

Received: 12 February 2015 – Accepted: 19 March 2015 – Published: 15 April 2015

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Published by Copernicus Publications on behalf of the European Geosciences Union.

ACPD

15, 11143–11178, 2015

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Abstract

While Cloud Condensation Nuclei (CCN) production associated with atmospheric new particle formation (NPF) is thought to be frequent throughout the continental boundary layers, few studies on this phenomenon in marine air exist. Here, based on simultaneous measurement of particle number size distributions, CCN properties and aerosol chemical composition, we present the first direct evidence on CCN production resulting from NPF in the Eastern Mediterranean atmosphere. We show that condensation of both gaseous sulfuric acid and organic compounds from multiple sources leads to the rapid growth of nucleated particles to CCN sizes in this environment during the summertime. Sub-100 nm particles were found to be substantially less hygroscopic than larger particles during the period with active NPF and growth (0.2–0.4 lower κ between the 60 and 120 nm particles), probably due to enrichment of organic material in the sub-100 nm size range. The aerosol hygroscopicity tended to be at minimum just before the noon and at maximum in afternoon, which was very likely due to the higher sulfate to organic ratios and higher degree of oxidation of the organic material during the afternoon. Simultaneously to the formation of new particles during daytime, particles formed in the previous day or even earlier were growing into the size range relevant to cloud droplet activation, and the particles formed in the atmosphere were possibly mixed with long-range transported particles.

1 Introduction

Aerosol particles influence the Earth's radiation balance via aerosol–radiation and aerosol–cloud interactions, the latter effect constituting one of the largest uncertainties in understanding the anthropogenic climate change (IPCC, 2013). A key quantity related to aerosol–cloud interactions is the number concentration of aerosol particles able to act as cloud condensation nuclei (CCN) at water vapour supersaturation levels relevant for ambient clouds. Supersaturations in the atmospheric water clouds remain

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well below 10 % and most frequently below 1 % (Pruppacher and Klett, 1997). The probability by which an aerosol particle acts as a CCN at a given supersaturation depends primarily on its size and secondarily on its chemical composition (Dusek et al., 2006). The aerosol chemical composition may, however, have large impacts on the total CCN number concentration (Karydis et al., 2012; Padró et al., 2012).

CCN are emitted directly to the atmosphere by a variety of natural and anthropogenic sources, in addition to which CCN can also be produced in the atmosphere by the growth of both primary and secondary aerosol particles (Andreae and Rosenfeld, 2008; Pierce and Adams, 2009). Model studies suggest that a large fraction of CCN in the global atmosphere originates from atmospheric new particle formation (NPF) and growth. Merikanto et al. (2009) estimated that 45 % of the global low-level-cloud CCN at 0.2 % supersaturation result from nucleation (ranging between 31–49 %). Westervelt et al. (2014) estimated the average global increase of the boundary-layer CCN number concentration at 0.2 % supersaturation due to nucleation ranging between 49 and 78 %, depending on the simulation scenario used. The fraction of nucleated particles that can grow to CCN sizes in the boundary layer is likely to have large spatial variations, ranging from < 20 for 0.4 % supersaturation for Southern Ocean and exceeding 60 % for the tropical oceans, Antarctica, Eastern United States, Europe and North Atlantic, whereas in the vertical dimension CCN concentration generally decrease with an increasing altitude (Yu and Luo, 2009). Field studies directly investigating the connection between atmospheric NPF, subsequent particle growth and CCN production have been mostly limited to continental boundary-layer sites (see Kerminen et al., 2012, and references therein). An example of increase in CCN sized particles concentration after coastal nucleation is presented in Dowd (2001). In general, however, field measurements give support for the potentially important role of NPF in CCN production, at least regionally; nucleation observed was followed by increase in CCN number concentrations.

New particle formation is frequent in the Eastern Mediterranean atmosphere (Petäjä et al., 2007; Kalivitis et al., 2008, 2012; Manninen et al., 2010; Pikridas et al., 2012), although a bit more sparse than in other, mostly continental, European sites (Manninen

2.2 Instrumentation

The particle number size distributions were measured in the diameter range 9–848 nm using a custom-built Scanning Mobility Particle Sizer (SMPS). The system is closed-loop, with a 5 : 1 ratio between the aerosol and sheath flow, it consists of a Kr-85 aerosol neutralizer (TSI 3077), a Hauke medium Differential Mobility Analyzer (DMA) and a TSI-3772 Condensation Particle Counter (CPC), and it is operated following the recommendations by Wiedensohler et al. (2012). The sampling was made through a PM₁₀ sampling head and the sample humidity was regulated below the relative humidity of 40 % with the use of Nafion[®] dryers in both the aerosol and sheath flow. The measured number size distributions were corrected for diffusional particle losses.

The chemical composition of the non-refractive mass of submicron particles was specified with an Aerodyne Research Aerosol Chemical Speciation Monitor (ACSM; Ng et al., 2011). The ACSM provides real-time (30 min time interval) information on ammonium, sulfate, nitrate, chloride and organic mass in non-refractory submicron particles. More details and calculations of the mass concentrations can be found in Bougiatioti et al. (2014). During our measurements, the ambient air was drawn into the ACSM via a PM₁ aerosol inlet without sample drying. The concentration of black carbon (BC) was measured using an AE31 Aethalometer (Magee Scientific, AE31) operated with a PM₁₀ sampling head and under humidity controlled conditions.

In order to investigate size-segregated CCN properties, we utilized a coupled DMA-CCNc set-up. The sampled polydisperse aerosol were driven through a TSI 3080 DMA after being charged by a Kr-85 aerosol neutralizer (TSI 3077). The DMA had a closed-loop system for recirculating the sheath flow. The monodisperse aerosol, classified at the 60, 80, 100 and 120 nm diameters out of the DMA, were then supplied to a Continuous Flow Streamwise Thermal Gradient CCN Chamber (CFSTGC; Roberts and Nenes, 2005) in order to determine the number concentration of aerosol particle able to act as CCN with respect to supersaturation. The CFSTGC was operated in the “Scanning Flow CCN Analysis” (SFCA) mode (Moore and Nenes, 2009), in which the flow rate

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where M_w is the molar mass of water, σ_w is the surface tension of water, R is the universal gas constant, T is temperature, ρ_w is the density of water and D_d is the particle dry diameter. The value of κ is 0 for non-hygroscopic material and lies typically in the range 0.01–0.5 for slightly-to-highly hygroscopic organic compounds and in the range 0.5–1.5 for hygroscopic inorganic compounds (Petters and Kreidenweis, 2007).

We divided the organic mass measured with the ACSM into a few separate components using the positive matrix factorization (PMF) analysis (Paatero, 1999). For this purpose, we utilized the multi-linear solver ME-2 using the interface described by Canonaco et al. (2013). The estimated oxygen-to-carbon ratios (O/C) of the organic material were calculated following the approach by Aiken et al. (2008). Atomic O/C ratios characterize the oxidation state of organic aerosol which correlates to their density and water solubility. It has been shown that κ generally increases with the organic oxidation level (eg. Massoli et al., 2010; Mei et al., 2013), however it should be noticed that several other studies have shown that the link between hygroscopicity and oxidation level is not straightforward (Cerully et al., 2014 and references therein)

We determined the particle growth rate (GR) during the new-particle formation events along with the condensation sink (CS), using the approach described in detail by Kulmala et al. (2012). The values of GR discussed later in this paper refer to the particle growth rates of 9–20 nm diameter particles averaged over each NPF event.

