U.S. DEPARTMENT OF ENERGY | Office of Science

DOE/SC-ARM-15-051

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T Petäjä
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J Levula
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M Äijälä
J Aalto
JA Thornton

March 2016

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T Petäjä[1]
D Moisseev[1]
V Sinclair[1]
E O'Connor[2,3]
A Manninen[1]
J Levula[1]
R Väänänen[1]
L Heikkinen[1]
M Äijälä[1]
J Aalto[1]
JA Thornton[4]

[1]University of Helsinki, Finland
[2]Finnish Meteorological Institute, Finland
[3]University of Reading, UK
[4]University of Washington, USA

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Work supported by the U.S. Department of Energy,
Office of Science, Office of Biological and Environmental Research

Executive 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, 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) Climate Research Facility operated its second ARM Mobile Facility (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 data set 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 observational 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 data set is positioned in perspective with the long time series available from Hyytiälä, and used 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 of BAECC 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 using ARM's 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, and
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.

Acronyms and Abbreviations

ACTRIS	Aerosols, Clouds, and Trace gases Research Infrastructure Network
AMF2	second ARM Mobile Facility
AOS	Aerosol Observation System
ARM	Atmospheric Radiation Measurement
BAECC	Biogenic Aerosols – Effects on Clouds and Climate
BAECC-ERI	BAECC Extended Radiosonde IOP
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
HR-ToF-CIMS	High-Resolution Time-of-Flight Chemical Ionization Mass Spectrometer
FMI	Finnish Meteorological Institute
IOP	intensive observational period
NAIS	Neutral and Air Ion Spectrometer
NPF	new particle formation
PSM	Particle Size Magnifier
SMEAR-II	Station for Measuring Ecosystem – Atmosphere Relations II
SOSA	sulphuric acid and aerosols (model)
TROPOS	Leibniz Institute for Tropospheric Research
UHEL	University of Helsinki
UK	United Kingdom

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1.0 Background

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 the 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 the 1st of February and the 14th of September 2014 (Petaja et al., 2014). The BAECC campaign's goal was to provide a data set that 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) investigating the aerosol indirect effect on clouds and precipitation.

The United States Department of Energy's Atmospheric Radiation Measurement (ARM) Climate Research Facility brought the second ARM Mobile Facility (AMF2) to Hyytiälä, Finland, where it was located at the University of Helsinki's (UHEL's) Station for Measuring Ecosystem – Atmosphere Relations (SMEAR-II) (Hari and Kulmala, 2005). At 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 and surface measurements, as well as flight campaigns organized by the University of Helsinki and the Finnish Meteorological Institute during intensive observational periods (IOPs), supplemented the AMF2 observations.

The Principal
Investigator (PI) of the BAECC campaign was Prof. Tuukka Petäjä of 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), and
- 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[1,7], Gerrit deLeeuw[1,2], Ari Laaksonen[2], Douglas R. Worsnop[1,6,8] and Markku Kulmala[1].

2.0 Notable Events or 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.

[1] Department of Physics, University of Helsinki, Finland
[2] Finnish Meteorological Institute, Finland
[3] University of Reading, UK
[4] Department of Forest Sciences, University of Helsinki, Finland
[5] Department of Applied Environmental Sciences, Stockholm University, Sweden
[6] University of Eastern Finland, Finland
[7] Colorado State University, CO, USA
[8] Aerodyne Research Inc., MA, USA

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 used to attract transnational access and funding from the European Commission to host additional instrumentation for 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 and 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 operated 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 from 1 February to30 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 suite 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 the spring intensive measurement period, a suite of mass spectrometers and advanced aerosol instruments 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 a 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), National Center for Atmospheric Research (Jim Smith), and CNR (Paola Massoli). 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 in another similar Cessna 172 aircraft, and the planes measured simultaneously while flying in formation. Both instruments worked well and their results agreed with the other onboard aerosol instruments.

Additional research flights (a total of three flights in September, 2014) were conducted onboard Skyvan aircraft operated by the Finnish Meteorological Institute. The benefit of this aircraft is its larger payload, which enabled measurements of aerosol chemical composition with an 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 series of science team meetings was initiated to progress data analysis of the BAECC data set. The first science meeting of the BACC team was organized at the beginning of the BAECC measurement period in Hyytiälä. Here, the team discussed initial ideas to analyze the data and an 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 science and new collaboration possibilities.

In the next step, a break-out session in the ASR spring, 2015 meeting will be organized to increase collaboration within the BAECC research team and particularly with the various working groups of ASR. Additionally, connections and collaborations will be facilitated by the BAECC PI and science team when they participate in forthcoming science meetings, such as with the GoAmazon –project (Martin, 2013) at Boston, MA, May 2015.

3.0 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 because the science totally depends on this step.

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

One way to improve the situation is to increase both the liberties and the responsibilities of the onsite technical staff, leading to more effective performance. One example of such an occasion was an 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 bring an electrician to a foreign site at least for the starting period. In Hyytiälä this was not a crucial point, but this implementation would speed up the initial stages of the operation in measurement locations with less onsite support.

4.0 Results

A vast data set was collected during BAECC, which will be contrasted against the 18-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 data set 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 Figure 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.

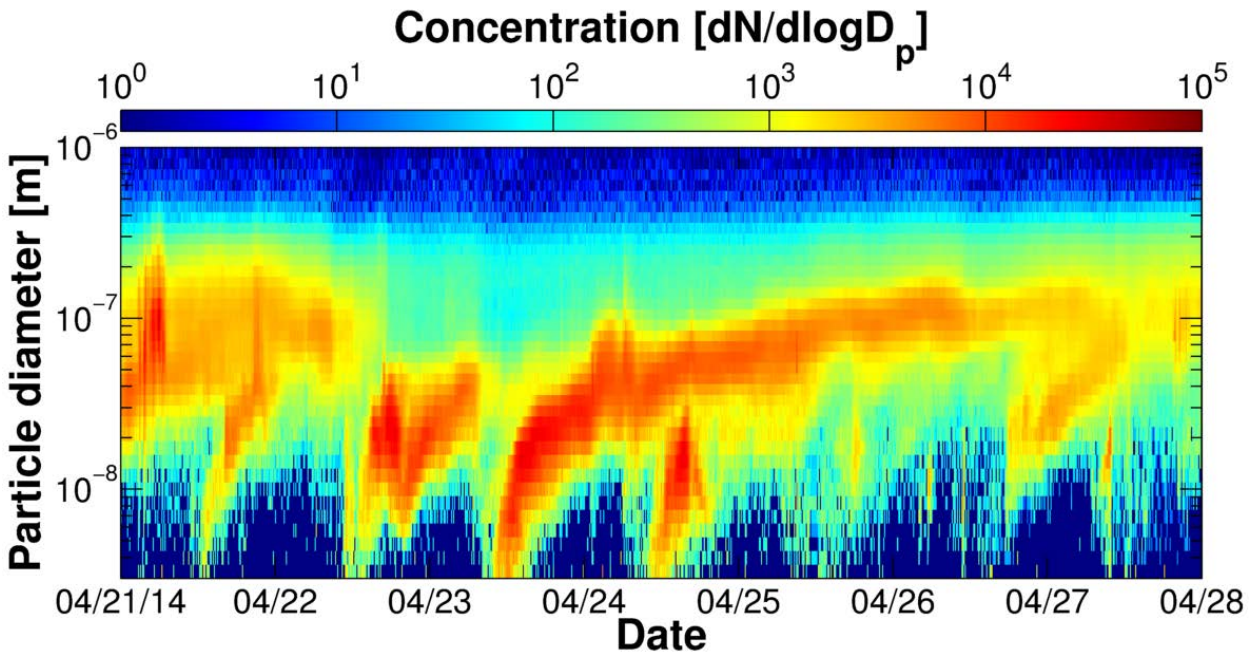

Figure 2. Sub-micron aerosol number size distribution measured with a SMEAR-II Differential Mobility Particle Sizer (DMPS) at Hyytiälä, Finland between 21 and 27 April, 2014 featuring the characteristic phenomenon observed at the site: formation of secondary organic aerosol and their growth to CCN active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

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 the BAECC period with the long-term cycle is presented in Figure 3. The BAECC measurements were conducted during a representative period and the event probabilities were in line with long-term averages.

