *Urban Geography* **Kallin** (Lecturer); **Krishnamurthy** (CF/Living with data); in *Political Geography* **Fitzpatrick** (Lecturer); in *Social Geography* **Rosenberg** (Lecturer); in *Environmental Geography* **Srinivasan** (Lecturer); in

Energy Social Science **Watts** (Senior Lecturer); in *Health, Environment & Inequality* **Clemens** (Interdisciplinary Lecturer); and in *Quantitative Human Geography/GIS* **Feng** (Senior Lecturer).

Recognising the diversity of epistemological and methodological approaches in our UoA, 24 % of our research outputs (including weighting for double counting) are cross-referred to UoA 14, Geography and Environmental Studies.

Environment and Society (ES) FTE 42.7: This theme addresses fundamental interactions and feedbacks between natural and anthropogenic processes, environments, resources, people and places. Our aim is to provide research-led solutions to global environmental and societal challenges, including RC1-RC7. Notable strengths include:

- *Transforming to a low carbon society* (RC4) we lead the *Scottish Government Centre of Expertise ClimateXChange (CXC)* (**Reay**) a national forum for studying methods to remediate climate change and prevent future CO₂ atmospheric emissions. Enabled by a combination of modelling expertise and a globally-unique experimental Geo-Reservoir (GREAT) cell, we recreated for the first time, subsurface reservoir conditions to a depth of 2.5 km (**McDermott**).
- *Sustainability of resources, including forests, landscapes and agriculture* (RC5) we use techniques enabled by *exploiting the potential of space and satellites in Earth Observation in the era of big data* (RC6). We helped protect and restore up to 300M hectares of tropical forests by improving satellite monitoring in six partner countries (**Williams**) and improved estimates of biomass of tropical trees (**Ryan**). We introduced the first global mapping of C residence times for vegetation pools (**Mitchard, Williams**). We determined climate controls on tundra biomes (**Myers-Smith**), continentally diverse fire-climate-savannah relationships (**Lehmann**) and quantified the surprising floristic turnover of dry forests (**Dexter**).
- *Natural hazards and disaster risk reduction* (RC2) we developed new methods using statistical tools for eruption forecasting using seismic data (**Bell**), and undertaking probabilistic volcanic hazard assessment in a way that accounts for, and quantifies, uncertainty (**Calder**). Using discrete element simulation, we improved the physical basis for evolving population dynamics of fractures in brittle porous media, explaining scaling relations used in seismic hazard calculation (**Main**).
- *Improving our understanding and management of the marine environment* (RC7). The ATLAS project transformed understanding of North Atlantic deep-sea biodiversity through the discovery/description of 30+ benthic communities and 12+ new species, and proved climate forcing is linked to a weakening of the Atlantic Meridional Overturning Circulation over the last ~150 years (**Roberts**).

During the REF period, we made 12 appointments, of which four are specifically interdisciplinary and one is a CF. Cluster hires were made in *Sustainable Landscapes & Forests* and *Disaster Risk Reduction* (section 1b, 4 and 3 staff respectively); Non-clustered appointments include: **Bendrey**, **Rubio-Campillo** (Lecturers/*Environmental Archaeology*); **Colesie** (Lecturer/*Plant Physiological Ecology*); **Staddon** (Lecturer/*Environment & Development*); and **Keane** (CF/Senior Lecturer/*Conservation interventions*).

1d. Research Impact strategy

Our Impact strategy aligns with the university strategy (e.g. REF5a section 2) and is rooted in our commitment to addressing real world challenges. We foster a proactive and supportive environment to deliver impact through a variety of fora and mechanisms: from working with grass-roots community groups (e.g. networks of community leaders in rural Guatemala and urban Ecuador) and relevant industries (e.g. *Ecometrica*, Space and satellites sector) through to influencing national or international government policy (e.g. Intergovernmental Panel on Climate Change, IPCC). Our Impact strategy involves six actions, to:

1. *Build or extend stakeholder networks to identify and co-produce impact.* We engage with a large and varied external network of stakeholders and end-users of research (section 4b), partners involved in our E3 and E4 Doctoral Training programmes (section 2e) and our strategic leadership of the *Scottish Centre for Carbon Capture and Storage (SCCS)*, *ClimateXChange* and the *Edinburgh Centre for Carbon Innovation (ECCI)*.
2. *Identify and support the development of opportunities for impact,* from initial early engagement and co-design of research to engaging with decision-makers or company spin-outs. We run impact workshops, provide impact and knowledge exchange support to academics writing grant applications and engaging with business and community groups to deliver impact. This significantly broadened the pool of staff engaged in impact activities (sections 1d(iii) and 4b).
3. *Support creativity and diversity in approaches to pathways to impact* including knowledge exchange, outreach and media engagement (Section 4b(ii)).
4. *Support applications for seed funding,* e.g. via UKRI Impact accelerator awards.
5. *Raise awareness of the value and benefits of Impact,* e.g. celebrating success on our news feeds, during the annual Professional Development Review, and as an element in the portfolio of activity considered in the academic promotion process.
6. *Service on External Advisory boards* (section 4d(ii)).

Academic and Research staff are supported by:

- an Impact Co-ordinator (across all sectors, 0.8FTE)
- three Business Development Executives (for impact on industry and commerce, 3.0FTE)
- a High Schools Liaison associate (0.6 FTE) for outreach activities
- 10.8FTE ECCI staff, working on allied externally funded projects, for mitigation of, and adaptation to, climate change (section 4a)

(i) Relationship to REF Impact case studies

Our **Nine** REF impact case studies (ICS) arise from strong thematic research programmes (section 1c) addressing our major research challenges. They have benefitted from continuity and long-term commitment in strategic policy and resource allocation, as well as increasing success in securing external large grants and investments over the last 20 years, and notably since 2014 (section 3a):

ICS1. *Attributing observed climate change to inform the Paris agreement Hegerl* is a long-term outcome of the major investment of the UoA in this research area over the last 20 years.

ICS2. *Carbon capture and storage and negative emission for UK net-zero emissions climate target delivery* **Haszeldine** benefitted from long-term investment in decarbonisation and sustained engagement with stakeholders including the UK Government.

Our investments in *Earth Observation* and the *Centre for Forestry and Landscapes* underpin:

ICS3. *Quantifying forest biomass change from space – benefitting local economies, supporting policy formation for sustainability, improving satellite observations and global modelling* **Williams**.

ICS4. *Constraining future sea-level rise from ice-sheet melt to aid policy and planning* **Bingham, Gourmelen**.

ICS5. *Supporting UN Paris Agreement commitments by estimating global terrestrial carbon fluxes from satellite data,* **Palmer**.

Our investments in the *geography of health* underpinned two case studies:

ICS6. *A new administrative data infrastructure for Scotland; transforming policy and practice* **Dibben** (RC3 and section 1b for its agile COVID response).

ICS7. *Assessing the overprovision of alcohol and tobacco in Scotland: improving health outcomes and influencing policy,* **Pearce, Shortt**.

Our investments in *natural hazards and risk* are generating several ongoing and emerging programmes in disaster risk management, the most mature of which is:

ICS8. *Implementation of Operational Earthquake Forecasting* **Main, Naylor**.

Our support for creativity and diversity in approaches to pathways to impact (action 3) underpinned cultural impact in:

ICS9. *The Rise and Fall of the Dinosaurs* **Brusatte**.

(ii) Additional notable examples of impact and developing impact

Actions 4-6 have been influential in generating a wider pool of staff actively engaged in impact, aided both by investment in new staff appointments (sections 1a, b) and successful engagement of existing staff.

Much of our current challenge-led research is driven by the GCRF agenda and the UN sustainable development goals, supported by match-funding from the University. These co-produced projects (action 1) are designed to have tangible international impact on partner country development over project lifetimes that will mature in the next REF period. Notable examples are the *Urban Disaster Risk Hub* **McCloskey** (Section 1cES) and the *Ixchel* project on *Multi-Hazards and Risk* in Guatemala **Calder, Cupples** (sections 1cAG and 1cES and Fig 2 below).



Fig. 2 GCRF Ixchel: Multi-Hazards and Risk in Guatemala – Key interdisciplinary approaches

Our thematic programme on *Disasters and Risk* delivered a new digital platform for 3D interactive volcanic hazard maps during the Fuego, Guatemala 2018 eruption, developed in collaboration with UK charity MapAction, and now taken up by six National Geological surveys, and applied to 16 volcanoes globally **Calder, Stuart, Cupples**.

Our strategy on maintaining and developing *state of the art facilities* (section 1a and 3b) led to **Gilfillan** providing critical evidence in a ~\$1 million lawsuit, involving tracing of subsurface fluids using natural geochemical fingerprints to enable carbon storage and improving hydrocarbon field appraisal.

Our investment in *marine science and policy* (Section 1b) has direct impact on North Sea oil and gas decommission policies, and provides guiding principles for sustainable seabed explorations and exploitation, supporting UN Sustainable Development Goal 14 **Hennige**.

Our participation in the UK *ecosystem services for poverty alleviation* (ESPA) programme prior to 2018 led to the launch of an online innovation hub (OPPLA) to share and access research outputs and examples of good practice to support land-use decision making **Metzger**.

Our participation in the UN Economic Commission for Europe Convention on Long-Range Transboundary Air Pollution (action 1) contributed to International policy development and co-operation in *air quality and health* **Doherty**.

Our staff launched **five new spin-out companies** (*Carbo-Map Woodhouse; Carbogenics Masek; Earth Wave Gourmelen; Earth Blox Patenaude; Space Intelligence Mitchard*) (action 2) currently employing 34 people. Three companies received external awards (section 4b(i)).