3 Results

We chose 28 August to 2 September 2012 as our case study period, since during that time several NPF events were observed at the Finokalia station as shown in the size distributions in Fig. 2. For three consecutive days (29–31 August), NPF formation was observed before noon at the lowest detectable sizes, with subsequent growth of the newly-formed particles over the rest of the day (Fig. 2). These days are typical examples of so-called regional NPF events, in which the particle formation and growth takes almost homogeneously place over distances of tens to hundreds of kilometers

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ation and subsequent CCN production, and affects the fraction of nucleated particles that eventually reach CCN sizes before being lost by coagulation scavenging or other removal processes (e.g. Kerminen et al., 2012; Westervelt et al., 2014). The observed values of GR on 29, 30 and 31 August were 3.3, 1.8 and 3.6 nm h⁻¹, respectively, which are lower than the annually-averaged (\pm SD) GR of 5.2 ± 3.4 nm h⁻¹ reported by Pikridas et al. (2012) at the same site for the 10–25 nm size range. By following the approach of Laakso et al. (2013), we could follow the growth of newly-formed particles up to about 50–60 nm in particle diameter until another NPF occurred or the particle growth was interrupted by an air mass or cloud cover change. These features are suggestive of the convolution of nucleation with condensational growth of both new and preexisting particles formed in the previous day (or even earlier) to produce CCN size range particles.

When no CCN measurements are available, a commonly-used proxy for the CCN number concentration is the total number concentration of particles larger than some threshold diameter, D , denoted as N_D (Paasonen et al., 2013; Laakso et al., 2013). Just prior to the nucleation event period (28 August–2 September) and after it, our CCN counter was offline the DMA due to technical problems, so that it was recording the total CCN number concentration at 0.2 % supersaturation, $CCN_{0.2}$. The measured values of $CCN_{0.2}$ correlated strongly with N_{90} , N_{100} , N_{110} , N_{120} and N_{130} (Fig. 4) when considering all the available data. The relation between $CCN_{0.2}$ and N_D prior to the three-day period with most active new particle formation and growth differed greatly from the corresponding relation after this period. Prior to the NPF events, the best correlation against $CCN_{0.2}$ was observed for N_{90} , but this quantity overestimated heavily the CCN concentration ($R^2 = 0.95$, slope = 1.73). With increasing diameters, D , the value of R^2 decreased as did also the slope, so that between N_{130} and $CCN_{0.2}$ the weakest correlation and smaller slope was observed ($R^2 = 0.78$, slope = 1.17). On the other hand, after the NPF events the picture was different: for N_{90} the correlation with $CCN_{0.2}$ was still very good ($R^2 = 0.94$, slope = 1.43), for diameters larger than 110 nm this correlation dropped below 0.45, and for particles larger than 120 or 130 nm there

was practically no correlation between N and $\text{CCN}_{0.2}$ (see the circled points in Fig. 4). The slope of the above regression analysis probably reflects the activation fraction for each diameter while R^2 values indicate that, especially in active NPF periods, the variability of CCN number may be controlled by sub-100 nm particle population. Overall, these data suggest that particles larger than about 100 nm in diameter were able to act effectively as CCN at 0.2 % supersaturation in the measured air masses, which is in line with observations made elsewhere (see Kerminen et al., 2012) and therefore we would recommend N_{100} as a proxy for $\text{CCN}_{0.2}$ at Finokalia with a linear correction in a form $\text{CCN}_{0.2} = a \times N_{100} - b$, where a and b are the slope and offset determined from our observations. For the slope (b) and offset (a) in Finokalia we recommend values $a = 0.57 \pm 0.01$ and $b = 180 \pm 9$, where the variation is calculated as the standard error of the parameters.

Next, we will examine the time evolution of the CCN proxies during our case study period (Fig. 5). We may see that the increase in the total particle number concentration, N_{tot} , caused by nucleation was often followed by an increase in N_{50} after some time lag, as one would expect due to the gradual growth of newly-formed particles up to 50 nm during the same day. The time evolution of both N_{100} and N_{130} resembled that of N_{50} , but with the difference that the base levels of N_{100} and N_{130} tended to increase gradually over time after 29 August. This latter feature supports our earlier speculation that CCN production was a multi-day process in measured air masses, at least when it comes to the CCN that are active at low supersaturations between about 0.1 and 0.3 %. It should be noted that the origin of the new CCN was not necessarily only atmospheric nucleation, but also the growth of sub-CCN-size primary particles during their transportation. The apparent co-variation of N_{50} , N_{100} and N_{130} reveals that, besides new-particle formation and growth, the measured air masses had been affected to variable extents by (i) dilution due to the free-troposphere entrainment, and (ii) long-range-transported primary aerosol particles.

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3.2 Aerosol chemical composition, hygroscopicity and CCN activity

To obtain a comprehensive understanding on particle CCN activity properties, we quantified the link between aerosol chemical composition and hygroscopicity. Figure 6 shows that the composition of submicron particulate matter was dominated by organic material (average concentration $1.9 \pm 0.9 \mu\text{g m}^{-3}$) and sulfate including associated ammonium ($1.8 \pm 0.8 \mu\text{g m}^{-3}$) during our case study period, while nitrate and black carbon contributed a minor fraction of the aerosol (average concentration 0.13 ± 0.08 and $0.34 \pm 0.15 \mu\text{g m}^{-3}$ respectively). Long-term measurements at Finokalia are in line with this pattern (eg Lelieveld et al., 2002; Bougiatioti et al., 2013), suggesting that the relative abundances of sulfate and organic matter dictate to large extent the hygroscopic and cloud activating properties of submicron particles at Finokalia.

In a broader picture, when averaged for the period 1 August to 30 September, the aerosol chemical composition displayed a clear diurnal pattern (Fig. 7a). In general, sulfate concentrations started to increase very rapidly around the noon and reached their diurnal maximum during afternoon, after which they decreased first gradually and then more rapidly until the following noon. The afternoon increase in the sulphate concentration can be ascribed to the intensive photochemical production of gaseous sulphuric acid from both natural and anthropogenic precursors during daytime, followed by the condensation of sulphuric acid into pre-existing aerosol particles together with gaseous ammonia (e.g. Zerefos et al., 2000; Kouvarakis and Mihalopoulos, 2002; Bardouki et al., 2003; Mihalopoulos et al., 2007). Since sulphate is practically non-volatile, the decreasing sulphate concentrations during night and morning hours are most likely a combination of air mass dilution by entrainment and aerosol deposition processes. Organic material declined less rapidly than sulfate during morning, suggesting that secondary organic aerosol (SOA) formation was very active already before noon or, alternatively, that the organic material was less sensitive to dilution than sulfate, i.e. the concentration gradient between the mixed layer and air above it was smaller for organic material than sulphate. After noon, organic material did not increase as rapidly

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(less hygroscopic) and those that were more aged (more hygroscopic) ones. The origin of the latter particle type, whether nucleation or primary emissions, remains unsolved. A similar observation has been reported for 40 nm particles by Cerully et al. (2011) in a boreal forest, attributing the low AF to not reaching the asymptote of the sigmoidal curve at the highest supersaturation measured for 40 nm spectra. The AF for 40 nm particles did not reach nevertheless as low AF as the ones shown in Fig. 10 for 60 nm particles.

3.3 Implications for cloud droplet activation

Figure 11 summarizes the cloud activating properties of 60, 80, 100 and 120 nm diameter particles during 29–30 August 2012, the two days with a pronounced new particle formation and growth in our case study period. There are several things to be noted. First, the supersaturation required for cloud droplet activation increased more steeply with decreasing particle size than it would do if all the particles were equally hygroscopic. A similar feature has been observed in a few earlier studies (Levin et al., 2012; Paramonov et al., 2013; Liu et al., 2014), and it has generally been ascribed to the enrichment of organic material in ultrafine (< 100 nm) particles. The main implication of this finding is that ultrafine particles tend to need higher cloud supersaturations to be able to act as CCN than one would expect based on the bulk chemical composition of the submicron particulate matter. Second, the hygroscopicity of 60–120 nm particles showed a clear diurnal cycle, with the minimum and maximum values of κ typically observed just before and after noon, respectively (Fig. 8). As discussed earlier, this feature was very likely due to higher sulfate to organic ratios (Fig. 7) and higher degree of oxidation of the organic material (Fig. 9) after noon. Figure 7b suggests that the notable diurnal variability in the efficiency by which different-size particles act as CCN may be a common feature at Finokalia during summer. Finally, the required supersaturation needed for CCN activation varied easily by more than a factor 2 for given particle size even at the same time of the day, while the corresponding variability in the smallest diameter of particles able to act CCN at given cloud supersaturation was 20–30 nm.

