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On secondary new particle formation in China

Kulmala, Markku

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On secondary new particle formation in China

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For Review Only

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56 111 **Abstract**
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6 113 Formation of new atmospheric aerosol particles is a global phenomenon that has been
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8 114 observed to take place in even heavily-polluted environments. However, in all
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10 115 environments there appears to be a threshold value of the condensation sink (due to
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12 116 pre-existing aerosol particles) after which the formation rate of 3 nm particles is no
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14 117 longer detected. In China, new particle production has been observed at very high
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16 118 pollution levels (condensation sink about 0.1 s^{-1}) in several megacities, including
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18 119 Beijing, Shanghai and Nanjing as well as in Pearl River Delta (PRD). Here we
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20 120 summarize the recent findings obtained from these studies and discuss the various
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22 121 implications these findings will have on future research and policy.
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30 **1. Background**
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36 125 Atmospheric aerosol particles affect our life and its quality in multiple ways. First of
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38 126 all, the interaction between aerosols and climate system is the dominant uncertainty in
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40 127 predicting the radiative forcing and future climate [1]. Secondly, aerosol particles
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42 128 deteriorate both human health and visibility, especially in urban areas [2, 3]. Thirdly,
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44 129 aerosol particles modify the intensity and distribution of radiation that reaches the
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46 130 Earth's surface, having direct influences on photosynthesis and terrestrial carbon sink
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48 131 [4]. Better understanding of the various effects in the atmosphere requires detailed
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50 132 information on how different sources (including those related to the biosphere) and
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52 133 atmospheric transformation processes modify the properties of aerosol particle
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54 134 populations.
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6 136 One of the most important phenomena associated with the atmospheric aerosol
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8 137 number concentrations is the secondary formation of new aerosol particles. This
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10 138 includes the production of molecular clusters from gaseous precursor vapors, the
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12 139 activation and growth of some of these clusters to detectable sizes, and the further
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14 140 growth up to the sizes at which the particles may act as cloud condensation nuclei
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17 141 [e.g. 5, 6]. Although atmospheric new particle formation has been observed to take
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19 142 place almost everywhere at favorable conditions in the boundary layer [7], our
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21 143 knowledge about this phenomenon is still far from perfect [5, 8]. The current
22
23 144 knowledge gaps in this regard range from the basic process-level understanding of
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25 145 secondary atmospheric aerosol formation to its connection with anthropogenic
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27 146 activities, biogenic emissions, atmospheric chemistry, and ultimately with climate
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29 147 change and human health.
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36 149 Secondary formation of new atmospheric aerosol particles is typically initiated by
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38 150 photochemical reactions in the gas phase, so that especially the production of
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40 151 extremely low volatility vapors like sulfuric acid [9, 10, 11] and highly-oxidized
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42 152 organic compounds [e.g. 12, 13, 14] is crucial. Pre-existing aerosol particles act as a
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44 153 sink for the low-volatile vapors, as well as for small clusters and growing
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46 154 nanoparticles, thereby hindering or even suppressing atmospheric new particle
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48 155 formation [e.g. 15, 16, 17]. The atmospheric new particle formation is affected by
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50 156 several meteorological quantities and phenomena, particularly in the planetary
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52 157 boundary layer, including the intensity of solar radiation and atmospheric mixing
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3 158 processes. The recent findings indicate that critical clusters may be surprisingly small
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5 159 in size, if existing at all, under atmospheric conditions [e.g. 18], and thus treatable by
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7 160 advanced quantum chemistry methods [19]. It is very probable that the atmospheric
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9 161 new particle formation is a two-step process, i.e. initial clustering and then
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11 162 condensational growth after activation of clusters, as suggested by Kulmala et al. [21]
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13 163 and verified by Kulmala et al. [18]. A summary of the current understanding of gas-
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15 164 to-particle conversion is presented by Kulmala et al. [5].

