NERC statement of Community Need

Lead author: Prof Jacqui Hamilton
Institute of lead author: University of York
Email address: jacqui.hamilton@york.ac.uk

Title: AMOF: An internationally leading facility for atmospheric measurements and observatories in the UK

Co-authors
Writing group
Dr Chris Westbrook, University of Reading
Prof Doug Parker, University of Leeds
Dr Eiko Nemitz, Centre for Ecology and Hydrology
Dr Jeremy Price, UK Met Office
Dr Jonathan Crosier, University of Manchester
Dr Rebecca Fisher, Royal Holloway
Dr Tom Bell, Plymouth Marine Laboratory
Dr Maria Val Martin, University of Sheffield

Review group
Prof Geraint Vaughan, University of Manchester
Dr Barbara Brooks, University of Leeds
Prof Martin Gallagher, University of Manchester
Dr David Birch, University of Surrey
Dr Grant Forster, University of East Anglia
Dr Keith Bower, University of Manchester
Dr Matteo Carpentieri, University of Surrey
Dr Kevin Wyche, University of Brighton
Dr Katherine Manfred, University of York
Prof Ruth Doherty, University of Edinburgh
Dr Chiara Giorio, University of Cambridge
Dr Kirsti Ashworth, University of Lancaster

Element 1 - Vision

To address some of humanity's greatest global challenges, such as climate change, extreme weather events and poor air quality, the atmospheric science community requires access to state of the art instrumentation, observations and expertise.

The Atmospheric Measurement and Observation Facility (AMOF) is an existing NERC facility that enables research across a wide range of disciplines, addressing problems in atmospheric dynamics and convection, surface exchange, cloud and aerosol microphysics, atmospheric composition, air quality and greenhouse gases. Our community vision for the next decade is an AMOF that can provide world leading, high quality field observations to improve the representation of complex atmospheric processes, supporting the development of evidence based mitigations.

AMOF was launched in 2020 and was a merger between the Atmospheric Measurement Facility (AMF) and the NERC Facility for Atmospheric Radar Research (NFARR).

AMOF provides

- Instruments to measure atmospheric physical and chemical properties during field experiments and from mobile platforms, remote sensing and surface meteorology, and access to user-configurable instrumentation. (Over 40 instruments, estimated capital value ~ £20 M)
- Logistical support, bespoke training and expert instrument scientists to deploy and operate complex instrumentation in the field
- Access to observatories (UK: BT Tower, Chilbolton, Weybourne, Capel Dewi. International: Cape Verde, Iceland) and globally unique laboratory facilities (EnFLo wind tunnel).
- Nationally accessible calibration facilities to underpin atmospheric measurements and drive best practice and standards

Staff required: research scientists (6.31 FTE), operational staff (1.5 FTE) and technical support (2 FTE)

To maintain a forward-looking facility, we propose that the community plays a stronger role in determining AMOF's direction. Existing user groups will be supplemented with research area specific working groups. The current steering group is made up from members of the research community and an independent chair from outside the UK. We expect the facility to commit to making this group as diverse as possible in terms of career stage, institution and protected characteristics. The steering group currently has limited scope and we propose this group has increased decision making capabilities in terms of allocation of staff time, financial resources and termination of activities that are no longer productive.

Through our community engagement, a number of common innovative technologies were proposed including calibration facilities (aerosol, bioaerosol, GHG), unmanned aerial vehicles, low cost sensors, investment in data analysis and software. Rather than request funds for specific

instruments/observatories at this stage, as a community we propose that NERC should introduce an AMOF innovation capital fund, managed by the steering group in a transparent manner. This should support emerging technologies and associated resources to provide trained operators. We expect this fund to be open to the breadth of atmospheric science and proposals must have evidence of substantial community support.

Innovation is the key to maintaining the UK's international leadership in atmospheric science research and growing our extensive collaborative network internationally. AMOF will allow the community to tackle these urgent challenges in a flexible and innovative way and enable the UK to maintain its world leading status.

Element 2 - Quality

The atmosphere plays a vital role in controlling the world we live in, impacting our health, ecosystem, weather and climate. High quality measurements of the atmosphere's composition provide vital information on emissions, chemical transformations, human health and ecosystem impacts. State of the art measurements of atmospheric dynamics, convection, clouds and precipitation processes are essential to test and evolve numerical weather and climate models.

Our community wants an innovative, user orientated, high quality facility to tackle key environmental challenges to further enhance the UK's world leading position in the global atmospheric science community. Understanding the impact of anthropogenic and natural emissions on our atmosphere cuts across all 8 of NERCs research priority areas and recent SPF investments by UKRI.

