

Institution: University of Reading
Unit of Assessment: 10 Mathematical Sciences
<p>1. Unit context and structure, research and impact strategy</p> <p>Overview</p> <p>Research in the Department of Mathematics and Statistics at the University of Reading covers both mathematical & statistical theory, and interdisciplinary research via extensive interactions with other disciplines including meteorology, biology, chemistry, food, pharmacy, agriculture and psychology. The department currently employs 23 research-active academic staff, of which 3 are joint appointments with the Department of Meteorology, and 10, mostly postdoctoral, research staff. Research is organised into three over-arching theme groups, each headed by a theme lead, with significant interaction and cross-pollination of ideas. These themes are:</p> <ul style="list-style-type: none"> • <i>Pure Mathematics</i> - principally pure & applicable analysis and number theory; • <i>Applied Mathematics</i> - chiefly in specific fields within environmental mathematics, numerical analysis, mathematical physics and mathematical biology; and • <i>Statistics</i> - predominantly applied statistics, with some probability & stochastic analysis. <p>The department is part of the School of Mathematical, Physical and Computational Sciences, along with the Department of Meteorology and the Department of Computer Science. The department leads the <i>Centre for the Mathematics of Planet Earth (CMPE)</i>, an interdisciplinary research centre which was established in 2017 and which is a key vehicle to integrate research across our three themes. Its aim is to be a catalyst for research ideas and initiatives in the intersection between mathematics and statistics, theoretical physics, data science and Earth system science. Our research is strongly collaborative with staff active in a number of the University's other institutes and centres, in particular: (i) the <i>Data Assimilation Research Centre</i>, which conducts research aimed at improving weather and other geophysical forecasts, and brings together expertise in mathematics and statistics, meteorology and Met Office research staff based at Reading; (ii) the <i>Walker Institute</i>, which is focused on developing climate-resilient societies; (iii) the <i>Institute for Cardiovascular and Metabolic Research</i>, which brings together scientists to understand the development of cardiovascular diseases; and (iv) the <i>Hugh Sinclair Unit of Human Nutrition</i>, which seeks to strengthen the evidence base for dietary recommendations for the prevention of chronic diseases.</p> <p>The department co-leads, with Imperial College London, the EPSRC Centre for Doctoral Training (CDT) in the Mathematics of Planet Earth (MPE), admitting students each year from 2014 to 2018 inclusive. It is a partner in the NERC-funded Doctoral Training Partnership (DTP) in the Science of the Environment: Natural and Anthropogenic Processes, Impacts and Opportunities (SCENARIO), which is based in the Department of Meteorology. During the REF period, staff have also been primary or co-supervisors of students in the NERC-funded Quantitative and Modelling Skills in Evolution and Ecology CDT, the EPSRC Technologies for Sustainable Built Environments CDT and the BBSRC DTP in Food Security, all based at Reading.</p> <p>Since REF 2014 the University's research has been structured around research divisions under four broad themes (see Section 2 of the Institutional Environment Statement). The Department of Mathematics and Statistics forms a research division in its own right and is one of nine such divisions within the Environment Theme, led by a Research Dean to facilitate cross-university working. Each research division has a Research Division Leader and an Impact Lead who provide leadership and management of research and impact for the division. The development and execution of our research plans is facilitated through the University's Research Division Operational Planning process. This yearly plan enables the Research Division Leader, Impact Lead and Research Dean to identify current and future opportunities for research and impact, as well as bring any issues to the attention of the Head of School and other leaders of research within the University, such as the Pro-Vice-Chancellors. The Research Division Leader meets with the Research Dean on a monthly basis to discuss overall progress of the division and forthcoming opportunities.</p>

Position since 2014**Research summary over the assessment period**

In REF 2014 we identified the following research priorities:

- (1) to support our stronger existing groups, in particular pure & applicable analysis, numerical analysis and applied statistics;
- (2) to support focused interdisciplinary activity through our work in several areas namely:
 - (2i) theoretical and computational aspects of research in weather & climate and Earth observation;
 - (2ii) mathematical neuroscience, inverse problems and data assimilation, as a partner in the Centre for Integrative Neuroscience and Neurodynamics (CINN);
 - (2iii) complex systems networks and applications to the digital economy and to the climate system; and
 - (2iv) mathematical biology, relevant to our role in the Reading Systems Biology Network;
- (3) to develop substantial new activity in probability, stochastic analysis, and theoretical statistics to support our interdisciplinary work and integrate research themes across mathematics & statistics; and
- (4) to consolidate and expand further the core mathematical research areas that constitute the essential support for progress in the endeavours listed above.

In the assessment period with respect to (1) we were highly successful in expanding our theoretical mathematics and statistics research with the appointments of Boedihardjo, Daw, Perfekt and Newton, all Early Career Researchers (ECRs), and Neves. The appointments have particularly broadened and strengthened our number theory and analysis groups. The appointments of Newton and Daw, both working in algebraic number theory, allowed us to create a coherent number theory group which previously included only Hilberdink in analytic number theory. The appointment of Perfekt, working mostly in operator theory and spectral theory, together with a fellowship award to Geher, substantially increased our analysis group, which currently also includes Katzourakis, Levitin and Virtanen. Together, analysis and number theory constitute a significant pure mathematics subdivision which has not existed at Reading for at least twenty years. Its creation has contributed to an increase in the number of visitors, as well as national and international collaborative projects, whilst supporting our endeavours to attract high-quality PhD students. The appointment of Boedihardjo (until 2020) in probability/stochastic analysis and Neves in theoretical probability/statistics expanded our presence in theoretical statistics and has allowed us to strengthen links between the *Pure Mathematics* and *Statistics* themes, and the links of both to the CMPE.

