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Science Plan
Biogenic Aerosols – Effects on Clouds and Climate (BAECC)

T Petäjä

December 2013

ARM CLIMATE RESEARCH FACILITY

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Office of Science, Office of Biological and Environmental Research

Summary

Atmospheric aerosol particles impact human health in urban environments, while on regional and global scales they can affect climate patterns, the hydrological cycle, and the intensity of radiation that reaches the Earth's surface. In spite of recent advances in the understanding of aerosol formation processes and the links between aerosol dynamics and biosphere-atmosphere-climate interactions, great challenges remain in the analysis of related processes on a global scale. Boreal forests, situated in a circumpolar belt in the northern latitudes throughout the United States, Canada, Russia and Scandinavia, are among the most active areas of atmospheric aerosol formation among all biomes. The formation of aerosol particles and their growth to the sizes of cloud condensation nuclei in these areas are associated with biogenic volatile organic emissions from vegetation and soil.

One of the world's most comprehensive observation sites in a boreal forest environment, measuring atmospheric aerosols, biogenic emissions, and an extensive suite of relevant atmosphere-biosphere parameters, is SMEAR II (Station for Measuring Forest Ecosystem-Atmosphere Relations II) in Hyytiälä, Finland. The station has been monitoring biosphere-atmosphere interactions continuously since 1996, and is operated by the University of Helsinki, Division of Atmospheric Sciences, together with the university's Forest Science department. The U.S. Department of Energy's Atmospheric Radiation Measurement (ARM) Program will bring its ARM Mobile Facility 2 (AMF2) to Hyytiälä, joining SMEAR-II for an intensive measurement campaign called the "Biogenic Aerosols - Effects on Clouds and Climate (BAECC)" experiment. The campaign started in February 2014**.**

The BAECC experiment will provide a bridge from an 18-year long SMEAR-II observation record to the impact of biogenic aerosols on clouds, precipitation, and climate. This will be achieved by simultaneous observations of precursor vapor emission and aerosol, cloud, and precipitation microstructure. This data set will be used to

1. link precursor emissions and aerosol
2. link aerosol at the surface to aerosol in the mixing layer and free troposphere
3. investigate the aerosol indirect effect on clouds and precipitation.

The AMF2 observations will be supplemented by tower- and surface-based measurements of aerosol and precursor gases. During field campaigns, aircraft observations of aerosol microphysics will be performed. The experiment will also benefit from existing measurements of precipitation provided by the Finnish Meteorological Institute observational network. The 8 month data set will be placed in perspective with the long time series available from Hyytiälä, and used in modeling efforts ranging from process models to global climate models, capitalizing on the ability to perform radiative transfer calculations with full closure.

The main goal of the activity is to understand the impact of biogenic aerosol formation on cloud properties and ultimately on global climate. The specific aims are the following:

1. Resolve the role of biogenic secondary aerosol formation in cloud processes for warm liquid, mixed-phase and ice clouds over a boreal environment.

2. By utilizing ARMs state-of-the-art active remote sensing together with process-scale modeling, complete the link between our comprehensive 18-year observational record of aerosol and biosphere-atmosphere interactions to cloud processes.
3. Expand our local observations over larger spatial scales up to the Earth system via a hierarchy of models (emissions, aerosol dynamics, atmospheric chemistry, cloud processes, radiative transfer, global climate model) and satellite observations.

Acronyms and Abbreviations

ACSM	Aerosol Chemical Speciation Monitor
ACTRIS	Aerosols, Clouds, and Trace gases Research InfraStructure Network
AMF2	ARM Mobile Facility 2
ANAEE	Infrastructure for Analysis and Experimentation on Ecosystems
AOS	Aerosol Observing System
ARM	DOE's Atmospheric Radiation Measurement (program)
BAECC	Biogenic Aerosols – Effects on Clouds and Climate (experiment)
BSRWP	beam steerable radar wind profiler
CCN	cloud condensation nuclei
CDP	cloud droplet probe
CIMS	chemical ionization mass spectrometers
COOL	an Academy of Finland project
CPC	condensation particle counter
ECHAM-HAMMOZ	a global aerosol-climate model
EXPEER	Distributed Infrastructure for EXPErimentation on Ecosystem Research
FMI	Finnish Meteorological Institute
ft	foot/feet
HSRL	high spectral resolution lidar
ICOS	Integrated Carbon Observation System
IGBP	International Geosphere-Biosphere Programme
iLEAPS	Integrated Land Ecosystem–Atmosphere Processes Study
km	kilometer(s)
LDIS	laser disdrometer
m	meter(s)
MLH	mixing-layer height
MPL	micropulse lidar
MWR3C	microwave radiometer 3-channel
nm	nanometers
NPF	new particle formation
PM_{10}	particles smaller than 10 micrometers
$PM_{2.5}$	particles smaller than 2.5 micrometers
PSAP	particle soot absorption photometer
PSM	particle size magnifier
QA/QC	quality assurance/quality control
RH	relative humidity
SALSA	an aerosol model

SMPS	scanning mobility particle sizer
SMEAR	Station for Measuring Forest Ecosystem-Atmosphere Relations
SOA	secondary organic aerosol
TNA	transnational access
TSI	total sky imager
UCLALES	a cloud resolving model
VDIS	video disdrometer
VOC	volatile organic compound

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1.0 Introduction

Formation of new aerosol particles by nucleation and growth has been observed to take place practically everywhere in the Earth's atmosphere (Kulmala et al. 2004a; Mirme et al. 2010; Zhang et al. 2012). In terms of the total aerosol particle number concentration, nucleation dominates all primary aerosol particle sources in the global atmosphere (Spracklen et al. 2006; Yu et al. 2010). Atmospheric aerosol formation has been estimated to provide a significant contribution to the global cloud condensation nuclei (CCN) budget (Merikanto et al. 2009; Pierce and Adams 2009), and to be responsible for significant uncertainties in both current and future indirect climate forcing by aerosols (Wang and Penner 2009; Kazil et al. 2010; Makkonen et al. 2012).

Of all biomes, boreal forests appear to have the largest biogeophysical effect on the annual mean global temperature (Bonan 2008). Boreal forests constitute a circumpolar belt in the northern latitudes throughout the United States, Canada, Russia, and Scandinavia. According to in situ measurements, boreal forests are among the most active areas of atmospheric aerosol formation associated with biogenic emissions (Tunved et al. 2006; Dal Maso et al. 2007; Kulmala et al. 2011a). Global model simulations support this view and suggest further that these aerosols make a significant contribution to CCN concentrations over this biome, thereby influencing cloud properties and climate (Spracklen et al. 2008; Merikanto et al. 2009; Makkonen et al. 2012). There is increasing observational evidence from ground-level measurements for the connection between biogenic aerosol formation and climate (Kerminen et al. 2005; Lihavainen et al. 2009; Sihto et al. 2011).

At the SMEAR II (Station for Measuring Forest Ecosystem-Atmosphere Relations II) station (Hari and Kulmala 2005) in Hyytiälä, Finland, we have been continuously monitoring biosphere-atmosphere interactions since 1996 (Makela et al. 1997; Aalto et al. 2001; Dal Maso et al. 2005; Kulmala et al. 2007). The site is representative of a boreal forest environment. The SMEAR II station provides the longest observational record of sub-micron aerosol number size distributions—the crucial ground-based information required for aerosol-cloud interaction studies (Rosenfeld et al. 2008). Chemical precursor species are routinely monitored at the site. Formation of fresh atmospheric particles was detected for the first time at this site (Makela et al. 1997). The initial aerosol formation is governed by sulfuric acid (Petaja et al. 2009), and the growth to larger sizes is dominated by organic vapors emitted from the surrounding biosphere (Kulmala et al. 2001; Riipinen et al. 2011; Figure 1). Furthermore, recent studies indicate differences between the chemotypes of the plants themselves (Bäck et al. 2012), leading to differences in emission profiles. However, as an overall process analysis, the long time series already collected has allowed identification of the seasonal cycle (Dal Maso et al. 2005), with the most active season being spring, when new particle formation events occur approximately every one to three days.

