Finnish Centre of Excellence in Physics, Chemistry, Biology and Meteorology of Atmospheric Composition and Climate Change

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1 Research plans 2008-2013

Research and operating plans 2008-2013

1. ■ Describe the research programme, priority areas, main approaches and hypotheses of the proposed Centre of Excellence (CoE) including research plans of the individual research teams during 2008-2013. The plans for the first three-year period (2008-2010) should be described as much in detail as possible.

Background

Atmospheric aerosol particles and trace gases affect the quality of our life in many different ways. In polluted urban environments, they influence human health and deteriorate visibility (e.g. Stieb *et al.*, 2002). In regional and global scales, aerosol particles and trace gases have a potential to change climate patterns and hydrological cycle (Lohmann and Feichter, 2005; IPCC, 2006, work in progress). Aerosol particles also influence the radiation intensity distribution that reaches the earth surface having a direct influence on the terrestrial carbon sink (Gu et al. 2003). Better understanding of the various effects in the atmosphere requires detailed information on how different sources (including those of biosphere) and transformation processes modify properties of aerosol particles and trace gases. Trace gases and atmospheric aerosols are tightly connected with each other via physical, chemical, meteorological and biological processes occurring in the atmosphere and at the atmosphere-biosphere interface. An important phenomenon as an example is atmospheric aerosol formation, which involves the production of nanometer-size particles by nucleation and their growth to detectable sizes (Kulmala, 2003). Human actions, such as emission policy, forest management and land use change and various natural feedback mechanisms involving the biosphere and atmosphere have an impact on the coupling between the aerosols and trace gases.

In 2001, the Intergovernmental Panel on Climate Change (IPCC) estimated the global and annual radiative forcing due to greenhouse gases and aerosols, along with natural changes associated with solar radiation. Emphasis was placed on the complexity of the combined direct and indirect forcing from both aerosols and gases as well as on the importance of improving our understanding of the role that each of these three individual components plays in radiative forcing in an integrated system. Such knowledge would reduce the uncertainty in current estimates of radiative forcing and enable a better prediction of the effects of anthropogenic activity on global change. The most important issue to resolve is how the different components affecting radiative forcing interact with one another. We have recently proposed a mechanism that couples the effect of CO_2 and aerosol particles on climate. This suggestion is based on connections between photosynthesis, emissions of non-methane biogenic volatile organic compounds (BVOCs), and their ability to form aerosol particles.

Figure 1 shows the mechanisms and novel coupling among processes in forest ecosystems (photosynthesis and BVOC emissions), aerosols, and climate, proposed by the present Finnish CoE (Kulmala et al., 2004b). Photosynthesis (GPP) drives plant gross primary production (GPP), the difference between net ecosystem exchange of CO_2 (NEE) and total ecosystem respiration (TER). In the boreal zone, photosynthesis occurs predominantly in sunlight during the growing season (Hari and Mäkelä, 2003) and is inhibited in winter. Forest ecosystems are usually sinks of CO_2, and a direct negative feedback (the higher the CO_2 concentration, the higher the rate of photosynthesis) exists between increasing atmospheric CO_2 concentrations and photosynthesis and positive feedback between ecosystem respiration and temperature. With higher temperatures water becomes more important factor influencing both GPP and TER. On the other hand, forest ecosystems also act as significant sources of atmospheric aerosols. Terrestrial vegetation contributes substantially to emissions of a variety of BVOCs (Fuentes et al., 2000), possibly as side products of photosynthesis (purpose of VOC emissions is still unclear and may vary between plant species), and newly formed particles in forested areas have been found to contain large amounts of organic material (O'Dowd et al., 2002a; Tunved et al., 2006). The ratio of BVOC emission to carbon assimilation is generally a few percent (Grace and Rayment, 2000), and if increased CO_2 concentrations enhance photosynthesis, formation and emissions of several BVOCs may increase and possibly modify the aerosol particle formation routes.

The mechanism described above linking photosynthesis and aerosol forcing in the novel way is only one among other connections and feedbacks. The climatic and other effects of aerosols and trace gases are coupled together via both human actions, such as emission policy and land use change, and via various natural feedback mechanisms involving the biosphere and atmosphere. As examples, reduced aerosol loads due to actions aiming to improve air quality already seem to have affected climate in certain regions of the world (Brasseur and Roeckner, 2005). A forestation enhances carbon sinks but at the same it decreases the surface albedo, which tends to compensate for the effect of carbon sink feedback (Gibbard et al., 2005). It is also very probable that some new feedbacks or new pathways for components of biogeochemical cycling (like Keppler et al., 2006) may appear in the future. One socio-economic challenge to our CoE is to react quickly to new needs and findings by assimilating the new knowledge in own research quickly and testing and validating its significance from the point of view of its own aims and objectives.

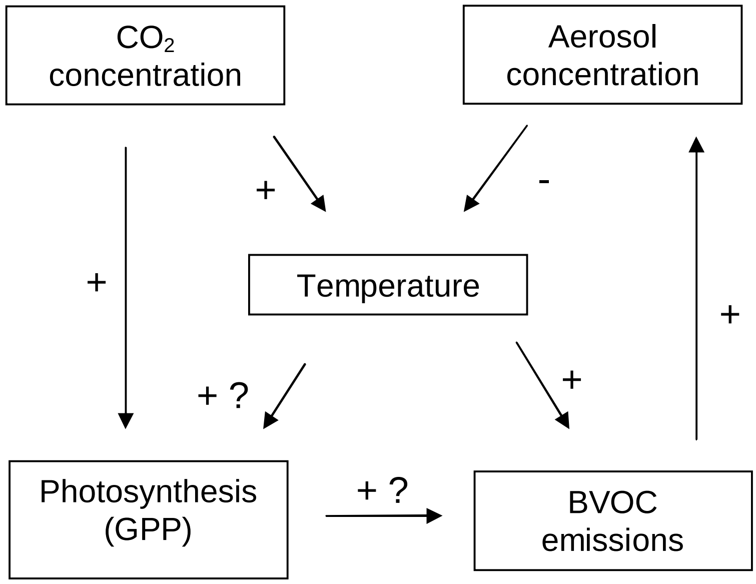

Figure 1. *Schematic figure of coupling of atmospheric CO_2 concentration, assimilation of carbon by photosynthesis (ecosystem gross primary production GPP), emission of biogenic volatile organic compounds (BVOCs), and aerosol particle concentration with atmospheric temperature (Kulmala et al., 2004b). Increased CO_2 concentration will increase temperature (+) and photosynthesis (+). Increased temperature will enhance BVOC emissions (+) and probably also photosynthesis (+?). Increased photosynthesis may enhance BVOC emissions (+?). Increased BVOC emissions will enhance aerosol formation and growth and therefore also enhance CCN concentrations (+). Enhanced aerosol and CCN concentrations will decrease temperature (-) due to increased reflection of sunlight from low clouds back to space (note that they also increase diffuse radiation, which has a positive influence on photosynthesis (Gu et al., 2003)).*

The Academy of Finland has appointed the Centre of Excellence (CoE) "Physics, chemistry and biology of atmospheric composition and climate change" (by Kulmala, Hari, Laaksonen, Vesala and Viisanen) for 2002-2007 and its main objective has been to study the importance of aerosol particles on climate change. The key issue has been to explain the biogenic formation routes and mechanisms of new particles and this physico-chemical problem is very closely linked to underlying ecosystem processes. The key issue has also been extensively studied within the Nordic CoE BACCI (Research Unit on Biosphere – Aerosol – Cloud – Climate Interactions; Kulmala, Laaksonen, Riekkola, Viisanen, Hari) and the underlying ecosystem processes within the Nordic CoE NECC (Vesala, Nikinmaa, Viisanen). These two closely operating CoEs form a common Nordic graduate school CBACCI (Carbon - Biosphere – Aerosol – Cloud – Climate Interactions). We are also part of one European Network of excellence (ACCENT; Kulmala, Laaksonen, Viisanen). The common work in these as well as in earlier projects has fine-tuned the co-operative, management and administrative practices of the research groups, sharing also the common research and education objectives.

The main focus of our existing research unit has been in the following topics (for all topics we have published several papers either in Nature or Science): 1) formation and growth mechanisms of atmospheric aerosols, aerosol dynamics: (Kulmala et al., *Nature*, 2000; Kulmala, *Science*, 2003; Berndt et al., *Science*, 2005; Tunved et al., *Science*, 2006) 2) the effect of secondary biogenic aerosols on global aerosol load: (O'Dowd et al., *Nature*, 2002a; O'Dowd et al., *Nature*, 2002b; O'Dowd et al., *Nature*, 2005) 3) aerosol-cloud-climate interaction: (Kulmala et al., *Nature*, 1997; Charlson et al., *Science*, 2001) 4) the relationships between the atmosphere and different ecosystems, particularly boreal forest:

(Valentini et al., *Nature*, 2000; Hari et al., *Nature*, 2003; Ciais et al., *Nature*, 2005). The scientists working in the new CoE have published over 450 scientific papers in peer reviewed journals during the last five years.

One of the most significant recent results obtained is the observation that the formation of new particles and their subsequent growth seem to be ubiquitous (Kulmala et al. 2004a). Such observations have been made in very different lower-tropospheric environments, including Antractica and surrounding oceans (Koponen et al., 2003), boreal forests in Northern Europe (Mäkelä et al., 1997; Held et al., 2004; Vehkamäki et al., 2004; Dal Maso et al., 2005), other remote and rural continental areas (Weber et al., 1997; Birmili et al., 2003), coastal environments around Europe and United States (O'Dowd et al., 1999, 2002b; Wen et al., 2006), various urban centers (Shi, 2003; Jeong et al., 2004; Stanier et al., 2004; Stolzenburg et al, 2005), and even heavily-polluted regions and megacities (Dunn et al., 2004; Wehner et al., 2004; Mönkkönen et al., 2005; Laaksonen et al., 2005). Aerosol formation has also been observed in the free troposhere, being a frequent phenomenon in the upper troposphere and in cloud-outflow regions (Twohy et al., 2002; Singh et al., 2002).

The points highlighted above has led us to a fruitful situation that, while biogenic aerosol formation mechanisms are known for the most part because of the research carried out during recent years, there is an urge for applying them in the global scale in the future. This calls for understanding and ability to observe how the biogenic formation mechanisms are linked to underlying ecosystem processes. At the same time the new centre will make an integrated attempt to understand various, but interlinked, biosphere-atmosphere interactions applying inter- and multidisciplinary approaches in a coherent manner. This has been a supporting theme also in the past; however, the emergence of new measurement techniques for detection of neutral and ion clusters and multitude of organic compounds together with chemical analysis methods of nm-scale particles, and the joint usage of these techniques are essential differences between our earlier and future studies. Beside this, we have collected long data series on biosphere-atmosphere interactions especially for carbon dioxide, methane and water vapour over different ecosystems. We are in the stage that the amount and representativeness of data can be used for developing improved parameterizations for large-scale models.

Our research unit has an internationally leading position in the research area of formation of atmospheric aerosols. We run a number of extremely versatile field monitoring stations (SMEAR I-III, Pallas GAW and fluxsites, Puijo site) that simultaneously follow aerosol particle formation, trace gas fluxes and the underlying atmospheric and ecosystem processes. Our research unit organises international conferences, workshops and seminars on our scientific areas of interest. The working links with other units and teams are an essential part of the implementation of the research program in the form of the research visits, common field campaigns and training of the students. We have direct working connections to more than 60 international laboratories. We have participated in more than 35 International projects (5 as coordinator), and we are hosting international iLEAPS (Integrated Land Ecosystem-Atmosphere Processes Study) project office, and we are closely connected to IPCC and IGAC programmes. We are participating e.g. in global Fluxnet (flux tower network) and GAW (Global Atmospheric Watch) programs and international field campaigns to investigate atmospheric aerosols and tropospheric chemistry. We are also co-operating with several companies like Vaisala, Nokia and Dekati Ltds. Our research also belongs to host organisations' main strategic areas.

Objectives

Our main objective is to contribute to the reduction of scientific uncertainties concerning global climate change issues, particularly those related to aerosols and clouds. We aim at creating a deep understanding on the dynamics of aerosol particles and ion and neutral clusters in the lower atmosphere, with the emphasis of biogenic formation mechanisms and their linkage to biosphere-atmosphere interaction processes, biogeochemical cycles and trace gases. The relevance and usage of the results in the context of global scale modelling, and the development and utilisation of the newest measurement techniques are addressed. The cores of activities are a) in continuous measurements and database of atmospheric and ecological mass fluxes and aerosol precursors and CO_2/aerosol/trace gas interactions in SMEAR field stations and GAW station and b) in focused experiments and modelling to understand the observed patterns.

Research methods

In order to be able to meet our objectives, and to answer our research questions we need to perform inter-, multi and cross-disciplinary research with a high level of technological and scientific innovation. The system involving atmospheric circulation, composition and impacts is tremendously complex. It requires a diverse range of scientific and technological expertise in the areas of chemistry, physics, biology, and meteorology, and involves laboratory studies, ground, ship, and airborne field studies, satellite remote-sensing and numerical modelling studies ranging from the molecular *ab initio* level to the global scale Earth system models. Individual efforts to address climate change and impacts of pollutants are clearly advancing, but in a disjointed manner, which inhibits the efficient exchange of knowledge between different communities. In addition, databases from disconnected field experiments are difficult to merge so as to tackle issues related to both atmospheric composition and climatic impacts. Our CoE will form the core of European Union Integrated project EUCAARI (2006-2010, coordinator M. Kulmala), which will integrate these diverse communities on the pan-European scale and, to a lesser extent, on the global scale by involving leading US scientists as members of the advisory board and Partners from four developing countries. EUCAARI therefore creates the critical mass required to adequately support European policy-making at the international level, relevant to climate change and environmental issues. Besides coordinating EUCAARI we also co-operate closely with European infrastructure projects namely those including the experimental facilities for laboratory studies (EUROCHAMP), ground sites (EUSAAR), airborne measurements (EUFAR) and the satellites.

The work in our CoE is divided into five inter-linked work packages (WP) that support each other. The necessary requirement for a high quality performance of the WPs is jointly working, truly inter-, multi- and cross disciplinary teams. From each WP we are expecting at least one scientific breakthrough. Our scientific approach starts from basic nucleation theories followed by models of detailed aerosol dynamic/atmospheric chemistry and vegetation – atmosphere exchange and well-defined laboratory experiments with versatile continuous field measurements in our research stations, and extends to global-scale modelling. Our approach thus covers both experimental (laboratory and field experiments) and theoretical (basic theories, simulations, model development, parametrizations) points of view. The main disciplines used cover aerosol and environmental physics, environmental technology, atmospheric chemistry and physics, analytical chemistry, micrometeorology, forest ecology and ecophysiology. The usage of knowledge on different areas under the common framework creates the added value and synergy benefits of co-operating research teams.

Gases and aerosol particles originating from natural and anthropogenic emissions are transported and transformed over geographically large areas. Understanding the spatial distribution of atmospheric pollutants and quantifying their climatic and air quality effects requires therefore mathematical models covering regional and global scales. Comparisons of large-scale model simulations with existing field measurements enhance the possibility to extrapolate results from *in-situ* measurements to regional and global scales. On the other hand, the computational intensiveness of large-scale models stresses the importance of developing reliable and efficient parameterizations for aerosol size and composition distributions, particle formation and growth processes and emissions of gaseous pollutants as well as model sub-grid-scale processes. Likewise, for the carbon and water cycle a better knowledge on dependence of photosynthesis and respiration processes and evapo-transpiration on environmental factors and climate are required for large-scale models. Finnish CoE has a code of a complex Earth System Model (COSMOS project, Max Planck Institute in Hamburg) and can modify and run the model by itself. All results of CoE concerning new aerosol and biogeochemical parameterizations are readily available and used in COSMOS project.