Appointments in theoretical research have been complemented by appointments in more applied branches of mathematics and statistics. Scott joined the department as Professor of Applied Mathematics in 2016 and is Director of the Reading EPSRC MPE CDT. Her specialisations in numerical analysis, sparse matrix computations and parallel computing link well with our existing research in numerical analysis (Chandler-Wilde) and data assimilation (Nichols, Dance, Lawless). The appointment of Wouters in applied mathematics/statistics has further added to our *Applied Mathematics* and *Statistics* groups, particularly linking with the CMPE (most notably the work of Lucarini and Kuna). Wouters' and Neves' research also links with our traditional strength in applied statistics (Todd, Baksh). The four new ECRs (Boedihardjo, Daw, Newton and Perfekt) joined ECRs employed in the last REF period, establishing a dynamic and forward-thinking atmosphere within the department. The success of our ECRs in the assessment period is evidenced by EPSRC First Grants / New Investigator Awards secured by Boedihardjo, Broecker, Daw, Everitt, Katzourakis, Moiola, Newton, Perfekt and Pryer, bringing a number of postdoctoral fellows and PhD students to the department. Our policies of strengthening our theoretical mathematics and statistics research, and also our emphasis on appointing and developing ECRs as described further in Section 2 below, have been rewarded by the award to Neves of an EPSRC RCUK Innovation Fellowship for a project on Multivariate Max-Stable Processes and, recently (October 2020), by the award to Newton of a UKRI Future Leaders Fellowship for her project on Diophantine Equations and Local-Global Principles.

We have invested significant effort and resources in coherent mathematical and statistical activity to further strengthen our interdisciplinary work as part of priorities in (2). In relation to 2(i), the establishment of the CMPE in 2017 led by Lucarini has been central to our work in theoretical and computational aspects of research in weather & climate and Earth observation. Furthermore, our mathematical and statistical expertise in the area has been boosted with the appointments of Scott, Neves and Wouters. Evidence of the University's commitment to this area has been the increase in funding for Lucarini from a fractional time commitment to 1FTE. The establishment of the CMPE and the MPE CDT during this REF period, and Lucarini's awards of the 2018 Whitehead Prize by the LMS and the Lewis Fry Richardson Medal of the European Geosciences Union for his research in the area of mathematics of climate, firmly consolidates our reputation as a leading player in this field. Research in the CMPE focuses on the development of fundamental results and quantitative methods for addressing real-life risks associated with climate change/extremes and food security. The Centre has recently been selected as one of ten flagship University Interdisciplinary Research Centres. It currently involves researchers at all career stages (including PhD) from the Departments of Mathematics and Statistics, Meteorology, Computer Science, and the Walker Institute, and has expanded during the REF period to bring together other academic and external partners. The CMPE has already played a key role in research projects and interdisciplinary training and dissemination events. Specifically, the CMPE has organised two Les Houches Schools of Physics; an Advanced Workshop at the International Centre for Theoretical Physics (ICTP); two Climathnet conferences; a joint meeting of the LMS and IMA; and a scientific programme at the Henri Poincaré Institute in Paris. The CMPE is a partner in Horizon 2020 projects: the Tipping Points in the Earth System (TiPES) project, the Co-ordinating Research in Earth Systems and Climate: Experiments, Knowledge, Dissemination and Outreach (CRESCENDO) project, the Blue-Action project, and is a partner in a Marie Skłodowska-Curie Innovative Training Network (CriticalEarth).

Through the three cross-departmental positions with Meteorology we are in a strong position to compete for large bids, particularly in data assimilation in line with (2ii). During the REF period colleagues working in data assimilation (Nichols, Dance and Lawless) were involved in nine successful grant applications. Additionally, Dance holds an EPSRC Senior Fellowship in Digital Technology for Living with Environmental Change. Whilst we have continued to maintain and develop key strength in this area, further enhanced by Potthast's role as head of the Numerical Weather Prediction section at the German Weather Service (and his broader activity in inverse problems), we have focused on climate and weather prediction, and our work in relation to neuroscience and neurodynamics has waned. This is partially due to staff movements, but it has allowed us to refocus our research priorities more intensively on environmental applications.

In respect of 2(iii), research in the area of complex systems networks for the digital economy continued for much of the REF period with strong impact under the leadership of Greetham (until 2018). Dance's Fellowship work has also contributed to this area, specifically in relation to climate research. With Greetham's departure, we decided not to pursue further research in this area as a separate core activity, but instead to incorporate remaining expertise in the field with our other research in environmental mathematics.

In respect of 2(iv), the mathematical biology group has continued to lead internal and external initiatives at the life science interface during the assessment period. It has attracted a number of industrially funded PhD studentships, one of which led to the group lead (Tindall) becoming involved in the newly developing field of Quantitative Systems Pharmacology (QSP), which is a systems approach to the development of pharmaceuticals. Tindall subsequently obtained EPSRC/MRC network funding (2015 - 2018) with colleagues in industry and academia to establish and lead the UK QSP Network. The network has attracted industry funding, organised eight major meetings comprising workshops, summer schools and problem-solving meetings, published two white papers and has subsequently become a self-funding network. Locally it has led to the cross-fertilisation of new PhD projects between Pharmacy and Mathematics & Statistics.