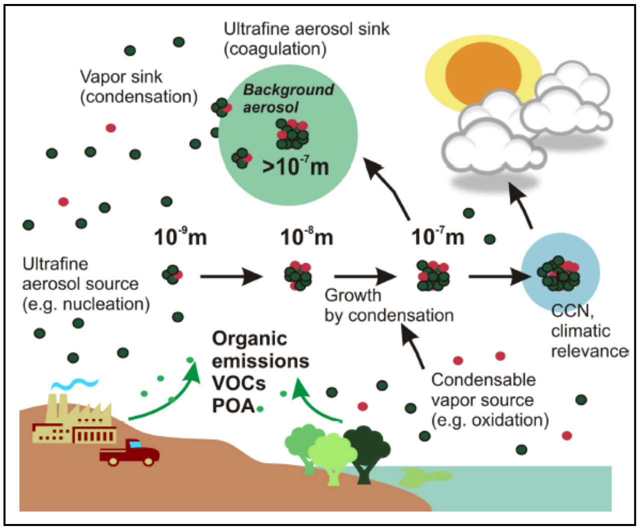


Figure 1. Condensation of Organic Vapors Originating from Emissions and Subsequent Oxidation in the Atmosphere Provide a Vital Link Connecting Aerosol Formation to CCN Concentrations (Riipinen et al. 2011). This project captures all the processes relevant to this phenomenon.

2.0 Scientific Objectives of BAECC Experiment

In the Biogenic Aerosols - Effects on Clouds and Climate (BAECC) experiment, we hypothesize that the boreal forest is a source of aerosol particles that form and grow to a size where they activate to become cloud droplets, altering the radiation balance of the Earth and, therefore, providing a direct link between the atmosphere and the biosphere.

The main objective of BAECC is to verify the effects of secondary aerosol formation on cloud properties with a combination of in situ observations and active remote sensing instruments provided by AMF2, and place these observations within a larger context through modeling efforts.

In particular, we aim to provide insights into:

1. the uncertainties of indirect effects on climate of the aerosol particles in the boreal environment, and, in particular, the role of secondary aerosol particles in CCN and IN concentrations and their effects on cloud microphysics;
2. the magnitude of the feedback mechanisms associated with aerosol-cloud-climate-air quality interactions using both in situ and active remote sensing data.

Furthermore, we envisage that BAECC will increase collaboration between European and U.S. research communities involved with the in situ observations, remote sensing measurements and modeling, as all of these tools must be operated in concert in order to fully understand aerosol-cloud-climate interactions in the boreal environment.

3.0 Observation Program

3.1 ARM Campaign at SMEAR II Hyytiälä

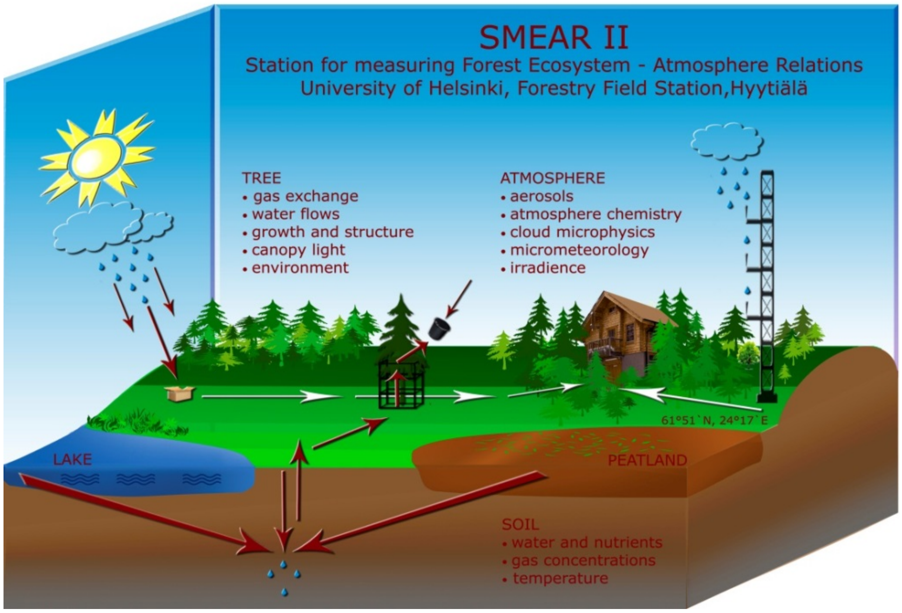
The BAECC experiment denotes the deployment of the full AMF2 capability for 8 months in Hyytiälä, Finland, the location of the main station of the continuously operated SMEAR network. SMEAR II is located in a rather homogeneous Scots pine (*Pinus sylvestris* L.) stand on flattish terrain at Hyytiälä Forestry Field Station of the University of Helsinki (61°51' N, 24°17' E, 181 m above sea level), 220 km Northwest of Helsinki.

Figure 2. The SMEAR II Station Represents Boreal Coniferous Forests, Which Cover 8% of the Earth's Surface and Store about 10% of the Total Carbon in the Terrestrial Ecosystem.

At SMEAR II, measurements are performed at a number of storage pools and interfaces involving three different layers, extending from the soil to the atmosphere. Several different methods, operating simultaneously but at different spatio-temporal scales, are applied to monitor the material and energy fluxes between the different pools, aiming at understanding the processes responsible for these fluxes. For example, the surface between a tree and the atmosphere, or between the soil and the atmosphere, can be enclosed in a chamber, and the corresponding flux of interest can then be 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. Electronic sensors are available to measure radiation fluxes.

SMEAR II is an Integrated Carbon Observation System (ICOS) site. One needs to keep in mind that by default our site considers smaller scale (<10 km) variability in space and other relevant ecosystems than the boreal forest. There is another long-term field site for carbon (carbon dioxide, methane and volatile organic compounds (VOCs)) and energy exchange studies together with soil (peat) processes, located close to SMEAR II at the Siikaneva wetland (fen) area, and there are also activities on the nearby Kuivajärvi Lake, where we determine fluxes of CO_2 and VOCs from the boreal lake system. We aim to explore the small-scale variability of the aerosol particles by installing an aerosol number size distribution instrument (DMPS) at the AMF2 deployment site.

