DOE-UHEL-SC0010711

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Biogenic Aerosols - Effects on Clouds and Climate

Final Technical Report

Period Covered: 1 September 2013 - 31 August 2015

November 2015

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on behalf of the BAECC community.

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DISCLAIMER

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ABSTRACT

"Biogenic Aerosols - Effects on Clouds and Climate (BAECC)", featured the U.S. Department of Energy's Atmospheric Radiation Measurement (ARM) Program's 2nd Mobile Facility (AMF2) in Hyytiälä, Finland. It operated for an 8-month intensive measurement campaign from February to September 2014. The main research goal was to understand the role of biogenic aerosols in cloud formation. One of the reasons to perform BAECC study in Hyytiälä was the fact that it hosts SMEAR-II (Station for Measuring Forest Ecosystem-Atmosphere Relations), which is one of the world's most comprehensive surface in-situ observation sites in a boreal forest environment. The station has been measuring atmospheric aerosols, biogenic emissions and an extensive suite of parameters relevant to atmosphere-biosphere interactions continuously since 1996. The BAECC enables combining vertical profiles from AMF2 with surface-based in-situ SMEAR-II observations and allows the processes at the surface to be directly related to processes occurring throughout the entire tropospheric column. With the inclusion of extensive surface precipitation measurements, and intensive observation periods involving aircraft flights and novel radiosonde launches, the complementary observations of AMF2 and SMEAR-II provide a unique opportunity for investigating aerosol-cloud interactions, and cloud-to-precipitation processes. The BAECC dataset will initiate new opportunities for evaluating and improving models of aerosol sources and transport, cloud microphysical processes, and boundary-layer structures.

ACKNOWLEDGEMENTS

This work was partly supported by the Office of Science (BER), U.S. Department of Energy via BAECC (Petäjä), BAECC-SNEX (Moisseev) and DE-SC0011791 (Thornton), ASR (Chandrasekar), European Commission via projects ACTRIS, ACTRIS-TNA, ACTRIS2, BACCHUS, PEGASOS and European Research Council via NANODYNAMITE (No. 616075), and Academy of Finland Centre of Excellence (project number 272041), KONE foundation (grant number 46-6817), Nordforsk via Cryosphere-Atmosphere Interactions in a Changing Arctic Climate, CRAICC, TEKES in the CLEEN/MMEA program and the Ministry of Transport and Communication through ICOS-Finland. The BAECC SNEX was also supported by NASA Global Precipitation Measurement (GPM) Mission ground validation program. The deployment of AMF2 to Hyytiälä was enabled and supported by ARM. Argonne National Laboratory's work was supported by the U.S. Department of Energy, Assistant Secretary for Environmental Management, Office of Science and Technology, under contract DE-AC02-06CH11357. The authors gratefully acknowledge the support of AMF2, SMEAR-II and the BAECC community for their support in initiating the BAECC campaign, its implementation, operation and data analysis.

ACRONYMS AND ABBREVIATIONS

ACTRIS	Aerosols, Clouds, and Trace gases Research InfraStructure Network
AMF2	ARM Mobile Facility 2
AOS	Aerosol Observation System
ARM	Atmospheric Radiation Measurement
BAECC	Biogenic Aerosols – Effects on Clouds and Climate
BAECC-ERI	
BAECC-SNEX	BAECC snowfall measurement experiment
BVOC	Biogenic volatile organic compounds
ToF-CIMS	Chemical Ionization Time-of-Flight Mass Spectrometer
CNR	Consiglio Nazionale delle Ricerche, Italian National Research Council
COOPEUS	Co-operation EU/US
CPC	Condensation Particle Counter
DMPS	Differential Mobility Particle Sizer
FIGAERO	Filter Inlet for Gases and Aerosols
FMI	Finnish Meteorological Institute
IOP	Intense Observing Period
NAIS	Neutral and Air Ion Spectrometer
NPF	new particle formation
PSM	Particle Size Magnifier
SMEAR IISMEAR-II	Station for Measuring Ecosystem – Atmosphere Relations
SOSA	model to Simulate the concentrations of Organic vapours, Sulphuric Acid and Aerosols
TROPOS	Leibniz Institute for Tropospheric Research
UHEL	University of Helsinki
UK	United Kingdom

SUMMARY

Atmospheric aerosol particles impact human health in urban environments, whilst 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, of all biomes, among the most active areas of atmospheric aerosol formation. The formation of aerosol particles and their growth to cloud condensation nuclei sizes in these areas are associated with biogenic volatile organic emissions (BVOC) 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) 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 operated its ARM Mobile Facility 2 (AMF2) in Hyytiälä next to SMEAR-II during an intensive measurement campaign called "The Biogenic Aerosols - Effects on Clouds and Climate (BAECC) experiment". The campaign started in February 2014 and ended in September 2014.

The BAECC experiment provided a bridge from an 18-year long SMEAR-II observation record to the impact of biogenic aerosol on clouds, precipitation and climate. Simultaneous observations of precursor vapor emission, aerosol, cloud, and precipitation microstructure enable such an analysis. The dataset provides key data 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 were supplemented by tower and surface-based measurements of aerosol and precursor gases. During intensive observation periods (IOPs), aircraft observations of aerosol microphysics were performed. The experiment also benefited from existing measurements of spatial distribution of precipitation provided by the Finnish Meteorological Institute radar network. The 8.5-month dataset is positioned in perspective with the long time series available from Hyytiälä, and utilized in modeling efforts ranging from process models to global climate models.

The main goal of the BAECC activity was to understand the impact of biogenic aerosol formation on cloud properties and ultimately on global climate. The specific aims were:

1. to 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, to complete the link between our comprehensive 18-year observational record of aerosol and biosphere-atmosphere interactions to cloud processes,
3. to expand our local observations over larger spatial scales up to the Earth System via a hierarchy of models (emission, aerosol dynamics, atmospheric chemistry, cloud process, radiative transfer, global climate model) and satellite observations.

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1 Introduction

On regional and global scales aerosol particles can affect climate by changing the physical properties and lifetime of clouds and thus affect the intensity of radiation reaching the surface of the Earth (Boucher et al., 2013). Recently, there have been major advances in understanding the links between aerosol dynamics and biosphere-atmosphere-climate interactions, and the formation processes of aerosol (Kerminen et al., 2005; Lihavainen et al., 2009; Sihto et al., 2011). However, great challenges remain in analyzing these related processes on a global scale.

Boreal forests located in the Northern latitudes in United States, Canada, Russia and the Nordic countries, are one of the most active areas in atmospheric aerosol formation. In these areas, the formation of aerosols is driven most actively by the biogenic volatile organic emissions from vegetation and soil (Tunved et al., 2006; Dal Maso et al., 2007; Kulmala et al., 2011).

The Biogenic Aerosols – Effects on Clouds and Climate (BAECC) campaign took place in Hyytiälä, Finland between 1st of February and 14th of September 2014 (Petaja et al., 2014). The BAECC campaign's goal was to provide a dataset, which will be used in: 1) linking precursor emissions and aerosols; 2) linking aerosols at the surface to aerosols in the mixing layer and in the free troposphere; 3) to investigate the aerosol indirect effect on clouds and precipitation.

The United States Department of Energy's Atmospheric Radiation Measurement (ARM) program brought the ARM Mobile Facility (AMF2) to Hyytiälä, Finland, where the University of Helsinki's (UHEL's) Station for Measuring Ecosystem – Atmosphere Relations (SMEAR-II; Hari and Kulmala, 2005) is located. At the SMEAR-II, various biogenic atmospheric aerosol physical properties and biosphere-atmosphere interactions have been continuously monitored during the last 19 years (Mäkelä et al. 21997; Aalto et al., 2001; Dal Maso et al., 2005; Kulmala et al., 2007; Nieminen et al., 2014). During BAECC, the SMEAR-II tower, surface measurements and the flight campaigns, which were organized by the University of Helsinki and the Finnish Meteorological Institute during intensive observation periods (IOPs), supplemented the AMF2 observations.

Principal investigator (PI) of the BAECC campaign was Prof. Tuukka Petäjä from the Department of Physics, University of Helsinki.

The main collaborating agencies, universities and institutes included:

- The Office of Science (BER), U.S. Department of Energy,
- Department of Physics, University of Helsinki,
- Finnish Meteorological Institute (FMI),
- Department of Forest Sciences, University of Helsinki.

The BAECC-Finland team included:
Dmitri Moisseev[1], Ewan O'Connor[2,3], Hanna Lappalainen[1,2], Janne Levula[1], Jaana Bäck[1,4], Michael Boy[1], Mika Komppula[2], Anders Lindfors[2], Radovan Krejci[5], Antti Manninen[1], Riikka Väänänen[1], Mikhail Paramonov[1], Harri Kokkola[2], Hannele Korhonen[2], Heikki Lihavainen[2], Sami Romakkaniemi[2], Victoria Sinclair[1], Veli-Matti Kerminen[1], Kari Lehtinen[6], V. Chandrasekar[7,1], Gerrit deLeeuw[2,1], Ari Laaksonen[2], Douglas R. Worsnop[1,6,8] and Markku Kulmala[1].

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6 University of Eastern Finland, Finland
7 Colorado State University, CO, USA
8 Aerodyne Research Inc., MA, USA

2 Notable events of highlights

The installation progressed within the estimated timelines and the operation started on February 1 2014, as planned. The first science team meeting was organized at the end of February with 25 participants from BAECC institutes in Finland. The presentations and discussions covered topics such as biogenic aerosol formation, associated emissions from the biosphere and their connection to the observed properties of clouds, identification of relevant gas-phase precursors to look at aerosol growth, data flows and quick looks from AMF2 and SMEAR-II.

Figure 1. The BAECC site in Hyytiälä, Finland, during spring. The long-term, continuous and comprehensive measurements from the 127-m SMEAR2 measurement mast and platforms (back) provide the ideal location for the AMF2 (front). Photo: Riikka Väänänen.

The BAECC deployment initiated a lot of attention within the European atmospheric research community. This was utilized to attract transnational access and funding from European Commission to host additional instrumentation on aerosols and trace gases during the BAECC campaign. A total of 188 eligible research access days were funded by the Aerosols, Clouds, and Trace gases Research InfraStructure Network (ACTRIS), which aims at integrating European ground-based stations

equipped with advanced atmospheric probing instrumentation for aerosols, clouds, and short-lived gas-phase species. Within ACTRIS, visiting scientists from CNR (Italy), TROPOS (Germany), University of Vienna (Austria) and University of Reading (UK) were able to perform gap-filling observations, such as detailed aerosol concentration measurements, advanced eddy covariance flux measurements with high resolution mass spectrometers to determine biosphere-atmosphere exchange processes in detail.

During the BAECC deployment, UHEL performed aircraft measurements to determine aerosol vertical profiles during three seasons with 144 flight hours on 30 different days. The Finnish Meteorological Institute (FMI) performed two research flights with their aircraft, which included aerosol chemistry and cloud condensation nuclei measurements inside the clouds. FMI included a RHI scan over Hyytiälä at regular intervals with their C-band weather radar in Ikaalinen. Furthermore, FMI participated also by operating their Polly^{XT} multi-wavelength Raman lidar in Hyytiälä, and Vaisala and Aerodyne operated their ground-based remote sensing instruments next to AMF2, providing additional information on aerosols, clouds and turbulence around the BAECC site.

2.1 BAECC-SNEX IOP

Of particular interest during the winter period was snowfall, during BAECC-SNEX IOP (The snowfall measurement Biogenic Aerosols – Effects on Clouds and Climate (BAECC) campaign. The IOP was a collaborative effort between DOE ARM, University of Helsinki, FMI, NASA and Colorado State University. The IOP took place in 1 Feb-30 April 2014 and was dedicated to documenting snowfall microphysics through a combination of multi-frequency (C, X, Ka, W -band) radar, microwave radiometer and lidar measurements supplemented by a comprehensive suit of surface-based precipitation observations.