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19 165 New aerosol particles formed in the atmosphere become climatically important when
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21 166 they reach sizes larger than about 50–100 nm in diameter [6]. Particles of this size
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23 167 and larger are able to act as cloud condensation nuclei and scatter visible light,
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25 168 thereby affecting cloud microphysical properties [e.g. 22], reducing the fraction of
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27 169 solar radiation reaching the Earth's surface and contributing to visibility degradation
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29 170 [e.g. 23]. Furthermore, health effects of airborne particles are related not only to the
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31 171 amount and toxicity of the particulate material, but also to the particle size because
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33 172 this property has a large effect on whether or not a particle is able to penetrate into the
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35 173 lungs [e.g. 20] and even further into the blood circulation [e.g. 24].

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43 175 The rapid, large-scale urbanization and industrialization of China are unique in
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45 176 history. Consequently, China's air pollution situation has worsened dramatically
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47 177 during the last 2–3 decades as emissions from industry, energy production and traffic
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49 178 have increased. China is currently responsible for 30–35 % of the global SO₂, NO_x,
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51 179 CO and Particulate mass (PM) emissions and 40% of global particle number (PN)
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53 180 emission in the 20–1000 nm size range (see <http://gains.iiasa.ac.at/gains3/>).

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3 181 Atmospheric concentrations of primary and secondary pollutants in China are 10 to
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5 182 100 times (sometimes even 1000 times) higher than currently in Europe or Northern
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7 183 America. However, highly non-linear processes, such as atmospheric chemistry and
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9 184 aerosol dynamics, transform the urban pollution cocktail and generate secondary
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11 185 pollution, such as ultrafine particles and ozone, during their residence in the
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13 186 atmosphere [25, 26]. The fact that new particle formation does occur in polluted
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15 187 Chinese megacities like Beijing [27] and Shanghai [28], or even during dust-storms
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17 188 [29, 30], suggests that there are several major physical and chemical mechanisms in a
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19 189 heavily-polluted atmosphere that have not been recognized before and may not even
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21 190 be operating in clean or moderately-polluted environments. At present, atmospheric
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23 191 air pollution in China threatens the health of hundreds of millions of people [e.g. 3,
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25 192 31], and causes major problems to the environment and economy as a whole by
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27 193 decreasing, e.g. severely the agricultural and industrial productivity of the nation as a
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29 194 whole. This pollution also reduces visibility, thereby decreasing the attraction of these
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31 195 mega-cities for tourists, and hinders the possibilities to use solar energy a source for a
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33 196 clean energy on a local scale.
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42 198 A holistic scientific understanding on the atmospheric phenomena associated with air
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44 199 quality as a whole, as well as on the connection between air quality and climate, is
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46 200 lacking at the moment [31-33]. Together with emission reductions, the key way to get
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48 201 forward is to perform long-term, continuous and comprehensive observations on
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50 202 aerosol particles (mass, number, chemical composition, optical properties), on
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52 203 concentrations of trace gases (SO₂, NO_x, CO, VOCs, sulphuric acid, HONO, HNO₃,
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54 204 NH₃ etc.), and on atmospheric oxidant levels (O₃, HO_x, RO_x, NO₃, Criegee
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3 205 intermediates etc.), as well as on greenhouse gas concentrations [31]. With a network
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5 206 of such observation stations [34], we will be able to understand the interactions and
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7 207 feedbacks associated with the urban pollution mixture [e.g. 35-37], and ultimately, be
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9 208 ready to make targeted strategies for the pollution control. In the following we take
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11 209 recent advances in studying secondary new aerosol formation in China as an example
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13 210 to show how increased process-level understanding will help us to understand air
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15 211 quality-climate-weather interactions and how the feedbacks and interactions affect the
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17 212 air quality in highly-polluted environments such as those frequently encountered in
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19 213 Chinese megacities.
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215 **2. Results from recent studies on New Particle Formation in China**

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217 New particle formation events have been observed in many different locations in
218 China, including coastal/marine, rural, regional and polluted urban environments [28,
219 30, 38-47].
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221 The first long-term study on NPF events was performed in the urban of Beijing at
222 PKU Urban Atmosphere Environment MonitoRing Station (PKUERS), starting at
223 2004 [27, 48, 49]. On average, every fifth day (~21%) displayed a NPF event [50]. An
224 evident seasonal variation profile for NPF events was observed, showing that a high
225 frequency the NPF events (~ 40%) occurred during the spring and winter [27, 50],
226 while fewer events were observed in summer [51, 52]. The observed formation rates