Table 1. The Main Components of the SMEAR II Station.



i) **Instrumented, 124-m-tall mast**: monitoring 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, OCS, aerosols, and VOCs between the canopy and the atmosphere. Aerosol, CO_2, H_2O, O_3, OCS and VOC fluxes from different heights, below and above the canopy.

ii) **Systems for monitoring aerosols and air ions**: Aerosol (1 nm – 10 μm) and ion size distributions (0.5 nm – 45 nm) are measured in order to study ion, cluster and aerosol dynamics. The characterization includes online chemical characterization, EC/OC analysis, black carbon concentrations, volatility analysis, aerosol total mass ($PM_{2.5}$/PM_{10}) and size-resolved CCN activation of sub-micron aerosols. Optical characterization includes scattering, absorption and extinction measurements.

iii) **Instrumentation for monitoring tree functions and radiation (two 25-m towers)**: Chamber techniques are used to monitor tree processes generating the fluxes between trees or soil and the atmosphere. The most relevant processes are photosynthesis, respiration, transpiration, NO_x emission and deposition, O_3 deposition, and emission of VOCs. Stem diameter changes are monitored both above and under the bark continuously with a precision of less than 1 μm. This allows us to indirectly estimate the water tension in xylem and phloem, which is an ecophysiologically important parameter, but is difficult to determine. The water content and tension, CO_2 and temperature profiles are monitored. Solar radiation is the source of energy for several processes in the trees and the atmosphere. Irradiance, diffuse irradiance, photosynthetically active radiation and radiation balance are monitored above the canopy. A spectroradiometer is operated to provide data for photochemical understanding.

iv) **Two instrumented mini-catchments**: The fluxes between the soil and the atmosphere, as well as between the soil and the canopy, are also important. The catchments are closed with a dam, and the runoff from the area is monitored. The leakage of substances with the runoff is monitored by taking samples for chemical analysis.

v) **Two flux sites in Siikaneva fen**: These provide CO_2, H_2O, and CH_4 fluxes at locations in a nearby wetland for comparing the fluxes in different boreal ecosystems.

vi) **Instrumented raft in Kuivajärvi**: Provides CO_2 and H_2O fluxes from nearby Kuivajärvi Lake including measurement of the lateral transport of water.

vii) **Instrumented tall walk-up platform**: Vertical profiles of trace gases and nanoparticles are obtained from an instrumented 35 m walk-up tower. This tower is currently being built and should be operational by spring 2014.

Table 2. List of Instrumentation at SMEAR II Provided by University of Helsinki, University of Eastern Finland and Finnish Meteorological Institute during the BAECC Experiment.

Parameter	Instruments	Contact Person
Detailed in situ aerosol physical characterization size distribution between 1 nm and 10,000 nm	PSM;DMPS; APS, ELPI, OPC;	Tuukka Petäjä; Pasi Aalto
Ion and naturally charged aerosol number size distribution (1–45 nm)	AIS/NAIS; BSMA; Sigma	Tuukka Petäjä; Hanna Manninen
In situ aerosol chemical characterization	ACSM; MARGA	Tuukka Petäjä; Mikko Äijälä MARGA: Hannele Hakola
Aerosol optical properties	3λ nephelometer, AE-31 aethalometer, MAAP, CAPS, PSAP	Tuukka Petäjä; John Backman
In situ CCN concentration (total and size-segregated CCN)	CCN counter	Tuukka Petäjä; Mikhail Paramonov
Aerosol hygroscopicity and volatility; mixing state of aerosol population	VDMPS, VHTDMA	Tuukka Petäjä; Pasi Aalto
Trace gases (O_3, NO, NO_2, NO_x, SO_2, CO, CO_2)	trace gas sensors, vertical gradient	Tuukka Petäjä; Petri Keronen
Trace gases (VOC, VOC fluxes, inorganic gases)	PTR-Q-MS, CIMS, MARGA	PTRQMS: Jaana Bäck PTRTOFMS: Taina Ruuskanen MARGA: Hannele Hakola, FMI
Trace gases (OCS)	Aerodyne instrument	Timo Vesala
Greenhouse gas (GHG) concentrations, GHG fluxes, micrometeorological fluxes	CO_2, OCS, CH_4, H_2O, momentum	Timo Vesala
Ion chemistry	API-ToF	Tuukka Petäjä; Mikko Sipilä
Solar radiation	spectroradiometer (Bruker), UVA, UVB, PAR, Global, IR, albedo)	Tuukka Petäjä; Erkki Siivola
Radon, environmental radioactivity	Geiger counter	Jussi Paatero, FMI
Ecophysiological measurements; forest growth from cell level to canopy level	various instruments	Jaana Bäck, UHEL
Column aerosol burden	sun photometer (Cimel CE-318, part of AERONET	Veijo Aaltonen, FMI
Cloud base height,	Vaisala ceilometer	Tuukka Petäjä; Pasi Aalto
Aerosol vertical profile, boundary layer height, horizontal wind profile	Halo photonics lidar	Ewan O'Connor, FMI

CIMS = Chemical Ionization Mass Spectrometer
FMI = Finnish Meteorological Institute
PSAP = Particle Soot Absorption Photometer
PSM = Particle Size Magnifier

Table 3. AMF2 Instrumentation during BAECC Experiment.

	Aerosol Observing System (AOS) - a duplication of certain aerosol instruments already installed by the University of Helsinki providing a resource for benchmarking, repeatability, and representativeness, including:
•	CCN counter CCN100, single column
•	Ambient nephelometer and variable relative humidity (RH) nephelometer for f(RH)
•	Condensation particle counter (CPC)
•	Hygroscopic tandem differential mobility analyzer (HTDMA)
•	Particle soot absorption photometer (PSAP)
•	Ozone concentration
•	Cimel sun photometer
	Atmospheric sounding system
•	Balloon-Borne Sounding System (4 ascents a day to provide sufficient temporal coverage)
	Vertical structure and radiation
•	Laser disdrometer (LDIS)
•	Micropulse lidar (MPL)
•	Microwave radiometer, 3-channel (MWR3C), liquid water path for mixed-phase clouds.
•	High spectral resolution lidar (HSRL) extinction profile for aerosol and cloud, together with unambiguous detection of liquid layers.
•	Total sky imager (TSI)
•	Radiometers (ASSIST, MFRSR, GNDRAD and SKYRAD) for radiation and water vapor profiles.
•	Beam steerable radar wind profiler (BSRWP) at 1290 MHz.
	Cloud observations
•	X & KA-SACR – for 3D mapping of clouds and precipitation plus dual-frequency retrievals
•	KAZR and SWACR – for dual (triple)-frequency retrievals of liquid, ice, and mixed-phase layers.
	Surface observations
•	Local meteorology (Vaisala WXT520 weather station)
•	Snow observations, video disdrometer (VDIS), 2D
•	Rain gauges

3.2 SMEAR Stations Network Supporting the ARM-BAECC Campaign

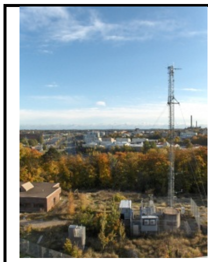
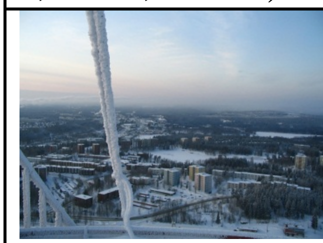
The SMEAR network covers the boreal forest conditions in the Scandinavian part of the global band of taiga in the northern latitudes (Figure 3). The measurements from the SMEAR station network are descriptive for conditions ranging from a remote boreal environment north of the polar circle to a more temperate boreal environment in southern Finland. The measurements in Helsinki provide an outlook on the effect of urban emissions. The wide spatial range also provides a possibility to probe into the role of forest fires and the resulting large-scale biomass burning in Russia, with plumes aging during their transport to the SMEAR network stations.

Figure 3. SMEAR Atmospheric Observation Network. Station descriptions are listed in Table 4.

Table 4. The SMEAR Network Stations and Pallas-Sodankylä GAW Station.

