

Institution: University of Exeter
Unit of Assessment: 10 Mathematical Sciences
<p>a. Context.</p> <p>Substantial growth within the UoA over the last few years has been made possible through the University of Exeter's £27M staffing and infrastructure investment in "Science Strategy" themes http://www.exeter.ac.uk/research/inspiring/keythemes/science/ including: Climate Change and Sustainable Futures (CCSF), Systems Biology (SB), Exoplanets (EP), Functional Materials (FM) and Translational Medicine (TM). These themes have enabled researchers within the UoA, as part of a larger critical mass of researchers, to play a key role in contributing to impact of STEM/M research across the University because of links to industrial and commercial activities, contributions to policy development and the development of highly trained individuals.</p> <p>The five research groups within the <i>Mathematics Research Institute</i> form an outward-facing, research-intensive community where, in addition to enquiry-driven research, Mathematical Sciences at the University of Exeter addresses research topics of direct and significant impact. Substantial but indirect impacts also occur from research of this UoA; the EPSRC-commissioned Deloitte report <i>Measuring the benefit of mathematical sciences research in the UK</i> (2012) notes:</p> <p style="padding-left: 40px;"><i>"Mathematical sciences research has a record of significant socio-economic impact over a wide and sometimes unexpected range of fields, and over a wide range timescales".</i></p> <p>The Centre for Geophysical and Astrophysical Fluid Dynamics (CGAFD) works with the UK Met Office on development of new generation operational weather forecasting (Case study 1) and climate models as well as on solar and planetary flows and magnetic fields. The Centre for Systems, Dynamics and Control (CSDC) undertakes collaborative research with aerospace (Case study 2) as well as defence, medical and biotechnology companies. Exeter Climate Systems (XCS) undertakes statistical research applied to insurance and health service allocation (Case studies 3 and 4). Research from XCS across UoAs 7 and 10 is having a world-leading influence on understanding and modelling of climate, exemplified by four lead authors within XCS for the <i>Intergovernmental Panel on Climate Change Fifth Assessment Report</i> published in 2013. Research has impact areas that include agricultural and land-use policy, energy policy, health policy and insurance valuation. Pure Mathematics (Pure) research includes engagement with and a secondment to the Heilbronn Institute. The Maths and the Environment (MaE) research group focusses on bringing mathematical expertise to a range of applications including ecosystems analysis and management, epidemiology and renewable energy. The Exeter Initiative for Statistics and Applications ExISta links members within the UoA to other academics and individuals from commerce and industry who are looking for statistical expertise.</p>
<p>b. Approach to impact</p> <p>We encourage researchers within the UoA to establish and develop relationships with end-users that will maximise the translation and impact of basic research. Indeed, several researchers who work within the Mathematical Sciences on a day-to-day basis are returned to UoA 1, UoA 7 and UoA 11. Academics are encouraged, as part of their annual development review process, to consider paths to impact when applying for research council or other funding, and the unit has significant funding streams from NERC, BBSRC, EPSRC and STFC that lead to impact.</p> <p>Impact on industry and commerce: One significant route to impact is via the University's ongoing academic partnership with the Met Office. The Met Office has jointly funded three Chairs in Mathematics over the past few years, each for three years at 50%, with two of those extended for a further three years at 20%. The Chairs are able to spend a significant fraction of their time interacting directly with Met Office staff. In 2010, the Met Office signed an academic partnership with the Universities of Exeter, Leeds, Oxford and Reading, which demonstrates a long-term commitment to the collaboration. The agreement gives scientists at the Met Office access to the University as visiting scientists or as joint appointments. Exeter is a founding partner in the Willis Research Network (WRN) and a key member of the Climate Risk Hub within the WRN which has funded a PDRA at Exeter since Jan 2007. Other external funding in this area comes from the insurance company AXA. Townley from MaE has EU funding to work with Engineers in collaboration with Ocean Power Technologies. Their work has developed novel signal processing</p>