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The maximum supersaturation remains usually below 0.3% in polluted boundary layer clouds, while higher supersaturations close to or even larger than 1% have been reported under clean conditions and in convective clouds (Ditas et al., 2012; Hammer et al., 2014; Hudson and Noble, 2014). As discussed in Sect. 3.1, we were able to follow the growth of nucleated particles up to 50–60 nm in air masses measured in Finokalia during our case study period. Such particles would probably contribute little to the population of cloud droplets around Finokalia. However, we also found that the nuclei growth very likely continued to larger sizes, but at this point nucleated particles could not be separated from aged primary particles with the available measurements. We conclude that aerosol nucleation taking place in the Eastern Mediterranean environment is capable of producing new CCN at cloud supersaturations encountered in this environment.

4 Conclusions

The case study presented in this paper provides, for the first time, direct evidence on CCN production associated with atmospheric NPF and growth in the Eastern Mediterranean atmosphere. We found that, simultaneous with the formation of new particles during daytime, particles formed in the previous day or even earlier were growing into the size range relevant to cloud droplet activation, and that particles formed originally in the atmosphere were possibly mixed with long-range transported primary particles in the measured air masses. The complicated connection between primary and secondary CCN suggests it will be very difficult to close the regional CCN budget in terms of the most important CCN sources in this environment.

Aerosol chemical measurements suggest that both gaseous sulfuric acid and organic compounds play important roles in growing nucleated particles to CCN sizes over the Eastern Mediterranean during summertime. The organic compounds contributing to the nuclei growth appear to have multiple sources at this time of the year, including biogenic emissions, biomass burning and possibly other anthropogenic sources of distant

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origin. The hygroscopicity of particles critical to the cloud droplet activation (< 150 nm diameter) were found to vary with both particle size and time of day. Small particles were substantially less hygroscopic than larger ones, probably due to enrichment of organic material in the sub-100 nm particles. Particles larger than 100 nm in diameter may be used as a proxy for CCN in the area. The aerosol hygroscopicity tended to be at minimum just before the noon and at maximum at some time in afternoon, which was very likely due to the higher sulfate to organic ratios and higher degree of oxidation of the organic material during afternoon. The diversity in the hygroscopic properties of sub-150 nm particles is clearly an issue requiring further attention.

This case study has demonstrated the power of simultaneous particle number size distribution, CCN and aerosols chemical measurements in investigating the origin of CCN in a polluted marine environment, as well as their limitations in distinguishing sources and sinks. Understanding and quantification of the contribution of NPF to the CCN budget over Eastern Mediterranean would require comprehensive observations at extended time periods in this environment complemented with regional-scale aerosol dynamical model simulations. Such measurements should include not only those applied here but also near-real time measurements of the size-resolved chemical composition of ultrafine (< 100 nm) particles, gas-phase compounds responsible for the nuclei growth (sulphuric acid and extremely low-volatile organic compounds; see Ehn et al., 2014), potential precursors for low-volatile vapours (e.g. terpenes and organic compounds associated with biomass burning, see Vakkari et al., 2014), as well as the concentrations and size distributions of small (< 3 – 10 nm) neutral and charged clusters. Interpretation of such measurements would benefit from some information on the diurnal evolution of the atmospheric boundary layer, volatility distributions as well as from both regional and smaller-scale modeling of aerosol–trace gas interactions in this environment.

Acknowledgements. The research project is implemented within the framework of the Action “Supporting Postdoctoral Researchers” of the Operational Program “Education and Lifelong Learning” (Action’s Beneficiary: General Secretariat for Research and Technology), and is co-

financed by the European Social Fund (ESF) and the Greek State. This research is supported by the Academy of Finland Center of Excellence program (project number 1118615). We acknowledge funding from the EU FP7-ENV-2013 program “impact of Biogenic vs. Anthropogenic emissions on Clouds and Climate: towards a Holistic UnderStanding” (BACCHUS), project no. 603445. The authors would like to acknowledge the NOAA Air Resources Laboratory (ARL) for the provision of the back trajectory data (<http://www.arl.noaa.gov/ready/hysplit4.html>). A. Nenes acknowledges support from an NSF CAREER proposal, NASA Lagley and NOAAOGP funding.

References

- Aiken, A. C., DeCarlo, P. F., Kroll, J. H., Worsnop, D. R., Huffman, J. A., Docherty, K. S., Ulbrich, I. M., Mohr, C., Kimmel, J. R., Sueper, D., Sun, Y., Zhang, Q., Trimborn, A., Northway, M., Ziemann, P., Canagaratna, M. R., Onasch, T. B., Alfarra, M. R., Prévôt, A. H., Dommen, J., Duplissy, J., Metzger, A., Baltensperger, U., and Jimenez, J. L.: O/C and OM/OC ratios of primary, secondary, and ambient organic aerosols with High-Resolution Time-of-Flight Aerosol Mass Spectrometry, *Environ. Sci. Technol.*, 42, 4478–4485, doi:10.1021/es703009q, 2008.
- Alfarra, M. R., Good, N., Wyche, K. P., Hamilton, J. F., Monks, P. S., Lewis, A. C., and McFiggans, G.: Water uptake is independent of the inferred composition of secondary aerosols derived from multiple biogenic VOCs, *Atmos. Chem. Phys.*, 13, 11769–11789, doi:10.5194/acp-13-11769-2013, 2013.
- Andreae, M. O. and Rosenfeld, D.: Aerosol–cloud–precipitation interactions. Part 1. The nature and sources of cloud-active aerosols, *Earth-Sci. Rev.*, 89, 13–41, doi:10.1016/j.earscirev.2008.03.001, 2008.
- Bahreini, R., Keywood, M. D., Ng, N. L., Varutbangkul, V., Gao, S., Flagan, R., Seinfeld, J., Worsnop, D. R., and Jimenez, J. L.: Measurements of Secondary Organic Aerosol (SOA) from oxidation of cycloalkenes, terpenes, and m-xylene using an Aerodyne Aerosol Mass Spectrometer, *Environ. Sci. Technol.*, 39, 5674–5688, doi:10.1021/es048061a, 2005.
- Bardouki, H., Berresheim, H., Vrekoussis, M., Sciare, J., Kouvarakis, G., Oikonomou, K., Schneider, J., and Mihalopoulos, N.: Gaseous (DMS, MSA, SO₂, H₂SO₄ and DMSO) and particulate (sulfate and methanesulfonate) sulfur species over the northeastern coast of Crete, *Atmos. Chem. Phys.*, 3, 1871–1886, doi:10.5194/acp-3-1871-2003, 2003.

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5 Bougiatioti, A., Nenes, A., Fountoukis, C., Kalivitis, N., Pandis, S. N., and Mihalopoulos, N.: Size-resolved CCN distributions and activation kinetics of aged continental and marine aerosol, *Atmos. Chem. Phys.*, 11, 8791–8808, doi:10.5194/acp-11-8791-2011, 2011.

Bougiatioti, A., Zarrmpas, P., Koulouri, E., Antonou, M., Theodosi, C., Kouvarakis, G., Saarikoski, S., Mäkelä, T., Hillamo, R., and Mihalopoulos, N.: Organic, elemental and water-soluble organic carbon in size segregated aerosols, in the marine boundary layer of the Eastern Mediterranean, *Atmos. Environ.*, 64, 251–252, doi:10.1016/j.atmosenv.2012.09.071, 2013.