 **Hyytiälä.** The SMEAR II station in Hyytiälä (61°51' N, 24°17' E, 181 m a.s.l.)	- extensive facilities for measuring forest-atmosphere interactions operational since 1996 (Hari and Kulmala 2005) - aerosol size distribution measurements with a twin-DMPS system since January 1996 - surrounded by Scots pine forest, with the managed stand established in 1962 by sowing after the area had been treated with prescribed burning and light soil preparation - the nearest urban pollution sites are Tampere (ca. 50 km to the southwest) and Jyväskylä (ca. 100 km to the northeast)
 **Värriö**. The SMEAR I station in Värriö (67°46' N, 29°35' E, 400 m a.s.l.)	- situated in Lapland, in a remote rural area - surrounded by a Scots pine (Pinus sylvestris l) forest, which is over 40 years old in the station's immediate vicinity. The measurements are performed on a hilltop (Hari et al. 1994) - no pollution sources are nearby, but emissions from industrial activities (e.g., smelters) from the Kola Peninsula area may be advected over the station - aerosol size distribution measurements started in December 1997 with a system of a single DMA and CPC measuring particles in the 8–460 nm size range. In April 2003 a twin-DMPS system was installed, decreasing the minimum observable particle size to 3 nm. The sampling is done at 2 m above ground inside the forest canopy. - the station records a range of atmospheric parameters, including trace gas concentrations along with temperature, RH, solar radiation and wind speed.

Table 4. (contd)

 **Helsinki**. The SMEAR III station in Helsinki **(**60°12' N, 24°57' E, 26 m a.s.l.)	- started operations in Helsinki in Autumn 2004 - instrumentation covers aerosol dynamics and atmospheric chemistry, micrometeorology, weather monitoring and ecophysiology of trees growing in the urban environment - situated in two different locations, Kumpula and Viikki. The Kumpula site located about 4 km from downtown Helsinki - measurements by a 31 m-high tower equipped with meteorological instrumentation at several heights
 **Puijo.** The SMEAR IV station in Kuopio (62°55' N, 27°40' E, 224 m)	- located on top of an observation tower where the measurements are performed. - continuous measurements of aerosols, cloud droplets, weather parameters and trace gases (Leskinen et al. 2009; Portin et al. 2009) since 2005/06. - station frequently located within cloud, especially in October (more than 40% of days). - two inlet lines used for aerosol sampling: an interstitial inlet equipped with a PM1 impactor and the total air inlet with a heated inlet in order to dry the cloud droplets. - aerosol size distribution from both inlets is measured with the same DMPS by using a synchronized valve system in two 6-minute cycles, giving a 12-minute time resolution for the whole measured size range from both sampling lines. - difference in particle size distribution between the two lines provides information on the partitioning of particles between cloud droplets and interstitial particles in the cloud.
Pallas. The Sammaltunturi Global Atmospheric Watch station (67°58' N, 24°07' E, 565 m a.s.l.)	- operated by the Finnish Meteorological Institute. - situated on top of a hill in western Lapland (Hatakka et al. 2003). - vegetation in the immediate vicinity of the station consists of mixed pine, spruce and birch forest. - station itself is above the tree line and the sampling inlet is 7 m above ground. - Pallas area located in the sub-Arctic region near the northern limit of the boreal forest zone. - no significant local or regional pollution sources, with about 20 km to the nearest town (Muonio with 2500 inhabitants). - DMPS system, operational since April 2000, measures particles in 7–500 nm size range.

3.3 Airborne Field Campaigns

During the AMF operation period, there will be up to four airborne field campaigns, one in every season, with each lasting for 2–3 weeks with up to 40 flight hours. The typical duration of 3 hours per flight corresponds to 12–15 measurement flights per campaign. The airborne measurements will be conducted aboard the University of Helsinki Cessna 172 research aircraft (Schobesberger et al. 2013). The instrumental setup is planned to provide a full physical characterization of ambient aerosol particles from 1 nm to 10 µm along with water vapor and CO_2 mixing ratios. Flight operations will be carried out in a 30 × 30 km domain around the SMEAR II station at Hyytiälä (Figure 4). The size of the domain represents several grids of the typical regional model and is on the same order of magnitude as state-of-the-art GCMs. It will also provide direct in situ observations for comparison and validation of the active remote sensing instruments. Both vertical profiles from approx. 300 ft to 10,000 ft and the spatial extent of the atmospheric aerosol properties in the planetary boundary layer and lowermost free troposphere will be studied. We are also investigating the possibility of performing additional research flights with the Skyvan aircraft, which is operated by Aalto Technical University in collaboration with Finnish Meteorological Institute (FMI), and for which the consortium can apply for flight hours. Skyvan airborne observations will complement Cessna measurements with aerosol chemistry (aerosol mass spectrometer), aerosol cloud forming potential based on CCN measurements, and additional trace gases.

Figure 4. Cessna 172 Operational Area during the Airborne Intensive Observation Period.

Table 5. University of Helsinki Cessna 172 Research Airplane Instrumentation.

Parameter	Instruments	Contact Person
Ultrafine aerosol number density >3 nm, 1 Hz resolution	UCPC, TSI 3776	Tuukka Petäjä; Riikka Väänänen
Ultrafine aerosol number density >1 nm, 1 Hz resolution	particle size magnifier (PSM)	Tuukka Petäjä; Riikka Väänänen
Aerosol number size distribution 10–500 nm, 2 minute resolution	scanning mobility particle sizer (SMPS)	Tuukka Petäjä; Riikka Väänänen
Water vapor mixing ratio, 1 Hz resolution	Licor LI-840	Tuukka Petäjä; Riikka Väänänen
Carbon dioxide mixing ratio, 1 Hz resolution	Licor LI-840	Tuukka Petäjä; Riikka Väänänen

3.4 Sampling Clouds and Precipitation

Data from active and passive remote sensing instruments will be used for the retrieval of cloud and precipitation microphysical properties. Continuous operation is planned for all measurements during the duration of the campaign. We will use the well-established ARM and CLOUDNET algorithms for deriving vertical profiles of cloud properties, together with algorithms developed within EARLINET for deriving vertical profiles of aerosol properties. Ground-based aerosol and gas retrievals will be performed according to Aerosols, Clouds, and Trace gases Research InfraStructure Network (ACTRIS) and EUSAAR protocols.

AMF2 cloud radars will be collocated to provide multi-frequency radar retrievals. These observations will be combined with lidar and radiometer observations to document microphysical properties of liquid and mixed-phase clouds. The BAECC measurement site is located 65 km from the closest operational dual-polarization C-band weather radar, which is positioned in Ikaalinen (see Figure 5). This radar will be used to map precipitation over a larger area. The Ikaalinen radar uses FMI's operational scan strategy (Saltikoff and Nevvonen 2011). To provide additional radar measurements of cloud and precipitation vertical structure over the site, this weather radar will perform RHI scans in the direction of Hyytiälä every 15 minutes.