and control systems tools to improve the performance of wave energy converters. Menon from CSDC has industrial collaborations with a number of aerospace companies, including contract research from Astrium and NGC Aerospace. Terry and Tsaneva-Atanasova have direct collaborations with medical clinicians, which has led to impact within the NHS and funding from MRC, Epilepsy Research, EPSRC and BBSRC. Tsaneva-Atanasova works with collaborators in computer science (EPSRC EP/L000296/1) on new approaches to personalised medicine, and with veterinary pathologists on hen health issues (BBSRC BB/K001906/1). Terry is leading the modelling part of significant MRC funded work on the HPA-axis which promises to lead to improved cortisol-based treatments, as well recently obtaining a patent for novel diagnostic methods for epilepsy (Terry JR, et al: "Assessing susceptibility to epilepsy and epileptic seizures", June 2012. British filing 1209975.0; US Serial Number 61/656, 121). Bailey's research includes projects funded by NIHR, Wellcome and FERA.

Influence on policy: Researchers influence policy in the following ways: expert advice from XCS to Parliamentary Office of Science and Technology note on "Renewable Energy in a Changing Climate"; member of World Meteorological Organisation Joint Working Group on Forecast Verification; member of Royal Society working group on ground level Ozone in the 21st century; member of Royal Society working group on Geoengineering; member of Copenhagen Climate Diagnosis group preparing an update to the IPCC report for input to CoP15; member of advisory committee for the NSF-funded Centre for Magnetic Self-Organization in Laboratory and Astrophysical Plasmas; member of Technical Advisory Committee Subgroup on Verification Measures at the European Centre for Medium Range Weather Forecasts. Stephenson is lead author for the forthcoming 5th assessment report of the Intergovernmental Panel on Climate Change (IPCC) AR5. The EPSRC-funded LWECC network "CliMathNet" incorporates members from XCS, CSDC and CGAFD and aims to encourage effective collaboration between Mathematicians, Statistics, Climate Scientists and Policymakers. Berger is a consultant for Helio Research, a research company based in Los Angeles. Other examples of direct funding include funding of a fraction of Bailey's advisory input to the NHS national funding mechanism for mental health provision in UK Primary Care Trusts. Chapman undertook a period of secondment by the Heilbronn Institute at Bristol during 2009-10. Recker and Tildesley in MaE work on human and animal disease epidemiology and collaborate closely with clinicians and policymakers.

Collaborative projects. Staff within the UoA engage in a range of collaborations with potential users of research. Wieczorek works with Sandia National Laboratory (USA) on nonlinear laser physics; Thuburn works with the National Centre for Atmospheric Research and Los Alamos National Laboratory (USA) while Zhang works with JPL and UCLA (USA) on the NASA JUNO spacecraft related problems. Stephenson collaborates with the European Centre for Medium Range Weather Forecasting. Academic staff are encouraged and supported to take study leave when appropriate, to develop their research and to maximize its impact through visits to industry, secondment, international visits, etc. For example, Zhang (2011-12) and Thuburn (2011-13) have recently had research leave supported by external funding. The University's department of **Research and Knowledge Transfer (RKT)** supports academics to find links with industrial partners, identifying pathways to impact at an early stage of when projects are being developed and to exploit the results of research. The University's legal team manages complex contract negotiations on grant awards. RKT have met the standard of the ISO 9001:2008 - an internationally recognised Quality Management standard which recognises the quality of the processes and procedures we have in place to support academics. RKT supports the development of impact through a dedicated Impact Manager and budget of £120k/annum.

Collaborative Postgraduate Research studentships. Since 2008, several mathematics PGR students have received CASE funding for collaborative research projects with the Met Office. Four other studentships have received part funding from industry, two with the Met Office, one with New Generation Biogas / North Wyke Research and one with Bookham Technology (now Oclaro). Further CASE funding with Willis is looking at clustering of insurance losses. Researchers from this UoA are contributing to a range of impacts via their further careers (e.g. Dr Dan Holdaway, a PhD student from CGAFD now works at the NASA Goddard Space Flight Centre).