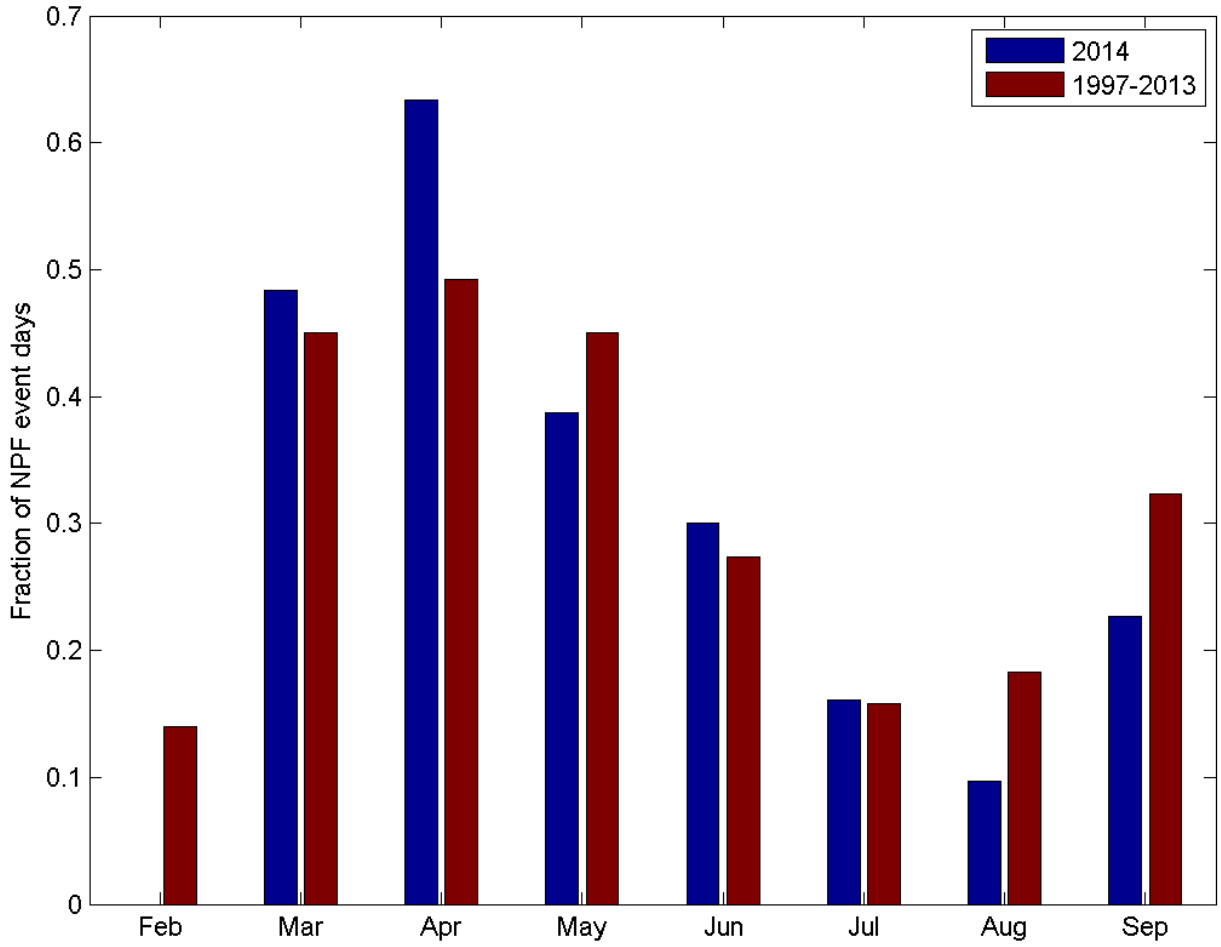

Figure 3. The monthly new particle formation event frequency during the BAECC campaign and comparison with long-term average characteristics (Petäjä et al. 2015, in preparation).

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 the 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 4. 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 of 2014 was very mild and ecosystem activity was already very high in early spring. The onset of net carbon uptake (NEE) in early February (Figure 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 2-3 times higher monoterpene emissions than other times in spring (Aalto et al., 2015 submitted manuscript). The maximum emission rates were observed 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.

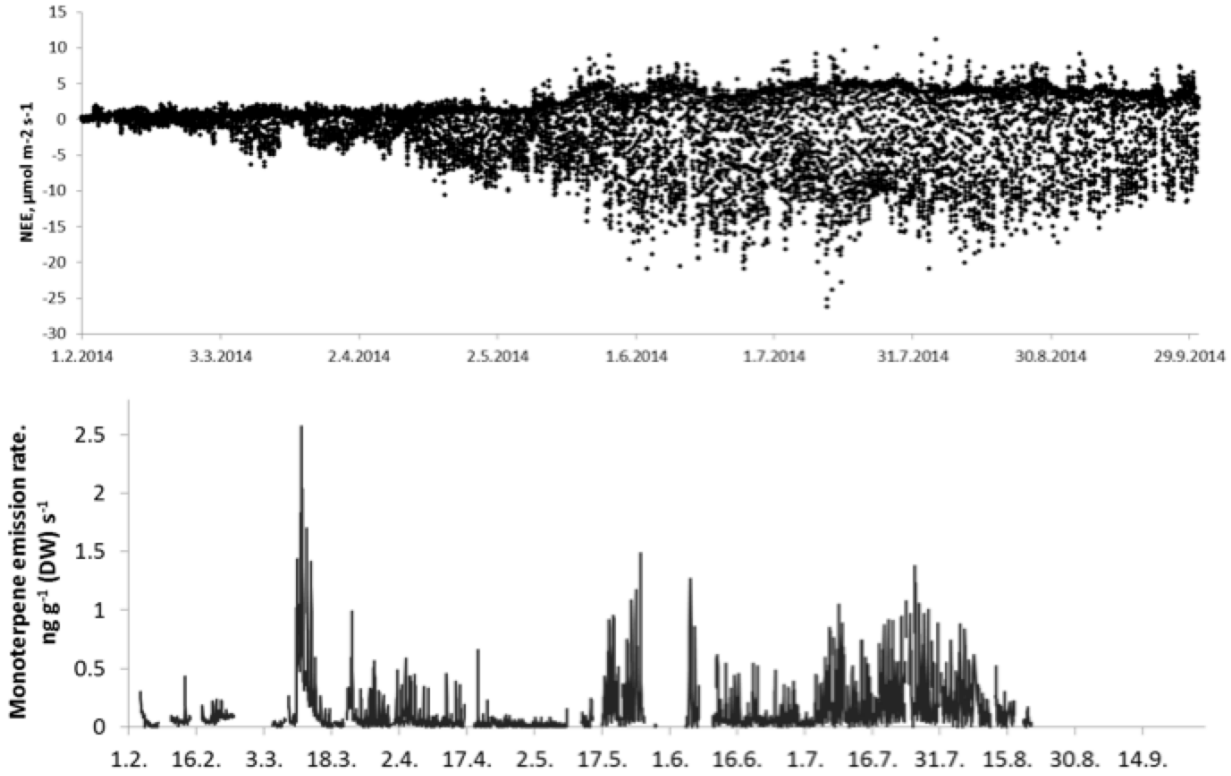

Figure 5. Net ecosystem exchange (umol m^{-2} s^{-1}, top panel) and monoterpene emission rate (ng g $(DW)^{-1}$ s^{-1}, bottom panel) during the BAECC campaign in 2015 (DW = dry weight of the needles; modified from Aalto et al., 2015 submitted manuscript).

4.2 Ground-Based Aerosol and Trace Gas Results

Several continuous in situ measurements were carried out. Total number concentration of aerosols was measured at SMEAR-II with a DMPS (from now on referred as SMEAR-II DMPS) (Aalto *et al*., 2001) and a Condensation Particle Counter (CPC) (McMurry, 2000). The AMF2 facility also included a CPC as a part of the Aerosol Observation System (AOS) (Jefferson, 2011), the measurements of which were compared to the SMEAR-II DMPS and the SMEAR-II CPC measurements. Additionally, UHEL provided a DMPS designated for the duration of the BAECC campaign. This designated DMPS (referred to as BAECC DMPS in Table 1) was located in the main instrument field at Hyytiälä, next to the remote-sensing and snow and ice in situ instrumentation. Ozone concentration and aerosol total scattering coefficient measurements were also compared between the AMF2 and SMEAR-II facilities. Both the SMEAR-II and the AMF2 included a TSI dry nephelometer measuring in the 450, 550, and 700 nm spectral regions. Also, the cloud condensation nuclei (CCN) measurements were analyzed and the results were compared to previous findings.

Comparison of the SMEAR-II DMPS, CPC, and AMF2 CPC as well as the comparison of the ozone measurements are shown in Table 1. The table includes correlation coefficients between the different instruments measuring the same physical property. The total aerosol concentration was assumed to follow a lognormal distribution and was taken into account when calculating the correlation coefficients. The

ozone concentration was not assumed to follow a lognormal distribution. The SMEAR-II DMPS was used as a benchmark for the other instruments measuring the total aerosol number concentration.

Table 1. Monthly correlation coefficients of the comparison between the SMEAR-II and the AMF2 aerosol and ozone concentrations measured at Hyytiälä, Finland between 1 February and 14 September 2014 (Petäjä et al., 2015, in preparation).

	AEROSOL TOTAL CONCENTRATION				OZONE CONCENTRATION
	SMEAR-II DMPS cut-off > ~3 nm **vs** cut-off > 3 nm **SMEAR-II CPC**	**SMEAR-II DMPS** cut-off > 10 nm **vs** cut-off > 10 nm **AMF2 CPC**	**SMEAR-II DMPS** ~6 - ~800 nm **vs** ~6 - ~800 nm **BAECC DMPS**	**SMEAR-II CPC** cut-off > 3 nm **vs** cut-off > 10 nm **AMF2 CPC**	**SMEAR-II vs AMF2**
February	0.9946	0.8740	0.9242	0.8851	0.9930
March	0.9963	0.7637	0.8910	0.7961	0.9839
April	0.9968	0.6543	0.7469	0.7279	0.9449
May	0.9970	0.7711	0.8058	0.8027	0.9611
June	0.9978	0.7863	0.9537	0.8013	0.9792
July	0.9970	0.8160	0.9243	0.8212	0.9170
August	0.9980	0.8254	0.9368	0.8239	0.9759
September	0.9962	0.8216	0.9157	0.8092	0.9750
Median	0.9969	0.8012	0.9200	0.8060	0.9755
Standard dev.	0.0011	0.0649	0.0725	0.0431	0.0247

Aerosol number concentration between the SMEAR-II and AMF2 instrumentation during co-located measurements showed a good overall correlation during the BAECC campaign. Comparison of the total aerosol number concentration showed a decrease in correlation between the SMEAR-II and the AMF2 instruments during spring months, especially April.

The scattering coefficient measurements from SMEAR-II and AMF2 TSI dry nephelometers agreed very well during the whole period. The CCN number concentration measurements and especially the hourly median two-day cycle were compared to the results of Paramonov et al. (2013). The CNN number concentration was observed to increase after a new particle formation (NPF) event day. The observed increase agrees tentatively with the findings of Paramonov et al. (2013), although deeper analysis of the results is needed to verify this.

To assess spatial variability in small scale, three DMPS measurements fairly close to each other were compared. At SMEAR-II, there is one DMPS continuously measuring from the SMEAR-II tower, one continuously measuring inside a cottage shown in Fig. 8, and as mentioned earlier there was a third DMPS measuring at the main AMF2 instrument field. The tower-DMPS showed very similar concentrations with the SMEAR-II DMPS and there was no measurable difference between the starting times of the NPF event at tower and ground level. Figure 6 shows diurnal median concentration of nucleation mode particles measured with tower-DMPS and BAECC-DMPS divided by SMEAR-II DMPS

concentration. Comparison shows that concentration from the tower and from ground level agreed quite well during daytime. The nighttime relative difference is larger and the tower-DMPS measures more particles. BAECC-DMPS shows a smaller concentration both day and night times, and also smaller concentration for small particles. This is also true when comparing DMPS measurements from the whole time period (Figure 7). For larger particles, 90–800 nm in diameter, the difference was opposite but much smaller.

