**Annex A: Capacity for atmospheric science and health research of relevance to this call**

**India**

All advanced online air quality monitoring analysers (Ozone, $PM_{2.5}$, $PM_{10}$, CO, BTX, HCs, $NO_x$) are available along with AWS on 10 locations within NCT of Delhi for the program.

**UK**

UK science capabilities in air pollution and related human exposure science are distributed across a wide range of academic, public and private institutions and it is impractical to attempt to list all possible contributions. Nonetheless a number of key nationally unique facilities exist that may support the science requirements of this call and these have been highlighted below along with a summary of some of the wider capabilities. **This information was provided largely by the academic community and applicants should liaise directly with the providers of any facilities in order to determine its capability and availability before submitting a proposal**.

1. **Aircraft**

The UK has a number of aircraft capable of supporting air pollution research.

**1.1 Facility for Airborne Atmospheric Measurements (FAAM) aircraft,** www.faam.ac.uk

The Facility for Airborne Atmospheric Measurements is based on a BAE-146 aircraft, run jointly by the NERC and the UK Met Office. This is a four engine jet aircraft, capable of carrying a large suite of instruments together with up to 19 scientists on a mission lasting up to 5 hours. The maximum flight altitude is 10.7 km. FAAM is based at Cranfield University in Bedfordshire, and has a dedicated team of 16 scientists and engineers. Research groups from the Universities, NERC Centres and the Met Office use the facility, often in large collaborative consortia which take the aircraft to far-flung locations. FAAM made a first assessment of the air pollution emissions from an African megacity (Lagos, Nigeria) in 2009. The aircraft has been used on numerous occasions to determine the fate of urban air pollution as it is carried over the Atlantic, Pacific and upwards to the stratosphere and the interactions between pollution, radiation and regional climate properties.

Instrumentation on the aircraft is categorised as core and non-core. The core measurements, operated by FAAM staff, are available to all users, and comprise:

- aircraft position and velocity: GPS, inertial navigation system
- temperature, deiced and non-deiced: Rosemount/Goodrich type 102
- humidity: General Eastern GE 1011B Chilled Mirror Hygrometer and Buck CR2 Hygrometer
- turbulence: 5 hole probe
- ozone: TE49C analyser
- sulphur dioxide: TE43C TL
- carbon monoxide: Aerolaser AL5002
- PCASP passive cavity aerosol spectrometer probe
- PSAP particle soot absorption photometer
- Cloud droplet probe (cloud particles 2 – 50 µm)
- Cloud imaging probes CIP15 and CIP100 (cloud particles up to 6 mm)
- Johnson-Williams total water probe (hot wire)
- Broadband radiometers
- AVAPS dropsonde system using Vaisala RS93 dropsondes

FAAM are also able to operate a number of non-core instruments, depending on the aircraft fit: TSI3786 condensation particle counter, cloud condensation nucleus counter, AQD fast chemiluminescent $NO_x$, Los Gatos $CO_2$/$CH_4$ fast greenhouse gas analyser, Grimm Optical Particle Counters, BCPD-CDP (backscatter version of Cloud Droplet Probe), AIMMS turbulence probe, Whole Air Samples as per FGAM. Total Water Content (Lyman-alpha), Aircraft Weather Radar, Met Office WVSSII water vapour instrument, Bulk liquid/ice water detector (Nevzorov) probe.

Other non-core instruments are operated by the Met Office and University groups. For a full list of FAAM instrumentation consult the FAAM website, but instruments are available spanning radical gas phase species such as OH, primary emissions such as CO, $NO_x$, VOCs, $CO_2$, $CH_4$, halocarbons etc., secondary species such as oxygenated compounds and PAN, and a range of chemical and physical characteristics of aerosols and particulate matter from the nanometre range through to supra-micron.

### 1.2 Airborne Remote-Sensing Facility (ARSF), http://arsf.nerc.ac.uk

Smaller aircraft operated by the Airborne Remote-Sensing Facility (ARSF) and British Antarctic Survey (BAS) carry more modest payloads than the FAAM aircraft but can operate more easily at low altitudes in dense urban areas and fly slower allowing estimation of emissions using eddy covariance techniques.

