Institution: University of Liverpool

Unit of Assessment: UoA7

1. Unit context and structure, research and impact strategy

Our vision is to excel in Earth and environmental sciences by providing an inclusive research culture which supports the development of global research leaders, while recognising that everyone plays a part in our collective research effort. We generate impact through interdisciplinary research which benefits society and our planet by informing environmental hazard management and the transition to a cleaner, safer, and more sustainable future.

1.1 Research structure and context

The Department of Earth, Ocean and Ecological Sciences brings together three research groups, comprising 33.8 FTE staff across Earth Sciences (17.6 FTE), Ocean Sciences (7.6 FTE), and Ecology and Marine Biology (8.6 FTE). These three groups address the research themes *Geohazards & Tectonics*, *Future Energy*, *Deep Earth*, *Oceans & Climate*, and *Ecosystem Dynamics*. Our themes drive fundamental research and address the strategic needs of our external stakeholders *via* two impact challenges: *Hazards in the Environment* and *Transitioning to a Sustainable Future* (Fig. 1.1).

We are one of the two departments which make up the School of Environmental Sciences. The School provides an overarching framework and context for our strategy, alongside integrated support for academics, research staff, PhD students and equipment. Research and impact are led by the School's Research Strategy Group which – alongside four academic impact leads – consults with researchers across the Department to foster an inclusive environment.

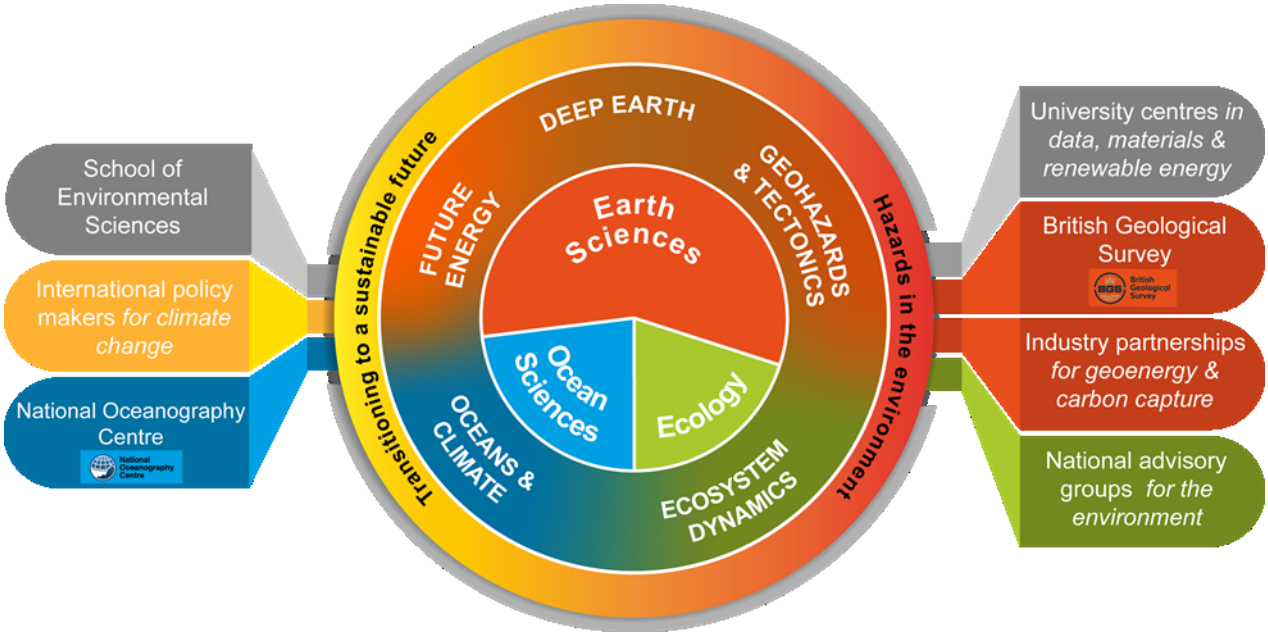


Fig. 1.1. Research groups (inner circle), themes (middle circle), impact challenges (outer circle), and key partners.

1.2 Research strategy during the assessment period

1.2.1 Achievements and evolution of our research strategy

In REF2014, our strategic aims were to strengthen research activity, and raise our national and international profile, including leading more major grant programmes. We have focussed on:

(i) Addressing fundamental questions about how the Earth system operates

We have strengthened the focus and breadth of our research by evolving our structure to host five cross-group research themes. Recruitment of new staff was informed by these themes (Section 2.1) and has led to a significant boost in publication metrics, funding awards (Section 3.1), and stakeholder engagement (Section 4). This activity has led to the development of a new University research theme, *Climate Futures*, addressing the science, societal impacts, and solutions related to climate change.

(ii) Raising our profile and enhancing grant funding

We have enhanced our grant funding and global profile through key appointments (Section 2) and by implementing a programme of activities to support our staff (Sections 2 & 3). Our annual research income increased from £2.5M per year for REF2014 to £2.8M per year for the last 5 years of the current REF. The number of research grants led by our researchers and valued greater than £1M has increased from one for REF2014 to six awarded during this REF period, including funding from European Research Council (Tagliabue), Leverhulme (Biggin), NERC (Mahaffey), UKRI (Kavanagh), Royal Society (Parr) and the Human Frontier Science Programme (Patrick).

Research highlight: strengthening the quality and reach of our publications

- 688 outputs with 10,249 citations an average of 14.9 citations per publication (field-weighted 2.06). 76% of our outputs have an international collaborator, rising from 68% (2014) to 81% (2020).
- 171 publications (24.9% of our outputs) are within the top 10% of worldwide most-cited papers and 12 of our outputs are within the top 1% of worldwide most-cited papers.
- We focus on disseminating our research through substantial articles in discipline-specific, high quality journals. We have also broadened the reach of our research through 32 articles in more general science journals, including *Science* (7), *Nature* (6), *Nature Geoscience* (9), *Nature Communications* (5), and *Proceedings of the National Academy of Sciences* (5), compared with 18 outputs in the same journals for REF2014. We are 10th in the UK and 92nd globally in the Nature Index 2020 for Earth and environmental sciences.

(Scopus data, SciVal)

(iii) Strengthening equality and diversity

We are committed to staff equality, diversity, and well-being, as evidenced by our progression in Athena Swan awards from Bronze (April 2016) to Silver (May 2019). We identified an imbalance in the diversity of our grant awardees: of the 20 investigators who received an award as principal investigator (PI) during the period 2013/14 to 2015/16, only five were women. To address this, we introduced a series of support mechanisms, including grant workshops and internal grant review processes, which led to an increase in the proportion of female PIs and the number of large grants they won. Four of our female PIs were awarded grants during the REF period worth over £1M (Kavanagh, Mahaffey, Parr, Patrick). We have instigated research-led national events to provide support for staff and students from minority ethnic groups and the LGBT+ community (Section 2.2.4).

1.2.2 Mechanisms to enable and develop research strategy

(i) Strategic leadership and staff consultation

We evolve our research strategy through staff engagement at a series of events. Monthly departmental meetings are complemented by Head of Department coffee mornings with each of our three research groups, allowing specific issues to be addressed in small-group settings. Regular research fora bring together all staff from across the School over lunch every two months, where research progress and support are standing items. Dean-led annual school away days are held, for group activities and strategic thinking. Topics have included "*How to maximise time for research*" (May 2016), which motivated our move to introduce online assessments and marking (with iPad Pros provided to all academics), and "*Progress since 2015 review and strategy beyond REF2021*" (July 2019).

(ii) Strengthened research themes

We have made strategic appointments of new staff from a range of career stages to create critical mass and strengthen our five research themes (Sections 1.2.3 and 2.1).

(iii) Staff development

We strengthened training for submission of publications and grant applications via our 'Raising the Level' workshops. We have also improved support for promotion applications with an emphasis on encouraging early-career and female staff through mentorship. We increased the number of female professors from none at REF2014 to two (Mahaffey; Parr), equating to half of professorial appointments during this REF period including the established Chair in Oceanography.

(iv) Fellowship support

We have proactively increased research fellow recruitment by appointing a dedicated School fellowship lead establishing mentoring and review panels for prospective applicants, and committing to match-fund Leverhulme Early Career Researcher Fellows. This support has generated a more than five-fold increase in our number of externally-funded fellows since REF2014 (Section 3.2).

1.2.3 Interdisciplinary research

We have advanced our interdisciplinary research themes through mechanisms including:

(i) Hiring strategy

We are able to address environmental challenges by identifying potential for collaboration across traditional discipline boundaries (Section 2.1).

