Institution: University of Glasgow

Unit of Assessment: 10 – Mathematical Sciences

a. Overview

The School of Mathematics & Statistics was formed in August 2010, merging the former Departments of Mathematics and of Statistics into a single unified structure, now one of seven research-led schools in the College of Science & Engineering. Our new structure, based on single School committees and – vitally – a single School Coffee Room, allows us to exploit the increasing connections within the mathematical sciences and aligns us with the interdisciplinary nature of wider research.

Research Group	Leader	Staff	RAs	PGs
Algebra	Brown	6	1	7
Analysis	Zacharias	3	1	4
Biostatistics & Statistical Genetics	Macaulay	4	0	5
Statistical Methodology	Husmeier	4	1	8
Environmental Statistics	Scott	4	2	7
Continuum Mechanics	Ogden	8	2	3
Geometry & Topology	Baker	4	0	3
Integrable Systems & Math. Physics	Strachan	6	0	3
Mathematical Biology	Hill	4	2	9

Each member of academic staff and each PhD student is a member of one primary research group, as in the table above where the numbers refer to a snapshot on the REF census date. In practice, these groups are flexible and overlapping structures, with many staff participating in more than one.

Indicators of **vitality** include:

- 10 competitive fellowships held
- 5 major honours (OBE, Prager Medal, EdMS Whittaker, Int. Environ. Soc. x2)
- research income (per fte p.a.) close to doubled since 2008.

Indicators of **sustainability** include:

- only 1 REF-omitted staff (cf. 8 in RAE 2008)
- improved age profile, with 20 new staff, many at early career stages
- 49 current research students

In the text below, references to outputs are denoted by [name number].

b. Research Strategy

Modern developments in the mathematical sciences, and in wider science, often take place at the boundaries between fields. Our research strategy is therefore based on breadth, from deep issues of mathematical and statistical theory and methodology to high impact applications and interdisciplinary collaborations. We support this strategy by appointing individuals who are excited by cross-boundary opportunities. This is exemplified by the collaboration of Cobbold and Leinster on a unified framework for species diversity [Cobbold 1], which connected mathematical biology with category theory, and led to substantial interest from ecology as well as a new theorem in analysis. The wide range of activity in the unified School creates many opportunities for our research to be applied to, and be motivated by, real world problems. The collaboration of Luo and Husmeier on heart modelling (see GlasgowHeart in (e) below) is an excellent example.

Our activity is structured around the interlocking research groups listed in (a). While breadth is central to our strategy, some selectivity is necessary. Research directions are continually reviewed by the School Research Committee, informed by interactions with our collaborators, funders and research users. Implementation of our research strategy is targeted firstly at the recruitment, retention, support and development of top-class staff in appropriate fields; secondly, at the development and sustenance of a lively and large postgraduate programme; and thirdly, at the provision of excellent facilities and support for research and teaching.

Significant changes since 2008

In RAE 2008 we submitted 86% of staff within the three mathematical sciences UoAs. Subsequent departures and retirals have enabled us to change the staff profile significantly, with 98% of staff returned in REF 2014. Of the 43 staff submitted (omitting only 1 FTE), nearly 50% have been appointed since RAE 2008. This constitutes a radical re-energising and renewal, aligned with the strategy outlined above. This investment in new staff demonstrates the University of Glasgow's strong commitment both to our core research and our interdisciplinary activity.

Research developments broadly correspond to those planned in the three mathematical sciences submissions made to RAE 2008. One difference is the strategic decision not to maintain our small Combinatorics group after retirals, but instead to ensure critical mass and growing strength through new appointments in other research areas. For example, the School decided to rebuild its long-standing Analysis group through a series of exciting appointments. While Analysis, Statistics and Continuum Mechanics have all been substantially strengthened, in line with the recommendations of the report of the 2010 International Review of Mathematical Sciences (IRMS), the scale of staff recruitment has allowed all of our research groups to be enriched by new recruits.

Research highlights

In the remainder of this Section we provide evidence for the success of our research strategy through examples of noteworthy developments since RAE 2008. These are highly selective as a result of limited space but indicative of the breadth and depth of our work.

