Aerosol Properties, PRocesses And InfluenceS on the Earth's climate
Science Plan for the NERC APPRAISE programme

CONTENTS

1. Introduction

As stated in the NERC Delivery Plan 2005-2008: "The Intergovernmental Panel on Climate Change identifies atmospheric aerosols as one of the largest sources of uncertainty in quantifying and predicting global and regional climate change and its impacts. Aerosols affect climate through direct radiative effects (scattering and absorbing radiation), and indirect effects (e.g. controlling cloud properties). The challenge is to provide major advances in understanding the nature and life cycles of atmospheric aerosols, to enable substantial reductions in climate change uncertainties."

NERC has recognised that climate change policy makers need this information now and that it is critical to initiate this work immediately. Therefore NERC has pledged to invest £4M in this area of research over the SR2004 period. The UK is ideally placed to meet this challenge, given current strengths in scientific and technical expertise in the NERC and Hadley Centre communities.

Following the meeting of the aerosol task force, NERC invited a writing group (see **Appendix 1**) to develop a Science Plan and an Implementation Plan for a programme of research in this area for consideration at the September 2005 SISB meeting. To ensure transparency and inclusivity of the community, NERC convened a cross-disciplinary Expert Advisory Group (EAG) of 16 members (excluding writing group), to review and provide comment on the plans as they have developed. Membership and terms of reference of the EAG can be found in **Appendix 1.** All 16 members provided reviews and comments and these have been considered and worked into the final version of the Science Plan as presented in this document. Six members of the EAG are independent, ie they cannot bid for NERC funding. The EAG will have a continuing role, providing advice and guidance, on the development of the programme.

The programme that has been developed is called Aerosol Properties, PRocesses And InfluenceS on the Earth's climate (APPRAISE)

2. The NERC APPRAISE programme

APPRAISE is a major 5 year scientific programme that will run from 2005-2010 (science beginning summer 2006 – see section 7). APPRAISE will seek to tackle key research challenges that include understanding and quantifying:

(i) the direct effect of aerosols on the Earth's radiation budget, via scattering and/or absorption of radiation;

(ii) the influence of aerosols on cloud properties and hence indirect effect on climate and influence on the hydrological cycle;

(iii) the role of aerosols in feedback processes between land, the biosphere and climate.

To reduce these uncertainties a much-improved understanding of the atmospheric aerosol lifecycle and better representations of this in climate simulations are needed.

APPRAISE will fund targeted and strategic activities and provide a platform for focussing and co-ordinating NERC's present and future investments in this area. The programme will maximise the potential of the NERC community's expertise and build links between science activities that are already internationally competitive. In line with NERC's Delivery Plan 2005-2008, APPRAISE will collaborate with the Hadley Centre and will "complement aerosol research in NERC's UK Surface-Ocean, Lower-Atmosphere Study (UKSOLAS), QUEST, Centre for Ecology and Hydrology (CEH) and NERC Centres for Atmospheric Science (NCAS) programmes, utilising the new state-of-the-art research aircraft facility (FAAM)". Exploitation of experimental facilities including the aircraft and instrumentation, and synergistic links to existing modelling programmes, will allow APPRAISE to develop the aerosol area of NERC's science strategy into an internationally leading activity. APPRAISE will provide a framework, within which UK science can work collaboratively with US, European and Asian scientists. (Details of the above are in the Science Plan provided).

In summary, APPRAISE will provide key information on aerosol and cloud properties, processes and effects on climate, which can be used to develop further the Hadley Centre's climate model. This will allow improved representation of aerosol and cloud processes in the model, leading to a reduction in uncertainty in climate change predictions and feedbacks. By working closely with the Hadley Centre, the NCAS Centre for Global Atmospheric Modelling (CGAM) and the NCAS Distributed Institute for Atmospheric Composition (DIAC), APPRAISE will ensure effective transfer of information from the programme into the global climate models.

Specifically, APPRAISE will:

- Provide a focus for UK research in the key area of aerosols, clouds and climate over the next 5 years
- Deliver improved knowledge on aerosol and cloud properties, processes and impacts through detailed field and laboratory measurements
- Use process models to develop parameterisations for use by global and regional transport and climate models.
- Test and demonstrate the climatic importance of key aerosol and cloud processes through a coordinated hierarchy of models linking process scales to global climate models through transport models
- Identify and quantify key biosphere-atmospheric aerosol couplings at the process scale and so provide improved data from which to develop parameterisations.
- Deliver a coordinated internationally leading activity in the APPRAISE area

The EAG will provide NERC with an assessment of progress, uncertainty and future developments in the area at the end of 2007.

APPRAISE will need to: enhance the existing activity of the UK Chemistry and Aerosol model (UKCA), a partnership between the Met Office and NCAS; complement other major NERC investments such as the directed programmes: Polluted Troposphere; QUEST; UK SOLAS (see

Appendix 5 for glossary of acronyms), and the new Environment and Human Health programme; work with international programmes such as IGBP/iLEAPS, SOLAS, and QUANTIFY.

APPRAISE will develop and maintain national collaborations with the Hadley Centre and the Environment Agency, and forge international links with European networks (eg ACCENT and ESF) and with the US National Science Foundation. The latter will be encouraged within the programme's activities through joint research activities, such as the present participation of the NERC-funded Intercontinental Transport of Ozone and its Precursors consortium within the International Consortium for Atmospheric Research into Transport and Transformation (funded by the US, France, Germany and the UK). In addition, APPRAISE will aspire to develop a joint NERC/China partnership for future aerosol research activities (within the lifetime of APPRAISE). This will take advantage of the recently established NERC/China Memorandum of Understanding on climate change research. APPRAISE will make maximal use of synergies with other activities worldwide, including international projects and programmes such as IGAC, GEIA/ACCENT, ACE-Asia, AMMA and LBA.

The outcomes of APPRAISE will need to provide guidance to policy makers. Through its Knowledge Transfer plan (see section 6), APPRAISE will work very closely with the recently NERC-funded UK Atmospheric Aerosols Network (UKAAN) to transfer the outputs of the programme to the user community. This includes government departments, public agencies and industry. In addition, APPRAISE will provide funds to extend UKAAN for the duration of the programme. It is anticipated that within the programme itself, APPRAISE will work closely with the users of the research, namely the Hadley Centre, Met Office, Defra and the Environment Agency, so ensuring effective transfer of knowledge to its main users.