Our scientific plan is designed as a research chain that aims to advance our understanding of climate and air quality through a series of connected activities beginning at the molecular scale and extending to the regional and global scale. The research plan has been designed specifically to focus on those aspects of the research chain where uncertainties are largest. In practice we start from molecular simulations (Monte Carlo and Molecular Dynamics) to understand nucleation and aerosol thermodynamic processes. These microscopic processes of nucleation together with condensation/evaporation and coagulation are required to understand aerosol dynamics, particle concentrations and composition. Significant advances in laboratory data and modelling techniques are needed for a number of important aerosol systems. Similarly, photosynthesis, autotrophic respiration and VOC synthesis are modeled in cell, stomatal and leaf (or shoot for conifers) scales together with chamber measurements in laboratory and field. Fundamental aerosol and carbon cycle processes need to be understood in order to quantify aerosol radiative properties and the influence of aerosols on cloud microphysics and dynamics at the scale of individual clouds, and to understand changes in carbon uptake dynamics. At larger scales, advances in our understanding of boundary layer meteorology are needed to understand atmospheric aerosol transport, trace gas (e.g. CO_2, methane, N_2O, O_3, SO_2, NOx, VOCs) and water vapor exchange and deposition processes. Boundary layer studies form a link to regional-scale processes and further to global-scale phenomena. In order to be able to simulate global climate and air quality, the most recent progress on this chain of processes must be compiled, integrated and implemented in Climate Change (CC) and Air Quality (AQ) numerical models via novel parameterizations.

Figure 2 shows the general philosophy for our All-Scales-Modelling and actually the whole approach from nanoclusters to integrated Earth System Models (EMS).

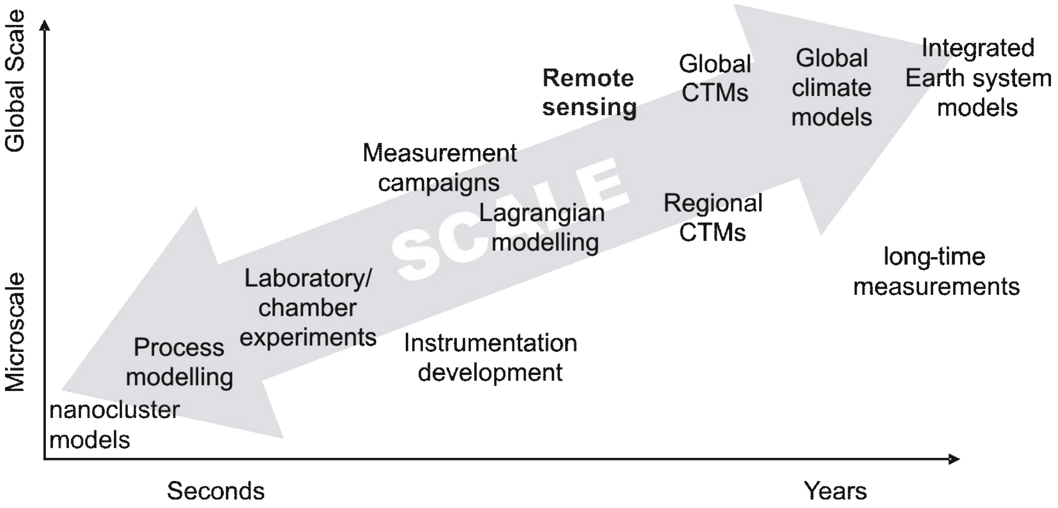

Figure 2. *Model and Data Integration Philosophy over spatio-temporal scales. CTM is Chemical Transport Model*

Laboratory studies of aerosol properties are required for two reasons; first, we need realistic input parameters for our models, and secondly, in certain cases we need to conduct experimental work to verify our theoretical and model approaches. The aerosols can be generated either from well-defined pure or mixed compounds, or by processes imitating those in the atmosphere (e.g. ozonolysis of plant-released VOC's in controlled laboratory environment, dispersion of collected rainwater/seawater/lakewater samples etc.). Properties that will be studied include i) water vapor uptake at varying relative humidities, especially for nm-sized particles, ii) cloud condensation efficiency at varying supersaturations and iii) the chemical composition of particles (e.g. aerosol mass spectra of known particle types for reference to atmospheric studies; composition of plant derived particles; ethanol uptake and volatility of different particle types).

The research unit operates five different field stations. All of them have comprehensive scientific program to investigate aerosol and trace gas concentrations, biosphere-atmosphere interactions, aerosol formation and growth and biogenic background for processes leading to aerosol formation. Also comparisons between urban environment and natural environment can be done by comparing urban stations and with background stations. The stations are GAW (Global Atmosphere Watch) station in Pallas (FMI, 1994-), Puijo Tower (FMI and UKU, 2005-) and three SMEAR stations (SMEAR I, Värriö, 1991-; SMEAR II, Hyytiälä, 1994-, Urban SMEAR III, Kumpula, Helsinki, 2004-). So far the investments to these stations are around 20 MEuro. Particularly SMEAR II has turned out to be a leading station in its research field due to its comprehensive research program and to its unique time series of fresh aerosol formation.

Workpackage descriptions

WP 1. Formation and growth of atmospheric aerosol particles

Professors and senior researchers involved: Kulmala, Kerminen, Laakso, Laaksonen, Lihavainen, Riekkola, Vehkamäki, Viisanen, Hyötyläinen, Jussila, Hartonen, Hari, Hakola

This WP creates the overall framework and forms an integrative basis for all other work packages. It provides information and data for global scale modelling and required parameterisations for aerosol processes. The freshly formed particles can, depending on the location, increase the concentrations of cloud condensation nuclei (CCN) by a factor more than two over the course of one day (e.g. Laaksonen et al., 2005) and ultimately lead to significant enhancements in cloud droplet concentrations (Kerminen et al., 2005). We conclude, therefore, that atmospheric new-particle production is an important process that must be understood and included in global climate models. Future work includes continuous observations of aerosol particle size distributions in diverse locations, measurements of gaseous compounds participating in aerosol formation and determination of the chemical composition and other properties of nucleated particles. These measurements would significantly improve our understanding of the formation process itself. On the other hand also new aerosol dynamic models will be developed in order to be able to test different hypotheses in aerosol formation and growth.

Atmospheric aerosol formation consists of a complicated set of processes that include the production of nanometer-size clusters from gaseous vapours, the growth of these clusters to detectable sizes, and their simultaneous removal by coagulation with the pre-existing aerosol particle population. Once formed, aerosol particles need to grow further to sizes >50-100 nm in diameter until they are able to influence climate, even though smaller particle may have influences on human health and atmospheric chemistry. Although aerosol formation followed by growth has been observed to take place almost everywhere in the atmosphere (Kulmala *et al.* 2004a), yet serious gaps in our knowledge regarding this phenomenon exist. These gaps range from the basic process-level understanding of atmospheric aerosol formation to its various impacts on atmospheric chemistry, climate, human health and environment. According to our recent studies (e.g. Kulmala *et al.*, 2004b; and Nature and Science papers listed on page 3) biosphere plays an important role in aerosol fromation. Actually, to understand the effect of natural ecosystem – atmosphere relationships helps to recognize the anthropogenic effects on climate generally and particularly on aerosol load.

Sulphuric acid (SA), which is known to be one of key components in new particle formation and growth, cannot alone explain the observed growth (Kulmala *et al.*, 2004a), and typically organic molecules are needed for that growth process. Particularly, mono- and sesquiterpenes are known to have a high potential to participate in secondary organic aerosol formation (Hoffmann *et al.*, 1997; Bonn and Mortgat, 2003; Jaoui *et al.*, 2003), lately also polymers of isoprene have been detected in organic aerosols (Claeys *et al.*, 2004). The study of organic composition of freshly-nucleated particles is currently impossible with commercially-available instrumentation. Several *in situ* systems have been developed for on-line measurements, including aerosol mass spectrometer (AMS) for the particle phase (Sullivan and Prather, 2005) and proton-transfer ion-trap mass spectrometry for the gas phase (Warneke *et al*, 2005). The i*n situ* measurements are a requisite in order to obtain highly time-resolved analyses that are capable to show changes in aerosol chemistry. Indirect information of particle composition can be obtained from measurements of hygroscopic and ethanol uptake properties of aerosol particles and their volatility (e.g. Vaattovaara et al., 2005, Wehner et al., 2005; Varutbangkul et al., 2006). These results give *in situ* indication of changes on particles composition as a function of time and size.

Task 1.1. Field measurements

Field measurements are a core activity of this CoE. They include continuous measurements, intensive measurement periods and seperate measurement campaigns. Continuous measurements will be conducted in all our stations (SMEAR I-III, Pallas, Kuopio) and they include particle number size distribution, trace gas and basic meteorological measurements. Intensive measurements will be conducted roughly once a year at each station. During the intensive periods, very detailed measurements of trace gases, aerosol chemistry and various boundary layer parameters will be conducted. Separate field campaigns will be made in different locations all over the world either as part of the international projects or in co-operative basis.

Task 1.2. Development of measurement methods and analytical tools

Despite considerable efforts already put on analysing the chemical compounds responsible for the formation and growth of freshly produced aerosol particles, the actual specific pathways have not been experimentally verified. This task is devoted to getting information on the chemical composition of the nucleation mode and on the gaseous compounds participating into aerosol formation. For this purpose, novel instrumental sampling techniques, such as particle-into-liquid sampler (PILS) modified for organic analytes with solid phase trapping, and *in situ* analyzing techniques, like aerosol time-of-flight mass spectrometer (AMS) with unique size selective sampling valve, and portable comprehensive two-dimensional gas chromatography (GCxGC) with on-line sampling, will be developed and utilized. The main emphasis is on the identification of oxidation and oligomerisation/polymerisation products of terpenes. Standards necessary for quantitative analysis of the oxidation products will be produced by neoteric liquid phase reaction method. By simultaneous measurements with the novel AMS and GCxGC instruments, detailed qualitative and quantitative information of the organic composition of aerosols will be produced within fast analysis cycles (10-30 min). Moreover, comprehensive two-dimensional liquid chromatography (LC×LC) will be employed in the analysis of complex mixtures of nonvolatile to volatile and polar compounds, such as oxidation products. All the systems mentioned above will be used for chamber studies as well. For indirect composition determination we will further develop different hygroscopic, organic and volatility differential mobility analysers (HTDMA, OTDMA and VTDMAs) and also CPC Batteries.

Task 1.3. Laboratory experiments

Laboratory experiments will be conducted in order to investigate biogenic aerosol formation, especially the participating vapors and associated processes such as condensation and heterogeneous chemistry.

Besides condensation and coagulation, atmospheric aerosol particles can age either by oligomerization reactions or by oxidative, photo-chemically induced, particle-phase degradation. These two routes affect the hygroscopic and optical properties of aerosol in totally different ways. Oligomerization will reduce the solubility of the original organic compounds, while oxidative processes will enhance the oxygen to carbon ratio, thus the polarity, hydrophilicity and functional group density of the organic component. Aged organic particles may absorb UV and even visible light accelerating further their aging.

The formation and growth of particles in a chamber containing different plant species will be studied at the Julich Research Centre (FZJ) within EUCAARI co-operation and also in Kuopio plant chamber (see also activities in WP4). The interaction of aerosols with water vapor and the most climate relevant fresh particle properties will be measured. Particle formation and nucleation from plant emissions will be investigated for pine, birch, beech, and oak. Environmental donditions (T, RH, trace gases) conditions will be varied in a systematic way. The aerosol formation potential will also be tuned by the physiological state of the plant. In addition, the nucleation of photo-oxidants from individual precursors in conjunction with other nucleating species, such as sulphuric acid, will be investigated. The plant emissions will be characterized with respect to their nucleation potential. The secondary organic aerosol will be characterized with respect to i) the production of particulate mass, ii) gas-particle partitioning, iii) marker compounds for biogenic aerosols, and iv) near-field hygroscopic and CCN forming properties of the particles.

Task 1.4. Aerosol modeling

Aerosol models are used here for two purposes: to interprete and understand field observations on one hand, and to develop new parameterizations for large-scale atmospheric models on the other hand. The employed models will be either box models or one-dimensional chemical transport models. The box models will have a very detailed description of aerosol dynamical processes and various degrees of complexity in simulating gas/aerosol chemistry. The one-dimensional models will be somewhat simpler in terms of aerosol dynamics and chemistry but allow more detailed description of various boundary layer processes including transportation and surface-atmosphere interactions. The new hypothesis and theories for aerosol dynamical processes can be first studied and tested in box models, and then parameterized for one-dimensional models and further local and global models. The direct chain from basic understanding to global climate models (see WP5) and also to policy oriented models (like EMEP-models) will be established.

Expected scientific breakthroughs (2008-2013):

- Detection of nuclei mode (3-25 nm) particle composition using developed novel instrumentation
- Understanding the formation and growth mechanisms of secondary biogenic aerosol particles
- Parameterized formation and growth mechanisms for global climate models

Deliverables during 2008-2010

- Data from continuous measurements of aerosol formation and growth at three background sites and at two urban sites
- Development of Aerosol Mass Spectrometer, PILS, GCxGC, LCxLC, hygroscopicity and volatility TDMAs and CPC batteries to detect nucleation mode particle composition *in situ*
- Data from campaign wise (1 year) experiments on particle hygroscopicity and their composition in two stations (SMEAR II (Hyytiälä) and SMEAR III (Helsinki)
- Participation in different international campaigns around the world and data from those
- Process-based parametrisations on aerosol growth and composition
- Interpretations of experimental results and comparison with model results
- Reporting the results in scientific Journals and scientific Conferences

WP 2. Ion and neutral clusters

Professors and senior researchers involved: Kulmala, Kerminen, Laakso, Laaksonen, Napari, Vehkamäki, Lihavainen

This WP gives insight on cluster dynamics and existence of neutral clusters. It has recently been suggested that the formation of new aerosol particles is connected with the existence of atmospheric clusters (Kulmala *et al.,* 2000). The existence of small ion clusters in the atmosphere has been known already for several decades (see e.g. Laakso *et al.*, 2004), but the existence of neutral atmospheric clusters has remained an open question (Kulmala *et al.*, 2005). The latter is due to our inability to measure neutral clusters directly. In this WP, we will analyse observations of ion dynamics in order to obtain indirect information on the existence of neutral clusters.

Atmospheric nucleation events produce new aerosol particles almost everywhere in the troposphere. Candidate chemical systems to explain these events include sulphuric acid-ammonia-water, organic acids-ammonia-water, organosulphates, and in coastal environments iodide compounds probably together with sulphuric acid. We have recently proposed a mechanism whereby existing clusters are activated for further growth by e.g. organic vapours (Kulmala et al., 2006). Ions may have an effet on all of these nucleation mechanisms. In order to investigate the potential impacts and atmospheric implications of different nucleation processes, new instrumental techniques to detect clusters are needed. In addition, atmospheric observations and laboratory experiments on the evolution of clusters and atmospheric particles need to be performed. Deeper theoretical understanding is also required.

It has been proposed, and confirmed by observations, that atmospheric new particle formation depends on the sulphuric acid concentration. In laboratory experiments (Viisanen et al., 1997, Bernd et al., 2005), this dependence has been found to obey a power-law form having exponents of order 5-10. In atmospheric conditions the dependence is not as strong (see e.g. Weber et al., 1996, 1997; Kulmala et al., 2006), with an exponent of only 1-2.