The ARSF has the ability to make individual or combined remote sensing and atmospheric observations. Airborne remote sensing provides an efficient method for the rapid collection of data over a specified area; consequently it is a cost effective means of monitoring the atmospheric environments, provides a transitionary scale with which to validate satellite data and enables the rapid acquisition of data for sudden or unexpected events, such as fires. Since 1983 the facility has supported a wide range of applications, including environmental science, geomorphology, archaeology, ecology, geologic surveying, pollution control and disaster management.

#### 1.2.1 Field Spectroscopy Facility (FSF), http://fsf.nerc.ac.uk/

The ARSF is supported by the Field Spectroscopy Facility (FSF) who can supply ground-based remote sensing measurements in support of this. Such facilities have been used in the past for estimating fire emission factors and monitoring pollution.

## 2 Atmospheric observation instrumentation

There has been considerable investment in observing capability over the past decade within NERC centres and also in the University sector.

### 2.1 Atmospheric Measurement Facility, https://www.ncas.ac.uk/index.php/en/about-amf

The Atmospheric Measurement Facility (AMF) provides an observational capability for ground-based and airborne observations and is run by the National Centre for Atmospheric Science (NCAS). It has four divisions: Observatories, Laboratories, Airborne instrumentation and Ground-Based instrumentation, the latter two providing support to field campaigns. Access to AMF facilities is through application to NCAS.

#### 2.1.1 Airborne observational support

AMF instruments are used in campaigns with FAAM and other research aircraft. Unless indicated,

these instruments may be operated on aircraft or on the ground, depending on the requirement.

Aerosol instruments:

- Aerosol Mass spectrometer, measuring chemical composition of non-refractory, sub-micron aerosol.
- Scanning Mobility Particle Spectrometer (SMPS), 20-350 nm, including a 3786-LP CPC.

Cloud measurements:

- Cloud Particle Imager – images and counts particles in the 15 – 2500 µm range.
- Cloud, Aerosol and Precipitation Spectrometer: aerosol cloud size distributions from 0.5 to 50 µm, particle shape (discrimination between water and ice), particle optical properties (refractive index), precipitation size distributions from 25 µm to 1550 µm, liquid water content from 0.01 to 3 $g/m^3$.

Chemistry measurements:

- Whole air sampling system and gas chromatograph with FID for C2 - C7 hydrocarbons, selected oxygenated volatile organic compounds and dimethyl sulphide at the parts per trillion level.
- PAN-GC, peroxy acetyl nitrate at the low parts per trillion level and 90 second sampling frequency.
- Fluorescence Assay by gas expansion OH, $HO_2$ and IO radical measurements (aircraft version).

#### 2.1.1.1 Ground-based observational support

In addition to the above, AMF operates the following instrumentation in support of ground-based field campaigns:

- Meteorology and dynamics
- Campbell Scientific automatic weather station
- Campbell scientific sonic anemometer and temperature probe
- HALO Doppler lidar
- Radiometer Physics microwave radiometer
- Vaisala Radiosonde station (x2)
- Scintec FAS64 sodar
- Degreane 1.29 GHz wind profiler (trailer-mounted)
- X-band scanning precipitation radar
- Chemistry measurements
- Ozone: TE49C analyser
- $NO/NO_2/NO_x$: TE42C analyser
- Carbon monoxide: Aerolaser AL5002
- FAGE, OH, $HO_2$ and IO radical measurements (ground-based version)
- GC-FID, C2 - C7 hydrocarbons, selected oxygenated volatile organic compounds and dimethyl sulphide at the parts per trillion level
- Aerosol-ozone lidar
- Aerosol measurements
- Differential mobility particle sizer, an instrument designed to measure aerosol size spectra down to very small sizes, currently from 3.5 nm to approx 470 nm
- Aerosol mass spectrometer, chemical composition of sub-micron, none refactory aerosol, incl. mass loadings as a function of size and mass spectra
- Hygroscopic tandem differential mobility analyser, to measure size resolved aerosol hygroscopic properties, i.e. how an aerosol distribution responds to a change in relative humidity
- CPCs – several CPCs with a Dp50 of between 2.5 and 10 nm, although some of the CPCs are

used as part of the DMPS and SMPS systems
- Scanning Mobility Particle Spectrometer (SMPS)

### 2.2 Other atmospheric observation instrumentation

Nationally there are a number of highly specialised, sometimes unique, air pollution assets. Some examples include:

- Boundary Layer Profiling, including aerosol LIDARs
- Urban meteorology, heat flux and turbulence
- Spectral Radiometry
- Aerosol composition via Aerosol Mass Spectrometry
- Aerosol size, number, physical and hygroscopic properties
- Molecular (inorganic and organic) aerosol composition via IC and LC-MS
- Organic Nitrogen speciation via a range of methods
- Oxidised and Reduced Nitrogen speciation via a range of methods
- VOC variability via PTR-MS and CI-MS
- VOC composition via GC-MS
- Reactive gas phase intermediates via CI-MS, BBCEAS and FAGE
- Passive and static samplers for off-grid sampling
- Surface flux instrumentation of primary pollutants using eddy covariance
- Tailpipe emissions estimates using optical absorption/number plate recognition
- Toxicity of particulate matter measurement offline and in real-time
- Surface to atmosphere flux measuring capabilities for volatile organic compounds, oxides of nitrogen and other trace gases
- Cavity ringdown system for the measurement of night time radicals ($NO_3$, $N_2O_5$, $NO_2$ and HONO), fitting to a super site, alone at a fixed site or on the aircraft
- The Online Monitor for Reactive Oxygen Species, an instrument which is able to determine specific, health-relevant components in particles such as reactive oxygen species (ROS)

The application of these instruments in the field almost always requires some supporting infrastructure to house instruments, to provide suitable sampling locations and inlets systems for sample collection at varying heights. The UK has 6-8 fully equipped containerised laboratories that can be deployed temporarily for process studies, and significant practical experience in mounting short-term experimental campaigns. Co-location of temporary instrumentation alongside long-term measurements and in locations where there is science support is desirable.

## 3 Earth Observation

There are important capabilities in the UK for air pollution science relating to the derivation and exploitation of data from Earth Observation. This includes at the NERC funded National Centre for Earth Observation (NCEO).

Satellites can now provide spatially resolved estimates of air pollution at national and region scales for species such as $NO_2$, $O_3$, HCHO, and aerosol index – for example from the platforms EUMETAT Metop, GOME-2 and IASI. These air quality observations have the potential to be linked to surface emissions processes through new Sentinel 5 observations from TROPOMI which will provide detail on CO and $CH_4$, and also potentially from GOSAT and OCO-2 for $CO_2$ and $CH_4$. There is specific UK technical capability to combine a range of remote sensing observations and models to derive emissions estimates, which if used in combination with other UK experimental capabilities, allow for experimental verifications from scales ranging from single vehicle, through to $km^2$ (via eddy flux towers), city scales via tall buildings or aircraft and to the regions and beyond via satellites.

## 4. Modelling and data capabilities

### 4.1 Modelling

There are an extensive range of modelling tools available in the UK that can be applied to support air pollution science.

Key model capabilities:

- Emission models. Local models could be enhanced using UK experimental capabilities in emissions verification.
- Chemical process models. NCAS lead the internationally recognized Master Chemical Mechanism (MCM) which is an explicit zero-dimensional benchmark air pollution model which is used to test the representativeness of reduced schemes used in regional and global models and to probe directly understanding of local air pollution reactions.
- Urban and regional air pollution models. The UK has capabilities to develop new parametrisations of both gas phase and aerosol chemistry within CMAQ and WRF-Chem tailored to specific geographic of urban environments. Many other regional air quality models exist, for example within the UK the Met Office has developed AQUM, an air pollution forecasting version of their weather model. The UK also has technical capabilities to embed urban street canyon scale processes, via ADMS and Large Eddy Simulations. ADMS, developed by the consulting organization CERC, is used world-wide for fine scale air pollution assessment, including for planning and for exposure estimates to air pollution.
- Regional and global models. UKCA is a UK model capability that uses the Met Office unified model meteorological framework and has within it advanced treatment of gas and aerosol processes (via a sub-model GLOMAP) and which can provide a link back to the detailed process modeling of the MCM, via a mechanism simplification approach using Common Reactive Intermediates (CRI). There is further UK capability for global pollution modelling via the open source GEOSChem model, which is used by a substantial number of researchers in both India and the UK and has been used extensively to test the impact of new process knowledge and via inversions to derive emissions.
- Managing Data. The UK has a well-developed infrastructure for data management and sharing, via the Centre for Environmental Data Archival (CEDA), which includes the NERC funded British Atmospheric Data Centre (BADC). CEDA provide petabyte-scale storage facilities for research programmes and also includes a data reanalysis facility called JASMIN. All NERC-supported air pollution experimental data is lodged alongside related metadata, at BADC, as are related model outputs. CEDA can provide capabilities to support data and informatics requirements and could provide a data sharing platform.