As part of priority (3) the appointments of Boedihardjo and Neves introduced new activity in probability, stochastic analysis and theoretical statistics to the department and we have sought to identify opportunities to integrate research themes across mathematics and statistics. This has been achieved to a large degree by the CMPE, whose members from within the department are drawn from all three of our over-arching theme groups.

In line with priority (4) our core mathematical research areas have continued to be consolidated with the award of over twenty individual / small-group grants, particularly to our ECRs. These include the nine EPSRC First Grants / New Investigator Awards, and LMS networks (Katzourakis and Virtanen). Newton's recently awarded (October 2020) UKRI Future Leaders Fellowship is further evidence of future consolidation and expansion.

Over the REF period, we have embraced the University's emphasis on the Open Research agenda. Members of the department, particularly in pure mathematics, use arXiv as a repository for preprints/accepted papers. Over the period 16% of all our publications are in open access journals, whilst 85% are Open Access compliant. Where research generates data or programming code, such information is made available on individual staff websites and/or submitted to University or online data repositories with due references in the published work. In respect of funded research, where data plans are required these are prepared following funder guidelines and data/code are published accordingly. The division follows the University's procedures for research ethics for individual research projects where applicable. This is a tiered system and projects in mathematics and statistics which require ethical review can very often be dealt with at the School level by the School Research Ethics contact (Todd).

Impact summary over the assessment period

There are three main approaches to the way in which the Department of Mathematics and Statistics establishes impact for its work:

- *Bespoke research* where research is effectively commissioned either by direct contracts with the private or public sector, or industrial involvement via grant awards or PhD CASE studentships;
- *Targeted research* undertaken in areas of potential impact, but not initially driven by a specific private or public sector group or another academic discipline's involvement; and
- *General research* which is initiated by individual academics, but then identified as relevant to industry or policy at a later date.

In REF 2014 we identified the following impact priorities:

- (1) to continue expansion of all three modes of operation (bespoke, targeted and general research activities);
- (2) to enhance interdisciplinary research within and beyond the university;
- (3) to create wider awareness of theoretical work; and
- (4) to continue with our current appointment strategy.

Progress in respect of priority (1) has been facilitated by the University's *Building Outstanding Impact Support Programme (BOISP, see Section 3)*, which provides the Research Division Impact Lead with a structured approach for identifying new, and developing existing, impacts of our research. Two members of the department have been members of the University's review panel for BOISP projects (Todd and Tindall), strengthening our Unit's critical view of successful approaches to impact. Our Unit of Assessment impact case studies were developed through the BOISP framework. One is an example of *bespoke research* (Nichols and Dance) where interactions with collaborators have resulted in research being incorporated into operational forecast models at major international weather centres and other institutions throughout the world, including the UK Met Office, the European Centre for Medium-Range Weather Forecasts (ECMWF), the US Navy, the US National Centres for Environmental Prediction, the US National Aeronautics and Space Administration (NASA), the German Weather Service, and the Japan RIKEN Research Institute Centre for Computational Science. The other case study is an example of *targeted research* (Todd), where research in adaptive designs has underpinned the design and conduct of three recent clinical trials in the public sector, has been instrumental in

the development of two software packages, and has fed into the development of two sets of trial reporting guidelines for clinical trials. *Bespoke research* with Scottish and Southern Electricity, for the fisheries sector of Cefas (Centre for Environment, Fisheries and Aquaculture Science), and with the geophysics group in the National Centre for Monitoring and Alerts of Natural Disasters (CEMADEN), Brazil, has also led to impact.

In line with priority **(2)** we have expanded our impact-oriented interdisciplinary research both within and beyond the University. We have substantially expanded our activities in the mathematics of weather and climate with the opening of the CMPE, through the MPE CDT, and the appointment of Scott, Neves and Wouters. Staff have successfully won grants and fellowships in collaboration with industry (for example Dance's EPSRC Senior Fellowship in Digital Technology for Living with Environmental Change and Neves' EPSRC RCUK Innovation Fellowship for the project on Multivariate Max-Stable Processes) and we have expanded our activities in the pharmacological sciences by establishment of the UK QSP Network.

We continue to pursue our priority **(3)**, to create wider awareness of our core theoretical work. Newton initiated a collaboration with Microsoft to explore cryptographic applications of number theory and Katzourakis has been investigating collaborations with the Institute for Advanced Automotive Propulsion Systems in Bath, and with the support of Tesla Canada and Abellio / Transport for London, on the optimisation of metal-ion batteries. This latter work is aimed particularly at the challenges arising in the automotive industry in respect of electric cars.

Priority **(4)** is related to making strategic appointments to capitalise on and strengthen impact where appropriate. As noted above we appointed five new staff in theoretical mathematics and statistics, several of whom have been proactive in promoting impact of our theoretical work, for example Neves' EPSRC RCUK Innovation Fellowship and the work of Newton. Appointments in applied mathematics and statistics have particularly focused on our area of key strength – mathematics of weather & climate, where impact of work is considerable.