Key future research objectives to be addressed by this facility include;

- Quantify changing emissions in urban and rural areas as a result of sustainability and net zero, grow the evidence base linking pollutants to specific human health effects, and identify how the distribution of pollution leads to inequalities in exposure and harm.
- Improve climate and weather predictions by determining how atmospheric particles and gases affect weather patterns, precipitation and the Earth's radiation budget.
- Validate satellite products with AMOF data, and support the development of future satellite missions with customisable instrumentation (e.g. cloud radars), maximising the value from national and international investments in Earth Observation.
- Elucidate the mechanisms that control synoptic scale weather systems, convective cells, clouds, fog and stable boundary layers through application of state of the art meteorological observations. Applying this knowledge in a new generation of km-scale weather and climate prediction models would transform our ability to predict impacts and hazards on timescales from hours to decades.
- Continue to provide rapid access to instrumentation for deployment in emergencies to support UK Government decision making on hazards.

AMOF will enable cross-council research through the EPSRC Resilient Nation theme, MRCs Prevention and Early Detection and Global Health themes and the BBSRC Bioscience for Renewable Resources and Clean Growth theme.

Element 3 - Users and community engagement

To develop the statement in collaboration with the atmospheric community, a virtual initial scoping meeting was held. This meeting was organised by the current leadership of AMOF and included a wide range of atmospheric researchers including AMOF staff, previous users of the facility and scientists who had never used the facility. There were 46 attendees on the day from 19 institutions, including current and emerging leadership in atmospheric chemistry, physics, meteorology, polar, marine and climate science. The meeting incorporated breakout rooms, where google documents were used to brainstorm ideas for each of the sections of the application. These documents were left open for a further 24 hrs and were a vital resource to form the basis of this statement of community need. The future of atmospheric science will be driven by the next generation of researchers and so an online survey was created for PhD students and early career researchers with three questions covering; what science they think is important over the next 10 years, the nature of the measurement and/or observations they want to make and what other services would they like a national facility to provide? This was disseminated via a range of routes including direct emails via DTPs, mailing lists and via social media (twitter: 8913 impressions). The responses from the ECR survey were combined with the meeting responses to develop and refine this statement.

The statement has been written by a multidisciplinary group, covering the breadth of atmospheric science and including staff from both Universities (York, Reading, Leeds, Manchester, Sheffield, Royal Holloway) and Research Organisations (Centre for Ecology and Hydrology, Plymouth Marine Laboratory and the Met Office). The first draft was scrutinised by a review group and comments incorporated into the statement. It was released online for supporting signatures for a period of one week (183 signatories, 36 institutions).

The main users of AMOF are the major UK research hubs in atmospheric science though it is also used by other research disciplines (marine, polar, biosphere, volcanic emissions, circular economy, CCS). We propose to facilitate enhanced interaction with the UK science community through the creation of focused research working groups, allowing greater interaction with smaller research groups in a two-way fashion, a key step to ensure inclusivity and grow the user base.

It is difficult to determine the total number of users of AMOF since it was only launched in 2020. Between 2014-2020, 299 applications for access were made to the previous AMF. We project a growth in the user base of at least 20 % over the next 5 years. This is based on the increase in usage over the last 10 years and the addition of novel capabilities. Through increased advertising of the facilities available and participation in external activities, the user base and access will be enhanced further.

Element 4 - Importance and context

The UK's position as a global leader in atmospheric sciences relies heavily on facilities that provide long-term stewardship of equipment and, crucially, the expertise to run these instruments efficiently and to the highest possible standard, while contributing to the training of the next generation of scientists. Unique features of AMOF include its distributed nature and community access. AMOF works alongside the Facility for Airborne Atmospheric Measurements. This statement has been developed collaboratively with other UK facilities (Centre for Ecology and Hydrology, Plymouth Marine Laboratory and Met Office).

AMOF is currently part of international networks including the Global Atmosphere Watch programme (WMO), ACTRIS (pan-European research infrastructure producing high-quality data on short-lived atmospheric constituents) and ICOS (standardised and open GHG data in 13 European countries). Internationally, the most comparable facility is the US Atmospheric Radiation Measurement facility, funded by the Department of Energy. They provide access to instruments and observatories, but on a larger scale (2020; $70M, 1000 users) and can award funding. Within the global landscape, Chilbolton Atmospheric Meteorological Radar and the EnFlow wind tunnel are unique capabilities. The strategic importance of the facility is evidenced by its role in underpinning numerous national and international projects. Example large scale international collaborations are highlighted below and it is essential that the facility can continue to support this kind of ground breaking research.