(ii) Staff networking

We have promoted inter-disciplinary research challenges via dedicated networking workshops on "*Interdisciplinary research and large grants*" (January 2017), "*GCRF scoping workshop on sustainable coastal cities*" (July 2017), "*Data Analytics and Ocean Sciences*" (December 2017, January 2018), and "*Living with volcanoes"* (March 2018). An example of this activity includes a collaboration of marine biogeochemist (Mahaffey) and big-data machine-learning specialist (Arribas-Bel) winning a NERC grant to examine nitrogen cycling in the Arctic.

(iii) Links to external partners

We have strong links with external partners (Section 4.2), particularly the National Oceanography Centre (NOC), where we have established an ongoing Framework Agreement since 2015. Close alignment in operational and strategic operations is achieved via annual meetings between University and NOC senior leadership teams, and quarterly meetings of the cross-faculty Partnership Operations Group. This collaboration has resulted in significant joint scientific research (9% of our outputs - Scopus, SciVal), co-supervision of eight PhD students, joint seminars, and public events for social impact, including the naming of the RRS Sir David Attenborough in 2019.

(iv) Leadership of interdisciplinary initiatives

We lead the new University research theme, *Climate Futures*, addressing the science of climate change, alongside the societal response, and solutions (Williams). In its first year, *Climate Futures*

worked with civic and metropolitan councils in Liverpool, contributed to the development of a N8 Universities research initiative informing Government on reframing activities post- COVID-19, and led to the University being a COP26 Universities Network partner.

1.3 Impact strategy during the assessment period

1.3.1 Achievements and evolution of our impact strategy

We have focused our research effort upon two impact challenges (Fig. 1.1; Section 4.2). Below, we provide examples of substantial impact we have made under these two challenges, including our three REF2021 impact case studies.

Challenge 1: Hazards in the Earth System

Our work on hazards has concentrated on:

- Monitoring and understanding volcanic activity to assist risk management and policymaking in Official Development Assistance countries (De Angelis, Lavallee, **REF2021 impact case**).
- Assessment of risks linked to induced seismicity that led to the Government placing a moratorium on fracking in England in 2019 (Edwards, **REF2021 impact case**)

Challenge 2: Transitioning to a Sustainable Future

Our work on transitioning to a more sustainable future has focussed on:

- Assessing the health of the coastal seas, driven by providing Marine Climate Change Impact Partnerships report cards for both the Department for Environment, Food and Rural Affairs, and the Centre for Environment, Fisheries and Aquaculture Science (Sharples, Mahaffey, Mieszkowska, Jeffreys).
- International activity connected to climate change policy, driven by contributions to, and authoring of IPCC reports, and participating in COP25 (Tagliabue, Williams).
- Assessment of reservoir quality for current oil and gas fields, and suitability for subsurface CO_2 storage (Worden, Faulkner, **REF2021 impact case**).

1.3.2 Processes to support impact

To implement our impact strategy, two departmental impact leads were appointed in 2016 to raise the profile of impact and develop a rolling portfolio of events. Specific activities included:

- Externally commissioned ‘Impact and Intellectual Property Audit’ (May 2016)
- Impact-evidencing ‘Speed Dating’ session (July 2016)
- ‘Dragon’s Den’ impact support pitching events (October 2016)

Practical steps were taken to support our impact culture:

- Two university teachers were appointed in 2018 for two years, to release time for four researchers (De Angelis, Edwards, Kavanagh, Worden) to develop impact opportunities, including assessing seismic and volcanic hazards, developing carbon capture, and providing wider training for secondary school geology teachers.
- Impact contribution is now part of every staff member’s annual ‘Performance and Development Review’, and is considered in promotion evaluations.
- Pump-priming is provided to staff through competitive, annual funding calls (Section 3.3).

1.4 Research integrity and an open research environment

We embrace an ethical approach to research and view an open research environment as a key component of research integrity.

Our **research papers** are made publicly accessible through our Institutional Repository for Green Open Access (OA) publications. We have published 172 papers in Gold OA journals and support this practice using a combination of internal funding and external block grants.

We are committed to making our **research data** widely available for re-use, depositing data in accessible archives, such as the British Oceanographic Data Centre. To drive this agenda, we play a leading role in initiatives including:

- International GEOTRACES: Developing new platforms for data provision; led by Tagliabue, co-chair of GEOTRACES data management committee.
- Generic Mapping Tools: Delivering widely used, free, open-source software for Earth, ocean and planetary science; Uieda, a core team member, received a fellowship from the UK Software Sustainability Institute in 2020 to further develop workshops on best practices for research software.
- European Plate Observing System: Trans-national access network for widening availability to state-of-the-art facilities and data that includes our Geomagnetism and Electron Microscopy Laboratories (Biggin & Mariani).

In line with the institution's policy, we are committed to providing a rigorous process of ethical review. Our dedicated Ethics Officer (Tagliabue), advises on ethical aspects of research projects and on processes for seeking ethical approval. Every staff member completes the university-produced "*Research Ethics Training*" online module.

1.5 Our research and impact strategy for the next five years

Our overarching vision is to excel in Earth and environmental sciences by pursuing the following strategic aims (Table 1.1):

Strategic aim	Measure of success
1: Consolidate and strengthen our disciplinary excellence by supporting and developing our individual junior researchers to become research leaders.	Strengthen research outputs including the proportion of highly-cited papers. Increase research income from UKRI, industry, and charities.
2: Extend our interdisciplinary research agenda to address pressing global challenges.	Increase engagement with the broader scientific community and external stakeholders via joint studentships, workshops, grant activity, and papers.
3: Continue to emphasise equality, diversity, and staff well-being, as central to our research environment.	Consolidation of activities from our Silver Athena Swan award and work towards the Gold award.
4: To deliver impactful research addressing the challenges of "Hazards in the Earth system" and "Transitioning to a Sustainable Future".	Provide a leading role in delivering the University's '*Climate Futures*' theme to provide a safer and more sustainable future through public policy and industry.

Table 1.1: Strategic aims for the next five years

2. People

2.1 Staffing Strategy

People are the heart of our Department and enable us to achieve our strategic aims. We believe in excellence in diversity and equality of opportunity; these principles underpin our recruitment, induction, development, and support of all our researchers - from research students to professors.

Our Department's recruitment strategy has been identified as sector-wide good practice by the national Equality Challenge Unit within Advance HE (in Athena Swan award letter) in terms of how

posts are advertised and shortlisted. Shortlisting and interviews take place with a gender-balanced panel and an external member (external to the Faculty, or external to the University for professorial appointments). We train panels on 'Understanding Unconscious Bias' and reinforce this by using Royal Society videos before shortlisting and interviews. Our policy is to ensure at least one female applicant is shortlisted, otherwise posts are re-advertised or new individuals approached. The University is a *Disability Confident*, *Stonewall Diversity* and *Time to Change* employer, and is applying for Advance HE's *Race Equality Charter*.

In making new appointments, (Fig. 2.1), we seek to advance our research strategies, develop our multidisciplinary impact challenges (Section 1.3), and best utilise our physical infrastructure (Section 3.3). Specifically, we have made appointments to:

Fig. 2.1. Some of our new colleagues

- Develop unique cross-discipline skillsets, involving junior appointees in sedimentology/coasts and oceans (Stevenson, 2017), geophysical modelling/geographic data science (Uieda, 2019), deep Earth-bio/environmental magnetism (Paterson, 2019), and oceanography/marine ecosystems (Whitby, 2020; Jeffreys, 2016);
- Enhance our cross-cutting impact challenges with early career appointments made in *Transitioning to a Sustainable Future* (McNamara, geothermal energy, 2019) and *Hazards in the Environment* (Jones, volcanology, 2020);
- Expand the scope of established facilities (Jeffreys, Jones and Paterson recruited to the Environmental Geochemistry, Analogue Modelling, and Geomagnetism labs, respectively) (Section 3.3);
- Provide leadership through senior appointments to the *Future Energy* (Burgess, 2016) and *Ecosystem Dynamics* (Hirst, 2017) research themes.

The balance of our staff profile is shown in Fig. 2.2. We made two professorial appointments in this REF period; the remainder had joined at lecturer level and rose through our structure.