Future strategic aims and goals for research and impact

Our vision is to grow complementary cores of niche, world-class pure and applied mathematical and statistical research, enabling new developments in these areas, and their use in progressing challenges in fields such as weather & climate (including mitigation of, and adaptation and resilience to, associated risks), biology & health, polymer physics & soft matter.

In terms of our three theme groups, we have identified the following future strategic aims and goals, with delivery supported by the Research Division Leader, Impact Lead and Research Dean.

- *Pure Mathematics:* We will consolidate our research in analysis, including applicable analysis and number theory, through colleagues exploring joint research topics. We seek to develop our presence in geometric analysis and analytic number theory and look to strengthen the interface between pure mathematics and statistics particularly theoretical probability / stochastic analysis through both acquisition of grant funding and relevant new appointments.
- *Applied Mathematics:* We will work to grow and foster our research in our specific fields of interest within environmental mathematics, numerical analysis, mathematical physics and mathematical biology through acquisition of grant funding and relevant appointments. In each area, we will develop further rigorous mathematical methods with concrete impact.
- *Statistics:* We will continue to pursue methodological research in our area of traditional strength, applied statistics, whilst seeking to grow our presence in theoretical statistics through appointments and links with pure mathematics. We will couple our research in novel statistical methodology to strong research impact through collaborations with industry and the public sector.

The CMPE is particularly important to our future strategy as members from within the department are drawn from all three of our over-arching theme groups. The goal of the CMPE

will continue to be to develop the mathematics and statistics underpinning new methodologies for better evaluating, anticipating, and predicting extreme events and tipping points in the area of weather & climate risk. This has great relevance in terms of basic knowledge as well as in the management of natural hazards, in food production, in finance, in logistics, and many other related fields of impact. The CMPE will continue to strengthen our existing interactions with end-users such as the Met Office, ECMWF, and many international institutions by fostering student placements and staff exchange. We are currently involved in an EU H2020 proposal (AIACE) dealing with practical use of machine learning to study the impacts of climate extremes on logistics.

2. People

Staffing strategy and staff development

Our strategy for developing both the core research and interdisciplinary collaborations, described in Section 1, is founded on successful recruitment of outstanding researchers, and on providing a supportive environment in which they can fulfil their potential. We have, as a strategy for developing a strong research environment, worked particularly to attract outstanding researchers early in their career, on several occasions within two to three years of their PhD awards, supporting them to grow strong track records and develop as future leaders.

Our aim is to build a thriving research environment, supportive of all research division members, and with particular assistance for our ECRs. The University provides detailed guidelines on career progression and promotion, many reflecting being a signatory to national concordats, and making use of these frameworks we strive to support our staff to achieve their full potential. We have mechanisms in place to ensure consistent and regular review of progress and to facilitate career development.

New members of staff are given a personalised induction programme which comprises both central and local department activities. The University's Central Induction Day provides new employees with an introduction to the University via interactive discussions and group work, allowing them the opportunity to network with other new starters. Within the department, we hold our own induction programme and assign a mentor to all new staff, irrespective of grade, to support them during the first few years at Reading.

We provide strong support to our ECRs. We view the role of a mentor as particularly important here, since they help new early career staff to successfully develop as teachers, achieving Fellow membership of the Higher Education Academy, and assisting in developing a research profile, as well as guiding them through the probation process. For those in their first academic post, mentors can discuss topics such as how to win grant funding, opportunities for personal fellowships and raise awareness of important initiatives within the mathematics and statistics community. During the REF period nine ECRs secured an EPSRC First grant / New Investigator Award (out of a total of eleven submitted) and all were mentored throughout the application process. We prioritise ECRs when allocating departmental PhD studentships, as well as support their applications for research grants by providing dedicated PhD funding. We have also successfully supported them in internal competitions for funding from the University's EPSRC DTP award. Indicative of the value we place on our ECRs, we quickly involve them in appointment processes for new members of staff, indeed we aim to have at least one ECR member of staff on each appointment panel.

For those further along in their career, possibly in a management or leadership role, the University offers a range of support mechanisms including workshops to develop specific skills and longer programmes accredited by the Institute of Leadership and Management. In total over 20 staff have engaged with this training in the period. Within the department, staff at middle career and senior levels are encouraged to share their experiences and ideas regarding the development of their research via Academic Exchange Meetings, in which topics directly or indirectly related to a staff member's research interests are presented and discussed. These were initiated in the Autumn of the 2019/2020 academic session and are helping to foster cross-departmental discussions around research collaborations, as well as keeping staff informed at all

levels about research-related aspects such as ensuring the impact of their work. In the future they will continue to enhance an active research environment, by providing avenues for exploring future funding applications both internally and with prospective external partners.

All staff, permanent and fixed-term, have an annual Performance and Development Review (PDR) with a regular reviewer for consistency across years. Through the process we aim to encourage and support excellent performance and discuss career development plans, including plans for research development via the University's 5-year horizon Personal Research Plan process. As part of preparing for a PDR, staff reflect on their contributions over the previous 12 months and consider their focus and priorities over the next 12 months. Staff are encouraged to discuss promotion with line managers and, if a case is to be put forward, they are assigned a separate Promotions Mentor to help them through the process. The role of the Promotions Mentor is to explain the criteria and selection process involved and to discuss and comment on drafts of the application documentation. The University runs annual promotions training / information sessions for staff considering future promotions. Researchers on fixed-term contracts are additionally supported through the School's Post-Doctoral Research Assistant Forum, which gives them the chance to network and to raise issues.