BAECC-DMPS systematically measures smaller concentrations for small particles. In the next step, we will check whether instrumental issues cause the bias or if it is due to real differences in the aerosol concentration. The conclusion will be based on laboratory calibrations of the BAECC-DMPS, which is currently ongoing.

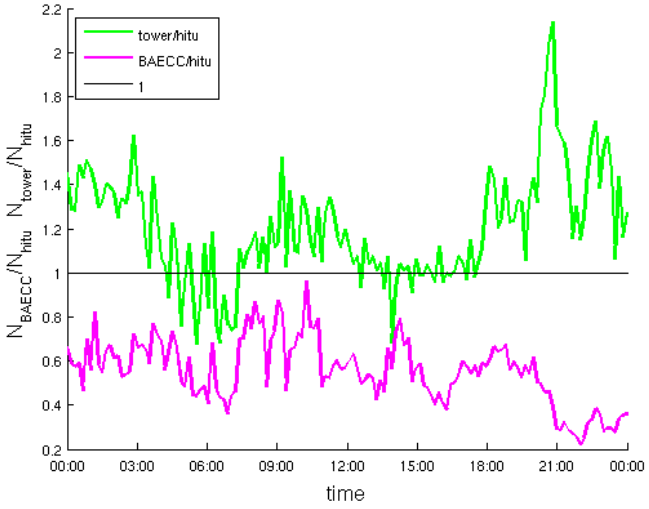

Figure 6. Fraction of tower- and BAECC-DMPS compared to SMEAR-DMPS for 6 to 25 nm nucleation mode particles. Comparison is carried out for diurnal median concentrations for event days between March and August 2014.

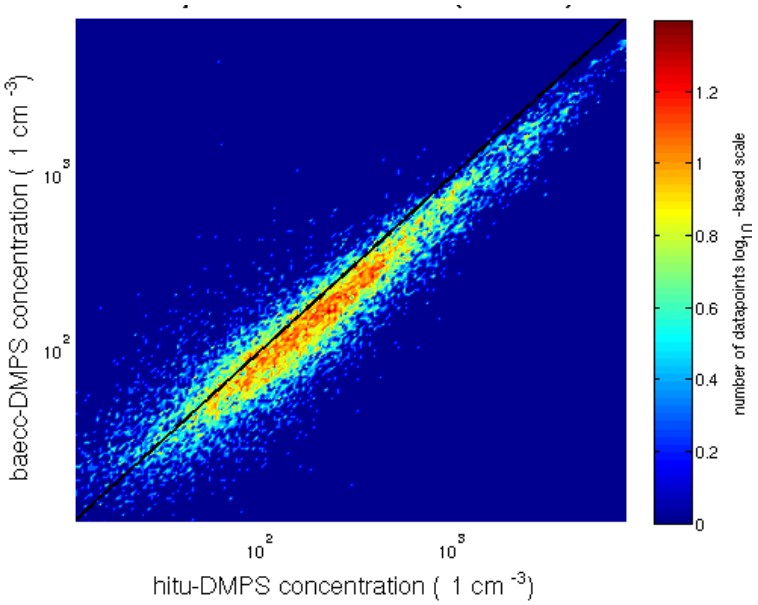

Figure 7. Total number concentration for nucleation mode particles (3-800 nm) for all measurement days, where the color bar indicates the number density of the data points.

4.3 Vertical Concentration Gradients based on In Situ Aerosol and Ion Measurements

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

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

Figure 9 shows the diurnal median number concentration for negative ions measured at ground level and on the 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 an exception during the burst period, the concentrations for ground measurements are generally larger than the tower measurements due to an 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).

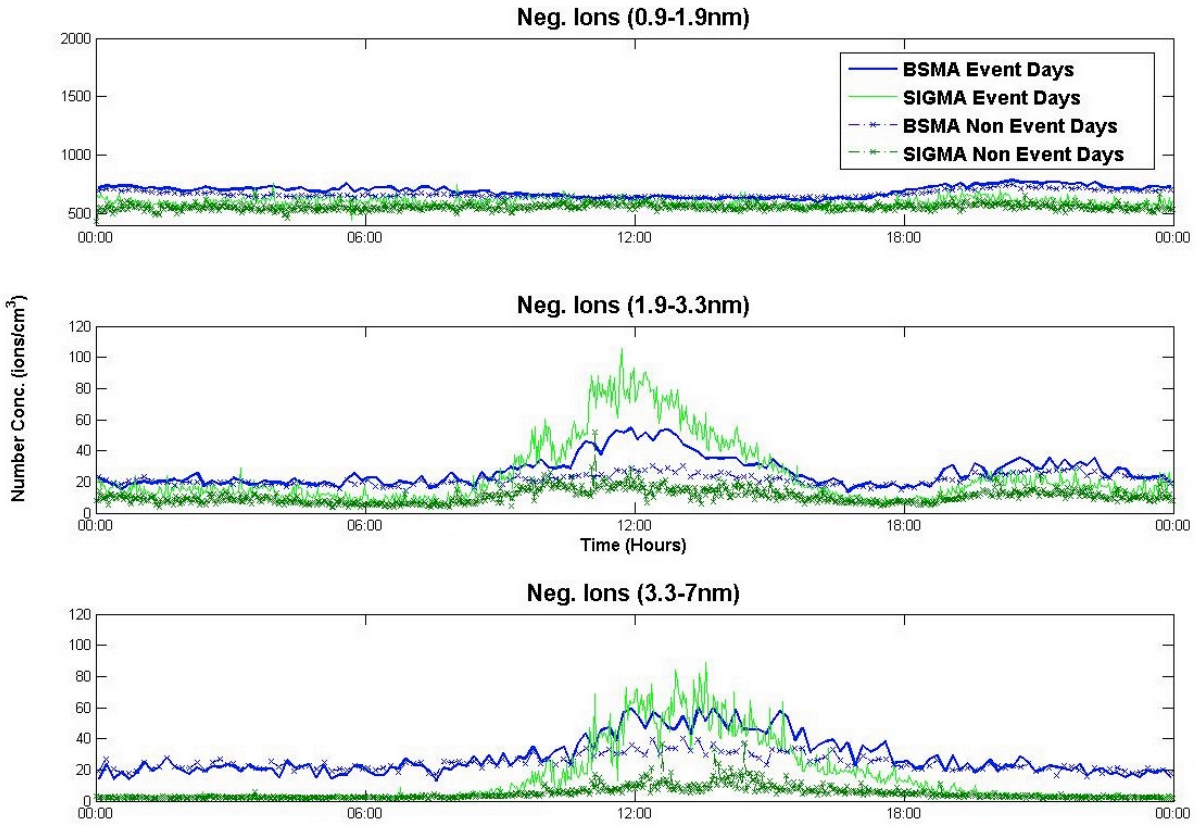

Figure 9. A typical diurnal cycle of negative atmospheric ions of different mobility equivalent sizes during new particle formation event days and non-event days, measured at the ground level with BSMA and in the tower with SIGMA instrument (Xausa et al., 2014).

For the neutral particle measured with PSM, there was also a clear difference between event days and non-event days, which can be seen from the diurnal median in Figure 10. The difference is very clear especially for 2-3 nm particles. With a smaller size range, there was some weird behavior because concentrations in the tower at non-event days are very high.

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

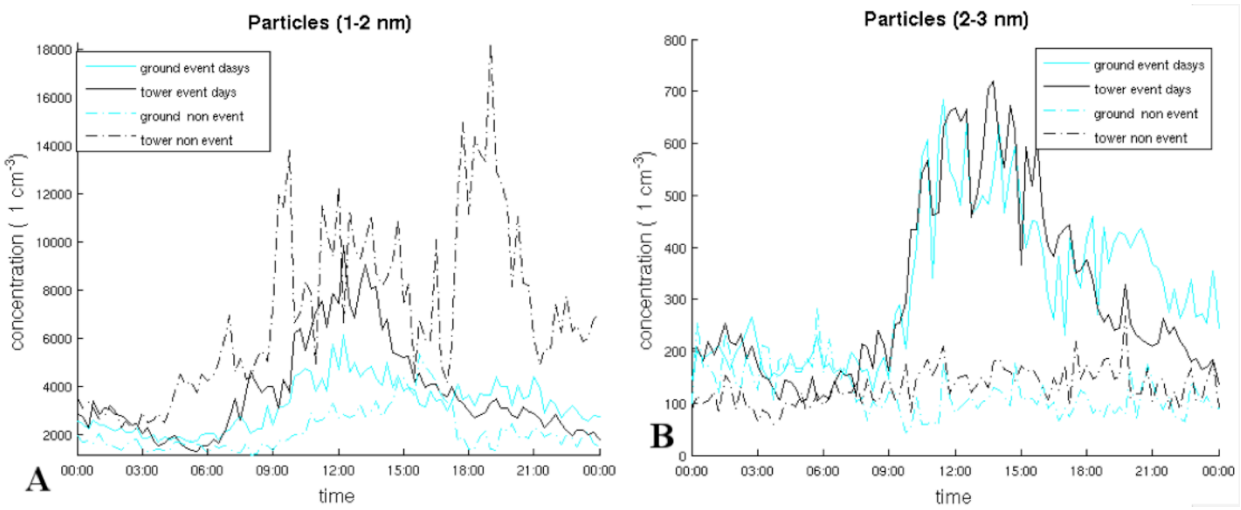

Figure 10. Diurnal median concentration for (A) 1-2 and (B) 2-3 nm particles for event days and non-event days at ground and tower levels (PSM data).

4.4 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 data set 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 Figure 11 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 a 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.