During the IOP, more than 20 snowfall events were recorded. Microwave radiometer observations detected the presence of supercooled liquid water in more than 80 % of the profiles in these events. Due to an extensive suite of instruments, and their excellent performance during the IOP, detailed snow microphysical studies are possible and will be used to augment radar-based analysis.

2.2 Spring intensive

During spring intensive measurement period a suite of mass spectrometers and advanced aerosol instrumentation were operated at Hyytiälä. One of the aims of this activity was to connect mechanistic insights into new particle formation and growth to in situ and vertically resolved observations of aerosol and cloud properties by the ARM Mobile Facility. Prof. Joel Thornton from University of Washington deployed Filter Inlet for Gases and Aerosols (FIGAERO) coupled to high-sensitivity, field-deployable mass spectrometer that is capable of providing near real-time measurements of the molecular-level composition of gas and particle phase organic matter. With his instrument, organic aerosol components are then assayed by temperature-programmed thermal-desorption and detection with the ToF-CIMS.
This multi-dimensional speciation makes FIGAERO-ToF-CIMS highly useful for secondary organic aerosols source attribution and model-relevant characterization of its chemical and physical properties.

Additional instrumentation during the spring IOP included contributions from University of Helsinki (Tuukka Petäjä, Jaana Bäck), Finnish Meteorological Institute (Hannele Hakola), University of Eastern Finland (Annele Virtanen), University of Vienna (Paul Winkler) and National Center for Atmospheric Research (Jim Smith) and Paola Massoli (CNR). These activities were partly supported by ACTRIS-I3 Trans National Access to SMEAR 2 site.

2.3 Flight IOPs

To obtain better understanding of the vertical and horizontal scales of atmospheric phenomena, aircraft-borne measurements were performed using a Cessna 172 light aircraft as a platform. Three flight IOPs were flown: 24 March - 11 April, 19 May – 7 June, and 18 August – 19 September. Two new aerosol instruments were added to extend the airborne measurements towards smaller particles. In the second flight IOP a new Airmodus Particle Size Magnifier (PSM, Vanhanen et al., 2011) was tested under varying airborne conditions. During the third flight IOP the Neutral and Air Ion Spectrometer (NAIS, Mirme et al., 2007) was installed to another similar Cessna 172 aircraft, and the planes measured simultaneously flying in a formation. Both instruments worked well and their results agreed with the other on-board aerosol instruments.

Additional research flights (a total of three flights in September, 2014) were conducted onboard Skyvan aircraft operated by Finnish Meteorological Institute. The benefit of this aircraft is larger payload, which enabled measurements of aerosol chemical composition with Aerosol Mass Spectrometer and determination of number concentrations of cloud condensation nuclei with a CCNC counter.

2.4 BAECC-ERI

Two IOPs involving intensive radiosonde campaigns were undertaken, one in May and the other in September 2014, involving collaboration between DOE ARM and University of Reading, UK. This involved additional instrumentation designed by University of Reading attached to the standard radiosonde package, including novel miniaturized solar radiation, charge and turbulence sensors. This required some modification of the standard ARM radiosonde ingest procedures by ARM personnel to allow the extra research data to be captured separately while allowing the standard radiosonde data to be transferred as normal.

2.5 Science team meetings

A set of science team meetings was initiated to make progress in data analysis of the BAECC data set. The first science meeting of the BACC team was organized already at the beginning of the BAECC measurement period in Hyytiälä. Here, the team discussed initial ideas to analyze the data and discusses hypothesis based on previous activities at SMEAR-II site in Hyytiälä.

The second science meeting of the BAECC team was organized at the end of the campaign in September. The participants discussed their current work with the AMF2 and SMEAR-II data from the BAECC and planned for joint publications. The meeting was timed to be concurrent with COOPEUS (Connecting Research Infrastructures), which is an infrastructure program supported by the European Union in cooperation with the NSF that aims at enhancing collaboration between Europe and USA. The joint dinner in Hyytiälä and tour around AMF2 and SMEAR-II provided ample opportunities for the scientists and program managers to discuss about science and find out new collaboration possibilities.

The collaboration within the BAECC research team and particularly with the various working groups of ASR, were strengthened in a break-out session in ASR spring 2015 meeting organized in Washington, DC. Additionally, the BAECC PI and science team facilitated connections and collaborations by participating in science meetings of GoAmazon –project (Martin, 2013) at Boston, MA, May 2015.

3 Lessons Learned

Overall, the interaction and co-operation with the scientific staff and the technical staff of AMF2 and SMEAR-II was excellent. Furthermore, the technical performance was outstanding. The whole chain from planning and installation to operation and data delivery was truly excellent. The key here was the combined expertise, commitment, and teamwork of AMF2 and SMEAR2 technical staff. This is not a small thing as the science is totally dependent on this step.

However, from the SMEAR-II technician's point of view there were some issues that we'd suggest ARM to consider. The organizational structure of the ARM seems to be well defined and somewhat inflexible. This sometimes seemed to cause unnecessary inertia to co-operation due that technicians on site have to get everything approved by the mentors. This inertia was somewhat amplified by time difference between the USA and Finland.

One way to improve the situation is to increase both the liberties and the responsibilities of the on-site technical staff leading to more effective performance. One example of such occasion was initial reluctance to deal with problems relating to mains power. This was the case even with changing the fuse. We understand that this is probably due to safety regulations but we suggest that ARM would bring an electrician on a foreign site at least for the starting period. In Hyytiälä this was not a crucial point, but the implementation would speed up the initial stages of the operation in measurement places with less on-site support.

4 Results

A vast data set was collected during BAECC, which will be contrasted against the 10-year data set already available from SMEAR-II. As a technical example, we validated co-located AMF2 aerosol measurements against SMEAR-II instrumentation. Furthermore, additional aerosol measurements operated approximately 300 m apart enabled us to study spatial variability of aerosol number concentration and number size distribution in small scale.

Analysis of the BAECC dataset is under way, and will continue for many years. One of the characteristic features of the in-situ aerosol number size distributions is shown in Fig. 2 that depicts formation of aerosol particles from biogenic gas phase precursors. Such events were observed frequently during the BAECC campaign. The co-location of the AMF2 with the SMEAR2 provided benchmarking of the in-situ aerosol measurements.

Overall, the measurements were in good agreement taking into account that initially the fresh aerosol particles were below the detection limit of the AMF2 instruments. The combination of the in-situ data with lidar-derived vertical profiles enables assessment of aerosol effects on cloud properties.

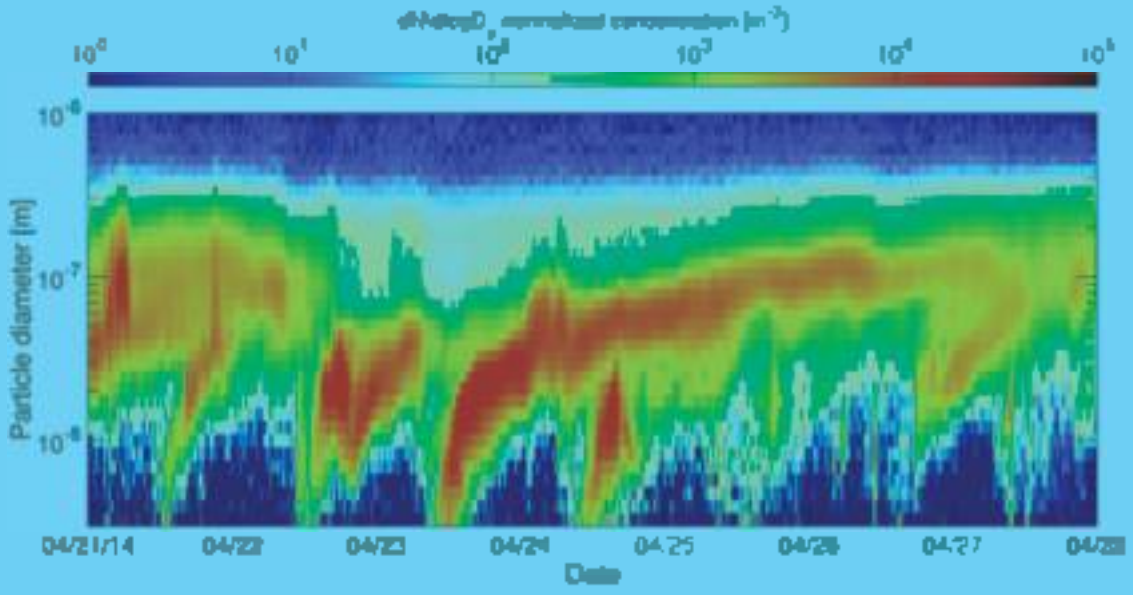

Figure 2. Sub-micron aerosol number size distribution measured with a SMEAR-II Differential Mobility Particle Sizer (DMPS) at Hyytiälä, Finland between 21st-27th of April 2014 featuring the characteristic phenomenon observed at the site: formation of secondary organic aerosol and their growth to CCN active sizes.

4.1 Results from precursor emission measurements

The site hosts online measurements of gaseous precursor emissions and above-canopy concentrations as well as of ecosystem activity in general. As Scots pine is the dominating tree species in the vicinity of BAECC campaign location, the ecosystem measurements are conducted in the SMEAR-II station situated in a 50-year-old pine forest, ca. 500 m from the main measurement field. We measure carbon uptake and volatile organic compound (VOC) emissions simultaneously from the mast and from shoot, stem and soil enclosures.

Figure 3. The emission of biogenic volatile organic compounds (BVOCs) were determined using branch cuvettes (top left) and soil chambers (top right). Eddy covariance technique together with fast response Proton Transfer Reaction Mass Spectrometer (PTR-MS, Taipale et al. 2011) allows us to determine ecosystem scale fluxes (bottom)

Overall, the winter 2014 was very mild and ecosystem activity was very high already early in spring. The onset of net carbon uptake (NEE) already in early February (Fig. 5) indicates that the potential for biogenic production of precursor gases was high during the spring months. Monoterpenes are the main emitted compound group from coniferous forests. The shoot scale enclosure measurements with PTR-MS reveal that, as in many previous years, extremely high emission rates in early spring

coincided with the spring recovery period of trees during early-to-mid March, and that these peaks provide a 2-3 times higher monoterpene emissions, compared with other times in spring (Aalto et al 2015 submitted manuscript). The maximum emission rates were observed in March 11-12, 2014. Another high emission period was seen during the new foliage growth in late May-early June (Aalto et al 2014). During summer the highest emissions were observed along with high temperatures in early and late summer, whereas the colder weeks around midsummer resulted in period of lower monoterpene emissions.