Permanent members of staff have a dedicated Staff Development Account (SDA) which is topped up annually from general department funds. Individuals can boost their SDAs through a share of the overheads from their research grants and via external activities such as consultancy. SDAs help support an individual's academic goals, funding activities such as additional research visits and visitors, conference attendance, personal skills training, equipment and PhD student support.

For academic staff, a workload model is used to manage department activities, taking account of funded research, teaching, PhD supervision, leadership roles and certain administration tasks. For new ECR staff, teaching and administration duties are built up gradually over the early period of their employment. This gives them the chance to adapt to the ways of working within the department and to begin establishing their research base. We have a study leave scheme which allows staff to apply for one term's paid study leave every nine terms. This term is free of teaching and administrative duties allowing the holder to devote their time wholly to the purpose for which the leave has been granted. In most academic years we have one or two members of staff on study leave in each of the Spring and Autumn terms.

Training and supervision of PGR students

The department is home to on average 45 PhD students at any one time (currently approximately 80% FT and 20% PT, with approximately 55% male and 45% female). We recruit around 8 to 10 new students per year from across the globe, including currently the UK, Cyprus, Egypt, Germany, Greece, India, Italy, Lithuania, the Netherlands, Portugal, Saudi Arabia, Spain and Sweden. Around 45% of our students are from the UK, with 55% being international. Students are supervised by staff in the department across all our research themes. The majority of UK students are funded by EPSRC, along with a small number of awards from BBSRC and NERC, with international students generally supported by funding from their home country. A number of PhD studentships are held jointly with other university departments including meteorology, pharmacy and biological sciences, as well as with external partners (funding and/or supervision) including the ECMWF, Syngenta and Pfizer. The department co-leads, with Imperial College London, the EPSRC MPE CDT and is involved in the NERC funded SCENARIO DTP which is based in Meteorology. The University of Reading has and continues to support research in the Mathematics of Planet Earth. As the CMPE is one of only ten interdisciplinary research centres currently recognised by the University, it is eligible for direct internal support. Three EPSRC DTP awards were strategically allocated to the CMPE in the 2019/2020 academic session.

One student in the department currently holds a highly competitive University of Reading International Studentship, providing full funding. University funding is also available for part-time students who undertake a PhD related to their employment, including the Wilkie Calvert award

(one student is currently funded in the department via this route). The department holds memoranda of agreement which cover postgraduate training, amongst other aspects, with several international universities including institutions in Japan, Kazakhstan, Saudi Arabia and Thailand.

Students join the department throughout the year, and upon arrival take part in an induction programme. This provides them with an introduction to departmental and University facilities, training opportunities (departmental and University), executive and welfare support, expectations in terms of progress / the monitoring process, and who to contact should they experience difficulties during their studies. Students are supported on a day-to-day basis by the departmental Postgraduate Research Administrator and Director of Postgraduate Research Studies, both of whom work closely with the University Graduate School to assist students with any academic or welfare queries which may arise during their studies. The departmental Director of Postgraduate Research Studies has regular contact with their counterparts in the other departments within the School (Computer Science and Meteorology) and is also supported by the School Director of Postgraduate Research Studies. All students are required to have two supervisors. Where the lead academic supervisor is within the department, co-supervisors may comprise other staff within the department, other University departments, external institutions or industrial partners. Students meet with their lead supervisor, who is primarily responsible for their project, on average once a week. Meetings with other members of the supervisory team may occur less frequently, for example monthly or quarterly, as required.

The department is part of the MAGIC consortium of 21 UK mathematics departments supplying teaching and assessment of PhD-level mathematics courses across the UK, systematically using these courses for our own PhD students' development, and contributing to delivery of the training offered. All students in the department are required to undertake 100 hours of training during their PhD, with the exception of MPE CDT students whose first of four funded years comprises an MRes. The 100 hours may comprise undertaking 3rd/4th year UG modules and/or modules from the MAGIC consortium as well as participation in summer schools, workshops and other internal or external training events related to their research. A specific training needs assessment is undertaken at the beginning of each PhD by supervisors in collaboration with their students. Students must also complete a number of Reading Researcher Development Programme (RRDP) sessions (13 for full-time students, 9 for part-time) which are run by our Graduate School. Sessions generally last from one to three hours and cover generic skills training including knowledge & intellectual ability, personal effectiveness, research governance & organisation and engagement, influence & impact. Staff within the department deliver some of these RRDP courses.

Each student is allocated a Monitoring Committee upon arrival and meets with them on average every six months to assess progress. Monitoring Committees comprise two academic members of staff, one of whose research areas is closely aligned to the student's project. With the exception of the first meeting at three months, the student produces a 6–10-page report in advance of a Monitoring Committee meeting, which may be supported by other materials, for example a thesis plan and/or draft. At the meeting, student progress is discussed and assessed, with respect to both their specific project and wider training, and future plans for both. Students are also asked about their supervision and any concerns are acted on as appropriate. Members of the committee engage students in a discussion about their work to ensure adequate understanding and communication, and where concerns arise these are indicated in the Monitoring Committee Report. Students about whom concerns are raised are referred to the departmental Director of Postgraduate Research Studies for possible academic and/or welfare interventions, which are determined following further meetings with the student. The department thus applies a strategy of being a supportive, encouraging environment for PhD students, whilst ensuring any issues are resolved quickly and/or action taken to ensure all students have the highest likelihood of completing their studies in the required time and developing as ECRs. This is evidenced by successful completion rates; 93% of those who study full-time and complete their PhD studies submit within a four-year period.

