Institution: Manchester Metropolitan University

Unit of Assessment: B7 Earth Systems and Environmental Sciences

a. Overview

Continuity: Manchester Metropolitan University (MMU) undertakes world class applied research within the scope of the Earth Systems and Environmental Science (ESES) unit of assessment. The enduring nature, vitality, coherence and social relevance of our research is evidenced by our sustained funding and high quality output since 1993. 'Impact' has always been at the core of our research, which has been used repeatedly by international, national, and regional policy developers to formulate responses to the challenges of environmental change (see REF3a & 3b). The Dalton Research Institute located in the Faculty of Science and Engineering, provides a supportive, stable research environment through the Faculty's school structure enabling delivery of our research strategy.

Building upon our submission in RAE2008 we have continued to strengthen our research which is organised around the following three core groups:

i) the environmental impact of aviation and maritime transport led by the Centre for Aviation, Transport and the Environment (CATE), ii) marine renewable technology through the development of computational fluid dynamics methods and tools (led by the Centre for Mathematical Modelling and Flow Analysis (CMMFA) and iii) the response of Earth systems to recent and projected environmental change led by the Centre for Earth and Ecosystem Responses to Environmental Change (CEEREC).

Quality: The increased reach and significance of ESES research is evidenced by the quality of its outputs, in for example*, Nature, Science, Proceedings of the National Academy of Sciences, Environmental Research Letters, Environmental Science and Technology, Proc. Royal Soc., Global Change Biology, Natural Hazards and Earth System Sciences, Coastal Engineering*, *New Phytologist, Journal of Ecology*.

Income: Over the REF period ESES been awarded over £40M of research funding through more than 80 international research projects in partnership with internationally leading university groups in, for example, Bath, Cambridge, Cardiff, Bayreuth, Imperial College, Linkoping, Manchester, MIT, Sheffield, Oxford, Plymouth Universities, Queen's Belfast, Reading and Utrecht. Our audited annual Research Expenditure has increased since RAE2008 by 40% predominantly from awards from research council (£2m), European and government departments (£2.8M), and prestigious academic society and charity sectors (£0.5 M).

Sustainability: In recognition and support of the strategic importance and achievements of our research to the University, MMU has invested £15M in staffing, studentships and specialist facilities within the faculty. The sustainability of the ESES research environment has been achieved by supporting a stable staff core and nurturing new growth. This is evidenced by i) 42% of the current REF2013 UoA7 ESES staff were also returned in 2008, ii) during the 2008-13 period seven staff have been promoted to Reader or Professor, iii) 12 strategic appointments have been made to ESES of which seven are mid-career and five Early Career Researchers (ECRs).

b. Research strategy

Strategy: The strategy of ESES is to undertake high impact research focused on the environment by bring together the multi-disciplinary expertise within our three core groups. This is achieved through research in i) the environmental impact of aviation and maritime transport ii) the development of marine renewable technology using computational fluid dynamics methods and tools and iii) the response of the Earth and its ecosystems to recent and projected environmental change.

To deliver our research strategy our approach is to:

i) Attract, support, develop and retain outstanding research staff by being an ideal environment for career development in which talented staff can pursue and achieve their research ambitions (Sec 5c)

ii) Build upon our collaborative research strengths to formulate and lead research

programmes with international impact

iii) Be key players in setting the agenda for international and national research priorities

iv) Obtain peer reviewed funding to support and sustain the integrity of ESES research

v) Raise the international profile of ESES research by increasing the dissemination of our research in high quality journals

vi) Retain a focus upon the impact of climate change on the environment by maintaining distinctive multi-disciplinary research with a critical mass

vii) Maintain a strategic focus on research that is commensurate with the expertise of our core groups

viii) Make our high impact research output openly accessible to policy makers and the wider community through public engagement

ix) Engage with Government and industry to influence both policy and practice

Since 1993, we have developed enduring relationships with our end users and collaborators in academia, industry and government, by demonstrating excellence in delivering research of reach and significance. This has enabled achievement of our key RAE2008 objectives as evidenced below.