It is proposed that APPRAISE uses the available funds (£4M) in the following way: up to £3M for a single competitive funding round to support three targeted consortia, one each in the areas of (i) Direct aerosol impacts on climate, (ii) Indirect aerosol-cloud impacts on climate, and (iii) aerosol–climate coupling through feedbacks with the terrestrial biosphere. The remaining allocation will be spent on cross-cutting scientific activities which underpin all 3 consortia, knowledge transfer activities, and logistical and management costs. The funding for the programme will be committed during the current Spending Review period but spending will be over 5 years (2005-2010).

3. Scientific Rationale and Importance to NERC

If NERC is to successfully deliver outputs in its priority science area of climate change prediction (as defined in the science strategy document - "Science for a sustainable future"), it must invest in improving the understanding and knowledge of the processes affecting the Earth's radiative balance. The largest uncertainties in this area are, at the present time, linked to aerosol particles and clouds, through their scattering and absorption of radiation. In addition, changes in climate may have an impact on the properties of aerosols and clouds themselves and thus feedback, in an uncertain way, on future climate responses. These issues need to be addressed to ensure improved representation of the Earth System in climate models, and provide increased confidence in future regional and global climate predictions.

Recently, there has been a significant improvement in the accuracy of in-situ measurements, and in deriving ground based remote sensing and satellite retrievals of aerosol and cloud parameters. Only now are these techniques able to offer the physical and chemical detail required to close some of the required budgets and provide long term, globally representative measurements. In addition, models are beginning to include all major aerosol components and most of the relevant physical phenomena, and are starting to encapsulate some of the cloud effects induced by aerosols. In short, the measurement and modelling tools required to make significant progress in improving the prediction of the impact of aerosols and clouds on climate, are starting to come available. APPRAISE will provide the funding, and co-ordination framework necessary to exploit these developments and to make the UK a world-leader in this area of research.

4. Science Plan

4.1 Background and General Principles of APPRAISE

The APPRAISE programme seeks to significantly develop knowledge of the impact of aerosols on our climate by conducting basic scientific research on key processes involved in the lifecycle of the aerosols in the atmosphere. The programme approach will be through an integrated hierarchy of laboratory studies, field and global observations, process models, regional models and global/climate models, providing interconnected tools for use in the three key science areas below. The effort needs to be driven by both top-down and bottom-up methodologies. Outcomes should include identification and quantification of the key processes in general circulation models (GCMs) and simplification and parameterisations of these processes, tested using the model hierarchy. Such a system of models will be used to deliver improved confidence limits for the description of aerosol and cloud impacts in model predictions, on global and regional scales. Global-scale modelling activities are anticipated to build upon established modelling frameworks (e.g. Hadley Centre, QUEST), to exploit synergies with complementary activities in the UK and international scientific community and to maximise resources to improve process-level understanding within APPRAISE.

It is anticipated that novel science will arise from the observational part of the programme through the detailed study of basic processes. New technology is developing in this area within the UK and this will be utilised effectively within the programme. Where appropriate, the programme may fund new instruments where a specific need can be identified.

APPRAISE will provide co-ordination and exploitation of expertise across an internationally renowned science community. The mechanism for delivery will be through consortia grants, supported by a core programme of key strategic scientific activities:

4.2 Key Scientific Areas for Consortia

For NERC to address the UK science needs in this area and to improve our basic skill in modelling present climate, APPRAISE seeks a single consortium in each of the three areas below. The consortia will all adhere to the APPRAISE philosophy of integrating laboratory, *in situ* and satellite field- and modelling-studies. Details of the science rationale and approach of each of these areas can be found in **Appendix 2**. The key objectives of each consortium are outlined below:

4.2.1 The Direct Impacts of Aerosol on Climate

Objectives:

- To quantify better the key parameters controlling the evolution of the single scattering albedo and radiative effect of key aerosol types
- To assess the relative contributions of primary and secondary aerosol to the global aerosol budget and their effects on the radiative budget
- To assess the regional variabilities in aerosol and their effects
- To provide an initial framework for assessing the climatic impacts of air quality regulation of particulate material.

4.2.2. Aerosol Cloud Interactions and Climate

Objectives:

- To assess the relative importance of the key processes by which aerosol control cloud microphysics in mixed phase clouds

- To determine the properties and role of ice nuclei and their interaction with mixed phase clouds
- To assess the role of absorbing material above, below and within clouds

4.2.3. Aerosol coupling in the Earth System

Objectives:

- To provide quantitative descriptions of key biogenic surface flux processes between aerosol and their precursor gases.
- To quantify biogenic volatile organic compound chemistry and aerosol formation in and above vegetation canopies through integrated field studies
- To assess the impact of such processes on regional aerosol burden and precipitation.
- To assess the impact of land use changes on aerosol emission and deposition and develop predictive capability

4.3 Key Underpinning Science Areas – The Core Programme

To achieve its overall objectives, add value to the consortia activities and provide a strategic vision for aerosols research, APPRAISE will additionally seek to fund several key scientific areas that provide underpinning science to the programme. They are specifically targeted at areas not covered by NCASII and other NERC institutes and facilities, though they will work closely with these frameworks. The activities have been targeted such that they will facilitate and assist more than one of the consortia. There are potentially many such activities, however the level of funding has required their prioritisation. This has been successfully achieved through detailed consultation with the EAG. The four activities outlined below will be bid for in open competition as described in more detail in section 7. Details of the rationale and targets of each of these areas can be found in **Appendix 2**. The key objectives of the elements of the core programme are outlined below:

4.3.1 Formation Pathways and Properties of Organic Aerosols

Main deliverables:

- An improved description of secondary organic aerosol production
- A framework for assessing its role in the behaviour of mixed component aerosol

4.3.2 Improved Representation and Validation of the Radiative Properties and Impacts of Aerosols and Clouds

Main deliverables:

- A community radiative transfer model that can be both simplified or made more complex and so be incorporated into a wide range of aerosol models, and an assessment of the quality of the required inputs
- Provision of aerosol optical depth, size distribution and refractive index such as is available from the AERONET sun-photometer installed at a site in Cardington, UK.
- A database of aerosol products including aerosol optical depth, aerosol Angstrom coefficients, aerosol size distributions, and single scattering albedo, and similar products for specific FAAM aircraft operations/dedicated aerosol measurement campaigns

4.3.3 Development of a Global Model to Investigate Key Aerosol and Cloud Processes

Main deliverables:

- A global aerosol model that is capable of (i) carrying the main aerosol types, (ii) deal with complex mixing states and (iii) act as a key stage in the hierarchical testing of aerosol processes in APPRAISE
- Coordination of the development of the hierarchical model development, interfacing with other modelling effort in the UK

4.3.4 Improved Coupling of In Situ Cloud Measurements with Novel Model Schemes

Main deliverables:

- Improved treatment of cloud/aerosol interactions in cloud resolving models including explicit aerosol and cloud microphysics that is based on an improved knowledge of the interaction of clouds and aerosol especially mixed phase clouds.