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3 227 of 3-nm particles and their growth rates were in the ranges of $3.3\text{-}81.4\text{ cm}^{-3}\text{ s}^{-1}$ and
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5 228 $0.1\text{-}11.2\text{ nm h}^{-1}$ [27, 50, 53], respectively.
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11 230 Generally, NPF is an unexpected phenomenon in the polluted atmosphere of China
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13 231 due to typically high loadings of pre-existing aerosol particles. For example, the mean
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15 232 condensation sink (CS, [54]) values during the nucleation event days were 0.025 s^{-1}
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17 233 ($0.003\text{-}0.086\text{ s}^{-1}$) and 0.026 s^{-1} ($0.004\text{-}0.082\text{ s}^{-1}$) at the rural (Kaiping) and urban
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19 234 (Beijing) environments, respectively, which are approximately 5 to 10 times higher
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21 235 than the values of CS observed in clean environments [55-57]. This high
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23 236 concentration of pre-existing aerosol particles significantly inhibits the growth of
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25 237 newly-formed particles. In fact, the observed NPF event is an end product of the
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27 238 competition between the low-volatile vapor sources (such as SO_2 or sulfuric acid) and
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29 239 sinks (such as pre-existing particles), as shown by Kulmala et al. [55]. The abundant
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31 240 SO_2 emissions and high oxidation capacity in the polluted atmosphere of China
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33 241 indicate that there is a sufficient source of sulfuric acid [40, 52]. Therefore, in the case
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35 242 of both higher source and sink, their inter-competition is the most likely factor that
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37 243 determines the occurrences of NPF events in polluted environments.
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46 245 Two years (2011-2013) of continuous particle number size distribution measurements
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48 246 were conducted at the Station for Observing Regional Processes of the Earth System
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50 247 (SORPES [35, 36]) station about 20 km northeast of urban Nanjing. The location can
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52 248 be considered as a regional background site of Yangtze River Delta in eastern China.
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54 249 During this time period, 44% of the sampling days were NPF event days (see Figure 1
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3 250 as an example). The formation rates of 6-nm particles varied from 0.24 to 10.9 cm⁻³ s⁻¹
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5 251 ¹, the subsequent particle growth rates varied from 3.6 to 23 nm h⁻¹, and the values of
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7 252 CS during the event days varied from 0.007 to 0.068 s⁻¹ [47]. Most of the NPF events
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10 253 took place in spring, summer and autumn with the frequencies of 55, 54 and 49 %,
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12 254 respectively, whereas only 15 events (11.2%) were observed in winter.
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18 256 **Figure 1.** A typical nucleation event measured using Air Ion Spectrometer (AIS) at
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20 257 the SORPES station, Nanjing, in China. The background cluster ions are seen in both
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22 258 negative and positive ion modes in the sub-2 nm size range. Negative ion clusters are
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24 259 smaller than positive ones. The new particle formation is seen in both polarities
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26 260 starting at around 8.30 am. Here J_6 is 1.8 cm⁻³ s⁻¹ and GR (6-30 nm) is 6.6 nm h⁻¹.
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33 262 The typical NPF event in Nanjing is shown in Figure 1. In Nanjing, many of the NPF
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35 263 events occurred on the days associated with heavy pollution. As shown by Xie et al.
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37 264 [30], frequent NPF events were observed when the PM_{2.5} and PM₁₀ concentrations
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39 265 were in excess of 100 µg m⁻³ and 200 µg m⁻³, respectively. The reason for this is still
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41 266 an open question. One hypothesis is that nucleation can be promoted by
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43 267 heterogeneous reactions on the surface of the dust [29, 30]. This is supported by many
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45 268 observations from both SORPES station and another mountain top site, Mt. Heng in
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47 269 southern China. In the spring of 2009, relatively high new-particle formation rates
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49 270 (0.46 cm⁻³ s⁻¹) and growth rates (7.2 nm h⁻¹) were observed when the loading of pre-
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51 271 exist particles was higher than 600 µg m⁻³ at Mt. Heng. Combined with laboratory
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3 272 investigations [58], dust-induced heterogeneous photochemical processes were
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5 273 supposed to provide additional gaseous oxidants to promote the NPF [29].
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11 275 In urban Shanghai, particle size distributions were measured from November 2013 to
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13 276 January 2014 on the rooftop of a teaching building (31°18'N, 121°30'E) on the
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15 277 campus of Fudan University [28], which can be regarded as an urban site. During this
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17 278 62-day campaign, 13 NPF events were identified with strong bursts of sub-3 nm
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19 279 particles and subsequent fast growth of these particles. The observed nucleation rate
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21 280 ($J_{1.34}$), formation rate of 3 nm particles (J_3), and CS were in the ranges of 112.4-
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23 281 $271.0 \text{ cm}^{-3} \text{ s}^{-1}$, $2.3\text{-}19.2 \text{ cm}^{-3} \text{ s}^{-1}$ and $0.030\text{-}0.10 \text{ s}^{-1}$, respectively. The growth rates of