1e. Research governance

The Head of SoG has overall responsibility for research governance in the UoA, supported by the Directors of Research for SoG and HCA, a deputy Director of Research for SoG, an academic REF UOA coordinator, an Ethics and Integrity committee chair, a SoG Research Support Organisation (GSRO) of five professional services staff, and a full-time professional Health & Safety manager.

(i) Ethics and Integrity

Our research spans a diversity of disciplines and analytical and methodological approaches, necessitating specialist ethical review which we provide through our Ethics & Integrity Committee. This committee is embedded in the university processes (see REF5a section 2h) and provides a timely and targeted review of ethics applications, ethics training to all UG, PGT and PGR students, and promotes a culture of ethics and integrity across all of our staff and students. Our UoA developed a unique **authorship policy** to promote best practice in co-authored papers (particularly involving students and collaborators). We run a monthly **seminar series** to promote shared learning around the negotiation of ethical challenges in our research, and, most recently, we have initiated a series of **written reflections** on what ethical research means to those across the UoA and how they maintain the integrity of their research. In line with the UoA's extensive global and ODA-related research and leadership, our ethics and integrity team are leading debates and providing practical support to promote the highest ethical standards and equitable partnerships in such research endeavours e.g. the GCRF Urban Disasters Risk Hub, where safeguarding training for key staff was delivered by an external enabler. Working alongside UoE Research Office and Gender Equality Working Group (**Cupples** sits on this committee) this group helps to develop delivery strategy for GCRF in relation to safeguarding; monitoring, evaluation and learning, KE, research ethics and integrity approval processes with GCRF partners. The unique expertise of our committee chair (**Staddon**), who sits on the University's Research Ethics and Integrity Review Group, has resulted in her participation in the GCRF-funded project **Ethical Action in Global Research: A Toolkit**.

(ii) Creating an open research environment

We have engendered a positive cultural shift to **open access** for outputs and data by

- Investing in professional administrative staff (1FTE) to assist researchers in ensuring, wherever possible, all outputs adhere to Open Access policy, regardless of inclusion in REF2021. Our overall Open Access compliance rate to March 2020 is 89.07%.
- Securing Gold open access for 198 articles at a total cost of **£339K** from funds provided by the RCUK-UKRI Open Access Fund since April 2016
- Encouraging staff to utilize systems supporting open research including ORCID, Pure, Research Explorer and using the Edinburgh Datashare repository as well as other national data centres to ensure data are open and available.

1f. Future plans

We foresee and are planning for major new opportunities to develop the following thematic areas:

Data-driven innovation (see REF5a section 2b) by delivering new platforms, techniques and applications to analyse large Earth system data sets of varying size, and veracity, analysed over different timescales to reflect differences in the timing of relevant decision-making. Our global lead in Earth Observation, focussing on *Space and Satellites* and our broader '*data driven innovation*' expertise, enabled by our role in the Edinburgh City Region Deal, will underpin an ambitious programme for wider applications in geosciences and human geography, and address aspects of all of our Research Challenges.

Environmental health inequalities, by providing expanded longitudinal evidence for the relative effects of environmental, social and economic conditions vs medical and genetic factors that

influence health outcomes via analysis of secure digitised data types (with colleagues in the School of Medicine). We foresee a major appraisal of the effectiveness of the evidence-based COVID policy response in Scotland, and the development of a mature understanding to facilitate secure policy debate and the response to future pandemics.

Disaster Risk and Resilience, by delivering success in the newly-established GCRF *Urban Disasters Risk* Hub and the *Ixchel* GCRF project, as well as other funded activities. We will lead research in natural hazards with a strong interdisciplinary element to improve the quantification, management and social justice aspects of societal risk, loss and recuperation. Our aim is to improve the lives of those most disadvantaged and exposed to multi-hazards and disasters in the global South by embedding DRR within human rights frameworks.

Mitigation and adaptation to climate change (see the University 'Societal and planetary sustainability' theme REF5a section 2i) through our research in this field, and by maintaining strong connection to policy e.g. contributing to the IPCC and the UN Framework Convention on Climate Change. We will support global initiatives to mitigate the effects of climate change and to accelerate transition to a low-carbon economy, most immediately with a large UoA presence at COP26 in Glasgow, with new applications in agriculture through the GCRF *South Asia Nitrogen* Hub, and several initiatives in Geo-energy.

2. People

2a. Staffing strategy

Our staffing strategy is centred on delivering world-class education, research and impact, and recognising the desirability of recruiting a variety of early career and more experienced staff in strategic areas while also maintaining a balance of both established and emerging thematic research programmes. We incentivise individuals to excel in their own research areas, and to engage, communicate or work beyond disciplinary boundaries in a fundamentally multi-disciplinary environment.

Strategic research and interdisciplinarity: During the REF2021 period, we strengthened our strategic thematic areas (section 1b(i)) with 33 appointments, including six senior staff and five appointments that were specifically designed to be interdisciplinary. A further five tenure-track Chancellor's Fellowships were appointed through a competitive University-wide scheme. Key interdisciplinary appointments showcase our engagement with a wide stakeholder base, e.g. with companies involved in satellite monitoring (**Collins**) and humanitarian organisations dealing with resilience to natural hazards (**Crowley**). Our growing strength in interdisciplinary research is exemplified by the nature of the funding awards we are securing (section 3a), the success of our PGR programmes which hold addressing interdisciplinary challenges as a core value (section 2e), and our REF2021 outputs (18% interdisciplinary).

Attracting Independent Research Fellows: We initiated a bespoke system to attract and support new applicants for Independent Research Fellowships (IRFs) in 2015, which involves an internal champion to assist with the proposal development, an internal reviewer, and mock interviews. As in all our recruitment policies we particularly encourage female and BAME staff to apply, as well as those who prefer part-time or flexible working. As a result, during this period five new IRF-holders funded by NERC (four) and Royal Society of Edinburgh (one), joined our staff (section 4e(i)) compared to 3 reported in REF2014.

Working environment: An integrated system of measures, governance, academic and professional services staff support the wellbeing of all staff and research students. Numerous improvements since 2014 include: (i) Our Equality, Diversity and Inclusion co-ordinator and Athena SWAN co-ordinators sitting on all promotion panels and management committees, (ii) independent pastoral advisors assigned to each postgraduate research student for the period of their study, (iii) greater awareness and significant take up of flexible-working arrangements by male and female staff, (iv) all meetings arranged in core working hours, supporting engagement of those with caring responsibilities.

Numerous additional support measures were implemented through the Covid-19 lockdown period to address personal issues, workload and stress. We discouraged meetings and non-essential messages during lunch hours and all day Fridays, and were successful in our bid to secure UKRI funding for extensions to research grants and to back-fill for losses incurred. Laboratories and facilities were maintained throughout lockdown and safe access restored with new working protocols as soon as public restrictions eased. Monthly virtual meetings provide an essential opportunity for all staff to connect with and gain support from colleagues.

2b. Staff development and support

Induction programmes: All academic staff, IRFs, Post-Doctoral Researchers and PhD students are provided with a comprehensive, tailored, induction programme. Through group and face-to-face meetings with senior staff, including the Director of Research, we discuss realistic and sustainable work-life balance, existing and cognate research activity, the potential for collaboration, innovation and impact, and where to seek support and advice. Staff are supported by their appointed induction 'buddy' and academic mentor, who may be external to the UoA via the University's Mentoring Connections programme.

Annual reviews: All staff, have annual personal development reviews (PDRs) with their line manager. Line managers attend mandatory training on undertaking effective PDRs. IRFs have a review at least one year before the end of their Fellowship, to assess progress, determine whether the Fellow's skills, achievements and trajectories match the ambitions and opportunities for the School. As a result, the four externally funded fellows who completed their fellowship, as well as seven Chancellors Fellows all transferred to lecturer positions (see section 2c).

Workload allocation: Our workload allocation model (reviewed with full consultation in 2018/19) is a decision-support tool for line managers who assign staff time to research, teaching and academic leadership/administration. There is a default minimum of 40% time *pro rata* for research time for academic staff, with additional allowances for fellowship awards and for managing research grants as Principal or Co-investigator through FEC. Workload allocation incorporates allowances for parental leave, part-time working, secondments and sabbatical cover. Newly appointed academic staff are provided with start-up funds, have reduced teaching and administrative duties in their first year and have preferential access to PhD studentships. We offer one semester of sabbatical leave for every seven semesters of service, subject to approval of a proposal submitted in the year prior, with an average of 12 staff taking sabbatical leave annually.

Professional Development: All staff are encouraged to participate in professional development opportunities offered by the UoA, the UoE Institute for Academic Development (IAD), and external agencies including UKRI. These include courses and training opportunities on managing research staff and budgets, PhD student supervision, outreach, and media communications. The UoA offers dedicated courses in:

(i) **Research Excellence:** Some 86 academic and research staff have participated in our Research Excellence Workshops, which provide a forum for grassroots discussion on what constitutes research excellence and how this is achieved. We also run frequent and regular, supportive and informal, peer-to-peer events such as: Pitch-to-your-Peers where early-stage ideas and proposals are presented and discussed in a rigorous, but constructive manner; Writing retreats to afford staff time and space to concentrate on crafting proposals or writing papers; and Good Research: Sharing Experience to discuss a range of ethical concerns and share experiences with academic and research staff, and doctoral students.