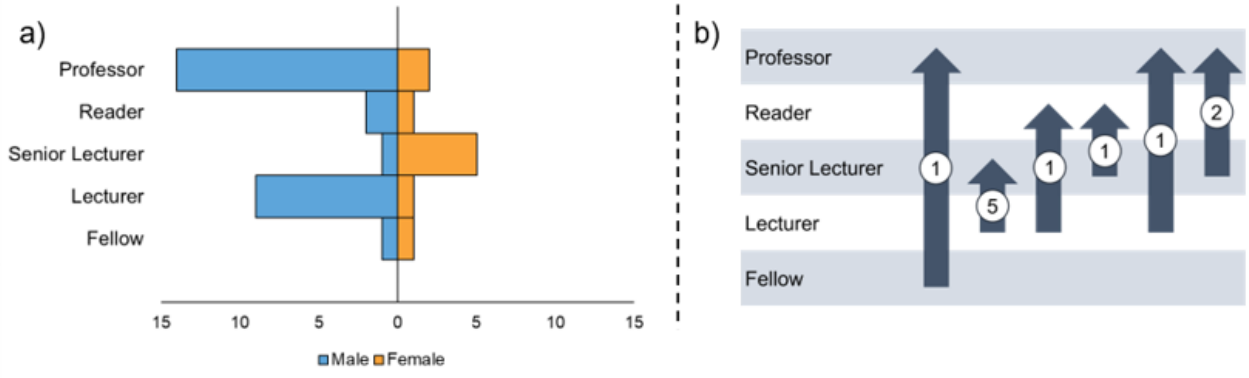


Fig. 2.2. (a) Staff profile by career stage and gender; (b) number of staff promoted since 2014.

2.2 Staff development and support

Our goal remains to consolidate and expand our disciplinary excellence by supporting and developing researchers, from induction onwards, to become research leaders. We achieve this through:

2.2.1. Career development and mentoring

Individual meetings with Department and School heads occur at least three times during the first year of employment to support colleagues to become integrated. New academic staff receive start-

up funds (typically £8k) to initiate their research activities. They have a reduced administration and teaching load for their first 24 months (equivalent to 0.25 FTE/year), to facilitate teaching certification and establish their research programme. Early career academic events offer networking opportunities, advice on funding applications and achieving promotion, and coaching sessions on managing time and strengthening working relationships.

Annual Personal Development Reviews between every staff member and a senior colleague develop action plans which address career trajectory and aspirations. Mentoring relationships are established during the induction period. Based on feedback from our School's 2018 staff survey, we have developed our in-house programme to support staff interests and needs, including improving induction and encouraging more staff to take up training opportunities.

We support staff through the promotions process with workshops and one-to-one meetings. Since 2014, we have seen 18 instances of promotion (10F/8M), including four to chair (2F/2M), five to Reader (3F/2M), and eight to Senior Lecturer (5F/3M).

To develop the research potential of our staff, particularly early career researchers, we have implemented a proactive recruitment and support process for fellowship applications (Section 3.2), which has increased the number of externally-funded fellowships awardees from two in the last REF cycle to 11 in the current. Six of these new fellowships were for early career staff for three years or more.

People highlight: a new generation of research leaders

Four staff, representing all three research groups, have progressed from Senior Lecturer to Professor since 2015. The rapid progression of these colleagues was facilitated by support for grant writing (total awards averaging £2.3M each), appointment to leadership roles (Postgraduate Student Director, Research Group Lead, Doctoral Training board membership, United Nations panel), reduced teaching load following maternity leave, support for facilities, and mentorship by senior staff.

Clockwise from top left: Claire Mahaffey, Kate Parr, Andy Biggin, Alessandro Tagliabue

Our Postdoctoral Researcher Forum, established in 2016, allows for experiences to be shared, concerns raised, and guidance offered. Events have included a postdoctoral and early career network mentoring event in October 2018 to discuss recent experiences of academic progression.

We have included early career academics and researchers in decision-making committees, alongside our Senior Management Team. This increases prospects of individual progression and ensures the sustainability of the Department. We support staff to complete *Aurora,* Advance HE's leadership development initiative. Participation by Parr, Mahaffey, and Kavanagh preceded promotion and major research awards from the Royal Society, NERC, and UKRI, respectively.

2.2.2 Research development opportunities

All part- and full-time academic staff are eligible for one semester of research leave every five years, independent of other special leave, to dedicate time to achieve specific research goals and/or develop impact activity. Each case is discussed at the applicant's annual Professional

Development Review. Teaching and administration activity during the research leave period is reallocated amongst colleagues and not transferred to another semester. Successful sabbatical outcomes include Mariani securing £500k for a new electron microscope facility and Faulkner developing a new collaboration with Caltech on modelling earthquakes.

People highlight: raising the level workshops

Following staff feedback (*via* a School survey), we identified the need for a mechanism to enable authors of papers to articulate the importance of their studies in the title, abstract, and main text of their journal submissions. This was achieved by initiating '*Raising the Level'* workshops, which run three times per year and are open to all staff members of the UoA. At these workshops, individuals attend with draft manuscripts and receive and provide reciprocal feedback aimed at increasing the recognition of the study's significance amongst non-specialists. This activity led to over 30% of colleagues benefitting from regular pre-submission review.

We have enhanced the support for staff to compete for research funding. We have extended our internal peer review of research grant applications to ensure substantive and constructive feedback is provided to all applicants, thereby increasing confidence and resilience. All staff at Lecturer, Senior Lecturer, and Reader levels receive unconditional annual awards to support research activities of £500, £400, and £300, respectively. The Department holds an additional training budget of £10,000/year, which is dispersed through our research groups. Applications and awards are monitored to ensure equality of opportunity.

2.2.3 Recognising success and promoting wellbeing

Our School newsletter includes news of grants and prizes awarded to researchers and reports of research fieldwork and findings, ensuring that colleagues learn of one another's successes. Our end-of-year away day to Ness Botanic Gardens includes the presentation of our annual staff awards.

The wellbeing of our research community is important to us (Fig 2.3). Our 2018 School survey showed that 92% of colleagues enjoy their work and 88% feel a sense of personal achievement from it. We were the first School in the University to survey staff regarding their wellbeing during COVID-19 disruption. We are committed to the University's Wellbeing Week, running a full programme of events every year since 2014.

Fig. 2.3. A 2016 School event addressing work-life balance, which included interactive workshops and panel discussions

2.2.4 Championing equality and diversity

We are fully committed to an inclusive and supportive environment with equality and diversity at the core of this commitment.

(i) Athena Swan and LGBT+

The School of Environmental Sciences achieved Bronze (2016) and Silver (2019) Athena Swan Awards, demonstrating our progress in promoting equality and diversity. Our School Diversity and Equality Committee has taken the lead in driving forward our Athena Swan applications and includes the Chair of the University Staff and Postgraduate LGBT+ Network. Activities include demonstrating a positive environment for LGBT+ staff with presentations at the National LGBT+ STEMinar at the Institute of Physics (January 2019), and leading the organisation of the University's first staff and postgraduate LGBT+ STEM Day (July 2019). In 2019, the School was the first in the University to encourage the use of rainbow lanyards and include pronouns in email

signatures to promote visibility and discussion of LGBT+ issues.

All staff undertake mandatory Diversity and Equality Training. Diversity and Equality is a standing item in departmental meetings and features in every school newsletter (Fig 2.4).

Fig 2.4. Dr Andy Heath, Senior Research Fellow, was awarded the University Good Practice in Equality award in 2014, recognising his contribution to equality and diversity and co-founding a flagship initiative that coordinates University LGBT+ events and media.

(ii) Flexible working
Flexible working arrangements are available upon return from all types of extended leave. Adjustments are made to workloads and patterns as needed, including a phase-in of teaching and supervisory responsibilities. Mahaffey and Jeffreys achieved research grant success soon after returning from leave, aided by flexible working arrangements. We operate a local policy whereby staff can reduce their FTE to accommodate their needs, and then return to full time in future, allowing us to retain motivated and committed members of staff.

The School appoints a primary contact for colleagues before, during, and after they take maternity, parental, and adoption leave, offering consistency as well as a reliable source of information and support. '*Keep in Touch'* days during leave are paid, allowing staff to attend work, meetings, or conferences, and facilitate ongoing connection to the Department. As a safety net for PDRAs and PhD students whose funding does not allow for maternity payments, the School provides direct financial assistance (total of £17,500 over the period 2015 to 2018).

(iii) Ongoing challenges and wider sector engagement
We recognise that there are challenges in terms of diversity of our researchers, and have delivered events to provide support and raise awareness of:

- *Women in science*: '*Science and Gender: a personal perspective'* (July 2017) and '*Pathways through Academia: Women in* Science' (November 2017).
- *Minority ethnic groups*: Kavanagh co-organised and hosted a series of national Equality, Diversity and Inclusivity Panel events in 2020. The theme '*talent is equally distributed, opportunities are not'* focused on improving diversity, particularly minority ethnic groups in volcanology and geosciences. Over 80 attended live and more than 300 watched the recorded videos on YouTube, and the event led to the publication of a report. At a more local level, our Diversity and Equality Committee has focused on enhancing BAME diversity by discussing and implementing a number of actions aimed at recruitment and inclusion.
- '*Being LGBT+ in academia'*: members of the School organised and contributed two out of five panellists (one UoA7) to an event for National Postdoc Appreciation Week (September 2020), highlighting the challenges that LGBT+ researchers face and strategies to overcome/mitigate these barriers. This online event was attended by 43 early career researchers from eight different institutions (two non-UK).