5. Logistical Support

The APPRAISE programme will require the use of a significant number of NERC and other resources. These are simply listed below for information. More details on these, including how they will be integrated into the programme and funded, are given in **Appendix 3**.

5.1 The FAAM Aircraft
5.2 Ground Sites
5.3 The Chilbolton RADAR facility
5.4 Satellite Data
5.5 Key Laboratory Facilities
5.6 Modelling and Computer Support
5.7 Data Management

6. Knowledge Transfer

As currently envisaged, two main routes for knowledge transfer will be explored:
(i) Transfer via close liaison between the consortia, the UK Met Office and the Hadley Centre - these collaborations will ensure that the knowledge acquired through the programme is used in climate modelling activities funded by Defra.
(ii) Transfer through the extension of the recently NERC-funded UK Atmospheric Aerosols Network (UKAAN). The key aims of this network, set up in July 2005, are: to establish links between the UK academic aerosol research base in atmospheric sciences and the aerosol user community, thereby improving the uptake of science by users; to facilitate the transfer of ideas, experimental techniques and knowledge between academia and users of NERC science; to promote UK atmospheric aerosol research and user activities, nationally and internationally; and to provide a strategic view at the interface between core science and policy over the next decade. UKAAN will achieve this by running Knowledge Transfer workshops, producing summary and advisory publications, and establishing an exchange programme between scientists and user communities. APPRAISE will work together with UKAAN to host joint workshops and, if appropriate, will make use of the visit-programme available in UKAAN. The UKAAN website can be used to host the APPRAISE web pages. Current members of UKAAN include DIAC, many UK university groups; CEH, the Met Office, the Hadley Centre, the Environment Agency, Defra, Department of Health, several large businesses with interests in atmospheric science such as Powergen and Ford, several SMEs such as CERC, and several learned societies including the Aerosol Society, the Royal Meteorological Society and the Royal Society for Chemistry.

The network is currently funded through the NERC Knowledge Transfer funding scheme and in the first instance lasts for 2 years. It will therefore be well established at the start of the APPRAISE science programme and will provide an ideal portal for disseminating the key scientific findings from APPRAISE. The EAG recommends that APPRAISE support the extension of UKAAN, from the end of the UKAAN knowledge transfer award period (June 2007) until the end of APPRAISE (April 2010). Members of the APPRAISE EAG are also on the management team of UKAAN, ensuring a close relationship.

7. Implementation Plan

The EAG recommends:

7.1 That the three key scientific areas described in section 4 of this document be carried out via consortia grants. These targeted consortium bids will be solicited competitively from the community, with the expectation that one will be selected for each area in order to deliver the necessary interdisciplinary activities. These proposals will undergo full peer-review and be assessed by a moderating panel that includes members of the NERC Peer Review College, who have relevant expertise, and a subgroup of the EAG.

7.2 That the consortia areas are supported by a core programme of underpinning science activities, as described in section 4.3. Whilst key structural support is available through NCAS, FAAM, BADC and through links with other programmes, e.g. QUEST and SOLAS, there are a number of areas in which APPRAISE should invest to maximise its scientific delivery through the consortia. The EAG recognise that funding this core programme is essential in providing cohesion to the programme via integration across the consortia. Importantly, funding these underpinning activities will ensure a strategic vision for APPRAISE and future aerosol activities. As these underpinning activities will take the form of specific packages of work with specific questions to answer, the EAG recommends that funding is carried out via an open call for bids, prior to the AO for consortia. External peer-review will not be necessary nor beneficial as the activities are being clearly defined by the EAG. The bids will contain a description of what the applicant/research group can achieve, how they will achieve it and the credentials they have for this responsibility. It is likely that the bids will take the form of one or more postdoctoral positions in each area. A Tender Evaluation Board (which will include members of the EAG) will assess the bids and decide on which are to receive awards.

7.3 The EAG recommend that the deadlines for the consortia and core activity AOs be staggered in order that the consortia applications can clearly demonstrate their co-ordination and integration with the core activities.

7.4 The EAG has carefully targeted the APPRAISE programme towards key bottlenecks in the development of a knowledge base from which a quantified assessment of the climatic effects of aerosols and clouds, and their couplings with the biosphere can be developed. However, the EAG wishes to point out that a programme of the size and duration of APPRAISE will be unable to solve these problems in their entirety. Rather, the work outlined in the science case represents the most important areas of concern at the present time and areas in which the UK has expertise to fully contribute internationally. For information the EAG will provide NERC with an assessment of progress, uncertainty and future developments in the area at the end of 2007, prior to the next spending review.

8. Management

8.1 Co-ordination: The EAG recognise that a part-time role is required to carry out the day-to-day management, co-ordination and administration (outside Swindon Office) for this programme. The EAG recommend an approximately half-time (2days per week) manager/co-ordinator post to carry out this role, to ensure co-ordination *between* the core programme and the consortia. (A full-time co-ordinator position is not required as co-ordination within each consortia will be a pre-requisite of funding). The EAG recommends that the part-time APPRAISE coordinator be appointed, through open competition, in June/July 2006 for 4 years.

The APPRAISE co-ordinator will: ensure overall scientific integration of the programme, notably securing effective exchange of information and co-ordination of the core strategic and targeted activities; work closely with the APPRAISE Expert Advisory Group to execute the programme Science, Implementation, Data Management and Knowledge Transfer Plans; monitor progress against programme objectives; play a major role in promoting awareness of the programme's aims and achievements; seek to maximise the programme's output through forging close links with similar research programmes funded overseas, including the USA, Europe and China; ensure that all data are conserved and made available to the public at the end of the programme as outlined in NERC’s data policy guidelines.

8.2 Steer of the programme: It is envisaged that the EAG, along with the lead authors of this document, will form a steering group that provides scrutiny and steer for the programme and will meet at least annually. To provide coordination across NERC’s programmes, representatives from QUEST and SOLAS and other relevant programmes will be invited. It is anticipated that APPRAISE will hold an open annual science meeting, where all its activities are represented. The steering group will meet immediately after this meeting and annual reports of the main consortia and strategic activities will be evaluated.