Equality and diversity

The University, School and Department are strongly committed to equality, diversity and inclusion. We seek to enable staff and students to fulfil their potential through fostering a working environment that is supportive and inclusive and protects their physical and mental well-being. The School was awarded an Athena SWAN Silver award in 2010, renewed in 2014 and 2017, in recognition of our work on gender equality. The School Director of Wellbeing, Inclusion, Diversity and Equality (WIDE), supported by the WIDE committee with diverse School representation including across career stages, has supported these submissions, the monitoring of associated actions, and wider diversity and inclusion (D&I) work throughout the assessment period. As a recent example of their activities, the group organised a survey to identify the main causes of stress amongst staff, identifying such things as workload, communication and short-term contracts. In response, an action plan has been created focusing on training for staff and managers, regular communications and a school-wide review of contract processes.

Department staff have been proactive through the assessment period in wider D&I work across the University and for mathematical sciences, including as members of the LMS Women in Mathematics Committee, UK Coordinator for the European Women in Mathematics association, membership of the SIAM Ethics Committee, and Chair of the University's LGBT+ staff network contributing to Stonewall Top 100 Employer status in 2019, 2020. Chandler-Wilde was appointed in a job share as the University's inaugural Dean for D&I 2015 – 2019, leading and/or coordinating action-planning groups for gender, race & ethnicity and LGBT+. Several staff have given invited D&I seminars in UK mathematics departments.

We have a strong commitment to work-life balance and are supportive of flexible working arrangements. During the REF period five staff made arrangements for differing patterns of flexible working including short-term part-time arrangements, flexible working in respect of childcare and shifted hours to fit in with home arrangements. The School's flexible working website (showcasing flexible working examples) and its promotion of job shares (including a male/female job share as Mathematics and Statistics Head of Department in the assessment period) are seen as good practice at the University level - job shares are now used routinely across the University at senior levels, including those of Pro-Vice-Chancellor. This practice has also been shared externally by our staff, including at the Advance HE annual conference. Supporting work-life balance, the School has policy and guidance on timings for meetings and on reading and responding to e-mails after working hours, and a very active School Mentoring Pool, providing mentoring support for all career stages. The department workload model is monitored to ensure that work is distributed as fairly and equally across the department as possible.

Since 2013 the School has held an annual Edith Morley Seminar, named after the first woman to be appointed a university professor in the UK (in 1908 at Reading). Mathematical Sciences speakers have been Margaret Wright (2013), Alison Ethridge (2015) and Gwyneth Stallard (2019). In 2019 and 2020 the department hosted outreach events to mark International Women in Mathematics Day featuring female speakers at many career stages in both academia and industry, attracting 150 attendees in 2020.

Within the Department of Mathematics and Statistics there has been an increase in staff diversity through the REF period, in part through proactively seeking strong female candidates and advertising Athena SWAN status and our supportive environment at recruitment. In REF 2014, 12% of submitted staff to this UoA were female, whilst for REF 2021, this has risen to 23%. In 2014, 48% of submitted staff were non-UK nationals which has risen to 55% in REF 2021. For this REF submission, 12% of submitted staff are BAME, compared to 7% for REF 2014. Of staff submitting as less than 1 FTE to this REF, two are male and two are female. We have a gender-balanced Department Management Group which includes both full-time and part-time senior members of staff.

Our output selection process followed the University's REF Code of Practice. The leads for each of our research themes and the CMPE, together with the former Dean for D&I, formed the group

who considered the pool of outputs for submission. All have experience of research evaluation and had undertaken D&I and unconscious bias training. The group's gender and nationality splits (4:1 Male:Female and 2:3 UK:International) mirror those of our staffing profile. Outputs were put forward following the process described in the Code of Practice. Within the group, two independent assessments were made for each output in the set. These assessments informed the establishment of the output portfolio for submission. The University's interim Equality Impact Assessment (2020) and bias analysis (2021) identified no statistically significant differences for protected characteristics in our selection.

3. Income, infrastructure and facilities

Income

During the REF period we have made applications to a wide variety of funders and have seen our grant income increase from £4049k in the last REF period (2008-2013) to £6716k in the current one (2013-2020). This is an increase in the average yearly amount from £810k to £960k, with our average annual income per Category A FTE increasing 61% over the period, from £30,563 to £49,457. Our main source of income remains the Research Councils, predominantly EPSRC, but also NERC, BBSRC and MRC. The amounts have risen through the REF period. Taking groupings of two years, the averages for 2013-15, 2015-17 and 2017-19 for research council income are £441k, £659k and £793k respectively. For 2019/20 the amount is £828k. We have had particular success with First Grants / New Investigator Awards amongst our newer members of staff (nine in total) and the EPSRC CDT in the Mathematics of Planet Earth was a particular highlight in the period.