2.3 Research students

Postgraduate students are a valued component of our unit and make a major contribution to our research success. We have recruited 118 research students (3.5 per staff member) since 2014, comprising 41% female, 59% male, and 26% from overseas. 23% are from BAME backgrounds, including 8% Black British and 7% Chinese.

Our overall doctoral completion rate is 96%.
2.3.1 Postgraduate Research Funding

We have benefited from a diverse range of funding sources, including involvement in two NERC Doctoral Training Partnerships, specifically '*Adapting to Challenges of a Changing Environment*' (ACCE; 2014-2018, renewed in 2019 and led now by Liverpool; two to four studentships per year) and *Earth, Atmosphere and Oceans involving Manchester* and the *National Oceanography Centre* (2014-2018; eight studentships per year).

We have also benefited from PhD funding from within the Faculty, the EPSRC Centre for Doctoral Training in *Quantification and Management of Risk & Uncertainty in Complex Systems & Environments,* and the Leverhulme Research Centre for *Functional Materials Design*.

Postgraduate students are supported and integrated into large research projects through major grants funded by the European Research Council (five studentships), the Marie Skłodowska-Curie Actions Innovative Training Network (2019-2022, three studentships), Leverhulme (four studentships), and UKRI (three studentships). We have successfully recruited PhD students supported by overseas and industrial funds, including Petroleum Technology Development Fund (Nigeria), Science without Borders (Brazil), China Scholarship Council, and Conacyt (Mexico).

2.3.2 PhD support, training, skills and opportunities

Every PhD student is supported by at least two Liverpool-based academics who have received supervisor training and provide constructive feedback at each milestone.

We prepare our PhD graduates for both academic and non-academic careers. Completion of a 'Development Needs Analysis' early in the postgraduate journey, with training sessions delivered through our programmes, has driven an increase in student satisfaction in training plans since 2014, up by 20% between 2015 and 2019, and 25% higher than the Russell Group average*.

Since REF2014, there have been >250 authorships or co-authorships by PhD students in international journals, including papers in multidisciplinary, high-impact journals. 82% of our graduates have published first-authored papers, with more than half publishing two or more.

We hold an annual School PhD student conference, in addition to DTP specific conferences, that develops confidence in presentational skills and has led to the following prizes and awards:

- Best presentation three years running at the Geological Society's Tectonic Studies Group annual conference (2017-2019);
- PICO Award from European Geosciences Union (2018);
- First prize at 14th International Seabird Group conference (2018);
- Best Talk at International Union for the Study of Social Insects meeting (2018).

Our emphasis on gaining experience with non-academic partners has driven an increase in PhD student satisfaction for advice received on career options (up by 16%, 13% higher than Russell Group*). More students are now taking part in placements or internships (up by 10%, 6% above Russell Group*) through initiatives including NERC Doctoral Training Partnerships (with up to 60% CASE studentship allocation), a Marie Skłodowska-Curie Actions ITN requiring a six-to-nine-month placement outside of the UK, and winning international internships (UKGEOS; Royal Society).
*UoA7 University of Liverpool, PRES 2015 & 2019 results and benchmarking data for Q16:1 - Agreeing a personal development plan, Q16:4 – Receiving advice on career options, Q16:5 – Taking part in a placement.

People highlight: PhD achievements

In July 2019, PhD student Yael Engbers led the Instagram coverage of our stand at the Royal Society Summer Science Exhibition. In 2020 she was first author on a paper in PNAS, spoke to Dutch newspaper NRC Handelsblad about her research, and wrote an article with more than 250,000 reads on TheConversation.com which will form the "action" component of her thesis (see Table 2.1)

In 2018, Maddie Brasier was one of three UK PhD students to win a place on the all-female Homeward Bound leadership expedition in Antarctica. On completing her PhD, she took up a post-doctoral position at the Antarctic Climate and Ecosystems Cooperative Research Centre in Tasmania.

In 2019, we developed a new strategy for PhD student training in Earth and ocean science (Table 2.1), which embeds impact across the PhD experience. The Faculty supported this strategy with three studentships in 2019-20 to enhance our position for the next national Doctoral Training Partnership competition. Final year students have been encouraged to submit a "solution" or "action" component/chapter in their thesis. The first of these (a thesis chapter describing the results of a six-month placement with Schlumberger) was awarded in 2020 and elicited highly positive feedback from the examiners.

<table>
<tr><th>Year</th><th>Challenge</th><th>Solution</th><th>Action</th></tr>
<tr><td>1</td><td rowspan="4">Research training
• Background context
• Specialist techniques
• Academic skills
• Annual Conference
• Annual Progression</td><td>Professional training
• Data analytics
• Entrepreneurship
• Practical environmental challenges</td><td>Professional training
• Outreach, impact and social media
• Environmental management and policy</td></tr>
<tr><td>2</td><td colspan="2">Engagement with partners through a one-week problem solving and "Dragon's Den" pitching event</td></tr>
<tr><td>3</td><td>Option 1: 1-3 month collaboration with partners (industry, charities)</td><td>Option 2: 1-3 month collaboration with social scientist, policy maker or science communicator</td></tr>
<tr><td>4</td><td colspan="2">Output: Report on solution / action related to environmental challenge as thesis component</td></tr>
</table>

Table 2.1: Summary of new Liverpool "Challenge, Solution, Action" doctoral training programme for Earth and ocean sciences

2.4 Our REF submission

Our selection of outputs follows an anonymised annual review of nominated outputs, with oversight from a School Review Panel (comprising 12 people including early career staff, and with one third female, reflecting the departmental gender balance, and ensuring fair representation). The assessments inform our REF selection panel, which includes the Head of Department, Director of Research, Diversity & Equality Lead, two early career researchers, and three other colleagues.

3. Income, infrastructure and facilities

3.1 Funding and facilities strategy

Our strategy has been to provide directed, bespoke support to staff, particularly early career researchers, to develop outstanding research and impact profiles by enabling them to generate income, access the best facilities, and contribute to the discipline base. Specifically, we provide first-class training, structured mentoring, and dissemination of best practice in raising research income across the Department (Section 3.2). We have also provided tailored support to researchers, via pump-priming funding, staffing, and scheme-awareness (Section 3.3), to help build their income potential and research capability. Notably, our funding base has evolved in the following ways:

(i) Increases in grant funding and diversity in funding
Our research income has increased over the REF period (Fig. 3.1) from an annual average of £2.5M per year in REF2014 to £2.8M per year for the last 5 years of the current REF. There has been substantial growth in larger prestigious grants awarded to key facilities. The Unit has received £2.4M of in-kind research income from UKRI, mainly for ship time.

In accord with our research strategy (outlined in Section 1), we have maintained and strengthened our UKRI support (increasing from 37% (REF 2014) to 57% of our research income, Fig 3.1) and expanded our funding from UK charitable organisations (Leverhulme Trust, Royal Society). We have additionally increased the number of externally-funded fellowship awardees in the Department from two in 2008-2014 to 11 in the current cycle.

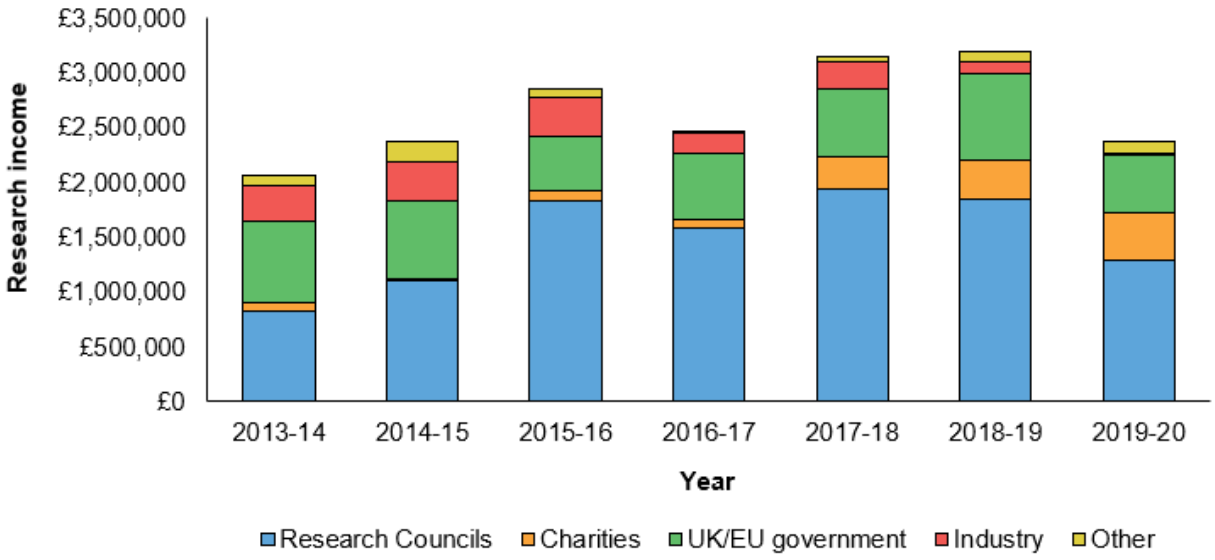


Fig. 3.1. Research income for each year separated by funder with an upward trend in the three-year average.