The high profile of our **Environmental Statistics** group exemplifies the strategy of pursuing statistical methodology which is motivated by important scientific questions and able to deliver high-impact answers, in line with recent IRMS recommendations. The methodological focus includes spatiotemporal models [Scott 4], environmental epidemiology [Lee 2] and functional data analysis [Ray 1]. Recent success includes the development of an innovative flexible regression model for spatiotemporal data over networks [Bowman 2], with computational efficiency which allows the handling of large and complex datasets. During the REF period the group has attracted 5 postdocs and 25 postgraduate students and its research has been supported by excellent grant income (£2.6m, including EPSRC 2013; NERC 2008, 2009, 2012; ESRC 2010, 2013). The high standing of the group is indicated by its extensive range of collaborators and research users (Met Office, Scottish Environment Protection Agency, Centre for Ecology and Hydrology, Environment Agency, Scottish Water, PML, Information Services Division of Scottish NHS, Health Protection Scotland).

The revitalised **Analysis** group is already one of the strongest groups in the UK focusing on operator algebras and non-commutative geometry; we aim over the next few years to make it a European leader. Zacharias (appointed as Reader in 2012) introduced (jointly with Winter) the nuclear dimension of a C*-algebra [Zacharias 3]. This concept has transformed the study of the structure of nuclear C*-algebras (the focus of a £355k EPSRC grant held by Zacharias and White) and was the theme of a 2011 Copenhagen Masterclass. White and his collaborators further developed the nuclear dimension and used these ideas in their solution of the Kadison-Kastler perturbation problem for separable nuclear C*-algebras [White 3,4]. Voigt, appointed in 2012, brings expertise in quantum groups and non-commutative geometry, thus fostering strong links with the **Algebra** Group members Brown and Kraehmer. Current activity in analysis has received external recognition through the award to White of the prestigious Whittaker Prize of the Edinburgh Mathematical Society in 2013.

Research in **Continuum Mechanics** illustrates the significant benefits of exploiting the strong connections across research areas. For example, in ongoing work on blood circulation, the initial key was the modelling of the nonlinear elastic properties of soft biological tissues, specifically the wall tissue of arteries and the myocardium, through a structurally-based model of the passive response of myocardium tissue [Ogden 1,3]. This has now been extended to take account of residual and active stresses in models of the left ventricle, gallbladder, heart valves, and arteries [Luo 1]. The left-ventricle model is being developed into a complete model of the systemic arterial circulation by the **Mathematical Biology** group, with more extensive modelling of cardiac electrophysiology [Simitev 1,4], fluid-structure interaction, and growth and remodelling [Luo 2, Hill

4], and by coupling the flow to a structured-tree model of the systemic arteries [Hill 1]. Work in continuum mechanics in general has benefited from 4 new permanent appointments, it is supported by grant income totalling £1.8m and its quality is recognised by the award of the Prager Medal to Ogden (2010).

Geometric representation theory has been strengthened by the permanent appointment of EPSRC post-doctoral fellow Bellamy and of the Lie theorist Fourier, whose outputs include collaborations with Littlemann and Chari. There are interactions with the **Integrable Systems and Mathematical Physics** group and major international collaborators. One example is the representation theory of rational Cherednik algebras [Bellamy 1], jointly with Ginzburg, Chicago, and its applications to generalized quantum Calogero-Moser systems [Feigin 3]. Another example is the study of tilting modules, fusion rings and quantum cohomology using techniques from exactly solvable lattice models [Korff 3, jointly with Stroppel, Bonn]. These results have been recognised internationally: Research Fellowship at MSRI (Bellamy), EPSRC first grant (Feigin), Royal Society Fellowship 2004-12 (Korff), invitation to Hausdorff trimester Bonn 2012 (Feigin, Korff).

Following the appointments of Owens in 2008 and L. Watson in 2013, the University of Glasgow has excellent strength in **low-dimensional topology**, with synergistic overlap with our geometric group theorists Brendle and Thomas. Highlights in the REF period include Owens' completion of the table of unknotting numbers for 9 crossing knots [Owens 4]; Owens' ongoing collaboration with Bieri and Kropholler on configuration spaces of tame subsets of spheres [arXiv1208.5041]; and L. Watson's work on left orderability and L-spaces [Watson 3] including his influential conjecture with Boyer & Gordon [Watson 1].