10 Bougiatioti, A., Stavroulas, I., Kostenidou, E., Zarrmpas, P., Theodosi, C., Kouvarakis, G., Canonaco, F., Prévôt, A. S. H., Nenes, A., Pandis, S. N., and Mihalopoulos, N.: Processing of biomass-burning aerosol in the eastern Mediterranean during summertime, *Atmos. Chem. Phys.*, 14, 4793–4807, doi:10.5194/acp-14-4793-2014, 2014.

15 Canonaco, F., Crippa, M., Slowik, J. G., Baltensperger, U., and Prévôt, A. S. H.: SoFi, an IGOR-based interface for the efficient use of the generalized multilinear engine (ME-2) for the source apportionment: ME-2 application to aerosol mass spectrometer data, *Atmos. Meas. Tech.*, 6, 3649–3661, doi:10.5194/amt-6-3649-2013, 2013.

20 Cerully, K. M., Raatikainen, T., Lance, S., Tkacik, D., Tiitta, P., Petäjä, T., Ehn, M., Kulmala, M., Worsnop, D. R., Laaksonen, A., Smith, J. N., and Nenes, A.: Aerosol hygroscopicity and CCN activation kinetics in a boreal forest environment during the 2007 EUCAARI campaign, *Atmos. Chem. Phys.*, 11, 12369–12386, doi:10.5194/acp-11-12369-2011, 2011.

25 Cerully, K. M., Bougiatioti, A., Hite Jr., J. R., Guo, H., Xu, L., Ng, N. L., Weber, R., and Nenes, A.: On the link between hygroscopicity, volatility, and oxidation state of ambient and water-soluble aerosol in the Southeastern United States, *Atmos. Chem. Phys. Discuss.*, 14, 30835–30877, doi:10.5194/acpd-14-30835-2014, 2014.

30 Chang, R. Y.-W., Slowik, J. G., Shantz, N. C., Vlasenko, A., Liggio, J., Sjostedt, S. J., Leaitch, W. R., and Abbatt, J. P. D.: The hygroscopicity parameter (κ) of ambient organic aerosol at a field site subject to biogenic and anthropogenic influences: relationship to degree of aerosol oxidation, *Atmos. Chem. Phys.*, 10, 5047–5064, doi:10.5194/acp-10-5047-2010, 2010.

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Ditas, F., Shaw, R. A., Siebert, H., Simmel, M., Wehner, B., and Wiedensohler, A.: Aerosols-cloud microphysics-thermodynamics-turbulence: evaluating supersaturation in a marine stratocumulus cloud, *Atmos. Chem. Phys.*, 12, 2459–2468, doi:10.5194/acp-12-2459-2012, 2012.

5 Dowd, C. D. O.: Biogenic coastal aerosol production and its influence on aerosol radiative properties, *J. Geophys. Res.*, 106, 1545–1549, doi:10.1029/2000JD900423, 2001.

Draxler, R. R. and Hess, G. D.: An overview of the HYSPLIT 4 modeling system of trajectories, dispersion, and deposition, *Aust. Meteorol. Mag.*, 47, 295–308, 1998.

10 Duplissy, J., Gysel, M., Alfarra, M. R., Dommen, J., Metzger, A., Prevot, A. S. H., Weingartner, E., Laaksonen, A., Raatikainen, T., Good, N., Turner, S. F., McFiggans, G., and Baltensperger, U.: Cloud forming potential of secondary organic aerosol under near atmospheric conditions, *Geophys. Res. Lett.*, 35, L03818, doi:10.1029/2007GL031075, 2008.

15 Dusek, U., Frank, G. P., Hildebrandt, L., Curtius, J., Schneider, J., Walter, S., Chand, D., Drewnick, F., Hings, S., Jung, D., Borrmann, S., and Andreae, M. O.: Size matters more than chemistry for cloud-nucleating ability of aerosol particles, *Science*, 312, 1375–1378, 2006.

Dusek, U., Frank, G. P., Curtius, J., Drewnick, F., Schneider, J., Kürten, A., Rose, D., Andreae, M. O., Borrmann, S., and Pöschl, U.: Enhanced organic mass fraction and decreased hygroscopicity of cloud condensation nuclei (CCN) during NPF events, *Geophys. Res. Lett.*, 20 37, L03804, doi:10.1029/2009GL040930, 2010.

Ehn, M., Thornton, J. A., Kleist, E., Sipilä, M., Junninen, H., Pullinen, I., Springer, M., Rubach, F., Tillmann, R., Lee, B., Lopez-Hifiker, F., Andres, S., Acir, I. H., Rissanen, M., Jokinen, T., Schobesberger, S., Kangasluoma, J., Kontkanen, J., Nieminen, T., Kurten, T., Nielsen, L. B., Jorgensen, S., Jaergaard, H. G., Canagaratna, M., Dal Maso, M., 25 Berndt, T., Petäjä, T., Wahner, A., Kerminen, V.-M., Kulmala, M., Worsnop, D., Wildt, J., and Mentel, T. F.: A large source of low-volatility secondary organic aerosol, *Nature*, 506, 476–479, doi:10.1038/nature13032, 2014.

Engelhart, G. J., Moore, R. H., Nenes, A., and Pandis, S. N.: Cloud condensation nuclei activity of isoprene secondary organic aerosol, *J. Geophys. Res.*, 116, D02207, doi:10.1029/2010JD014706, 2011.

30 Hammer, E., Bukowiecki, N., Gysel, M., Jurányi, Z., Hoyle, C. R., Vogt, R., Baltensperger, U., and Weingartner, E.: Investigation of the effective peak supersaturation for liquid-phase

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clouds at the high-alpine site Jungfrauoch, Switzerland (3580 m a.s.l.), *Atmos. Chem. Phys.*, 14, 1123–1139, doi:10.5194/acp-14-1123-2014, 2014.

Hildebrandt, L., Engelhart, G. J., Mohr, C., Kostenidou, E., Lanz, V. A., Bougiatioti, A., De-Carlo, P. F., Prevot, A. S. H., Baltensperger, U., Mihalopoulos, N., Donahue, N. M., and Pandis, S. N.: Aged organic aerosol in the Eastern Mediterranean: the Finokalia Aerosol Measurement Experiment – 2008, *Atmos. Chem. Phys.*, 10, 4167–4186, doi:10.5194/acp-10-4167-2010, 2010.

Hudson, J. G. and Noble, S.: CCN and vertical velocity influences on droplet concentrations and supersaturations in clean and polluted stratus clouds, *J. Atmos. Sci.*, 71, 312–331, doi:10.1175/JAS-D-13-086.1, 2014.

IPCC: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, edited by: Stocker, T. F., Qin, D., Plattner, G.-K., Tignor, M., Allen, S. K., Boschung, J., Nauels, A., Xia, Y., Bex, V., and Midgley, P. M., Cambridge University Press, Cambridge, UK and New York, NY, USA, 1535 pp., doi:10.1017/CBO9781107415324, 2013.

Kalivitis, N., Birmili, W., Stock, M., Wehner, B., Massling, A., Wiedensohler, A., Gerasopoulos, E., and Mihalopoulos, N.: Particle size distributions in the Eastern Mediterranean troposphere, *Atmos. Chem. Phys.*, 8, 6729–6738, doi:10.5194/acp-8-6729-2008, 2008.

Kalivitis, N., Stavroulas, I., Bougiatioti, A., Kouvarakis, G., Gagné, S., Manninen, H. E., Kulmala, M., and Mihalopoulos, N.: Night-time enhanced atmospheric ion concentrations in the marine boundary layer, *Atmos. Chem. Phys.*, 12, 3627–3638, doi:10.5194/acp-12-3627-2012, 2012.