In 2016, we provided additional support for grant writing and widening participation initiatives (Section 3.2). The average total awarded to PIs per year increased by 46%, from £1.98M in the period prior to the interventions (2013/14 to 2015/16) to £2.89M in the subsequent interval (2016/17 to 2019/20). Furthermore, the average size of awards increased between these two intervals, with female PIs seeing an especially strong increase (from £175k to £379k) (Fig 3.2) drawing upon our targetted initiatives (Section 3.2).

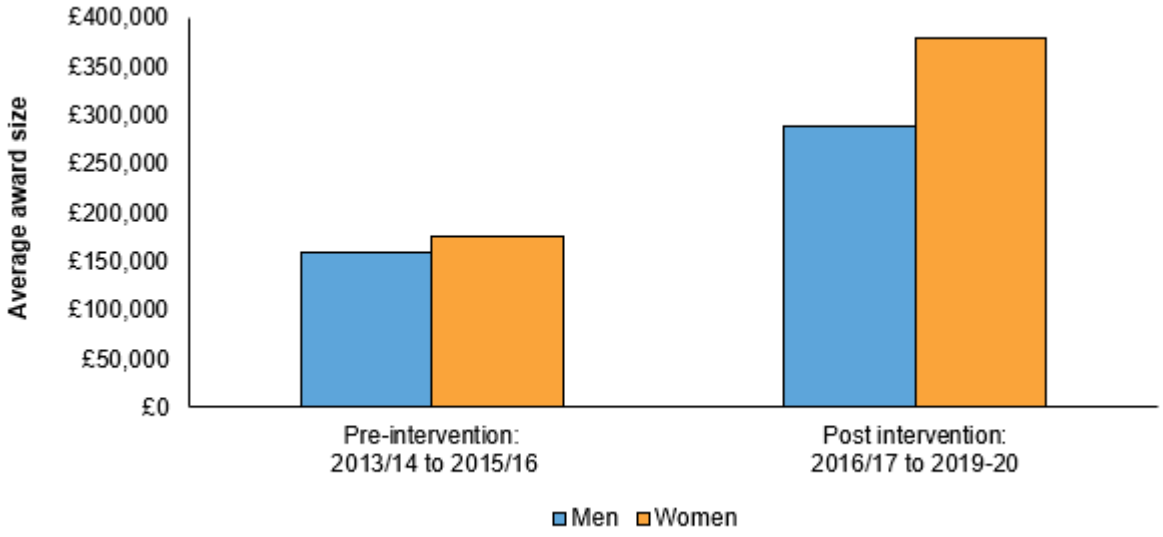


Fig 3.2. Average size of awards made to PIs, before and after the intervention described in the text.

(ii) Increase in large grants
The number of large grants (>£1M) awarded to the Department has increased from one to six between 2014 and 2021. These include one award from the European Research Council (a consolidator grant), a Leverhulme Trust Research Leadership Award, and a NERC Strategic Grant. We have eight facilities which have attracted more than £1M in external funding in this REF cycle (Section 3.3; Table 3.1).

3.2 Organisational infrastructure

We support staff in two main ways. Firstly, we provide innovative supportive mechanisms to help our researchers submit stronger grant and fellowship proposals so they can win external funds to undertake independent research projects. Secondly, we facilitate pilot studies and small-scale projects by providing internally sourced, responsive funding opportunities. The success of this approach is indicated by the increased value of grants and fellowships awarded (Section 3.1). Since NERC established demand management measures for Standard Grants in 2015, Liverpool has seen its applications capped in only four of the 10 rounds, whilst UoA7 Category A staff have achieved a success rate of 28%.

The School's Research Strategy Group organises biannual grant-writing workshops (also run by an external consultant Parker-Derrington in 2015 and 2019), grant- and fellowship-pitching events (two per year), and a comprehensive process to support the submission of competitive applications. The latter consists of presentation of outline research proposals 3-4 months before submission deadlines, feedback on two-page "concept notes" 2-3 months pre-deadline, and internal peer review of the full bid one month prior to submission. Demand management is undertaken at the School and/or University level *via* an independent panel process which offers constructive feedback and support to all applications.

Dedicated Fellowship application support has increased the number of awarded 3+ year fellowships from two during the last REF cycle to six in the current. Staff and PhD students are directed to schemes and actively encouraged to apply or connect with a potential external applicant. Individuals are then supported *via* one-to-one mentoring, workshops, and peer reviews of concept notes and draft applications. An online fellowship pitching event in July 2020 featured six keynote speakers and ten pitches of proposal ideas, attracting more than 55 participants. Schemes in which we have successfully competed include the UKRI Future Leader Fellowship, NERC Independent Research Fellowship, Leverhulme Early Career Fellowship, and Leverhulme Emeritus Fellowship.

Funding highlight: Leverhulme Early Career Fellowships

In 2016, a new School-level process was initiated to manage demand for the Leverhulme Early Career Fellowship scheme, which is popular among graduating PhD students and early-stage PDRAs *but* has financial requirements (50% salary from host funds) and necessitates careful oversight. Short "concept notes" are solicited three months prior to the submission deadline and are reviewed by a School panel which provides feedback on all applications and nominates one per year to go forward to a full bid. In three of the four years that a departmental candidate was put forward, the applications were successful and supported fellowships in our Themes Geohazards & Tectonics (Kendrick, 2016), Ecosystem Dynamics (Bishop, 2017) and Deep Earth (Bono, 2020).

Since 2017, internal research support budgets have operated via fixed and responsive modes. The fixed mode ensures that every independent researcher (excluding professors) receives an unconditional annual award, which can be used to sustain research activity and thereby increase the likelihood of future external funding, regardless of current external grant income (see 2.2.4). For the responsive mode, annual budgets are devolved to the three research groups. Several calls for applications are made each year and a transparent process makes awards based on the potential for pump-priming of future externally-funded projects, conference networking, and research visits. Over £30,000 of responsive mode funding has been made available to over 20 colleagues (mostly early career academics) since September 2017. Applications and awards are monitored to ensure equality of opportunity is realised.

3.3 Operational Infrastructure

Our facilities support the activities of the research groups and themes, and are well-known laboratories internationally. We have identified two primary needs for sustaining these high-performing facilities such that they can maximise their income, access, and output potential: baseline equipment and the provision of dedicated, trained technical staff. This strategy has been effective in supporting 11 facilities across all five research themes (Table 3.1), enabling them to obtain associated external awards of >£18M over the REF period and support access to 40+ researchers external to the Department. Our facilities are widely accessible, with several early career appointees in the REF period (Jones, Paterson, Whitby) directly benefitting from placement in established labs (Analogue Modelling, Geomagnetism, and Trace Metals respectively).

Table 3.1: Summary of facilities

	Deep Earth	Geohazards and Tectonics	Future Energy	Oceans and Climate	Ecosystem Dynamics	Associated external awards 2014-2020	Associated peer-reviewed papers 2014-2020
Seismology						£3.0M	80
Rock Deformation						£3. 5M	65
Scanning Electron Microscopy						£2.2M	23
Geomagnetism						£2.1M	50
Analogue Modelling						£1.5M	7
Volcanology & Geothermal						£2.1M	94
Sedimentology						£140k	6
Diagenesis						£1.5M	48
Environmental Geochemistry						£1.84M	15
HPC Computing						£1.48M	>90
Trace Metals						£66k	22

During the REF period, £260k has been provided from the School and Faculty, and £500k from the University to purchase equipment. Our dedicated research facility technicians (7.4 FTE) across the Department work in specialised roles and provide continuity in the facilities, ensuring that specialised instrumentation is maintained and can be further developed using their unique skillsets. In-house technicians also perform training of new staff, students, and visitors. They are provided with opportunities to develop expertise in both the technical and interpersonal aspects of their role via formal training and interactions with other members of their research group. Technicians form a collaborative cohort within our professional services team, but also report directly to individual academic facility leads in their day-to-day activities.