Public and schools outreach. Activities to inform the public about recent research include presentations to Ripon Rotary Club and Exeter Cafe Scientifique on climate change. Researchers

from the UoA are closely involved in the development of the innovative new *Exeter Mathematics Free School*, due to open in 2014. This school was set up jointly between the University and Exeter College and aims to nurture the development of brilliant young mathematicians within the region. Researchers are also enthusiastically working with school pupils in activities such as *Royal Institution Mathematics Masterclasses* and web resources “*mathMETics*” that bring some of the mathematical issues of weather forecasting into school mathematics lessons.

c. Strategy and plans

Several recent appointments to the UoA have been targeted at areas that bridge between Mathematical Sciences with the University’s “Science Strategy” themes: **CCSF**, **SB**, **TM**, **FM** and **EP** (see section a.) These areas have great potential for interactions with end users, industry and/or the public. We plan to continue this focussed strategy whilst ensuring that core mathematical strength is maintained. The College has an *External Advisory Board* with business and industrial stakeholders that provides us with industrial consultation and input to UoA and College research strategy.

With regard to the themes **CCSF** and **EP** we will continue to lead joint research programmes with the Met Office such as the NERC - Met Office Joint Weather and Climate Research Programme and the NERC-STFC-Met Office Next Generation Weather and Climate Prediction programme. Further opportunities exist to work with the Met Office and the global reinsurance industry on the statistical modelling of weather and climate related risk. With regard to the themes **SB** and **TM** we are moving towards projects that will achieve lasting impact in medical research. The nature of mathematical and statistical knowledge is its transferability between disparate areas; e.g. control theory developed for the **SB** area has been applied to space mission design, and vice-versa. The Environment and Sustainability Institute on the Penryn campus facilitates collaboration with end-users that include local industry, epidemiologists and ecologists.

Institutional and College-level support In addition to support from RKT and the College, an institutional EPSRC-funded “Bridging the Gaps” programme ran 2010-2013 with Co-Is Ashwin and Bailey from this UoA. This is being continued with University funding as a mechanism to support novel cross-disciplinary activities. The College uses a workload planning system for all academic staff, and this can include time to develop activities that will specifically create impact from research undertaken within the UoA. The University runs an annual “impact award” to spread best practise and to encourage all researchers to think about the impact of their research.

d. Relationship to case studies

The selected impact case studies are examples of the strategy outlined above – they give examples of impact of work undertaken in the UoA (mostly related to the University’s science strategy themes). This work was supported via a range of commercial and research sponsors. Specifically, we comment below on the alignment of the case studies CS1-CS4 to the groups and science strategy themes, as well as to partnerships and sponsors.

CS1: *Improving the Met Office Weather and Climate Prediction Model* is based on work of Thurnburn within CGAFD that relates to both CCSF and EP themes; this is sponsored as part of the ENDGame project with the Met Office and is supported by the Met Office academic partnership.

CS2: *Changing the way the European space industry verifies the safety of complex systems* is based on work of Menon within CSDC applied in the aerospace industry. It benefits from links to the Engineering UoA and the commercial sponsors Astrium, GMV, Deimos, SCISYS and NGC.

CS3: *Improved pricing of European natural catastrophe insurance by statistical modelling of storm clustering* is based on work of Stephenson within XCS and is aligned to the CCSF theme. Its impact has come about via sponsorship of the Willis Research Network and it benefits from the Met Office academic partnership.

CS4: *Development of mathematical models for Practice based Commissioning budgets for adult mental health in the UK* links work of Bailey in XCS and is aligned to the TM theme. It benefits from regional collaboration of Statistics within the UoA with the University of Plymouth. These links have recently been strengthened through the creation of ExIStA.