Task 2.1 Detection of neutral and ion clusters

Critical clusters – if electrically neutral – formed by atmospheric nucleation events cannot yet be measured quantitatively due to instrumental limitations. Only one measurement of clusters during nucleation events has been reported, and it showed that clusters were present when 2.7-4 nm particles were detected (Weber et al., 1995). More work on the distribution and composition of such clusters is needed to refine our understanding of atmospheric nucleation. However, ion clusters can be and have been measured during nucleation events (e.g. Hörrak, 2001; Laakso et al., 2004)

The state-of-the-art aerosol instrumentation is capable of detecting atmospheric particles larger than about 2.5-3 nm in diameter. Critical nuclei sizes are typically around 1 nm, and therefore instruments capable of detecting particles and clusters smaller than 3 nm are needed. The recently-developed air ion spectrometers (see e.g. Laakso et al., 2004) will be further developed and tested in order to investigate the existence of neutral clusters. As seen in several studies, both negative and positive ion clusters exist commonly in the atmosphere. The air ion spectrometer can measure ion concentrations and mobilities down to about 0.4 nm (e.g. Laakso et al., 2004). The new version designed to detect neutral clusters which are charged using a radioactive source will be aimed to be able to measure down to 0.8-1 nm. On the other hand, also condensation particle counters with different condensing liquids and temperature difference between saturator and condenser will be developed, tested and used to find out the number concentration and composition of clusters smaller than 3 nm. The existence of reliable cluster spectrometer (ion and neutral clusters) will improve significantly our understanding of atmospheric nucleation phenomena. Also condensation particle counters with different condensing liquids and temperature difference between saturator and condenser will be developed, tested and used to find out the number concentration and composition of clusters smaller than 3 nm (see Kulmala et al., 2005).

Effective theoretical tools are already available, by which observed changes in the aerosol size distribution in the size range >3 nm can be used to calculate both nucleation rate and the number concentration of sub-3 nm clusters with a reasonable accuracy (Kerminen and Kulmala, 2002). These theoretical approaches will be combined with increasing measurement data from <3 nm size range. This two-way approach will enhance substantially our understanding on cluster dynamics in real atmospheric aerosol system, which is necessary for the quantification of the early steps of atmospheric aerosol formation.

Task 2.2. Nucleation experiments

Nucleation experiments for the sulphuric acid–ammonia–water and various organic acid–water–ammonia systems, as well as activation experiments for both neutral and ion clusters, will be carried out to produce data for reliable nucleation rate parametrizations. Particle formation experiments will also be performed in the system O_3/alkene/SO_2/H_3O under experimental conditions, including reactant concentrations close to tropospheric conditions. These experiments will be extended investigating the influences of NH_3. Furthermore, experiments will be performed without contributions from the alkene ozonolysis process. Observed nucleation rates from both experimental approaches, with and without NH_3 added, will be compared. Nucleation rate measurements in various organic acid-water systems with and without added ammonia will be performed in a laminar flow chamber with a turbulent vapour mixing unit. The first systems to be studied are formic acid–water and acetic acid–water. Thereafter, acids of higher molecular weight and the effect of added ammonia will be studied. Nucleation probability studies (heterogeneous nucleation, activation of clusters) of different type of neutral and ion clusters will be performed in the presence of several organic compounds. The first experiments will include neutral and charged metal clusters, iodide clusters, organic clusters and inorganic salt clusters in the presence of organic and water vapours. The newly development instruments will be used in these experiments together with the size analyzing nucleus counter (SANC) in co-operation with University of Vienna.

Task 2.3. Nucleation Modelling

Nucleation of the candidate systems (sulphuric acid–ammonia–water, organic acids, organosulphates) will be investigated. Molecular dynamics and Monte Carlo calculations will be made for sulphuric acid–water, sulphuric acid–ammonia–water and organosulphates systems with and without the effect of ions (see task 2.4). For the binary sulphuric acid–water system intermolecular potential models exist, whereas for the ternary sulphuric acid–ammonia–water and for organosulphates system such potentials will be developed. Calculations based on the classical nucleation theory (CNT) will be made for a series of organic acid-water systems. CNT calculations of organic acid-ammonia-water nucleation are complicated because the necessary thermodynamic data for these systems is scarce. Therefore, the first CNT calculations will assume that the critical nuclei compositions correspond to ammonium salt of the organic acid in question plus water. The effect of ions on all above mentioned nucleation mechanisms will be studied. Parameterisations based on theoretical, modeling and experimental results for sulphuric acid–ammonia–water, organic acid and organosulphate systems will be developed. In addition to the above-mentioned thermodynamic nucleation mechanisms, the kinetic nucleation and activation of existing clusters will be investigated and parameterized.

Task 2.4. *Ab initio* calculations

At the molecular level, we employ a variety of quantum chemical methods to obtain data on the reactions of atmospherically relevant nucleation precursors. Our main systems of interest are both neutral and charged sulfuric acid–water–ammonia clusters, together with complexes of biogenic vapours with sulfuric acid. To facilitate this, we have carried out extensive error analysis studies (Kurtén *et al.*, 2006) which help explain the discrepancies between earlier theoretical and experimental studies (Ianni and Bandy, 1999; Re *et al.* 1999; Al Natsheh *et al.* 2004; Hanson and Eisele, 2000) and also assist us in selecting the most appropriate computational methods for each studied system.

Our main research topics can be divided into three groups. First, we will extend the range of quantum chemical nucleation studies by computing formation thermodynamics for sulfuric acid–ammonia–water clusters with up to three sulfuric acid molecules and up to two ammonia molecules. From the data calculated for larger clusters we have, for example, been able to show that the nucleation-enhancing effect of ammonia becomes apparent only when clusters containing more than one sulfuric acid are considered.

Second, we will investigate the thermodynamics and kinetics of the formation of charged clusters containing either HSO_4^- or NH_4^+ ions. Recent experimental evidence (Eisele *et al*., 2006) indicates that the formation of $HSO_4^- \bullet H_2SO_4$ -clusters occurs more slowly than the collision rate, indicating either the presence of an activation barrier or (more probably) a multi-step formation mechanism. Both alternatives will be investigated using quantum chemical methods. Recent theoretical studies (Nadykto et al., 2006; Froyd and Lovejoy, 2003) have shown that quantum chemistry can be used to obtain qualitatively correct information and new insights into ion-induced nucleation. However, no quantitatively reliable quantum chemical studies on atmospherically relevant systems have been performed so far.

Finally, we will use quantum chemistry to determine which organic species are most important for the nucleation events observed *e.g.* at Hyytiälä (e.g. Dal Maso et al., 2005). Currently, the most promising candidates (Bonn *et al*., 2002) are the stabilized Criegee intermediates (sCIs), which are biradicals formed in the ozonolysis of sesquiterpenes emitted by vegetation. We have postulated a reaction mechanism between sulfuric acid and the sCI which leads to the formation of a hydrogen-bond stabilized peroxysulfate complex. Preliminary calculations on several biogenic sCIs indicate that the reaction is highly exothermic in atmospheric conditions. However, as the sCIs are highly reactive, thermodynamic calculations may not be sufficient to determine the atmospheric relevance of different reaction pathways (see *e.g.* Aplincourt and Ruiz-Lopez, 2000). Thus, also kinetic parameters such as activation barriers and rate constants need to be calculated.

Expected scientific breakthroughs (2008-2013):

- Detection of neutral clusters using developed novel instrumentation
- Reliable *ab initio* calculations on formation of neutral clusters
- Understanding the atmospheric nucleation mechanism
- Global map of ion cluster properties

Deliverables during 2008-2010

- Data from continuous measurements of ion cluster at SMEAR II station
- Development of instrumentation to detect neutral clusters
- Data from campaign wise experiments on neutral clusters at SMEAR II and SMEAR III
- Data from laboratory experiments on existence of neutral clusters
- Data from laboratory studies on activation of neutral and ion clusters
- Results from nucleation modeling
- Results from *ab initio* calculation results
- Participation in different international campaigns around the world
- Interpretations of experimental results and comparison with model results
- Reporting the results in scientific Journals and scientific Conferences

WP 3. Aerosol-cloud interactions

Professors and senior researchers involved: Laaksonen, Kerminen, Lihavainen, Kulmala, Viisanen, Laakso

This WP aims at quantifying the effect of cloud condensation nucleus (CCN) formation from biogenic emissions to the global CCN budget, and clarifying the effects of aerosols and various chemical factors on cloud activation and subsequent properties. We will also develop the theory and modelling of onset of precipitation in warm clouds. Data analysis of long-term data sets and detailed process modelling will be used in order to derive parameterisations for GCM's that enable us to improve estimates of the climatic importance of these factors.

We have recently shown that atmospheric nucleation and growth of secondary particles can contribute significantly to regional CCN budgets both in clean (Komppula et al, 2005) and polluted (Laaksonen et al., 2005) environments. Less attention has been given to the possibility that atmospheric nucleation may have been a very important source of CCN in the pre-industrial world. In this context, it should be noted that atmospheric aerosol formation is thus a source of CCN that is currently missing from climate models; even though nucleation of sulfate particles is described in some climate models, no models treat nucleation of sulfate particles and their subsequent growth due to biogenic (or anthropogenic) secondary organics to sizes above 50 nm.

In order to quantify CCN formation from atmospheric aerosol formation influenced by biogenic and anthropogenic organic emissions, we will in WP3 perform long-term and intensive campaign measurements at all our measurement stations and also at San Pietro Capofiume (Po Valley, Italy). Each of these stations has different characteristics with respect to natural and anthropogenic influences. The Pallas station has very clean air quality most of the time, while Värriö is almost similar but with occasional strong influence from the Kola Peninsula industrial activities (smelter emissions) and more influences from biogenic forest emissions. Hyytiälä and Puijo represent relatively clean environments, in which the anthropogenic influence depends on the air mass origin. Puijo is situated beside the city of Kuopio and local wind direction determines whether or not the influence from the city emissions is detectable. Helsinki is a moderately polluted area and, finally, San Pietro Capofiume represents a heavily-polluted environment. This host of stations thus offers us an opportunity to study the biogenic vs. anthropogenic influence on CCN formation from atmospheric nucleation events in different environments, and to quantify the importance of the events to the local CCN budgets in such a way that larger scale (regional/global) assessments become possible.

Task 3.1. Laboratory experiments

Quantification of the CCN activity of particles formed in the atmosphere requires information of their ability to activate to cloud droplets at different supersaturations. To this end, we will perform laboratory measurements using our flow-type CCN counter. We will study both selected organic and mixed organic/inorganic particles, as well as particles produced in ozonolysis of terpenoid species released by plants in a laboratory growth chamber (Joutsensaari et al., 2005). Laboratory experiments performed in different WPs are supporting each other. In WP 3 the main focus is in the CCN and ice nuclei (IN) activation.

The influence of aerosol particles on ice forming nuclei properties is poorly understood because of the variety of heterogeneous ice crystal nucleation modes. Aerosols can act as IN by coming into contact with supercooled cloud droplets (contact freezing), or by initiating freezing from within a cloud droplet by immersion or condensation freezing, or by acting as deposition nuclei. If, in addition to mineral dust, hydrophilic black carbon aerosols are assumed to act as ice nuclei at temperatures between 0°C and –35°C, then increases in aerosol concentration from pre-industrial times to present-day can pose a glaciation indirect effect. Here increases in contact and immersion ice nuclei in the present-day climate can result in more frequent glaciation of supercooled clouds and increase the amount of precipitation via the ice phase. This might decrease the global mean cloud cover and lead to more absorption of solar radiation, which could partly offset the indirect aerosol effect on warm clouds (see e.g. Cantrell and Heymsfield, 2005).

Task 3.2 Field observations

Field investigations related to aerosol-cloud interactions have started from CCN measurements (e.g. Hudson and Xie, 1999) and advanced to dedicated aerosol-CCN-droplet number closure studies (Conant et al., 2004; Sotiropoulou et al., 2006), as well as to studies investigating the influence of aerosols on precipitation (Givati and Rosenfeld, 2005). Long term measurements of cloud properties at fixed locations (e.g. Dong et al, 2005) are useful for monitoring cloud climatology and the variability in their micro- and macrophysical properties, and for model validation purposes. Usually such studies are carried out using remote sensing techniques (e.g. lidars). In WP3, we perform long-term measurements of cloud properties at two locations which are frequently covered by low-level stratus clouds: at Pallas station, which is situated on top of a fjell (560 m above sea level) in Lapland, and at Puijo where we have instrumentation on top of a TV tower 225 m above the local lake level. Sampling inside cloud gives us an opportunity to study not only cloud microphysics but also cloud chemistry, especially during intensive campaign periods. We will use the data obtained from both the long-term measurements and the intensive campaigns to validate our theoretical and modelling approaches (see below).

Task 3.3. Cloud microphysics

The influence of different chemical factors (water solubility of aerosols, their surfactant properties, effects from condensable gases, see Charlson et al. 2001, McFiggans et al., 2005) have received considerable attention in recent years. It is now becoming clear that some of these effects are relatively minor; for example we have shown using a cloud parcel model that atmospherically realistic surfactants have only a very weak influence on cloud drop concentrations (Kokkola et al., 2006). Also a recent study by Dusek et al. (2006) demonstrated that aerosol size distribution has a much stronger influence on cloud activation than the chemical composition of the particles. However, there are chemistry issues influencing cloud activation that need to be studied further. Thus, we will in WP3 develop a theoretical formulation of the activation of wettable, insoluble organic particles, which have in the laboratory been found to activate as easily as water soluble organics (Raymond and Pandis, 2002), whereas nonwettable particles need much higher supersaturations for activation. Another issue that remains worth pursuing is the influence of soluble gases on activation. We have recently developed a parametrized representation of the influence of nitric and hydrochloric acids on cloud drop formation (Romakkaniemi et al., 2005a). The parametrization is yet to be tested in a climate model. We are especially interested in clarifying the influence of HNO_3 under a future scenario in which the atmosphere has cleaned up from particulate pollution but NO_x emissions remain at a similar level as presently. We also aim to extend our HNO_3 parametrization to include the effect of ammonia, although we now know that this is a difficult task due to the fact that ammonia may partition to the aqueous phase already considerably below 100% relative humidity, depending on the acidity of the droplets (Romakkaniemi et al, 2005b).

Task 3.4. Model studies

Recent model studies have brought a lot of insight into the complex interaction between aerosols, clouds, radiation and associated rain forming processes (e.g. Johnson 2005, Lu and Seinfeld, 2005; Jiang and Feingold, 2006). However, the so-called second indirect climate effect of aerosol particles, that will cause the average cloud lifetime to be prolonged, is still incompletely understood as the factors controlling the start of the precipitation in warm clouds remain somewhat unclear. It has been suggested that turbulence enhanced coalescence of micron sized droplets (Falkovich et al., 2002; McGraw and Liu, 2003) or enhanced diffusion of water vapor due to turbulent fluctuations in temperature and water vapor concentration (Tisler et al., 2005) enable a fraction of droplets to grow large enough to precipitate. We will study the effects of aerosols and chemical factors on the onset of precipitation by different theoretical methods including Monte Carlo computation (Tisler *et al.*, 2005) and one-dimensional cloud modelling.

We will also use our long term data sets to verify the modelling results. Describing indirect aerosol effects in global climate models is only possible using effective parameterizations. In terms of cloud droplet activation, advanced parameterizations have been developed and tested (Menon et al., 2003; Meskhidze et al., 2005; Peng et al., 2005; Ming et al., 2006). Development of respective parameterizations describing the rain formation is initiated and in active progress (e.g. Liu et al., 2006). Our aim is to produce, based on our modelling results, new and improved parameterizations of the different influences on onset of warm precipitation.