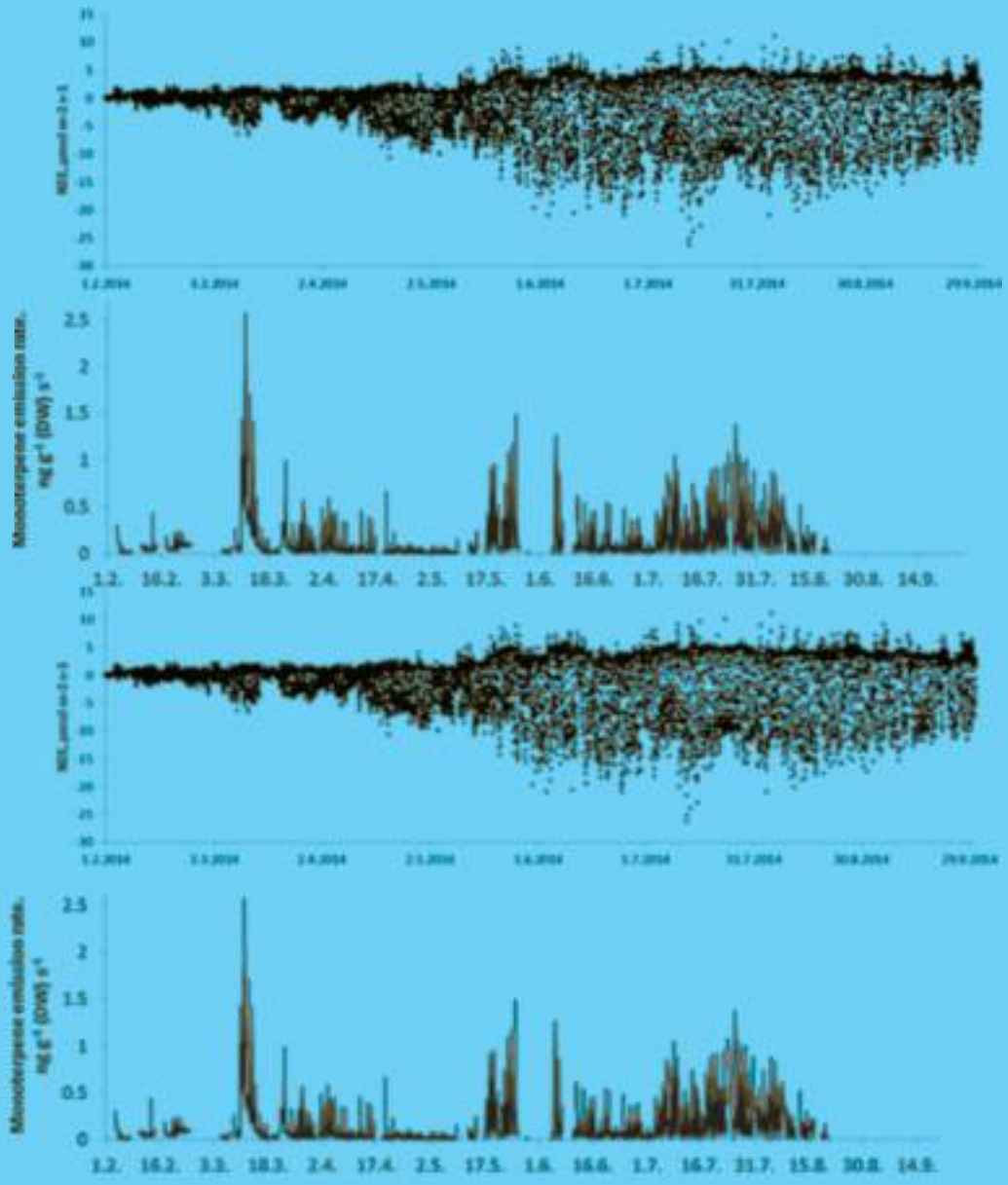

Figure 4 Net ecosystem exchange (umol m^{-2} s^{-1}, top panel) and monoterpene emission rate (ng g (DW)$^{-1}$ s^{-1}, bottom panel) during the BAECC campaign in 2015 (DW = dry weight of the needles; Aalto et al., 2015 submitted manuscript).

4.2 Ground-based aerosol and trace gas results

4.2.1 Comparison of AMF2 and SMEAR 2 in-situ aerosol measurements

The in-situ aerosol measurements carried out during the BAECC campaign by the AMF2 AOS were compared with the corresponding continuous SMEAR-II measurements: total aerosol concentration, CCN concentration, and light scattering coefficient of aerosol at ambient relative humidity.

The total aerosol number concentration was measured continuously during the BAECC campaign by several instruments (the short titles used in figures are in parentheses): CPC and a DMPS in a SMEAR-II cottage (SMEAR-II CPC and SMEAR-II DMPS, respectively), a DMPS on the SMEAR-II 35 m tower (tower DMPS), a DMPS designated for the BAECC campaign at the main AMF2 instrumental field (BAECC DMPS), and a CPC inside the AMF2 AOS (AMF2 CPC). The co-located TSI 3010 CPC in the AOS, i.e. the AMF2 CPC, and the TSI 3776 ultrafine CPC, i.e. the SMEAR-II CPC, which are capable of measuring particles > 10 nm and > 3 nm in diameter, respectively, were compared. The comparison indicated that there were an offset in the concentrations between the two CPCs, and the cause was determined to be a clogged inlet inside the AMF2 CPC (Fig. 5a). To correct for the offset the concentrations were compared during the non-NPF-event days (Dal Maso et al., 2005) when the amount of particles less than 10 nm in diameter can be assumed to be insignificant. A correction factor c was found by:

$$c = \left(\frac{med(N_1)}{med(N_2)}\right)^{-1},$$

where N_1 and N_2 are the total aerosol concentrations measured with the AMF2 CPC and the SMEAR-II CPC, respectively.

After applying the correction factor, the total aerosol concentrations agreed very well between the two CPCs taking into account the different cut-off values (Fig. 5). As both total aerosol concentrations measured with the two CPCs are log-transformed, during the non-NPF-event days (Fig. 5b), 10% change in the SMEAR-II concentration corresponds to 9.9% change in the AMF2 concentration in Fig. 5c. During the NPF-event days, the 10% change in the SMEAR-II concentration corresponds approx. 7.64% change in the AMF2 concentration (Fig. 5d).

In other words, when the amount of particles with diameter <10 nm is significant and when the total aerosol concentration is in the region of 10^4 cm^{-3} the AMF2 CPC measures lower total aerosol concentration by default.

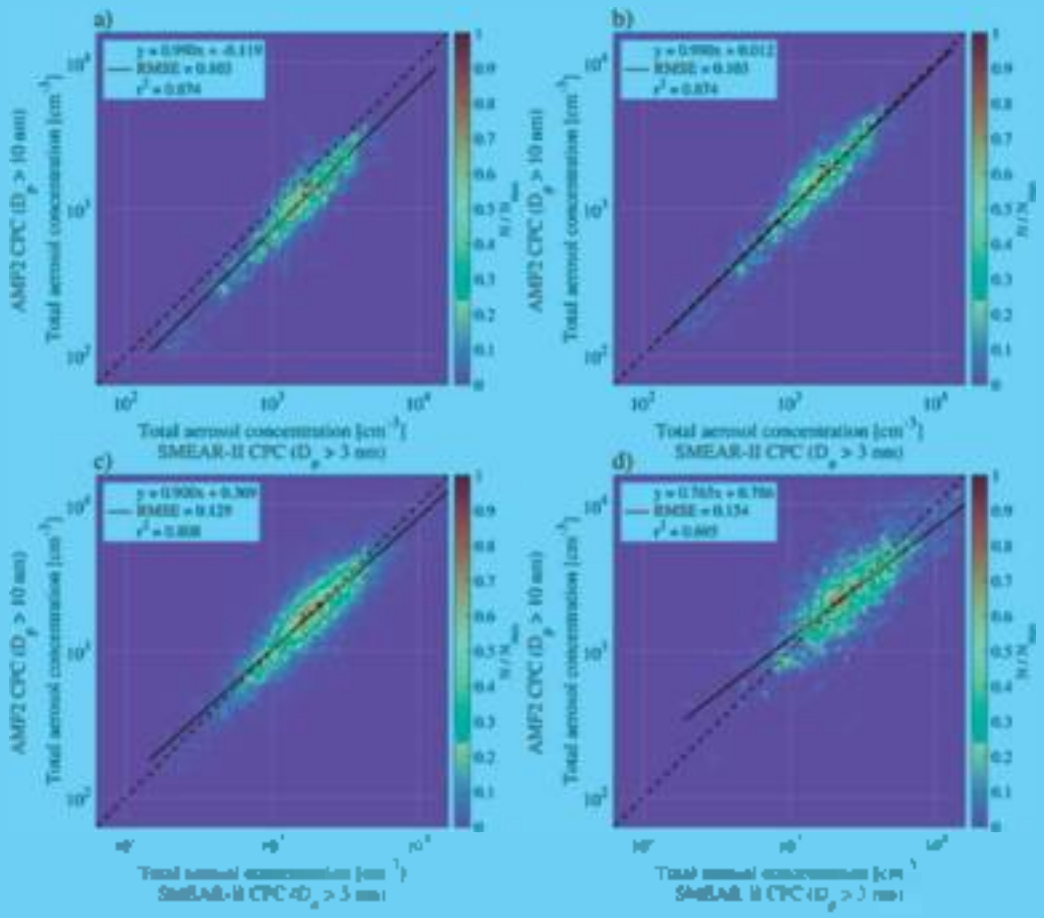

Figure 5. Comparisons of the uncorrected (a) and the corrected (b) total aerosol concentration during non-NPF-event days, together with the corrected total aerosol concentration during all (c) and NPF-event days (d) measured by the AMF2 and the SMEAR-II CPCs at Hyytiälä, Finland between 2 February and 14 September 2014.

The nephelometers measuring the light scattering from aerosols at ambient RH, showed excellent correlation during the campaign: 10% change in the SMEAR-II total scattering coefficients correspond to 10.01–10.04% change in the AMF2 total scattering coefficients (Fig. 6)

The AMF2 CCN concentration data set is marked as "data questionable" for the duration of the whole BAECC campaign. When comparing the time series to the corresponding SMEAR-II measurements, a clear offset can be observed at the lowest supersaturation set points.

The offset gradually decreases towards the higher SS Comparison of the measurements at different SS, show a very good correlation at all of the SS: a 10 % percent change in the SMEAR-II CCN concentration corresponds to 9.93–10.06 % change in the AMF2 CCN concentration.

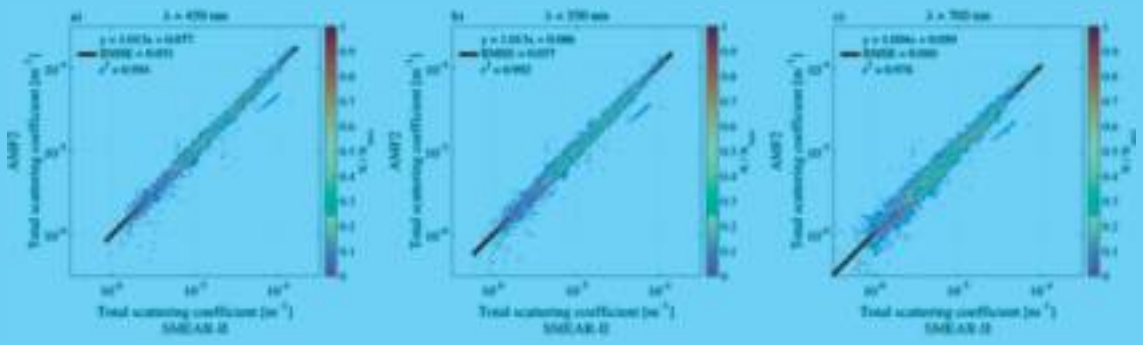

Figure 6. Comparisons of the total aerosol scattering coefficients at 450 nm (a), 550 nm (b), and 700 nm (c) wavelengths measured at Hyytiälä, Finland during 2 Feburary and 14 September 2014.