Achievements linked to our departmental facilities include:

- Environmental Geochemistry (Mahaffey): funding from NERC Changing Arctic Ocean programme and NERC Large grant COMICS on the biological carbon pump.
- Analogue Modelling (Kavanagh): awarded UKRI Future Leader Fellowship and subsequent new full academic appointment made (Jones).
- Diagenesis (Worden): leads the Chlorite Consortium, a major industry partnership with Shell, BP, Chevron, Equinor, Eni, Chevron, Woodside, and Petrobras since 2014.
- Rock Deformation (Faulkner): seven of its previous members have progressed to independently establish their own rock deformation labs.

We are part of, and contribute leadership to, the Faculty Shared Equipment Facilities, which provides technician support and long-term maintenance costs, and access to all researchers. This includes the Scanning Electron Microscope facility (led by Mariani since 2020) that incorporates new high-resolution Zeiss imaging instruments (including a state-of-the-art X-ray CT microscope) supported via University funding (£500k, Mariani) and an EPSRC equipment award (£2.3M, Worden) for research into carbon capture and sequestration.

Funding highlight: infrastructure support - Geomagnetism facility

Facility lead, Biggin was a NERC Fellow in 2014 who benefited from training and mentoring in grant writing to successfully win eight grants as PI over the REF period, with a combined value of £1.7M. Over the same period, the Geomagnetism facility was awarded £50,000 of internal responsive research funding for instrument purchase, upgrades, and repairs and bridging funds to secure the permanent employment of a 0.9 FTE dedicated technician. The investment contributed to making this facility world-leading, attracting a NERC Independent Research Fellow (Paterson) in 2018 and a Leverhulme Early Career Fellow in 2020 (Bono). The facility was also able to widen access to diverse early career researchers including two undergraduates on NERC research experience placements, one high school student on a Nuffield research placement, and a 12-month PhD student visitor from Brazil.

Our facilities have underpinned successful applications for funds to promote impact activities and engagement with stakeholders, with internal funding totalling £120k (such as EPSRC Impact Acceleration Account awards, UKRI Industrial Strategy Challenge Fund and Higher Education Innovation Fund); see an example from the trace metals facility in section 4.1.3.

3.4 University support for our unit

A priority of the University's *Strategy 2026* is to re-locate our School's two departments within a new, £48M state-of-the-art physical space by 2024. Architect's plans for this 9,000 m^2 School of Environmental Sciences building include provision for a total of 16 state-of-the-art laboratories to house our research facilities. Despite widespread disruption to capital plans due to COVID-19, the project remains on track, with the University committing a further £1M in 2020-21 to move the project to RIBA Plan of Work Stage 2 for the design and construction of the building.

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

We lead and participate in national and international collaborative projects with governments (including the UK, Netherlands, Switzerland, and Guatemala), international advisory bodies (such as the IPCC), and industry. Our research achieves impact through our two impact challenges: '*Hazards in the Earth System'* and '*Transitioning to a Sustainable Future*' and helps to define the future of our discipline.

4.1 Research collaborations, networks, and partnerships

4.1.1 International collaborative networks and partnerships

Of our 688 publications during the REF period, 76% included an international co-author based in leading scientific nations or in smaller countries with less well-developed scientific research programmes (Fig. 4.1)

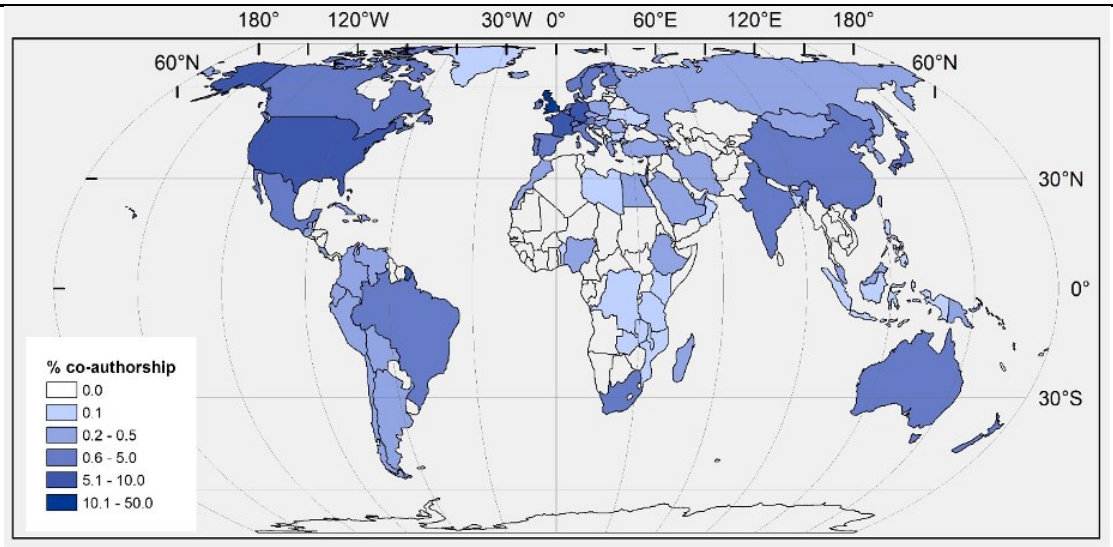


Fig. 4.1. Distribution of research collaboration measured as % of all output co-authorships across countries in 2014-2020 (Scopus - SciVal) from 688 papers from Liverpool.

Contributions to international collaborative initiatives include:

Ocean Sciences:

- NERC Strategic Changing Arctic Ocean brings together seven UK universities/research institutes and 22 international collaborators from seven countries, alongside stakeholders (Mahaffey, Jeffreys, Tagliabue, Wolff).
- GEOTRACES includes scientists from over 35 nations working on the marine biogeochemical cycles of trace elements (Tagliabue, Whitby).
- Overturning in the Subpolar North Atlantic (NERC/NSF large grant) involves scientists from seven countries, with a directed grant providing modelling and observational continuation (Williams).
- The Global Ocean Observing System is a network of satellite systems, UN agencies and governments, which has developed the use of bottom pressure as a novel constraint on sea-level change (Hughes).
- ATLAS includes a partnership between the UK, Denmark, Netherlands, USA, and Canada on sponge grounds in the Davis Strait has led to the Atlantic Project Award 2020 for “Developing International Cooperation” (Wolff).

Ecology and Marine Biology:

- AfricanBioServices (Horizon 2020) includes a project on the impact of human activity on herbivore migration routes and resilience to drought in the Serengeti-Mara ecosystem, working with 11 institutions and the Tanzanian Government (Parr).

Earth Sciences:

- The Virtual Earthquake and Seismology Research Community involves ten EU partners and is developing an e-science environment for computationally intensive applications (Rietbrock, Edwards).
- NERC Centre of Excellence for Observation and Modelling of Earthquakes, Volcanoes and Tectonics is using satellite measurements alongside ground-based observations and geophysical models (Gonzalez).
- ACT Acorn (Horizon 2020) involves eight partner organisations from three European countries working towards the first UK Carbon Capture and Storage facility, with findings presented to the UK Government’s Committee on Climate Change (Worden, Faulkner).

4.1.2 National collaborative networks and partnerships

Of our 688 papers, 30% are co-authored with national government institutions or charities including: National Oceanography Centre, Plymouth Marine Laboratory, British Antarctic Survey, Centre for Ecology and Hydrology, The Natural History Museum, Royal Society of Protection for Birds, Marine Biological Association, Scottish Association for Marine Science, British Geological Survey, and UK Met Office (Fig. 4.2). 89 papers include co-authors in energy and engineering companies.

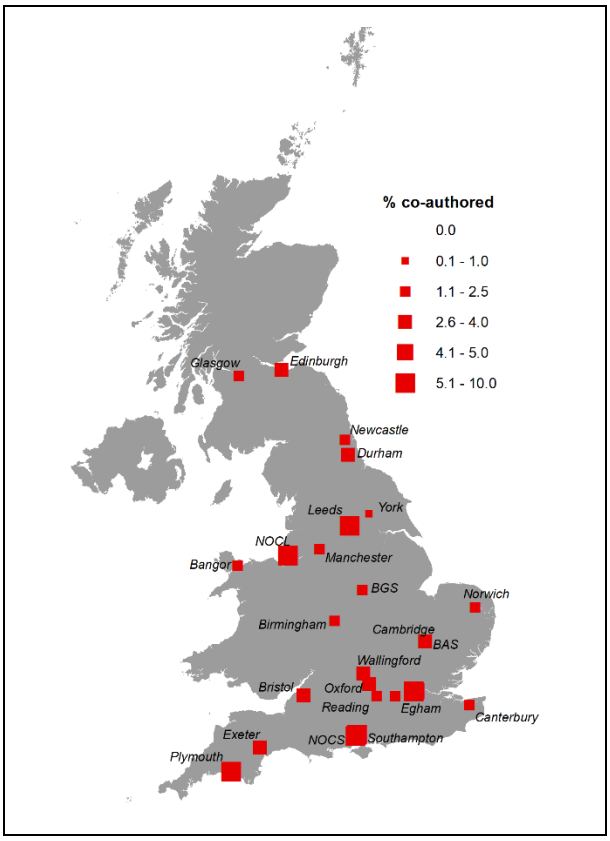


Fig. 4.2 UK research collaboration measured as % of all co-authored outputs in the period 2014-2020 from 688 papers from UoA7 (Scopus - SciVal).