- Providing critical wind profile data for a year in the Arctic as part of MoSAic, largest polar expedition in history (42 nations, > 400 data users)
- Deployment of core air quality instruments in Beijing as part of the NERC/MRC funded Air Pollution and Human Health programme (38 institutions, > 400 publications by March 2021)
- Radar at Chilbolton has played a key role in evaluating WIVERN, one of 4 projects competing to be the 11th Earth Explorer mission (ESA)

Continuing investment will allow us to develop new collaborative partnerships to address future UK strategic priorities and international global sustainable goals.

The facility is central to the delivery of key elements of NERC's Delivery Plan, including discovery science, research programs, industry collaborations and the development of environmental solutions. AMOF is used extensively within NERC's DTP and CDTs. It is central to NERC's delivery under Healthy Environment, Environmental Solutions and Digital Environment priority areas. AMOF will support current UKRI Strategic Priority Funds (Clean Air and UK Climate Resilience) and will provide the observations needed to underpin Defra's 25-year Environment Plan, the UK commitments to achieve climate neutrality and the attainment of more challenging standards as set out in the 2021 Environment Bill.

Element 5 - Impact

AMOF enables transformative research cutting to the heart of existential problems facing humanity. We believe that the loss of this facility would be catastrophic for the whole UK atmospheric science community, including researchers, industry and policymakers. The loss of expertise, capability and datasets would have substantial detrimental effects on the ability of the UK to respond to a wide range of challenges associated with current and future sustainability, net zero, climate and air pollution policies.
Air pollution is the biggest environmental threat to health in the UK, with between 28,000-36,000 deaths a year due to long-term exposure. Reducing the scale of health impacts requires evidence on the pollutants causing harm, their emissions and trends. Improved weather forecasts of severe events have a high economic impact in enabling actions to be taken that are targeted and timely to minimise losses and reduce the emotional and psychological damage to the lives of the people affected. Over the next decade, AMOF should continue to make high quality observations of the atmosphere and innovate with new technologies and methodologies providing the evidence base needed to develop mitigations and improve the quality of life for the UK and global population.

AMOF provides training to enable best practices in atmospheric science measurements, including instrumentation maintenance, calibration and data analysis. AMOF should continue to play a key role in supporting graduate students including the annual Atmospheric Measurements summer school, which leverages world class expertise in AMOF to train the next generation of students in effective field work design and management. During international field work and through the observatories, AMOF will engage with local institutions, providing valuable networking and training opportunities in developing economies and co-design of experiments and interventions. AMOF will act as a role model for sustainable research practices.

For the UK to be a world leader in technology and innovation, greater collaboration between industry and research is needed. Examples of AMOF capabilities working across disciplinary boundaries and with industry include regulation of soot emissions from aircraft engines, new emissions from bio-fuelled vehicles, and with consumer product industries to reduce pollution emissions in the home.

Continuing the capability of AMOF is essential to ensure the UK has the ability to react rapidly to important emergent issues and emergency response, particularly providing evidence in a responsive manner to Government. This includes use of AMOF facilities evaluating the effectiveness of face masks to reduce aerosol transmission of COVID, the link between UK air quality exposure and COVID-19 mortality, the safe recovery from a major gas leak from the Elgin platform (2012) and the eruption of Eyjafjallajökull volcano (2010).

Element 6 - Justification

AMOF delivers a substantial pool of state of the art instrumentation, strategically located observatories, unique reference laboratories and internationally recognised staff expertise. AMOF provides access to instrumentation for multiple types of atmospheric measurements and enables users to easily identify available instrumentation. Emerging research leaders can access cutting-edge capabilities and expertise that would be impossible to obtain individually. This also allows non-instrument scientists to obtain the observational data they require. Through its multidisciplinary and distributed structure, AMOF is a UK-wide provision that leverages other UKRI investments in research.

The community requires a shared infrastructure for equipment which is too expensive to be purchased and maintained by any single institution. Pooling of instruments maximises their benefit to the broadest group of researchers and reduces duplication of effort. AMOFs unique capabilities and expert staff provide more opportunities for international collaboration. For instance, the high instrument density at the Chilbolton observatory encourages co-location of new cutting-edge observations, providing synergistic research outcomes.

Mobile equipment requires high levels of expertise to deploy successfully, especially in remote and challenging environments. AMOF provides calibration, quality control and data standards to a level which would not be achieved by individual research groups (e.g. ISO9001 certification) and by providing centralised facilities there is an economy of scale. AMOF can do this by employing and training a critical mass of scientists who can become experts in instrument deployment and data acquisition, delivering high quality data that maximizes opportunities for exploitation. The skills and experience involved take years to develop and long-term commitments are needed to retain these expert staff.

The AMOF leadership and steering group will foster input and engagement with existing and new communities. Through the proposed innovation fund, AMOF has the potential to be responsive to community needs and for innovation in line with emerging, cutting-edge research needs, allowing growth of the user base, developing atmospheric science capabilities within new institutions or communities.