Expected scientific breakthroughs (2008-2013):

- Quantitative understanding of CCN production from nucleation events in present and pre-industrial conditions
- The effect of trace gases on CCN activation as a function of pollution
- Parameterised CCN, cloud droplet and rain droplet formation mechanisms for global models

Deliverables during 2008-2010

- Data from long-term monitoring of CCN formation in atmospheric nucleation events at six measurement stations
- Data from long-term monitoring and intensive campaign measurements of stratus cloud microphysical and chemical properties at two measurement stations
- Data from laboratory measurements of the CCN activity of nucleation related particles
- Development of a one-dimensional cloud model for studying onset of precipitation
- Interpretations of experimental results and comparison with model results
- Development of parametrizations of CCN, cloud drop and rain drop formation applicable in large-scale models
- Reporting the results in scientific Journals and scientific Conferences

WP 4. Biosphere-atmosphere interactions

Professors and senior researchers involved: Nikinmaa, Vesala, Viisanen, Kulmala, Hakola, Rinne, Sogachev, Mammarella, Suni, Hari, Bäck, Pumpanen, Mäkelä, Riekkola

This WP studies the coupling of biosphere to physical and chemical processes of atmosphere. It studies how the biosphere on one hand and the atmospheric turbulence on the other hand control the atmospheric concentrations of gases and particles, especially carbon dioxide, methane and volatile organic compounds

(VOCs), and the exchange of material, energy and momentum between the atmosphere and earth surface. Linking aerosol processes, organic chemistry (WP1) and biosphere processes requires quantification of the exchange rates of compounds between the surface and the atmosphere and understanding of the biological processes driving the exchange.

The factors controlling carbon exchange between forest soil and the atmosphere, and the magnitude of the carbon flows are still uncertain and under a debate (Valentini et al. 2000). Variation in directional distribution in radiation reflects on radiation interception and radiation use efficiency (Gu et al. 2003). Radiation use efficiency may be limited due to linked factors such as water availability and in particular low temperatures in boreal environment (Hari and Mäkelä, 2003; Öquist and Huner, 2003; Mäkelä et al., 2004). Periods when imbalances in energy capture and consumption are prevailing have also been suggested to be linked with biogenic VOC (BVOC) production (Peñuelas and Llusia, 2003; Bäck et al., 2005). Although recent research has revealed many biochemical details of their biosynthetic pathways, the mechanisms controlling BVOC formation and emissions are still far from being fully elucidated. Changes in the atmospheric CO_2 concentration can thus have both positive and negative effects on the BVOC emission rate through direct effects on their synthesis (Rapparini et al., 2004), or through indirect effects via changes in temperature and light conditions, for example to stomatal control (Niinemets et al., 2002), and changes in leaf biomass.

It has been estimated that soil organic matter contains about twice the amount of carbon stored in the atmospheric (Kirschbaum, 2000) and even small changes in it may cause substantial impact in the atmosphere. Particular interest is in the role of fast decomposing root exudates in the forest carbon balance (Högberg et al., 2001) as it influences the estimates of carbon turnover times in the soil (Pumpanen et al., 2003). The type of carbon input to soil is linked to nitrogen cycle influencing the conditions that give rise to emission of gaseous nitrogen (NO, N_2O) from the ecosystems. Soil carbon may also be emitted as methane to atmosphere in anaerobic conditions. Most important biogenic sources of methane into the atmosphere include high latitude wetlands (Prather et al., 1995). However, recent study also suggested that trees may emit methane (Keppler et al., 2006). There is less information on the possible emissions of BVOCs from soil processes and what is the role of carbon sources in this.

Different BVOCs take part in different phases of aerosol formation and growth. Sesquiterpene oxidation products may take part in the aerosol formation (Bonn and Moortgat, 2003) while isoprene and monoterpene oxidation products are mainly connected to aerosol growth (Claeys et al., 2004; Tunved et al., 2006). The oxygenated VOCs (OVOC) such as carbonyls can also affect the light absorption properties of sulfate aerosols (Noziere and Esteve, 2005). In order to understand the role of the terrestrial vegetation on the atmospheric aerosol formation, growth and properties we need to investigate the poorly known emissions of sesquiterpenes and OVOCs (alcohols and carbonyls) and in particular the regulating factors underlying temporal and spatial variations in emissions from different plant species.

We will both monitor the fluxes between biosphere and atmosphere and conduct laboratory experiments to study the physiological mechanisms driving the exchange processes. Emissions will be measured in various temporal and spatial scales utilizing e.g. enclosure, gradient and micrometeorological techniques. Also the aerosol fluxes can be determined either with eddy covariance (Buzorius *et al.*, 2000) or relaxed eddy accumulation technique (Gaman et al., 2004). The results from the laboratory experiments and monitoring studies will be summarized with process models that link vegetation processes with atmospheric processes.

Task 4.1: CO_2 exchange and assimilation

We study the impact of light, temperature and water availability to photosynthesis (Gross Primary production, GPP) combining detailed photosynthesis, tree and canopy models (e.g. Mäkelä et al., 1996; Perttunen et al., 1996; Mäkelä et al., 2004; Porcar et al., 2006) with continuous measurement of meteorological variables and radiation both above and below canopy. The continuous monitoring of leaf gas exchange is complemented with short term response studies from leaves of different tree and understorey species in different light conditions during different times of the year.

The GPP-estimations are compared against above and below canopy eddy-flux data and tree and soil respiration and biomass studies including estimations of the variation in the stored carbohydrates. Both flux chambers on soil surface and buried CO_2 sensors that give soil CO_2-concentration profile are used for soil respiration studies (Pumpanen et al., 2003). From the seasonal variation in the GPP, measured biomass change and monitored fluxes and stable isotope studies we can estimate the annual variation in the soil carbon sink and relative contribution of autotrophic respiration, fast decomposing root exudates and slow decomposing organic matter (Tang et al., 2005) and how these depend on temperature and soil moisture. Also their linking to soil BVOC emissions will be studied.

The CO_2 exchange rates are linked to the activity of sources and sinks. Recent modelling studies on water and sugar transport in trees (Perämäki et al., 2005, Hölttä et al. 2005), in combination with pressure driven diurnal variation of tree stems (Sevanto et al., 2005), have created novel monitoring possibilities to link leaf gas exchange to whole tree physiology. These methods are linked with fluorescence method, isotope studies and experimental manipulations to study how low sink activity or stress conditions are linked with tree BVOC emissions.

Task 4.2 VOC emissions

The VOC emissions will be studied in different spatial scales both in laboratory and field conditions. The techniques utilized in the emission measurements will be enclosure and disjunct eddy covariance (Rinne et al., 2001, Karl et al., 2002) technique with fast-response proton transfer reaction mass spectrometry (PTR-MS, Lindinger et al., 1998), and gas chromatographic mass spectrometry techniques for compound identification. In order to interpret the measured above-canopy fluxes of the gas phase precursors, interaction between within- and above-canopy chemistry and turbulent transport will be studied using a stochastic Lagrangian transport model with a chemistry module (Strong et al., 2004).

Laboratory experiments with controlled environmental conditions will be used to study the mechanisms of the VOC synthesis and emission by plants and they are linked with the VOC and carbon metabolism studies in the field (see also WP 1). Also inhibitors and inducers of biosynthesis, isotopic fractionation and stable isotope labeling will be used. Studies on gene expression (using DNA microarrays) as well as on the seasonal changes in substrate (DMAPP) concentrations and isoprene and monoterpene synthase activities will be performed. The combined effects of the external (temperature, light) and inherently determined (stage of development, level of gene expression) factors affecting the biosynthesis both in the deciduous, isoprene-emitting aspen and birch, and in the evergreen, monoterpene-emitting pine will be embedded into a mechanistic, physiologically sound model structure describing BVOC biosynthesis and emissions (Bäck et al 2005).

The emissions determined at different spatial scales will be linked by up-scaling using vegetation inventories including the dominant tree species and minor species and ground vegetation. Currently the measured concentration ratio of isoprene and monoterpenes (Hakola et al., 2003) do not agree with the modeled emissions (Simpson et al., 1999; Lindfors et al., 2000). This may be due to the omission of minor species with high isoprene emission, such as willows and mosses (Hakola et al., 1998; Haapanala et al., 2006) in the emission models, or due to incomplete model parameterizations which do not fully account for e.g. seasonal variations in specific emission factors. The regional scale emissions will be modeled first using parameterized light and temperature responses but aiming at more mechanistic emission model which can be linked to global climate models. The experimental results will be used for improving emission parameterizations and for adjusting mechanistic models to different forest tree species, which can later be used as input in the regional and larger scale vegetation modeling.

Task 4.3 Methane and nitrogen

We will follow methane emissions from wetlands with micrometeorological eddy covariance technique. Long time series of methane emissions enable us to draw conclusions on the effect of environmental parameters, such as peat temperature, water table depth or changes in the atmospheric pressure, on the methane emission. We will also study the possible role of trees in methane emissions and the net methane emissions on mineral soils with fluctuating water table level. The carbon dioxide and methane studies are linked with studies on nitrogen cycle to detect conditions that give rise to emission of gaseous nitrogen (NO, N_2O) from the ecosystems resulting from the nitrification and denitrification processes.

Expected scientific breakthroughs (2008-2013):

- Quantification of OVOC emissions from boreal ecosystems.
- Detection and understanding of annual patterns of BVOC, other trace gases and aerosol particle fluxes
- Clarifying and quantifying processes behind BVOC formation and their acclimation to climate and atmospheric variation at different time scales
- Quantification of the role of root exudates in forest carbon balance
- Interaction between radiation distribution, soil water and GPP

Deliverables during 2008-2010

- Data from continuous monitoring of ecosystem gas exchange with chambers, concentration profiles and eddy- covariance techniques, tree stem sapflow, meteorological variables
- Data from continuous monitoring of sub-micron aerosol deposition with eddy covariance and relaxed eddy accumulation techniques and new parameterizations for deposition velocities
- Linking stand GPP estimations with above ground Net Primary Production and Net Ecosystem Exchange measurements with dynamics of soil CO_2 profile
- Developing continuous chlorophyll- fluoresence monitoring in the field
- Linking stable isotope measurements with leaf gas exchange and tree and soil respiration studies
- Data from controlled environmental laboratory experiments on BVOC emissions
- Development of BVOC flux measurement techniques
- Field campaigns on BVOC emissions in various spatial scales, including soil measurements
- Development of mechanistic emission models for a variety of plant species, linking the mechanistic models with dynamic vegetation and climate models on regional and global scale
- Interpretations of experimental results and comparison with model results
- Reporting the results in scientific Journals and scientific Conferences

WP 5 Earth system behavior

Professors and senior researchers involved: Vesala, Laaksonen, Kerminen, Viisanen, Kulmala, Nikinmaa, Sevanto, Rinne

This WP integrates the whole research, made in the other WPs, from nano and local scales up to regional and global scales. A major enterprise conducted at the international level is the development of complex Earth System Models (ESM). Such models integrate our knowledge regarding the atmosphere, ocean, cryosphere and biosphere, accounting for the couplings between physical and biogeochemical processes in these components of the Earth System. Our CoE can provide unique data and detailed information especially from boreal regions to ESMs. In the other WPs, we concentrate on obtaining results from processes that are not yet fully understood and have therefore not been implemented in integrated models. Our CoE is a part of COSMOS, a new project for community ESM, led by Max Planck Institute in Hamburg. Our CoE has the COSMOS ESM code and can readily modify and run it, which makes the implementation of the newest results in the model convenient. The activities are strongly linked to those in the Integrated EU Project EUCAARI (co-ordinated by our CoE), in which the Earth system behavior is investigated by means of similar approaches, for example the regional-scale EMEP model is used. The most novel aspect of WP5 is to couple the biogenic aerosol production with a global aerosol dynamics model for the first time in the context of global Earth System Modeling. The most recent findings in the biogeochemistry taking place in the boreal region are applied in parameterizations of carbon, water and nitrogen cycles.

Until very recently, different components of the Earth system have been investigated independently of each other and, especially in global scales, without any major attempts to combine various observational and modeling tools together. For example, a number of large-scale field studies have already been conducted around the world in order to characterize the physical, chemical and optical properties of atmospheric aerosols and to study their radiative effects. The studied systems include natural marine and dust aerosols (ACE-1, Bates et al., 1998; PRIDE, Reid et al., 2003), industrial pollution aerosols originating from North America or Europe (TARFOX, e.g. Russell et al., 1999; ACE-2, Raes et al., 2000; MINOS, e,g. Lelieveld et al., 2002; CLAMS, Smith et al., 2005), aerosols associated with biomass burning in different tropical environments (SCAR-B, Kaufman et al., 1998; SAFARI2000, King et al., 2003; LBA-SMOCC, e.g. Andreae et al., 2004) as well as a complicated mixture of pollutants and natural aerosols over Asia and surrounding oceans (INDOEX, Ramanathan et al., 2001; TRACE-P, Jacob et al., 2001; ACE-Asia, Huebert et al., 2003). At the same time, extensive separate studies of carbon and energy fluxes (Baldocchi et al., 2001) and nitrogen cycling (Nitroeurope Integrated Project) are going on. The work in WP5 also tends to unification of different communities and to improved knowledge transfer in these issues.

Over continental and global scales, determining aerosol climatic effects have long been possible using models only. Model-based forcing estimates are, however, still quite uncertain (Lohman and Feichter, 2005; Kinne et al., 2006; Textor et al., 2006). In case of the direct aerosol effects, existing uncertainties have recently been reduced significantly using suitable combinations of data from various remote sensing instruments and models (Bellouin et al., 2005; Chung et al., 2005; Yu et al., 2006). Indirect aerosol effects have been identified in many field investigations (e.g. Quaas et al., 2004; Chylek et al., 2006), but observational quantification of the associated forcing is not yet possible. A lot of progress has been made in modeling the indirect aerosol effects, yet uncertainties are still very large (Chen and Penner, 2005; Lohman and Feichter, 2005).

The experience obtained from various field and model experiments demonstrates that it is very important to combine observations from different platforms (ground based, airborne, satellite) with model investigations in order to get more quantitative understanding on global and regional aerosol and trace gas characteristics and associated climatic effects. General strategies to achieve this goal have already been suggested (Diner et al. 2004; Anderson et al., 2005).

Task 5.1 Aerosol forcing and properties

A major goal of this task is to narrow the uncertainty range for estimates of aerosol forcing. Hereby, the term aerosol forcing summarizes the overall impact on the radiative energy balance due to the aerosol presence (direct effect) and due to aerosol induced modifications to clouds and the hydrological cycle (indirect effects) over time. Aside from the climate relevant forcing at the top of the atmosphere also its sub-components, the forcing within the atmosphere and the forcing at the surface (the surface energy balance) will be investigated, to illustrate how aerosol impacts atmospheric dynamics and surface processes. A particular effort is needed to constrain modelling assumptions with new insights regarding processes and correlations between parameters.

Aerosol properties (composition, size, shape) vary strongly in time and space. Thus, despite computational constraints, new aerosol modules in global modelling now distinguish between different aerosol components (e.g. sulfate, organic carbon, black carbon, mineral dust and sea-salt). Advanced modules further discriminate aerosol size (e.g. size-bins or size-modes) and permit mixtures among components (see Textor et al., 2006, and references therein). A realistic representation of the aerosol properties is a key to improvements regarding aerosol processing and interactions with the climate system. In this task, by using the appropriate parameterizations obtained from the other WPs, computationally effective aerosol models will be developed and tested against observations and finally implemented into the COSMOS ESM.

Task 5.2 Interactions and feedbacks

In the Earth system, the climatic and other effects of aerosols and trace gases are coupled together via both human actions, such as emission policies and land use change, and via various natural feedback mechanisms involving the biosphere and atmosphere (e.g. Brasseur and Roeckner, 2005; Feddema et al., 2005; Gibbard et al., 2005; Sanderson et al., 2006). For example, increasing temperature and greenhouse gas concentrations are likely to affect natural aerosol and their precursor fluxes from various land ecosystems and oceans into the atmosphere (Barth et al., 2005; Lathiere et al. 2005). Changes in these fluxes alter, in turn, the hydrological cycle and related cloud forcing (e.g. Kulmala et al., 2004b; Gunson et al. 2006). A better understanding of interactions and feedbacks in the Earth System, involving aerosol processes and properties, is thus required. We will assess the strength of climate feedbacks involving aerosol precursors and aerosol species. The uncertainties in these feedbacks will also be quantified through a multi-model approach. This work is supported by IP EUCAARI, where several state-of-the-art aerosol modules tools to investigate climate feedbacks involving aerosol emissions driven by soil and vegetation and detailed representations of the aerosol microphysics are available.