Karydis, V. A., Capps, S. L., Russell, A. G., and Nenes, A.: Adjoint sensitivity of global cloud droplet number to aerosol and dynamical parameters, *Atmos. Chem. Phys.*, 12, 9041–9055, doi:10.5194/acp-12-9041-2012, 2012.

Kerminen, V.-M., Paramonov, M., Anttila, T., Riipinen, I., Fountoukis, C., Korhonen, H., Asmi, E., Laakso, L., Lihavainen, H., Swietlicki, E., Svenningsson, B., Asmi, A., Pandis, S. N., Kulmala, M., and Petäjä, T.: Cloud condensation nuclei production associated with atmospheric nucleation: a synthesis based on existing literature and new results, *Atmos. Chem. Phys.*, 12, 12037–12059, doi:10.5194/acp-12-12037-2012, 2012.

Kouvarakis, G. and Mihalopoulos, N.: Seasonal variation of dimethylsulfide in the gas phase and of methanesulfonate and non-sea-salt sulfate in the aerosols phase in the

Eastern Mediterranean atmosphere, *Atmos. Environ.*, 36, 929–938, doi:10.1016/S1352-2310(01)00511-8, 2002.

Kulmala, M., Petäjä, T., Nieminen, T., Sipilä, M., Manninen, H. E., Lehtipalo, K., Dal Maso, M., Aalto, P. P., Junninen, H., Paasonen, P., Riipinen, I., Lehtinen, K. E. J., Laaksonen, A., and Kerminen, V.-M.: Measurement of the nucleation of atmospheric aerosol particles, *Nat. Protoc.*, 7, 1651–1667, doi:10.1038/nprot.2012.091, 2012.

Kuwata, M., Shao, W., Lebouteiller, R., and Martin, S. T.: Classifying organic materials by oxygen-to-carbon elemental ratio to predict the activation regime of Cloud Condensation Nuclei (CCN), *Atmos. Chem. Phys.*, 13, 5309–5324, doi:10.5194/acp-13-5309-2013, 2013.

Laakso, L., Merikanto, J., Vakkari, V., Laakso, H., Kulmala, M., Molefe, M., Kgabi, N., Mabaso, D., Carslaw, K. S., Spracklen, D. V., Lee, L. A., Reddington, C. L., and Kerminen, V.-M.: Boundary layer nucleation as a source of new CCN in savannah environment, *Atmos. Chem. Phys.*, 13, 1957–1972, doi:10.5194/acp-13-1957-2013, 2013.

Lelieveld, J., Berresheim, H., Borrmann, S., Crutzen, P., Dentener, F., Fischer, H., Feichter, J., Flatau, P., Heland, J., Holzinger, R., Korrmann, R., Lawrence, M., Levin, Z., Markowicz, K., Mihalopoulos, N., Minikin, A., Ramanathan, V., de Reus, M., Roelofs, G., Scheeren, H., Sciare, J., Schlager, H., Schultz, M., Siegmund, P., Steil, B., Stephanou, E., Stier, P., Traub, M., Warneke, C., Williams, J., and Ziereis, H.: Global air pollution crossroads over the Mediterranean, *Science*, 298, 794–799, doi:10.1126/science.1075457, 2002.

Levin, E. J. T., Prenni, A. J., Petters, M. D., Kreidenweis, S. M., Sullivan, R. C., Atwood, S. A., Ortega, J., DeMott, P. J., and Smith, J. N.: An annual cycle of size-resolved aerosol hygroscopicity at a forested site in Colorado, *J. Geophys. Res.*, 117, D06201, doi:10.1029/2011JD016854, 2012.

Liu, H. J., Zhao, C. S., Nekat, B., Ma, N., Wiedensohler, A., van Pinxteren, D., Spindler, G., Müller, K., and Herrmann, H.: Aerosol hygroscopicity derived from size-segregated chemical composition and its parameterization in the North China Plain, *Atmos. Chem. Phys.*, 14, 2525–2539, doi:10.5194/acp-14-2525-2014, 2014.

Manninen, H. E., Nieminen, T., Asmi, E., Gagné, S., Häkkinen, S., Lehtipalo, K., Aalto, P., Vana, M., Mirme, A., Mirme, S., Hörrak, U., Plass-Dülmer, C., Stange, G., Kiss, G., Hoffer, A., Törő, N., Moerman, M., Henzing, B., de Leeuw, G., Brinkenberg, M., Kouvarakis, G. N., Bougiatioti, A., Mihalopoulos, N., O'Dowd, C., Ceburnis, D., Arneth, A., Svenningsson, B., Swietlicki, E., Tarozzi, L., Decesari, S., Facchini, M. C., Birmili, W., Sonntag, A., Wiedensohler, A., Boulon, J., Sellegri, K., Laj, P., Gysel, M., Bukowiecki, N., Weingartner, E.,

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Wehrle, G., Laaksonen, A., Hamed, A., Joutsensaari, J., Petäjä, T., Kerminen, V.-M., and Kulmala, M.: EUCAARI ion spectrometer measurements at 12 European sites – analysis of new particle formation events, *Atmos. Chem. Phys.*, 10, 7907–7927, doi:10.5194/acp-10-7907-2010, 2010.

5 Massoli, P., Lambe, A. T., Ahern, A. T., Williams, L. R., Ehn, M., Mikkilä, J., Canagaratna, M. R., Brune, W. H., Onasch, T. B., Jayne, J. T., Petäjä, T., Kulmala, M., Laaksonen, A., Kolb, C. E., Davidovits, P., and Worsnop, D. R.: Relationship between aerosol oxidation level and hygroscopic properties of laboratory generated secondary organic aerosol (SOA) particles, *Geophys. Res. Lett.*, 37, L24801, doi:10.1029/2010GL045258, 2010.

10 Mei, F., Hayes, P. L., Ortega, A., Taylor, J. W., Allan, J. D., Gilman, J., Kuster, W., de Gouw, J., Jimenez, J. L., and Wang, J.: Droplet activation properties of organic aerosols observed at an urban site during CalNex-LA, *J. Geophys. Res. Atmos.*, 118, 2903–2917, doi:10.1002/jgrd.50285, 2013.

15 Merikanto, J., Spracklen, D. V., Mann, G. W., Pickering, S. J., and Carslaw, K. S.: Impact of nucleation on global CCN, *Atmos. Chem. Phys.*, 9, 8601–8616, doi:10.5194/acp-9-8601-2009, 2009.

Mihalopoulos, N., Stephanou, E., Kanakidou, M., Pilitsidis, S., and Bousquet, P.: Tropospheric aerosol ionic composition in the Eastern Mediterranean region, *Tellus B*, 49, 314–326, 1997.

20 Mihalopoulos, N., Kerminen, V.-M., Kanakidou, M., Berresheim, H., and Sciare, J.: Formation of particulate sulphur species (sulphate and methanesulfonate) during summer over the Eastern Mediterranean: a modelling approach, *Atmos. Environ.*, 41, 6860–6871, doi:10.1016/j.atmosenv.2007.04.039, 2007.

Moore, R. H. and Nenes, A.: Scanning Flow CCN analysis – a method for fast measurements of CCN spectra, *Aerosol Sci. Tech.*, 43, 1192–1207, doi:10.1080/02786820903289780, 2009.

25 Moore, R. H., Cerully, K., Bahreini, R., Brock, C. A., Middelbrook, A. M., and Nenes, A.: Hygroscopicity and composition of California CCN during summer 2010, *J. Geophys. Res.*, 117, D00V12, doi:10.1029/2011JD017352, 2012.