Delivery of RAE2008 Objectives: CATE has fully met its RAE2008 objectives and consolidated its position both in the international science community and with stakeholders. For example, i) staff in CATE are Lead Authors in the IPCC Fifth Assessment Report, Working Groups 1 and 3, and authors of the 'most cited article award' in aviation-science (Elsevier) in 2011 to 2012, ii) CATE have provided leadership in science based activities for the International Civil Aviation Organization ('Impacts and Science Group') and a UNEP report presented at the 2011 Durban Conference of Parties meeting, iii) CATE has also invested heavily in advanced facilities, including a CRAY XS supercomputer (the only one in the UK) for running and developing computationally intensive global atmospheric chemistry models (MOZART3/4). It has also invested in unique UK emission sampling facilities (e.g. ALFA aerodynamic sampling probe linked to an Aerodyne mass spectrometer), iv) These facilities and model developments have resulted in publications in the Proceedings of the National Academy of Science, Science, Nature, and Environmental Science and Technology.

CMMFA key RAE2008 Objectives and their achievements include i) 'To study the survivability of the Pelamis and Bobber off-shore wave energy converters in extreme wave conditions', its success evidenced via EPSRC grant (EP/D077621/1) with Oxford, Bath and Manchester universities and outputs (REF2) and ii) 'To submit EPSRC grant proposals relating to the interaction between steep non-linear waves and fixed and floating marine structures', success likewise evidenced by the award of EPSRC grants: ‘Fundamentals and Reliability of Offshore Structure Hydrodynamics’ (EP/J012793) and ‘Modelling Marine Renewable Energy Devices - design for survivability’ (EP/J010197) and outputs (REF2). Further, CMMFA is now a principal academic partner in the EPSRC SUPERGEN Wind and Marine programmes.

CEEREC also delivered all its core RAE2008 objectives, i) the ESF funded BEGIN project (NE/D522238/1) achieved Europe wide testing of the relationship between nitrogen deposition and grassland biodiversity resulting in high impact papers (including PNAS, Dise), influencing policy via The European Nitrogen Assessment Report (Dise) and follow-on projects funded by DEFRA, Natural England and the €1.6 M Peatbog consortium project (NE/G002363/1), ii) the study of C cycling in dryland environments resulted in three high impact outputs, two Leverhulme and four NERC Life Sciences Mass Spectrometry Facility grants, iii) output from Ecology and Biodiversity projects on deforestation and conservation of biodiversity led to changes in the management of protected areas in the Philippines (Critical Ecosystem Funding Partnership), a follow-on project on the viability of large avian frugivore populations in protected areas (Luzon) and avian data from Peru being used by the US Fisheries and Wildlife Service in draft legislation for the US Endangered Species Act. Six publications were associated with these projects, iv) the study of environmental change and late Holocene response of reefs along the Great Barrier Reef coastline to elevated terrigenous sediment yielded five papers (Perry & co-workers, 2008-11), iv)

development of analytical facilities yielded six papers and a £61k NERC follow-on grant on arsenic uptake from aqueous solution (Taylor & co-workers, 2009-11).

Future strategic initiatives: Building on our success in establishing close relationships with end users our future strategy is to advance understanding of anthropogenic activity upon climate change and Earth systems. As a result of this understanding, we will devise appropriate adaptation and mitigation responses utilising inter-disciplinary programmes across CATE, CMMFA and CEEREC. A key objective is to use the ability of ESES to influence policy makers to increase our impact on stakeholders and end users.

CATE will continue i) to use its unique global emissions modelling facility to explore and understand the consequences of different emissions trading schemes. This will inform the European Commission and the international community in their negotiations on a revised emissions trading scheme for aviation, ii) to develop understanding of aviation and shipping non-CO_2 impacts in terms of 'equivalences' to CO_2 emissions through research and knowledge exchange using the positions within international fora that it occupies, iii) to branch out into new and fast-developing areas such as alternative fuels and their climate impacts, and the impacts of climate on aviation (as opposed to the traditionally-researched 'aviation on climate').