(ii) **Leadership/management:** The UoA runs a senior leadership course with an experienced external facilitator that has been attended by all current leaders, followed by group workshops on dedicated topics. 41% of all female staff have attended the course, supporting and increasing the pool for greater diversity in future appointments at senior level. The UoA also supported two female staff members to attend the HE Aurora programme, and eight staff attended the EQUATE 'Coaching for Success' scheme.

Promotion process: The UoA runs a two-stage, open, promotions process where **all staff** are eligible annually, and candidates are identified using a consistent set of criteria. As a consequence of our Athena SWAN action plan, the promotions panel is (i) gender-balanced, with representation from broad disciplinary areas, (ii) includes the chairs of both the Athena SWAN and Equality and Diversity committees, and (iii) includes discussion and consideration of a two-page, annually updated CV. The panel then invites cases with potential to be promoted to submit a full CV, with specific feedback and guidance to staff prior to submission of their formal promotion application. Unsuccessful colleagues receive written and face-to-face feedback from their line manager.

2c. Early-career researchers (ECRs)

Attracting ECRs: The UoA has an active programme of attracting, engaging with and supporting a growing cohort of early-career researchers, currently including 103 fixed-term Research Associates funded by the significant increases in income since August 2013 (section 3a). The improved support for applicants for IRFs, as well as the development of a more robust proposal feedback and reviewing system, has led to five IRF successes in the reporting period (section 2a).

Retention and support for ECRs: We converted four of our IRFs into open ended contracts (**Henley, Hennige, Kalnins, Street**), enabled promotion of three fixed term Research Associates to grade 8, one of whom went on to competitively secure Chancellors Fellowships (**Edlmann**), and converted seven Chancellors Fellows (**Bell, Brusatte, Gilfillan, Hein, Henry, Keane, Myers-Smith**) to open-ended academic contacts. These staff represent a major investment in the future vibrancy of the UoA.

Career Development support: Our ECRs have benefited from a number of structures and processes including: the induction and mentoring programme (section 2b); proposal development and independent internal review, mock interviews enabled by the UoA and/or the University Research Support Organisations; research support and training systems by UoA Research Support Organisation (section 2b); and internal seed funding/small grant opportunities (section 3b). This has led to significant subsequent success in grant applications for IRFs and Chancellor's Fellows. We regularly host events on Career Paths in Academia to highlight the various routes to permanent positions in academia, with a focus on the critical steps from Research Associate to Independent Research Fellow, and to a lectureship.

2d. Equality, Diversity and Inclusion (EDI)

The UoA has a strong commitment to enabling, and actively constructing, a diverse and inclusive workplace, including the transparent promotion process (section 2b) and in this REF submission. The UoA's demographic composition is 69% men, 31% women, with 3% BAME staff, ~1% staff with reported disabilities and ~1% staff disclosed LGBTQ+. The values have been stable throughout the REF period. Fewer than 20% of the professoriate are women, but since 2015/2016 the percentage of grade 10 promotions awarded to women has exceeded the proportion of women in the UoA.

The UoA REF2 output profile has 72% outputs proposed by male (for 69% of staff), and 28% proposed by female authors (for 31% of staff). Viewed within each research theme, these outputs are in line with our staff demographics (Fig. 3).

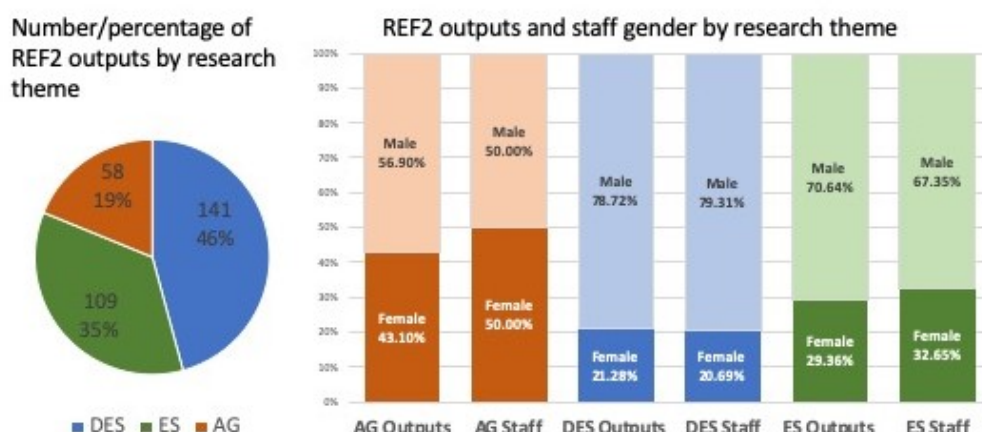


Fig. 3 Pie chart for REF2 output profile by research theme – and bar graph showing breakdown for research theme and gender.

We were awarded Athena SWAN (AS) awards for both SoG (Silver/Bronze) and HCA (Bronze). Numerous measures have been implemented across the UoA as part of ongoing EDI and AS action plans; including mandatory Equality and Diversity online training for all staff, and aspiring to gender balance on interview and promotions panels. This has had a tangible effect; whilst we continue to attract higher proportions of male applicants (65-70%), female appointments range from 41-52% since 2014 and there has been a significant and systematic increase in the proportion of research active female staff at lecturer grade (29% in 2014 to 42% in 2019). The proportion of successful external funding applications from women has also risen from 15%/annum in 2014 to 43% in 2019, greater than the proportion of current female staff in the UoA.

Separate Equality, Diversity and Inclusion and Athena SWAN conveners ensure equality and diversity are embedded and evaluated in all processes. Enhancement activities, including unconscious bias training have improved gender and race balance in all recruitment processes, professional development reviews, grant and fellowship proposals and promotion rates. A workshop with six inspirational external speakers in April 2019 kick-started a fresh EDI strategy, in particular to improve BAME recruitment and retention. This is now embedded in an action plan to promote diversity including aspects that go beyond the institutional procedures (REF5a). The action plan includes: (i) mandatory unconscious bias training workshops for those on appointment

and promotion panels; (ii) improving staff and PhD recruitment materials and processes to increase demographic diversity (careful drafting of advertisements; selective targeting of candidates); (iii) diversifying the demographic profile of invited seminar speakers in the School; (iv) establishing multiple points of contact, and clear management processes, for bullying and harassment complaints, and (v) running bi-monthly EDI forums to sustain dialogue and reflection on EDI concerns and activities. We also have a strong cohort of scholars working with critical race, feminist and decolonial theory who influence our debates on diversity through their own research, and who play key roles in university Race-Ed and Gender-Ed initiatives.

2e. Research students

The School hosts a vibrant and diverse postgraduate body of over 240 students (Jul 2020), compared with 197 in 2014. Since REF2014 we graduated 52.5 students/annum, an increase from an average of 35.5/annum for REF2014. International students make up 49% of the PGR student population (40% of whom are from the EU) and 51% of the PGR students are women. These students span a wide range of disciplines, and are funded by four research councils and various governments, companies and charities. We lead **NERC E3** and **E4 Doctoral Training Partnerships** (DTP), and the **SENSE Centre for Doctoral Training** (CDT) in Satellite data in Environmental Science, all awarded via competitive bids evaluated on the basis of excellent postgraduate research training and management. E4 and SENSE encourage multidisciplinary approaches and collaboration featuring partners across academia, industry, and the third sector. Many features of the DTP programmes have now been rolled out across our postgraduate research training environment for all our students, as described below.

Funding of PGR studentships: Our healthy funding streams ensure a vibrant and diverse student cohort and research programme. UKRI funds approximately a third of our students, mainly via NERC (103 students, including 5 funded through the National Productivity Investment Fund, 5 SENSE half-funded by SoG, and 6 funded via other NERC research grants), while 18 are supported by ESRC, AHRC, EPSRC, MRC and STFC. The remaining 134 students are funded through: research grants (12); university scholarships (37 students including 9 partially); international governmental programmes (e.g. with China, Chile, Mexico, Oman, Kuwait – 27); European Union International Training Networks (~5); competitive scholarships (e.g. Carnegie Trust, Leverhulme Trust, and the Scottish Alliance for GeoSciences Environment and Society (~5); and industry or NGO partners (e.g. Ford, Quintessa, Scottish Forest Trust, DEFRA (~10). We also attract self-funded students who secure funds from a variety of sources (~35 including 12 MScR). We have more than 30 CASE studentships, partly funded by industry partners (e.g. Reykjavik Energy, Space Intelligence Ltd), including two EPSRC Industrial CASE partnerships, and two AHRC Collaborative Doctoral Partnerships.

Doctoral Training Programmes: The SoG leads the Edinburgh Earth and Environment (E3) DTP and its successor the E4 DTP, both NERC-funded. Each host 18 PhD studentships per year at the University of Edinburgh prior to match funding, **equating to an £16M investment from NERC over the lifetime of the two DTPs**. The recent E4 DTP bid was ranked 2nd in the UK during the 2018 competitive bid process and is now the joint largest NERC DTP as well as the largest geographically clustered DTP. Feedback from NERC noted that *“the panel was particularly impressed with the provision for training, which highlighted many excellent aspects.”* The **SENSE CDT** secured **£2.2M** from NERC and is co-directed with University of Leeds. In a further example of interdisciplinary engagement **Pearce** is director of the **Scottish Graduate School of Social**

Science (SGSSS), an ESRC-funded DTP administered by the University of Edinburgh School of Social and Political Sciences.

Masters by Research programmes: Three MScR programmes, *GeoSciences Individual Project*, *Palaeontology & Geobiology*, and *Human Geography* combined with Integrated Masters degrees (MEarthSci/MEarthPhys) host around 34 students/annum.