8.3 Swindon Office management and administration: APPRAISE will be supported by a Programme Administrator (Science Programme Officer) based in Swindon Office. This person will work with the science co-ordinator, providing support for funding rounds, meetings and events and will ensure a link into Swindon Office and to the appropriate Science and Innovation Manager (SIM) at NERC Swindon Office. The SIM will provide an advisory role to the programme.

The success of the programme will be evaluated in line with normal NERC procedures.

Appendix 1

Membership and Terms of Reference for the Expert Advisory Group (EAG)

Membership:

- **Writing group**

Dr Hugh Coe (Reader, School of Earth, Atmospheric and Environmental Sciences, University of Manchester – specialising in properties and processes of atmospheric aerosols, aerosol-cloud interactions, atmospheric measurements, from ground, ship and aircraft platforms. He is currently chair of the FAAM Operations Committee)
Dr Ellie Highwood (Senior lecturer, Head of Aerosol Group, Meteorology Department, University of Reading – specialising in characterisation of the optical and radiative properties of aerosols; climate response to changing in tropospheric aerosols, She is the PI of the UK Atmospheric Aerosols Network, UKAAN)
Dr Louisa Watts: NERC co-ordinator and advisor

- **Advisory Group**

Note: Independent members (ie not eligible for NERC funding) are marked with an *

Dr Eric Achterberg (Reader in marine biogeochemistry, National Oceanographic Centre, Southampton)
***Professor Urs Baltensperger**, (Head of the Laboratory of Atmospheric Chemistry (LAC), Paul Scherrer Institut, Switzerland; LAC consists of the following groups: Gas phase and Aerosol Chemistry; Aerosol Physics; Ecosystem fluxes)
***Dr Olivier Boucher** (Head of Climate Chemistry and Ecosystems, Hadley Centre)
Professor Ken Carslaw (Director of Research, Institute of Atmospheric Science, University of Leeds – specialising in modelling of aerosols)
Professor Tom Choularton (Head of Atmospheric Science, University of Manchester – specialising in cloud microphysics and precipitation)
***Professor Mike DePledge** (Head of Science at the Environment Agency and member of NERC Council)
Professor David Fowler FRS CBE (Science Director of the NERC Centre for Ecology and Hydrology's Biogeochmistry research programme)
***Dr Jim Haywood** (Aerosol Research Manager, Met Office - specialising in observations, use of satellite data, and global modelling of the radiative properties of aerosols)
Professor Anthony Illingworth (Head of Radar Meteorology Group, University of Reading – specialising in weather radar and remote sensing)
Dr Eiko Nemitz (NERC Centre for Ecology and Hydrology - specialist in the measurement and modelling of surface/atmosphere exchange of gases and particles)
Dr Clive Oppenheimer (Reader in volcanology and remote sensing, Geography Department, University of Cambridge)
Professor Mike Pilling (Director of NCAS Distributed Institute for Atmospheric Composition (DIAC), Professor of Chemical dynamics, School of Chemistry, University of Leeds, Chairman of Defra Air Quality Expert Group)
Professor John Pyle FRS (Director of NCAS Atmospheric Chemistry Modelling Support Unit, Professor in Centre for Atmospheric Science, University of Cambridge – specialisong in modelling chemistry in stratosphere, troposphere, chemistry/climate interactions and chemical composition measurements)

Dr Jonathan Reid (Lecturer, School of Chemistry, University of Bristol – specialising in aerosol dynamics - laboratory based measurements)
***Dr Anne-Marie Schmoltner** (National Science Foundation (US) Programme Director of the Atmospheric Chemistry Programme)
***Dr Martin Williams** (Head of Air and Environment Quality Division, Technical Policy Branch, Defra)

Terms of Reference
The role of the EAG is to:

- Prepare a science plan for SISB outlining key themes and science areas that will be supported through a new NERC programme of research (£4M), in the area of aerosols and climate change. The science plan is based on a previously science case for a programme called AIMES (Aerosol IMpacts on the Earth System), approved by SISB in October 2004, and included in the NERC SR2004 bidding document.
- Prepare an implementation plan, stipulating the most appropriate model for implementing this programme of research.
- Once approved by SISB, the EAG (or subgroup of it) will be invited to play a future role in the steer and scrutiny of a resulting programme of research in this area.

In developing the Science Plan, the EAG will consider:
- The objectives and deliverables of the programme
- Identify those areas where NERC can maximise UK leadership and optimise synergies
- The interaction of the programme's activities with past, present and future investments in this area of science, both nationally and internationally
- The expertise and development of the NERC community with potential interest in aerosols and climate change

Appendix 2

Details for Consortia and Core Programme of the Science Plan

4.2 Key Scientific Areas for Consortia

4.2.1 The Direct Impacts of Aerosol on Climate

- **Justification**

"Brown haze" is now a global phenomenon, and arises from partially absorbing pollution aerosol found in much of the lower troposphere. Its existence has been established in a few key case studies, and its impact on radiation estimated in a few models, but we remain far from being able to model correctly the role of aerosol in climate on regional and global scales.

At the time of the Third Assessment Report of the IPCC (2001), several different types of aerosol were considered to be radiatively important: sulphate, fossil fuel combustion-derived organic and black carbon, biomass burning and mineral dust, although only sulphate aerosol was treated in substantial detail. The key parameter for determining whether an aerosol will warm or cool climate is the single scattering albedo, the ratio of scattering to absorption by particles. Both scattering and absorbing aerosol reduce the solar radiation reaching the surface, thereby tending to cause local surface cooling; however absorbing aerosol may warm the atmosphere itself, altering temperature and relative humidity profiles. Knowledge of this parameter is crucial in predicting whether increases in aerosol in the atmosphere warm or cool climate, but predictions of it must be based on changing aerosol composition. APPRAISE will therefore focus on understanding the sources, distribution, and optical and hygroscopic properties of carbonaceous aerosol, sulphate, nitrate and dust. It will focus on the basic properties of these aerosols and how they are modified when mixed together.

- **Current state of knowledge**

To date, many of the key radiative parameters of aerosols have been determined empirically, yet they depend on the basic chemical and physical properties of the aerosol. Since the impact of future changes in aerosols may not be accurately represented by current empiricisms, it is crucial that these parameters are redefined as a function of the basic physical and chemical properties of the aerosol itself, and that these calculations are tested against state-of-the art measurements of aerosol optical properties.