Contributions to national collaborative initiatives include:
Ocean Sciences:

- UK-wide Shelf Seas Biogeochemistry programme co-funded by NERC and the Department for Environment, Food and Rural Affairs, in partnership with 14 UK institutes. The project has increased understanding of shelf seas and aided future UK marine policy formation and forecasting (Sharples).

Ecology and Marine Biology:

- The Marine Biodiversity and Climate Change Project funded by Natural Resources Wales and Natural England maintains time-series since the 1950s for 87 climate indicator species over 100 sites around the UK and northern France, and made important contributions to the National Biodiversity Network 2019 State of Nature report (Mieszkowska).

Earth Sciences:

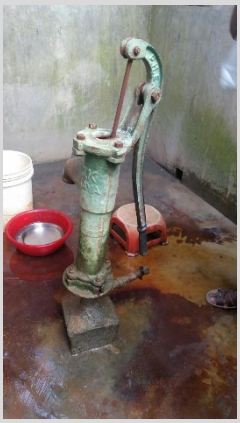
- NERC-ESRC UK Energy System Programme involving 21 UK universities and the British Geological Survey, identifying the potential environmental, social, and economic impacts of unconventional hydrocarbons (Faulkner).
- NERC Mantle Circulation Constrained large grant involving nine UK institutions to constrain the first 4D maps of Earth's mantle (Biggin).

4.1.3 Enabling and facilitating collaboration

We actively promote external networking activities through internal funding, such as Higher Education Innovation Funding grants (section 3.3), and PhD studentships with CASE partners.

Collaboration highlight: enabling and facilitating collaboration through impact pump-priming funding

Salaun received an EPSRC Impact Acceleration Award and Higher Education Innovation Fund grant to design, manufacture, test, and optimise a novel sensor for the detection of arsenic and other trace elements in contaminated water drunk by millions of people, in collaboration with the Mahavir Cancer Institute, India.



We promote collaboration through interdisciplinary workshops, conferences, and networks including:

- Joint assembly of the Tectonics Studies Group, British Geophysical Association and Volcanic and Magmatic Studies Group attracting more than 450 international interdisciplinary scientists (2017).
- Biennial Challenger Society Conference (jointly led with National Oceanography Centre) with over 350 attendees (2016).
- 14th International Seabird Group Conference with 215 attendees (2018).
- Deep-Sea Biology Society mentoring network working internationally with >100 participants (Jeffreys, launched 2018).

4.1.4 Collaborative arrangements for PhD student training

Our PhD students have close contacts with stakeholders in industry and government bodies. During the REF period, 24% of our graduated PhD students participated in a placement or internship. Examples include:

- British Antarctic Survey.
- Chilean Government Mining Agency/UCL Hazard Centre.
- Landsvirkjun National Power Company of Iceland.
- National Oceanography Centre.
- Schlumberger.
- Te Papa, New Zealand.

4.2. Developing impact through engagement with key research users and beneficiaries, and wider contributions to the economy and society

Our impact strategy concentrates on two impact challenges (Fig. 1.1). Through these cross-cutting impact challenges, we have fostered strong external relationships and have delivered significant and impactful contributions to society, both nationally and internationally.

4.2.1 Hazards in the Earth System:
Our work on hazards includes monitoring volcanoes and providing probabilistic risk assessments of ground shaking, coastal hazards from storm surges and contamination, and the impact of wind farms on biodiversity.

Geohazards & Tectonics Theme:
Our development of novel geophysical monitoring methods for volcanic eruptions (De Angelis, Lavallée, **REF impact case**) has saved thousands of lives in Guatemala and is being rolled out in Italy, Ecuador, and New Zealand. We collaborate closely with volcano observatories in Mexico, USA, Montserrat, Japan, Guatemala, Ecuador, and Iceland, focusing on the daily interpretation of signals monitored at active volcanoes worldwide.

Future Energy Theme:
A dense seismometer network has been established in North West England to monitor shale gas activity (Edwards, **REF Impact case**), enhancing an existing British Geological Survey regional network and leading to the Government placing a moratorium on fracking across England. Our seismological research is improving engineering design for the UK's nuclear industry and assessing seismic risk for school buildings in Switzerland.

Ecosystem Dynamics Theme:
Our ecological work with social scientists and economists (Robinson) has produced the first marine-specific approach to assess impact on ecosystem services for whole-regional seas, as part of an EC consortium grant (17 institutions and >6M euro budget). This was further developed to explore risk to the supply of ecosystem services across European aquatic systems.

4.2.2 Transitioning to a Sustainable future:
This area of increasing interest addresses the challenge of rising atmospheric CO_2 (Section 4.4.2), in terms of warming targets and strategies aimed at reducing carbon emissions.

Future Energy Theme:
Our geological research into carbon capture and storage over the last 16 years has played an important role in establishing the UK's capability. Potential long-term carbon capture sites (Worden, Faulkner, **REF impact case**) have been identified through an international EU Commission project *ACT Acorn*, involving eight partners from the UK, Norway, and the Netherlands and led by Pale Blue Dot Energy with Scottish Carbon Capture & Storage.

We have a strong and growing focus on geothermal energy resources. We have provided advice on superhot geothermal resources in Iceland (Landsvirkjun Power Company, Iceland and HS Orka) (Lavallée), applied experimental research outcomes to the thermo-mechanics and fluid flow of hot rocks linked to geothermal companies in New Zealand (Mighty River Power, Mercury, and Upflow, GNS Science) (McNamara, Lavallee, Faulkner) and investigated seismicity related to fluid injection for geothermal power in Switzerland (Edwards).

Ecosystem Dynamics Theme:
Our ecology research has established drivers of ecosystem change and facilitates better monitoring of environmental sustainability. We have demonstrated that albatross can be used to spot illegal fishing vessels and help identify hotspot areas where enforcement is needed (Patrick).

Oceans & Climate and Ecosystem Dynamics Themes:
The health of the UK coastal seas has been assessed by providing report cards for the Department for Environment, Food and Rural Affairs, and the Centre for Environment, Fisheries and Aquaculture Science (Sharples, Mieszkowska, Mahaffey & Jeffreys), and through developing policy-relevant assessments to aid decision-making on sustainable land-use management (Robinson).

4.3. Wider engagement with diverse communities and the public

The Department celebrated centenaries for Geology (2017) and Ocean Sciences (2019) and 50 years of Geophysics (2017). These celebrations involved several public events, including a major national Earth sciences research conference (the VMSG-TSG-BGA Joint Assembly with >450 delegates), and a series of public lectures and schools outreach events.

Our Earth sciences outreach and public engagement activities, including the annual Herdman Symposium with attendance of >300, have reached over 40,000 people since 2015, including engagement with 3,000 school children, 360 teachers, and the science-engaged public.

All three research groups have engaged substantially with national and international media, including TheConversation.com (five articles, totalling 465,000 reads), TV (BBC Breakfast and World News) and radio (BBC World Service, BBC Radio 5Live). Online coverage (Newsweek, IFLScience, The Guardian) of our research has reached tens of millions.

We participated in two Royal Society Summer Science exhibitions in 2016 and 2019. Our *'Magnetic to the Core'* stand in 2019 reached >12,000 people in one week (including 1,518 students and 187 teachers). The exhibit (Fig. 4.3) was supported by £20,000 of internal funds. Our Project Manager (van der Boon) was nominated for a public engagement award, and invited back to the Royal Society to give training on best practice for and participate in the 2020 event.

Fig. 4.3: 'Magnetic to the Core' team at The Royal Society Summer Science Exhibition, July 2019.

In 2019, we '*Borrowed the Moon'* as part of the celebrations of 50 years since the Apollo landings, where students interacted with lunar samples and meteorites provided by NASA. In 2017 and 2018, we worked with the University's English Department to host a '*Science and Poetry'* competition for children. In 2017, *'Rock Around Campus'* provided short, wheelchair-accessible trails, allowing the public to discover the origin of rocks used in the construction of buildings.

Our staff have participated annually in the *North West Big Bang* and *Mersey River Festival* for the past four years, as well as *Pint of Science* events in Liverpool. As part of the naming ceremony for the RRS Sir David Attenborough in 2019, Mahaffey and Jeffreys led a three-day '*Ice Worlds'* outreach programme on polar science, reaching over 6,500 people, including local school children.

As part of our international outreach work, we provided geological samples to Nigeria (Fig. 4.4).