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25 282 the formed clusters and nanoparticle showed a clear size dependence, with average
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27 283 values of $\text{GR}_{1.35\sim 1.39}$, $\text{GR}_{1.39\sim 1.46}$, $\text{GR}_{1.46\sim 1.70}$, $\text{GR}_{1.70\sim 2.39}$, $\text{GR}_{2.39\sim 7}$ and
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29 284 $\text{GR}_{7\sim 20}$ being 1.6 ± 1.0 , 1.4 ± 2.2 , 7.2 ± 7.1 , 9.0 ± 11.4 , 10.9 ± 9.8 and $11.4\pm 9.7 \text{ nm h}^{-1}$,
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31 285 respectively. Nucleation of particles during this campaign might be explained by the
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33 286 activation theory, since the formation rate of the smallest particles was proportional to
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35 287 a 0.65 ± 0.28 power of the sulfuric acid proxy. In addition, ammonia was very likely
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37 288 associated with NPF events, as the new particle formation rate was positively
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39 289 correlated with the concentration of gas-phase ammonia. The estimated sulfuric acid
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41 290 concentration was sufficient to explain the growth of 1.34–3 nm particles, but its
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43 291 contribution became smaller as the particle grew in size.
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3 293 The observed new particle rates, condensation sink and particle growth rates in the
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5 294 three megacities, i.e. Beijing, Nanjing and Shanghai, are of the same order of
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7 295 magnitude. These similarities reflect the urban nature of the Beijing and Shanghai
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9 296 sites, and hint that the Nanjing site, although considered as a regional background site
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11 297 of Yangtze River Delta in eastern China, might be characterized with a similar
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13 298 competition between the sources and sinks of low-volatility vapors. The seasonal
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15 299 pattern of the NPF frequency is very different between the two sites having long-term
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17 300 measurements, Beijing and Nanjing, in addition which the annual-averaged NPF
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19 301 frequency is clearly higher in Nanjing. The fundamental reason for these differences
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21 302 lies probably in a delicate balance between the factors that favor or suppress new
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23 303 particle formation and growth. At both Beijing and Nanjing, for example, NPF is
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25 304 favored by a low ambient relative humidity and low CS, whereas no consistent pattern
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27 305 can be seen between the occurrence of NPF and either the ambient temperature or
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29 306 sulfur dioxide concentration [27, 47]. The fact that high values of CS tend to suppress
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31 307 NPF is fully in line with theoretical expectations [16, 17], and it might explain the low
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33 308 NPF frequency observed in Shanghai during polluted winter conditions [28]. There is
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35 309 strong, yet indirect evidence that NPF events in these three megacities are connected
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37 310 to sulfuric acid [28, 29, 40, 52]. However, it is premature to conclude that the exact
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39 311 nucleation mechanisms are identical in three megacities without direct measurements
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41 312 of chemical composition of nucleating clusters and ions.
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52 314 Besides the direct connection between pre-exist aerosols (e.g. mixed dust) and NPF, a
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54 315 recent study found that biomass burning particles can enhance the conversion rate of
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3 316 NO₂ to HONO which is one of the main sources of OH and can in turn promote the
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5 317 formation of secondary aerosol mass and number [59]. Furthermore, it was found that
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7 318 when biomass burning particles are mixed with anthropogenic pollution, the HONO
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9 319 production potential from the conversion of NO₂ to HONO tend to be enhanced even
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11 320 more. Given that biomass burning particles are easily mixed with anthropogenic
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13 321 pollution in eastern China, their influences on the HONO budget, radical pool, and
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15 322 thus the formation of secondary aerosols are expected to be important [59].
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23 324 Heterogeneous, or multi-phase, processes influence the secondary aerosol formation.
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25 325 For example, most of aerosol sulfate has been believed to be formed from
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27 326 heterogeneous or aqueous-phase processes (cloud processes). Ozone and hydrogen
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29 327 peroxide are the major oxidants to drive these processes. Recent studies have shown
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31 328 that NO₂ can also be an important oxidant to convert SO₂ to sulfate when mineral dust
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33 329 and biomass burning plumes are present [30, 60]. Especially during the biomass
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35 330 burning-induced haze events [30], the oxidation processes by NO₂ became critical
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37 331 when the formation of other oxidants were suppressed. More interestingly, one of the
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39 332 “by-products” of the reaction of SO₂ and NO₂ is HONO, which can further enhance
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41 333 the atmospheric oxidation capacity. All these observations suggest that our current
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43 334 understanding on secondary aerosol formation processes need to be revised.
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53 336 **3. On future NPF studies**