CMMFA will continue to develop and apply computational hydrodynamics models within the offshore renewables area. Specifically the CMMFA will: i) investigate the survivability of offshore wave energy converters in steep waves, ii) model the performance of floating wind turbine platforms and iii) develop massively parallel versions of in-house code and combine it with state-of-the art visualisation.

CEEREC will build on success in establishing close relationships with end users and will advance understanding of anthropogenic impacts on global change, Earth and ecosystem response and subsequent environmental feedbacks affecting human society focusing upon: i) the carbon balance and biodiversity of maritime and degraded peat bogs with particular attention to novel techniques of restoration of peat forming *Sphagnum* and carbon sequestration function, ii) dryland carbon cycling and land degradation, iii) the response of terrestrial and marine geo-systems to contemporary and past climate change, iv) advance fundamental understanding of the Earth systems above by building on the pure and applied aspects of soil microbiomics programmes (via next generation 454-based DNA sequencing) extending this to soil development in glacial systems and v) the response of tropical avian species and ecosystems to climate change.

c. People, including:

i. Staffing strategy and staff development

The core stability of ESES staff over the past decade is evidenced by the return of ten staff to both RAE2008 and REF2014 five of whom are research leaders of international status (Causon, Dise, Lee, Mingham, RaperS). The excellence of the research environment is evidenced by i) the promotion of seven mid-career promotions to Reader (Marsden, Rhodes, Sen and Thomas) and Professor (Mingham, Perry and Taylor, all Readers in RAE2008) and ii) the return of RAE2008 ECR Brearley.

ESES both attracts and provides quality research staff. Its future sustainability is demonstrated by our ability to attract new high quality staff from other institutions and by the 33% increase in volume of REF2014 staff returned compared to RAE2008. Of the 12 new staff appointed seven are mid-career (Clarke, Cook, De Kort, Dunk, Harris, Lloyd, Potgeiter) and five ECRs (Cavan, Christie, Lind, Mossman, Symeonakis). Hoon and Lageard have joined CEEREC from within MMU, whilst RaperD has been promoted to a key strategic University leadership role responsible for MMU's research and knowledge exchange strategy and delivery, and Dempsey to Head of the Faculty Graduate School. Fielding has retired. Thus, in the current REF period ESES has grown and strengthened readily accommodating external promotions (Perry, Rhodes, Taylor and Thomas).

ESES's research strategy (Sec.b) is the key driver for staff appointments and promotion and the support of research and teaching. Appointments and promotion are primarily determined by how well an individual supports our research strategy. New staff are therefore able to demonstrate a strong research profile that is aligned with our research objectives and a potential to develop further. For example, Cook (cold environments) and Symeonakis (remote sensing) appointed

within CEEREC complement and collaborate with Readers Hoon, Marsden, RaperS and Sen, whilst, Lind (hydrodynamics), collaborates with Mingham and Causon. This approach has further enhanced the interdisciplinary nature of our research and will allow us to maximise the impact of our strategy in the future.

Professional Development of Staff:

Leadership by senior ESES staff is central to our research development. They define the research landscape and culture and enable staff to develop their careers. This University-wide culture of professional staff development was recognised in 2012 by an Investors in People Gold Award, which places MMU in the top 1.5% of organizations in the country, one of only five UK Universities to receive this award. The University also follows the Higher Education Role Analysis scheme, which has embedded a framework to support continuous career progression from PhD Student to Research Associate through to ECR and Professor (e.g. Lee, RaperD).