The postgraduate research (PGR) office: The PGR manager, the DTP and CDT manager and the PGR secretary provide administrative support from admission until graduation and the PGR team is the first point of call for any student concerns. The team develops a positive research culture by supporting student-led activities, organising an annual PGR conference, facilitating annual focus groups on PGR student experience, and maintaining an online PGR Student Hub that collates information. The team oversees progress monitoring, which comprises a formal confirmation process at the end of the first year, training needs analyses, and annual reviews in subsequent years.

Recruitment and support: We recruit students from a wide range of backgrounds, and consider the balance of academic qualifications and professional experience. The student voice is enabled via the PGR student committee and representation on UoA committees for ethics, health and safety, diversity and inclusion, and the E4 DTP Student Advisory Panel. To ensure stability and involve new supervisors, each student has a minimum of two supervisors from the UoA or an associated institution. PhD supervisors undertake mandatory PhD supervision training at least once every 5 years. Each student also has an independent academic Advisor who chairs progress and monitoring events, and can act as a potential intermediary between the student and supervisor if problems arise.

Highlights of our PGR training programme: We train graduate students for diverse futures, ensuring they are equipped to think critically, holistically and independently, and to communicate their work professionally. Our breadth allows our students to benefit from a wealth of internal and external training opportunities, organised across the DTP, CDT, ESRC-funded SGSSS, and AHRC-funded Scottish Graduate School for the Arts and Humanities programmes. Key hallmarks of our PGR training programme are:

- Support for **interdisciplinary research and collaborative projects** with Associated Institutes (including the Centre for Ecology and Hydrology, Scotland's Rural College, British Geological Survey, and the National Library of Scotland) and international universities (including Aarhus, Leuven, McGill and Helsinki).
- Our signature **annual PGR Conference**, is a key training and cohort-building event attended by students, supervisors and partners which provides a celebration of the diversity of research carried out across the UoA.
- **Industry engagement** (e.g. through CASE studentships) and the DTP **Professional Internship Programme** (PIP) to provide our students experience in non-academic workplaces.
- **Transferable skills training** through IAD (including data management courses, writing retreats, and media training) and **entrepreneurship, innovation and impact training** through the Edinburgh Centre for Carbon Innovation (ECCI).
- **Workshops to prepare students for progression milestones** including 'Surviving the Confirmation Process', 'Presentation Skills', 'PhD Thesis workshop' and 'Viva Survivor'.

The training programme also benefits from a vibrant culture of student-led initiatives including:

- The 'GradSchool' which organises regular social activities to support the PGR community, but also supports skills development and peer-feedback opportunities through monthly GradTalks where students present work and practice conference talks, and an annual 2-day conference with poster presentations, talks, and a ceilidh dinner.
- The Coding Club, attracted funding from the Data Lab, Scotland's innovation centre for data and AI, to produce an innovative GitHub based 'Data Science for Ecologists and Environmental Scientists' course which has recorded over 600,000 views and 130,000 hours of online coding practice.

Excellence in PGR research: As evidence of the excellent PGR research environment:

- our students publish first-author papers in internationally leading journals such as *Nature* (e.g., Dingle 2017; Tedstone 2015), *Science* (e.g., Clarkson 2015; Daskalova, 2020), and PNAS (e.g., Schwab 2020; Baynes 2015).
- student presentation awards at International conferences, including Singh (Society of Exploration Geoscientists, 2018), Clement (European Seismological Commission, 2018) and Daskalova (British Ecological Society, 2019).
- prestigious scholarship winners including the British Spanish Society Scholarship (Garcia Criado, 2020) and the IJURR writing grant (Acharya, 2019).

Research and employment preparation: While some PGR students pursue a career in academia, we recognise that the majority will choose other career paths. We ensure that students gain transferrable skills for wider career paths by working with our alumni, the IAD and the Careers Service. This includes a bi-annual non-academic careers event combining networking training with a series of talks from alumni who work outside academia. The ECCI run events twice a year that enable businesses in low carbon technology to network with students, which can be followed up by business placements. In 2018/19 NERC provided **£61K** from the National Productivity Investment Fund for student placements, and our DTP students all have the opportunity to undertake a 3-month placement in a non-academic setting through our PIP scheme.

Our exit surveys consistently show that over 90% of our graduates are in Highly Skilled Employment or Further Study (HSEFS) 6 months after graduation. Our graduates go on to significant success, with diverse careers in industry, government, international academia, global consulting, amongst others.

3. Income, infrastructure and facilities

3a. Research income and expenditure

A key goal of our strategy and thematic programmes (sections 1b and 1c) has been to nurture a vibrant culture of interdisciplinary research through expanding our staff cohort (from 104 for REF2014 to 126 for REF2021) and external funding. Through a series of support measures (detailed in sections 2 and 3b), we have won a total of **£138.6M** in research grants and contract awards from 98 different funding sources since August 2013, or **£1.12M per FTE** for this submission. Annual UoA awards averaged **£19.8M/annum** cf £13.3M/annum for REF2014, and annual income per FTE also increased from £128K to **£160K**. UoA expenditure/recovered income over the REF period is **£113.2M**, including overhead of **£31.5M**, and lags awards.

Our success in winning awards is a key performance indicator from our research strategy, notably the conscious and successful development of a thriving and vibrant culture of multi- and inter-disciplinary research, the thematic research programmes, key appointments (section 1) and the support and training environment (section 2). This has led to our being awarded a total of **£29.6M** for awards compatible with Official Development Assistance (ODA) goals (including GCRF and the Newton Fund), almost a quarter of our total.

We received 20 awards of over £1M in value during the REF period, including eight over £2M:

- **£20.1M** for the *GCRF Urban Disasters Risk Hub*, **McCloskey**
- **£7.87M** for the *Scottish Government Centre of Expertise on Climate (CXC)*, **Kerr/Reay**
- **£6.07M** for the *ESRC Administrative Data Research Centre Scotland*, **Dibben**
- **£3.37M** for the extension of *ESRC Administrative Data Research Centre Scotland*, **Dibben**
- **£3.19M** for the *GCRF Multi-hazards and Risk – Ixchel*, **Calder, Cupples**.
- **£2.90M** for the *IMS 7f-Geo System for the NERC Ion Microprobe facility*, **Harley**
- **£2.85M** for the *GCRF South Asian Nitrogen Hub*, **Reay**
- **£2.55M** for the *ESRC Digitising Scotland* project, **Dibben**

Smaller awards, notably in the standard grant range, remain a significant engine for our research (Fig. 4).

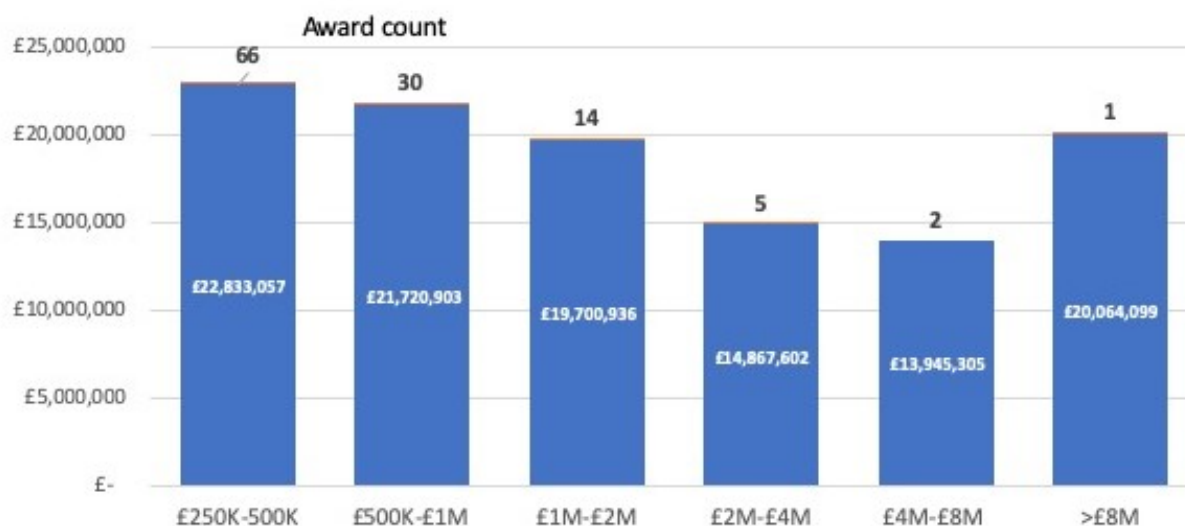


Fig. 4 Histogram of awards weighted by value. Count data is also shown for reference.

Our major funding source continues to be NERC - **£60.6M**, with **£17.1M** from ESRC, **£5.5M** from EPSRC and **£2.4M** from BBSRC.

We won **£17.4M** in total funding from the EU, including two ERC starter grants (*The Rise of Placental Mammals: Brusatte*, *Tropical Forest Degradation: Mitchard*) and two ERC consolidator awards (*Earth Core: Komabayashi*, *Ethnographic approaches to infrastructure development in South Asia: Ruwanpura*) totalling **£4.1M**. *Hegerl* successfully completed her ERC advanced grant in 2017.

£8.8M of our awards are for Data Driven Research in the Space and Satellites area, including **£3.9M** for 11 awards from the European Space Agency.

We won **£25.8M** in awards for industry-sponsored research projects, business development and innovation activity, ~18% of our total research and innovation total, as follows:

(i) The School operates the Edinburgh Centre for Carbon Innovation (ECCI) (see section 4a), which generated **£12.5M** of our awards, including **£8.6M** from CXC projects and **£2.6M** in separate awards as a Climate KIC project partner. ECCI generated a further **£2.74M** from innovation events, active low carbon small business incubator projects, and commercial activity related to carbon innovation. Overall, the total of **£15.2M** compares to a total ECCI spend of **£15.6M**, implying a cost recovery of 98% as a free-standing research and innovation centre.