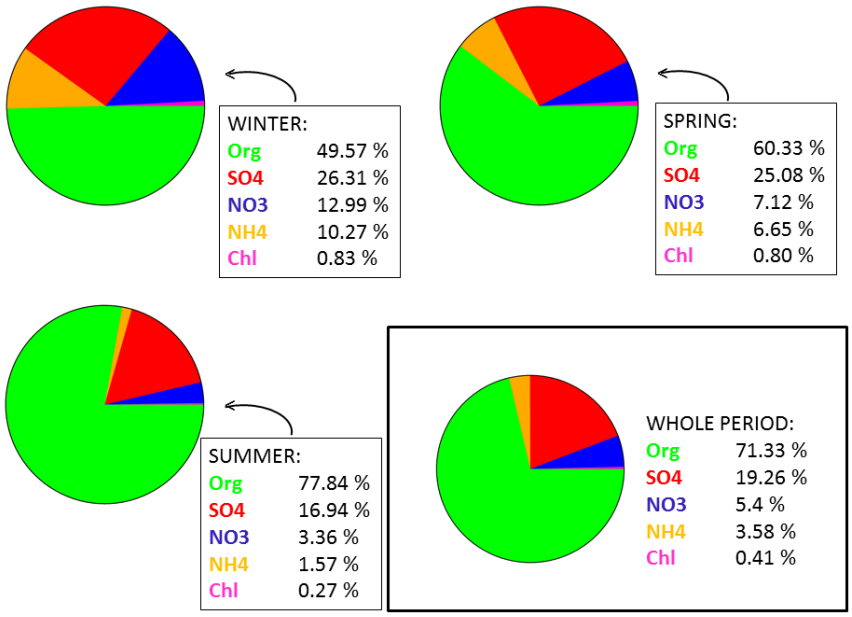

Figure 11. Average aerosol chemical composition during different seasons of a year. The higher organic aerosol fraction is explained by the increased biogenic activity relative to colder seasons, while the wintertime aerosol is barely dominated by the inorganic species.

The University of Washington (PI Thornton) deployed a Filter Inlet for Gases and AEROsols (FIGAERO) coupled to a High-Resolution Time-of-Flight Chemical Ionization Mass Spectrometer (HR-ToF-CIMS) operating in Iodide-adduct ionization. The FIGAERO HR-ToF-CIMS instrument was deployed at the top of the new 30 m-tall measurement tower at the SMEAR II field station at Hyytiälä from April 15-June 5, 2015. The instrument ran nearly continuously for the entire deployment period in its own weatherproof box at the edge of the tower platform, thereby requiring only a 1 m-long inlet to extend outside the influence of the tower into the prevailing wind direction.

The FIGAERO HR-ToF-CIMS allows in situ measurements of both gas and particle composition, with a specificity tilted towards oxygenated organic compounds, though a few select inorganic compounds (e.g., HNO_3, H_2SO_4, halogens, etc.) are also measured. The major scientific objectives for deployment of the UW FIGAERO HR-ToF-CIMS during BAECC were as follows:

1. Characterize the molecular composition and volatility of submicron aerosol particles as a function of time of day and season so as to constrain the predominant source types and aging mechanisms controlling organic aerosol mass (e.g., monoterpene oxidation, isoprene oxidation, NOx-influenced, sulfate-influenced).
2. Compare molecular composition and volatility of submicron particles measured during the growth phase of new particle formation events to the mean background composition and volatility determined outside of events in order to provide a means to assess how the mechanisms of local and regional aerosol formation and growth might be different from those sustaining the background organic aerosol mass.

3. Simultaneously, and without loss of capability for objectives 1 and 2, measure gas-phase composition at high time resolution and co-located with a sonic anemometer to quantify the flux of potential aerosol mass-forming compounds to/from the surface, a key aspect of three-dimensional chemistry-climate models that remains poorly constrained.

Preliminary results suggest that these objectives were met successfully. Data processing and quality control activities continue, but are nearly complete, and analysis of the observations is now advancing. The initial analysis of molecular composition and volatility measurements suggest a large contribution of organic aerosol mass is derived from monoterpene oxidation, with an extremely low volatility, containing compounds consistent with both accretion (dimers, trimers, etc.) and functionalization of monomers with oxygen (O/C > 0.7).

In Figure 12, an example of FIGAERO HR-ToF-CIMS data is shown from a nearly 24-hour period during a new particle formation and growth event. During the event, particles less than 10 nm in size appear, and grow over the course 12 hours up to 40-60 nm. The FIGAERO HR-ToF-CIMS measures several classes of organic components that increase in abundance correlated with the increase in particle mass carried by the small growing particles (middle panel). The components that show the most pronounced changes that correlate with growing particles are very low volatility (see below), such as monomers having O/C ~ 0.7 or higher, or larger molecular compounds such as dimers having compositions C_{18}-$C_{20.}$

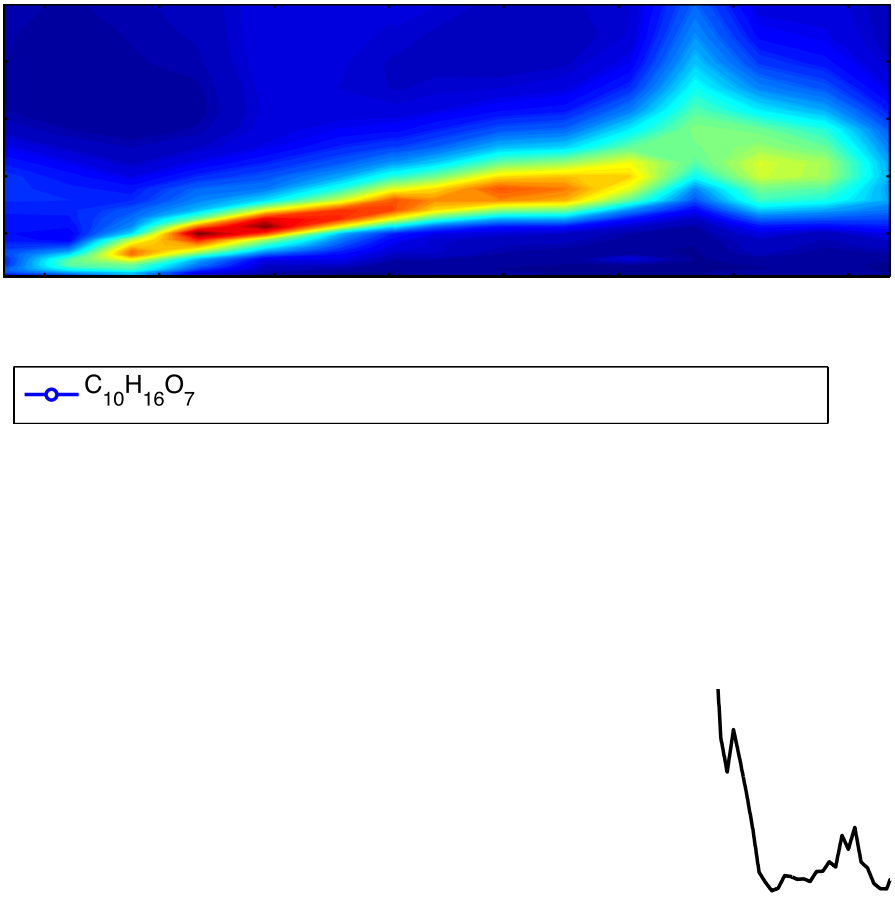

Figure 12. New particle formation and growth event during the BAECC campaign. The particle number diameter distribution is shown versus time of day in spring 2015 (top), specific molecular components measured by the FIGAERO HR-ToF-CIMS in the submicron aerosol particles are shown for the same period (middle), and particle mass concentration in different size bins is shown in the lower panel. The FIGAERO HR-ToF-CIMS shows that certain components (e.g., $C_{10}H_{16}O_7$) increase in abundance during the event correlated with the growing particles (50-100 nm).

The absolute abundance of the compounds shown in Figure 12 is uncertain, due to a lack of specific calibration standards, but using reasonable estimates of calibration coefficients, they likely total 10 ng/m^3 or possibly higher, of the order of 5 to 10% of the mass growth below 100 nm. These compounds are merely a small subset of those measured, suggesting it might be possible to explain the composition of a significant portion of the mass growth during such events, a piece of the puzzle that has been missing in studies of new particle formation and growth. As a result, these events (we sampled through about half a dozen) will form a central part of our ongoing analysis.

With each measurement of particle composition, the signal of a compound during the temperature programmed thermal desorption, known as a thermogram, provides insight into the volatility distribution

of particle components. Previously we have connected the desorption temperature at which the signal of a detected compound reaches a maximum to its sublimation enthalpy. In this context, the thermograms obtained during a new particle event suggest that the growing particles begin at an extremely low volatility state, and by the end of the event, the contribution of higher volatility compounds has become more significant. That said, even at the end of the event, the bulk of the mass we detect with the FIGAERO HR-ToF-CIMS is associated with volatilities much lower than any mechanistic based model is currently able to predict, but consistent with an important role for both ELVOC formation in the gas phase and potentially accretion reactions within the particle phase.

Figure 13 shows the blank corrected thermograms of a subset of compounds detected in the particle phase during a new particle formation and growth event, similar to that shown above. We sum the signals of all compounds containing 18-20 carbons that desorb. At the start of the growth event, the total concentrations are low, as evidenced by the area under the blue thermogram, but in subsequent desorptions, the total area grows consistent with the growing particle population. As the growth event continues, there is a shift in the temperature at which the desorbing mass in this subset reaches a maximum. The shift is from higher temperatures (later times on the x-axis) early in the event, to lower temperatures later in the event consistent with the early contributions to this subset being of extremely low volatility and a higher volatility fraction growing relatively more as the population ages. These unique insights provide constraints on the mechanisms controlling the formation of particle mass, at least in this subset, and thus provide guidance to how best to model these events. A working hypothesis that is consistent with this data is that: early in the event, extremely low-volatility compounds such as highly oxygenated dimers (C18-C20 compounds with > 8 oxygens) produced in the gas phase condense to the nascent particles, and the presence of these compounds in the particle phase then supports partitioning of less volatile compounds as well as accretion reactions that lead to less oxygenated dimers (C18-C20 with 5 oxygens). Given that this class of compounds alone explains ~ 5-10% of the mass growth between 30-75 nm, these measurements likely explain a significant fraction of the source of new particle growth.