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3 338 The importance of secondary aerosols has become apparent during the last decades,
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5 339 so there is an increasing need for understanding their formation mechanisms and
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7 340 atmospheric dynamics in detail. Although several field campaigns and a few long-
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9 341 term (over several years) observations on NPF have already been conducted in China,
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11 342 we need to perform additional long-term measurements, preferable continuous and
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13 343 comprehensive observations utilizing the full capacity of the current state-of-the-art
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15 344 instruments.
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346 In the coming decade, we need to utilize the full capacity of new aerosol and ion
347 instruments, such as the Particle Size Magnifier (PSM, [61]), Neutral cluster and Air
348 Ion Spectrometer (NAIS, [62]) and Sigma [63]. With these instruments, we will be
349 able to detect and analyze the frequency of NPF events, as well as to determine cluster
350 concentrations, particle formation rates and size-dependent particle growth rates [e.g.
351 64, 65]. Furthermore, we will be able to quantify the contribution of ion and neutral
352 pathways to NPF [66, 67].
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354 The aerosol and ion instruments together with the high-resolution mass spectrometers,
355 such as Atmospheric Pressure interface – Time of Flight mass spectrometer (APiTOF,
356 [68] and Chemical Ionization APiTOF [69], will make it possible to connect the NPF
357 to the concentrations of different vapors participating in this process. Such vapors
358 include sulfuric acid [9, 70, 71], ammonia [72], amines [12, 73] and organic vapors
359 [11, 13, 74]. Furthermore, the mass spectrometers can also be utilized in determining