MMU provides comprehensive training in skills development, leadership and management. New staff undertake the University's induction programme, which provides guidance on research and knowledge exchange policies and procedures. ESES is committed to supporting the professional development of staff at all career stages by providing training and internal funding. Staff have an annual allowance for research development, international conference attendance and networking. The annual Professional Development and Review (PDR) Scheme is key to staff development which identifies and agrees research and career objectives, supported by the Staff Development Programme and MMU Research and Knowledge Exchange (RKE). RKE provide regular training events in grant writing, grant peer review and internal workshops run by external funders (e.g. 'Bidding for Success', Leverhulme Trust, NERC, EPSRC, ERO). Further support is provided by the University's 'Knowledge Exchange and Innovation Fund' (KEIF) which promotes the development of Knowledge Exchange projects of up to £50,000 for taking research to market, e.g. Aviation Research Knowledge Exchange (Thomas, ARKE). Staff are also encouraged to enter the annual Research Studentship competitions. Staff demonstrating research prowess are mentored in order to develop their profile further and be in a position to respond to the annual University call for promotion to Professors and Readers, (e.g. Marsden, Mingham, Perry, Rhodes, Sen, Taylor, Thomas).

Resource distribution and ECRs:

Research, teaching, knowledge exchange, academic citizenship and administration are embedded into the University staff workload model. For ECRs and new staff, research time is prioritised over other activities whilst they establish themselves at MMU. ECRs are supported in developing their grant and output writing skills through training initiatives, peer review and mentoring. They benefit from a resource distribution model, which rewards and incentivises submission of research grant applications. Central support is available through RKE Research Accelerator Grants of £5000 to cover the costs of pump-priming research development (e.g. recipients Cook, Lind, Symeonakis). Mentorship is given by established research academics. Staff training in postgraduate supervision, thesis examination and chairing of *viva voce,* equality and diversity is mandatory. MMU embraces the Concordat principles and ECR staff new to research degree supervision join experienced colleagues before becoming lead supervisors (e.g. Symeonakis & Hoon, Lind & Mingham).

Post-Doctoral Research Staff:

Post-doctoral staff, numbering 37 over the return period, are important to the research vitality of ESES. PDRF posts represent a key stage on the career progression ladder between PhD and research independence. As part of this approach, PDRFs are encouraged to join PhD supervisory teams. The training by ESES and support from technical and experimental officers enables PDRF/PDRAs to progress to academic partners elsewhere (e.g. Bai, (CMMFA), PDRF to Assistant Professor at the National University of Singapore, Ekstrom (CATE) to Exeter and Hurley (CATE) to Oxford).

ii. Research students

MMU has thorough processes for the induction, support, and monitoring of research students. These processes have been commended by the QAA as "*good practice...contributing to the academic standards and the quality of learning opportunities* [with]*...comprehensive training and development opportunities provided for postgraduate research students*" (QAA Audit, 2010). Students are supported by the Faculty research community throughout their study period. The

Graduate School provides a programme of continuous professional development and support, and is fully engaged with the Vitae Research and Development Framework. The programme includes core skills such as research methods, experimental design, ethics, writing for publication, presentation skills. Through the annual monitoring process, research students identify and agree their personal training needs. These activities strengthen the ability of students to communicate and defend their research to the widest possible audience. Students have full access to an on-line virtual learning environment on and off campus and office and specialist laboratory space. This thorough approach to student support has led to increases in the quality of output, the MMU 4 year completion rates and student satisfaction as evidenced in annual monitoring reports, PRES 2011 and PRES 2013. ESES attracts and graduates students that progress to internationally recognised institutions. For example, Hilaire went to the Potsdam Climate Institute, Fichter to the German Aerospace Agency, and Armesto to Hydraulics Inst., Univ. Cantabria.

One of the strengths of ESES research is its international and national collaborative nature that exposes our students to a global research environment. Research students are integral to the Faculty research culture and have an important role within our research governance by participation in postgraduate research committees. Since 2008, we have supported the concept of high impact doctoral programmes of study that are consistent with the objectives stated in RCUK / AHRC *Joint Vision For Collaborative Training,* June 2013. This has been achieved by aligning PhD programmes with our research strategy and seeking collaboration with external bodies (e.g. DEFRA, DFT, Moors for the Future, Micropropagation Services Ltd, EPSRC Supergen Wind Consortium) to provide both bursaries and industrial relevance in line with the Wilson Review recommendations. ESES have awarded 37 doctorates during REF2014. Many of the graduates from our doctoral programmes have progressed to post-doctoral positions within internationally leading universities and industrial research centres (e.g. Oxford, Exeter, Free University Berlin, Southampton and Omnicon Engineering).