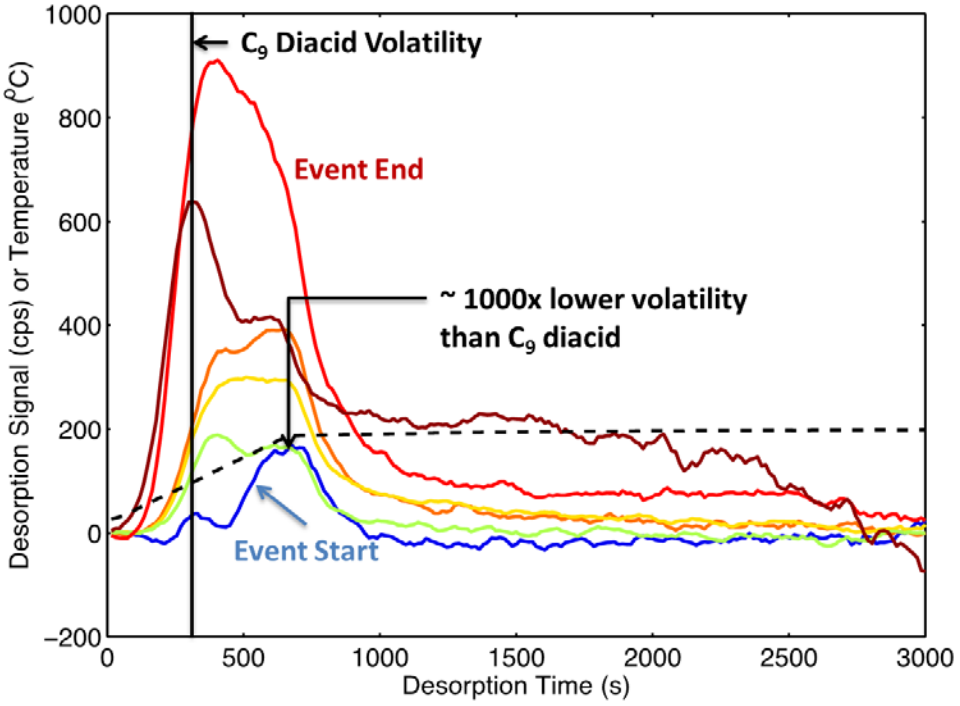

Figure 13. Thermograms of the sum of C18-C20 compounds are shown as signal versus desorption time (solid lines). The desorption temperature during the ramp and soak is shown as a dashed line. At the start of the event, total concentrations (proportion to area under the thermogram) are low, but the majority of the mass desorbs at higher temperature (later times), consistent with having a saturation vapor concentration orders of magnitude lower than a common monoterpene oxidation product. As the event progresses, the total mass of C18-C20 compounds increases, consistent with the overall growth of the ambient particle population, and both extremely low-volatility compounds and higher-volatility components increase in abundance.

The above results are focused on specific components of particles during growth events. While these events occur frequently during spring in Hyytiälä, and the components highlighted contribute significant mass concentration, we are also interested in the average composition of the "background" aerosol and how that relates to composition during growth events. **Error! Reference source not found.** shows a broader characterization of FIGAERO HR-ToF-CIMS measured particle composition, organized into carbon number groups: C_4-C_5, C_8-C_{10}, C_{18}-C_{20}, and those carbon number groups that also contain nitrogen in the form of an organic nitrate. In the top panel, the time series of these groups is shown for more than 4 weeks during spring as a stacked area plot. The absolute concentrations have not been calculated because calibration data is still being analyzed, but the maxima of the sum of all components shown correspond approximately to 1-5 ug/m^3, which is between 50 to 100% of total organic aerosol mass measured by an Aerodyne HToF-AMS.

The carbon number bins shown in Figure 14 are chosen to represent contributions from condensation or partitioning of predominant oxidation products from the major biogenic VOC precursors such as monoterpenes (C_8-C_{10}), isoprene and/or methyl butene-1-ol (MBO) (C_4-C_5), and tracers of either gas- or particle-phase accretion reactions (C_{18}-C_{20}) involving these biogenic precursor oxidation products. The

nitrates are, on the one hand, a tracer of anthropogenic influence, given that globally most NO_x now arises from anthropogenic emissions, but also nitrates can be a tracer of different types of chemistry—that driven by daytime photochemistry or that driven by nighttime chemistry involving ozonolysis or oxidation by the nitrate radical. In the top panel, it is clear that monoterpene oxidation products tend to dominant the fraction of mass characterized by the FIGAERO HR-ToF-CIMS, consistent with the biogenic emissions distribution upwind of the measurement site during spring. However, as spring progresses, there is a noticeable enhancement in the contribution of C_4-C_5 compounds, likely due to the onset of isoprene emissions with leaf-out and increasing temperatures. Overall, a rather consistent composition appears to dominate the background, with large contributions from monoterpene oxidation products, "dimers" indicating particle-phase chemistry, and organic nitrates, suggesting an important role for anthropogenic influence even in this more rural site location. An important caveat to the last point is that natural soil emissions of NO_x may constitute the dominant source of NO_x that leads to nitrates at this site. We will be assessing this aspect as our analysis progresses.

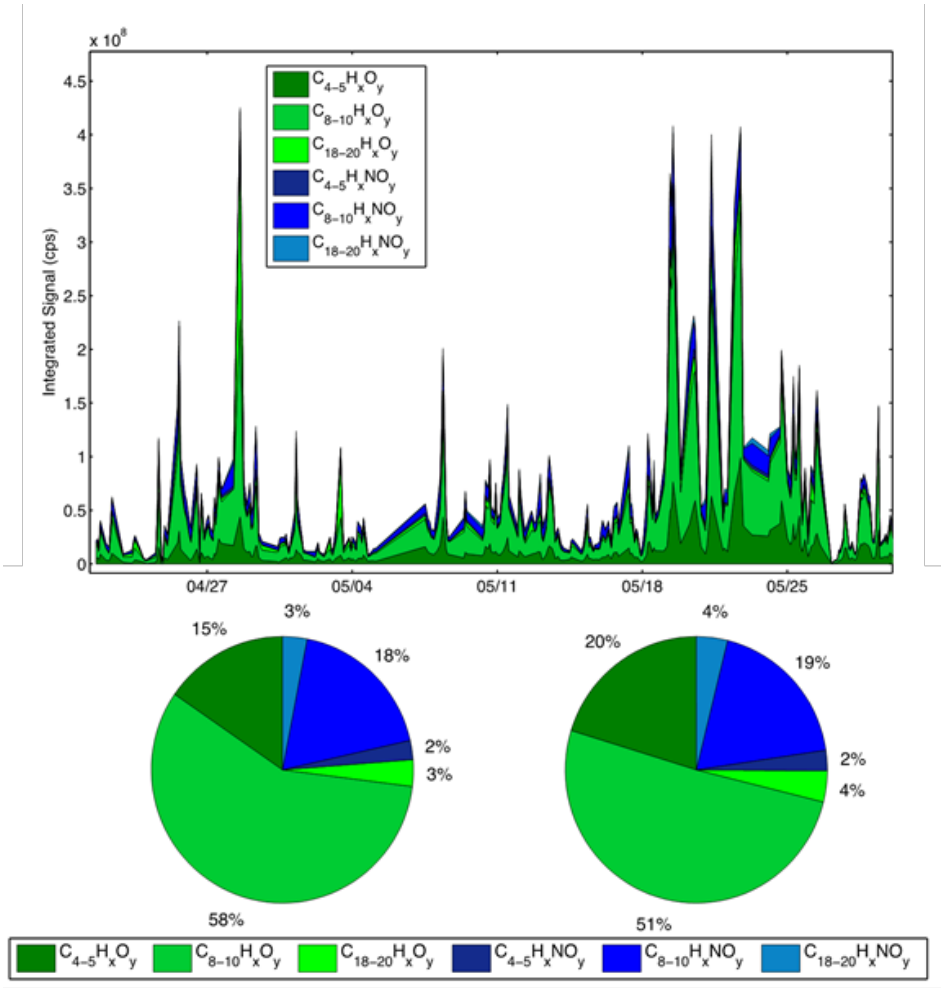

Figure 14. Time series (top) and pie charts of FIGAERO HR-ToF-CIMS-determined composition. In the top panel, the signal proportional to absolute mass concentrations is shown for different carbon number bins for more than four weeks of the campaign. The maxima in this panel correspond to of order 1-5 ug/m^3. The distribution of mass in these carbon number bins (pie charts) is approximate, and the specific contribution of the organic nitrates could be larger by a factor of 2.

In summary, the BAECC deployment of the FIGAERO HR-ToF-CIMS was successful in all aspects. We are embarking on an analysis which will provide unprecedented constraints on the emissions and chemical processes that drive the contribution of organic material to the growth of new particles and to regional background aerosol during springtime. These insights will be able to put constraints on mechanisms capable of being incorporated into large-scale chemistry-climate models, a goal for the outcome of future work on this project.

4.5 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 (Polly^{XT}, 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 Figure 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 data sets 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 the SMEAR-II station. The onboard 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 data set 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 15 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 in 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 data sets.

Here, the retrievals can be improved through harnessing data from the multi-wavelength Raman lidar system Polly^{XT}, 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 data set will help identify the relative impact of long-range transport of material and local sources, and we will also investigate the mechanisms for dispersion.