30 Ng, N. L., Herndon, S. C., Trimborn, A., Canagaratna, M. R., Croteau, P. L., Onasch, T. B., Sueper, D., Worsnop, D. R., Zhang, Q., Sun, Y. L., and Jayne, J. T.: An Aerosol Chemical Speciation Monitor (ACSM) for routine monitoring of the composition and mass concentration of ambient aerosol., *Aerosol Sci. Tech.*, 45, 780–794, doi:10.1080/02786826.2011.560211, 2011.

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Paasonen, P., Asmi, A., Petäjä, T., Kajos, M. K., Aijala, M., Junninen, H., Holst, T., Abbatt, J. P. D., Arneeth, A., Birmili, W., van der Gon, H. D., Hamed, A., Hoer, A., Laakso, L., Laaksonen, A., Richard Leaitch, W., Plass-Dulmer, C., Pryor, S. C., Raisanen, P., Swietlicki, E., Wiedensohler, A., Worsnop, D. R., Kerminen, V.-M., and Kulmala, M.: Warming-induced increase in aerosol number concentration likely to moderate climate change, *Nat. Geosci.*, 6, 438–442, doi:10.1038/ngeo1800, 2013.

Paatero, P.: The multilinear engine – a table-driven, least squares program for solving multilinear problems, including the n-way parallel factor analysis model, *J. Comput. Graph. Stat.*, 8, 854–888, doi:10.2307/1390831, 1999.

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

Padró, L. T., Moore, R. H., Zhang, X., Rastogi, N., Weber, R. J., and Nenes, A.: Mixing state and compositional effects on CCN activity and droplet growth kinetics of size-resolved CCN in an urban environment, *Atmos. Chem. Phys.*, 12, 10239–10255, doi:10.5194/acp-12-10239-2012, 2012.

Petäjä, T., Kerminen, V.-M., Dal Maso, M., Junninen, H., Koponen, I. K., Hussein, T., Aalto, P. P., Andronopoulos, S., Robin, D., Hämeri, K., Bartzis, J. G., and Kulmala, M.: Sub-micron atmospheric aerosols in the surroundings of Marseille and Athens: physical characterization and new particle formation, *Atmos. Chem. Phys.*, 7, 2705–2720, doi:10.5194/acp-7-2705-2007, 2007.

Petters, M. D. and Kreidenweis, S. M.: A single parameter representation of hygroscopic growth and cloud condensation nucleus activity, *Atmos. Chem. Phys.*, 7, 1961–1971, doi:10.5194/acp-7-1961-2007, 2007.

Pierce, J. R. and Adams, P. J.: Uncertainty in global CCN concentrations from uncertain aerosol nucleation and primary emission rates, *Atmos. Chem. Phys.*, 9, 1339–1356, doi:10.5194/acp-9-1339-2009, 2009.

Pikridas, M., Riipinen, I., Hildebrandt, L., Kostenidou, E., Manninen, H., Mihalopoulos, N., Kalivitis, N., Burkhardt, J., Stohl, A., Kulmala, M., and Pandis, S. N.: NPF at a remote site in the eastern Mediterranean, *J. Geophys. Res.*, 117, D12205, doi:10.1029/2012JD017570, 2012.

Pruppacher, H. R. and Klett, J. D.: *Microphysics of Clouds and Precipitation*, Kluwer Academic Publishers, Dordrecht, the Netherlands, 1997.

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Roberts, G. and Nenes, A.: A continuous-flow streamwise thermal-gradient CCN chamber for atmospheric measurements, *Aerosol Sci. Tech.*, 39, 206–221, doi:10.1080/027868290913988, 2005.

Vakkari, V., Kerminen, V.-M., Beukes, J. P., Tiitta, P., van Zyl, P. G., Josipovic, M., Venter, A. D., Jaars, K., Worsnop, D. R., Kulmala, M., and Laakso, L.: Rapid changes in biomass burning aerosols by atmospheric oxidation, *Geophys. Res. Lett.*, 41, 2644–2651, doi:10.1002/2014GL059396, 2014.

Westervelt, D. M., Pierce, J. R., and Adams, P. J.: Analysis of feedbacks between nucleation rate, survival probability and cloud condensation nuclei formation, *Atmos. Chem. Phys.*, 14, 5577–5597, doi:10.5194/acp-14-5577-2014, 2014.

Wiedensohler, A., Birmili, W., Nowak, A., Sonntag, A., Weinhold, K., Merkel, M., Wehner, B., Tuch, T., Pfeifer, S., Fiebig, M., Fjåraa, A. M., Asmi, E., Sellegri, K., Depuy, R., Venzac, H., Villani, P., Laj, P., Aalto, P., Ogren, J. A., Swietlicki, E., Williams, P., Roldin, P., Quincey, P., Hüglin, C., Fierz-Schmidhauser, R., Gysel, M., Weingartner, E., Riccobono, F., Santos, S., Grüning, C., Faloon, K., Beddows, D., Harrison, R., Monahan, C., Jennings, S. G., O'Dowd, C. D., Marinoni, A., Horn, H.-G., Keck, L., Jiang, J., Scheckman, J., McMurry, P. H., Deng, Z., Zhao, C. S., Moerman, M., Henzing, B., de Leeuw, G., Löschau, G., and Bastian, S.: Mobility particle size spectrometers: harmonization of technical standards and data structure to facilitate high quality long-term observations of atmospheric particle number size distributions, *Atmos. Meas. Tech.*, 5, 657–685, doi:10.5194/amt-5-657-2012, 2012.

Yu, F. and Luo, G.: Simulation of particle size distribution with a global aerosol model: contribution of nucleation to aerosol and CCN number concentrations, *Atmos. Chem. Phys.*, 9, 7691–7710, doi:10.5194/acp-9-7691-2009, 2009.

Zerefos, C., Ganev, K., Kourtidis, K., Tzortziou, M., Vasaras, A., and Syrakov, E.: On the origin of SO₂ above northern Greece, *Geophys. Res. Lett.*, 27, 365–368, doi:10.1029/1999GL010799, 2000.

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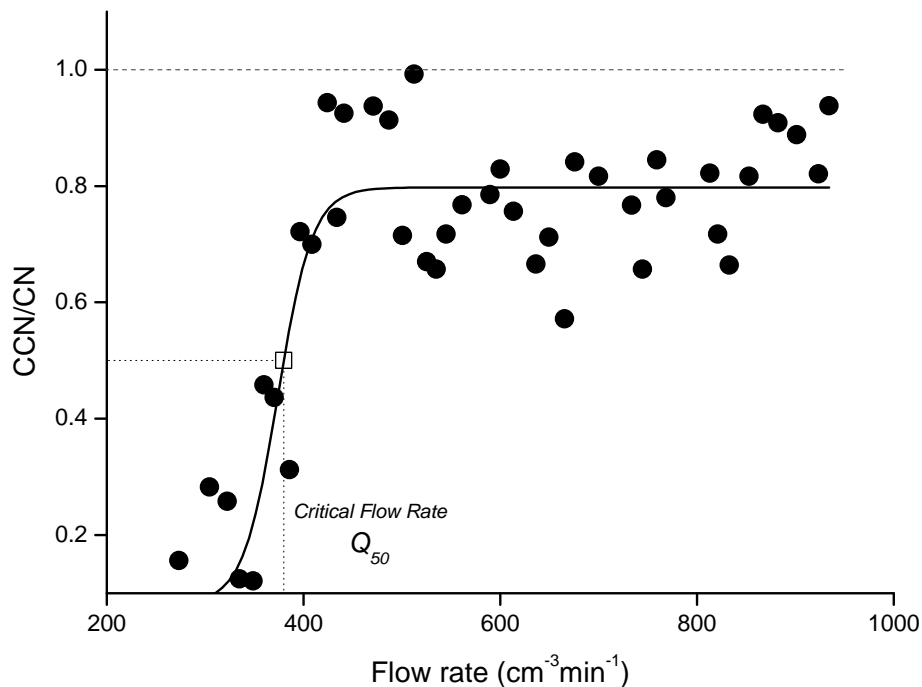


Figure 1. Example of an ambient CCN activity spectrum (at a constant temperature difference), with a sigmoidal fit and the associated critical flow Q_{50} .