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3 360 atmospheric radical concentrations [75, 76, 77] responsible for the oxidation of
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5 361 precursor vapors in the atmosphere.
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11 363 To support the NPF analysis, aerosol number size distributions need to be measured
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13 364 with harmonized instruments [78], enabling quantification of the condensation sink of
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15 365 a pre-existing particle population. On-line chemical analysis is important as well,
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17 366 since such information can be used to attributing the relative contributions of different
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19 367 aerosol sources [e.g. 26, 79].
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26 369 In order to have reliable data which can also be compared from one site to another,
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28 370 instruments need to be calibrated often enough in the laboratory. This should be
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30 371 conducted within specific calibration centers. In order to assure the data quality, open
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32 372 data flows and joint data analysis are preferable, which will lead to joint publications
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34 373 and provides novel avenues to exploit the data to improve both regional air quality
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36 374 and global climate.
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43 376 **4. Capacity building** 44

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48 378 Capacity building related to scientists, engineers and technicians operating
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50 379 instruments and stations are necessary pre-requisites for obtaining good data. For
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52 380 example, a proper use of instruments will optimize the efforts, improve the data
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54 381 quality and enhance data and publication flows.
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7 383 The new insights gained on the secondary aerosol formation and atmospheric
8 384 phenomena associated with air quality as a whole need to be disseminated from the
9 385 academia to the public and to the private sector. The academic experts need to keep
10 386 their knowledge and skills up-to-date and widen their knowledge base with horizontal
11 387 learning of the adjunct fields in science and technology. Atmospheric research
12 388 involves several fields of science, such as chemistry, physics, meteorology and Earth
13 389 system sciences, so deepening and widening the expertise is required. The horizontal
14 390 learning principle has been shown to be a good example of collaborative problem
15 391 solving and participatory action research [80]. The shift from discipline-tied
16 392 fundamental education towards a multi-disciplinarity is imperative for a successful
17 393 career in climate and global change science [81].
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35 395 In capacity building, we actually need to answer several questions: What are the target
36 396 groups? What knowledge needs to be transferred and what are the skills that each
37 397 target group needs? Concerning the comprehensive atmosphere earth system
38 398 measurements: Which kind of observation infrastructures is best to improve the air
39 399 quality in China? Concerning the effective knowledge transfer and innovative
40 400 thinking methods: What kind of knowledge transfer is needed for sustainable air
41 401 quality solutions?
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54 403 Solution-oriented thinking, need for updating skills as well as knowledge of rapidly
55 404 changing air quality situation, are crucial. Reliable, research-based education that has
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3 405 a holistic view on the whole big picture of causes and effects and their interactions
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5 406 and feedbacks affecting air quality will support long lasting solutions. Also basic
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7 407 understanding of the processes behind atmospheric phenomena is needed for building
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10 408 a foundation for evaluating new information. Learning lasts a lifetime, which actually
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12 409 is underlined by the fact that the university professors have pointed out that they
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14 410 deepen their knowledge when lecturing to students.
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20 412 **5. Future Outlook**

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26 414 Atmospheric new particle formation contributes significantly to local, regional and
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28 415 global aerosol number and CCN loads [e.g. 6]. Therefore, understanding of this
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30 416 phenomenon is central to solving the secondary air pollution problem as a whole. The
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32 417 following steps are needed in this process:
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- 36 418 1) to perform long-term continuous, comprehensive observations on aerosol
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38 419 precursors, oxidants, clusters, ions and aerosol particles together with proper
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40 420 metadata and meteorological data. If needed, new Station for Measuring
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42 421 Ecosystem – Atmosphere Relations II (SMEAR II, [82]) -type flagship stations
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44 422 should be established, since they will help understanding the connections between
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46 423 NPF and land surface – atmosphere interactions and feedbacks,
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49 424 2) to establish calibration centers for mass spectrometers, PSMs and ion
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51 425 spectrometers,
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53 426 3) to organize joint data workshops for analyzing atmospheric data in proper,
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55 427 comprehensive manner,
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3 428 4) to ensure open data and metadata fluxes to other users, and
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5 429 5) to organize joint paper writing workshops and publish the joint papers in peer-
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7 430 reviewed journals.
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10 431 It would be a big step forward to establish tight connections between different

11 432 Chinese research groups and support further deep collaborations in the future. The

12 433 second challenge is to establish open data policy and knowledge transfer at all levels.

13 434 The access to data is crucial to be able to answer research questions and to solve air

14 435 pollution problem(s). As a good sign, during the last years we have already seen

15 436 improvements regarding these issues. The third point is the capacity building,

16 437 including new infrastructures, data flows, databases etc. Furthermore, a new

17 438 generation of scientists needs to be educated to improve the knowledge base and

18 439 optimal use of infrastructures and data [86].
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34 441 Understanding the formation of secondary pollutants is extremely important, since it

35 442 enables deep understanding of air pollutant dynamics crucial to air quality.