Equality and Diversity*:* MMU's commitment to equality and diversity was recognised in May 2013 by the award of Athena SWAN Bronze status. MMU is fully compliant with the Equality Act 2010. Its commitment to equal opportunities is set out in MMU's Equality and Diversity Policy, Vision for Equality and Diversity and Single Equality Scheme. These policies and the 2010 Act guide and inform all of MMU's activities including research. Their implementation is supported by the Single Equality Scheme Action Plan and staff development activities. MMU's approach is underpinned by the principles of transparency, consistency, accountability and inclusivity. MMU also provides mandatory courses in support of its Equality and Diversity Policy. Staff participation is monitored through the Professional Development and Review scheme.

d. Income, infrastructure and facilities

Income*:* Research-eligible expenditure increased to £6.6M (2008-13), up 40%p.a. compared to RAE2008 with increased funding from Research Councils and the EU whilst maintaining income from major foundations and charities. This income has enabled ESES to generate research of high impact in its three core areas:

CATE: EPSRC grants and EU (FP6 and FP7) contracts have risen to over £1.8M. Current projects include ITAKA (Christie), a €10M collaboration to support the development of aviation biofuels in an economically, socially and environmentally sustainable manner. Partners include Airbus SAS, Neste Renewables, Embraer S.A. LANDAPP, Industrial and Government Agency contracts total over £1.2M including projects with Airbus, BAA, Eurocontrol, Airports Council International and the Department for Transport, Collaborative EPSRC grant £485k on Practical Abatement Techniques for Exhaust Jets (EP/H002987/1).

CMMFA: Causon and Mingham are named investigators on 5 EPSRC standard and 3 EPSRC consortium grants worth over £10M during the REF period (£2M to MMU) for work directly linked to the current Research Council energy programme policy of developing novel research to support 2050 deployment challenges associated with renewable energy generation via offshore wind farms and wave energy. (The substantive EPSRC CMMFA grant funding has been: £1.0M EP/K037889, £1.3M EP/J010197, £1.5MEP/J012793, £4.8 EP/H018662, £2.6MEP/D034566).

CEEREC: Staff have held 12 NERC grants with a contractual value of over £1.3M during the current REF assessment period for projects investigating the biodiversity of grassland, biotic

responses to environmental change, marine carbonates and rapid cyclone assessment. Over £104k of NERC and EPSRC Facility awards has also been obtained in support of isotope ratio, and structural analysis. A €100k FP7 Marie-Curie Action grant, (Symeonakis) is improving the understanding of land degradation and desertification, processes that have the potential to affect 30% of the Earth's land surface. New appointee Clarke transferred NERC grant NE/J012866/1 'developing novel proxies for sea water temperature' to MMU. Research has generated over £600K from foundations, international and national charitable trusts and societies including grants to the value of £360K from The Leverhulme Trust, Moors for the Future, Royal Geographic Society, British Ecological Society, DEFRA and Natural England, Loro Parque and Berghof foundations, Darwin Initiative, the Wildlife Conservation and Linnean Societies and Birdlife International.

Equipment and Facilities: ESES is located at a single site within MMU housing our laboratories, offices, technical and computing support, and infrastructure. This facilitates a high level of interaction between staff, essential to our vibrant interdisciplinary research culture. Since 2008, total spending on faculty equipment and infrastructure to support our research has exceeded £15M.