(ii) **£10.3M** of our awards come to the School from industry independent of ECCI, involving 20 companies, or from schemes targeted to translate fundamental discoveries into applications, overwhelmingly in the field of Geo Energy (**£10.1M**), five of which exceed **£1M**:

- **£3.24M** for a cluster of projects in the *International Centre for Carbonate Research* (Petrobras and Shell), **Wood**.
- **£1.78M** for the *Edinburgh Interferometry Project* phases II and III (Schlumberger, Total, Statoil, BG Group and Conoco Phillips), **Curtis**
- **£1.41M** for *HyStorPor - Hydrogen Storage in Porous Media* (EPSRC), **Haseldine**
- **£1.00M** for the *Forests 2020 project* (UK Space Agency and Ecometrica), **M. Williams**
- **£1.00M** for a prosperity partnership in geothermal energy *Smart Pumping for Subsurface Engineering* (EPSRC and the Weir Group), **McDermott**.

The value and diversity of our research award portfolio ensures we have a healthy funding base to support research and innovation success beyond REF2021.

3b. Infrastructure and facilities supporting research and impact

The UoA has an impressive range of supported laboratory facilities that provide an effective environment for delivering research excellence. We also operate field stations and associated facilities worldwide, enabling our researchers to lead and conduct research from the tropics to the poles. Our facilities were critical in generating **£21.9M** of research funding, and some 54% of current academic staff, 22% of research staff and 40% of PGR students depend on them.

(i) Organisational Infrastructure and Support for Research and Impact

All academic and research staff, and post-graduate students have access to our extensive laboratory, analytical and computational facilities described below. UoA researchers are supported by a team of 100 technical and professional services staff who provide research computing, laboratory support, small to large research facilities and services for safety, research administration, impact and public engagement; as well as being supported by University research services. All academic staff are allocated an annual baseline of funds (**~£750**) to enhance the

quality of their teaching and in furtherance of their research. In addition, all academic/research staff can apply competitively to a bi-annual small grants fund for research activities such as conferences, grant proposal workshops, and participation in professional development courses.

Facilities and Infrastructure are managed by the Academic Head of Facilities and the Head of Technical Services, in turn overseen by the SoG Facilities Committee, which comprises users at different career stages and facilities staff. The SoG sets aside an annual budget for research equipment, allocated competitively by the Facilities Committee. Its 2018 call (**£162K**) targeted early-career research staff, supporting independent fellows **Hennige** and **Street**. A further **£448K** has been invested in School social spaces to enhance PGR and researcher interaction, develop new collaborative research and impact activities.

The SoG funds a general-purpose computing facility used by researchers and invests **£22K/annum** in the Edinburgh Compute and Data Facility (ECDF). 1.5 FTE of SoG IT staff and associated costs (**£112K/annum**) was dedicated to research computing in the REF2021 period for training and guidance to facilitate use of the SoG/University/UK facilities and to directly support funded research projects. Some **£20K/annum** has been disbursed since a new scheme was launched in 2015 to 28 users of 13 of the 16 Small Research Facilities listed below, for pump-priming work.

(ii) Physical Infrastructure and Facilities

The Facilities and Infrastructure team has delivered several major investments during the REF2021 period:

- **£2.90M for the NERC Ion Microprobe Facility** through purchase of the new 7f-Geo ion microprobe (Fig.5). In combination with the large-format *ims1270* ion microprobe operating at the IMF, this provides high spatial resolution, high-precision multi-element and -isotope microanalysis capability unique in the UK, and world-leading internationally.
- **£1.59M in our facilities estate**, including new Changing Oceans, Palaeontology, Diamond Anvil and Geophysical Flow labs to support new research areas and activities (in turn bringing in **£8.09M** H2020, ERC, NERC and Leverhulme grants).
- **£619K to set up the Brian Price ICP Facility** for high-resolution ICP-MS and MC-ICP-MS, coupled to a seaFAST pre-concentration system and the NERC-funded laser ablation system (**£182K**).
- **£347K in additional research and technical staff** to support the development of the Brian Price ICP facility, to co-ordinate and support the School's field equipment, and for succession planning.
- a further **£1.33M in capital equipment**, notably supporting the set-up of the unique GREAT Cell (**£155K** see later for detail) and replacement SEM (**£442K**) and IR-MS (**£267K**) instruments, heavily used by UoA researchers.

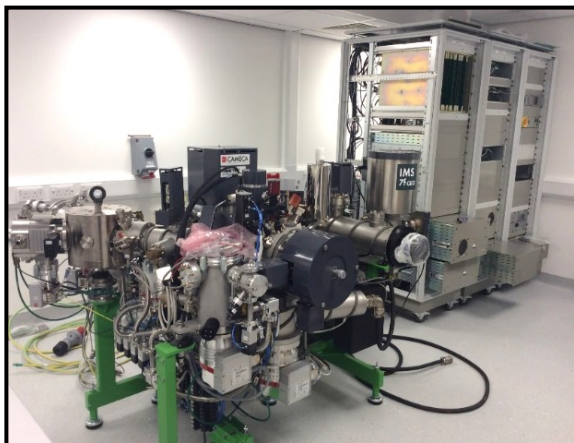


Fig. 5 Installation of the Cameca 7f-Geo SIMS instrument at the re-configured Edinburgh NERC Ion Microprobe Facility, November 2018. This instrument is now in full routine operation for the benefit of UK NERC, international and UoA users.

We operate 16 Small Research Facilities (SRFs), run by 13.5 FTE research and technical staff, and 36 underpinning (multi-user) or user-specific research facilities. Collectively these account for some 30% of the SoG built environment (c. 2900 m²). The SRFs include sample preparation facilities, a high-specification mechanical workshop, a multi-purpose geochemistry facility, and X-ray analysis (XRF) and characterisation (XRD) laboratories. Our SRFs also include Airborne GeoSciences (light aircraft and UAVs supporting research in ecology, agricultural science, micrometeorology, forest science, geomorphology, archaeology and palaeontology), Organic Geochemistry, Stable Isotope Mass Spectrometry of H, O, C and N, ICP-MS, and a Cosmogenic Nuclide facility producing sample targets for measurement of cosmogenic isotopes (¹⁰Be, ²⁶Al, ³⁶Cl) by accelerator mass spectrometry (AMS) and noble gas MS. We support and operate SRFs in high resolution micro-CT X-ray tomography, designed and built in-house and one of only a few instruments in the UK dedicated to in situ experimental work, Electron Microprobe analysis, FEG-SEM, Ion Microprobe microanalysis (non-NERC funded time), and a nationally-unique pilot pyrolysis facility in the UK Biochar Research Centre.

All facilities charge reduced rates for UG and PGR student use.

Selected highlights from UoA specialist research facilities during the REF2021 period

The **pilot pyrolysis facility** of the UK Biochar Research Centre (UKBRC, Fig. 6a) enables pyrolysis of biomass at scale. It has produced a set of 12 research-grade biochars that are now used by over 100 research groups worldwide. This pilot plant is unique in the UK, being the only continuous biochar production research unit with high-level instrumentation, with no more than five comparable plants globally, none of which utilise our bespoke technology. The award-winning start-up company *Carbogenics* (section 1diii) was established to commercialise biochar-based products that increase the efficiency of anaerobic digestion.



Fig. 6a) Pilot Pyrolysis facility of the UKBRC for generation of experimental biochar/fertiliser.



b) The 'true triaxial' GREAT cell (centre left), contained in the loading frame of the 'Big Rig'

The **GREAT cell** (Geo-Reservoir Experimental Analogue Technology; Fig 6b) is a transformative, globally-unique facility that creates a true triaxial, rotatable stress field, facilitates fluid flow through samples, and employs state of the art fibre optic strain and temperature sensing technology capable of thousands of measurements per hour **McDermott**. It has been the key to securing **£1.5M** of EU and Industry research funding. A second cell is under development at the University of Göttingen, Germany, generating a further **€2.3M** in collaborative EU funding.

The **ICP Mass Spectrometer Facility** measures elemental concentrations and ratios of rare earth elements, radionuclides and redox sensitive metals in rocks, sediments, river, and seawater samples to reconstruct biogeochemical processes associated with anthropogenic forcing, climate-induced ocean deoxygenation and circulation variations, and elucidate ore-forming processes in magmatic systems. New methods, enabled by installation of SeaFAST instrumentation and achieved by only a few laboratories worldwide, have been developed to reconstruct dramatic variations in marine nutrient cycling induced by climate change **Pichevin**.

The '**Terra-correlator**', initiated by **£298K** NERC funding, is a computing facility for massive real-time data assimilation in environmental science, tuned for optimal performance in operations involving cross-correlation. These include seismic ambient noise interferometry for crustal tomography studies **Curtis**, coda wave interferometry for earthquake location **Curtis**, and particle tracking of local strain and fracture during deformation experiments imaged in a synchrotron **Butler, Fousseis, Main**.