The **Statistical Methodology** group investigates techniques for evaluating analytically intractable problems, search and optimization methods, computer-intensive sampling, simulation and Monte Carlo methods, and approximate inference, with applications to complex systems and 'big data'. Research is supported by EU funding for computational inference in molecular systems biology and responsibility for a work package in a £5.8m EU project (Timet) to establish a connection between circadian regulation in plants and biomass production, with potential long-term applications to food security and biofuels. Group members also hold grants on functional data modelling, climate-ecosystem dynamics and global change, and multi-scale modelling of mass migration (total value £628k). The work of this group is close to the **Biostatistics and Statistical Genetics** theme where highlights are the modelling of data objects by capturing high-resolution shape information (Bowman, Wellcome Trust); evolution of morphology along a phylogeny using a Gaussian process framework (Macaulay, EPSRC); application of spatio-temporal modelling of risks to health (Lee, ESRC & EPSRC); extraction of demographic signals from genomic data, featured by the BBC and others [case study].

Research groups operate in a variety of ways, but all run regular seminars (typically weekly). Each series is based on external speakers, supplemented by longer-term visitors, and internal speakers, including postdocs and postgraduates; the latter give at least one group seminar during their studies. The School budget for its seminar programme in 2012-13 was £25k, a figure similar to that for previous years. Two key points are: (i) *all* students and staff are expected to participate in the seminar life of the School, and (ii) there are no rigid group boundaries, with much intermingling and frequent joint seminars. Pre-seminars, which prepare the background of seminar topics for the benefit of research students (and others), have been particularly successful. The seminars are supplemented by a rich diet of advanced courses and working groups, seasoned with the SALT (Sandwiches and Light Theorems) series of lunchtime talks. The School Colloquium meets around twice per semester to discuss research topics of broad interest across the School. Much of our School's seminar programme for recent years is recorded on our School web pages.

Future strategic aims and initiatives

Our primary aim is to maintain and enhance the position of the School as broad-based, internationally leading and research-led. Specific plans include:

- the development of our early-career researchers to fulfil their potential as international research leaders over the next decade;

- recruitment to a Chair in Pure Mathematics, to ensure leadership succession in this area;
- additional staff in Statistics research groups through increased overseas recruitment to the Statistics undergraduate degree and through involvement in the University of Glasgow's new Quantitative Methods Centre, funded by ESRC and the Nuffield Foundation (£1.2m), which will strategically develop collaborations with the social sciences;
- increased recruitment of research students, both home and overseas, with the additional income invested in new staff;
- further development of present leadership in University of Glasgow interdisciplinary research initiatives, including systems biology (Husmeier), sensors (Scott, Bowman), computational modelling and simulation (Luo).

c. People, including:

I. Staffing strategy and staff development

Staffing strategy

The School's strategy in making permanent academic appointments is to maintain an approximately equal balance between the three broad areas of Applied Mathematics, Pure Mathematics and Statistics, in order to fulfil the research aims described in section (b) above. In deciding on appointments, our goal is to appoint outstanding individuals to support the School's plans for excellence in all our activities. Future growth is planned principally through the development of new streams of funding, particularly through postgraduate activity (both taught and research).

Research leadership

This is exhibited at all levels, as detailed in section (e). Our 8 professors all lead a research group or give strategic leadership through other School managerial roles. Husmeier is a recent appointment to the Chair of Statistics (vacated by the retiral of Titterington) who has brought significant expertise in computational and Bayesian modelling, with particular applications in systems biology. Strachan was recently promoted to a chair in recognition of his leading work in Frobenius manifolds, connecting mathematical physics and geometry. Furthermore, research leadership is exercised widely within the School, recognised by the consistent promotion of lecturing staff to higher grades (within the REF period, 2 Professors, 4 Readers, 8 Senior Lecturers).

Early Career Researchers (ECR)

Newly appointed staff are each given a mentor who provides information and advice on all aspects of the School. For ECR staff, career and research advice is provided and the standard teaching reduction for new staff is extended throughout probation. Other mechanisms through which ECRs are developed and encouraged include the *Crucible,* an interdisciplinary event at University and Scottish levels where ECRs are brought together and novel research collaborations explored. Craigmile, Korff, Evers and Simitev have all benefited from this.

More generally, the University of Glasgow's plan for implementation of the *Concordat to Support the Career Development of Researchers* includes (i) ensuring that all staff benefit from an annual appraisal, including a tailored Performance and Development Review, (ii) promotion of the University of Glasgow's Code of Practice for the Management of Research Staff, (iii) implementation of the Researcher Development Framework, including piloting the Vitae on-line planner tool, and (iv) provision of mentoring, online resources, training workshops and mock interviews for research staff applying for internal or external Fellowships.