Climate change is expected to change the atmospheric cycling of natural and anthropogenic aerosols through changes in temperature and humidity (affecting aerosol thermodynamics), precipitation (affecting aerosol sinks), convection (affecting aerosol transport and sinks), and oxidant concentrations (affecting sulfate production). We will quantify the role of these processes to amplify or alleviate the aerosol radiative effects. The climate efficacy (per unit radiative forcing and per unit aerosol emission) will be estimated for present-day and future conditions.

Task 5.3 Impacts on surface-atmosphere exchanges

Biogenic VOC are thought to be a major, and probably dominant, source of organic aerosol at least in Northern Europe. Emissions of natural precursors to secondary organic aerosols (such as monoterpenes) from vegetation have been observed to depend strongly on temperature, at least on weekly to seasonal timescales. If the same temperature dependency holds on longer timescales, the concentration of secondary organic aerosols is expected to increase in a warmer climate, thus increasing the cooling effect of aerosols. This negative feedback may be modulated by shifts in plant functional types and/or decreases in plant productivity because of various environmental stresses. The ESM will be used to investigate the strength of the feedback and the role of modulating processes. Updated current emission databases, making use of improved databases on European forest cover, and recent work on improved European and global databases are utilized.

In this task the main effort will be put on modeling the interactions and feedbacks between forests and the Earth's climate system. Current large-scale models are to some extent capable of predicting responses related to, e.g., temperature changes and resulting feedbacks. However, the general significance of recently verified links and feedbacks between the temperature, photosynthesis, VOC emissions and particle formation (Kulmala *et al.*, 2004b, see also Fig. 1.), or between particle load, diffuse radiation and photosynthesis (Gu *et al.*, 2002), are not known. One of the shortcomings in large-scale models is also unsatisfactory description of phenology, photosynthetic parameters (e.g. stomatal conductance) and winter-time ecophysiology, of which importance is stressed for boreal region affecting the length of the growing season and contributing to inter-annual variations in various surface fluxes. The VOC emission databases will be coupled to improved phenological models driving biosphere-atmosphere exchange, enabling predictions of the effects of changes in temperature, CO_2 and soil moisture, as well as those of land-use, to be made for future scenarios. New findings, for example those on phenology (Hari and Mäkelä, 2003; Suni et al., 2003; Mäkelä et al., 2004) and winter-time processes (Sevanto et al., 2006), will be assimilated in the models. Applying updated phenology and photosynthetic parameters, we will explore the coupling between future changes in land use, O_3 concentrations, climate parameters, and organic aerosols.

Expected scientific breakthroughs (2008-2013):

- Reduced uncertainty of radiative forcing of atmospheric aerosols
- Development of a reliable aerosol module based on our parameterization to be used in climate and air quality models
- Development of biosphere-atmosphere interaction model to be included in climate models
- Estimate of impact of climate change on aerosol forcing
- Estimate of climate change impact on boreal surface-atmosphere exchanges
- Estimate of climate feedbacks involving natural secondary aerosols
- Holistic understanding of biosphere-atmosphere interactions over boreal region

Deliverables during 2008-2010

- Assessment of BVOC emissions for organic aerosol production
- Estimate of climate efficacy (per unit radiative forcing and per unit aerosol emission)
- Assessment of climate feedbacks in continental boundary layer

- Modifications and model runs of COSMOS ESM, especially for biogenic aerosol formation and global dynamics and more realistic treatments of boreal-region biogeochemical fluxes
- Interpretations of experimental results and comparison with model results
- Reporting the results in scientific Journals and scientific Conferences

■ How will the individual research plans contribute to the programme as a whole?

All work packages are linked with each other and contribute to the overall objectives. The whole research plan is made in the integrated manner and the structure accordingly follows the plan. There are no isolated, single individual plans. All research teams have been very experienced in working together and therefore our research plan is unified.

2. ■ Internationally, what will be the scientific significance and innovativeness of the research carried out by the proposed CoE (in terms of theories, methodology, main approaches, results)?

Internationally, the research unit lead by M. Kulmala has a leading position in the research area of formation of atmospheric aerosols. Our approach has started from basic nucleation theories followed by detailed aerosol dynamic / atmospheric chemistry models and well defined laboratory experiments and ended to very versatile continuous field measurements in our research stations and 3D modelling. We have also a leading position in the research area of measuring turbulent fluxes of aerosol particles and their precursors. We have a unique possibility to study biosphere – aerosol – cloud –climate interactions, since we have real interdisciplinary team. We have COSMOS earth System Model (Max Planck Institute, Hamburg) and it can readily be modified and run in the project. Satellite data is also used together with point measurements and 3D-models. Scientists involved in our research unit are key figures in international scientific organisations and networks such as ICCP, IGAC/IGBP and iLEAPS/IGBP.

The main focus of our existing research unit has been in the following topics (for all topics we have published several papers either in Nature or Science): 1) formation and growth mechanisms of atmospheric aerosols, aerosol dynamics: (Kulmala et al., *Nature*, 2000; Kulmala, *Science*, 2003; Berndt et al., *Science*, 2005; Tunved et al., *Science*, 2006) 2) the effect of secondary biogenic aerosols on global aerosol load: (O'Dowd et al., *Nature*, 2002a; O'Dowd et al., *Nature*, 2002b; O'Dowd et al., *Nature*, 2005) 3) aerosol-cloud-climate interaction: (Kulmala et al., *Nature*, 1997; Charlson et al., *Science*, 2001) 4) the relationships between the atmosphere and different ecosystems, particularly boreal forest: (Valentini et al., *Nature*, 2000; Hari et al., *Nature*, 2003; Ciais et al., *Nature*, 2005). The scientists working in the new CoE have published over 400 scientific papers in per reviewed journals during the last five years.

Expertise available through different collaborations with world leading scientists will provide new joint tools to tackle these fundamental scientific questions. E.g. the analytical techniques developed at the Center for Aerosol and Cloud Chemistry by the Director, Dr. Douglas Worsnop is at the leading edge in the world wide atmospheric aerosols community. Combining this knowledge with the expertise available at CoE will provide completely new possibilities to find solutions to these relevant and challenging scientific questions. This collaboration will strengthen our role as the world leading centre for atmospheric aerosol studies, especially in the area of aerosol mass spectrometry.

In connection to every WP we have listed several (altogether 22) potential breakthroughs.
Due to the long experience and recent outstanding results (e.g. Kulmala *et al.*, 2000; O'Dowd *et al.*, 2002a; Kulmala *et al.*, 2004b; Tunved et al., 2006) on aerosol formation and growth studies we have a unique possibility to find out the significance of the different formation and growth processes in atmospheric conditions. The results can be applied in understanding biogeochemical cycles, biosphere-aerosol-cloud-climate interactions, and specifically in estimations of the global effects of aerosol particles. The experimental results on small clusters and nanoparticle composition accompanied by theory developments are crucial in interpretation of the data obtained in different international field campaigns.

3. ■ Inter-[1] and multidisciplinary[2] work in the research programme, if any.

In order to be able to answer questions related to our objectives interdisciplinary approaches are needed. Our research groups in Finland are pioneers in utilising interdisciplinary methodologies and approaches in this field. We have, purposely, worked towards common goals for the last 15 years over the boundaries of two different faculties, Faculty of Science and Faculty of Agriculture and Forestry. Figure 3 shows schematically how chemistry, biology, physics and meteorology are related to each other and in which way we have utilised different disciplines. As an example we take organic compounds: since organic compounds are involved in aerosol processes and VOC emissions are linked to photosynthesis (although a mechanistic explanation of the linkage is weakly known) the research plan includes also extensive studies on ecophysiological phenomena, atmospheric chemistry, aerosol physics and analytical chemistry as well as micro and mesometeorology. Furthermore, photosynthesis is linked to phloem-xylem water and sugar transport processes, which still lacks the final physico-biological explanation. Naturally, part of the research has more multidisciplinary nature, but the main philosophy behind the objectives and the working methods of CoE are interdisciplinary.

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[1] Interdisciplinary approaches integrate separate disciplinary data, methods, tools, concepts, and theories in order to create a holistic view or common understanding of a complex issue, question, or problem. They go beyond a simple sum of the parts.
[2] Multidisciplinary approaches juxtapose disciplinary/professional perspectives, adding breadth and available knowledge, information, and methods. Members of a research team perform their work separately and supply separate reports. They do not iterrogate the status quo.

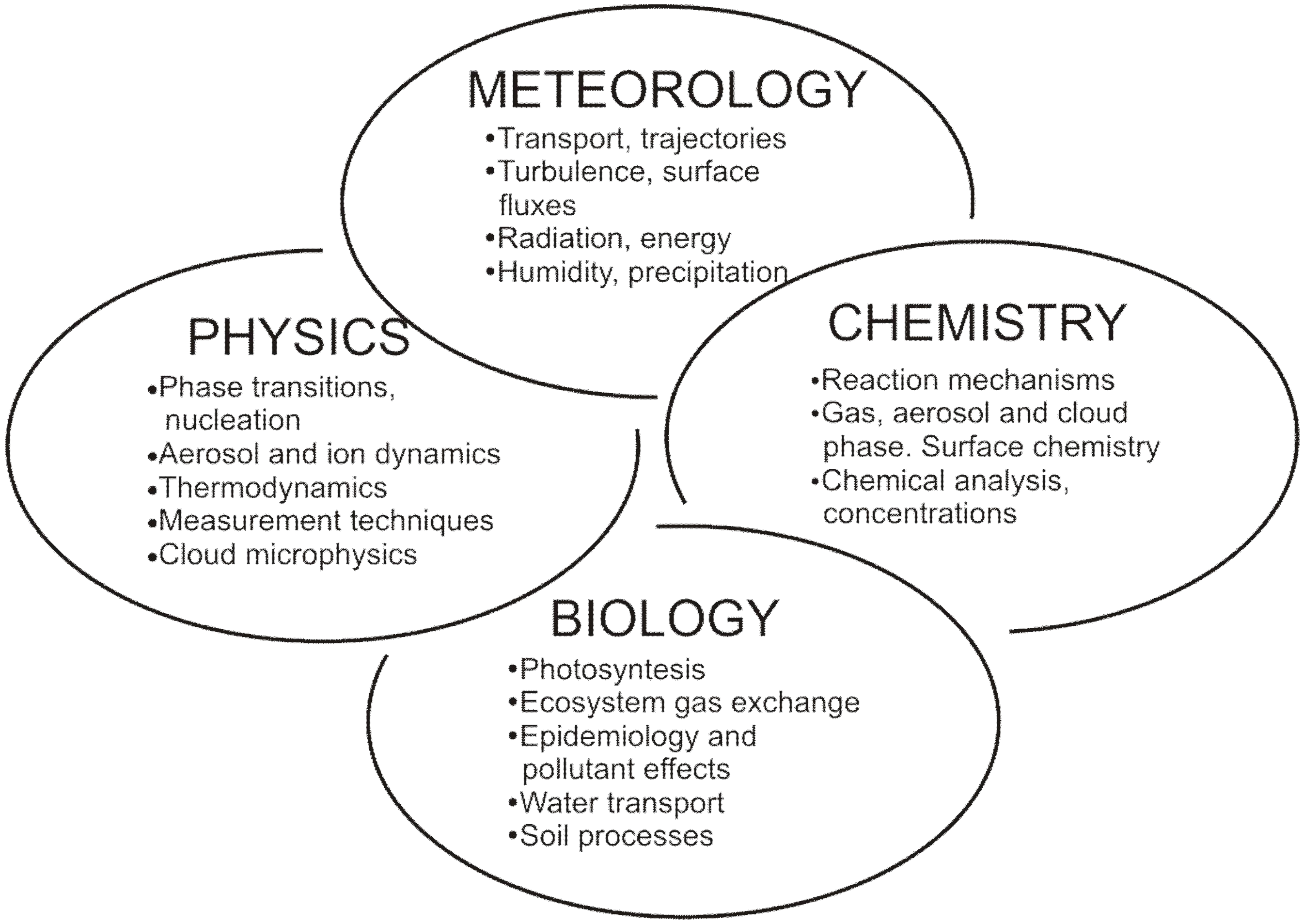

Figure 3. *Scheme of cross and multidisciplinarity of the CoE. All fields of CoEs science interlink closely to form much more effective scientific unit than the sum of the individual disciplines.*

4. ■ Integration of research with the host organisation's strategies.

A) University of Helsinki

The CoE proposal is in accord with the strategy of the University of Helsinki and especially with the strategy of the Department of Physical Sciences for 2004-2008, which states the following:

The mission of the Department of Physical Sciences is (i) to provide highest education at master and PhD levels in physical sciences (physics, theoretical physics, geophysics, meteorology), (ii) to perform internationally recognized high-level research in physical sciences and (iii) to generate, through teaching and research, knowledge that can be utilized in the society.

One of the focus areas of the Department activities is the development of research a) by facilitation of excellence in research and in education and b) by increasing multidisciplinary collaboration in research and education. The CoE proposal is clearly in agreement with these ideas. It should also be noted that atmospheric science is one of the main research areas of the Department, and that multidisciplinary environmental research belongs to the strategic focus areas in the University of Helsinki, at the levels of

Department, Faculty, and University. A good example of realisation of the strategy is the support received by the National Centre of Excellence “Research Unit on Physics, Chemistry and Biology of Atmospheric Composition and Climate Change”, as well as the two related Nordic Centres of Excellence. Also the systematic support to the extensive collaboration (see below) between the University of Helsinki and the Finnish Meteorological Institute is a manifestation of a strategic choice. The new CoE will clearly strengthen the atmospheric research at the University of Helsinki.

The proposal is also in accord with the strategy of Department of Chemistry and Department of Forest Ecology. They share the main objectives of education and research in their own fields. The proposal is in the core area of the strategy of the Department of Forest Ecology as one of their main tasks is to promote sustainable use of forest resources.

B) University of Kuopio

The strategy of the University of Kuopio states that the focus areas of the University are health sciences and environmental sciences, and related fields of technology and information sciences, and that the mission of the University is to increase the level of knowledge, know-how, and education through internationally high-level research and teaching. One of the focus areas related to the development of research is recruiting of foreign top-level researchers.

The strategy of the Faculty of Natural and Environmental Sciences states that the mission of the Faculty is to perform internationally high-level research that advances the well-being of the environment, and aerosol science is listed as one of the focus areas. The strategy of the Department of Physics emphasizes the international visibility of research. The CoE proposal is directly connected to these strategies. The University of Kuopio has consistently supported environmental research and especially aerosol science. Good manifestations of this are the support given to the National Centre of Excellence “Research Unit on Physics, Chemistry and Biology of Atmospheric Composition and Climate Change”, and the joint professorship created in 2004 together with the Finnish Meteorological Institute.

C) Finnish Meteorological Institute

The CoE proposal is in direct relation to the mission and activities of FMI, i.e. performing high-level atmospheric research. FMI has for years collaborated with the Universities of Helsinki and Kuopio. Examples of the collaboration include a measurement station at the Kumpula campus in Helsinki; widespread co-operation with the measurement station network outside the Helsinki area (Hyytiälä, Pallas, Helsinki, Puijo), atmospheric modelling projects, joint professorships with both Universities, and joint plans to establish a European Centre of Atmospheric Sciences (ECAS).

5. ■ The CoEs funded in the programmes 2000-2005 or 2002-2007 should compare its new research and action plan to the previous plans. It is essential to describe the innovativeness and renewal of the new research plan.