An area of recent growth is from EU Government bodies, predominantly the European Commission (with grants in complex fluids (CGcomplexfluidflow) and complex systems (SPARCS)) and Horizon 2020 (TiPES, CRESCENDO, Blue-Action and a Marie Skłodowska-Curie fellowship award). Our average annual income from these sources grew from £30,847 in REF 2014 to £72,614 in REF 2021, tripling our annual income per Category A FTE which grew from £1,164 in REF 2014 to £3,743 in this REF period. We have a strong track record of successful joint bids for interdisciplinary grants, particularly for the CMPE and with colleagues from meteorology, chemistry, biological sciences, food & nutritional sciences and psychology.

Applications for research funding are supported by the University's Research and Enterprise Services (RES). The Research Division Leader meets every four to six weeks with the department's Research Development Manager within RES, whose role is focused on providing colleagues with information on funding opportunities as well as providing expert advice and support for the development of applications and large collaborative bids, as necessary. The Research Development Manager operates a regular programme of contacting staff to provide support for research applications, which is tailored to their stage of research career. The Research Division Impact Lead meets regularly with the RES Impact Development Manager for the Environment Theme to discuss research projects which have the potential to lead to impact and to determine a pathway for impact delivery. During the REF period this has been via the BOISP framework which, as well as affording dedicated support from the Impact Development Manager, has provided pump-priming funds for impact activities such as workshops, attendance at meetings and small-scale impact achievement projects, plus structures and support for reviewing progress and exploring possible mechanisms for broadening impact (see Section 2.3 of the Institutional Environment Statement).

Infrastructure and facilities

Mathematics and Statistics staff are located in a single building on the main campus of the University Whiteknights campus; some of those with joint appointments also have space in their other department. All staff have access to a subject-specific research library, a joint staff-student common room and a staff-only meeting space. Academic staff have individual offices. Research and visiting staff share offices with a maximum of three other people. PhD students are located in a suite of six communal rooms close to one another and there is a dedicated study space room for final year undergraduates. Four small and four medium-sized classrooms are located in the department, in which we can schedule slots for seminars and discussion meetings via the

University's central time-tabling system. The rooms can also be booked by staff for holding external facing workshops and meetings.

All academic and research staff have up-to-date computing equipment which reflects their preferences, for example PC or laptop, Windows or Mac operating systems, and is upgraded on a periodic basis. During the assessment period, the University's support for academic computing has been centralised and we have a dedicated IT partner and support for the School. Programming, mathematical and statistical software are made available to all staff and students via the AppsAnywhere platform. Access to the Reading Academic Computing Cluster (RACC) provides resources for interactive research computing and batch job submissions.

4. Collaboration and contribution to the research base, economy and society ***Research collaborations, networks and partnerships***

The department has a wide range of collaborations with researchers in both academic and industrial settings.

In the mathematics of weather & climate area, we have key links which are important to us in achieving our research goals. We are members of the Met Office Academic Partnership, which is a formal collaboration of research excellence bringing together the Met Office and institutions who are among the leading UK universities in weather and climate science. Chandler-Wilde was a member of the Met Office Partnership Board (2010–2015) and Nichols was a member of the 'Flooding From Intense Rain consortium of Universities' with the Met Office. Members of the department are part of the National Centre for Earth Observation (NCEO), a NERC distributed research centre with scientists drawn from leading universities and research organisations across the UK. The CMPE has strong links with weather and climate research centres around the world including the Met Office, ECMWF, and the German Weather Service (DWD). As noted above, we are partners in several Horizon 2020 projects and partners in a Marie Skłodowska-Curie Innovative Training Network. Potthast's role as head of the Numerical Weather Prediction section at DWD strengthens our collaboration with researchers there.

The department is home to several research networks with international reach including i) Virtanen's LMS Network on "Orthogonal Polynomials, Special Functions, Operator Theory and Applications (OPSFOTA)", ii) Katzourakis' LMS "Southwest Network in Generalised Solutions of Nonlinear PDE" with Bath & Cardiff and iii) the UK QSP Network, which has strong buy-in from colleagues across the physical, pharmacological and life sciences in both industry and academia. There is involvement of three multi-national pharmaceutical companies (AstraZeneca, GlaxoSmithKline and Pfizer) in leadership of the UK QSP Network.

Scott is a Group Leader and Individual Merit Research Fellow for the Science and Technology Facilities Council at the Rutherford Appleton Laboratory, and Neves is a funded research collaborator at The Centre of Statistics and its Applications (CEAUL), based at the University of Lisbon. Both roles boost strategic collaborations important to our aims and goals.

The department has numerous collaborative projects with academic colleagues in the UK, France, USA, Germany, Canada, Finland, Israel, Belgium, Austria, the Netherlands and Japan. We have also fostered a range of links with industrial partners, including new and continued partnerships. Those that have led to measurable outputs (funding applications, publications, industrially funded events such as workshops or consultancy) have been with Abelio, AstraZeneca, Certara QSP, Crops for the Future Research Centre (Malaysia), EDF Energy, GlaxoSmithKline, GW Pharmaceuticals, MedImmune, Merck Serono, Microsoft, Pfizer, Roche, Scottish and Southern Electricity, Syngenta, Tesla, the European Bioinformatics Institute, the Institute of Occupational Medicine and Unilever.