Research fellowships

The following externally-funded competitive fellowships were held during the REF period. In addition, L. Watson held a NSERC post-doctoral fellowship at UCLA (2009-11) and Thomas held an ARC Postdoctoral Fellowship at the University of Sydney (2011-13).

Funder	Scheme	Fellow	Dates	Subsequent employment
Royal Society	RS Univ. Res. Fellow	Korff	2004-12	Reader, Glasgow
EPSRC	Advanced Fellow	Leinster	2006-11	Fellow, Edinburgh
EPSRC	Advanced Fellow	Bees	2006-12	Chair, York
EPSRC	RCUK Fellow	Roper	2006-12	Lecturer, Glasgow
EPSRC	Postdoctoral Fellow	Kraehmer	2007-10	Lecturer, Glasgow
German Res. Fnd.	Heisenberg Fellow	Pott	2008-10	Chair, Sweden
EU	Marie Curie Fellow	Szablikowski	2008-10	Lecturer, Poland
EU	Marie Curie Fellow	Villarroya	2008-10	Fellow, Sweden
EPSRC	Postdoctoral Fellow	Roitzheim	2010-12	Lecturer, Kent
EPSRC	Postdoctoral Fellow	Bellamy	2012-14	Lecturer, Glasgow

Staff development
New appointments are given a reduced (2/3) first-year teaching load to allow them to continue to develop their research and apply for grants. The annual Performance & Development Review provides an opportunity to discuss research activity and direction and to highlight opportunities. This also applies to research assistants, for whom a wide variety of training opportunities are provided. The University of Glasgow has been awarded 'HR excellence in research' status from the European Commission in recognition of its commitment to supporting its researchers' career, personal and professional development. The University of Glasgow is one of only 8 universities in the Russell Group to hold this award.

All staff are expected to apply for grant funding and, in addition to administrative support, advice is supplied and ideas developed through regular away-day and workshop events. When grants are awarded, salary buyouts are honoured through a workload model, with the money used to employ temporary staff, whose own research we support and encourage. The School itself provides substantial funding for research-related travel, amounting to £65k in 2012-13.

Academic staff are entitled to apply for paid study leave on a basis of one semester or year in seven, and unpaid (funded by fellowships or host institutions) study leave at any time. Leave is approved provided that that there is a clear plan indicating the benefit to the individual's and the School's research activity, and subject to appropriate cover for School duties. During the REF period the School has granted 12 periods of leave longer than 3 months, amounting to 85 months in total. Research visits lasting less than three months, of which there are very many, are handled routinely and informally.

International staff and visitors
Over 90% of our staff have held research positions outside the UK. The international context of our work is underlined by a stream of overseas visitors working on collaborative projects. In particular, we profit greatly from bequests which allow us regularly to invite researchers of particularly high international standing to spend time in the School for the benefit of all researchers. One example is the Mitchell Lectureship in Statistics which brings statisticians of the highest calibre (recently Harrell, Carroll, Gelman, Hall, Davison and Holmes) to spend a week in research discussion with staff and particularly with research students. Other examples among many prestigious visitors are Diaconis, Baez (both Rankin Lecturers), Borodin (London Mathematical Society Lecture Series), A. Gelfand, Lindsay, Jimbo, Novikov and Noumi. Peter Hall and Gerhard Holzapfel are regular visitors as Honorary Professors in the School.

c. II. Research students

Research students
Postgraduate students are a key part of our research strategy. There is a vibrant community of 49 PhD students across all the research areas in the School, with approximately half from outwith the UK. As there is a very high demand for places our aim is to continue to increase these numbers

over the next few years. Our participation in a newly funded NERC DTP (www.dur.ac.uk/iapetus) will assist in this.