(iii) Contribution to UK National Capability

The **NERC Ion Microprobe Facility** (IMF: 50% NERC-funded) enhanced its world-leading instrument capability through the installation of the new **£290M** (BEIS/NERC) Cameca 7f-Geo SIMS instrument in 2018-19, complementing its large-format ims1270 SIMS and replacing its ims4f ion microprobe. The latter, now supported entirely by the SoG, is dedicated to instrument-intensive research by early career researchers and training of the next generation of SIMS specialists. IMF microanalysis underpinned 163 research papers in the REF2021 period, of which 35 were co-authored by IMF, and a further 20 involved other UoA authors **Bromiley, Calder, De Hoog, Fitton, Harley, Hastie, Kirstein, Robertson, Talavera**. Total citations attributable to the IMF since 1989 exceed 30,000; its ISI and Scopus h-indices are both 93. Some 20 international users from 14 countries accessed the IMF in the REF2021 period.

The **Edinburgh NERC Geophysical Equipment Facility** (GEF:100% NERC-funded) was awarded **£440K** NERC capital equipment funding in 2019 to measure water and heat fluxes below ice sheets in order to improve predictions of sea level rise from climate warming. It supported 217 research papers, including 10 with UoA co-authors. 19 equipment loans were made to UoA staff and 28 UoA staff and PGR students were trained during the REF2021 period.

The NERC Field Spectroscopy Facility (100% NERC-funded, Fig. 7) was awarded **£1.1M** NERC capital equipment funding in 2019 for a UAV-mounted hyperspectral imager and an automated GHG monitoring network. During the REF2021 period it supported 76 research papers, including 16 with SoG co-authors, and made 15 equipment loans to SoG researchers.



Fig. 7 Field demonstration of NERC FSF equipment for training of PGR students prior to field deployment

(iv) External access to major national and international research facilities

Our staff use the best available facilities nationally and internationally to generate high-quality research.

Field stations and facilities worldwide: Our researchers work around the globe. In the Amazon the tropical forest drought experiment initiated by **Meir** has operated continuously since 2001 at the **Ferreira Penna Scientific Research Station**, it is the only such experiment to have run for over 5 years. This collaboration generated 40 UoA journal papers, and **£1.05M** research funding (NERC, EU, **Meir**). At the **Smithsonian Tropical Research Station, Panama**, **Meir** set up the world's first tropical forest soil warming experiment, unique in warming the whole soil profile, leading to 4 UoA journal papers and **£788K** in research funding (NERC, EU). Micrometeorological, ecological, biogeochemical and climate change research was conducted by several SoG staff at **Arctic research stations in Scandinavia, Greenland, Canada and USA**, e.g. **Myers-Smith**. Use of **Antarctic research stations and BAS support** by **Bingham** and **Henley** (BAS Rothera) and **Colesie** (Base Juan Carlos Primero, Spanish station; Scott Base, New Zealand station) resulted in 21 papers by **Bingham** and primary input into the management plan for the Botany Bay Antarctic Special Protected Area (SPA 154). Within the UK, the UoA developed GHG monitoring at the Heathfield tall tower observatory (**£199K** NERC, 2017), contributing data to the BEIS-sponsored DECC network 'Deriving Emissions linked to Climate Change'. This contribution will be enhanced by **Arnold, Palmer** and **M. Williams** through the DARE-UK NERC Highlight topic award (**£771K**) to study the UK's greenhouse gas emissions.

Laboratory and experimental facilities: Over 10 SoG researchers have been awarded **synchrotron beamtime** at facilities including the Diamond Light Source (UK), the European Synchrotron Radiation Facility (Grenoble, France), the Swiss Light Source (Villigen), DESY (Hamburg, Germany), and the Advanced Photon Source (APS, Chicago, USA). Supported by APS, **Butler** and **Fusseis** worked closely with our workshop and X-ray μ CT scanning facility to design and construct a unique x-ray transparent experimental fluid-rock reaction cell for microtomography imaging. SoG researchers accessed and utilised the **Scottish Universities Environmental Research Centre** (SUERC) to produce 33 papers co-authored by 23 UoA

academics during the REF2021 period. Collaboration with the SUERC Noble Gas Isotope and Stable Isotope Facilities resulted in 10 journal papers **Gilfillan** and **£2.18M** of research funding (Total, NERC, EPSRC, SFC). NERC-funded research to constrain predicted future sea-level rise due to melting of the West Antarctic Ice Sheet utilised the SoG Cosmogenic Nuclides laboratory and SUERC's Accelerator Mass Spectrometry facilities, capitalising on field support from the British Antarctic Survey **Hein**.

Ocean sciences infrastructure: SoG participation in the **International Ocean Discovery Program** (IODP, whose Forum is led by **Kroon**), and access to legacy materials and data from the Integrated Ocean Drilling Program and the Ocean Drilling Program (~£2M value), led to 28 research publications **Fitton, Jung, Kroon, Robertson, Thomas, Tudhope**. Our research on Antarctic Ocean biogeochemistry **Ganeshram, Henley** and on deep-sea structural habitats including cold-water corals and sponges **Hennige, Henry, Roberts**, benefited from access to the **UK research vessel fleet and its National Marine Facilities Sea Systems**. This included work through the UK ocean acidification research programme to understand implications for cold-water corals, identify the drivers of change in deep-sea habitats, and inform national and international policy advances for global implementation of Marine Protected Areas and management of cold-water areas. SoG researcher ship time on the US Palmer **Antarctica LTER project**, and the **GEOTRACES** marine biogeochemical cycles of trace elements and their isotopes programme led to 14 journal papers **Ganeshram, Henley, Pichevin**. Three ocean landers and instrumentation (~£300K), donated by University of North Carolina Wilmington, were deployed in 2018-19 in the Davis Strait between Greenland and Baffin Island. These remain in Canada to support the **£1.6M H2020 iAtlantic** project, funded in 2019.

Airborne facilities: NERC facilities for Airborne Atmospheric Measurements and Airborne Research (ARF), and NASA's Airborne Science Program have been used in NERC-funded campaigns (**£2.7M**) **Palmer**, to quantify UK Greenhouse gas (GHG) emissions, measure vertical profiles of CH₄ and CO₂ over the Amazon to ground-truth satellite observations, sample CH₄ over African wetlands, and fly a bespoke spectrometer for tropospheric and stratospheric GHG over the eastern Pacific.

High-Performance Computing (HPC) facilities: Research performed by groups led by **Curtis, Bollasina, Doherty, Goldberg, Gourmelen, Hegerl, Tett**, and **W. Williams** involve large parallel computing jobs run on ARCHER and MONSOON (UK National Capability) supercomputers, and **Curtis, Goldberg** accesses CIRRUS for parallel jobs of size in between those suited to ECDF and ARCHER. The JASMIN computer (UK National Capability) is also extensively used by School researchers for analysis of large climate and earth observation data sets in the CEDA Archive (**Bollasina, Doherty, Hegerl, Tett, M. Williams**).

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

4a. Arrangements and structures to support effective collaboration

Collaborative and cross/inter-disciplinary working to address real-world problems (see section 1a) is a core component of our research strategy (see section 1b). We have advanced this substantially during the REF2021 period through:

(i) Development of Interdisciplinary centres: The UoA has led or co-developed several interdisciplinary centres to boost collaborative work in research and innovation, including the **Edinburgh Centre for Carbon Innovation** (Executive Director **Reay**), the **Centre for**

Sustainable Forests and Landscapes (Director **Ghazoul**, launched in 2018 by Fergus Ewing MSP, Cabinet Secretary for the Rural Economy), and the **Centre for Science at Extreme Conditions (CSEC)** a shared facility in the College of Science and Engineering spanning the study of extremophiles, to the nature of Earth's core. All these centres are supported by staff appointments in the UoA. Two are hosted by the UoA:

Edinburgh Centre for Carbon Innovation (ECCI) is Scotland's leading knowledge exchange hub on climate change. It works with national and global partners on mitigation and adaptation agendas, notably as the primary research-into-policy channel for the Scottish Government. In the REF2021 period its projects included *Climate KIC* (£1.9M) and *ClimateXChange* (£7.9M, section 3a), providing decision-makers with the evidence base for future policy and funding priorities on climate change. ECCI also hosts the *Sustainable Scotland Network*, who work with local authorities and public bodies to inform de-carbonization strategies and the *Scottish Centre for Carbon Capture and Storage*, which has supported a major increase in activity related to former North Sea fields. ECCI provides advice and evidence to stakeholders on green recovery and climate change policy, including the *UK Government*, the *Scottish Parliament*, *Scottish Water*, the *National Farmer's Union Scotland*, and *Zero Waste Scotland*, **Reay**. The Edinburgh Climate Commission (**Van der Horst, Crowley**), is coordinated by ECCI alongside City of Edinburgh Council to deliver de-carbonization and resilience in support of their objective to make the City carbon neutral by 2030.

Our **Centre for Sustainable Forests and Landscapes (CSFL)** works with a wide range of partners to provide the critical interdisciplinary knowledge to deliver sustainable landscape management and policy development for forested landscape mosaics. It combines expertise from the public and private sectors, and across social and natural sciences. CSFL launched the £550K EU Climate-KIC project *Landscapes as Carbon Sinks* to support delivery of the Scottish Government's net-zero carbon target by 2045 through land-based approaches. The *FORLAND* Restoration project develops platforms to integrate spatial data with local community priorities for land-use decision support, while other research projects address the political ecology of woodland expansion.

(ii) Supporting new collaboration: We sought out and appointed interdisciplinary staff in areas where we see strategic opportunities for connecting and collaborating across research areas (see section 2a). We have engendered a culture of engaging early to codesign research with stakeholders, including partners, third sector and communities. These efforts are supported by a growing cohort of experienced and dedicated professional service staff and include a ring-fenced central University budget to organise and host meetings for co-producing research proposals and for in-project meetings between stakeholders and collaborating academic partners. These meetings have proven to be critical elements of our success in the larger GCRF applications with the global South (section 3a).