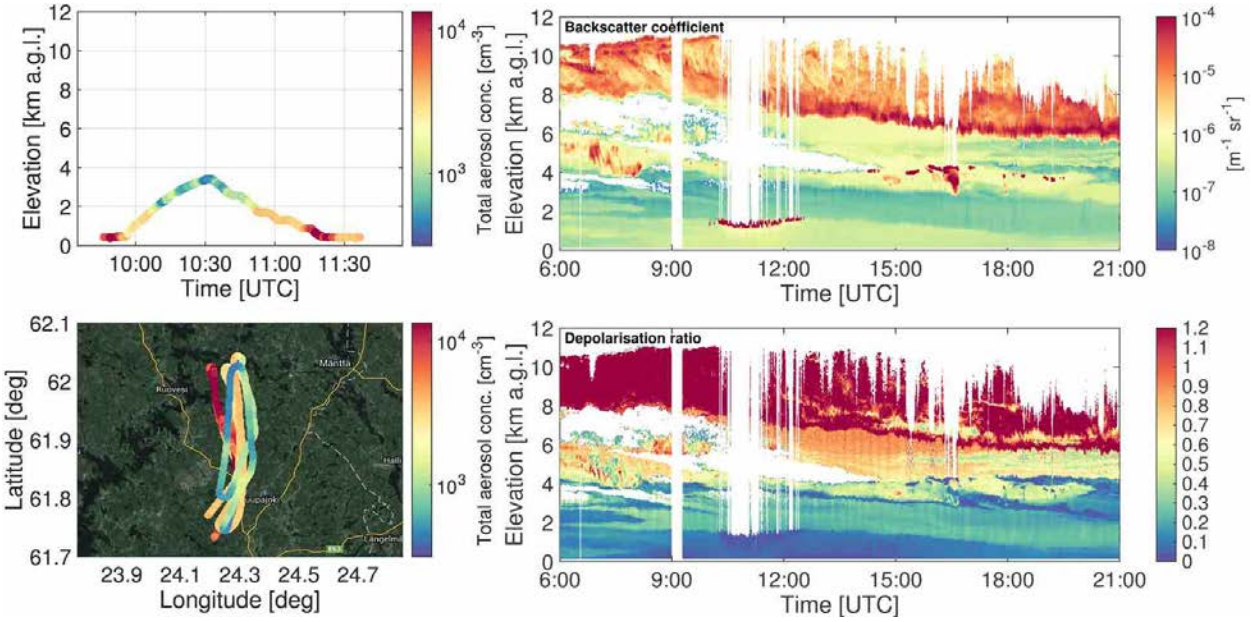

Figure 15. UHEL Cessna flight track (upper left) and altitude track (lower left) during an aircraft IOP centered on Hyytiälä during 2 April 2014. The color of the track provides the total aerosol number concentration. ARM HSRL (High Spectral Resolution Lidar) backscatter coefficient (upper right) and 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) provide 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 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).

4.6 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 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 Figure 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.

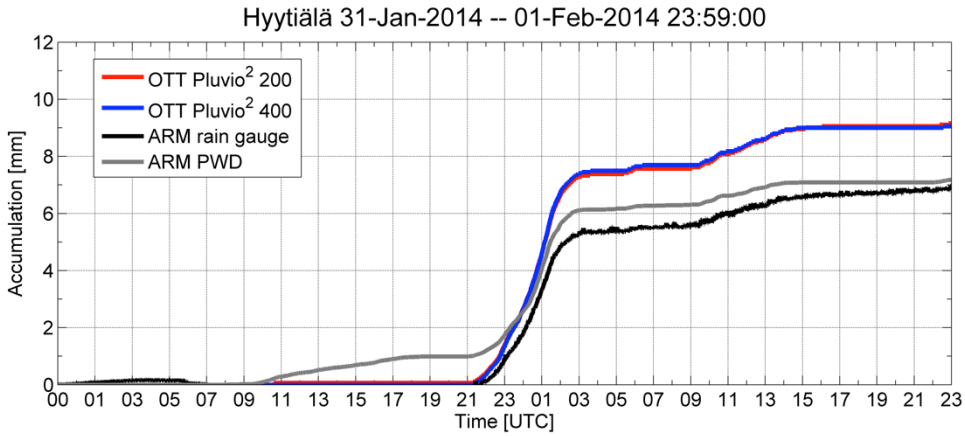

Figure 16. An example of precipitation accumulations measured by two University of Helsinki gauges (OTT Pluvio2 200 and 400) and ARM weighing gauge and PWD. Measurements were collected on February 1, 2014 during BAECC SNEX IOP. The OTT Pluvio2 200 gauge is located inside of DFIR and OTT Pluvio2 400 is 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 use 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 Figure 17.

Table 2. 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

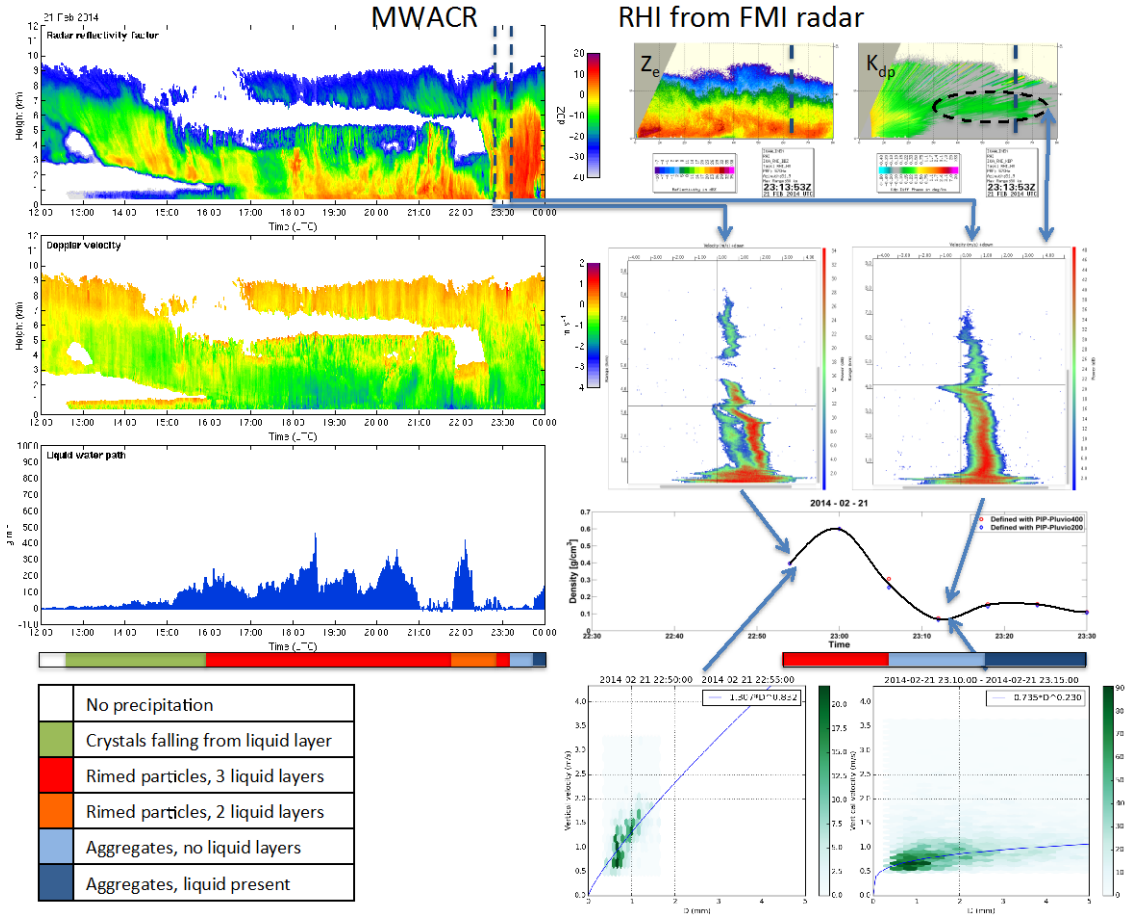

Figure 17. An example of application of cloud radar, Doppler radar spectra, surface precipitation observations, and scanning dual-polarization radar to characterize dominating precipitation processes. Measurements were collected on February 21, 2014 during BAECC SNEX IOP. FMI radar carried out RHI scans over the AMF2 location every 15 min.

5.0 Public Outreach

At the beginning of the operations, a 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 aired 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 13 February 2014 (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 (on the Helsingin Sanomat website).

Aamulehti, the largest newspaper in the Tampere region (close to Hyytiälä) and the second largest in Finland, ran an extensive article on the BAECC campaign in the Science section (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).

6.0 BAECC Publications

6.1 Journal Articles/Manuscripts

1. Aalto J, A Porcar-Castell, J Atherton, P Kolari, T Pohja, P Hari, E Nikinmaa, T Petäjä, and J Bäck. 2015. "Onset of photosynthesis in spring speeds up monoterpene synthesis and leads to emission bursts." *Plant, Cell and Environment* 38(11): 2299-312, doi:.10.1111/pce.12550.

2. Kneifel, S, A von Lerber, J Tiira, D Moisseev, P Kollias, and J Leinonen. 2015. "Observed relations between snowfall microphysics and triple-frequency radar measurements." *Journal of Geophysical Research: Atmospheres* 120(12): 6034-6055, doi:10.1002/2015jD023156.

3. Manninen, AJ, V Vakkari, EJ O'Connor, and T Petäjä. 2016. "A generalized background correction algorithm for a HALO Doppler lidar and its application to data from Finland." *Atmospheric Measurement Techniques* 9: 817-827, doi:10.5194/amt-9-817-2016.

4. Manninen, HM, J Bäck, SL Sihto-Nissilä, V Hiltunen, AM Pessi, PJ Hidalgo, JA Huffmann, A Rantio-Lehtimäki, M Kulmala, and T Petäjä. 2014. "Annual pattern of airborne pollen grains, fungal spores and particle mass in a boreal forest." *Boreal Environmental Research* 19(B): 383-405, http://www.borenv.net/BER/pdfs/ber19/ber19B-383.pdf

5. Petäjä, T, EJ O'Connor, D Moisseev, VA Sinclair, AJ Manninen, R Vaananen, A von Lerber, JA Thornton, K Nicoll, W Petersen, V Chandrasekar, JN Smith, PM Winkler, O Kruger, H Hakola, H Timonen, D Brus, T Laurila, E Asmi, M-L Riekkola, L Mona, P Massoli, R Engelmann, M Komppula, J Wang, C Kuang, J Back, A Virtanen, J Levula, M Ritsche, and N Hickmon. 2016. "BAECC: A field campaign to elucidate the impact of biogenic aerosols on clouds and climate." *Bulletin of the American Meteorological Society*, doi:10.1175/BAMS-D-14-00199.1.