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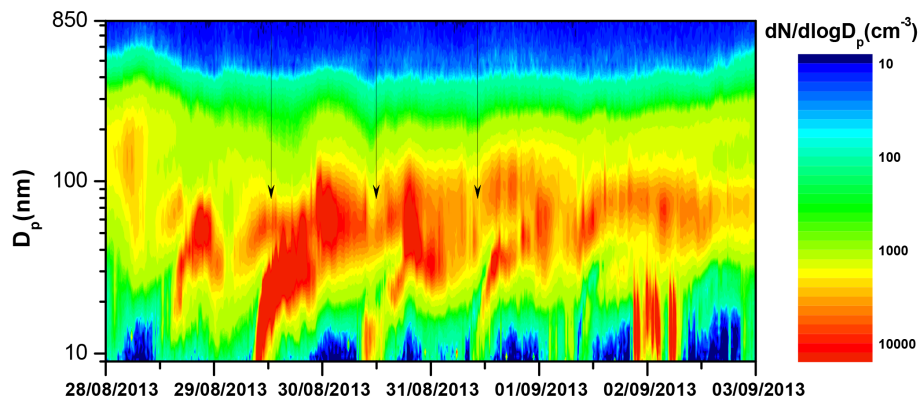


Figure 2. Time evolution of the particle number size distribution over the diameter range 9–848 nm between 28 August and 2 September 2012, a period of active new particle formation observed at Finokalia.

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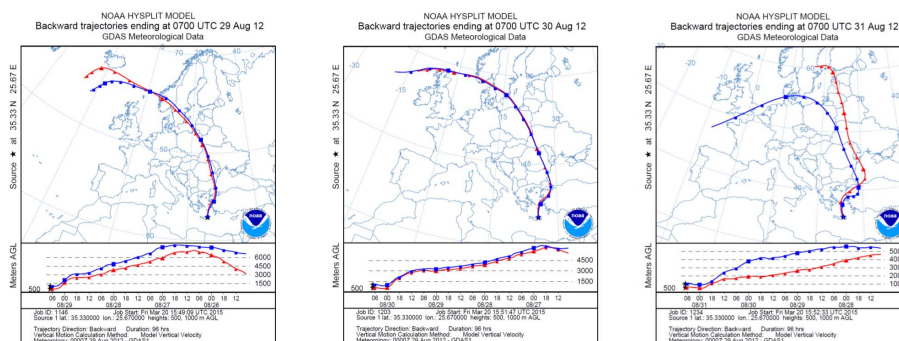


Figure 3. Four-day back trajectories for air masses arriving at Finokalia on 29, 30 and 31 August 2012.

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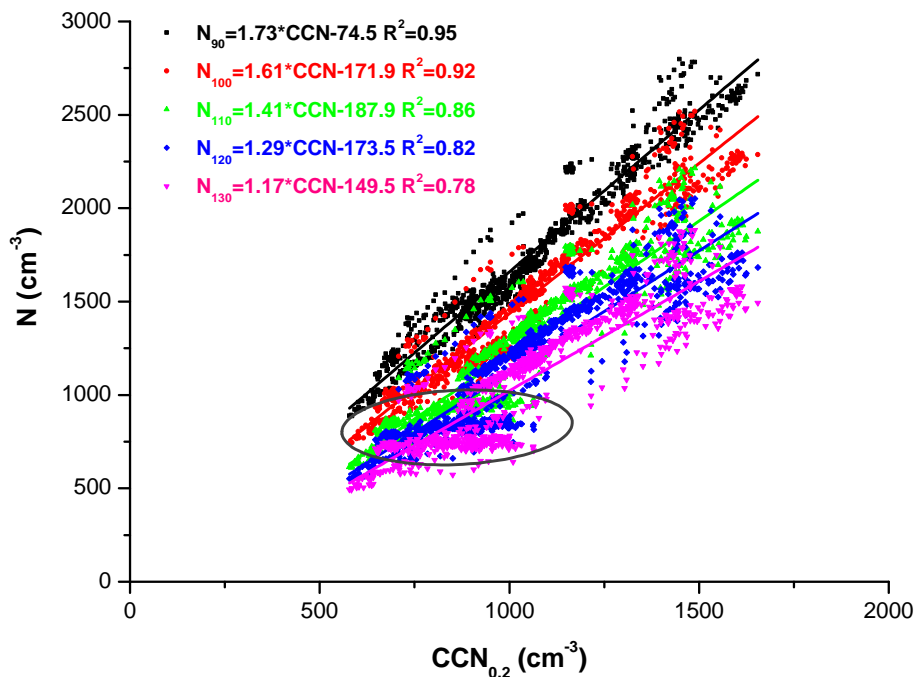


Figure 4. Relation between the total number concentration of particles with diameter larger than D , N_D , ($D = 90, 100, 110, 120$ or 130 nm) and measured CCN number concentration at the supersaturation of 0.2%. The data are from two periods in 2012: from 25 August at 23:05 to 28 August at 10:45 and from 1 September at 23:15 to 2 September at 17:15 UTC + 2. Circled points come for the period after NPF events that practically no correlation was found between N_D and $\text{CCN}_{0.2}$ for particles larger than 110 nm.

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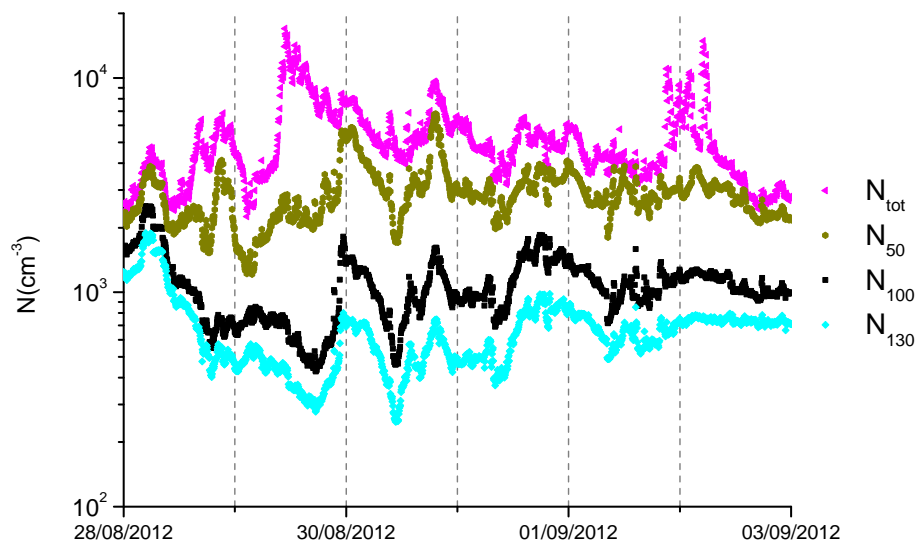


Figure 5. Time evolution of the total particle number concentration (N_{tot}) along with N_{50} , N_{100} and N_{130} during the period 28 August–2 September 2012.