Sulphate aerosols have been treated with more complexity than most other types, yet at present the formation and distribution of even this aerosol type cannot be modelled with any certainty. Organic material is often mixed with sulphate and may alter its optical properties significantly, yet the source, chemistry and effects of the organic fraction, and the role of anthropogenic and biogenic organic aerosol have so far not been either quantified or identified. Additionally, nitrates are forecast to become a major contributor to the direct effect, especially in Europe where sulphur emissions have already declined substantially. Yet nitrates are often only poorly, if at all, represented in current climate models and they are not included in the current Hadley Centre GCM. Clearly, the reflectance of the surface or clouds underlying the aerosol will significantly alter the role the aerosol plays. These vertical spatial heterogeneities have begun to be considered, though at present their effects have only been determined in a few specific case studies.

Large cities are significant sources of pollution aerosol and their precursor gases. Emissions legislation is driven by urban air quality and health impacts, but changes in such emissions are likely to change regional climate as a result of changes in the characteristics of the aerosol formed downwind. At the present time, research on air quality and climate impacts is decoupled and work is required to assess the linkage between them. This area is particularly important for future policy development.

APPRAISE' objectives:

- To quantify better the key parameters controlling the evolution of the single scattering albedo and radiative effect of key aerosol types
- To assess the relative contributions of primary and secondary aerosol to the global aerosol budget and their effects on the radiative budget.
- To assess the regional variabilities in aerosol and their effects
- To provide an initial framework for assessing the climatic impacts of air quality regulation of particulate material.

To achieve these objectives APPRAISE will conduct detailed field and laboratory work on some aerosol types but will also use recent results from concurrent field experiments (such as dust and biomass in DABEX, AMMA, SOLAS) and from recent developments in satellite retrievals. These measurements will be used to test detailed process models, in order to develop simplified treatments and parameterisations of the key behaviour. This information will, through a hierarchy of models, be used to predict global and regional impacts.

APPRAISE will collaborate with CGAM, QUEST and the EU programme QUANTIFY, to establish the anthropogenic, biogenic and volcanogenic contributions of several aerosol types and assess the climate sensitivities of each. Enhancing the development of models being carried out within the UKCA project, APPRAISE will focus on the regional variability of the impacts of aerosols. Large sources such as major cities, biomass burning or volcanic eruptions, may be particularly important.

4.2.2. Aerosol Cloud interactions and Climate

SOLAS International has a major focus on marine production of aerosol and its role as CCN. A more uncertain and less well studied area of aerosol-cloud interaction concerns mixed phase clouds and APPRAISE will target resources in this area.

- **Justification**

Many chemical and microphysical properties/processes of aerosol that affect clouds, such as the organic content, ice nuclei (IN) and absorbing aerosol component are not well understood, nor does modelling capability exist to predict such quantities. The critical role of clouds in climate change makes this a crucial topic. In addition, it is important to know whether absorbing aerosol is present within, above or below clouds.

- **Current state of knowledge**

Changes in the microphysical properties of the aerosol and their number entering clouds, induce a change in the optical properties and lifetime of the cloud, which then impacts on radiation. To determine the cloud droplet number in liquid cloud it is important to know the effectiveness of the aerosol population in forming cloud droplets (cloud condensation nuclei, CCN). This property is dependent on the size, number, chemical composition, and mixing state of the particles and their geographical distribution. Much progress has been made over the last twenty years in understanding the role of inorganic particulate as CCN, however, the role of the organic fraction, often mixed in with the same particles as the inorganic material, remains largely unquantified.

To date, progress in incorporating the climatic effects of clouds has been limited to those effects that directly affect the reflectance of the cloud through increase in cloud droplet number. However, there are several other parameters that change such as cloud lifetime, precipitation and cloud height that cannot be treated as straightforward effects without considering detailed feedbacks. At present such effects have not been directly quantified in the atmosphere, and are poorly predicted by global models. Mid and upper level clouds are often composed of ice crystals and aerosol can have a significant role in determining their properties as they act as nuclei for ice formation. At present, the number, composition and spatial distribution of ice nuclei are unknown and their control of cloud particle numbers and cloud dynamics uncertain. Whilst progress (for example by the NERC CWVC programme) has been made on the radiative impacts of warm clouds and also those of upper level ice clouds such as cirrus, mixed phase clouds remain very poorly understood.

APPRAISE' objectives:

- To assess the relative importance of the key processes by which aerosol control cloud microphysics in mixed phase clouds
- To determine the properties and role of ice nuclei and their interaction with mixed phase clouds
- To assess the role of absorbing material above, below and within clouds

To improve our understanding of changes in cloud microphysics, cloud cover and precipitation, APPRAISE will focus on the quantitative understanding of IN and the role of organics and absorbing aerosol. The role of the latter, in particular, needs to be much more fully understood than at present.

Previous work has focused on liquid phase clouds only, and ice clouds have been studied in the tropics recently during EMERALD, SCOUT and ACTIVE. APPRAISE will therefore focus on mixed phase clouds. Process-scale models must be developed to link between measurements and larger scale models. At present this remains something of a bottleneck. New satellites, such as CALIPSO and CLOUDSAT on the "A Train" include LIDAR and RADAR that are capable of probing clouds with unprecedented detail. APPRAISE will maximise this opportunity and play a significant role in interfacing these tools with in situ measurement and model development.

4.2.3. Aerosol Coupling in the Earth System

- **Justification**

Changes in past and future land use and the natural biosphere will significantly impact the physical and chemical characteristics of aerosols and their atmospheric burden, and hence will feedback on climate. Conversely, climate change will alter the biosphere, which may not be able to acclimatise rapidly and so will further change the aerosol load. Changes in precipitation patterns, surface insolation and wind patterns resulting from climate change will, for example, affect the uptake of mineral dust into the atmosphere in arid areas. Changes in cloud processes and patterns due to any climate change mechanism will affect the aerosol burden on regional and global scales and, conversely, aerosol changes may affect precipitation patterns. Changes in climate may influence the incidence of biomass burning. Such feedbacks are presently ill-defined and poorly understood. Integrating atmospheric, biospheric, hydrological and earth science expertise is needed to improve knowledge of these complex processes.

A clear area that is likely to be significant is the dependence of emissions of biogenic organic compounds on future temperature changes. Such compounds have been shown to be precursors to aerosol formation (eg NERC TORCH consortium), and changes in their emissions through, for example, raised temperatures, may affect the aerosol flux exponentially.