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

7. 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.

8. Zieger, P, PP Aalto, V Aaltonen, M Äijälä, J Backman, J Hong, M Komppula, R Krejci, M Laborde, J Lampilahti, G de Leeuw, A Pfüller, B Rosati, M Tesche, P Tunved, R Väänänen, and T Petäjä. 2015. "Low hygroscopic scattering enhancement of boreal aerosol and the implications for a columnar optical closure study." *Atmospheric Chemistry and Physics* 15: 7247-7267, doi:10.5194/acp-15-7247-2015.

6.2 Meeting Abstracts/Presentations/Posters

2015:

1. Brus, D, E Asmi, M Aurela, F Devoto, K Doulgeris, J Hatakka, R Hillamo, T Laurila, H Lihavainen, E O'Connor, E Rouhe, S Saarikoski, and H Timonen. Skyvan flights during BAECC campaign, Proceedings of the NOSA-FAAR Symposium 2015, Eds. A Leskinen and J Kontkanen. Report Series in *Aerosol Science* 165, p. 19.
2. Heikkinen, L, M Äijälä, M Ehn, T Petäjä, M Kulmala, and D Worsnop. 2015. Seasonal variation of aerosol chemical composition in the boreal forest, Proceedings of the NOSA-FAAR Symposium 2015, Eds. A Leskinen and J Kontkanen, Report Series in *Aerosol Science* 165, p. 41.
3. Hong, J, T Nieminen, J Duplissy, M Äijälä, L Hao, N Sarnela, M Kulmala, T Petäjä, and VM Kerminen. 2015. Hygroscopic properties of ambient aerosols during new particle formation events, Proceedings of the NOSA-FAAR Symposium 2015, Eds. A Leskinen and J Kontkanen, Report Series in *Aerosol Science* 165, p. 45.
4. Manninen, HE, K Lehtipalo, LR Ahonen, J Backman, S Buenostro Mazon, X Chen, J Duplissy, J Enroth, A Franchin, J Hong, N Kalivitis, J Kangasluoma, J Kontkanen, K Luoma, J Mikkilä, G Steiner, R Väänänen, R Wagner, D Wimmer, T Petäjä, and M Kulmala. 2015. Studies of atmospheric aerosol particles and ions: from molecular clusters to cloud droplets, Proceedings of the 1st Pan-Eurasian Experiment (PEEX) Conference and the 5th PEEX Meeting, Editors: Markku Kulmala, Sergej Zilitinkevich, Hanna K. Lappalainen, Ella-Maria Kyrö and Jenni Kontkanen, Report Series in *Aerosol Science* 163, 283-286.
5. Petäjä, T, D Moisseev, EO O'Connor, and the BAECC team. 2014. Biogenic Aerosol – Effects on Clouds and Climate, Breakout session at 2015 ARM/ASR Joint User Facility PI Meeting, Vienna, VA, USA.
6. Petäjä, T, A Manninen, D Moisseev, V Sinclair, E O'Connor, HK Lappalainen, VM Kerminen, and The BAECC Consortium. 2015. Progress within "Biogenic Aerosols – Effects on Clouds and Climate (BAECC) in the context of Pan Eurasian Experiment, Proceedings of the 1st Pan-Eurasian Experiment (PEEX) Conference and the 5th PEEX Meeting, Editors: Markku Kulmala, Sergej Zilitinkevich, Hanna K. Lappalainen, Ella-Maria Kyrö and Jenni Kontkanen, Report Series in *Aerosol Science* 163, 341-343.
7. Wang, H, A Pajunoja, L Hao, JS Kim, M Kulmala, T Petäjä, and A Virtanen. 2015. Effects of humidity conditions on hygroscopicity of freshly nucleated particles, Proceedings of the NOSA-FAAR Symposium 2015, Eds. A Leskinen and J Kontkanen, Report Series in *Aerosol Science* 165, 134.

2014:

1. Asmi, E, D Brus, A Hirsikko, R Hooda, A Hyvärinen, N Kivekäs, J Leppä, K Neitola, E O'Connor, T Raatikainen, J Svensson, O Tolonen-Kivimäki, V Vakkari, H Lihavainen, M Räsänen, U Rannik, T Aalto, L Järvi, T Laurila, A Ojala, ES Tuittila. 2014. Introduction to research at atmospheric aerosols group, Proceedings of 'the Center of Excellence in Atmospheric Sciences (CoE ATM), From Molecular and Biological Processes to the Global Climate' Annual Meeting 2014, Eds. M Kulmala, A Lintunen, and J Kontkanen, Report Series in *Aerosol Science* 157, 35-40.

2. Brus, D, E Asmi, M Aurela, F Devoto, K Doulgeris, J Hatakka, R Hillamo, T Laurila, H Lihavainen, E O'Connor, E Rouhe, S Saarikoski, and H Timonen. 2014. Skyvan flights during BAECC campaign, Proceedings of 'the Center of Excellence in Atmospheric Sciences (CoE ATM), From Molecular and Biological Processes to the Global Climate' Annual Meeting 2014, Eds. M Kulmala, A Lintunen, and J Kontkanen, Report Series in *Aerosol Science* 157, 212-216.

3. Lautaportti, S, J Tiira, L Alku, R Cremonini, T Voormansik, P Kollias, D Moisseev, and V Chandrasekar. 2014. Utilization of cloud radar Doppler spectra to investigate cloud to precipitation processes in mixed phase clouds duing BAECC, Proceedings of 'the Center of Excellence in Atmospheric Sciences (CoE ATM), From Molecular and Biological Processes to the Global Climate' Annual Meeting 2014, Eds. M Kulmala, A Lintunen, and J Kontkanen, Report Series in *Aerosol Science* 157, 385-390.

4. Manninen, A, V Vakkari, E O'Connor, and T Petäjä. 2014. A generalized background correction algorithm for a Halo Doppler lidar and its application to data from Finland, Proceedings of 'the Center of Excellence in Atmospheric Sciences (CoE ATM), From Molecular and Biological Processes to the Global Climate' Annual Meeting 2014, Eds. M Kulmala, A Lintunen, and J Kontkanen, Report Series in *Aerosol Science* 157, 423-426.

5. Manninen, A, T Nieminen, LR Ahonen, PP Aalto, and T Petäjä. 2014. A comparison of aerosol and trace gas measurements between SMEAR-II and AMF2 instrumentation in Hyytiälä, Proceedings of 'the Center of Excellence in Atmospheric Sciences (CoE ATM), From Molecular and Biological Processes to the Global Climate' Annual Meeting 2014, Eds. M Kulmala, A Lintunen, and Jenni Kontkanen, Report Series in *Aerosol Science* 157, 427-431.

6. Manninen, HE, J Bäck, SL Sihto-Nissilä, JA Huffmann, AM Pessi, V Hiltunen, PP Aalto, P Hari, A Saarto, M Kulmala, and T Petäjä. 2014. Patterns of airborne pollen and fungal spore concentrations and their mass fraction of total particles in boreal forest, Proceedings of 'the Center of Excellence in Atmospheric Sciences (CoE ATM), From Molecular and Biological Processes to the Global Climate' Annual Meeting 2014, Eds. M Kulmala, A Lintunen, and J Kontkanen, Report Series in *Aerosol Science* 157, 432-436.

7. Moisseev, D, A von Lerber, M Leskinen, V Chandrasekar, L Bliven, and W Petersen. 2014. Comprehensive snowfall experiment during DOE ARM AMF2 deployment in Finland. European Conference on Radar in Meteorology and Hydrology, Germany.

8. Moisseev, D, A von Lerber, L Alku, S Lautaportti, M Leskinen, J Tiira, K Nordling, R Cremonini, B Hickman, and V Chandrasekar. 2014. Radar meteorology group, Proceedings of 'the Center of Excellence in Atmospheric Sciences (CoE ATM), From Molecular and Biological Processes to the Global Climate' Annual Meeting 2014, Eds. M Kulmala, A Lintunen, and J Kontkanen, Report Series in *Aerosol Science* 157, 106-107.

9. Pajunoja, A, AT Lambe, J Hakala, N Rastak, MJ Cummings, JF Brogan, L Hao, M Paramonov, J Hong, NL Prisle, J Malila, S Romakkaniemi, KEJ Lehtinen, A Laaksonen, M Kulmala, P Massoli, TB Onasch, NM Donahue, I Riipinen, P Davidovits, DR Worsnop, T Petäjä, and A Virtanen. 2014. Identiying the dominant process in water uptake by amorphous solid secondary organic aerosols, Proceedings of 'the Center of Excellence in Atmospheric Sciences (CoE ATM), From Molecular and Biological Processes to the Global Climate' Annual Meeting 2014, Eds. M Kulmala, A Lintunen, and J Kontkanen, Report Series in *Aerosol Science* 157, 496-498.

10. Petäjä, T, D Moisseev, E O'Connor, and the BAECC team. 2014. Connecting new particle formation to clouds and climate, International Aerosol Conference IAC 2014, Busan, Korea (keynote lecture).
11. Petäjä, T, G de Leeuw, HK Lappalainen, D Moisseev, E O'Connor, et al. 2014. Connecting ground-based in situ observations, ground-based remote sensing and satellite data within the Pan Eurasian Experiment (PEEX) program, *SPIE Proceedings*, 9242-5, (Invited Paper).
12. Vakkari, V, A Manninen, T Petäjä, and E O'Connor. 2014. Identifying low altitude turbulent mixing at a continental location with a scanning doppler lidar, Proceedings of 'the Center of Excellence in Atmospheric Sciences (CoE ATM), From Molecular and Biological Processes to the Global Climate' Annual Meeting 2014, Eds. M Kulmala, A Lintunen, and J Kontkanen, Report Series in *Aerosol Science* 157, 649-651.

2013:

1. Petäjä, T, D Moisseev, E O'Connor, HK Lappalainen, J Levula, KEJ Lehtinen, M Kulmala, and the BAECC team. 2013. Overview of the Biogenic Aerosols – Effects on Clouds and Climate (BAECC) experiment, Proceedings of Nordic Center of Excellence in "CRyosphere-Atmosphere Interactions in a Changing Arctic Climate", Annual Meeting 2013, Report Series in Aerosol Science 141, 148-149.