Development of research students is given high priority. A comprehensive set of courses is provided through two EPSRC affiliated Taught Course Centres (TCC): the Scottish Mathematical Sciences Training Centre (SMSTC) and the Academy for PhD Training in Statistics (APTS). A standard SMSTC curriculum involves 3 courses from a set of 8, each with in-house tutorial support. This represents 50% of each student's effort for the first year. The courses include graded assignments and satisfactory performance is required for progression to year 2. The APTS programme in statistics comprises 4 week-long residential sessions. The School is committed to both programmes and our students are fully funded to attend. We are a founding member of, and members of the advisory board for, both TCCs. Our academics teach on both programmes and the University of Glasgow is currently one of the 4 APTS venues. The School also has taught MSc degrees in mathematics and statistics, allowing an extra year of study to be undertaken before a PhD if required. PhD students may also take courses from our undergraduate MSci degrees. The School runs postgraduate away-days, which provide general research training, such as thesis writing in LaTeX and in computational skills. Additionally, our students run their own seminar and reading groups. The 2013 Young Researchers in Mathematics conference, with over 200 participants, was part organised within the School and funded by a London Mathematical Society (LMS) grant of £5.8k.

Building on the successes of the Roberts funding, there is significant investment in training and development opportunities for PGR students at University (£300k pa) and College (£85k pa) levels. The University of Glasgow collaborated in a Scotland-wide programme, focussed on training for knowledge exchange, which received a THE award in 2010. All students undergo comprehensive generic skills and employability training, including presentation skills, team working, library research skills, CV workshops and employer-led mock interviews. Our "Making an impact with your PhD" programme was shortlisted for a THE award.

On entering the school, each student is assigned a supervisory team, consisting of primary supervisor(s), with whom contact is frequent, and a secondary supervisor who provides pastoral support. All students are provided with office space, desk, desktop or laptop computer, access to high-performance computer servers and to electronic journals and a dedicated mathematical sciences library. Access to the School building is 24/7. A rigorous annual review, involving a written report and a viva by academics not on the supervisory team, is overseen by the three postgraduate directors.

The School has an annual budget of £25k to allow students to attend national and international conferences, where they often present their work. The University of Glasgow's Jim Gatheral Scholarship for mathematical modelling financially supports students to spend between two months and a year at a world-leading university or research organisation outside the UK. Recent student destinations and hosts include Ohio State University (Cressie), SAMSI (Fuentes), NYU (Griffith x2), CSIRO (Petersen, ver Hoef).

The PhD students trained by the school are highly qualified when they arrive and produce high quality publications through their research. For example, our students' work has recently appeared in *Biometrics*, *Biostatistics*, *J. Reine Angew. Math.* and the *Journal of Fluid Mechanics*. Student prizes are regularly won at international conferences for presentations (TIES, IWSTM, IWSM, METMA). On graduation our students have prestigious careers, with examples in the last 5 years including university postdoctoral positions at Amsterdam, Marseille, Bonn, Munster, Erlangen, Warwick and John Hopkins, as well as non-academic careers such as teaching and the finance industry.

Equality & Diversity

The School is committed to promoting equality in all its activities and to providing a work, learning, research and teaching environment free from discrimination and unfair treatment. The University of Glasgow provides online equality and diversity training which is mandatory for all staff involved in

recruitment. The University of Glasgow joined the Athena Swan Charter in 2011 and is committed to advancing women in the STEMM disciplines. Its action plan (2012-15) identifies the steps being taken and a key performance indicator to increase the percentage of women in senior posts was set in its strategy 'Glasgow 2020: A Global vision'.

Women hold senior positions within the School, with two Professors (Luo, Scott) and the Head of School Administration (McIsaac) among the eight members of the School Management Committee. Brendle, Cobbold, Gilson, and Miller hold Senior Lecturer posts while Dean, Neocleous, Scardia and Thomas are lecturers. 23% of submitted staff are female. The School was recently rated highly by The London Mathematical Society following its survey of the processes for encouraging women within Mathematical Sciences Schools in the UK. We achieved particular commendation for: levelling appointment and promotion playing fields; career development activities; flexibility and sustainable careers; career breaks.

d. Income, infrastructure and facilities

Income

The School's research grant portfolio is constructed from a wide variety of funding agencies, including EPSRC, EU, NERC, BBSRC, Royal Society, the Wellcome Trust and the Leverhulme Trust, in addition to industrial funding and a wide variety of smaller grants which are invaluable in supporting staff visits, visitors and conferences. Some highlights are noted below:

- Total income has substantially increased from £3.8m in the last RAE to £5.3m for the period covered by the current REF, representing close to doubling of the funding income per fte per annum. There is a further £1.9m of guaranteed funding beyond 2013.
- 45 Research Council grants with a value of £3.1m were awarded during the REF period.
- We have had great success in the EPSRC First Grants Scheme with 4 awards since 2010.
- We have recently been successful as a collaborator on a £5.8m FP7 grant (Timet).
- The School has attracted just under £1m of consultancy and commercial income during the REF period. This includes over £200k from statistical consultancy projects for Senn involving problem-solving for the pharmaceutical industry, including companies such as Boehringer Ingelheim, GlaxoSmithKline, Novartis, Pfizer, Rochester, Merck and Bayer. A similar amount of funding has also been awarded to the Environmental Statistics group for the delivery of training and consultancy in environmental evaluation and protection, from the Scottish Environment Protection Agency, Sellafield, Centre for Ecology & Hydrology and NERC.