- **Current state of knowledge**

An increasing number of studies suggest that biogenic organic aerosol (BOA) dominates the organic carbon concentration in remote environments. It is well established that biogenic precursor gases (Biogenic Volatile Organic Compounds – BVOC) contribute to the formation of biogenic organic aerosol, while the yields have been poorly quantified. While most work to date has focussed on monoterpene chemistry, sesquiterpenes have been harder to measure in the natural environment (due to their short lifetime) and the aerosol yield from isoprene remains an area of active research. Only very few field studies at a very limited number of ecosystems have attempted to produce budgets of the role of BVOCs for aerosol production. 'Blue haze' has been reported in the literature well before the industrial revolution, but little is currently known about the natural state of the biogenic aerosol loading, making it difficult to estimate the anthropogenic impact. BVOC emissions (and to a lesser degree aerosol yields) are sensitive to changes in temperature, solar radiation, precipitation patterns and land cover.

There have been considerable changes in land use since 1850 which are likely to continue in the future, significantly impacting the atmospheric aerosol burden and its physical and chemical characteristics and hence providing a feedback on climate. BOA production in large forested regions, in particular, is thought to affect precipitation, creating a link between the biological and hydrological cycling through the effects of aerosol and cloud. Changes in patterns of nutrient transport (e.g. dust) will induce further vegetation responses. In addition, deposition rates of aerosol to vegetation are known to change with surface roughness, particle size and meteorological parameters, so that changes in climate and land cover may alter their atmospheric residence time. An improved process understanding of vegetation responses, BVOC emissions, BOA formation and its coupling to the climate system and hydrological cycle is needed to quantify and predict past, present and future feedbacks.

The impact of climate change on vegetation response, has been simulated by the Hadley Centre, and this may impact on aerosol production or loss. There is considerable CGAM activity in this area and APPRAISE will ensure that this is effectively coupled into the consortium. QUEST has made significant investments in large scale modelling of biosphere-atmosphere interaction and the incorporation of surface fluxes of biogenic aerosol and dust into the UKCA. However, these parameterisations are built on pre-existing knowledge, which, for the most part, falls short of being adequate and is based on very sparse data sets. APPRAISE will therefore focus on process-level, measurement-driven science and modelling, to build a sound basic understanding of surface exchange processes. The outcome will be improved parameterisations that can be included in global models of the Earth System and used to probe better the climate responses through global simulations. A suitable link to the UKCA or another existing global modelling activity will be identified by the APPRAISE consortia to ensure that the improved process-level understanding can be scaled-up without duplicating efforts made elsewhere.

APPRAISE' objectives:

- To provide quantitative descriptions of key biogenic surface flux processes between aerosol and their precursor gases.
- To quantify biogenic volatile organic compound chemistry and aerosol formation in and above vegetation canopies through integrated field studies
- To assess the impact of such processes on regional aerosol burden and precipitation.
- To assess the impact of land use changes on aerosol emission and deposition and develop predictive capability

QUEST and SOLAS programmes have already invested significantly in the areas of surface ocean–atmosphere, dust–ocean flux coupling and global parameterisation. However, at present our knowledge of the underlying detailed processes is very poor. Hence, APPRAISE will focus on such key interactions at the land-atmosphere interface. Recent studies such as TORCH and CEH activities (described above, in **Current state of knowledge**) provide clear composition and flux methodologies that APPRAISE may wish to extend. Such feedbacks are presently ill-defined and poorly understood. APPRAISE will develop capability to probe such feedback mechanisms and link process-understanding from detailed measurements, with model simulations of such behaviour. The links with QUEST will ensure that such detailed understanding is fed through into the Earth System modelling community. It is not proposed that a rival global modelling activity is conducted in this area. In addition, biosphere-aerosol-cloud interactions form one of the central themes of the Integrated Land Ecosystem – Atmosphere Processes Study (iLEAPS) of IGBP, which, unlike SOLAS, has currently no direct UK contribution. Such activities within APPRAISE, which are an area of strength for the UK, will provide an ideal synergy between NERC's output and the international community.

4.3 Key Underpinning Science Areas – The Core Programme

4.3.1 Formation Pathways and Properties of Organic Aerosols

Organic material often contributes the largest fraction to the mass of submicron aerosol, impacting the aerosol optical properties, and may play a critical but as yet ill-defined role in cloud activation. At present the processes dictating the formation of secondary organic aerosol, including photo-oxidation of gas phase precursors, are very poorly known and regional and global models grossly under estimate the amount of organic aerosol in the atmosphere by up to a factor of 10. Clearly this means the science community is not in a position to develop predictive modelling capability without a much better basic understanding of the processes. Once inside the particle, organic material affects the water affinity and cloud activation, yet a sound thermodynamic framework on which to base predictions of these properties is at present missing due to the lack of laboratory data on solution densities, surface tensions and chemical activities.

At present DIAC supports the development of detailed thermodynamic and sectional aerosol models that can utilise this information. DIAC also conducts gas phase and particle phase measurements of speciated organic material and aerosol composition and studies their properties in chambers and in the field. This area feeds into an activity in QUEST to develop a parameterisation for secondary organic aerosol in global models. This APPRAISE activity will provide be able to test the above activities on secondary organic aerosol formation and its properties in mixed component aerosol. APPRAISE will support the development of a model framework for prediction of secondary organic aerosol formation from the gas phase that can test chamber and field measurements. APPRAISE will seek to support a programme of basic laboratory data on mixed component aerosol properties and couple this with a development of model tools to predict aerosol properties such as activity and vapour pressures based on chemical structure or molecular dynamics. The UK has the internationally leading expertise in these areas and when combined with the available skills in DIAC, will form a world leading activity that will deliver a much improved description of secondary organic aerosol formation and its effect on aerosol behaviour in the atmosphere. It is anticipated that this activity will work closely with the current DIAC work in this area.

The main deliverables of this activity will be:

- An improved description of secondary organic aerosol production
- A framework for assessing its role in the behaviour of mixed component aerosol.

4.3.2 Improved Representation and Validation of the Radiative Properties and Impacts of Aerosols and Clouds

The direct impact of aerosols on climate is governed by their scattering and absorption of radiation. This APPRAISE activity should focus on the development of basic tools and methodologies for addressing radiative transfer in a range of applications to aerosols and climate, and the validation of those tools in terms of global and regional observations. A cohesive and process-based methodology is required for determining aerosol radiative properties using composition information newly available from the UK observational community, and incorporating new quantitative information from remote sensing instrumentation. A Community radiative transfer code dealing with aerosols (and clouds), which is capable of dealing with issues such as asphericity of aerosols (particularly mineral dust and ice crystals), growth of aerosols with relative humidity, internal inhomogeneous mixing of aerosol components and cloud droplets, will be developed. It is also necessary to develop simplified versions of this sophisticated model which can be reliably incorporated into global climate models in an inclusive but efficient way and this APPRAISE activity will coordinate and advise users appropriately. These tools will be of key importance to all 3 proposed areas of activity within APPRAISE and have much wider uptake throughout the UK community beyond the lifetime of APPRAISE.