The main underlying theme in the new CoE is the generalization and synthesis of obtained results, and utilisation of them in the global scale modelling, based on the understanding of coupled atmosphere-biosphere processes stemming from coherent inter- and multidisciplinary approaches. Compared to the present CoE, the new one approaches the problem in a much larger spatio-temporal scale ranging from molecular clusters (WP 2) to changes taking place in a global scale over tens of years (WP 5). Complementary use of measurement and modelling activities and development of parameterizations are now part of all work packages. A completely new aspect is the development and application of new instrumental techniques for detection of neutral and ion clusters as well as multitude of organic compounds together with chemical analysis of nm-scale particles (WP 1, 2 and 4). New theoretical approaches and model developments are also involved, since they tackle still widely unknown processes such as dynamics of clusters, ice nucleation and ecophysiological controls of organic compound production (WP 2, 3 and 4).

In structural point of view the new CoE consists also a new research group lead by prof. Marja-Liisa Riekkola. Also, prof. Pertti Hari is replaced (due to retirement) by prof. Eero Nikinmaa. Both still represent the same research area. In addition, the conditions for still more efficient and successful researcher training are much better in the new CoE (see answers to question 18). While the present CoE started without any formal training structure, the new CoE will be linked to two graduate schools (international and national ones) and one international master programme.

Personnel

6. ■ Personnel (as full-time equivalents, FTEs) of the proposed CoE in 2008 (**Forms 1a-1b**). FTEs should be counted as a proportion of the time used for working as a member of the proposed CoE. Please note that collaborators are not listed here (see items 10 and 11 under “Cooperation and organisation of activities”).

Forms 1a and 1b

Funding

7. ■ Funding planned for the years 2008-2013 (**Forms 2a-2b**).

Forms 2a and 2b

8. ■ A plan on how the CoE expects to continue the work it has done during its term as CoE in the event that it is no longer involved in the next CoE programme (exit strategy).

Exit Strategy

The main innovative “free” funding is related to CoE funding forming a basis to work in Nordic, European and Global level projects and networks. However, although essential, CoE funding is ca 10% from the whole funding. Our strategy is

a) to do our best to continue as CoE
b) in the case that we eventually are no longer involved in CoE program, we will seek other funding sources and also we need to partly prune the present research plan

2 Research environment

Cooperation and organisation of activities

9. ■ What would be the specific value to be added in working as a centre of excellence in 2008-2013 as compared to working as the researchers are working without such status?

The specific values of working as a Centre-of-Excellence are

- Greater national and international visibility and profile in the scientific world outside our individual areas of research.
- Stability and secured continuous funding to enable completion of the research programme, along with the ability for streamlined project management.
- Increased possibilities for outstanding research, through tight integration between research activities and increased research time as opposed to time spent on procurement of funding
- Spirit of being CoE creates its own working atmosphere for 1st year summer workers to senior scientists

10. ■ Systematic and deep cooperation with **foreign** research units and research teams during 2008-2013. Describe the collaboration in a table: collaborators, form of collaboration and expected results. Single out significance of this cooperation and contribution of the partners to the implementation of the research plan of the proposed CoE.

Our research groups have direct working connections to more than 60 international laboratories and has participated in more than 35 EU-projects. One example of deep and wide cooperation is the European Integrated Project on Aerosol Cloud Climate Interactions (EUCAARI) during 2006-2010. We host the international project office of iLEAPS (Integrated land Ecosystem – Atmosphere Processes Study) programme. We have also working connections to IPCC (International Panel of Climate Change) and IGAC (International Global Atmospheric Chemistry) programmes. We are participating e.g. in global Fluxnet (flux tower network) and GAW (Global Atmospheric Watch) programs and international field campaigns to investigate atmospheric aerosols and tropospheric chemistry.

Our CoE has an international leading position in the research area of formation of atmospheric aerosols and one of the most visible members in the community of biogeochemical cycles, especially of carbon dioxide and energy fluxes. Our research unit organises international conferences, workshops and seminars on our scientific areas of interest. The working links with other units and teams are the essential part of the implementation of the research programme in the form of the research visits, common field campaigns and training of the students.

The most important co-operating foreign research units and teams are given in Table below:

Collaborator	Form of Collaboration (all includes joint articles)	Results	Significance
Aerodyne Ltd, Boston, USA; Douglas Worsnop	Visiting professor	New experimental innovations and new type of field data	Essential to nano-scale cluster measurements
LSCE; Philippe Ciais	Student / post doc exchange	Greenhouse gases	Essential to carbon, nitrogen etc. balance determination
California Institute of Technology, USA; John Seinfeld	Student / post doc exchange	Aerosol-cloud-climate interactions	Important to atmospheric chemistry, and aerosol-cloud-climate interaction investigations
CSIRO, Canberra, Australia; John Finnigan, Tanja Suni	Student / post doc exchange	Field data on aerosol formation and methodological improvements of flux measurements	Essential for verifications for different ecosystems and more reliable measurements
University of Göteborg, Sweden; Leif Klemedtsson	Student / post doc exchange	Carbon isotope measurements	Helps in biosphere-atmosphere exchange analysis
Harvard University, USA; Steve Wofsy	Student / post doc exchange	Biosphere-atmosphere exchange	Covers different ecosystems for exchange studies
Julich Research Centre (FZJ); Thomas Mentel	Student / post doc exchange	Plant and atmospheric chamber, chamber experiments	Essential to related plant emissions and aerosol growth studies
Karpov Institute of Physical Chemistry, Moscow, Russia; Alex Lushnikov	Visiting professor	Development of nucleation theories	Essential for improved understanding of fundamental processes
University of Leeds; Ken Carslaw	Student / post doc exchange	Global modeling	Essential for global modelling perspectives
Max-Planck Hamburg Joachim Feichter	Student / post doc exchange	Climate modeling, ESM, COSMOS	Crucial for climate modeling
NCAR, Boulder; Jim Smith, Alex Guenther	Student / post doc exchange	Instrument development, aerosol chemistry	Essential for aerosol chemistry
National University of Ireland, Galway, Gerard Jennings, Colin O'Dowd	Student / post doc exchange	Aerosol data for verifications and access to Mace Head Atmospheric Research Station	Important to aerosol dynamic
Risoe National	Student / post doc	Field data on various	Essential for

Laboratory, Roskilde, Denmark; Kim Pilegaard	exchange	fluxes and methodological improvements of flux measurements	verifications for different ecosystems and more reliable measurements
University of Bayreuth, Germany; Thomas Foken	Student / post doc exchange	Methodological improvements of flux measurements	Essential for mor reliable measurements and footprint analysis
University of Copenhagen; Merete Bilde,	Student / post doc exchange	Thermodynamics	Essential to obtain thermodynamic data
University of Edinburgh, John Grace	Student / post doc exchange	Ecophysiological analysis	Essential for fundamental understanding of ecophysiological processes
University of Lund, Sweden; Anders Lindroth, Erik Swietlicki, Almut Arneth	Student / post doc exchange	Flux data from different ecosystems for various compounds and integrated modelling of biosphere-atmosphere interactions	Essential for verifications for different ecosystems and up-scaling of results
University of Minnesota, Peter McMurry	Student / post doc exchange	Atmospheric nucleation	Essential for studies at diffent environments
University of Stockholm, Sweden; H.-C. Hansson, Douglas Nilsson	Student / post doc exchange and visiting professors	Atmospheric aerosols, Boundary Layer Models	Essential for Nordic studies and co-operation
University of Tarto; Hannes Tammett, Aadu Mirme	Student / post doc exchange	Air ions	Essential for developing new instruments for cluster studies
University of Vienna, Austria; Paul E. Wagner	Visiting professors and Student / post doc exchange	Laboratory data on phase transition and coagulation processes	Essential laboratory results for development of more reliable atmospheric nucleation and aerosol dynamic models
University of Viterbo, Italy; Riccardo Valentini	Student / post doc exchange	Biosphere-atmosphere interactions	Essential for European flux studies
University of Washington, USA; Robert Charlsson	Student / post doc exchange	Cloud microphysics	Improving general understanding of Cloud microphysics
INRA Bordeaux, France, Roderick Dewar and Dennis Lousteau	Student / post doc exchange	Ecophysiological analysis, GPP modeling	Robust model for GPP estimation

11. ■ Systematic and deep cooperation with **Finnish** research units and research teams (either in the same organisation or in other organisations) during 2008-2013. Describe the collaboration in a table: collaborators, form of collaboration and expected results. Single out significance of this cooperation and contribution of the partners to the implementation of the research plan of the proposed CoE.

Collaborator	**Form of Collaboration (all includes joint articles)**	**Results**	**Significance**
Finnish Environmental Research Institute	Exchange of ideas and data	Development of carbon and nitrogen cycle models and field and laboratory data on cycles	Essential to improved understanding of carbon and nitrogen cycle
Finnish Forest Research Institute	Exchange of ideas, students and data	Modelling and measurements of soil processes	Essential for improved understanding of fundamental soil proceses
Finnish Institute of Occupational Health	Common professorship, exchange of students and data	Field studies on health effects of aerosol particles	Essential for improved understanding of health-related phenomena
Helsinki Institute for Information Technology	Exchange of post docs, students, ideas and data	Development of data mining techniques for atmospheric data	Important to understand large data sets
Technical Research Centre of Finland,	Exchange of ideas, laboratory data and field data	Aerosol dynamics	Important for improved understanding of aerosol emissions (industry + traffic)
Tampere University of Technology,	Exchange of ideas, laboratory data and field data	Aerosol tenchology	Essential for understaning air ions and aerosol measurement technique
University of Kuopio, Department of Environmental Sciences	Exchange of ideas, students and field data	Field data on nitrogen fluxes	Important for verifications for different ecosystems
University of Oulu,	Exchange of computer codes	Molecular level simulations	Important to achieve proper potentials for simulation

The working links with other units and teams are the essential part of the implementation of the research programme.

12. ■ Possible collaboration with enterprises. What kind of collaboration?

The co-operation with several industrial enterprises already exists. During the CoE period we aim to enhance our co-operation with Vaisala Ltd, Nokia Ltd, Dekati Ltd and Genano Ltd in Finland, and AIREL ltd in Estonian and also Aerodyne Ltd in USA. The American working ideas related to research enterprises will be applied in the Finnish conditions, particularly in co-operation with Dr. D. Worsnop. This kind of highly innovative companies would enhance the innovation networks and chains in Finland.

Management and cohesion between research teams

13. ■ Organisation and practices of the scientific and administrative management of the proposed CoE including organisation chart.

■ The scientific cooperation and division of tasks between the proposed CoE leader, the team leaders and the various research teams.

■ The administrative relationship and division of tasks between the proposed CoE leader and the team leaders.

The leadership by the unit leader (coordinator) and unit board will give the direction and the guidelines for the research unit. The unit represents a broad scientific and technical competence and the individual members of the unit board complement each other to manage the specific tasks of the project in an efficient and most cost effective way. All members of the unit board are also jointly the Work Package leaders, establishing a clear link between individual Work Package tasks and overall CoE objectives. The administration strategy aims to keep all the partners fully informed about the status of the research program, planning issues and all other issues which are important to partners in order to obtain maximum transparency for all involved and to increase the synergy of the cooperation. The communication strategy (plans for publications, conference presentations, etc.) will be discussed, and day-to-day progress during the project will be monitored through frequent communication via Internet (e-mails and project web pages), telephone, informal and formal meetings, fax and mail. The workpackages are led by the person mentioned first in the beginning of the WP description in the research plan. CoE organizes regularly general information, discussion and planning meetings for the whole staff as well as smaller meetings (5-10 persons) in individual research areas and WPs.

At the beginning of CoE an International Advisory Group (IAG) will be established. The role of the IAG is to act as external non-dependent board to help the unit board and coordinator to fulfill the CoE objectives and to give new points-of-view in strategic development of the CoE.

The core of research unit is the APFE-group, which was established 1990 by the Laboratory of Aerosol and Environmental Physics in the Department of Physics and by the Department of Forest Ecology. The cooperation between laboratories had already started in 1979. The group is directed by Professors Markku Kulmala and Pertti Hari and APFE was appointed Centre of Excellence at University of Helsinki for 1997-2001. Timo Vesala leads his own group working under APFE. The close co-operation between different scientists from APFE and FMI started in 1985, consisting of numerous common projects and publications as well as common researchers and students. For example, Yrjö Viisanen is a docent in physics at the University of Helsinki, while Ari Laaksonen was a member of APFE group before receiving his professor position at the University of Kuopio, where he established his own research team. His group still has very close scientific co-operation with APFE and FMI groups. Marja-Liisa Riekkola has started her co-operation with Kulmala in 1997. After that her laboratory has established closer co-operation with existing CoE and will now be a full partner in new CoE. The relationship and means of communication and administration between the team leaders within the unit have been fine-tuned through years of collaboration and personal contacts.

In our CoE we have six research groups. Coordinator, Academy professor M. Kulmala (professor in physics, Univ. of Helsinki) is leading a research group in Aerosol and Environmental Physics (atmospheric aerosols and air ions) consisting of 40 people. Prof. Ari Laaksonen (professor in environmental physics, UKU) is a leader of the Aerosol Physics research group consisting of ca. 20 people. Prof. Eero Nikinmaa (professor of silviculture) steps in after professor Hari (retiring in 2008) to lead the research group of about 15 people in ecophysiology and ecosystem dynamics (Univ. Helsinki, Dept. Forest Ecology). Prof. Marja-Liisa Riekkola (Professor in analytical chemistry, University of Helsinki, Department of Chemistry) is leading a research group ca 25 people in the field of analytical instrumental techniques. Prof. T. Vesala (Professor in meteorology, Univ. Helsinki) is leading a research group of ca 10 researchers (micrometeorology, biosphere-atmosphere interactions). Professor Yrjö Viisanen (Director of research and development unit in Finnish Meteorological Institute) is leading a research group of about 30 people in the area of Atmospheric Composition and Climate Change. Every Ph.D. student is nominated to one specific research group, but most of the students have supervisors from different groups and many have cross-disciplinary topics for their theses.

The following diagram (Figure 4) illustrates the connections between the research teams and team leaders.