Wider activities and contributions of the department to the research base, economy and society

A number of awards have been made to staff in the department since REF 2014. Lucarini was the recipient of an LMS Whitehead Prize in 2018 and the L.F. Richardson Medal of the

European Geosciences Union in 2020. Perfekt was awarded the Zemánek prize in Functional Analysis in 2018 and Geher was awarded the Grünwald Géza Award from the János Bolyai Mathematical Society, Hungary as well as the Journal of Mathematical Analysis and Applications JMAA Ames Award for the best paper in pure mathematics published in 2016. Two members of staff have been awarded fellowships during the REF period: Dance (EPSRC Senior Fellowship) and Neves (EPSRC RCUK Innovation Fellowship).

Our members have held positions in external bodies, such as: invited member of the Conference Panel for the IMA (Lucarini), elected member of the Council of the Royal Statistical Society (2014-2017; Todd), elected member of the Council of the IMA (2013-2016; Scott), elected Vice President of SIAM UKIE (2015-2017; Scott), chair of the appointments committee for the Editor-in-Chief of ACM Transactions on Mathematical Software (2018; Scott), member of the Women in Mathematics Committee of the LMS (2006–2014; Scott), UK coordinator/treasurer for European Women in Mathematics (2007–2015; Scott), member of the SIAG/LA Early Career Prize Selection Committee (2017; Scott), member of the SIAM Fellows Canvassing Committee (2020 – 2022; Nichols), member of the SIAM Fellows Selection Committee (2017 – 2019; Nichols), member of the SIAM Committee on Committees and Appointments (2015 -2017; Nichols), member of the LMS Early Career Research Committee (2017- now; Newton), member of the EPSRC Early Career Researchers Forum (2018 – present; Newton),) and member of the Steering Committee of an international network Women in Numbers (2016 – now; Newton).

During the REF period staff have been active on Editorial Boards or Invited Editors of the following journals: *ACM Transactions on Mathematical Software* (Scott), *Acoustics* (Chandler-Wilde), *Chaos* (Wouters), *Dynamics and Statistics of the Climate System: An Interdisciplinary Journal* (Lucarini & Wouters), *Earth Systems Dynamics* (Editor-in-Chief: Lucarini), *Nature Scientific Reports* (Tindall), *Nonlinear Processes in Geophysics* (Lucarini), *Mathematics of Climate and Weather* (Lucarini), *Mathematical Population Studies* (Neves), *PLoS Computational Biology* (Tindall), *Polymers Journal* (Ilg), *Statistics in Medicine* (Todd), *Proceedings of the Royal Society of Edinburgh A: Mathematics* (Editor-in-Chief: Pelloni & Tindall) and *SIAM Journal on Scientific Computing* (Scott).

Members of the department have organised numerous conferences and workshops for the mathematical community, both at Reading (over 20) and elsewhere (over 15). Meetings with substantial participation hosted at Reading include the joint LMS-IMA meeting on Mathematics of Climate, the LMS-CMI Research School on Modern Topics in Nonlinear PDE and Geometric Analysis, the LMS meeting in Diophantine Geometry, the LMS meeting on Prospects in Mathematics, and the British Society of Rheology Midwinter Meeting on Polymer Dynamics & Rheology together with a Symposium on "The Science of Alexei Likhtman". Meetings elsewhere have been hosted all over the UK and the world including Canada, France, Italy, Japan, Mexico, Portugal, Spain, and the USA. Research-active members of staff are regularly involved in imparting their research via a range of outreach activities. The department is involved with the Reading Scholars programme, which focuses on enabling students from deprived backgrounds to experience University life. This involves hosting events on campus and in schools where members of staff present and discuss their research in fun interactive ways. Topics cover a wide range of areas including analysis (Virtanen and Perfekt), infectious diseases (Tindall), number theory (Daw), numerical methods and weather prediction (Lawless) and polymer physics (Wang). The department actively runs events connected to the role of mathematics in society, such as the recent two-day lecture event followed by a reception in celebrating International Mathematics (Pi) day in March 2020.

Members of the department have taken part in several grant funding panels. Since 2014 these have included the Review Panel for Swiss National Science Foundation COST Grants (Lucarini), the International Advisory Board for a H2020 Programme (Marie Skłodowska-Curie Actions) of the European Commission's Innovative Training Networks (Wang), the EPSRC Mathematical Sciences Prioritisation panel (Neves) and EPSRC Mathematics Responsive Mode Grants panels (Scott; Levitin), the NIHR Clinical Scientist Awards panel (Todd), the National Centre for Refinement, Reduction and Replacement of Animals in Experiments (NC3Rs) Studentship panel

(Tindall), the NCS3Rs CRACK-IT panels (Tindall), the Inserm Plan Cancer grant panel (Tindall) and the National Science Foundation panel (Newton).

The Department of Mathematics & Statistics at the University of Reading is committed to conducting high quality research within each of its themes, that impacts both nationally and internationally, together with engaging relevant stakeholders and the wider community. We continue to seek collaborative opportunities with external partners, both academic and industrial, relevant to our areas of research. Our overall ethos and vision mean we will continue to pursue our core goals of niche, world-class research in mathematics and statistics, together with leading and enhancing the development of exciting cutting-edge interdisciplinary areas such as the Mathematics of Planet Earth and QSP.