### 4.2 Data and analyses

#### 4.2.1 Centre for Environmental Data Archival (CEDA), JASMIN and Climate and Environmental Monitoring from Space (CEMS) facility, http://www.ceda.ac.uk/services/analysis-environments

The Centre for Environmental Data Archival (CEDA) at the STFC Rutherford Appleton Laboratory (RAL) is responsible for two national infrastructures for the climate and earth system modelling community and the earth observation community.

The JASMIN super-data-cluster is deployed on behalf of NCAS at RAL. JASMIN supports the data analysis requirements of the UK and European climate and earth system modelling community. It

consists of multi-Petabyte fast storage co-located with data analysis computing facilities.

On the JASMIN infrastructure, CEDA also hosts the academic part of the Climate and Environmental Monitoring from Space (CEMS) facility, a collaboration with the Space Applications Catapult. CEMS is a purpose-built facility offering space-based climate change and EO data and services. Its goal is to nurture growth in EO and climate-based services by providing, within a single facility, high performance computing, extensive data collections and various user services and software applications

#### 4.2.2 Community Intercomparison Suite (CIS), http://jasmin-cis.readthedocs.org/en/latest

The Community Intercomparison Suite (CIS) is an automated model/data intercomparison tool simplifying a wide range of time-consuming tasks in intercomparison (read-in of heterogeneous gridded and ungridded model data and observations, reduction, co-location, and analysis) to a set of simple commands. CIS can handle both observational datasets (e.g. remote sensing like AERONET sun photometers, MODIS and MISR satellite imagers, the space born lidar CALIOP and radar CloudSAT and ESA Climate Change Initiative data or in- situ data, such as the largest archive of aircraft measurements of aerosol collected in the NERC project GASSP) as well as global models, such as ECHAM or AeroCom models used in this project. The colocation tool in CIS allows selection of user specified colocation kernels (e.g. interpolation, nearest neighbours) and is optimised for efficiency for the handling of large datasets.

## 5. Sensor technology

Across the UK institutes there has been much investment in the development of sensors. These include:

- Static sensors, e.g. air quality sensors/networks of sensors which collect minute by minute information and upload using cellular technology. Some databases exist of information already collected with such sensors.
- Personal exposure monitors, e.g. for particulates ($PM_{10}$, $PM_{2.5}$ and $PM_{1.0}$), $NO_2$, $O_3$ which communicate wirelessly with mobile platforms such as phones, tablets to either store or upload data to the server.
- Health sensors, e.g. respiratory rate/effort and activity level monitors worn as a plaster for monitoring COPD and Asthma patients.

## 6. Molecular analyses

### 6.1 NERC Biomolecular Analysis Facility (NBAF), http://nbaf.nerc.ac.uk/

The NERC Biomolecular Analysis Facility (NBAF) provides access to high-level genomics, metabolomics and bioinformatics provision through its four sites: Edinburgh, Birmingham, Liverpool and Sheffield. NBAF offers the very latest, class-leading technologies, including next-generation sequencing (Roche 454, Illumina and IonTorrent), Sanger sequencing, microarray- and sequencing-based genotyping and expression profiling including the in silico design of oligoarrays (Agilent, Nimblegen). NBAF also supports metabolomics, medium-scale genotyping, bioinformatics and advanced data analysis techniques (genome and transcriptome assembly and annotation, expression analysis, etc.).

### 6.2 MRC-NIHR National Phenome Centre, http://www1.imperial.ac.uk/phenomecentre/about/

The National Phenome Centre, funded by the MRC and NIHR and led by Imperial College London and King's College London, aims to deliver broad access to a world-class capability in metabolic

phenotyping, that will benefit the whole UK translational medicine community. The Centre is open to the whole UK research community (academic and industry) and offers a wide range of services from broad profiling untargeted assays to targeted assays. These services are offered on a collaborative project basis or as a fee-for-service offering.

## 7. Cohorts

### 7.1 MRC Cohort Directory, http://www.mrc.ac.uk/research/facilities/cohort-directory/

The Cohort Directory is a searchable tool of UK population cohorts. The aim of the directory is to signpost users to individual cohorts to maximise the use and translation of findings of these valuable UK assets. These cohorts could be utilised in order to develop protocols or make comparisons.