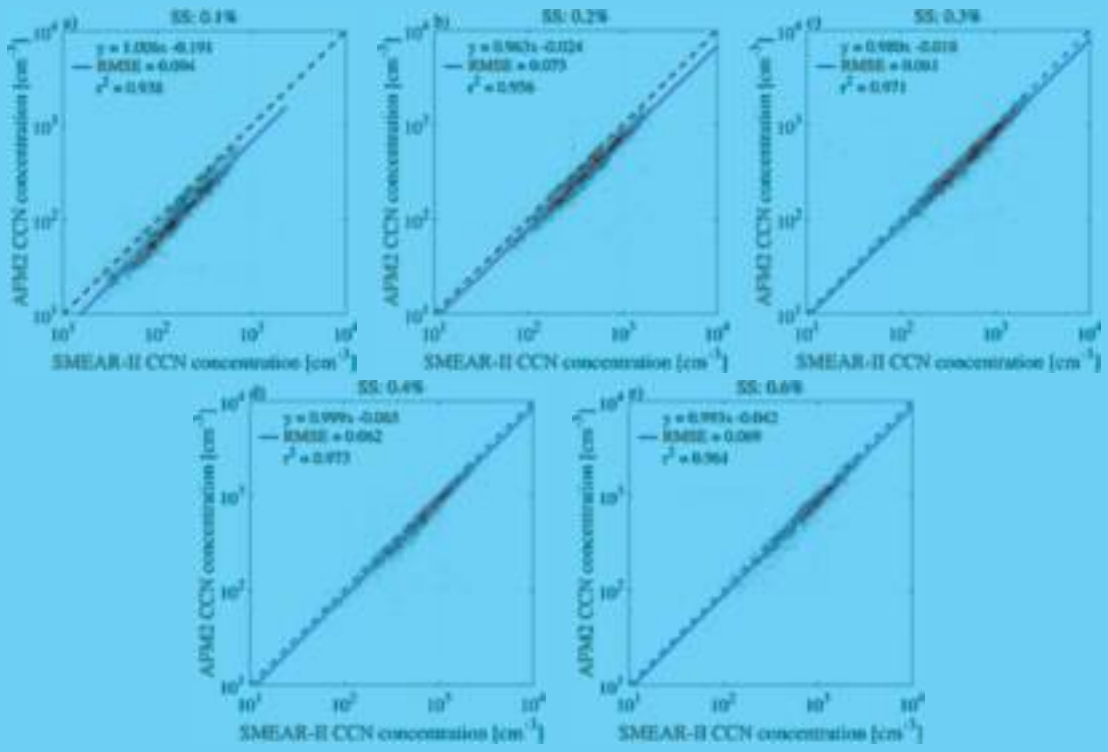

Figure 7. Comparisons CCN concentration at different supersaturation set points (SS): (a) 0.1 %, (b) 0.2 %, (c) 0.3 %, (d) 0.4 %, and (e) 0.8 %. At SS in (d,e) the SMEAR-II CCN concentrations were interpolated from the nearest SS. Measurements carried out by AMF2 and SMEAR-II CCN counters at Hyytiälä, Finland during 2 February and 14 September 2014.

4.2.2 Representativeness of BAECC intensive for Hyytiälä aerosol in general

The new particle formation in Hyytiälä is a frequent phenomenon with two seasonal maxima, one in spring and a secondary maximum in autumn (Dal Maso et al., 2005). The comparison of BAECC period with the long-term cycle is presented in Fig. 8. The BAECC measurements were conducted during a representative period and the event probabilities were in line with long-term averages. The comparison of formation rate of particles larger than 3 nm in diameter, J_3 between the BAECC campaign and the measurements before it (1996-2013) shows that the J_3 has been several times or an order of magnitude larger before than during the campaign (Fig. 9a). However, during the campaign the monthly median growth rates were very typical as compared to 1996–2013 measurements (Fig. 9b).

In terms of the median diurnal behavior of total aerosol concentrations the BAECC intensive period was very typical as compared to the time period of 1996-2013 (Fig. 10 and 11). The increase of CCN concentrations after an NPF event days and the decrease after an NPF non-event days show similar behavior during BAECC as well as during the preceding years 2009-2013, and agree with the previous studies (Paramonov et al. 2013).

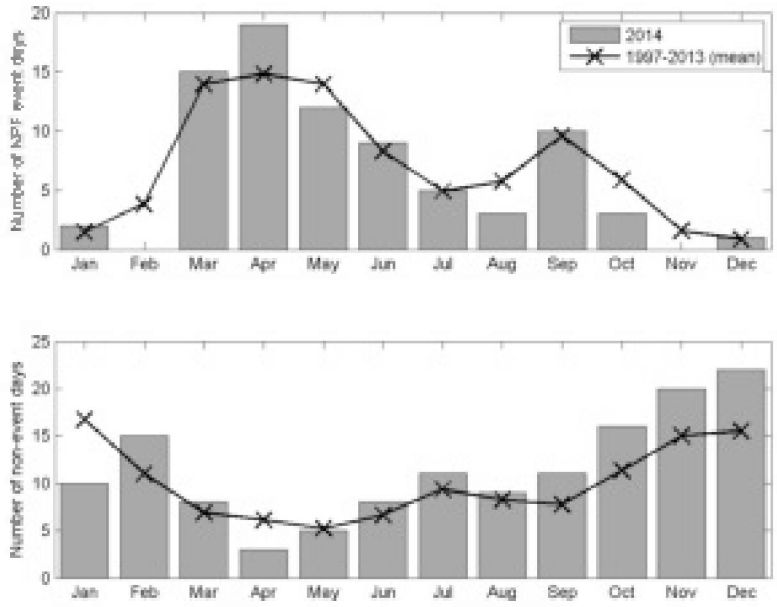

Figure 8. The monthly new particle formation event frequency during the BAECC campaign and comparison with long-term average characteristics (Petäjä et al. 2015, in preparation).

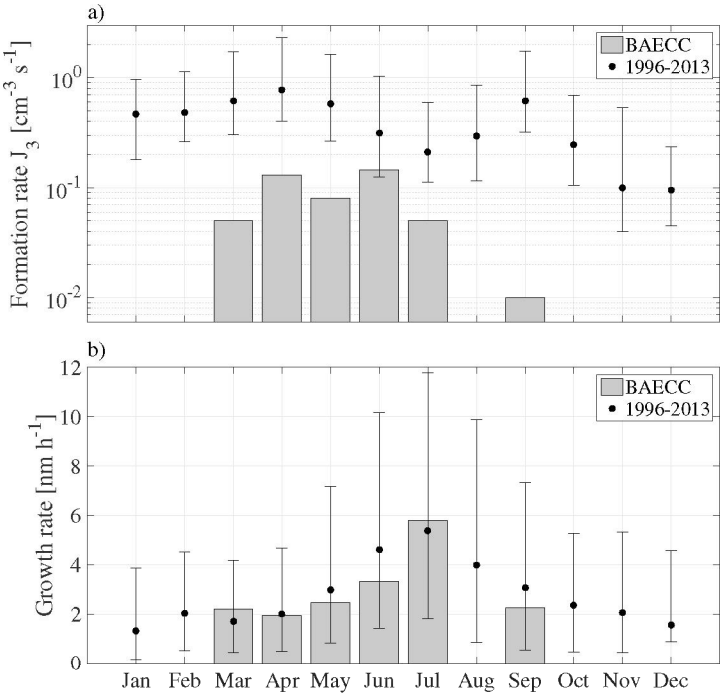

Figure 9. Comparison between the monthly median formation rate of particles larger than 3 nm in diameter, J_3 (a) and monthly median growth rate (b) during the BAECC campaign (a,b: bars) and 1996–2013 (a,b: dots with whiskers). The whiskers illustrate the 25th and the 75th percentiles.

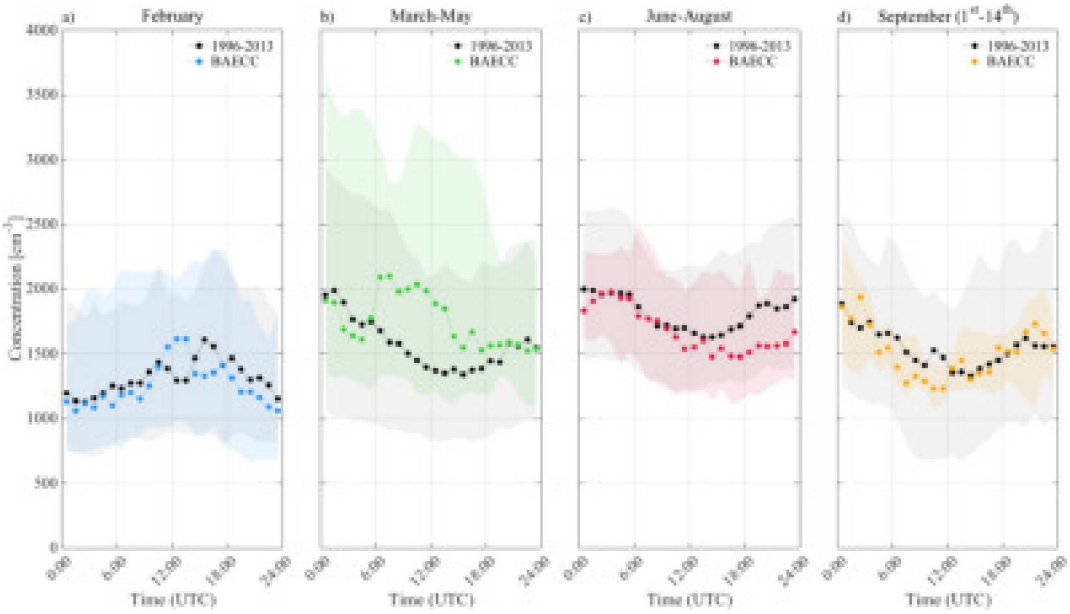

Figure 10. Comparison of median diurnal behavior of total aerosol concentrations at non NPF event days during February (winter; a), March-May (spring; b), June-August (summer; c), and September (autumn; d) between the time period of 1996-2013 and BAECC campaign measured at SMEAR II station at Hyytiälä, Finland. The shaded areas correspond to the respective 25th-75th percentile intervals.

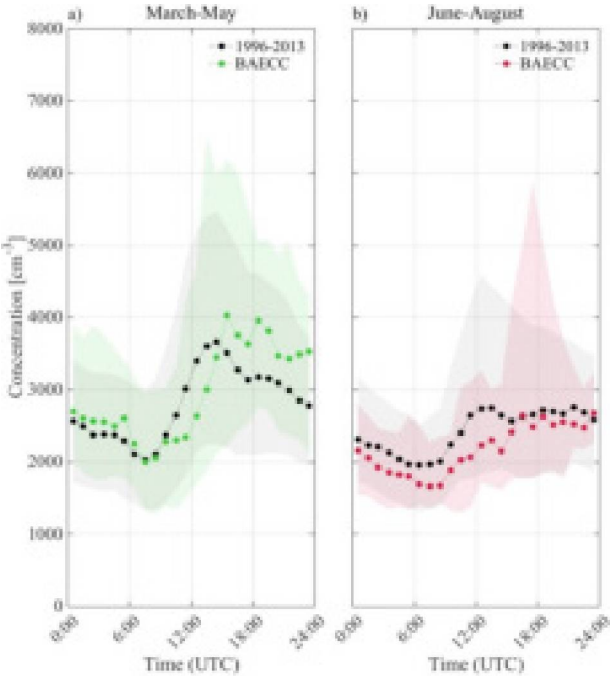

Figure 11. Comparison of median diurnal behavior of total aerosol concentrations at NPF event days during March-May (spring; a) and June-August (summer; b) between the time period of 1996-2013 and BAECC campaign measured at SMEAR II station at Hyytiälä, Finland. The shaded areas correspond to the respective 25th-75th percentile intervals.

