

Biogenic Potassium Salt Particles as Seeds for Secondary Organic Aerosol in the Amazon

Christopher Pöhlker,^{1*} Kenia T. Wiedemann,^{2,3,4} Bärbel Sinha,^{5,6} Manabu Shiraiwa,^{1,7} Sachin S. Gunthe,^{1,8} Mackenzie Smith,³ Hang Su,¹ Paulo Artaxo,² Qi Chen,³ Yafang Cheng,¹ Wolfgang Elbert,¹ Mary K. Gilles,⁹ Arthur L. D. Kilcoyne,¹⁰ Ryan C. Moffet,^{8,11} Markus Weigand,¹² Scot T. Martin,³ Ulrich Pöschl,^{1*} Meinrat O. Andreae¹

The fine particles serving as cloud condensation nuclei in pristine Amazonian rainforest air consist mostly of secondary organic aerosol. Their origin is enigmatic, however, because new particle formation in the atmosphere is not observed. Here, we show that the growth of organic aerosol particles can be initiated by potassium-salt-rich particles emitted by biota in the rainforest. These particles act as seeds for the condensation of low- or semi-volatile organic compounds from the atmospheric gas phase or multiphase oxidation of isoprene and terpenes. Our findings suggest that the primary emission of biogenic salt particles directly influences the number concentration of cloud condensation nuclei and affects the microphysics of cloud formation and precipitation over the rainforest.

Organic aerosols are ubiquitous in the atmosphere and play important roles in the climate system. They can cool Earth's surface by scattering sunlight or serve as nuclei for water droplets and ice crystals in clouds and precipitation. The properties and origin of organic aerosol particles are, however, still poorly understood, and their effects are among the largest uncertainties in the current understanding of climate (1–3). For reliable assessment and control of the human influence on climate, it is important to understand the natural background sources of atmospheric aerosols (4). One of the few continental regions where aerosols can be studied under near-natural conditions is the Amazon Basin, which has an aerosol burden that is mainly driven by an intensive biosphere-atmosphere interaction (5). Recent investigations indicate that the fine particles serving as cloud condensation nuclei (CCN) in pristine Amazonian rainforest air consist predominantly of secondary organic aerosol (SOA), formed by oxidation of

volatile organic compounds (VOC) and condensation of low- or semi-volatile oxidation products (6, 7). The actual mechanism of initial particle formation, however, remains unclear. In contrast to other vegetated continental regions, ultrafine particles with diameters < 30 nm (nucleation mode particles), which are characteristic for new particle-formation events in which gaseous species condense to form secondary aerosol particles, are almost never observed in pristine boundary layer air over the Amazonian rainforest (5, 8). One possible explanation for the lack of nucleation mode particles in the Amazonian boundary layer could be that the nucleation and the initial growth of new particles take place in the free troposphere, followed by downward transport in the course of convective overturning (9, 10). Alternatively, as we suggest here, the secondary organic material may condense onto preexisting primary particles directly emitted from the rainforest.

We applied scanning transmission x-ray microscopy with near-edge x-ray absorption fine

structure analysis (STXM-NEXAFS), scanning electron microscopy (SEM), and secondary ion mass spectrometry (NanoSIMS) to determine the microstructure and chemical composition of Amazonian organic aerosol particles in the accumulation mode (0.1 to 1 μm diameter). This size range is most relevant to the activation of cloud condensation nuclei (6). The aerosol samples were collected during the wet season (May 2011) at a remote rainforest site [Amazonian Tall Tower Observatory (ATTO) site] 150 km northeast of Manaus, Brazil. The investigated air masses came with the trade wind circulation from the northeast and traveled over some 1000 km of mostly pristine tropical rainforest. For comparison, we also investigated laboratory-generated SOA reference samples from isoprene and terpene oxidation, as well as reference samples generated by spray-drying of pure organic compounds in aqueous solution (11). We used STXM-NEXAFS for the determination of elemental and functional group composition in individual organic aerosol particles (12, 13) and SEM and NanoSIMS for further morphological characterization and independent confirmation of elemental composition.

The Amazonian aerosol samples comprised a mixture of homogeneous droplets and droplets containing internal structures that may be indicative of their atmospheric aging history (Fig. 1, A and B, and fig. S8). The NEXAFS spectra revealed characteristic similarities and differences between the chemical composition of the Amazonian aerosol and laboratory-generated reference samples. The terpene SOA reference particles exhibit a sharp peak representative of carboxylic acid groups (COOH), as well as shoulders indicating carbonyl groups (C=O) and carbon-carbon double bonds (C=C), but no pronounced signal of hydroxy groups (C-OH). Spectra of the isoprene SOA reference particles show a broad peak resulting from COOH and C-OH signals of comparable intensity, a C=O shoulder, and no C=C signal. Spectra of the carbohydrate reference particles exhibit a sharp C-OH peak, no COOH signal, and very weak C=O and C=C shoulders (Fig. 2A).

¹Biochemistry Department, Max Planck Institute for Chemistry, Mainz 55020, Germany. ²Institute of Physics, University of São Paulo, São Paulo 05508-900, Brazil. ³School of Engineering and Applied Sciences, Harvard University, Cambridge, MA 02138, USA. ⁴Ecology and Evolutionary Biology Department, University of Arizona, Tucson, AZ 85721, USA. ⁵Particle Chemistry Department, Max Planck Institute for Chemistry, Mainz 55020, Germany. ⁶Department of Earth and Environmental Science, Indian Institute of Science Education and Research Mohali, S.A.S. Nagar, Manauli PO, India. ⁷Division of Chemistry and Chemical Engineering, California Institute of Technology, Pasadena, CA 91125, USA. ⁸Environmental and Water Resources Engineering Division, Department of Civil Engineering, Indian Institute of Technology Madras, Chennai 600036, India. ⁹Chemical Science Division, Lawrence Berkeley National Laboratory, Berkeley, CA 94720, USA. ¹⁰Advanced Light Source, Lawrence Berkeley National Laboratory, Berkeley, CA 94720, USA. ¹¹Department of Chemistry, University of the Pacific, Stockton, CA 95211, USA. ¹²Max Planck Institute for Intelligent Systems, Stuttgart 70569, Germany.