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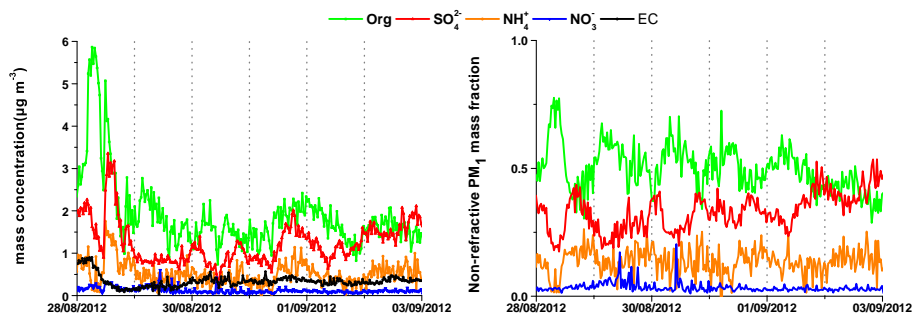


Figure 6. Time evolution of the aerosol chemical composition during the period 28 August–2 September 2012. Left panel: absolute concentrations in $\mu\text{g m}^{-3}$. Right panel: relative contributions to the non-refractive PM_{10} mass.

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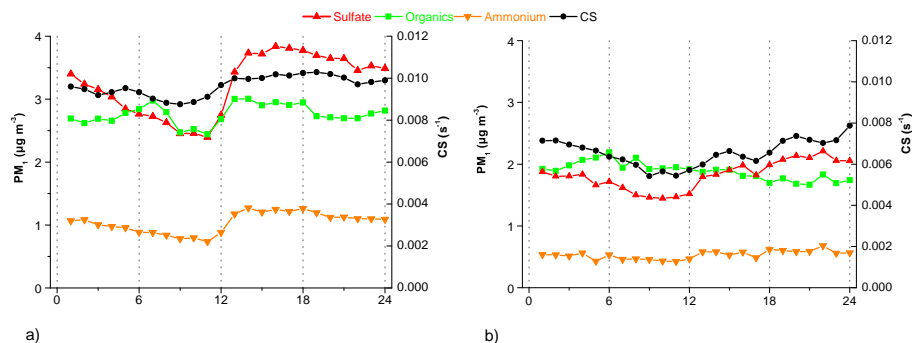


Figure 7. Diurnal concentration cycles of sulfate, ammonium and organic material in sub-micron aerosols, as well as the diurnal cycle of condensation sink, CS, averaged over the 1 August–30 September period **(a)** and over the period 29 August–2 September **(b)** in 2012.

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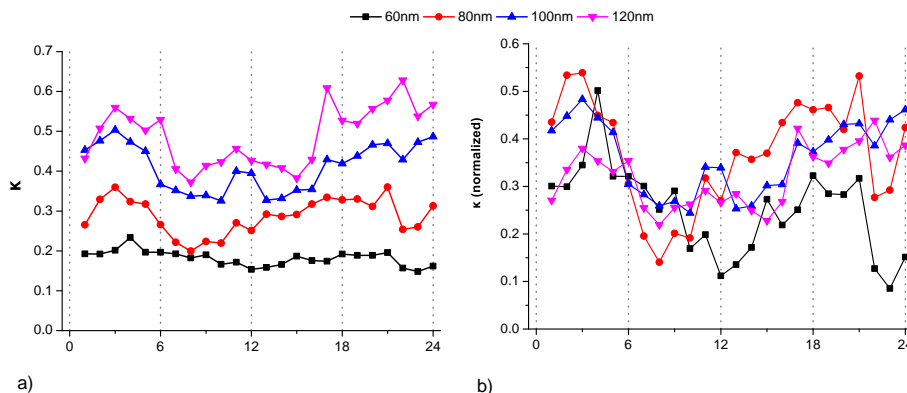


Figure 8. Diurnal variability during the period from 28 August at 12:00 to 30 August at 12:00 UTC + 2 of (a) the hygroscopicity parameters κ for 60, 80, 100 and 120 nm particles and (b) the corresponding values normalized into the range [0, 1].

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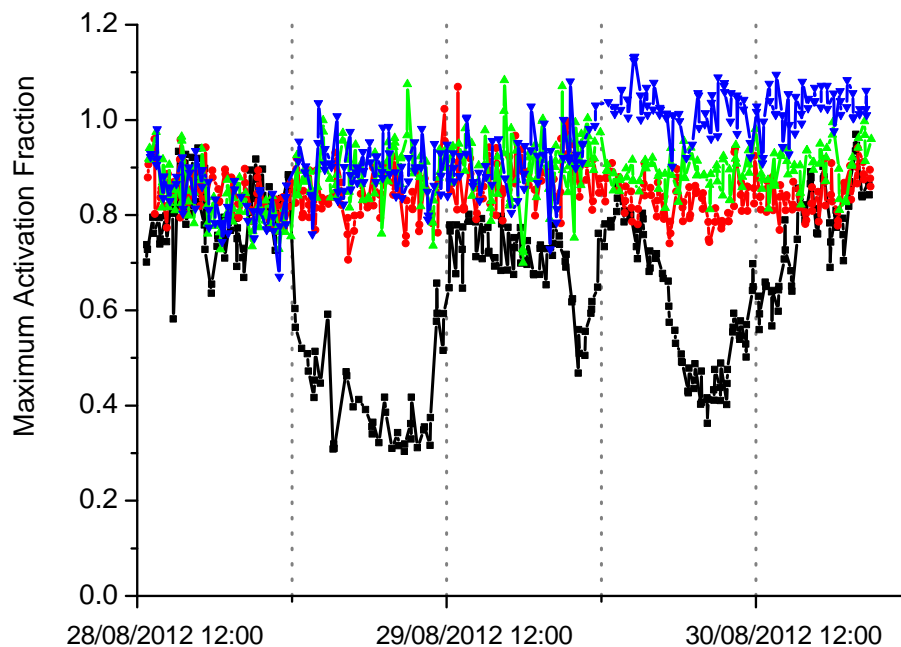


Figure 10. Maximum activation fraction of 60, 80, 100 and 120 nm particles between 28 and 30 August 2012.

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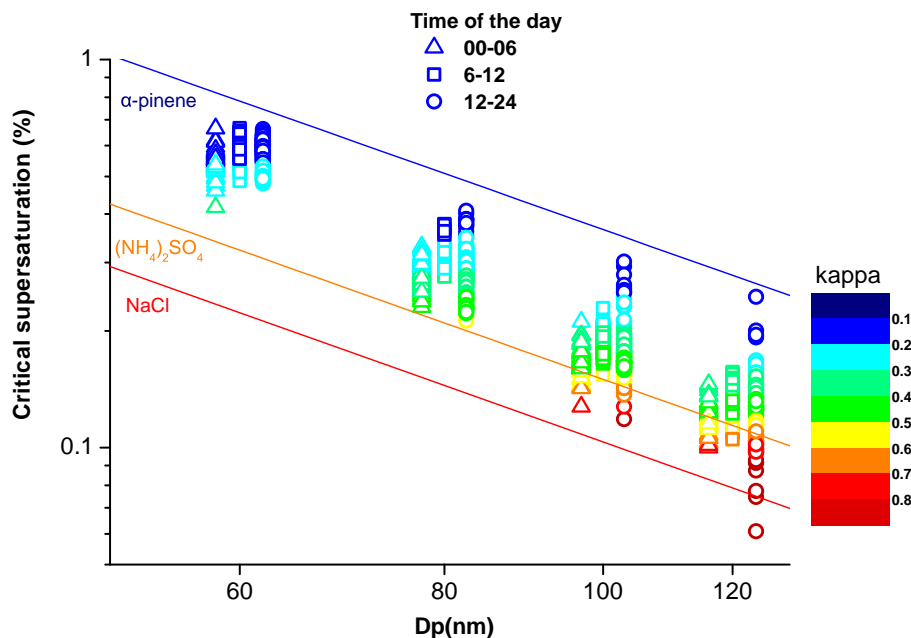


Figure 11. Measured critical supersaturations of 60, 80, 100 and 120 nm diameter particles during different times of the day on 29 and 30 August 2012. The color scale indicates different values of the particle hygroscopicity parameter, κ . Also, theoretical curves for α -pinene, ammonium sulfate and sodium chloride.

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