7.0 References

Aalto, J., P Kolari, P Hari, VM Kerminen, P Schiestl-Aalto, H Aaltonen, J Levula, E Siivola, M Kulmala, and J Bäck. 2014. "New foliage growth is a significant, unaccounted source for volatiles in boreal evergreen forests." *Biogeosciences* 11: 1331–1344, doi:10.5194/bg-11-1331-2014.

Aalto, P, K Hämeri, E Becker, R Weber, J Salm, JM Mäkelä, C Hoell, CD O'dowd, H-C Hansson, M Vakeva, IK Koponen, G Buzorius, M Kulmala. 2001. "Physical characterization of aerosol particles during nucleation events." *Tellus B* 53(4): 344–358.

Boucher, O, D Randall, P Artaxo, C Bretherton, G Feingold, P Forster, VM Kerminen, Y Kondo, H Liao, U Lohmann, et al. 2013. "Clouds and Aerosols. In Climate Change 2013: The Physical Science Basis." *Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, T Stocker, D Qin, G Plattner, M Tignor, S Allen, J Boschung, A Nauels, Y Xia, V Bex, and P Midgley, eds. Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press.

Boy, M, A Sogachev, J Lauros, L Zhou, A Guenther, and S Smolander. 2011. "SOSA – a new model to simulate the concentrations of organic vapours and sulphuric acid inside the ABL – Part 1: Model description and initial evaluation. "*Atmospheric Chemistry and Physics* 11: 43–51, doi:10.5194/acp-11-43-2011.

Dal Maso, M, M Kulmala, I Riipinen, R Wagner, T Hussein, PP Aalto, and KEJ Lehtinen. 2005. "Formation and growth of fresh atmospheric aerosols: eight years of aerosol size distribution data from SMEAR II, Hyytiälä, Finland." *Boreal Environment Research* 10: 323–336, http://www.borenv.net/BER/pdfs/ber10/ber10-323.pdf

Dal Maso, M, L Sogacheva, PP Aalto, I Riipinen, M Komppula, P Tunved, L Korhonen, V Suur-Uski, A Hirsikko, T Kurtén, V-M Kerminen, H Lihavainen, Y Viisanen, H-C Hansson, and M Kulmala. 2007. "Aerosol size distribution measurements at four Nordic field stations: identification, analysis and trajectory analysis of new particle formation bursts." *Tellus B* 59(3): 350–361, http://www.tellusb.net/index.php/tellusb/article/view/16995

Hari, P, and M Kulmala. 2005. "Station for Measuring Ecosystem–Atmosphere Relations (SMEAR II)." *Boreal Environment Research* 10: 315–322, http://www.borenv.net/BER/pdfs/ber10/ber10-315.pdf

Jefferson, A. 2011. Aerosol Observing System (AOS) Handbook. U.S. Department of Energy, Office of Science, Office of Biological and Environmental Research.

Johnson, N and S Kotz. 1972. *Distributions in Statistics: Continuous Multivariate Distributions* New York, NY: Wiley.

Kerminen, V-M, H Lihavainen, M Komppula, Y Viisanen, and M Kulmala. 2005. "Direct observational evidence linking atmospheric aerosol formation and cloud droplet activation." *Geophysical Research Letters* 32(14), doi:10.1029/2005GLO23130.

Kulmala, M, I Riipinen, M Sipilä, HE Manninen, T Petäjä, H Junninen, M Dal Maso, G Mordas, A Mirme, M Vana, A Hirsikko, L Laakso, RM Harrison, I Hanson, C Leung, KEJ Lehtinen, V-M Kerminen. 2007. "Toward Direct Measurement of Atmospheric Nucleation." *Science* 318: 89–92, doi:10.1126/science.1144124.

Kulmala, M, P Alekseychik, M Paramonov, T Laurila, E Asmi, A Arneth, S Zilitinkevich, and V-M Kerminen. 2011. "On measurements of aerosol particles and greenhouse gases in Siberia and future research needs. "*Boreal Environment Research* 16: 37–362, http://www.borenv.net/BER/pdfs/ber16/ber16-337.pdf

Lihavainen, H, V-M Kerminen, P Tunved, V Aaltonen, A Arola, J Hatakka, A Hyvärinen, and Y Viisanen. 2009. "Observational signature of the direct radiative effect by natural boreal forest aerosols and its relation to the corresponding first indirect effect." *Journal of Geophysical Research*: *Atmospheres* 114(D20), doi:10.1029/2009jD012078.

McMurry, PH. 2000. "The History of Condensation Nucleus Counters." *Aerosol Science and Technology* 33(4): 297–322, doi:10.1080/02786820050121512.

Mäkelä, JM, P Aalto, V Jokinen, T Pohja, A Nissinen, S Palmroth, T Markkanen, K Seitsonen, H Lihavainen, and M Kulmala. 1997. "Observations of ultrafine aerosol particle formation and growth in boreal forest." *Geophysical Research Letters* 24(10): 1219–1222, doi:10.1029/97GL00920.

Makkonen, R, A Asmi, V-M Kerminen, M Boy A Arneth, P Hari, and M Kulmala. 2012. "Air pollution control and decreasing new particle formation lead to strong climate warming." *Atmospheric Chemistry and Physics* 12: 1515–1524, doi:10.5194/acp-12-1515-2012.

Martin, S. 2013. Observations and Modeling of the Green Ocean Amazon: Year-to-Year Differences U.S. Department of Energy, Office of Science, Office of Biological and Environmental Research.

Merikanto, J, DV Spracklen, GW Mann, SJ Pickering, and KS Carslaw. 2009. “Impact of nucleation on global CCN.” *Atmospheric Chemistry and Physics* 9: 8601–8616, doi:10.5194/acp-9-8601-2009.

Mirme, S, A Mirme, E Tamm, and J Uin. 2007. Evaluation of Neutral Cluster and Air Ion Spectrometer (NAIS). Salzburg, Austria.

Ng, NL, SC Herndon, A Trimborn, MR Canagaratna, PL Croteau, TB Onasch, D Sueper, DR Worsnop, Q Zhang, YL Sun, and JT Jayne. 2011. “An aerosol chemical speciation monitor (ACSM) for routine monitoring of the composition and mass concentrations of ambient aerosol.” *Aerosol Science and Technology* 45(7): 780–794, doi:10.1080/02786826.2011.560211.

Nieminen, T, A Asmi, M Dal Maso, PP Aalto, P Keronen, T Petäjä, M Kulmala, and V-M Kerminen. 2014. “Trends in atmospheric new-particle formation: 16 years of observations in a boreal-forest environment.” *Boreal Environment Research* B19:191–214, http://meetingorganizer.copernicus.org/EGU2012/EGU2012-10036.pdf

Paatero, P and U Tapper. 1994. “Positive matrix factorization: A non-negative factor model with optimal utilization of error estimates of data values.” *Environmetrics* 5(2): 111–126, doi:10.1002/env.3170050203.

Paramonov, M, PP Aalto, A Asmi, N Prisle, V-M Kerminen, M Kulmala, and T Petäjä. 2013. ”The analysis of size-segregated cloud condensation nuclei counter (CCNC) data and its implications for cloud droplet activation.” *Atmospheric Chemistry and Physics* 13, 10285–10301, doi:10.5194/acp-13-10285-2013.

Petäjä, T, D Moisseev, E O’Connor, H Lappalainen, J Levula, J Bäck, M Boy, M Komppula, A Lindfors, R Krejci, et al. 2014. Science Plan: Biogenic Aerosols – Effects on Clouds and Climate (BAECC). U.S. Department of Energy, Office of Science, Office of Biological and Environmental Research.

Peterson, MR and MH Richards. 2002. Thermal-optical-transmittance analysis for organic, elemental, carbonate, total carbon, and OCX2 in PM2. 5 by the EPA/NIOSH method. In *Symposium on Air Quality Measurement Methods and Technology*, Air & Waste Management Association, Pittsburgh, PA, pp. 83–1.

Sihto, SL, J Mikkilä, J Vanhanen, M Ehn, L Liao, K Lehtipalo, PP Aalto, J Duplissy, T Petäjä, V-M Kerminen, M Boy, and M Kulmala. 2011. “Seasonal variation of CCN concentrations and aerosol activation properties in boreal forest.” *Atmospheric Chemistry and Physics* 11, 13269–13285, doi:10.5194/acp-11-13269-2011.

Spracklen, DV, B Bonn, and KS Carslaw. 2008. “Boreal forests, aerosols and the impacts on clouds and climate.” *Philosophical Transactions of the Royal Society A* 366(1885), doi:10.1098/rsta.2008.0201.

Taipale, R, et al. 2011. *Disjunct eddy covariance measurements of volatile organic compound fluxes using proton transfer reaction mass spectrometry*. University of Helsinki.

Tammet, H, U Horrak, L Laakso, and M Kulmala. 2006. ”Factors of air ion balance in a coniferous forest according to measurements in Hyytiälä, Finland.” *Atmospheric Chemistry and Physics* 6: 3377–3390, doi:10.5194/acp-6-3377-2006.

Tunved, P, H-C Hansson, V-M Kerminen, J Ström, M Dal Maso, H Lihavainen, Y Viisanen, PP Aalto, M Komppula, and M Kulmala. 2006. “High natural aerosol loading over boreal forests.” *Science* 312(5771): 261–263, doi:10.1126/science.1123052.

Vanhanen, J, J Mikkilä, K Lehtipalo, M Sipilä, HE Manninen, E Siivola, T Petäjä, and M Kulmala. 2011. “Particle size magnifier for nano-CN detection.” *Aerosol Science and Technology* 45(4): 533–542, doi:10.1080/02786826.2010.547889.

Xausa, F, L Dada, L Ahonen, A Waza, LS Iversen, KH Kjær, SB Mazon, M Vana, K Komsaari, S Mirme, and T Petäjä. 2014. Particle formation events and vertical profiles for SMEAR I & II, Finland, and SMEAR-E, Estonia in boreal forest. Course report, University of Helsinki, Finland, p. 31.

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