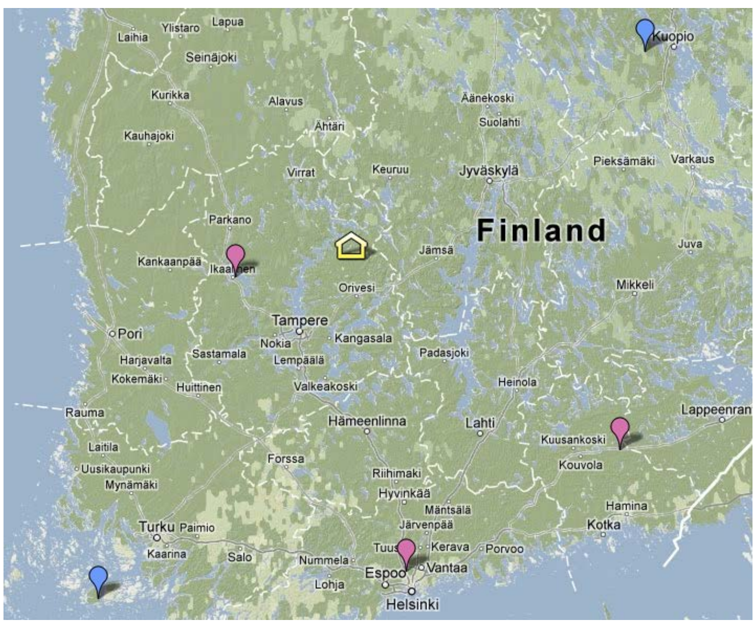


Figure 5. Location of FMI C-band Weather Radars (cyan indicates dual polarization). The closest radar to SMEAR II is located 65 km away in Ikaalinen.

4.0 Scientific Objectives

4.1 General Overview

In practice, the overall objective of verifying the effects of secondary aerosol formation on cloud properties with a combination of in situ observations and active remote sensing instruments provided by

AMF2 is divided into five scientifically focused themes, containing both measurement and modeling activities. With these cross-cutting activities, we are planning to probe into the processes governing secondary organic aerosol (SOA) formation, to generate parameterizations, and to scale up the research to regional and global scales.

The themes divide the target objective into a chain as follows. The phases of activities are listed in Table 6 underlining the added value of the combination of AMF2 and SMEAR observations. First we characterize the volatile organic vapors from the biosphere and link them to the formation and growth of secondary aerosol particles in situ. Then we link the

Table 6. Summary of the Added Value of the AMF and the Outcomes of the Different Study Phases.

Study Phase	Added Value of AMF	Outcome
From emissions to aerosol	• Gap-filling instrumentation of wet nephelometer • Small-scale variability • Quality Assurance/Quality Control (QA/QC) for the AMF in situ and SMEAR II instruments	• A complete, quality-controlled and comprehensive data set of aerosol properties, fluxes and VOC emission rates as a function of temperature, radiation, photosynthetic activity, season and air mass origin • Vertical profiles of aerosol particles inside the mixed layer based on aerosol characterization from the 127 m mast
From aerosol to clouds	• Comprehensive measurements of vertical profiles, including aerosol and cloud properties and turbulence • Vertical profiles of aerosols and clouds consistent with surface measurements	• Understanding the transport of biogenic aerosols within the boundary layer and the role of biogenic secondary organic material in determining liquid cloud properties through cloud droplet activation and other processes
From clouds to precipitation	• Comprehensive active measurements of mixed-phase cloud microphysics • 3D volumes of precipitation intensity and its variation in time	• Understanding the role of BSOA in mixed-phase cloud microphysics
Feedbacks and interactions, integration with existing activities	• A unique combined data set with in situ observations and remote sensing techniques • Provision of means to fill the gaps and quantify uncertainties in the proposed climate feedback	• Quantification of the climate feedback involving biogenic emissions and resulting aerosol formation over the boreal forest zone • Assessment of the sensitivity of this feedback to anthropogenic influence • Extension of our results into a global scale

4.2 From Emissions to Aerosol

IN SITU OBSERVATIONS OF AEROSOL PARTICLES AND PRECURSOR GASES AT THE SURFACE LAYER OF THE ATMOSPHERE

New particle formation (NPF) from precursor vapors provides a source of particle numbers in clean boreal forest (Kulmala et al. 2001). Although many precursors (sulfuric acid, amines, and various organics) have been attributed to initial gas-to-particle conversion, the dominant process growing these clusters to climatically relevant sizes is, without doubt, condensation of organic vapors (Riipinen et al. 2011). This fact is also underlined by the average chemical composition, which indicates that the majority of the particulate mass in natural boreal forest is made up of organic compounds (Jimenez et al. 2009).

Figure 6. Chamber Measurements are Used to Determine Emission and Uptake of Various Compounds (CO_2, VOC). From the left: a shoot chamber, a branch chamber and a soil chamber.

4.2.1 Determination of Precursor Vapor Emission Rates

Emissions of VOCs by coniferous trees originate from evaporation from the storage pool (Guenther et al. 1995) and from de novo biosynthesis (Ghirardo et al. 2010). Both of these processes depend on the temperature and the amount of photosynthetically active radiation, while the latter is also affected by environmental stress factors (e.g., drought, ozone concentration). Our previous research has shown large temporal and spatial variabilities in both emission strengths and emission quality of VOCs from boreal forest trees (e.g., Tarvainen et al. 2005; Hakola et al. 2006; Bäck et al. 2012). One of our goals is to determine branch-scale emissions of VOCs using dynamic enclosure cuvette measurements and canopy-scale emissions using micrometeorological techniques (Taipale et al. 2008) on a 127-m measurement mast. We also probe the emissions of reactive gases from soil, which originate from microbial activity and decomposition processes (Bäck et al. 2010; Aaltonen et al. 2011), which may also potentially affect aerosol formation and growth (Kulmala and Petäjä 2011). Other relevant condensable vapors (sulfuric acid, amines) will be measured using chemical ionization mass spectrometers (CIMS, Petäjä et al. 2009; Jokinen et al. 2012). All of these techniques are well-established methods and are continuously operated at the SMEAR II station in Hyytiälä.

Process-scale models of photosynthesis, emissions and combined aerosol physics–atmospheric chemistry box models link the measurements to boundary layer evolution and mixing of the precursor species to higher altitudes. We parameterize the emission fluxes and amounts of condensable vapors from the surface source using 1D process models, which include aerosol dynamics, chemistry and the atmospheric boundary layer properties (Boy et al. 2011) and entrainment of the free tropospheric air to the convective boundary layer.

4.2.2 Aerosol In Situ Measurements

Aerosol measurements in the surface layer are conducted by both SMEAR II infrastructure and ARM AOS, if it is available. These measurements include a comprehensive physical and chemical characterization and the life cycle of aerosol particles from 1 nm to 10 μm in size. Within SMEAR II, the continuous aerosol measurements are carried out by a PSM (Vanhanen et al. 2011), ion spectrometers (AIS/NAIS/BSMA/Sigma, Manninen et al. 2010), DMPS (Aalto et al. 2001), APS, outdoor ELPI and

OPC. Chemical composition of growing clusters is determined with high-resolution mass spectrometry (APi-TOF, Ehn et al. 2010) and the bulk composition is determined by the Aerodyne ACSM. The CCN concentration is determined with a size-segregated droplet measurement technique CCN counter and calculated from the combined information from the measured number size distribution and from the mixing state of aerosol based on hygroscopicity and volatility properties (HVTDMA, Cappa et al. 2012). The optical properties are monitored with MAAP, Aethalometer AE-31, PSAP and TSI 3-wavelength dry nephelometer. The total extinction is measured with CAPS. With these ground-based instruments we cover the scattering and absorption of radiation due to aerosol particles. The gap-filling instrument, the wet nephelometer, will be provided by AOS.

The detection of the process of NPF phenomena relies on nanoparticle instrumentation and data analysis methods described in Kulmala et al. (2012). The vertical profile of horizontal winds and turbulence intensity will be measured with a sodar from FMI below 500 m and Halo Doppler lidar (as part of the FMI lidar network).