4b. Collaboration beyond the Academy

We engage in a number of ways with communities outside the University sector including those already mentioned in section 1(d). These include (i) engagement with private sector and (ii) engagement with other with key research users, beneficiaries and audiences including communities, civil society organizations, governments and policy-makers, and media.

(i) Engagement with Private Sector

We collaborate with a range of industry partners, enabled by funding from at least 20 companies (section 3a). Our strategy for industry collaboration has a planned focus on two areas: **Space and Satellites** and **Low Carbon Innovation**, while developing a broader portfolio in **Geo-Energy** for low carbon solutions, such as low-enthalpy geothermal heat extraction, and supporting subsurface storage solutions to the hydrogen economy. Industry collaboration is supported from conception to delivery by our three business development executives and by *Edinburgh Innovations Ltd* – (EI Ltd) the University of Edinburgh's commercialisation service. We won £25.8M in awards for industry-sponsored research projects, business development and innovation activity, with a further £8.8M of our awards for Data Driven Research in the Space and Satellites area, including £3.9M for 11 awards from the European Space Agency (section 3a). EI Ltd report £3.91M income generated through external consultancy contracts won by UoA staff.

UKRI Impact Accelerator Account funds: UKRI (NERC, STFC and EPSRC) provided £312K to promote industry collaboration by seed funding co-developed projects to pull through its science into the private sector, including with *Ecometrica* (two projects total £48K), *Alba Orbital*, *Orbital Micro Systems* (£20K), *Edinburgh Group Build and Low Carbon Homes* (£26K).

Scottish Funding Council (SFC): The Scottish Funding Council awarded support for Edinburgh and Scotland's participation in the Research England funded (£4.8M) SPRINT programme, under the Connecting Capability Fund, to leverage the UK Industrial Strategy (July 2018). A new three-year Business Development Executive was appointed, making Edinburgh a full partner in the SPRINT consortium programme with 5 UK universities supporting SMEs and exploiting technologies, data and expertise developed for space. The programme enables access to a UK-wide innovation ecosystem (research, facilities, IP, Skills, data and finance).

UoA support for thematic programmes: A secondment to *European Marine Energy Centre Ltd.*, by *Watts* contributed to data strategy development for a flexible-response integrated energy system (ReFLEX), embedded in the community and landscape of the Orkney Islands. Expert advice provided to *Aquatera Ltd.* (environmental consultancy SME) supported establishment of a £30M membership-based localised energy company increasing access to low carbon home energy assets, with planned worldwide replication sites.

Spin-out Companies: Staff launched five new spin-out companies currently employing 34 people. Three of these received external awards:

- *Carbogenics Masek*, 2015 uses biochar-based additives from disposable coffee cups to increase efficiency of anaerobic digestion. Won the Shell Springboard competition prize (£40K) from the Anaerobic Digestion Network/Scottish Enterprise (4 employees)
- *Space Intelligence Mitchard*, 2015 support the net zero transition by providing data for nature-based solutions (Fig. 8a). Won £60K from UK government to support peatland restoration and £100K from the Scottish Enterprise 'AI for Good Challenge'. Voted 8th out of 50 top Scotland tech businesses (Business Cloud), 2020 (9 employees)
- *Earth Blox Paternaude*, 2020 provides a new interactive power tool for Earth observation data that avoids clients having to write code. Won top prize of £50K (Fig. 8b) plus £21K-worth of support from the Converge Challenge Awards for academic innovation and entrepreneurship (10 employees)



Fig. 8a) Space Intelligence provide data for nature-based solutions



b) Earth Blox win the top 2020 Converge Challenge Award.

(ii). Engagement with key research users, beneficiaries and audiences

Early engagement with stakeholders has been key to our success in developing, funding and delivering on collaborative research (section 4a) and impact (section 1dii and Impact Case Studies), of which we now present some exemplars:

Engagement with Communities: Our work with communities is heavily, but not exclusively, focused on countries in the global South where we engage on topics related to disaster risk reduction, resource management and geographies of social disadvantage, including;

- Afro descendant communities in Colombia, and Central America working on advocacy and cultural production through URACCAN, Carabantú, Townbook Limón, and the Afro Voices Center of Nicaragua (AVOCENIC), **Cupples**
- Community-based conservation, resource management and ecosystem services with communities in Nepal, East Africa and Ecuador, **Keane, Staddon, Fisher**
- Work on housing and tenancy rights with housing activists in Edinburgh, London, Rome, Barcelona, Lisbon, Cape Town, Buenos Aires, and Santiago, **Slater, Kallin**

Engagement with civil society organizations: Much of our work with NGOs and other organizations focusses on UKRI's Global Challenges and contributes towards the United Nations Sustainable Development Goals (SDG's). Exemplars include:

- Disaster risk reduction (seismic and volcanic risk) and social justice working with emergency response NGOs in more than seven countries across Europe, Asia, Africa, and Latin America, **Bell, Calder, Cupples, Main, McCloskey, Naylor, Whaler.**
- Flood risk and resilience working with NGOs in Nepal & India, **Sinclair, Attal, Mudd**
- Sustainable marine farming working with a charity in Madagascar, **Tudhope, Wilson**
- Quantifying forest carbon resources working with an NGO in Tanzania, **Williams**
- Ecosystem services working with NGOs in Mozambique Zimbabwe, **Ryan, Patenaude.**
- Public health in UK, working with Tobacco and Alcohol NGOs, **Pearce, Shortt.**

Engagement with Governments and Government Agencies: We directly engage with Government at Local and National level, and through Inter-Governmental Agencies such as the IPCC – **Hegerl** (see section 1d and her Impact Case study), **Rounsevell**, as lead author and member of the summary for policy makers writing team for the IPCC special report on *Climate change and land*, 2019, and **Tett** a review editor on the 5th IPCC Working Group 1 report, Oct 2013. Other exemplars not reported in section 1d or in our Impact case studies include:

- Advice on volcanic hazards with Government institutions in Ecuador, Chile, Colombia, Peru, Guatemala, and the Caribbean, **Calder, Bell**
- Advice and evidence to Scottish Parliament, Scottish Government, Scottish Land Commission, Scottish Forestry, and Scottish Wildlife Trust on national forest strategy **Ghazoul**, role of woodlands **Ghazoul, Yang**, land use policy, **Valluri-Nietsch, Metzger**, and governance **Metzger**
- Engagement with SEPA to develop measures to reduce pollution of waters from historical mining sites 2017-18, **Graham, Heal**
- Advice to European Commission resulting in inclusion of CO₂ transport in their €4.7Bn, Connecting Europe energy programme **Haszeldine, Scott**
- Disaster Risk Reduction in Tomorrow's Cities, with local Government in Istanbul, Quito, Kathmandu and Nairobi, **Bell, McCloskey, Main, Naylor**
- Advice to the Scottish Government on Climate change and Rural Policy, **Kerr, Reay**
- **Wood** was appointed as Honorary Consul for Namibia as a consequence of her research work there.

Engagement/co-production with media: We are frequently quoted in the media on emerging issues from climate change to dinosaurs and many staff are strongly media-engaged through UoE channels and UK-wide networks such as the science media centre. With respect to co-production of significant media initiatives:

- We collaborate in media production for, and with, Indigenous and Afrodescendant communities e.g. Canal 5, Noticias de Bluefields and TV7 in Nicaragua and Black Crab Studios and Teleislas, San Andrés and Providence, Colombia, **Cupples**.
- We are co-producing and have supported funding of a feature documentary film on the 2018 eruption of Fuego volcano, Guatemala, **Calder, Cupples**.
- We support the science content in mainstream movies such as the *Jurassic Park* series **Brusatte** and documentaries such as *Climategate* (BBC4; **Hegerl**) or *Chasing quakes* (Terra Mater; **Main, Naylor**).

Public Outreach: Since 2014 our UoA has undertaken 188 reported in-person public engagement events, involving at least 53 academics and reaching an estimated 37,650 people. We utilize a broad array of approaches and medias, aimed at engaging diverse national and international audiences. Our staff have published several acclaimed books aimed at the general reader as well as academic audiences:

Brusatte *The rise and fall of the Dinosaurs;*

MacDonald *Escape from Earth - A Secret History of the Space Rocket;*

Reay *Climate-Smart Food;*

Watts *Energy at the End of the World.*

Our **Cockburn Museum**, with its collection of 130,000 geological specimens (Fig. 9) and historical objects reflects Edinburgh's prominent position in geological sciences since the time of James Hutton. The Museum facilitated over 5500 interactions with collection specimens through hosting visitors and offering mobile events at other venues such as local schools. We also supported the UoE Main Library in acquiring Charles Lyell's 294 notebooks detailing his engagement with scientific and social issues, field notes, and travel accounts.



Fig. 9 Cockburn Museum; (left) display of modern corals and fossil fish with artwork by artist in residence Hannah Imlach, and (right) Edinburgh College of art students working with museum specimens.

In 2016 the Edinburgh International Festival included a Deep Time light show (Fig. 10), projected on the castle and set to music. This was the biggest outdoor, ticketed, multi-media show of its kind ever to be held in the UK. It offered a spectacular and engaging platform to share world-class research from Edinburgh staff and students including **Sinclair**, and engaged with an audience of 27,000 people in Edinburgh and approximately 133,000 online.



Fig. 10 International Festival Deep Time show, with ichthyosaur (left) and lava flow (right) projected on Edinburgh castle.