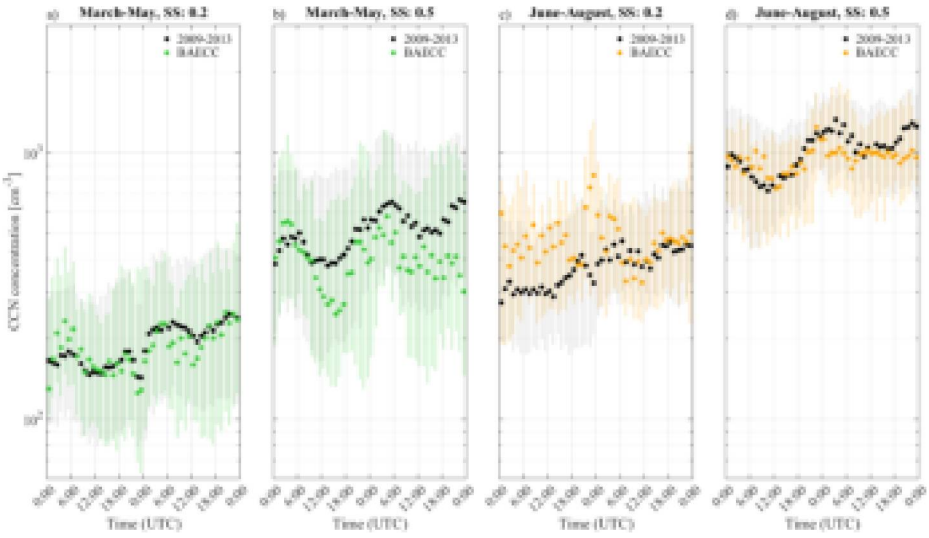

Figure 12. 48-hour cycle median CCN concentrations measured during BAECC and 2009-2013 spring (a,b) and summer (c,d) months on NPF event days at two different supersaturaton set points 0.2 % (a,c) and 0.5 % (b,d). The vertical lines depict the 25th and 75th percentiles.

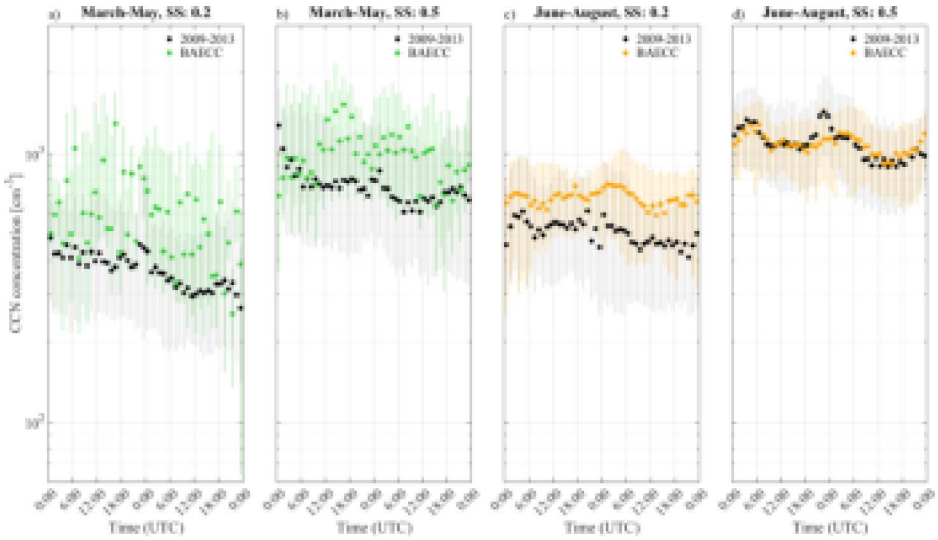

Figure 13. 48-hour cycle median CCN concentrations measured during BAECC and 2009-2013 spring (a,b) and summer (c,d) months on NPF non-event days at two different supersaturaton set points 0.2 % (a,c) and 0.5 % (b,d). The vertical lines depict the 25th and 75th percentiles.

4.2.3 Spatial variability of ground level aerosol

The DMPS deployed at the main AMF2 instrument field (referred as BAECC DMPS from now on) was compared to another DMPS located in a SMEAR-II cottage (referred as hitu) to study the spatial variability of ground level number size distribution of aerosols. During 18–22 Jan 2014 both of the instruments were co-located inside the same cottage. Figure 9a shows the relative difference between the two instruments calculated from 30 minute median total concentrations, with interpolated corresponding bin sizes. The linearly increasing difference between the two instruments in the 6–25 nm size range was taken into account by correction the BAECC DMPS concentrations with the modeled relative difference. After the correction the correlation improves: 10 % change in the SMEAR-II DMPS concentrations corresponded before the correction to approx. 8.65 % change in the BAECC DMPS concentrations and after the correction to approx. 8.78 % for all days during BAECC. During the NPF-days the correlation was better than during the non-NPF-days: 10 % change in the SMEAR-II DMPS concentrations corresponds to approx. 9.0 % for the former and approx. 7.7 % for latter. During the campaign, the SMEAR-II DMPS measured slightly higher concentration during the period when the total aerosol concentration was > approx. 10^2 cm^{-3}. The spatial variability was also investigated by utilizing several flight campaigns, which are described in detail in Sect. 2.3.

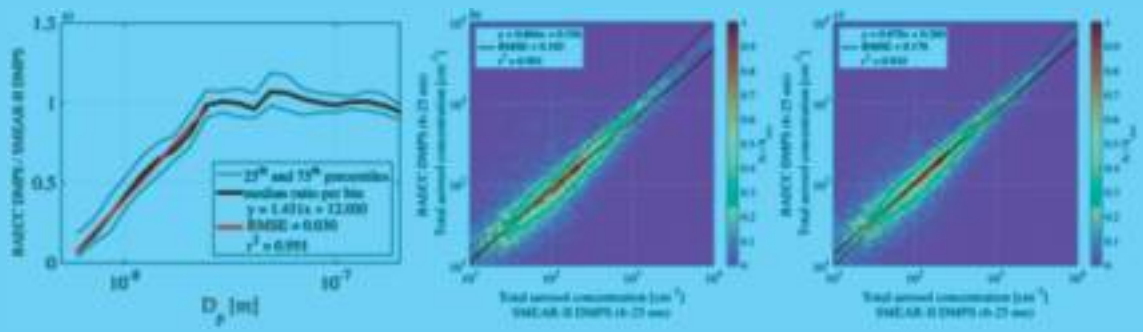

Figure 14. Relative difference of 30 minute median total aerosol concentrations, with interpolated corresponding bin sizes between the DMPS, which was deployed at the main AMF2 instrumental field during the BAECC campaign, and the SMEAR-II DMPS (a) during the period when both of the instruments were co-located inside the same SMEAR-II cottage. The uncorrected (b) and the corrected (c) BAECC DMPS measurements compared to the SMEAR-II DMPS measurements.

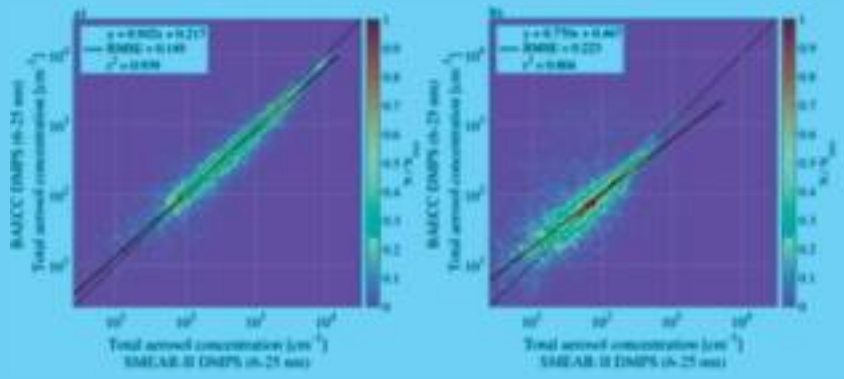

Figure 15. Comparison of the corrected and uncorrected SMEAR-II DMPS and BAECC DMPS total aerosol concentrations during non- (a) and NPF-event (b) days measured at Hyytiälä, Finland between 2 Feb and 14 Sep 2014.

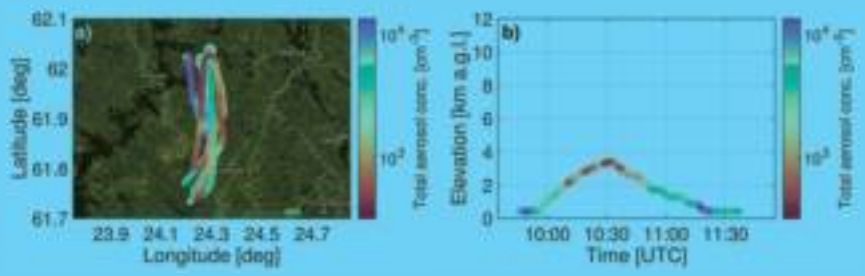

Figure 16. Total aerosol concentration measured with a CPC onboard a Cessna aircraft illustrated with respect to latitude–longitude (a) and elevation over time (b) on 2 April 2014 at Hyytiälä, Finland.

4.2.4 Vertical variability of aerosol number size distribution

To assess small scale vertical variability of aerosol and atmospheric ion concentrations, we utilized measurements conducted at close to ground level and compared them with the measurements obtained on 35-m measurement tower equipped with similar instrumentation (Fig. 8).

Figure 17. SMEAR-II aerosol measurements are conducted with comparable instrumentation from 35-m tower platform (left) and at 8-m above ground (right).

Figure 12 shows the diurnal median number concentration for negative ions measured at ground level and tower for three predetermined size ranges. The concentration for nonevent days is generally lower than for event days for tower and ground level respectively and no significant increase in ion concentration is seen for non-event days during noon, when events would take place. The concentration of cluster ions is several factors higher than the concentration of intermediate ions. Intermediate ions show a burst at noon for event days for both tower and ground level, which is not seen for cluster ions. With exception during burst period the concentrations for ground measurements are generally larger than the tower measurements due to increased ionization rate near the ground (Tammet et al., 2006). For the cluster ions an increase during evening is observed due to lowering of the boundary layer reducing vertical mixing (Tammet et al., 2006).

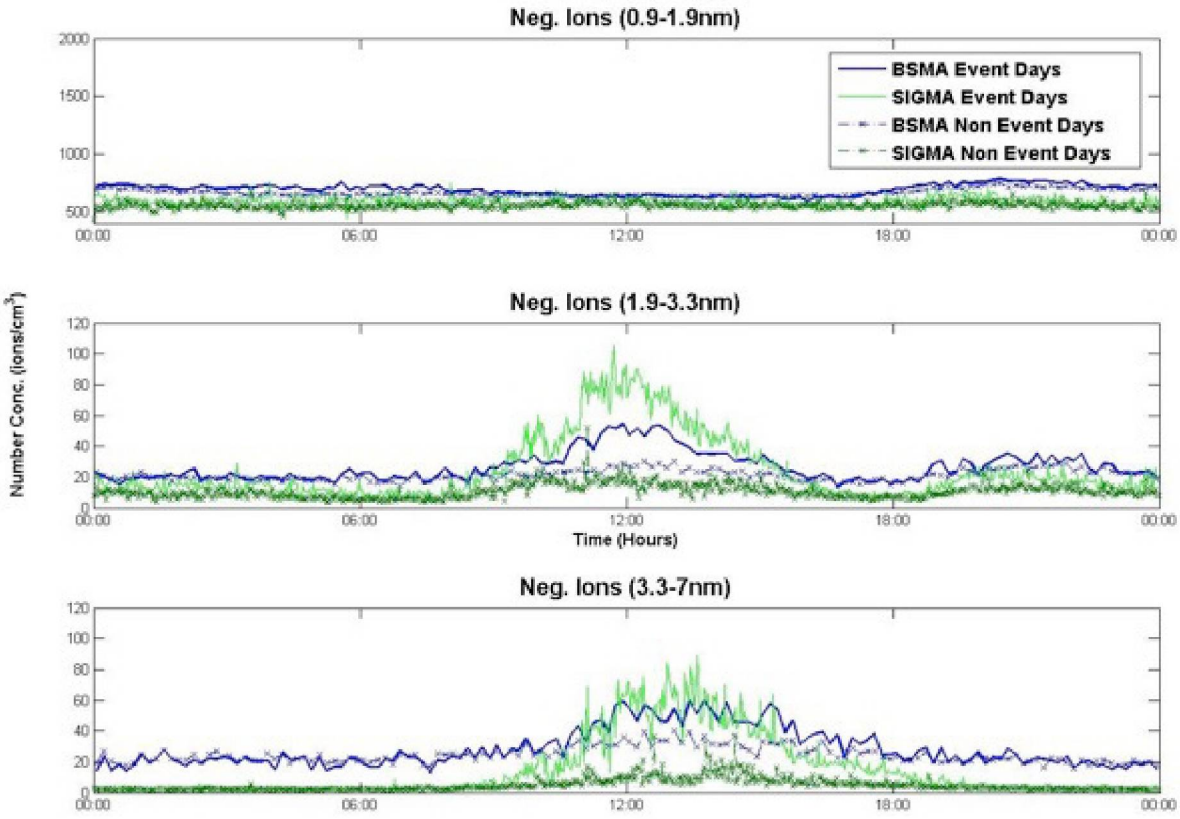

Figure 18. A typical diurnal cycle of negative atmospheric ions of different mobility equivalent sizes during new particle formation event days and non-event days measured at the ground level with BSMA and in 35m tower with SIGMA instrument (Xausa et al., 2014).