The 8-month AMF period will be compared to the long-term aerosol data set of SMEAR II to assess the representativeness of the 1-year data set and interannual variability. The full suite of the available AMF aerosol characterization will be inter-compared with the SMEAR II instruments for QA and QC purposes based on the full time series when the fixed sites can be considered co-located. The spatial variability on a local scale (10 km) is explored by additional in situ measurements from deployment at another location where aerosol number size distribution, number concentration, and the amount of precipitation is measured during an intensive observation period. This will be performed by the University of Helsinki. This extends the representativeness of the point measurements in Hyytiälä through the atmospheric column above the area. Furthermore, the University of Helsinki will obtain aerosol number size distribution measurements at the surface and at the 22 m and 100 m levels of the 127 m mast in Hyytiälä.

Regional representativeness on a larger scale is obtained in two ways. First, besides SMEAR II, continuous coordinated aerosol observations are made at five other sites in Finland: Helsinki, Utö, Kuopio, Varriö, and Pallas. The latitudes of the sites provide good coverage, ranging from 60 to 70 degrees north, covering both the Arctic and the Baltic Sea, natural boreal forest environment, and areas with anthropogenic influences. The measurements at all sites are conducted with similar instruments and data QA/QC practices. Second, during the campaign period we will perform four aircraft field campaigns onboard an operation-ready Cessna 172 (Schobesberger et al. 2012) or onboard a Cessna 185, which is currently being prepared. Additional options are provided by collaboration with FMI, who can deploy a Skyvan with a larger scientific payload. This will characterize the sub-grid variability of the aerosol properties that can be assimilated into global chemical transport and climate models and compared with satellite NPF proxies (Kulmala et al. 2011b).

Figure 7. The Flight Campaign around the Hyytiälä Measurement Station in Spring 2013.

4.3 From Aerosol to Clouds

Next, we extend the comprehensive measurements of biogenic aerosols from the surface to the atmospheric column where cloud formation occurs. To unravel the mechanisms by which biogenic aerosols interact with clouds, we will characterize the vertical profile of aerosols, clouds and turbulence. The process can be split into two main steps: the transport of biogenic aerosols from the surface into the boundary layer and free troposphere, and the participation in cloud formation.

4.3.1 Aerosol Transport

The transport of biogenic aerosols from the surface into the boundary layer is driven by turbulent mixing, whereas the mixing-layer height (MLH) determines the level to which air in contact with the surface reaches (Emeis et al. 2008). The MLH can be defined in terms of the turbulent kinetic energy dissipation rate (Barlow et al. 2011), which will be determined directly from high-resolution vertically pointing Doppler lidar data (O'Connor et al. 2010) provided by FMI in Hyytiälä. In combination with the surface and tower measurements, we will also derive aerosol fluxes from the surface through the boundary layer.

In close proximity to the Doppler lidar, the MPL and HSRL, provided by AMF, will measure the vertical profile of aerosol (layer boundaries, optical thickness and particle typing). Additional in situ aircraft observations onboard a Cessna 172 (Schobesberger et al. 2013) during four field campaigns will allow for the determination of the aerosol sources.

In order to capture the spatial representativeness on a mesoscale, an additional site at Kuopio (200 km northeast from Hyytiälä) will measure the vertical profile of aerosol (layer boundaries, optical thickness, particle typing and size distribution) and humidity with a multi-wavelength PollyXT lidar (3 backscatter, 2 extinction, depolarization and water vapor channels). In addition, from the multi-wavelength lidar data, the inversion routines can provide columnar values for particle surface area, volume, effective radius, refractive index and single scattering albedo. A Doppler lidar and surface instrumentation are also present at this site. The equipment for this site is provided by the FMI.

The atmosphere column model SOSA (Boy et al. 2011), combining different emission modules, boundary layer dynamics and both chemical and aerosol dynamic processes, will be used to investigate the formation, vertical transport and aging of atmospheric aerosols inside the mixing layer. The model simulations will link our knowledge based on long-term ground observation with the new measurements by the AMF instruments.

4.3.2 Cloud Properties

Based on direct observations inside clouds, Kerminen et al. (2005) showed that secondary aerosols formed from biogenic emissions can be activated into cloud droplets. We expect that aerosol-cloud interactions are similar for both supercooled and warm liquid clouds. In order to investigate the influence of biogenic aerosols on clouds, we will document the macro- and microphysical properties of clouds. The process we will study is the influence of CCN on the liquid cloud droplet size spectra. Liquid clouds will be classified according to their aerosol source—biogenic, background or other aerosol source—and whether or not they are coupled with the boundary layer. Synoptic regime classification, based on NWP and ECMWF reanalysis (from FMI), will provide the meteorological context.

The Doppler cloud radar (KAZR) and lidars will measure the vertical profiles of clouds, including layer boundaries, optical thickness and phase. Combinations of various radar wavelengths (including scanning instruments operating in a vertical direction), together with lidars and microwave radiometers, will be used to retrieve the cloud microphysical properties, such as water content and flux, size distributions and ice morphology.

Continuous operation is planned for all measurements mentioned above for the duration of the campaign. We will use the well-established ARM and CLOUDNET algorithms (Illingworth et al. 2007) for deriving vertical profiles of cloud properties, together with algorithms developed within EARLINET for deriving vertical profiles of aerosol properties. Ground-based aerosol and gas retrievals will be performed according to ACTRIS and EUSAAR protocols.

During the active periods of biogenic aerosol formation, supercooled liquid water clouds may also be present in the boundary layer. In addition to in situ and active remote sensing measurements in Hyytiälä, we will use ongoing aerosol and cloud measurements at the Puijo tower (SMEAR IV) and Pallas station (GAW station). These measurements are conducted inside the clouds, which enables a direct connection between the interstitial aerosol concentration and composition (SMPS, HiRes AMS), CCN counter (CCNC, DMT) and cloud droplet probe (CDP, DMT) data. With this data we are able to probe partitioning of organics between the droplets and the interstitial particles.

The measured aerosol size distributions, chemical composition and atmospheric vertical profiles will be used as an input for the air/cloud parcel models to simulate the cloud droplet forming potential of biogenic aerosols in different conditions. With the model we are able to study the effect of size-resolved chemical composition and mixing state of aerosol on the cloud droplet number and composition, as well as the freezing of cloud droplets and phase of clouds. This information can be later used in cloud resolving modeling and global modeling activities where detailed information of aerosol cannot be included.

4.4 From Clouds to Precipitation

The majority of the precipitation in Finland occurs from cold clouds (either as snow or as rain from melting ice). Hence, the microphysical processes leading to precipitation are often those of mixed-phase clouds, and, to understand cloud-aerosol-precipitation interaction, we need to decipher the impact of aerosols on the microphysics of mixed-phase clouds. Lohmann and Feichter (2005) have hypothesized that the following three cloud-aerosol interaction mechanisms could play a role in mixed-phase cloud:

1. glaciation indirect effect – more aerosol implies more IN, therefore more ice particles
2. riming effect (e.g., Borys et al. 2003; Saleeby et al. 2009) – more aerosol implies more CCN, therefore more numerous but smaller cloud droplets, reduced riming efficiency, and a reduction in ice particle density
3. thermodynamic indirect effect – more aerosol implies more CCN, therefore more numerous but smaller cloud droplets, reduced efficiency in secondary ice production, and a reduction in ice particle number concentration.

To investigate the potential role of these processes in the formation and growth of ice particles, measurements of both liquid and ice cloud microphysics are required.

4.4.1 Mixed-Phase Cloud Microphysics

Formation and growth of ice particles will be documented by utilizing synergistic radar and lidar retrievals in the vertical dimension, together with a combination of Doppler radar spectra observations at vertical incidence and dual-polarization, dual-wavelength scanning radar observations.