Fully autonomous vehicle mounted rapid-scanning LIDAR technology is used extensively by CATE staff (Bennett, Christie) to map the dispersion of exhaust emissions from aircraft. The system was core to an EPSRC funded study into the use of aerodynamic baffles to abate the impact of aircraft emissions on air quality and jet blast near airports (Bennett REF2, Output1). This demonstrated that both surface pollutant concentrations and jet blast could be halved locally. CATE is also well equipped with atmospheric particle monitors enabling study ultrafine aerosols, which are responsible for significant mortality and morbidity have significant negative health impact. A CRAY XS supercomputer is enabling the development and publication of predictions from complex 3D global atmospheric climate response models (e.g. the chemistry / transport model MOZART) incorporating aviation emissions, contrail coverage and radiative forcing (Lee, RaperS).

MMU has assembled a unique aircraft exhaust measurement facility (Alfa) with the Universities of Sheffield and Manchester. The joint facility comprises: A gas and aerosol-sampling rake capable of traversing the core of the aircraft plume; High-resolution time of flight Mass Spectrometer (WToFMS) system for incorporation into an existing Aerodyne Aerosol Mass Spectrometer (AMS) at the University of Manchester; and a fully equipped mobile combustion laboratory at the University of Sheffield. Elements of the Alfa joint facility have been used by the three partners in a number of programmes. These include work for Shell and Rolls Royce on aircraft engine exhaust emissions composition. The joint facility, based at the University of Sheffield, is part of the EU Aviation Safety Agency funded programme on biofuels, '*I*nitiative *T*owards sust*A*inable *K*erosene' (ITAKA) will be central to measurement of aircraft engine gases and particulate emissions.

CMMFA has two dedicated laboratories for its computational work housing an NEC SX6 vector supercomputer, a Broadberry Cyberserve desk side supercomputer and a WS-Tesla x4 NVIDIA Tesla Desktop Super Computer' GPU system. Lind uses the Raven supercomputer at Cardiff University and GPU computing facilities to accelerate software applications, and has developed a powerful tool capable of modelling extreme coastal waves and associated phenomena. PhD student McCabe used the NVIDIA S1070 GPU cluster at UK STFC Daresbury Laboratory to accelerate simulations of breaking waves.

CEEREC: utilises the full range of national EPSRC and International central research facilities, external NERC analytical services and the UK Diamond synchrotron as well as modern analytical equipment and laboratory facilities invested in by MMU. Elemental, nutrient and gaseous (CH_4, N_2O, CO_2) assays are undertaken in support of biogeochemistry research (e.g. Dise, Caporn and Hoon). Portable field CO_2 analysers, soil probes and hyperspectral reflectometers enable a wide range of fieldwork in remote locations from tropical to Arctic and dryland to wetland (e.g. Caporn, Cook, Dise, Hoon, Marsden and Symeonakis). The Environmental Sciences laboratories enable liquid and gas phase chromatography and metal, elemental C and N analyses, nuclide and compound analysis of, water, sediments and soils including molecular microbiological and ecological DNA analysis. Advanced pyrosequencing molecular DNA analyses are outsourced. Dedicated environmental growth cabinets permit simulation of a wide range of ecosystem conditions (e.g. Caporn, Cook, Hoon, and Sen).

e. Collaboration and contribution to the discipline or research base

High Impact Journal Publications: The contribution of staff to the ESES discipline is evidenced by the increased frequency of peer-reviewed articles appearing in the best journals in the field: e.g. *Nature*, *Science*, *Proceedings of the National Academy of Science* (PNAS), *Proceedings of the Royal Society B* and *Atmospheric Environment*. Lee and Dise have received awards for producing the most cited articles in *Atmospheric Environment* (2010, 11) and *Global Change Biology* (2011, 12). The Model for the Assessment of Greenhouse Gas Induced Climate Change (MAGICC), one of the most widely used climate models in IPCC assessment reports, has been refined and continually extended by RaperS and co-workers.

Book Chapters and Other Outputs: Causon, Mingham, Qian, *Advances in Numerical Simulation of Nonlinear Water Waves, in Developments* in *Multi-Fluid Finite Volume Free Surface Capturing Methods*, 397-428, 2010; Hoon et al *Soil Organic Carbon and Soil Respiration in Deserts: Examples from the Kalahari*, Ch.3, in *Changing Deserts: Integrating People and their Environment*, 2012, ISBN 978-1-874267-69-0; Marsden et al, 2010, Facing Extinction: the World's Rarest Birds and the Race to Save Them, Christopher Helm, London, ISBN 978-1-4081-8966-5.