For the neutral particle measured with PSM there was also a clear difference between event days and non-event days. It can be seen from the diurnal median in Fig. 13. The difference is very clear especially for 2–3 nm particles. With smaller size range there was some weird behavior because concentrations in the tower at non-event days are really high.

This is most likely due to some instrumental artifact because it can't be seen at ground level. Also the amount of classified non-event days for the measurement period is really small, only 7 non-event from 50 measurement days against the 22 event days in same period. In the size ranges 1–2 and 2–3nm there were more particles in the ground level at nighttime and more in the tower level from morning to afternoon time. For 3-10nm particles, a similar difference was not that clear and the DMPS in the tower counted most of the time slightly higher concentrations.

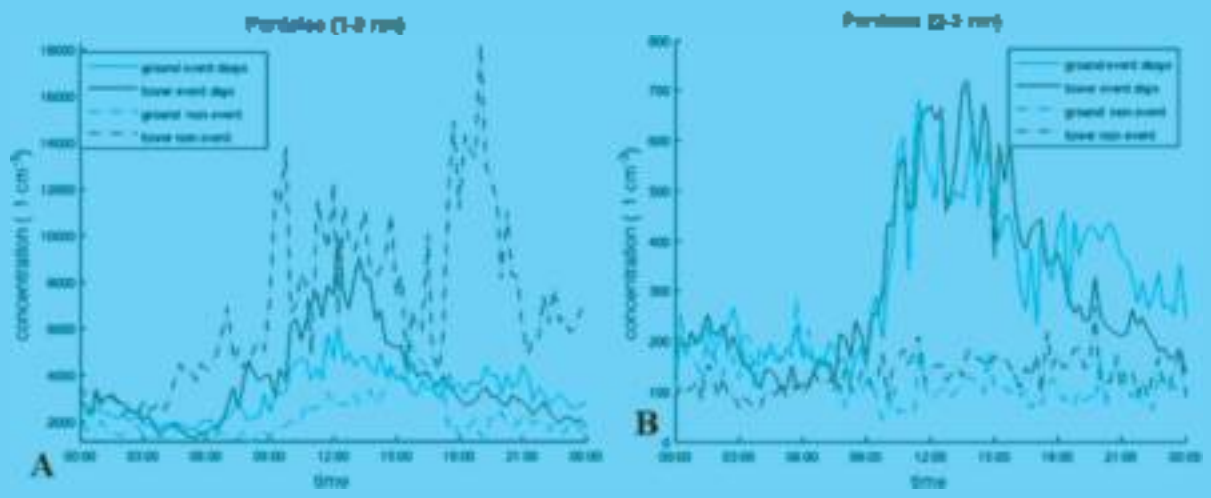

Figure 19 Diurnal median concentration for (A) 1-2 and (B) 2-3 nm particles for event days and non-event days at ground and tower level (PSM data).

4.2.5 Aerosol chemical composition

Aerosol chemical composition measurement was performed using an Aerosol Chemical Speciation Monitor (ACSM; Aerodyne Research Inc.; Ng et al., 2011). Data coverage during the BAECC campaign was extensive, and we obtained a good dataset for the study of seasonality of the aerosol phase composition. Further, a more detailed analysis also aims to connect the ACSM results to observations from the atmospheric column. In Fig. 14 the seasonal average composition of aerosol is presented. The seasons are defined using their thermal definitions. We observe clearly increased organic contribution during the photosynthetically most active seasons, whereas the wintertime composition is dominated by anthropogenic, inorganic chemical species.

In addition, an OC/EC analyzer (Sunset Technologies Inc) was deployed at the SMEAR-II station. With it, we measured the absolute mass concentrations for both organic carbon (OC) and elemental carbon (EC) compound, determined with a two-step thermal-optical method for the determination of OC and EC (Peterson et al., 2002) The results of especially the refractive EC complement the ACSM measurement in a useful way, providing a comprehensive picture of aerosol chemical speciation.

In the next phase of the analysis, we will perform Positive Matrix Factorization (Paatero and Tapper, 1994) to the aerosol chemical composition and include also data from High Resolution Aerosol Mass Spectrometer operated during the BAECC

This provides us the data on aerosol sources and relative contributions from different organic mass fractions. The aim is then to combine the PMF analysis with detailed measurements of organic precursor vapors to capture the contributions of aerosol precursors to the aerosol growth to CCN sizes based on in-situ observations

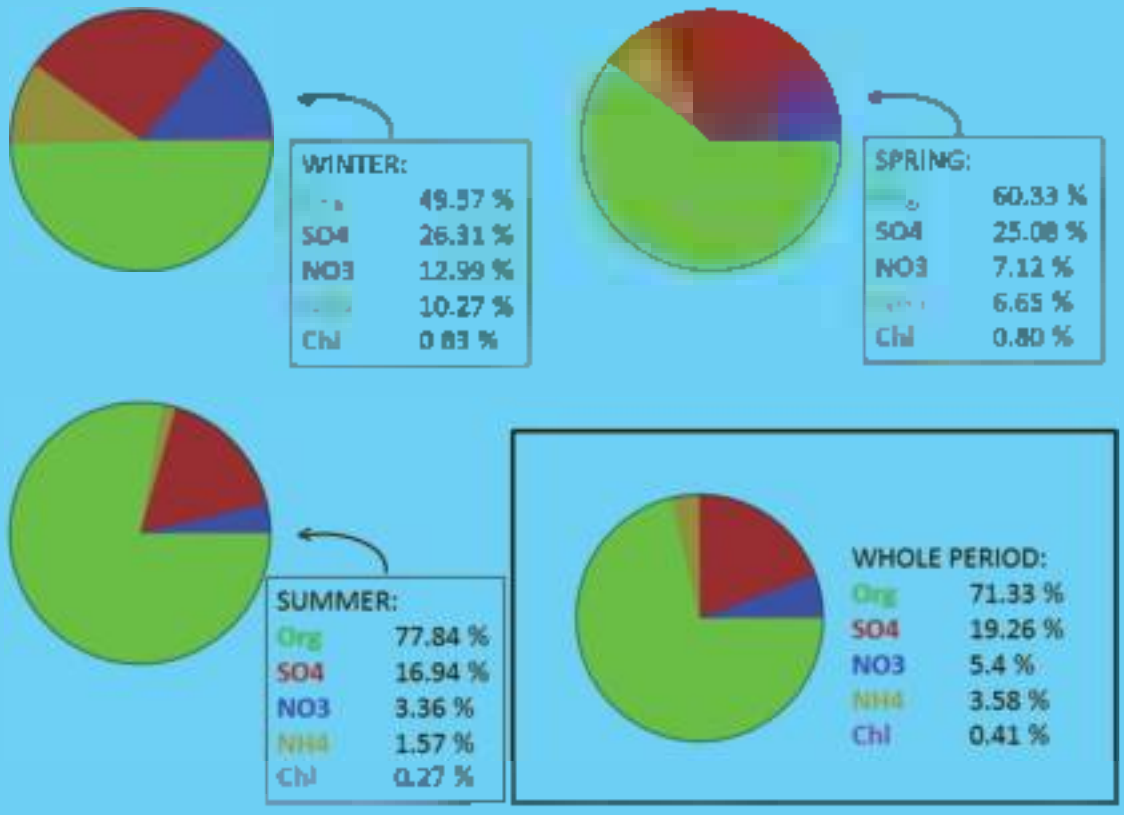

Figure 20. Average aerosol chemical composition during different seasons of a year. The higher organic aerosol fraction is explained by the increased biogenic activity relative to colder seasons, while the wintertime aerosol is barely dominated by the inorganic species.

4.3 Aerosol vertical profiling

The vertical profile of aerosol above the SMEAR-II site was studied extensively through the use of remote sensing by lidar, and by in-situ measurements performed with aircraft-based observations during three Flight-IOPs. Continuous remotely-sensed vertical profiles of aerosol were obtained from a multitude of lidar instruments, including the ARM High Spectral Resolution Lidar (HSRL), ARM Micropulse lidar (MPL), ARM ceilometer, and FMI/UHELs Doppler lidar. These operated quasi-continuously throughout the entire campaign period. In addition, a multi-wavelength Raman lidar (PollyXT, FMI) and latest generation ceilometer

(Vaisala CL51) were operated for a portion of the campaign. The potential for aerosol layer identification and aerosol typing through a combination of backscatter coefficient and circular depolarization ratio is clearly shown in Fig. 15. Humid boundary layers, dry elevated layers, and humid elevated layers can all be distinguished in HSRL data. The transport and mixing of aerosol will be investigated through combining HSRL data with information from the co-located Doppler lidar. Such datasets from powerful instruments will also be used to inform the retrieval of layers from single-channel low-power ceilometers.

The Flight-IOPs took place in three seasons: early spring, beginning of summer, and beginning of autumn. In total 144 flight hours were flown during 33 days, and all flights were in the vicinity of SMEAR-II station. The on-board setup included aerosol instruments to measure number concentrations with nominal cut-off size of 3 nm (TSI 3776 uCPC) and 2 nm (Airmodus Particle Sizer Magnifier), and particle number size distribution between 10-300 nm (Scanning Mobility Particle Sizer). During the third IOP, the ion and neutral cluster size distribution between 2- 40 nm was also measured by the Neutral and Air Ion Spectrometer. Additionally, the basic meteorological parameters (temperature, relative humidity, water vapor concentration and pressure) were measured. This dataset provides a unique time series of airborne aerosol properties within a horizontal scale of 30 km and from altitudes of 300 m up to 3.5 km.

Aircraft data will be used to validate the remote sensing methods. Figure 12 shows simultaneous measurements with Cessna and ARM High Spectral Resolution Lidar (HSRL) on 2 April 2014. The flight path for this particular day is typical of the route selected during the flight campaigns. It is oriented to the south-north direction, and consists of an ascent up to 3.5 km, and then several legs at different altitudes above and inside of the boundary layer. Synthetic backscatter coefficients will be generated from the measured in-situ aerosol size distributions to compare with the observed lidar profiles. This then provides the means to derive the vertical distribution of aerosol properties inside, and above, the boundary layer, which can then be extended through the longer-term lidar-only datasets.

Here, the retrievals can be improved through harnessing data from the multi-wavelength Raman lidar system PollyXT, where available, through collaboration with EARLINET (now within ACTRIS). Combination of multiple channels through use of the "3 backscatter + 2 extinction + 1 depolarization" approach allows the independent retrieval of the aerosol size distribution, refractive index, single-scattering albedo, etc., which can then be independently verified at the surface and from aircraft.

Such a dataset will help identify the relative impact of long-range transport of material and local sources, and we will also investigate the mechanisms for dispersion.