This activity should also ensure the availability of input parameters to the code, for example the refractive indices of aerosol types as measured in the laboratory, and the outputs constrained by laboratory measurements and regional and global observations of aerosol properties. To achieve the latter, retrievals of aerosol optical depth, aerosol size distributions, and scattering and absorption properties are available from satellite remote sensing methods. Additionally, the AERONET sun-photometer network supplies high quality data on the aerosol optical depth, the aerosol size distribution and the refractive indices of the aerosol. A CIMELS sun-photometer coupled to the AERONET network will be installed at the Cardington site, which is geographically a few miles from the location of the FAAM aircraft at Cranfield. Therefore aerosol data are available routinely from the aircraft for cross validation of the aerosol size distribution, aerosol scattering and absorption etc. This activity will work closely with UFAM and DIAC aerosol scientists to ensure FAAM data are delivered for this task in an appropriate way. Additionally, the compilation of a database of global aerosol products derived from current and future satellite instrumentation (e.g. MODIS, MISR, AATSR, SEVIRI, GERB, CALIPSO) will be coordinated from 2000 onwards. Data relevant to specific measurement campaigns (e.g. AMMA, DODO etc) in specific areas will be coordinated and developed. These will provide essential data for validating the aerosol global models and for cross calibration with aircraft measurements.

The main deliverables of this activity will be:

- A community radiative transfer model that can be both simplified or made more complex and so be incorporated into a wide range of aerosol models, and an assessment of the quality of the required inputs.
- Provision of aerosol optical depth, size distribution and refractive index from such as is available from the AERONET sun-photometer installed at the Cardington site.
- A database of aerosol products including aerosol optical depth, aerosol Angstrom coefficients, aerosol size distributions, and single scattering albedo, and similar products for specific FAAM aircraft operations/dedicated aerosol measurement campaigns.

4.3.3 Development of a Global Model to Investigate Key Aerosol and Cloud Processes

Clearly a global aerosol model is a critical tool for testing much of the process-level understanding that will be gained through APPRAISE. It provides an environment for developing simplified schemes that reflect these key mechanisms and for testing them before they are incorporated into global and regional climate models. UKCA (an NCAS/Met Office initiative) is a major vehicle for incorporation of much of this work, and will be useable over the lifetime of APPRAISE. At present, much of the NCAS UKCA model development has been focused on the implementation of a working global model and the inclusion of parameterisations of aerosols within it. Such activities are supported by NCAS and QUEST. What has not been developed, however, is an activity that will work closely with the process-modelling development being carried out within NERC DIAC and elsewhere, to understand the key parameters and processes required in large scale, complex models and test them thoroughly. This activity is vital to APPRAISE. It provides the key rung in the hierarchy of aerosol models that exist to progress from process-understanding to predictive capability.

This activity must be carried out closely with the development of the aerosol component of the UKCA and with DIAC aerosol models. The activity should coordinate and develop the ability to integrate aerosol models of varying complexity and is therefore central to the hierarchical model development envisaged by APPRAISE. The activity should allow aerosol transport models to be used offline from the climate models so that the aerosol schemes can be tested more thoroughly. The incorporation of tested schemes into the Hadley Centre GCM, however, will be resourced elsewhere, for example through NCAS.

This aerosol-transport modelling activity will work closely with all of the major components of APPRAISE in the design and planning of experiments and so improve the representation of measurement-based aerosol processes in the model.

The activity will be responsible for ensuring that the hierarchical development of aerosol models in APPRAISE is carried out in a strategic way. This will include a workshop to identify strategic needs and the development of a staged plan for tackling the key problems for APPRAISE. The activity will work in a complementary way with other modelling activities, for example those in QUEST and NCAS.

The main deliverables of this activity will be:

- A global aerosol transport model that is capable of (i) carrying the main aerosol types, (ii) deal with complex mixing states and (iii) act as a key stage in the hierarchical testing of aerosol processes in APPRAISE
- Coordination of the development of the hierarchical model development, interfacing with other modelling effort in the UK.

4.3.4 Improved Coupling of In Situ Cloud Measurements with Novel Model Schemes

Cloud Resolving Models (CRMs) are key tools for linking detailed measurements of cloud microphysical, radiative and dynamical properties, at the cloud-scale and larger. CRMs are the primary framework for testing model representations of aerosol-cloud interaction and developing parameterisations for inclusion in larger scale models. This task will focus on improving the aerosol and cloud physics in CRMs and on comparing simulation of these with observational data so to challenge and verify the model representation. The work will consider and contrast different levels of sophistication in the representation of aerosol and cloud physics. The primary output to APPRAISE will be improvements in aerosol-cloud interaction within such schemes. A wide range of cloud types should be addressed that include both stratiform and convective clouds and the task will treat warm clouds and their aerosol interactions, cold clouds and the role of ice and mixed phase clouds. The task will act as a key interface between aerosol and cloud measurement using NCAS facilities such as the UK FAAM aircraft and laboratory process studies, and larger scale models that may be used regionally and globally to investigate the climatic impact of clouds.

The main deliverables of this activity will be:

- Improved treatment of cloud / aerosol interactions in cloud resolving models including explicit aerosol and cloud microphysics that is based on an improved knowledge of the interaction of clouds and aerosol especially mixed phase clouds.

Appendix 3

Details of Logistical Support and Integration

5.1 *The FAAM Aircraft:* It is anticipated that this will be a core element to the programme. As with blue skies applications to NERC, it is anticipated that costs such as those associated with detachment, operations away from home, T&S costs etc should be met by the consortia budget. NCAS UFAM will provide key instrumentation and instrument scientist support to the programme as required by the consortia or strategic activities. Collaboration with Met Office should be developed through the consortia to ensure access to their expertise and some of the critical aircraft instrumentation likely to be necessary for APPRAISE.

5.2 *Ground Sites:* Access to ground sites for in-situ and remote sensing purposes is likely to form part of some consortia bids. Access to all existing sites, university run, Chilbolton and Met Office sites such as Cardington should be considered.