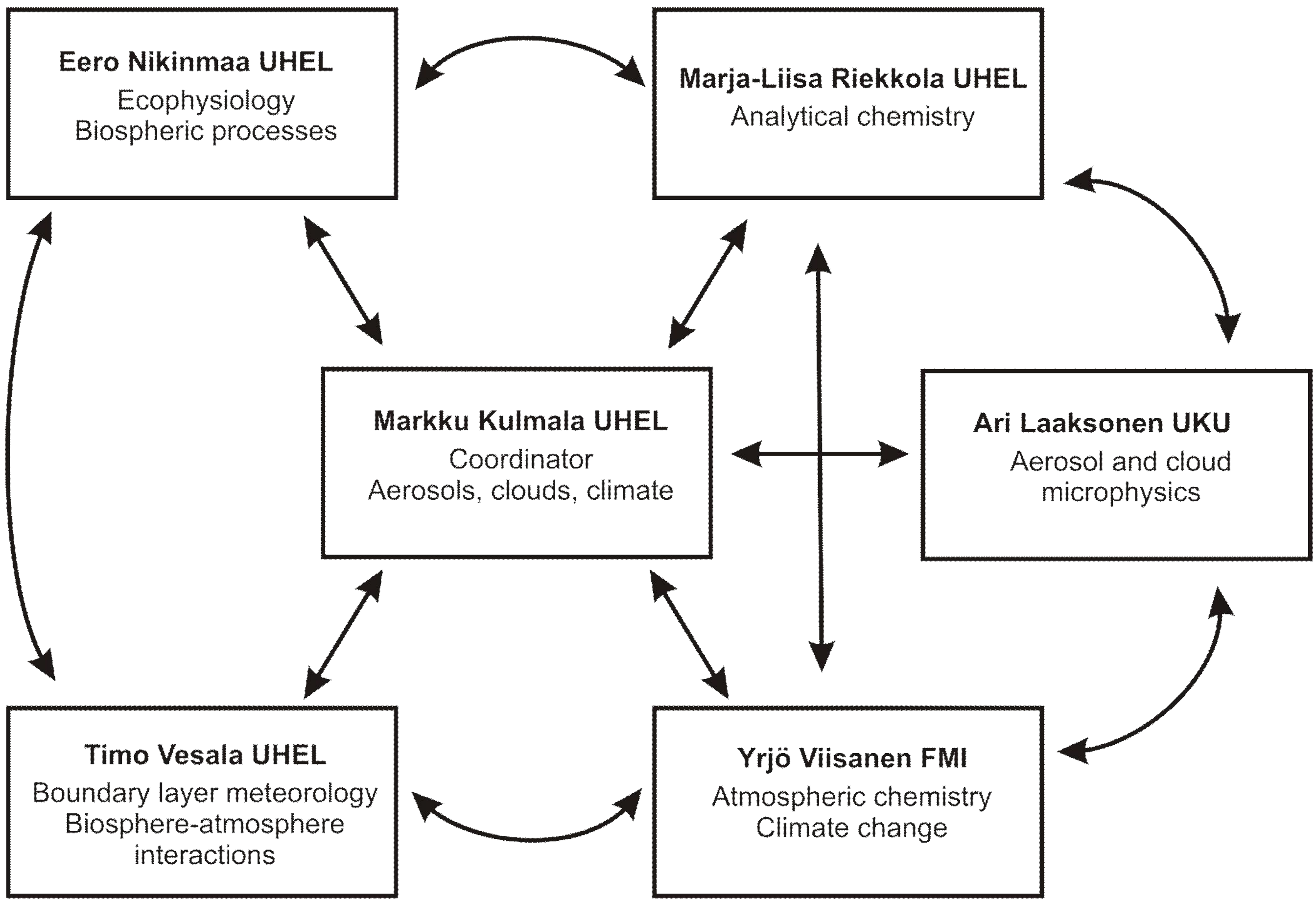

Figure 4. *CoE Chart, Unit board specialities and interactions.*

Promotion of research careers

14. ■ Concrete actions to promote research careers of women and young researchers in the proposed CoE.

Our research unit comprises a total of 123 researchers, including 14 females in senior and doctor positions, and 30 female students. From this total, 33 % are under 30 years old. The research careers of female and young scientist will be promoted by supporting their individual ideas, giving to them creative and fruitful topics for investigation and by helping their international contacs as well as their daily life problems in an equal-opportunity manner. Every year many summer workers are recruited from students attending 2^{nd}-3^{rd} year courses. It is important that students obtain touch and feeling of day-to-day routines of scientific work as early as possible. Several regular summer schools and field courses promotes united actions of students and young and senior scientists.

Facilities

15a. ■ Present facilities of the proposed CoE (premises, equipment, instruments, material, data, archives, libraries etc.).

The Finnish research groups operate five different field stations (see Figure 5.), and all data and analysed results as well as infrastructures themselves are generally available. All of field stations have comprehensive scientific program to investigate aerosol and trace gas concentrations, biosphere-atmosphere interactions, aerosol formation and growth and biogenic background for processes leading to aerosol formation. Also comparisons between urban environment and natural environment can be done by comparing urban stations with background stations. The stations are GAW (Global Atmosphere Watch) station in Pallas (FMI, 1994-), Puijo Tower (FMI and UKU, 2005-) and three SMEAR stations (SMEAR I, Värriö, 1991-; SMEAR II, Hyytiälä, 1994-, Urban SMEAR III, Kumpula, Helsinki, 2004-). So far the investments to stations are around 20 MEuro. Particularly SMEAR II has turned out to be a leading station in field due to its comprehensive research program and to its unique time series of fresh aerosol formation.

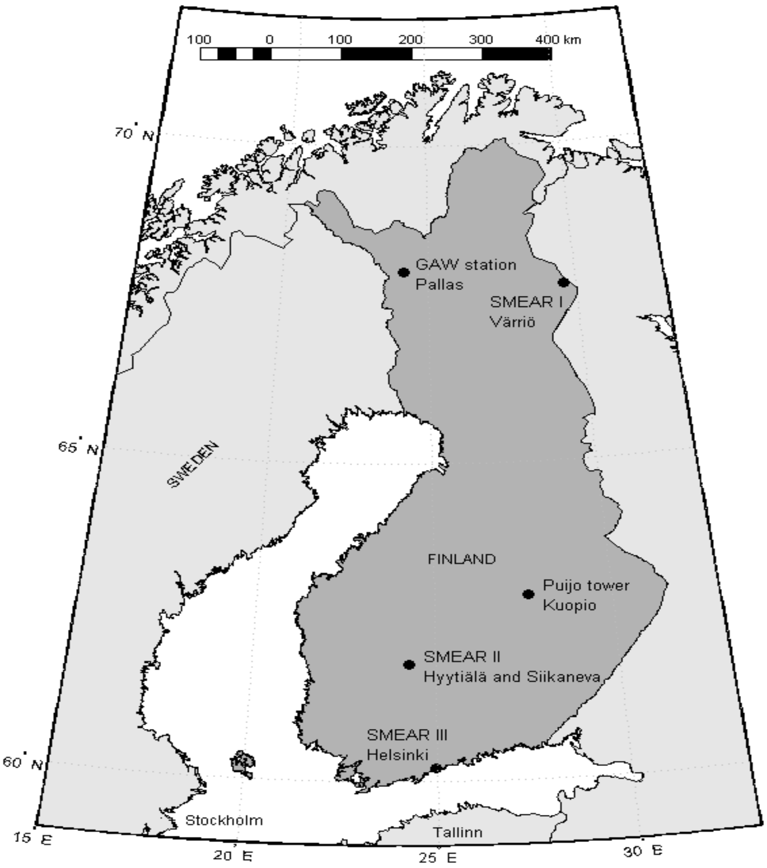

Figure 5. *Location of field stations*

We have also possession of a) aerosol and micrometeorological instruments for field campaigns; b) 2 laboratories for research of aerosol microphysics (Department of Physical Sciences, UHEL and Department of Applied Physics, UKU); c) laboratory for plant gas exchange measurements (Department of Forest Ecology); d) laboratory for studies of nucleation of aerosol particles (FMI); e) laboratory for analysis of volatile organic compounds (FMI); f) computer codes for aerosol dynamics, cloud microphysics, nucleation, condensation/evaporation; g) databases from field stations.

15b. ■ Core facilities used jointly by various units of an umbrella organisation (e.g. a Biocenter): premises, equipment, instruments, material, data, archives etc. (To be answered only by proposed CoEs belonging to an umbrella organisation.)

Core facilities are SMEAR II field station (Hari and Kulmala, 2005) and iLEAPS (http://www.atm.helsinki.fi/ILEAPS).

SMEAR II

SMEAR II (Station for Measuring Forest Ecosystem--Atmosphere Relations) station is located in a rather homogenous Scots pine (*Pinus sylvestris* L.) stand on a flat terrain at Hyytiälä Forestry Field

Station of the University of Helsinki (61°51'N, 24°17'E, 181 m above sea level) 220 km NW from Helsinki. The managed stand was established 1962 by sowing after the area had been treated with prescribed burning and light soil preparation. The station represents boreal coniferous forest, which covers 8% of the earth's surface and store about 10% of the total carbon in terrestrial ecosystem. The biggest city near the SMEAR II station is Tampere, which is about 60 km from the measurement site with about 200 000 inhabitants. For more details see e.g. Kulmala et al. (2001). Another long-term field site for carbon (carbon dioxide, methane and VOC) and energy exchange studies and soil (peat) processes is located close to SMEAR II station at Siikaneva wetland (fen) area.

In SMEAR II, measurements are made in a number of storage pools and interfaces involving three different layers extending from the soil to the atmosphere (Figure 6). Several different methods, operating simultaneously but at different spatio-temporal scales, are applied to monitor the material and energy fluxes between the different pools in Figure 6 and to understand the processes responsible for these fluxes. For example, the surface between a tree and atmosphere, or between the soil and atmosphere, can be closed in a chamber, and the corresponding flux of interest is determined from the mass balance of the chamber. Turbulent fluxes can be measured by micrometeorological techniques. Concentration gradients in the air and soil can also be used for making flux estimates by applying available transport coefficients. Electric sensors are available to measure radiation fluxes. In more details see Hari and Kulmala (2006).

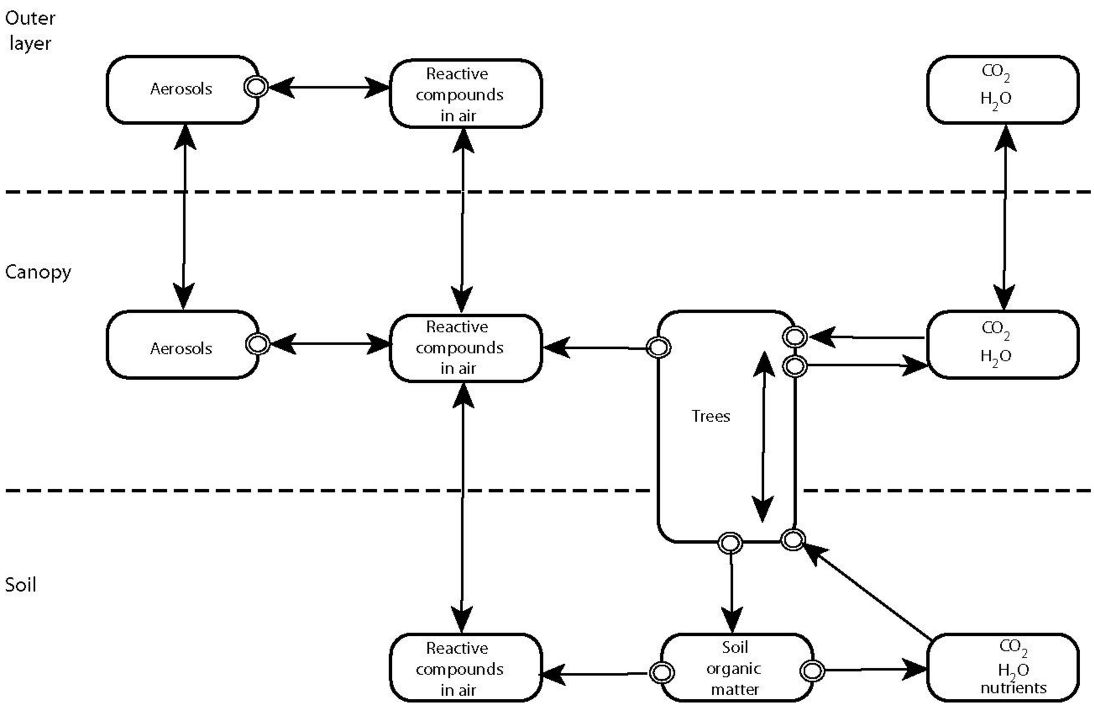

Fig. 6. *Most important storages, flows and processes in a forest ecosystem and between the ecosystem and atmosphere. Boxes indicates storages, arrows flows and double rings processes.*

The main components of SMEAR II are i) an instrumented, 73-m-tall mast, ii) systems for monitoring aerosols and air ions, iii) an instrumentation for monitoring tree functions and radiation (by two 25 m towers) and iv) two instrumented mini catchments. The mast monitors CO_2, H_2O, CO, O_3, SO_2, NO, NO_2, temperature and wind speed profiles, properties of solar and thermal radiation of the stand and fluxes of CO_2, H_2O, O_3 aerosols and several volatile organic compounds between the canopy and atmosphere. The mast measurements are usually reported as half- hour means (for more details see Kulmala et al., 2001). Aerosol and ion size distributions are measured in order to be able to detect ion, cluster and aerosol dynamics. Chamber technique is used to monitor tree processes generating the fluxes between trees or soil and atmosphere. The most relevant processes are: photosynthesis, respiration, transpiration, NO_x emission and deposition, O_3 deposition and emission of volatile organic compounds. The fluxes between the soil and atmosphere, as well as between the soil and canopy, are also important. The catchments are closed with a dam and the run off from the area is monitored. The leakage of substances with the run off is monitored by taking samples for chemical analysis. The water content and tension, CO_2 and temperature profiles are monitored. Solar radiation is the source of energy for several processes in trees and atmosphere. This is why irradiance, diffuse irradiance, photosynthetically active radiation and radiation balance are monitored above the canopy. Stem diameter changes are monitored both above and under bark continuously with the precision less than 1 μm. This allows us the indirect estimation of water tension in xylem and phloem, which is ecophysiologically important parameter but very difficult to determine.

One of the basic principles of CoE research groups has been the utilization of continuous, long-term field measurements. Therefore the system operates the year around, and only those rare instruments, which may be damaged by freezing water, are turned off during winter. In addition, the growth of the trees around the measuring station has been measured retroperspectively to the age of three years. All data is available for the research community in the database of SMEAR II and much of data is also available at various databases of international projects (like CarboEurope) and programmes (like Fluxnet). Note finally, that the description given above provides only general methodological framework and most important measurement set-ups. The SMEAR II station is actually all the time under development due to construction and installation of new set-ups or modifications of existing ones.

iLEAPS

iLEAPS (integrated Land Ecosystem Atmosphere Processes Study) is the land-atmosphere project within the framework of the second phase of IGBP. It aims to improved understanding of processes, linkages and feedbacks, and changes due to human activities in the land-atmosphere interface affecting the Earth System. The research ranges from cell level to global scale, diurnal to centennial and past to future. It encourages international and cross- and multi-disciplinary collaboration. The main themes are land-atmosphere exchange, feedbacks between land biota, aerosols and atmospheric composition, teleconnections in the land surface-atmosphere-water-system, transfer of material and energy in the soil/canopy/boundary-layer system. Both measurements and modelling of interaction processes are applied.

iLEAPS provides the forum and facility which support directly the themes and work packages of CoE. It is especially important regarding the linkages of different tasks and merging the results by means of Earth System Modelling.

15c. ■ New facilities needed in the period 2008-2013, if any.

The field stations of CoE are under continuous reconstruction and development, although the basic facilities remain the same. The most significant improvements concern instrumentation and set-up for atmospheric chemistry further linked to aerosol formation. OH-radical and sulphuric acid concentrations are known to be key factors and their continuous measurements are needed. While the instrumentation for measurements of charged nano-scale clusters have been recently available, the urgent need is for continuous measurements of neutral clusters. They form a kind of “missing link” in the context of biogenic aerosol formation and among molecular, neutral cluster and aerosol concentrations, which are far better known. Also nucleation mode aerosol composition is an essential component to be determined.

A chemical compound important also for biogeochemical cycles, beside aerosol-linked atmospheric chemistry, is ammonia. There exist also instruments for direct micrometeorological NH_3 flux measurements, but under low background concentrations and small fluxes the determination of the flux is a challenge. Direct flux measurements of NO/NO_2 are also missing. Since direct flux measurements are not possible for all gases or some methodological improvements are still required for reactive gases its is important to determine the exchange rates by different, but simultaneous approaches. As traditional chamber measurements may be also prone to biases for several reasons, the most recent and promising method is based on the determination of concentration gradient in the soil and the assessment of the flux using the known, but dependent on soil properties, transport coefficient. The gradient could be determined by required accuracy, for example gases like CO_2, CH_4 and N_2O.

New instrumentation is also needed to improve other field stations and laboratories.

Promotion of creative research

16a. ■ Describe how the research and other activities of the proposed CoE would foster the development of the wider (i.e. outside the proposed CoE) research environment in its field of study.