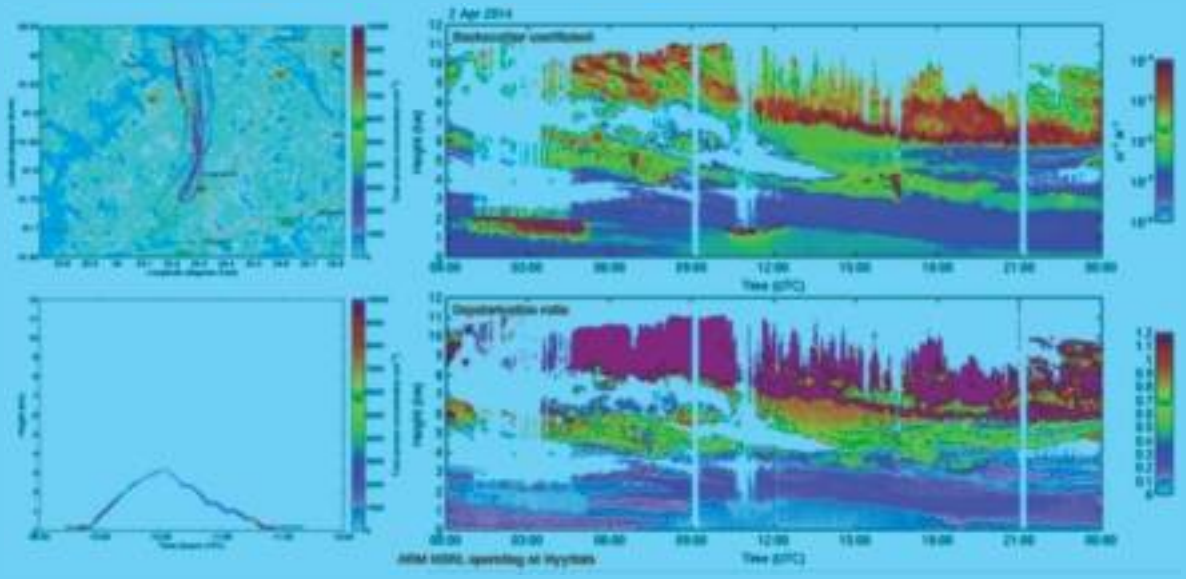

Figure 21. UHEL Cessna flight track (upper left) and altitude track (lower left) during an aircraft IOP centered on Hyytiälä during 2 April 2014. The color of the track provides the total aerosol number concentration. ARM HSRL (High Spectral Resolution Lidar) backscatter coefficient (upper right) and circular depolarization ratio (lower right) data for the same day, showing the potential for aerosol layer identification and aerosol typing. Aircraft data from three IOPs (a total of 144 flight hours during 33 days) provides essential validation of remote-sensing techniques. Besides confirming the remote sensing methods, the in-situ data obtained by the aircraft will be used either as an input or validating data for different atmospheric models, such as SOSA (model to Simulate the concentrations of Organic vapours, Sulphuric Acid and Aerosols; Boy et al., 2011).

4.4 BAECC-SNEX

During the IOP the standard AMF2 surface-based precipitation measurement instruments were supplemented by an array of sensors. The operations schedule of the nearest FMI dual-polarization weather radar was changed to allow for one RHI scan over the location of AMF2.

To facilitate accurate surface measurements of snowfall properties a double fence inter-comparison reference wind protection for the weighing precipitation gauge, optical disdrometer (OTT Parsivel) and 2D-video disdrometer was built on site. Due to the duplication of some of instruments, namely disdrometers and weighing gauges, the data set can be also used to characterize their measurement errors as a function of wind speed; see Fig. 16 for a comparison of precipitation accumulations from ARM and University of Helsinki gauges. The wind measurements were done at the instrument heights inside and outside of the fence and at 10 m height.

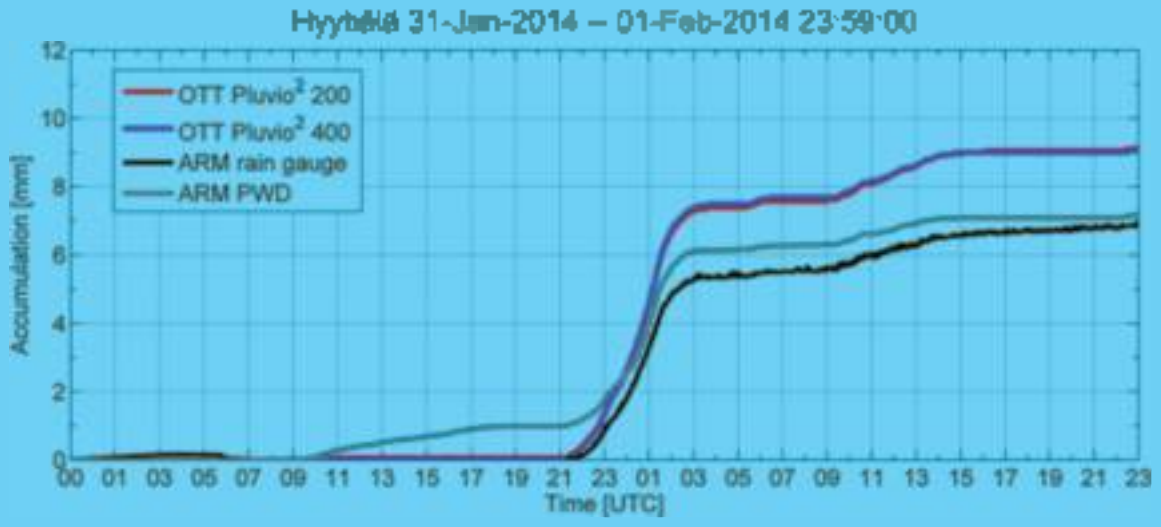

Figure 22. An example of precipitation accumulations measured by two University of Helsinki gauges (OTT Pluvio2 200 and 400) and ARM weighing gauge and PWD. Measurements were collected on Feb 1, 2014 during BAECC SNEX IOP. The OTT Pluvio2 200 gauge is located inside of DFIR and OTT Pluvio2 400 is located outside.

During the IOP more than 20 snowfall events were sampled. A preliminary analysis of all of the events was carried out and tentative classification of the events is given in the Table.

It was observed that in more than 80 % of the precipitation cases the ARM microwave radiometer has detected presence of liquid water in the column above, so in all those cases mixed-phase microphysics is of importance to precipitation formation

As a part of the IOP we have focused on utilization of a combination of remote sensing and surface based observations of precipitation and its properties. One of the topics we are currently looking into is how PSD, density, etc. change with time and how the changes relate to the vertical structure of precipitation. A sample of such analysis is shown in Fig. 17.

Table 1. List of notable events during BAECC-SNEX

Starting time	Ending Time	Description	Temperature (C)
31 January 22 UTC	1 February 04 UTC	snow	-8.7- (-8.5)
1 February 10 UTC	1 February 16 UTC	snow (riming)	-7.6 - (-3.7)
2 February 14 UTC	2 February 15 UTC	snow/freezing rain	-4.3 - (-4.0)
2 February 16 UTC	2 February 22 UTC	snow	-5.0 -(-4.6)
7 February 22 UTC	8 February 05 UTC	snow/melting snow	-0.8 - 0.8
8 February 16 UTC	9 February 22 UTC	melting snow/rain	0.7 -2
10 February 21 UTC	11 February 05 UTC	snow/early state of melting	0.2-0.6
12 February 04 UTC	12 February 10 UTC	snow (aggregates)	-0.8- 0.14
13 February 00 UTC	13 February 06 UTC	snow/melting snow	0.3-0.6
15 February 21 UTC	16 February 02 UTC	snow (riming)	-1.8 - (-0.9)
18 February 17 UTC	18 February 22 UTC	snow	0.4-0.7
21 February 00 UTC	21 February 06 UTC	snow	-9.5 -(-5.7)
21 February 16 UTC	22 February 08 UTC	snow(riming)/melting snow	-2.4-0.9
22 February 10 UTC	22 February 11 UTC	melting snow/rain	1.4-1.8
22 February 22 UTC	23 February 10 UTC	melting snow/rain	0.9 - 2.9
26 February 12 UTC	27 February 11 UTC	PIP very light snow, larger particles 07 but very few particles	-1.1 - 0.3
28 February 22 UTC	1 March 06 UTC	PIP very light snow, higher velocities 02 but very few particles	-1.1 -(-0.6)
2 March 06 UTC	2 March 15 UTC	melting snow/rimed small particles	-1.8 - 0.4
3 March 02 UTC	3 March 16 UTC	melting snow / aggregation (07, 11 UTC)	-0.2 -0.8
7 March 12 UTC	7 March 18 UTC	light rain	3.1 - 5.1
7 March 22 UTC	8 March 08 UTC	rain/melting snow	0.6 - 2.8
13 March 21 UTC	13 March 22 UTC	rain	4.4 - 4.7
15 March 02 UTC	15 March 08 UTC	snow/ aggregation large particles	-1.2 - (0.1)
15 March 14 UTC	16 March 11 UTC	first melting, in the night snow aggregates, in the morning maybe riming	-3.4 -2.2
18 March 05 UTC	19 March 19 UTC	large aggregates/ riming (maybe 8 UTC and 21 UTC)	-8.5 - (-1.5)
20 March 13 UTC	21 March 00 UTC	snow/riming	-3.9 - (-3.0)
21 March 06 UTC	21 March 15 UTC	rain	4.2-7.6
23 March 11 UTC	23 March 16 UTC	rain/melting snow	2.0-3.7

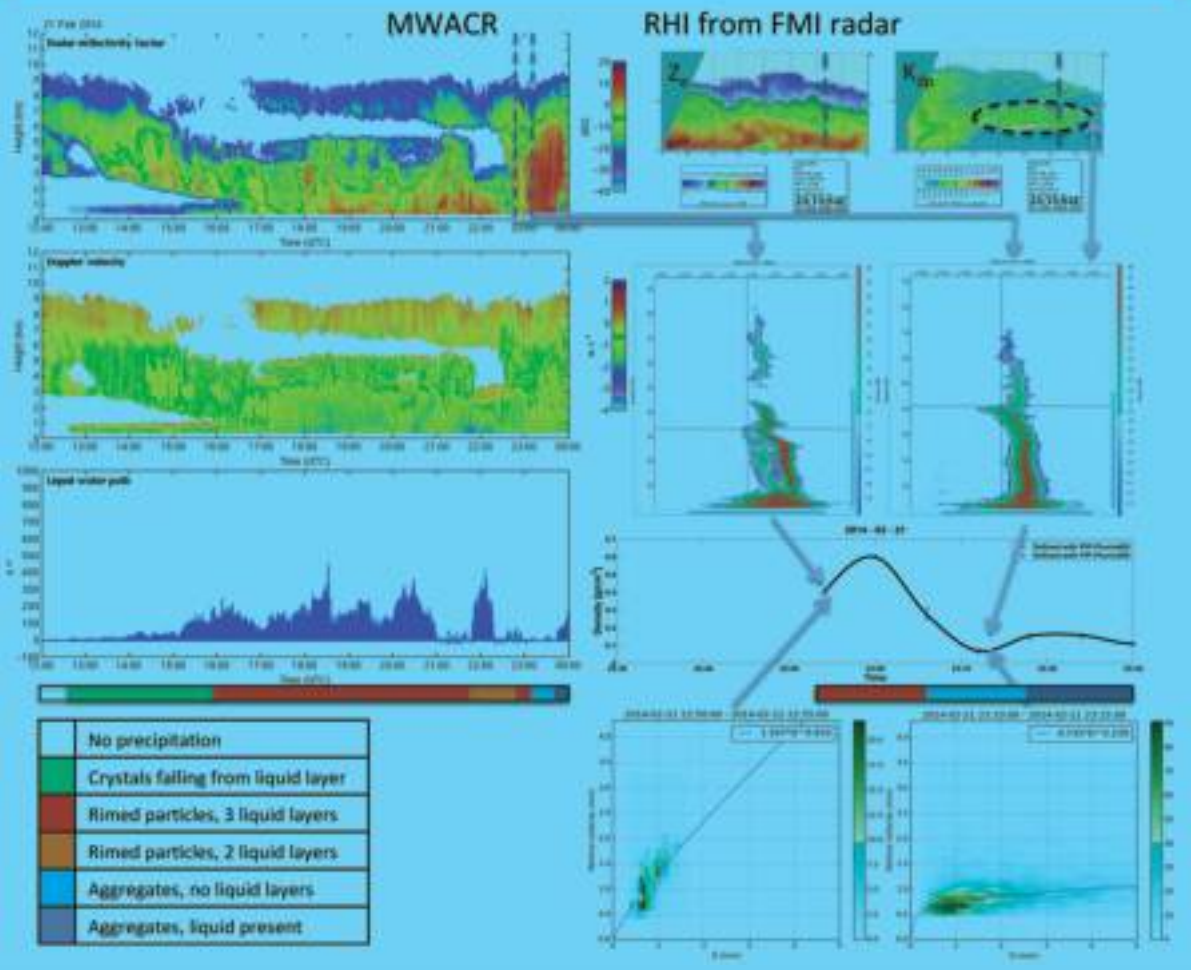

Figure 23 An example of application of cloud radar, Doppler radar spectra, surface precipitation observations and scanning dual-polarization radar to characterize dominating precipitation processes. Measurements were collected on Feb 21, 2014 during BAECC SNEX IOP FMI radar carried out RHI scans over the AMF2 location every 15 min.