Journal Editorial Board Membership: Staff are editorial board and advisory members of eight journals: *Biogeochemistry*, Dise; *Bird Conservation International*, Harris; *Birdlife International*, Marsden; *Greenhouse Gas Measurement and Management*, Dunk; *New Phytologist*, *Journal of Plant Interactions*, *ISRN Soil Science*, Sen; *Journal of Airport Management*, Thomas. Staff act as editorial reviewers and referees on 64 journals including *Nature*, *Science*, *PNAS*.

International Reports: ESES has contributed to the United Nations Environment Programme (UNEP) (*Bridging the Emissions Gap Report 2011*), World Meteorological Society (WMO) (*Aviation and the Environment report*) the UK Committee on Climate Change (*Aviation Report*), DEFRA (*Review of Transboundary Air Pollution*), the European Science Foundation (*The European Nitrogen Assessment*), the International Maritime Organisation (IMO).

Committee Membership: ESES staff are active on committees and advisory panels making a significant contribution to the wider discipline. They have been instrumental in providing the scoping work for the European Commission's policy on incorporating aviation into its Emissions Trading Scheme. MMU is currently one of only three international universities in a large stakeholder group dominated by industry and governments developing a CO_2 emissions regulation for the International Civil Aviation Organization (ICAO) on behalf of the UK Government. Lee and Clarke are members of the NERC Peer Review College and Causon has been a member of the EPSRC College of Peers for over ten years. Thomas is a member of the Airports Commission Experts Panel that is considering the provision of extra runway capacity in the SE of England. He is also a member of the Institution of Civil Engineers Aviation Life Panel, the UK Civil Aviation Authority Environment Panel and UK Trade & Investment Airports Advisory Council.

Policy: The research of CATE has been instrumental in influencing pollution policy through international organisations such as the Convention on the Long Range Transport of Air Pollution (2011 revisions of critical loads). CEEREC provide expertise to global conservation charities and NGO's and projects such as the Kenya Wildlife Service (mammal conservation), the Wildlife Conservation Society (primate and jaguar conservation), Fauna and Flora International (Philippine protected areas), RSPB, Birdlife International, The Peregrine Fund (neotropical raptors), Moors for the Future, The Forestry Commission and various moorland restoration business partners and charities. Marsden and Brearley were central to developing biodiversity and conservation policy serving as advisors to the Secretariat of the Convention on Biological Diversity and governments in the bio diverse tropics (e.g. Ethiopia, Ghana, and Peru). Other policy-level committee membership includes the Pennine Sphagnum Restoration Technical Advisory Group and the Natural England Upland Restoration Review Committee (Caporn), the UK Committee on Climate Change, and the DEFRA Review of Transboundary Air Pollution (Dise, Caporn). Cook provided expert advice to the Swiss Expert Advisory Panel on Glacial Erosion and Nuclear Waste Burial for Nagra (National Cooperative for the Disposal of Radioactive Waste). Mossman's work on managed coastal realignment has changed the thinking behind its success and been used as evidence in Parliamentary briefing POSTnotes (Biodiversity & Planning Decisions, POSTnote 429, 2013; Environmental Impact of Tidal Barrages, draft 2013). Lloyd is a legislative advisor to the US Fish

and Wildlife Service and Sen to the Soc. of General Microbiology and the Parliamentary and Science Committee dealing with tree health and biosecurity (e.g. 'ash dieback').