Element 7 -Responsible research

Sharing essential instrumentation and calibration facilities across the entire atmospheric community, reduces resources and duplication of instrumentation. The high cost of equipment creates a barrier to entry. AMOF provides a critical mechanism to support the science of early career researchers, and those working on research outside of large university hubs. AMOF is a distributed facility and all host institutions are expected to commit to sustainability, including increased renewable and low carbon energy production, minimisation of waste and impact on local communities and biodiversity. The observatories in AMOF continue to evolve in line with NERCs responsible research policies *e.g.* installation of solar panels at the Cape Verde observatory. Training and collaborations with local scientists builds vital local expertise and promotes new research directions.

Other innovations include a green fieldwork kit, with the aim of greening campaigns and reducing waste. Centralised calibration and accreditation at the facility level ensures the highest data quality standards,

reducing the potential environmental impacts if low quality data is collected. Applications should include a section on responsible research and the facility can act as a repository for good practice. We will appoint environmentally responsible suppliers and assess the environmental impact of instrumentation across its lifecycle. Policies will be developed to ensure maximum reuse of components and recycling in line with WEEE requirements. Miniaturisation and replacement of high energy demand instrumentation will further enhance environmental benefits. Open access data files follow the FAIR data principles.

There is a lack of diversity in environmental science in the UK as recognised by NERC. AMOF would look to be an active partner in practical initiatives launched. We expect host institutes to have commitments to EDI and for these to be reviewed regularly. Job adverts and specification will be checked for gendered language and promotional material designed to ensure representation of the diversity of NCAS scientists. For those with caring responsibilities, the facility will ensure meetings can be attended virtually where possible, short deadlines avoided and flexible working practices available.

The data obtained by AMOF over the next decade is essential for understanding the impact of UKRIs sustainability decision making and implementation. Atmospheric composition measurements will allow us to estimate the economic and societal benefits of reductions in harmful pollutants. Understanding the role of changing emissions to the atmosphere as a result of net zero policies is essential to benchmark their performance to reduce climate change. Improved weather predictions are needed to mitigate against the effect of extreme weather events and their effect on human populations and ecosystems.

Element 8 - Indicative resources

- There will be future steps to establish the scope and scale of any funded activity. At this point, we require indicative costs only over five years of operation. These should be split into capital requirements and yearly resource costs.
- In cases where there are existing UK capabilities or equipment that the activity could utilise, the statement of community need should describe both:
    - the costs of supporting this facility if the existing capabilities or equipment did not exist.
    - the costs of this facility if it were to use existing capabilities and equipment.

Costs to support this enhanced facility using existing capabilities and equipment over 5 years = £9.35 Million

This is split between resource and capital as shown below
Total resource required over 5 years = £8.35 Million (£1.67 M per year)
Capital requirements for innovation fund = £1M

The total resource costs is split as follows
Staff (9.81 FTE) over 5 years = £6.27 Million (average £1.25 M per year)
Travel and subsistence over 5 years = £75,000 (average £15,000 per year)
Service maintenance and instrument consumables over 5 years = £2M (average £400,000 per year). This is an increase compared to current budget to account for recent investments.

Additional capital costs required if existing capabilities / equipment did not exist
These have been estimated using the cost of replacing the instrumentation and infrastructure. They do not take into account the loss of expertise, which would be a further substantial loss of capability.

1. Instrumentation (£19.615 M)
    - Mobile Instrumentation: £6.785M
    - Laboratory Instrumentation: £1.23M
    - Static Radars/Lidars: £11.6M
2. Infrastructure (£1.8M)
    - Laboratories - excluding EnFlo: £0.8M
    - Field sites - excluding Capel Dewi and Chilbolton: £1.0M

3. All the following are internationally recognised facilities with unique capabilities that are irreplaceable.
    - Chilbolton: The replacement costs of the actual radar and lidar instruments at this site (£6.6M) is included in the instrumentation costs. The site at Chilbolton is shared with STFC as the site also hosts a range of non-atmospheric science capability. Estimated replacement cost in the many 10s of millions (> £50M).

- Capel Dewi: This site exists to support the MST radar (£5M replacement cost of the radar included in the instrumentation costs). Estimated replacement cost in the many 10s of millions (< £50M).
- EnFlo: The EnFlo meteorological wind tunnel is unique and it is estimated that to replace the tunnel (capable of simulating stratified atmospheric flows) and the supporting infrastructure would cost in the many 10s of millions (< £50M).
- Cape Verde Atmospheric Observatory: A WMO GAW global status monitoring station, operated as part of an international partnership agreement between the UK, Germany and Cape Verde, located on a unique unpolluted island site provided by the Government of Cape Verde.