We will continue to seek funding from a diversity of sources. We expect to see a rise in our income as our new staff and early career researchers contribute to this activity. Our ambition to increase income from the EU is being supported by substantial University of Glasgow investment in its European Office with three new appointments in 2013, in addition to two current posts, to support proposal writing and project management. We are significant partners in current (CENSIS, Future Cities, Systems Biology, Big Data) and planned (Modelling and Simulation) major University of Glasgow initiatives which offer excellent prospects for future collaborations. We will continue to build our relationships with industry and government agencies in the expectation of further exciting funding and research opportunities.

PGR Funding

Postgraduate research students form a critical part of the research environment and it is a measure of our commitment that we have invested significant School and University funding in studentships. In 2007, the University of Glasgow established the Kelvin Smith Scholarship scheme for interdisciplinary postgraduates which focuses on the creation of research partnerships between members of staff in different discipline areas that have not previously collaborated. The School has benefited from 5 of these awards, with Geography & Earth Sciences, Medical, Veterinary and Life Sciences, Urban Studies and Cardiovascular Research. Four further studentships have been awarded under a Sensors Initiative, with Geography & Earth Sciences, Physics & Astronomy, Computing Science and Engineering. Seven general University of Glasgow Scholarships were also awarded. In addition, our student submissions to a wide variety of external agencies have regular success, including the Carnegie Trust (4), the British Heart Foundation (1) and the Chinese Scholarship Council (6). We have also had regular success through EPSRC and NERC CASE and

similar industrial arrangements, including with Shell and Skills Development Scotland. Our Statistics MSc by research has also received significant industrial sponsorship (£350k; see impact template).

General infrastructure and facilities
The School has exclusive occupancy of its own building with sufficient office space to house all staff and PhD students, as well as lecture and tutorial rooms, computer labs, library and study space. Over the REF period, £1.8m has been spent on maintenance and refurbishment. Interactions within the School are fostered by our large blackboard-equipped common room, with water cooler and state-of-the-art coffee machine. Two video-conferencing suites are located in the School with modern Polycom and Cisco systems. These are used for postgraduate and research level courses and to support international research collaborations.

The School has a robust and technically advanced IT structure that connects to the University of Glasgow campus backbone at 10Gb/sec and provides wireless access throughout the building. The School has 4 IT support staff and invests £70k per annum to maintain and regularly modernise its IT infrastructure and thus ensure it provides the highest standards of support for teaching and research. Licenses are available for all the major mathematical and statistical software packages, including Matlab, Minitab, SPSS, Maple and Mathematica. Research facilities are provided by a dedicated set of 24 high performance Linux workstations with a total capacity of 210 processing cores (656 Mb RAM), which are heavily used. Desktop computers are replaced every 4 years, with staff also having laptops and/or tablet devices to support collaborative research projects with other schools and external organisations. A new School 'cloud' server provides highly flexible access to files.

Mathematics and Statistics library provision at the University Glasgow is of outstandingly high quality, enhanced by the many exchange agreements with the Glasgow Mathematical Journal. Library spending in the mathematical sciences is in excess of £126k per annum.

Over the next 15 years the University of Glasgow will be investing up to £750m to create a state-of-the-art research environment on a redeveloped campus, following the recent acquisition of an adjacent 14-acre site. The School will be a significant participant in this.

Specialist Infrastructure and facilities
Unusually, specialist areas of our research are supported by two dedicated laboratories, one in three-dimensional imaging and one in mathematical biology. The former is equipped with a stereo-photogrammetric camera which can capture three-dimensional surface images and is used in extensive data capture of human faces. This features in collaborative studies in medicine, biology and psychology, but also provides a stimulus to methodological research in shape analysis. Led by Bowman, the lab has benefited from College investment (£15k).