5.3 *The Chilbolton RADAR facility:* This may well be a key part of the cloud element of the programme as it provides observations of the vertical properties of clouds, aerosols and ground radiative fluxes on a 24h/365 days basis. Again it is envisaged that costs for use within consortia are met from within the consortia budgets.

5.4 *Satellite Data*: Whilst it is expected that much use will be made of satellite data products and this is very much encouraged by the APPRAISE EAG, it is not anticipated that APPRAISE will resource a major satellite development programme, it is expected that this will come through a close liaison with EOS, utilising experience within the university community, and within DARC, ESSC and CEH, and exploiting the new height resolved aerosol observations from CALIPSO and CLOUDSAT. New measurements from the NERC-funded GERB experiment, and the SEVIRI imager, on the Meteosat Second Generation satellite series may also be exploited.

5.5 *Key laboratory facilities:* These include the RAL facility and several universities have the capability for conducting experiments on single particles or ensembles. Collaborative use of international facilities with capability not presently available in the UK, is also encouraged (e.g. AIDA and EUPHORE). APPRAISE offers NERC an opportunity for combining these facilities and maximising their potential through participation in appropriate international collaborative experiments.

5.6 *Modelling and Computer Support:* The UK has a large range of models, covering all scales of process. These include: detailed single particle thermodynamic models for studying key interactions and developing basic understanding; partitioning models to probe the chemical sources of organic precursors; parcel models for studying detailed time varying development of aerosols and clouds; large eddy simulations to investigate interactions between aerosols and clouds and links to dynamics; regional and global scale transport models to investigate the impact of sources and distributions on the aerosol and cloud budget; column, regional and global scale radiation models to investigate impacts and radiation budgets; coupled biosphere, atmosphere models to investigate feedbacks. Whilst these models are available in the UK they are in varying states of development. APPRAISE will endeavour to provide linkages between these models and ensure that process-understanding, tested through laboratory and field measurement, is fed through to larger scale, complex, coupled models. The global modelling core activity, in conjunction with the DIAC aerosol modelling activity, will act to coordinate this area.

It is anticipated that as the HPC requirements of consortia are best realised by the consortia themselves, these should be met through consortia budget.

5.7 *Data Management*: APPRAISE will make use of BADC facilities for data provision and storage. A particular demand is likely to be the rapid provision aircraft data.

Appendix 4

Provisional Implementation Plan for the NERC APPRAISE Programme

Date		Task
July	2005	Core writing team meet; invite members of expert advisory group (EAG)
August	2005	EAG appraise and comment on draft SISB paper
September	2005	EAG produces information paper for SISB outlining key themes and scientific areas to be supported, and associated spend on logistics.
September	2005	SISB approve paper and project formally begins

February	2006	Announcements of Opportunity (AOs) issued for APPRAISE underpinning tasks, consortia and Science Co-ordinator post (note all have different closing dates)
21 April	2006	Closing date for Bids for underpinning activities
May	2006	Successful bids for underpinning tasks identified by moderating panel (EAG or subgroup of it)
June	2006	Results of review of bids for underpinning tasks published via website
June/July	2006	Earliest anticipated start date of underpinning tasks (however, panel may recommend later starts where appropriate)
June/July	2006	Anticipated start date for APPRAISE co-ordinator
22 August	2006	Closing date for APPRAISE consortia bids for full peer review
December	2006	APPRAISE funding meeting for consortia (moderating panel)

January	2007	Funding decisions issued for consortia
March	2007	Anticipated start date of consortia funding
April September	2007 - 2008	Anticipated that FAAM aircraft available for UK based flying with an aerosol, cloud and radiation instrument fit for joint missions with the UK Met Office
October September	2007 – 2008	Anticipated main field deployments and aircraft use period
December	2007	Provisional date for Science meeting and steering group meetings

February	2008	Progress and future development assessment provided to NERC by the EAG.
Summer	2008	Provisional date for Science meeting and steering group meetings

July	2009	Anticipated end of underpinning activities

February	2010	Anticipated completion of Data Conservation for core programme
March	2010	Anticipated end of APPRAISE consortia funding
February	2010	Provisional date for final Science meeting and steering group meetings
June/July	2010	Anticipated end of APPRAISE co-ordinator appointment

Appendix 5

Glossary of Acronymns

ACCENT - Atmospheric Composition Change The European Network of Excellence (EU)
ACTIVE - Aerosol and chemical transport in tropical convection (NERC funded consortium grant)
AIDA - Aerosol Interactions and Dynamics in the Atmosphere (EU)
APPRAISE – Aerosol Properties, PRocesses And InfluenceS on the Earth's climate
AMMA - African Monsoon Multidisciplinary Analysis (NERC consortium, also International and EU programmes)
CEH - Centre for Ecology and Hydrology (NERC Research Centre)
CERC - Cambridge Environmental Research Consultants
CGAM - Centre for Global Atmospheric Modelling (part of the NERC Centres for Atmospheric Science – NCAS)
CWVC – Clouds Water Vapour Climate directed programme
DABEX - Dust and Biomass Experiment (Met Office, NERC funded)
DARC – Data Assimilation Research Centre (NERC centre)
EMERALD - Egrett microphysics experiment with radiation, lidar and dynamics (NERC, part of Clouds Water Vapour Climate directed programme)
ESSC - Environmental Systems Science Centre (NERC centre)
ESF - European Science Foundation (EU)
EUPHORE - European Photoreactor
FAAM - Facility for Airborne Atmospheric Measurements (part of NCAS)
GCM - General Circulation Model
IGBP - International Geosphere-Biosphere Programme
ILEAPS - Integrated Land Ecosystem Processes Study (international/US)
IPCC - Intergovernmental Panel on Climate Change
NCAS - NERC Centres for Atmospheric Science
NERC -Natural Environment Research Council
NSF – National Science Foundation, US
QUANTIFY -Quantifying the Climate Impact of Global and European Transport Systems (EU)
QUEST -Quantifying and Understanding the Earth System (NERC directed programme)
SCOUT - Stratosphere-Climate links with Emphasis on the UTLS (EU FP6)
SISB - Science and Innovation Strategy Board (NERC)
SOLAS - Surface-Ocean/Lower Atmosphere Study (International programme, NERC directed programme)
TORCH - Tropospheric Organic Chemistry Experiment (NERC Polluted Troposphere directed programme)
UFAM - The Universities Facilities for Atmospheric Measurements (part of NCAS)
UKAAN - UK Atmospheric Aerosols Network (NERC Knowledge Transfer initiative)
UKCA - UK Chemistry and Aerosol Community Model (NCAS and Met Office)