To understand the role of aerosol on mixed-phased clouds, we need measurements of vertical profile of cloud microphysical properties, i.e., ice water content, liquid water content and number concentration of cloud droplets. The profile of liquid cloud microphysics can be obtained as described in the previous WP. However, we note that this is not always possible, e.g., in cases such as optically thick ice layers and multiple cloud decks. Cloud properties will be retrieved using multi-wavelength radar techniques and the radar-lidar technique of Delanoë and Hogan (2008) where appropriate.

Furthermore, vertical structure of mixed-phase clouds will also be determined by vertically pointing Doppler spectral observations and corresponding scanning radar dual-polarization measurements. As was shown by Luke et al. (2010), Doppler spectra can be used to detect supercooled cloud layers in mixed-phase clouds. A similar approach will be used here to diagnose such layers and study their potential impact on ice particle growth. This work will be carried out in combination with the analysis of supercooled liquid layer properties. As the outcome of this study, we hope to understand whether aerosols can be linked to supercooled liquid layer properties, and whether those are linked to snow growth processes.

4.4.2 Surface Precipitation Mapping

The surface precipitation will also be documented by scanning weather radars and surface stations.

These measurements will be carried out using FMI operational weather radars, scanning KA-SACR, the FMI surface observation network, and surface precipitation instruments that will be deployed during the experiment.

The site in Hyytiälä is within 65 km of the operational FMI radar, a C-band dual-polarization Doppler weather radar located in Ikaalinen. There are three more operational and research radars that are less than 200 km from the experiment site. The operational radars carry out low-level scans every 5 minutes and complete a volume scan in 15 minutes.

These large-scale precipitation observations will be augmented with high temporal and spatial resolution observations from the research radars deployed at the experiment site, i.e., X/KA-SACR. To understand the properties of precipitation, and to tune the dual-polarization radar retrieval algorithms, a number of disdrometers will also be deployed.

4.5 Feedbacks and Interactions, Integration with Existing Activities

Here we integrate the results in terms of i) the different spatial and temporal scales involved, and ii) feedbacks and interactions.

4.5.1 Radiative Transfer Modeling and Integration with Satellite Products

Using the detailed vertical aerosol and cloud profile information, radiative transfer calculations will be performed to test the estimates of the radiative energy balance of the entire atmospheric column, including the effects of both aerosols and clouds. Radiative closure is given by AMF surface radiation measurements (e.g., MFRSR, SKYRAD) and satellite observations such as CERES or MODIS. The results of these radiative transfer calculations can also be used to test the link between observed aerosol and cloud properties and global climate models. Here, the scanning cloud radar will be used for characterizing the 3D volume to describe the heterogeneous cloud field, which is vital for comparing 1D radiative transfer calculations with satellites and global climate models.

The data collected during the measurement period will provide a unique opportunity to also assess processes other than particle production and growth from the biogenic emissions. For example, smoke from wildfires in Russia may be transported into the region of interest. Previously, such events have occurred on a semi-regular basis. In 2006, for example, a plume of aerosols over southern Finland from burning biomass reduced the noontime solar surface radiation by 15% compared to typical unpolluted conditions (Arola et al. 2007). With the additional data available through AMF, a more detailed analysis on the radiative effects of aerosols will be possible, particularly with regard to the combined effect of aerosols and clouds. Satellite data from, for example, MODIS and CALIOP, can further aid the analysis (e.g., Mielonen et al. 2012).

A satellite/lidar simulator is a forward model from which a simulated satellite/lidar signal can be obtained using radiative transfer equations that use modeled aerosol size, composition and spatial distribution as input. Since the models explicitly describe the aerosol size and composition, the satellite sensor response can be calculated from the model data. This makes sure that we have fully comparable data when climate model simulations are compared against actual observations.

We will adopt an aerosol-lidar simulator within an aerosol-climate model ECHAM-HAMMOZ for producing synthetic lidar signals that correspond to the ground-based lidar measurements and CALIPSO observations. This model-simulator combination will be used to evaluate global model aerosol fields and the quality of retrieval algorithms. Using the aerosol-climate model, we will examine the causes of discrepancies in modeled and measured aerosol distribution, especially the effects of removal processes and aerosol mixing on transport of aerosols and their vertical distribution. Ultimately, we will improve the estimates of the magnitude of climate change in boreal regions.

4.5.2 Development of New Parameterizations to be Used in Models

The Aerosol Modeling group at UEF studies aerosol-cloud interactions, especially the activation of particles to form cloud droplets, and removal processes due to wet scavenging, using the cloud resolving model UCLALES together with the aerosol model SALSA. Currently, this activity is funded through the Academy of Finland project COOL. Measurements of size-resolved aerosol activation and chemical composition from the Puijo tower (SMEAR IV measurement station) are used to validate the model. In addition, the group is active in studying the microphysics of cloud droplet formation and the effect of chemistry, especially organics, on cloud droplet formation potential.

It has been shown from measurements conducted at the Puijo tower that cloud droplet number concentrations in low-level stratiform clouds are dependent on the aerosol number concentration of accumulation mode particles as long as CCN concentration is $<500\ cm^{-3}$. Above that concentration, no clear correlation exists. Similar, albeit weaker, correlation has been observed in the satellite data using the MODIS instrument. With the measurements conducted in the SMEAR II station during this project, and the supporting measurement activities at the other SMEAR stations, we will be able to evaluate the results from MODIS cloud products and upscale our observations to a large extent of the boreal environment.

The main parameters affecting cloud droplet formation in liquid clouds are the updraft velocity prevailing at the cloud base and the number of aerosol particles that are large enough to act as CCN. Updraft velocity controls the growth of particles able to activate as cloud droplets and is a crucial parameter for understanding biogenic aerosol-cloud interaction. We have seen from in situ measurements and satellite observations that, in low-altitude clouds over boreal forest, modeled updraft velocities are probably so low that, with cloud droplet concentrations already exceeding $200\ cm^{-3}$, the aerosol effect on clouds is limited, and an increase in aerosol concentration no longer has an effect on droplet concentration. However, the applicability of these results is limited due to the lack of information on cloud and boundary layer vertical structure and dynamics. This information will be provided by AMF. The results will lead to new knowledge of updraft velocities at the cloud base and cloud formation potential of aerosol, which can be used to evaluate and improve the performance of global models over the boreal environment.

4.5.3 Quantification of the Main Feedbacks and Interactions

The main feedback to be investigated in this project is as follows: temperature increase → increase in VOC emissions → increased concentration of aerosol particles → increased concentration of cloud droplets → negative radiative forcing → temperature decrease. Such sequence constitutes a negative climate feedback mechanism over the continental biosphere. This feedback was proposed by Kulmala et al. (2004b), and its first two links have been recently confirmed by Paasonen et al. (2012). The last three links of this feedback have not been tackled experimentally before.

The third step of the above feedback sequence has not been quantified experimentally yet, as the role of convection is difficult to assess without measurements of vertical profiles. This step can be quantified by experimental and modeling tools provided by WP2-WP4. The last two links are more challenging, but the measurements conducted at the SMEAR II station combined with the satellite observations and modeling methods provide us with the best possible tools to experimentally quantify the above feedback as completely as possible.

We further aim to put the feedback into a global context using global climate models. The observations of aerosol optical properties and the cloud activation potential of biogenic aerosol precursors will be used in a global aerosol-climate model ECHAM-HAMMOZ. The observed optical properties will be evaluated against model parameters. In addition, a recent study has shown that condensing organic vapors enhance cloud activation of aerosol particles (Topping et al. 2013). Applying the approach by Topping et al. (2013) in the model and using measured biogenic organic vapor concentrations as an input to the model will allow us to estimate the CCN activity of biogenic compounds.