The School also hosts a state-of-the art laboratory for quantitative experiments on bioconvection, and the fluid mechanics of swimming microorganisms such as single-celled algae including Taylor dispersion, with applications to biofuel reactors. Led by Hill, the lab was set up with funding from an EPSRC Advanced Research Fellowship held by Bees, and the School continues funding for consumables and equipment. Hill & Bees' experimental work has set the agenda for bioconvection research for over 15 years. The lab has supported the research and publications of a 3-year PDRA and 3 PhD students.

Research in computational & mathematical systems biology is supported by a dedicated computer cluster of 7 servers, funded to 50% by an EPSRC institutional grant, and jointly owned with the School of Computing.

e. Collaboration and contribution to the discipline or research base

Research collaborations
All staff have active international research collaborations. Some of these are small-scale but with high impact; for example, Simitev is one of 3 investigators on a NASA Project Grant ($657k) on the

modelling and forecasting of properties of Solar cycles. As illustration of a more informal collaboration on a slightly larger scale, White has co-ordinated a group of analysts from Copenhagen, Edinburgh, Munster and Texas A&M, as well as the University of Glasgow, in work funded by individual RC grants that has resulted in 5 highly influential publications since 2009, including [White 2,3]. These examples are typical of many others.

The School is a leading participant in interdisciplinary research consortia; examples include:

- ***Face3D:*** Bowman leads this *Wellcome Trust* funded (£334k) international group in statistics, computer science, geometry, neuroscience and medicine. The aim is to study facial shape, quantify the effects of surgery and investigate the developmental origins of face/brain conditions. The statistical tools developed, and the imaging facilities available in the School, have led to further high profile collaborations, particularly with physics at the University of Glasgow, with joint work on computational imaging in *Science* (2013, vol.340, 844-847).
- ***STATMOS***: The University of Glasgow is the only UK node of this NSF funded ($5m) research network for Statistical Methods for Atmospheric and Oceanic Sciences. The themes align well with those of our Environmental Statistics group, including spatiotemporal models, extremes, uncertainty estimation and large datasets. There are 3 hubs (North Carolina SU, Chicago, Washington) and 14 additional nodes, with only two outside the USA.
- **GlasgowHeart:** The School leads this interdisciplinary consortium for cardio-vascular research (www.glasgowheart.org), with £1.3m of external funding, bringing together the BHF Glasgow Cardiovascular Research Centre and the Golden Jubilee National Hospital (one of the largest cardiothoracic centres in Europe). International collaborating groups include Graz, NYU and Karolinska.
- **Scottish Sensors Systems Centre:** We have been leading partners in this Scottish Funding Council (SFC) initiative (£2.5m, to which the University of Glasgow has added £3m for internal investment) which prepared the ground for a successful bid for the recently announced CENSIS Innovation Centre. The School has so far had two funded projects (river network modelling, visualisation; partners Scottish Environment Protection Agency and Scottish Water), supplemented by EPSRC KT funding. The results were used as a showcase for the whole initiative.
- **GloboLakes**: Miller leads the University of Glasgow node of this new NERC (£2.5m) consortium project, led by Stirling University and with four other UK partners. This brings together statisticians, environmental scientists, lake ecologists, lake ecosystem modellers and other specialists to investigate the state of lakes and their response to environmental drivers of global change. Our School will be responsible for a work package to develop the statistical methods required to investigate coherence in lake signals globally.

The School is an active member of a wide variety of local, regional and national seminar groups, funded by bodies such as the LMS. Examples include ARTIN, NBFAS, Classical & Quantum Integrability, the Scottish Topology Seminar and the Centre for Mathematics Applied to the Life Sciences (CMALS). Funding is available for postgraduate students to attend the meetings.

Research collaborations with research users

The School has many collaborations with researchers from other scientific disciplines and industry where expertise in the mathematical sciences is needed. For example, Cobbold's work with biologists has made significant contributions to understanding how Trypanosome parasites challenge the immune system, while the high profile of Senn in the pharmaceutical industry has led to regular influential consulting on significant issues of drug development. (Senn moved to direct biostatistics research in Luxembourg, 2011.) There is also notable activity with environmental agencies where high-level collaboration with Scott, Bowman, Lee and Miller has informed environmental policies by high quality analysis.

The School provides extensive research training for non-specialists, for example the annual residential course in statistical methods for 35 environmental scientists, NERC-funded for the past 10 years. Bespoke courses are also provided for the Scottish Environment Protection Agency, the Centre for Ecology and Hydrology and the National Oceanography Centre.