The Unit will promote creative research by

- Supporting creative ideas and aims with risk of failure
- Supporting international collaboration
- Acting as source of ideas as well as a test bench for them.

16b. ■ By which means would the proposed CoE promote the development of creative research and training environments?

- Participation in European and global research networks
- Participation in Nordic graduate school and international master program
    - Developing courses, seminars etc. for those programs
- Organising international scientific conferences such as the European Aerosol Conference, International Aerosol Conference (will be held in Finland in 2010), International Conference on Nucleation and Atmospheric Aerosols or iLEAPS science conferences.
- Organising international scientific workshops and seminars like workshop on formation of atmospheric aerosols, aerosol fluxes, photochemistry and aerosol formation, micrometeorology
- Scientists in our CoE have and will have freedom and full support to follow their new ideas within the wide scope of CoE

Contribution to various sectors of society

17. ■ The applicability and national / international relevance of the research carried out by the proposed CoE.

■ Possible contribution to any new cultural / social / technological findings or innovations.

■ Contribution to nationally / internationally important debate of current interest.

The CoE will help us understanding the formation and growth of atmospheric aerosol particles, therefore it will contribute directly to the current debate concerning the National and European Union Strategies for Sustainable Development and the European Strategy for Environment and Health. Its contributions will include tackling the role of anthropogenic and natural factors on climate change, air quality, public health, and quality of life. The European implementation of air quality standards and coherency of all air legislation and related policy initiatives is expected to take place during the next ten years. The basis for this challenging task is the enhanced understanding of emissions and the corresponding atmospheric processes.

The CoE brings a lot of new information on the global climatic effects of aerosol particles and trace gases and their interactions with chemical and biological processes as well as on indirect feedbacks. The results can be applied in Finnish and European environmental policy like in giving air pollution directives and deciding the climate policy. The results can also be applied interpreting the data obtained in different international and national field campaigns and in studies of biosphere-atmosphere interactions, especially in estimating the source and sink strengths of particulate and gaseous compounds. Long-term flux measurements, as a part of the global community, help to estimate spatio-temporal changes in carbon sinks and hydrological cycles leading to more accurate knowledge for decision-makers to use in multinational negotiations for mitigation of climate change.

The work contributes directly to research on climate change and constraints of biological and anthropogenic factors. The Intergovernmental Panel on Climate Change (IPCC) gave in their 2001 report an estimation of the globally and annually averaged radiative forcing for direct and indirect contributions of greenhouse gases and direct and indirect aerosol effects. Since each of these contributions reflects the integrated effects of various anthropogenic and biogenic pathways, a critical task is to describe the content of each contribution, its sources and reduce the uncertainties. Climate change is very wide and global problem tightly connected to other global problems like air pollution and all these uncertainities should be studied simultaneously. Particularly we contribute to the debate on artic and boreal environmental changes. This kind of wide perspective will also support European governmental policy, since European countries have also typically signed the Vienna Convention on the Protection of the Ozone Layer and the Convention of Long-range transport of Air Pollutants.

The results are relevant to assessments by IPCC, to verification of the Kyoto protocol and to measures to control and mitigate emissions of gaseous and particulate pollutants. The non-scientific end-users of the data (such as forestry or public health monitoring bodies) are informed using distributed written material and press conferences and invitations to project meetings. At the midterm and end of the project a workshop for dissemination of the results and data will be organised. UHEL is presently working also in close co-operation with elementary and high-schools to familiarise pupils and students with simple analyses of environmental data and the scientific world, and by means of generating improved awareness of environmental awareness and issues.

From a technological point of view, new aerosol, cloud droplet and trace gas instruments will be developed, and the environmental information technology will be promoted. The co-operation with several industrial enterprises already exists. The aim of co-operation with companies is to develop new instrumentation for aerosol and cloud droplet as well as trace gas detection and investigations.

3 Success and potential of the proposed CoE in researcher training

18. ■ Organisation of researcher training (supervision, methods) in the proposed CoE.

■ International cooperation in researcher training.

■ Involvement of the proposed CoE in graduate schools.

The research group has a long and successful experience on research training. In 2001-2005 38 doctors have been educated in our research unit. The Ph.D. students involved in our research have detailed student plans and their realistic aim is to finish their Ph.D. thesis in 3-4 years. Nordic graduate school CBACCI started in 2003 and in 2006 an international master programme (ABS – Atmosphere-Biosphere-Studies) linked to it will start its operation, including University of Helsinki, University of Kuopio, University of Lund, University of Gothenburg and University of Copenhagen. The national graduate school ”Ilmakehän koostumuksen ja ilmastonmuutoksen fysiikka, kemia, biologia ja meteorologia” (http://www.atm.helsinki.fi/tutkijakoulu) has started in the beginning of 2006 and at the present it includes 90 students with detailed study plans. M. Kulmala is co-ordinating all of these activities. CoE is naturally very closely linked to these organised and established researcher training activities.

Our education structure combines following four steps: i) M.Sc. education (ABS), ii) Ph.D. education via graduate schools, iii) post doc education via seminars, workshops and other research training and also iv) training for established scientist via workshops and mentor programs. In steps iii) and iv) we focus on different aspects of teaching, supervising and communication skills. Our education plan in steps i) and ii) includes around 90 ECTs of courses, seminars and workshops, of which 60 ECTs must be adopted. This is composed of 10-40 ECTs of general studies related to

- Scientific planning, how to write publications, how to write proposals
- Methodology, statistics
- Physics and chemistry of air pollution and their effects, practical data analysis
- Environmental measurements techniques
    - fluxes and states in terrestrial ecosystems
    - aerosol measurement techniques
- Forest-Atmosphere interactions
- Thermodynamics, fluid mechanics
- Atmospheric chemistry and aerosol physics for non specialists

Beside this, one can include 20-50 ECTs of special studies related to a) Formation and transformation of atmospheric aerosols; b) Air-Sea exchange; c) Condensation and cloud microphysics; d) Aerosol-cloud-climate interactions; e) Upscaling of land surface – atmosphere properties; f) Arctic air pollution; g)

Carbon balance and biodiversity f) Carbon and nutrient dynamics in different ecosystems; h) Ion and aerosol dynamics

Our international research environment with inter- and multidisciplinary approaches affects also the educational experience of student working in the centre. Our research unit has been very effective in doctoral education. Challenging problems, combination of theoretical and modelling approaches with laboratory experiments and field measurements, and topics having both fundamental scientific relevance and socio-economic values (climate change, health effects, carbon sinks, forest growth) can make students uniformly enthusiastic. We estimate that in 2008-2013 65 students would finish their post graduate studies in the CoE. The number of Graduate students is ca 65 and the number of supervisors/advisors is 30. The CoE provides also an excellent environment for post doctoral research training. Recently we have 24 post docs working within CoE. In 2001-2005 6 and 7 persons, trained by CoE research groups, has started in Academy researcher position or university professor, respectively.

19. ■ Doctor's and licentiate's degrees supervised by the personnel planned to work in the proposed CoE (listed in Form 1 b) during 2001-2005 (**Form 3a**).

Form 3a

20. ■ A plan of doctor's and licentiate's degrees to be earned within the proposed CoE during 2008-2013 (**Form 3b**). If names of candidates are unknown, use N.N.

Form 3b

21. ■ Need of researchers and experts trained in the proposed CoE (research and other sectors of society, please specify the sectors).

In recent years the need of researchers and experts in our area has been increased significantly. Today we need more people who have obtained interdisciplinary education in the field of aerosol related environmental science. In particular, we need

- Scientists in Universitites and research organisations
- Teachers in Universitites
- Experts in administration
- Experts in different enterprises, e.g. in companies designing and devoloping instruments, in pharmaceutical companies etc.
- Consults (experts) to give advise in aerosol related environmental problems (air quality, environmental health etc.)

4 Scientific merits and output

The quality and quantity of scientific output

22a. ■ Number of publications and other output during 2001-2005 (**Form 4a**).

Form 4a

22b. ■ A list of publications, preferably during 2001-2005 (**Form 4b**). Each professor, senior researcher and postdoctoral researcher (personnel groups 1, 2, 3, 8, 9, 10) may list a maximum of 10 most significant publications in order of preference.

Form 4b

22c. ■ A list of other output than scientific publications of the proposed CoE during 2001-2005 (**Form 4c**).

Form 4c

22d. ■ Description of the most significant (maximum 5) scientific discoveries and other innovations (listed in Forms 4b and 4c) during 2001-2005 (**Form 4d**).

Form 4d

Improving professional and public understanding of science

23a. ■ Plans to publish other than scientific articles.

The results by the CoE have been and will be presented in popular science magazines and in newspapers as well as in the television and radio. We plan to give press release at least twice per year.

23b. ■ Plans and means to improve public understanding of the research carried out by the proposed CoE.

The research unit is presently working also in close co-operation with elementary as well as high schools to familiarise pupils and students with simple analyses of scientific data and environmental issues. This kind of activity will also be a part of the CoE and it relates also to their similar activities in other projects, like CarboSchool in CarboEurope and science cafes in ACCENT. The results by the groups have been and will presented in popular science magazines and in newspapers as well as in the television.

23c. ■ Other plans to develop and improve professional culture.

All results will be published in peer reviewed journals. The results will also be presented in international and national conferences and workshops.

Professional culture will also be improved by organising well defined project, conferences, workshops, seminars etc.

The status of researchers in their field

24. ■ Prizes and scientific honours received by researchers of the proposed CoE (**Form 5**).

Form 5.

25a. ■ The most important international positions of trust held by researchers of the proposed CoE in 2001-2005 (**Form 6a**).

Form 6a.

25b. ■ The most important domestic positions of trust held by researchers of the proposed CoE in 2001-2005 (**Form 6b**).

Form 6b.

Researcher mobility and involvement in international research programmes

26a. ■ Visits abroad (a minimum of one month) by researchers of the proposed CoE during 2001-2005 (**Form 7a**).

Form 7a.

26b. ■ Significant visits (a minimum of two weeks) by foreign researchers to the proposed CoE during 2001-2005 (**Form 7b**).

Form 7b

26c. ■ Description of very short, but exclusively significant visits of less than two weeks by foreign researchers to the proposed CoE during 2001-2005 (**Form 7c**). These short visits are not listed in Form 7b.

Form 7c.

27. ■ Involvement as a coordinator or as a partner in international research programmes during 2001-2005.

The unit has acted as a coordinator in 5 international research programmes: CORE (Climate-biosphere interactions, 2000-03, EU, Timo Vesala), Random walk models for the footprint problem in the turbulent atmosphere (2000-03, INTAS, Timo Vesala) , QUEST (Quantification of Aerosol Nucleation in the European Boundary Layer, 2001-2005, EU, Ari Laaksonen), BACCI (Biosphere-Aerosol-Cloud-Climate Interactions, 2003-2007, Nordic Centre of Excellence, Markku Kulmala) and CBACCI (Biosphere-Carbon-Aerosol-Cloud-Climate Interactions, 2003-2007, Graduate School, Nordforsk, Markku Kulmala).

The unit has acted as a partner in 24 international research programmes/projects: CARBOAGE (Age-related dynamics of carbon exchange in European forests, 2000-02, EU, Pertti Hari), CARBOEUROFLUX (An investigation on carbon and energy exchanges of terrestrial ecosystems in Europe, 2000-03, EU, Timo Vesala), OSOA (Origin and formation of secondary organic aerosol, 2000-01, EU, Markku Kulmala and Ari Laaksonen), INCA (Interhemispheric difference in cirrus properties from anthropogenic emissions, 2000-01, EU, Markku Kulmala), CARBOMONT (Effect of land-use changes on sources, sinks and fluxes of carbon in European mountain areas, 2001-2004, EU, Pertti Hari), HEAPPS (Health effects of air pollution on susceptible subpopulations – Traditional air pollutants, ultrafine particles and myocardial infarction: Database and health assessment, 2001-04, EU, Markku Kulmala), LAPBIAT (Lapland Atmosphere-Biosphere Facility, EU, 2001-2004, EU, Markku Kulmala), BOND (Biogenic Aerosols and Air Quality in the Mediterranean Area, EU, 2001-2004, EU, Markku Kulmala), CASOMIO (Condensational growth and Surface reactivity of Mixed Inorganic/Organic Aerosols, 2001-2005, EU, Markku Kulmala), NOFRETETE (Nitrogen oxides emissions from European forest ecosystems, 2001-2004, EU, Timo Vesala), PARTS (Particles in the upper Troposphere and lower Stratosphere and their role in the climate system, 2001-2004, EU, Markku Kulmala), RUPIOH (Relationship between Ultrafine and fine Particulate matter in Indoor and Outdoor air and respiratory Health, 2002-2004, EU, Markku Kulmala), SAPPHIRE (Source Apportionment of Airborne Particulate Matter and Polycyclic Aromatic Hydrocarbons in Urban Regions of Europe, 2002-2005, EU, Markku, Kulmala), METH-MONITEUR (Methane monitoring in the European Union and Russia, 2002-2005, EU, Yrjö Viisanen), COST C15 (Technical infrastructure and vegetation-improving relations and preventing conflicts by an interdisciplinary approach, 2002-2006, EU/ESF, Eero Nikinmaa), AIRGENE (Air Pollution and Inflammatory Response in Myocardial Infraction Survivors: Gene-Environment-Interactions in a High-risk Group, 2003-2006, EU, Markku Kulmala), CREATE (Construction, Use and Delivery of an European Aerosol Database, 2003-2005, EU, Markku Kulmala and Yrjö Viisanen), NECC (Studies of Ecosystem Carbon Exchange and its Interaction with the Climate System, 2003-2007, Nordic Centre of Excellence, Timo Vesala/Tuomas Laurila), CARBOEUROPE (Assessment of the European Terrestrial Carbon Balance, 2004-2008, EU, Timo Vesala), ACCENT (Atmospheric Composition Change: An European Network (European Network of Excellence, 2004-2009, EU, Kulmala/Laaksonen/Viisanen), MAP (Secondary Marine Aerosol Production from Natural Sources, 2005-2008, EU, Kerminen/Kulmala/Laaksonen), COST-729 Action (Assessing and managing nitrogen fluxes in the atmosphere-biosphere system in Europe, 2005-2009, European Science Foundation, Tuomas Laurila), SIFLEX-2002 (the Solar Induced Fluorescence Campaign, 2002-2003, European Space Agency, Tuomas Laurila), Changes in ozone episodes due to emission reductions - a Nordic Study (Nordic Council of Ministers, NMR, 2001-2002, Tuomas Laurila), Ozone exposure scenarios in the Nordic countries during the 21st century (NMR, 2001-2003, Tuomas Laurila).

Besides that we are participating in one big Integrated project as coordinator and 3 as partners which are just stated or stating during next months, where all planning, proposal writing etc. have been done during 2005, namely EUCAARI (European Integrated project on Aerosol Cloud Climate and Air Quality interactions, 2006-2010, coordinator Markku Kulmala), NITROEUROPE (The Nitrogen Cycle and its Influence on the European Greenhouse Gas Balance, 2006-2010, EU, Timo Vesala/Tuomas Laurila), EUSAAR (European super-sites for atmospheric aerosol Research, 2006-2010, EU, Markku Kulmala and Veli-Matti Kerminen), EUROHYDROS, European network for atmospheric hydrogen observations and studies, 2006-2009, EU, Tuula Aalto),

Our unit is also organizing the scientific activities of iLEAPS (integrated land ecosystem atmosphere processes study), which is one of the core activities in IGBP (International geosphere bioshere program). The international project office of iLEAPS is located in Helsinki. Research group at the FMI runs the Global Atmosphere Watch (GAW) station at Pallas (Yrjö Viisanen), and to large extent the Finnish background air quality network, which is part of the European Monitoring and Evaluation Programme (EMEP).

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