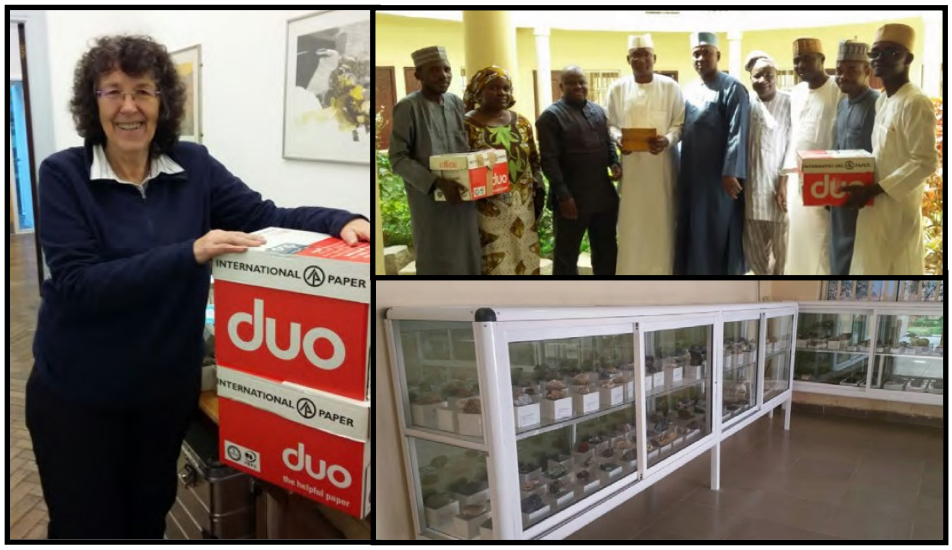


Fig. 4.4: Maggie Williams coordinated the distribution of materials to Bayero University, Nigeria, including 2,500 geological samples, a well core, 41 boxes of teaching sets of mineral/rock samples, 150+ geological maps and books, and 2000+ thin-sections.

4.4. Contribution to the discipline

4.4.1 Sustainability and inter-disciplinary research

We are leading efforts to reverse the decline in geoscience student recruitment and highlight the transition from the traditional oil industry to future geo-energy solutions, including sourcing critical minerals and technology such as carbon capture and storage. In 2015, we played a key role in writing the new subject criteria for the Geology A-Level curriculum in the UK, as part of the reform process administered by the Department for Education. Burgess is outreach officer on the executive committee of University Geoscience UK, addressing undergraduate recruitment challenges at a national level, including a major website project, and McNamara was invited to join the Energy group of the Geological Society of London to promote geothermal power solutions.

Collaboration highlight: Continuing Professional Development to train geology teachers

University of Liverpool was the first in the UK to offer Continuing Professional Development courses to A-Level Geology teachers. Since 2014, we have reached 55% of A-Level Geology teachers in the UK and, through them, over 50% of Geology A-Level students. Our geoscience and pedagogical, teaching and assessment resources are included on the recommended list of GSCE and A-Level syllabus exercises and have been embedded within examinations. An independent report by the data analysis company Education Datalab reported that since 2014, participation in our course has increased A-Level attainment by up to 33% of a grade, compared to students taught by teachers who did not attend our course. The popularity of geology classes taught by teachers who attended our course also increased, with the average number of students 44% higher than in other classes in 2018.

An interdisciplinary regional network that developed from the REF2014 strategy is the Liverpool Institute for Sustainable Coasts and Oceans, a partnership between the University, Liverpool John Moores University, and the National Oceanography Centre, bringing together our combined local coastal and maritime expertise to meet the future challenges of changing oceans and growing coastal societies. This partnership demonstrates a collective Liverpool-focused commitment to drive long-term collaborative and sustained research forward in this area.

4.4.2 Responsiveness to national and international priorities and initiatives

Our research and impact activities are shaped by national and international grand challenges, delivering solutions for clean energy and water, and addressing the physical, biogeochemical, and ecological impacts of climate change. These include threats of volcanic eruptions and hydraulic fracturing (section 4.2.1); threat of oxygen decline in coastal seas, changes in intertidal zones, ocean stratification and deep-sea habitats (addressed via policy report cards for the Marine and Climate Change Impacts Partnership in 2020), feasibility of carbon capture sites, and future use of geothermal energy (section 4.2.2).

We have contributed to international policymaking via the Intergovernmental Panel on Climate Change (IPCC): Tagliabue was a lead author for the Summary for Policy Makers and Chapter text for the 2019 IPCC Special Report on Oceans and Cryosphere in a Changing Climate and a contributing author for IPCC AR6 Working Group 1 Chapter 2. Our research outputs have contributed to the IPCC AR6 assessment cycle via Working Group 1 and 2 drafts, Special reports on 1.5°C Warming, and Oceans and Cryosphere in a Changing Climate (Williams and Tagliabue providing >10 papers for AR6).

4.5. Indicators of wider influence

During the REF period, of Category A academics surveyed in 2019/2020:

- 70% served on national or international grants committees.
- 49% served on learned societies, scientific advisory boards, and professional bodies.
- 62% served on journal editorial boards.
- 76% participated in national and international conference organization
- 62% engaged with industry and policy stakeholders through research or advisory roles.
- 68% undertook schools' outreach and public engagement

We have provided 226 invited talks, including 53 plenary and keynote speeches across the globe.

The examples below illustrate the range of prestigious roles our academics undertake. Our academics have led four international field expeditions at sea, supporting national and international research priorities on UK research vessels (Mahaffey, Sharples, Tagliabue);

- Faulkner was elected chair of the 2020 Gordon Research Conference on 'Rock Deformation' (postponed to 2022 due to COVID-19) with $95k funding secured from GRC, NSF and Department of Energy;
- Faulkner was elected as President-elect of the Tectonophysics section of the American Geophysical Union and will serve as President from 2022-2024;
- Lavelle was elected Chair of the Science & Engineering for the Young Academy of Europe between 2014 and 2020;
- Tagliabue was an invited participant in a 'British-German cooperation to study climate change and adaptation options' workshop in the lead-up to COP26, sponsored by British Embassy in Berlin and the Helmholtz Zentrum.

Awards and Prizes:

- Tagliabue: Challenger Society UK Fellow 2016
- Kendrick: European Geosciences Union Division Outstanding Young Scientists Award 2016
- Holme: Royal Astronomical Society Price medal 2017
- Lavallee: 2017 James B. Macelwane Medal and made Fellow of the AGU; 2017 Wager Medal of the International Association of Volcanology and Chemistry of the Earth's Interior
- Kusznir: Lyell Medal 2019 – Geological Society of London

Senior Fellowships:

- Lavallee: Leverhulme Research Fellowship on "Explore the magma frontier to unlock the full potential of geothermal energy."
- Faulkner: Royal Society Leverhulme Trust Senior Research Fellowship "Mechanics of

earthquake slip"

4.5.1 Contributions to review panels and committees

Service to the wider scientific community is provided by our contribution to research grant panels and scientific steering committees including NERC (panel chair, Williams, and three members: Green, Hirst, Tagliabue); UKRI Future Leaders Fellowships (Biggin, Mahaffey), EPSRC (Edwards), NERC National Environmental Isotope Facility (Jeffreys), Newton International Fellowships (Parr), Royal Society Global Environment Research Committee (Tagliabue), British Ecological Society review college (Thomson), UK Government Volcano Advisory Scientific Committee (de Angelis), and Committee for Energy Group of Geological Society of London (McNamara).

4.5.2 Contributions to major national and international advisory bodies

Our climate research has contributed to international policymaking via the Intergovernmental Panel on Climate Change, and our environmental and ecological research has provided policy advice to national government (Section 4.4.2).

Oceans staff were key to a Royal Society workshop in 2020 to scope UK science contributions to the UN Decade of Ocean Science for Sustainable Development (Tagliabue as lead and Sharples as speaker).

Faulkner co-organised an NSF workshop held at Caltech and was a lead author on a 2019 white paper on the future strategy for NSF funding for modelling earthquake processes.

Nationally, our outputs have been included in a range of UK Government reports, including the 2017 Future of the Sea report (marine biodiversity and ocean acidification), the 29th UK Government Offshore Oil and Gas Licensing Round screenings, 2015 Offshore energy scoping report, and the 2017 Marine Management Organisation report (seasonal bird density and key foraging areas).

4.6. Outlook

We are harnessing our high-quality research expertise, working with collaborators worldwide and aligning these strengths to explore impacts of ecosystem dynamics, oceans and climate, develop solutions to environmental challenges, and address knowledge gaps for policy makers. The climate emergency is a long-term global threat and we are focused on delivering impactful and tangible research that benefits society and our planet, whilst developing our future researchers to ensure that we meet these challenges in a sustainable and inclusive way.