Collaborations: A large number of academic collaborations are evidenced in this submission. CMMFA is the only UK research group to be involved as partners in both the EPSRC Supergen WIND and EPSRC Supergen MARINE Consortia, EPSRC's world-leading programmes on all aspects of fundamental research into offshore wind and marine renewable energy sources. From 2007–9 ESES led the £5M HEFCE-funded OMEGA research partnership investigating sustainable development of the UK air transport sector. OMEGA included 40 high-impact research partnerships and eight universities. ESES is also a partner in the Aeronet, ECATS and X-Noise international aviation networks. ESES leads the £1.6M European Research Agency project PEATBOG (NE/G002363/1), working with an international team of scientists and European policy representatives, international and UK conservation and resource management representatives. This submission represents collaborations with over 60 different universities of which 5 are in the world top 40 (including 35 UK, e.g. Cambridge, Oxford, Imperial College, Manchester, Liverpool, Lancaster, Leeds, Loughborough, QML, QUB, Sheffield, Cranfield and 30 international e.g. Kyoto, Bayreuth, Beijing Normal University, Berlin, Cornell, Dalian, Gothenburg, Iowa State, Leiden, Sichuan, Utrecht). Examples of the international nature and reach of the ESES CFD research include collaboration, exchanges, and visiting Professorships, with universities in Japan, (Kyoto, Disaster Prevention Research Institute), China (Shanghai Jiao Tong, Dalian and Sichuan Universities (SKF-OF-0801, £11k, 2011), ranked respectively 4th, 21st & 22nd in China; see also Causon Output 1, REF2). Dr C. Greenhough of Rutherford Appleton Laboratories is a visiting professor with CMMFA.

Academic Exchanges: Lee is a Visiting Fellow at Oxford University's Atmospheric, Oceanic and Planetary Physics Department and Visiting Scientist to the DLR Institute for Atmospheric Physics, Oberpfaffenhofen, Germany. de-Kort is a Visiting Fellow at the Lab of Ornithology at Cornell University. Sen holds a Docent Fellowship in Microbiological Ecology at the University of Helsinki and is an Honorary research fellow of the School of Biological Sciences at Aberdeen. Symeonakis is a Visiting Scientist at the Maths, Informatics & Statistics Division of the Commonwealth Scientific and Industrial Research Organisation (CSIRO). Thomas, Research Director, is an Adjunct Professor at the Civil Aviation University in Tianjin, China. Overseas visitors to ESES include Professors Ponater, Eyring and Petzold (German Aerospace Agency), and Wang (Dept. of Ocean Engineering and Naval Architecture, Shanghai Jiao Tong University). ESES also has researcher exchange programmes with Groningen and Sichuan Universities.

Training / beneficiaries: CATE provides research-based training to the aviation industry. It holds a preferred supplier training contract with the Airports Council International World Training hub (Montreal) and has delivered regional courses in the Gulf (Abu Dhabi), Latin America and Caribbean (Jamaica), Asia and Pacific (South Korea). Staff advise the European Space Agency on bird strike risk at airports and provide collaborative research to airlines (e.g. BA, Virgin Atlantic and Delta) and manufacturers (e.g. Rolls Royce and Airbus). CATE signed a Memorandum of Understanding (MoU) with the Civil Aviation University of China in Beijing to develop a joint programme of research and knowledge transfer. This resulted in hosting a Chevening Scholar from the Chinese CAA to study aircraft noise and convening workshops in the UK and China.

Instruments and tools: Staff have developed tools, models and instruments that have been taken up widely across the sector and beyond. Novel instrumentation has been developed for studying carbon cycling in pulse-driven dryland soils, both in the field and in laboratory microcosms (Hoon), and LIDAR instrumentation for the determination of atmospheric pollutants (Bennett, Christie). Sen made a key contribution to the open access rRNA gene marker database (UNITE) for the identification (barcoding) of kingdom fungi (Abarenkov *et al, 2010*) DOI: 10.1111/j.1469-8137.2009.03160.x.

Conference organisation & dissemination: Staff have organised six international conferences within the period and delivered public lectures and keynotes papers at, for example, WETPOL 2011, Fifth International Nitrogen Conference 2010 (Dise), and the British Association for Advancement of Science, the UN Framework Convention on Climate Change, Bonn 2009, and the 25th Anniversary of the Proudman Oceanographic Institute, Liverpool 2008 (RaperS).