Our recent pilot projects with Scottish Water, Sensors Systems, Scottish Environment Protection Agency and the Scottish Government have identified a new strategic direction in the development of innovative statistical methods for data linkage and `big data'. This includes the validation of data quality, appropriate inferential tools, visualisation and quantification of uncertainty. Progress in the development of methodology will allow significantly greater insight into major issues such as sustainability, health and wellbeing, social and environmental policy.

We place great strategic emphasis on research which is driven by, and feeds into, other disciplines and important applications. Husmeier's recruitment to the Chair of Statistics is an excellent example of this strategy in action. His collaborative development of novel computational techniques for identifying gene regulatory networks led to success in an international competition (Nature Methods 9,796–804, 2012). Similarly, the recent appointment of Stewart strengthens GlasgowHeart. Luo has further examples of high profile collaborations (Nature Geoscience 2013; 6, 770-774) and the School is now an institute partner in the NSF-funded Mathematical Biosciences Institute.

Research leadership

- ***Honours, fellowships, prizes***: OBE (Scott, 2009); Int. Environmetrics Society (Craigmile, 2012, El-Shaarawi Young Researcher's Award; Bowman, 2012, Stuart Hunter Lecture); William Prager Medal, Soc. of Eng. Sci., USA (Ogden, 2010); Whittaker Prize, Edinburgh Math. Society (White, 2013); Governor General of Canada's Gold Medal (L. Watson, 2010); Corcoran Prize (Evers, 2009). The School has 1 FRS (Ogden), and 4 FRSE (Bowman, Brown, Ogden, Scott).
- ***Government, industry, funding body and advisory boards***: Lead, Scot. math. science pooling negotiations, SFC, (Brown, 2007-09); Royal Commission on Environmental Pollution (Scott, 2010-11); Scottish Science Advisory Council (Scott, 2010-15); Management Committee of Int. Review of UK Math. Science (Brown, 2009-10).
- ***Editorial***: Solid Mechanics Editor, Int. J. of Non-Linear Mechanics (Ogden);
  Guest editors: Stat. Methodology, J. Fluid Mech., Int. J. for Num. Meth. in Biomed Eng.;
  numerous associate editors of high-ranking journals.
- ***The Glasgow Mathematical Journal*** (GMJ) was fully revamped during the REF period. Strachan is Editor-in-Chief, with an international editorial board and a fully electronic submission and paper management system. The profits finance the GMJ Trust which supports Mathematics within Scotland (budget £25k in 2012-13).
- ***Learned societies and professional bodies***: Vice-president London Math. Soc.; Board of Council for Math. Science (Brown, 2009-); Amer.Stat.Assoc. Adv. Comm. on Climate Change Policy (Craigmile, 2011-); Stat. Modelling Soc. Secy. (Miller, 2011-); Chair RS Int. Exch. Panel (Ogden, 2010-12); Chair, Math.&Theor.Phys. group, Institute of Physics; RSS: Env.. Stat. Sect. Secy. (Lee, 2012-), Hon. Off. (Scott, 2011-), Long-term Strategy Group (Bowman, 2011-13).
- ***Conference organisation****: Chairs of significant conferences*: Euromech Conference Committee (Ogden, 2008-13); European Solid Mechanics Conference (Ogden, 2009, 2012); Amer.Stat.Assoc. General Methodology, Joint Stat. Meetings (Craigmile, 2011); GADUDIS, an INI satellite workshop (Nimmo, 2009); Tropical Geometry and Integrable Systems (Korff, Athorne, 2010). *Major conferences organised in Glasgow***:** the ISLAND series of integrable systems conferences (Athorne, Gilson, Nimmo); Categorification Conference (Brown, Kraehmer, Stroppel, 2009); Int. Workshop on Statistical Modelling (Miller, Bowman, 2010); International Soft Tissue Modelling workshops (Luo, 2012, 2015); LMS Fluid Mechanics of Swimming Microrganisms (Hill, Bees, 2010).
- ***Visiting positions****:* ETS Walton Visitor Award, Science Foundation Ireland (Ogden, University College Dublin, 2009-10); Royal Academy of Engineering Global Award (Luo, NYU and UBC, 2007-08); CSIRO Distinguished Visiting Scientist (Scott, 2013-15).