5 Public Outreach

At the beginning of the operations, press release was sent out that provided visibility for the BAECC. Jointly with Lynn Roeder et al. a general flyer and school children info package was released in Finnish and in English.

The Finnish broadcasting company YLE had a story on the morning news broadcast on national TV. YLE interviewed BAECC campaign Principal investigator Prof. Tuukka Petäjä and BAECC-SNEX researcher Annakaisa von Lerber from the Finnish Meteorological Institution.

YLE also covered the BAECC campaign on 13th of February 2014 (can be found on the YLE website).

Helsingin Sanomat, the largest newspaper in Finland covered the BAECC campaign in an article interviewing Prof. Tuukka Petäjä together with the AMF2 technicians Patrick Dowell and Brad Bersche (the news article can be found on the Helsingin Sanomat website).

Aamulehti, which is the largest newspaper in the Tampere region (close to Hyytiälä) and the second largest in Finland, made an extensive article of the BAECC campaign on the Science section (the news article can be found on the Aamulehti website, but requires a subscription).

Acatiimi (a journal for professors, scientists and university teachers) featured PI Tuukka Petäjä and the BAECC project in a profile paper: (http://www.acatiimi.fi/7_2014/07_14_12.php)

6 BAECC Publications

6.1 Journal Articles/Manuscripts

Aalto, J., Porcar-Castell, A., Atherton, J., Kolari, P., Pohja, T., Hari, P., Petäjä, T. and Bäck, J. (2015) Onset of photosynthesis in spring speeds up monoterpene synthesis and leads to emission bursts, Plant, Cell & Environ. 38, 2299-2312.

Arnold, S.R., Law, K.S., Brock, C.A., Thomas, J.L., Starkweather, S.M., von Salzen, K., Stohl, A., Sharma, S., Lund, M.T., Flanner, M.G., Petäjä, T., Tanimoto, H., Gamble, J., Dibb, J.E., Melamed, M., Johnson, N., Fidel, M., Tynkkynen, V.-P., Baklanov, A., Eckhardt, S., Monks, S.A., Browse, J. and Bozem, H. (2015) Arctic air pollution: challenges and opportunities for the next decade, Elementa (submitted).

Hansen, A.M.K., Hong, J., Raatikainen, T., Kristensen, K., Ylisirniö, A., Virtanen, A., Petäjä, T., Glasius, M. and Prisle, N.L. (2015) Hygroscopic properties and cloud condensation nuclei activation of limonene-derived organosulfates and their mixtures with ammonium sulfate, Atmos. Chem. Phys. Discuss. 15, 17317–17365.

Kangasluoma, J., Franchin, A., Duplissy, J., Ahonen, L., Korhonen, F., Attoui, M., Mikkilä, J., Lehtipalo, K., Vanhanen, J., Kulmala, M. and Petäjä, T. (2015) Operation of the Airmodus A11 nano Condensation Nucleus Counter at various inlet pressures, various operation temperatures and design of a new inlet system, Atmos. Meas. Technol. Discuss. 8, 8483-8508.

Kristensen, K., Bilde, M., Aalto, P.P., Petäjä, T. and Glasius, M. (2015) Denuder / filter sampling of organic acids and organosulfates at urban and boreal forest sites: gas / particle distribution and possible sampling artifacts, Atmos. Environ. (in press). doi: 10.1016/j.atmosenv.2015.10.046.

Manninen, H.M., Bäck, J., Sihto-Nissilä, S.-L., Huffmann, J.A., Pessi, A.-M., Hiltunen, V., Aalto, P.P., Hidalgo, P.J., Hari, P., Saarto, A., Kulmala, M. and Petäjä, T. (2014) Patterns in airborne pollen and other primary biological aerosol particles (PBAP), and their contribution to aerosol mass and number in a boreal forest, Boreal Environ. Res. 19 B, 383-405.

Manninen, A.J., Vakkari, V., O'Connor, E.J. and Petäjä, T. (2015) A generalized background correction algorithm for a HALO Doppler lidar and its application to data from Finland, Atmos. Meas. Technol. Discuss. 8, 11139-11170.

Pajunoja, A., Lambe, A.T., Hakala, J., Rastak, N., Cummings, M.J., Brogan, J.F., Hao, L., Paramonov, M., Hong, J., Prisle, N.L., Malila, J., Romakkaniemi, S., Lehtinen, K.E.J., Laaksonen, A., Kulmala, M., Massoli, P., Onasch, T.B., Donahue, N.M., Riipinen, I., Davidovits, P., Worsnop, D.R., Petäjä, T. and Virtanen, A. (2015) Adsorptive uptake of water by semisolid secondary organic aerosols in the atmosphere, Geophys. Res. Lett. 42, doi:10.1002/2015GL063142.

Petäjä, T., O'Connor, E.J., Moisseev, D., Sinclair, V.A., Manninen, A.J., Väänänen, R., von Lerber, A., Thornton, J.A., Nicoll, K., Petersen, W., Chandrasekar, V., Smith, J.N., Winkler, P.M., Hakola, H., Timonen, H., Brus, D., Laurila, T., Asmi, E., Riekkola, M.-L., Mona, L., Massoli, P., Engelmann, R., Komppula, M., Wang, J., Kuang, C., Bäck, J., Virtanen, A., Levula, J., Ritsche, M. and Hickmon, N. (2015) BAECC, A field campaign to elucidate the impact of Biogenic Aerosols on Clouds and Climate, Bull. Am. Met. Soc. (submitted).

Petäjä, T., Manninen, A., Nieminen, T., Ahonen, L.R., Aalto, P.P. et al. (2014) Physical characterization of aerosol particles at the surface layer and small scale horizontal and vertical variability during BAECC intensive in Hyytiälä (in preparation for Atmos. Chem. Phys. Discuss.)

Petäjä, T. (2013) Science Plan Biogenic Aerosols – Effects on Clouds and Climate (BAECC), US Department of Energy, Office of Science, DOE/SC-ARM-13-024.

Zieger, P., Aalto, P.P., Aaltonen, V., Äijälä, M., Backman, J., Hong, J., Komppula, M., Krejci, R., Laborde, M., de Leeuw, G., Pfüller, A., Rosati, B., Tesche, M., Tunved, P., Väänänen, R. and Petäjä, T. (2015) Low hygroscopic scattering enhancement of boreal aerosol and the implications for a columnar optical closure study, Atmos. Chem. Phys. Discuss. 15, 3327-3379.

6.2 Meeting Abstracts/Presentations/Posters

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7 Conclusions

The focus of the BAECC campaign was characterizing the surface particles physically and chemically with simultaneously observing clouds and precipitation. This was made possible by combining two state-of-the-art facilities, the SMEAR-II research station at Hyytiälä, and the AMF2 mobile research facility brought to Hyytiälä by the ARM program of the U.S. Department of Energy. Additional resources were provided by the co-located NASA Global Precipitation Measurement (GPM) mission ground-validation in surface particle size distribution and water equivalent rate gauges. Also the European Commission contributed via the ACTRIS TransNational Access, which provided gap-filling aerosol physical and chemical measurements as well as additional cloud observations.

The BAECC campaign provided successfully a vast eight-month-long dataset covering three seasons with multiple types of cloud and precipitation systems. Overall, the measurements of in-situ aerosol properties with AMF2 and with SMEAR-II instrumentation correlated well. This underlines the well-structured and operated infrastructures. The representativeness of the dataset can be thoroughly evaluated with the just under 20-year-long continuous measurements of the surface aerosol at SMEAR-II together with the extensive flight campaigns performed during the campaign.

A negative continental climate feedback was suggested by Kulmala et al. (2004), where the increasing temperatures and CO_2-levels lead to higher biomass production and volatile organic compound emissions, which, in turn, will increase biogenic secondary organic aerosol (SOA), cloud condensation nuclei (CCN) concentrations, and cloud albedo. The aerosol particles, radiation and photosynthesis can be included into this feedback mechanism as well (Kulmala et al. 2013a), together with aerosol-cloud albedo effects (Paasonen et al., 2013). Thus, this feedback mechanism has two major overlapping loops, which are both initiated by increased CO_2 concentrations and suppress global warming.

The first quantitative estimates of the two feedback loops have been made based on the long-term observation at SMEAR-II and other continental stations (Paasonen et al. 2013, Kulmala et al., 2014). The BAECC dataset will be used in a detailed analysis of the aerosol-cloud interactions and improve the estimates.

There remain great challenges in connection the aerosol measurements carried out at the surface to the cloud properties. The quantification of this connection can now be tackled with the vertical profiling during BAECC combined with modeling tools. The aim is to estimate how the of aerosols and clouds affect the radiative energy balance of the entire atmospheric column. Particular interests are CCN concentrations and columnar concentration of aerosols. Combining the measurements obtained during BAECC with satellite data will enable carrying out larger spatial scale studies in boreal environment.

Furthermore, the comprehensive data will be utilized in verification of multi-scale modeling, including detailed process level models, different emission modules, boundary layer dynamics and both chemical and aerosol dynamical processes as well as vertical transport and aging of atmospheric aerosols inside the mixing layer. Additionally, different cloud microphysics parameterizations of WRF-Chem model and multi-frequency radar observations available from AMF2 can be used in valuable sensitivity studies.

Future work will utilize the success of the BAECC campaign and concentrate to study the following aspects: 1) interactions between the turbulent mixing within continental boundary layer and aerosol microphysics, together with the aerosol transformation while being transported from surface to clouds; 2) impacts of long-range transport and how aerosol are transformed to act as CCN; 3) roles of regional and long-range transported aerosol long-range transported aerosol; 4) evolving cloud-precipitation processes and their sensitivity on CCN concentrations; 5) aerosol removal and transformation mechanisms as a function of particle size and precipitation type; 6) aerosol removal and transformation mechanisms as a function of particle size and precipitation type.

In practical and infrastructural point of view, the BAECC campaign was a state-of-the-art collaboration providing practical steps in co-location and co-operation of demanding research infrastructures. These practical steps will be important for the Pan Eurasian EXperiment (PEEX, Kulmala et al. 2015, Lappalainen et al. 2014), which goal is multilateral and multidisciplinary scientific collaboration in the circumpolar Arctic and boreal regions. In these regions the comprehensive observations on the atmospheric composition is currently lacking (Hari et al. 2015, Arnold et al. 2016).

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