36 443 Improving air quality in China has several co-benefits, as it will lead to reduced

37 444 greenhouse-gas and black carbon emissions and concentrations, together with

38 445 improved fresh water quality and food supply. The cleaner air will decrease adverse

39 446 health effects caused by pollutants significantly [83, 84]. Efforts to prevent adverse

40 447 health effects must be well planned and should occur on multiple levels and places

41 448 simultaneously. Successful efforts will lead to significant gains in population health,

42 449 personal well-being and environmental quality as well as improving economy in

43 450 personal, local and national levels together with other significant co-benefits [85].
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3 451 Reducing the use of fossil fuels does not only reduce emissions of air pollutants, but
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5 452 also CO₂ and black carbon (BC), thereby decreasing radiative forcing in national and
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7 453 global scales. Also, agricultural production and ecosystem services will benefit from
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10 454 lowered pollutant levels. Healthier food will further improve peoples' health, and less
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12 455 pollution damage improves yields of vegetables and crops. Better insulation of
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14 456 buildings will lower the need for indoor heating, thus reducing emissions, but can also
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16 457 reduce outdoor-indoor penetration of air pollutants. New technology in industry,
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18 458 traffic and energy production will decrease emissions. The reduced pollution will
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21 459 increase solar radiation in ground level and increase potential for solar energy.
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461 Thus, tackling the air quality rapidly can lead to significant improvement on the
462 quality of life of the population as a whole and can lead to a positive feedback cycle,
463 which will encourage further progress towards cleaner environment.

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2 Research highlights
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6 1) Formation of new atmospheric aerosol particles is a global phenomenon that has been observed
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8 to take place in even heavily-polluted environments. A holistic scientific understanding on the
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10 atmospheric phenomena associated with air quality as a whole, as well as on the connection
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12 between air quality and climate, is lacking at the moment.
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17 2) In China, new particle production has been observed at very high pollution levels (condensation
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19 sink about 0.1 s^{-1}) in several megacities. With a network of observation stations, we will be able to
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21 understand the interactions and feedbacks associated with the urban pollution mixture, and
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23 ultimately, be ready to make targeted strategies for the pollution control.
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28 3) This paper summaries the recent advances in studying secondary new aerosol formation in China
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30 to show how increased process-level understanding will help us to understand air quality-climate-
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32 weather interactions and how the feedbacks and interactions affect the air quality in highly-polluted
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34 environments such as those frequently encountered in Chinese megacities.
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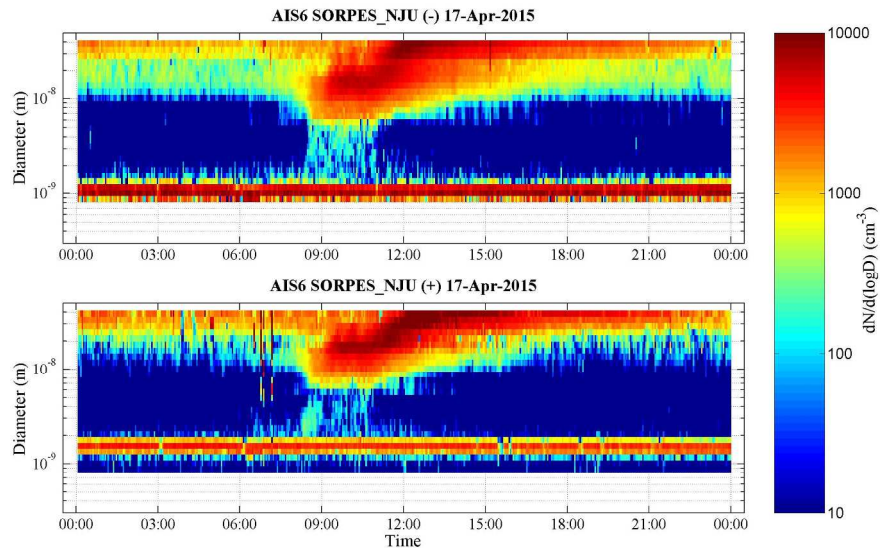


Figure 1. A typical nucleation event measured using Air Ion Spectrometer (AIS) at the SORPES station, Nanjing, in China. The background cluster ions are seen in both negative and positive ion modes in the sub-2 nm size range. Negative ion clusters are smaller than positive ones. The new particle formation is seen in both polarities starting at around 8.30 am. Here J_6 is $1.8 \text{ cm}^{-3}\text{s}^{-1}$ and $\text{GR}(6-30 \text{ nm})$ is 6.6 nm/hr .
871x523mm (72 x 72 DPI)