Another purpose of this task is to investigate interactions between biogenic and anthropogenic aerosol systems over our study areas. Direct interactions between biogenic and anthropogenic trace gases are crucial in the very first steps of atmospheric NPF (Kerminen et al. 2010; Paasonen et al. 2010) and very likely also in SOA formation (Spracklen et al. 2011). Anthropogenic primary particle emissions may have indirect effects on biogenic aerosol formation, which we aim to quantify here as well.

The extensive AMF2 data set in combination with our long-term data set (18 years at the time of the field measurements) will provide a possibility to probe into the interannual variability and assess the representativeness of the one-year measurement data set by AMF in Hyytiälä. The SMEAR II station in Hyytiälä is unique in this respect as no other measurement site has been operating in a continuous manner for such a long time. We will be able to look into decadal behavior of the atmosphere-biosphere interactions, including the measured aerosol and cloud properties and vertical profiles of different parameters.

5.0 International Collaboration and Transnational Access

The SMEAR station network is offering transnational access (TNA) via EU projects, such as ACTRIS, EXPEER (Distributed Infrastructure for EXPErimentation on Ecosystem Research), INGOS and ICOS, to support collaborators from other groups in Europe and the United States. ACTRIS (Aerosols, Clouds, and Trace gases Research InfraStructure Network) is a European Project aimed at integrating European ground-based stations that are equipped with advanced atmospheric probing instrumentation for aerosols, clouds, and short-lived gas-phase species. ACTRIS has an essential role in supporting the acquisition of new knowledge as well as policy issues on climate change, air quality, and long-range transport of pollutants. ACTRIS is building the next generation of the ground-based component of the EU observing system by integrating three existing research infrastructures (EUSAAR, EARLINET, and CLOUDNET), and a new trace gas network component into a single coordinated framework. ACTRIS is funded within the EC 7th Framework Programme under "Research Infrastructures for Atmospheric Research."

One of the grand goals of ACTRIS is to provide a coordinated framework to support TNA to European advanced infrastructures for atmospheric research, strengthening high-quality collaboration inside and outside the European Union, and access to high-quality information and services for the user communities (research, environmental protection agencies, etc.).

ICOS is a new European Research Infrastructure for quantifying and understanding the GHG balance of the European continent and of adjacent regions. The mission of ICOS is to provide the long-term atmospheric and flux observations required to understand the present state and predict future behavior of the global carbon cycle and GHG emissions and to monitor and assess the effectiveness of carbon sequestration and/or GHG emission reduction activities on global atmospheric composition levels, including attribution of sources and sinks by region and sector.

The consortium and the SMEAR II infrastructure are part of EXPEER and a core of the new European Research Infrastructure ICOS, which integrates diverse research communities on the pan-European scale in studies regarding biosphere-atmosphere exchange. The infrastructures and all supporting measurements (fluxes, concentrations, meteorology and ecosystem observations) are freely available, and access to data from several other sites is provided via ICOS and collaboration. We also actively participate in the ANAEE (Infrastructure for Analysis and Experimentation on Ecosystems) PP project, funded in 2012–2014 through the ESFRI research infrastructures. Scientific interaction is further provided within iLEAPS (the Integrated Land Ecosystem–Atmosphere Processes Study), the land-atmosphere interface core project of the International Geosphere-Biosphere Programme (IGBP). The SMEAR stations also belong to the national ESFRI roadmap and to the SHOK CLEEN.

The activities of this project for remote sensing from satellites are directly linked to the ALANIS-AEROSOLS project, which aims specifically to investigate, develop and validate novel algorithms, solely exploiting as input currently available Earth Observation-based products for discriminating natural from anthropogenic aerosols in boreal Eurasia; in particular, the feasibility of using satellite products to determine the occurrence of nucleation events will be investigated.

The collaboration of scientists from Colorado State University is accomplished through the Finnish Distinguished Professor Appointment of Prof. Chandra with the University of Helsinki.

BAECC will seek additional collaboration to integrate the results from the nano scale to the global scale, both in terms of measurements and modeling (Kulmala et al. 2011b). Via EU projects (ACTRIS, EXPEER, INGOS, ICOS) we will offer TNA to support the leading groups in Europe and the United States to participate this study. This campaign will initiate national funding for additional activities in the field.

6.0 Concluding Remarks

BAECC goals are co-aligned with the long-term goals of the U.S. Department of Energy's Office of Biological and Environmental Research, which include the delivery of improved climate data and models for policy makers, and a substantial reduction in the differences between observed temperature and model simulations at sub-continental scales using several decades of recent data. The BAECC experiment will improve

1. the data availability for the Earth system modeling community

2. the scientific understanding of the processes related to the boreal forest zone as a source of aerosol particles for cloud droplets—a direct link between the atmosphere and biosphere

Furthermore, BAECC will provide a processed and quality-controlled data set from a boreal environment location. The combination of the SMEAR and the ARM Mobile Facility, satellite observations and Earth system modeling will result in high-quality publications examining the impact of biogenic aerosols on cloud formation and the implications for the global climate. The project provides relevant links to European-scale infrastructures and Earth system research communities such as ICOS, ACTRIS, ANAEE, and EXPEER.

6.1 Improved Scientific Understanding

At the proposed site in Hyytiälä, we will have an 18-year record of ground-based aerosol, trace gas and ecosphere measurements. Together with the comprehensive cloud radiation and aerosol remote sensing instrumentation provided by the ARM Mobile Facility, this campaign will provide an excellent opportunity to understand the impact of biogenic sources of aerosols on cloud formation and, thus, the global climate. The results will be used in the Earth system modeling work. The work is targeted at identifying and reducing scientific uncertainties in current Earth system models, creating a deep understanding of several processes associated with biosphere-atmosphere interactions, biogeochemical cycling of climatically relevant compounds, and soil processes. One of the specific objectives in this collaborative is to construct a plan for a new innovative test bench for Earth system models using both observational data and proxy-based palaeoclimatological data.

We use integrative science as the approach to solve the scientific questions related to the BAECC project. The core of the project lies in the processes and interlinks connecting the boreal forest with its emissions, secondary aerosol formation, cloud formation and processes, and precipitation. The scientific questions arising from the process level, both from models and from the observations, are upscaled to cover spatial scales from microphysics to regional and even global scales and temporal scales from seconds to years.

6.2 Added Value of the AMF Deployment

The added value of the AMF operation, together with the existing long-term data, will be to provide avenues for exploring

- aerosol – air quality – cloud interactions (Arneth et al. 2009). Hyytiälä represents a boreal background site, but is occasionally affected by anthropogenic pollution and long-range transport of pollutants from central Europe.
- effect of biomass burning. High aerosol loads from forest fires in Russia can be transported over Finland during the spring, summer and autumn.
- interannual variability. How representative is the AMF observation period?

All aerosol and other relevant data recorded within the SMEAR II station in Hyytiälä are already distributed in near-real time through a web-based interface, SMART-SMEAR (Junninen et al. 2010, www.atm.helsinki.fi/~junninen). The final data will be delivered to the ARM Data Archive within 6 months after the end of the field study.

As a final product, BAECC will provide a processed and quality-controlled data set from a boreal environment location. The combination of the SMEAR and ARM facilities, satellite observations and Earth system modeling will provide high-quality publications examining the impact of biogenic aerosols on cloud formation and the implications for the global climate.

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