4c. Contributions to the sustainability of the discipline

We significantly strengthened our disciplinary foundation and ensured its application to increasingly cross-and inter-disciplinary challenges. Specifically, we have:

- made **38 new appointments** in the UoA (listed in section 1c), nine of which were interdisciplinary
- maintained the vibrancy and excellence of our underpinning research facilities (section 3b) including many provided as a service to the broader UK community.
- improved grant support for research and innovation (section 3a).
- responded to the challenges of evolving national priorities & initiatives, notably the emergence of the GCRF and other ODA-compatible agendas (section 3a) and Impact related to the UN Sustainable Development goals more widely (section 1dii).
- led major international and national research consortia, including **Kroon**: Chair the International Ocean Discovery Program (IODP) Forum, **Roberts**: PI of international H2020 ATLAS and iAtlantic projects, in addition to the GCRF success (section 3a).
- developed capacity for an agile response to a rapidly-evolving research agenda, for example securing three NERC Urgent awards, and supporting the Scottish Government directly in its response to COVID-19 pandemic.
- developed international research collaborations with global reach, an exemplar of which is the GCRF Urban Disaster Risk Hub, *Tomorrows Cities* (Fig. 11).

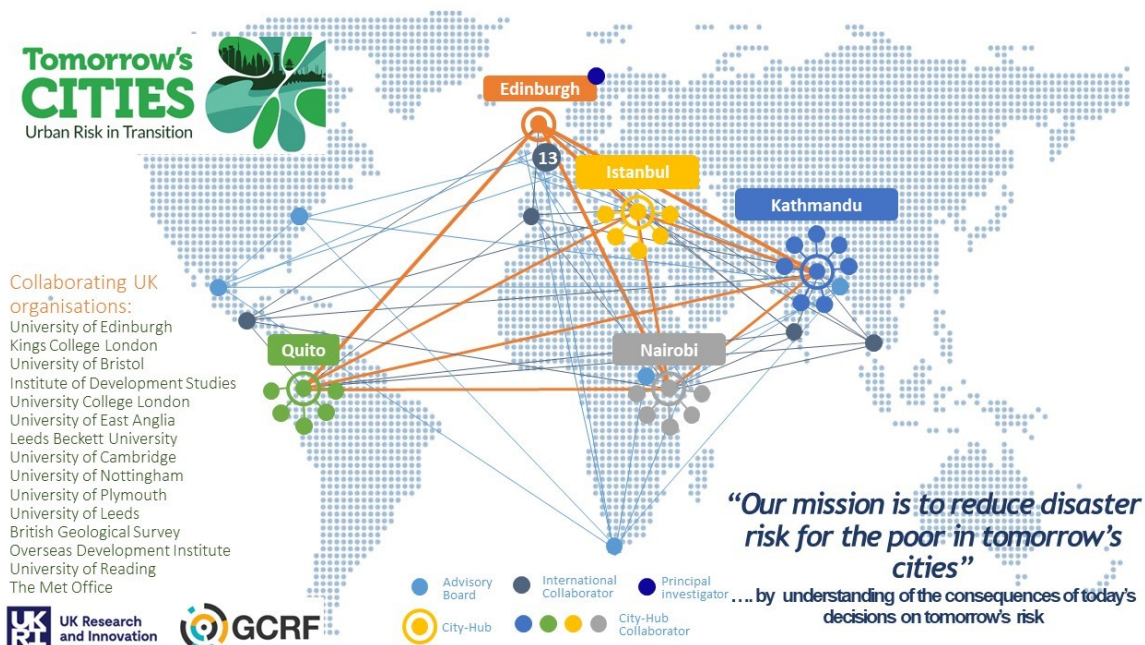


Fig. 11 The UoA leads a collective effort by 11 UK universities, and partners around the globe.

4d. Contributions to, and recognition by, the research base within the REF period

Our intellectual contribution to the research base is exemplified through the following esteem indicators (i) and leadership roles (ii):

(i) Honours, fellowships and other awards

Fellowship Elections: **Hegerl:** Fellowships of the Royal Society, the Leopoldina (German National Academy), the American Geophysical Union and the American Meteorological Society. **Cupples:** Fellowship of the New Zealand Geographical Society. **Meir:** Australian Research Council Professorial Research Fellowship, **Mudd, Nienow, Tudhope:** Fellowships of the Royal Society of Edinburgh (RSE). At an earlier career stage **Brusatte** and **Saunders** were elected Members of the RSE's Young Academy of Scotland.

Medals: **Brusatte:** Makdougall Brisbane Medal of the RSE for early career achievement in physical sciences. **Harley:** Schlumberger Medal, Mineralogical Society. **Hein:** W. S. Bruce Medal, Royal Scottish Geographical Society. **Main:** Néel Medal in Rock Physics, European Union of Geosciences. **Mudd:** Gordon Warwick Medal, British Society for Geomorphology. **Nienow:** The Polar Medal – the 5th member of UoA staff and precursor departments to have this award from the UK Sovereign. **Reay:** President's medal, Royal Scottish Geographical Society. **Robertson:** Dewey Medal, Geological Society. **Whaler,** Clough Medal, the Edinburgh Geological Society, **Williams:** Royal Society Wolfson Research Merit Award. **Wood:** Johannes Walther Medal, International Association of Sedimentologists and the Lyell Medal, Geological Society.

Awards: **Brusatte:** Clough Memorial Award, Edinburgh Geological Society, Palaeontological Association Hodson Award. **Creswell:** Finesterra Annual Lecture, University of Lisbon. **Curtis:** Reginald Fessenden Award, Society of Exploration Geophysicists. **Hegerl:** honorary degree from the University of Leeds. **Hinton:** Geological Society's Distinguished Service Award. **Main:** Ed Lorenz Lecture in Non-linear Geophysics, American Geophysical Union. **Myers-Smith:** Early Career Award, Canadian Society for Ecology and Evolution. **Slater:** David M Smith Lecture, University of London. **Wood:** Enhance Award, Association for Women Geoscientists. **Whaler:** The RAS Award for services to Geophysics and Officer of the Most Excellent Order of the British Empire (OBE). **Withers:** Geographer Royal for Scotland.

National Prizes: **Brusatte:** The Philip Leverhulme Prize. **Hegerl:** Hans Sigrist Prize, University of Bern. **Watts:** Winner of Cultural Innovation International Prize 2017, awarded by CCCB art gallery, Barcelona, for joint design-industry-community initiative with Community Energy Scotland.

Externally-funded Fellowships: We secured **four ERC Fellowships** (section 3a); 2 new **NERC Independent Research Fellowships (Street, Slater)**; and 1 Royal Society of Edinburgh Research Fellowship **Kalnins**. Other early-career Fellowships include **Henley:** The Woodward Fellowship, UK's Challenger Society for Marine Science, **Myers-Smith:** The Walters Kundert Fellowship, Royal Geographical Society and **Colesie:** Feodor Lynen Research Fellowship, Alexander von Humboldt.

(ii) Leadership and Membership of International/National Committees

Advisory board membership: Five staff serve on International boards/panels and 12 on National ones, including four who serve on UKRI advisory boards, and one who is early career **Srinivasan**.

International

- **Calder:** Member, UK Foreign Office Scientific Advisory Committee for Montserrat; Expert Witness, Government of New Zealand Inquiry into White Island Eruption Disaster
- **Haseldine:** Zero Emissions Platform: European industry and research advisory body to EU Commission
- **Roberts:** Member, Expert Panel United Nations Regular Process for Global Reporting and Assessment of the State of the Marine Environment
- **Srinivasan:** South Asia Advisor and Member, Board of Directors for US-based NGO, Farm Forward. Advisor to the Federation of Indian Animal Protection Organisations

National

- **Dibben:** Member, Scottish Advisory Group on Evidence for Policy Making
- **Ghazoul:** Member Expert Committee on Forest Science for Forest Research, the UK's national forest research provider
- **Harley:** Member, UK Committee on Radioactive Waste Management; the Advisory group to the Scottish Environmental Protection Agency.
- **Haseldine:** Member, Science Advisory Council - EPSRC Energy Programme; Carbon Capture and Storage: Ministerial Council; Government CCUS advisory group, Scotland
- **Hegerl:** Member (2009-2014), then Chair (2014-2016) of the Science Review Group of the UK Met Office Hadley Centre.
- **Main:** Member, UK Office for Nuclear Regulation Expert panel on external hazards
- **Pearce:** Member, Advisory Group, Tobacco pricing and availability, NHS Scotland.
- **Reay:** Member, Scottish Government Sustainable Renewal Advisory Group, Academic Advisory Panel on Rural Policy. Both report directly to the relevant Cabinet Secretary
- **Shortt:** Member, Scottish Government/NHS Scotland Advisory Board on Minimum Unit Price Evaluation; NHS Project Advisory Board on Price and Availability of Tobacco.
- **Tett:** Member, NERC Strategic Programme Advisory Group
- **Whaler:** Member, NERC Training Advisory Board; Advisory Committee for Earth Observation of ESA
- **Williams:** Member, NERC Science Board

Professional body senior leadership roles:

- **Bingham:** President, International Glaciological Society, British Branch; Member, UK National Committee of Antarctic Research
- **Calder:** International Association of Volcanology and Chemistry of the Earth's Interior, Executive Committee elected member 2015-2019
- **Heal:** President, International Commission on Water Quality
- **Mudd:** President, British Geomorphology Society
- **Whaler:** President, International Association of Geomagnetism and Aeronomy; Vice-President, International Union of Geodesy and Geophysics (nominated by UK National Committee)
- **Ziolkowski:** Vice president (Geophysics), Royal Astronomical Society