*To whom correspondence should be addressed. E-mail: c.pohlker@mpic.de (C.P.); u.poeschl@mpic.de (U.P.)

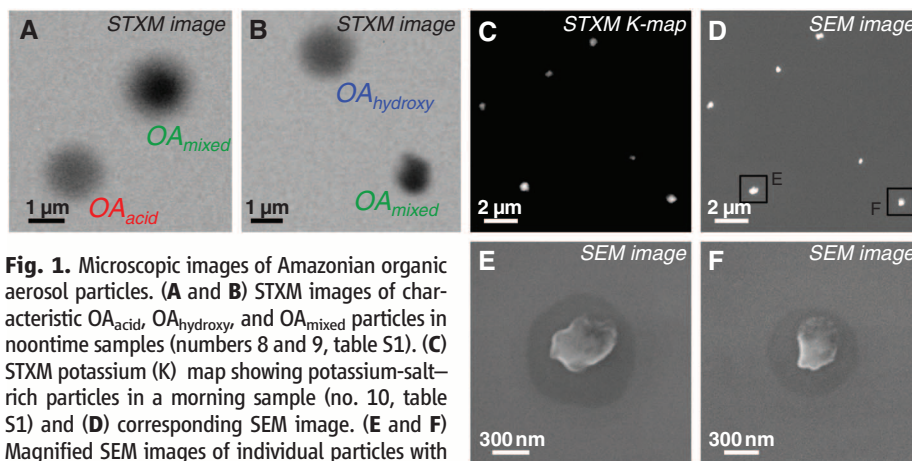


Fig. 1. Microscopic images of Amazonian organic aerosol particles. (A and B) STXM images of characteristic OA_{acid}, OA_{hydroxy}, and OA_{mixed} particles in noontime samples (numbers 8 and 9, table S1). (C) STXM potassium (K) map showing potassium-salt-rich particles in a morning sample (no. 10, table S1) and (D) corresponding SEM image. (E and F) Magnified SEM images of individual particles with salt core and organic coating [black frames in (D)].

In the Amazonian aerosol samples, three chemically distinct types of organic particles could be assigned to the following categories (Fig. 2A): (i) OA_{acid} particles exhibited spectra with a pronounced COOH peak similar to those of laboratory-generated SOA particles from terpene oxidation; (ii) $OA_{hydroxy}$ particles showed a strong hydroxy group signal similar to pure carbohydrate particles; and (iii) OA_{mixed} particles exhibited spectra resembling a mixture of OA_{acid} and $OA_{hydroxy}$ spectra. All three particle classes contained variable amounts of potassium. The coexistence of chemically distinct types of organic particles indicates the influence of different sources and formation mechanisms in the Amazonian boundary layer. Categories OA_{acid} and $OA_{hydroxy}$ each accounted for about 25% of all particles analyzed in this study, whereas OA_{mixed} was the most abundant particle type and contributed about 50%. Previous studies in Amazonia had shown that terpene- and isoprene-based SOA dominated the mass of organic aerosol (6, 7, 14), which is consistent with our observation of OA_{acid} , $OA_{hydroxy}$, and OA_{mixed} as a mixture of both. In addition to isoprene and terpene oxidation products, carbohydrates associated with primary particle emissions may also contribute to the observed organic matter (15, 16).

The most unexpected finding of our study was the presence of pronounced potassium signals in the NEXAFS spectra of nearly all analyzed organic particles (Fig. 2B). The potassium mass fraction is strongly size-dependent and decreases from ~20% at volume-equivalent particle diameters around 0.15 μm down to ~0.3% for diameters around 1 μm (Fig. 3), with a median value of 2.6% (11) (supplementary text S1.5). This observation suggests that small potassium-salt-rich particles from primary emissions act as seeds for the condensation of organic material and that the primary potassium content is diluted upon particle growth. The occurrence of these potassium-bearing particles has been confirmed by a combination of STXM, SEM, and NanoSIMS. In particular, samples collected during the morning hours show a high abundance of fine particles (~0.2 μm) with strong potassium signals and a low content of organic matter (Fig. 1, C to F, and fig. S7). The STXM and NanoSIMS results indicate that the potassium-rich particles also contain substantial quantities of ammonium cations as well as chloride and sulfate counteranions (11) (supplementary text S1.7).

Potassium-rich particles, in association with soot carbon, are an important component of biomass-burning smoke (17, 18). In our samples, however, we can exclude biomass burning as a source of the potassium-rich particles, because we did not find any particles containing soot carbon. Also, there were no fires detected in the region along the airmass trajectories during our study period (19, 20). Hence, biogenic emissions are the only potential source. Earlier investigations, including online high-resolution time-of-flight aerosol mass spectrometry (HR-ToF-AMS)

(fig. S12), had already reported substantial amounts of potassium associated with biogenic submicrometer aerosol in the Amazon during the wet season (21–23). They were not able to relate the presence of potassium to specific particle types, but the combination of potassium and sulfur has been attributed to local biogenic sources (24–26), which is consistent with the observation of potassium- and sulfate-rich particles in our study. The median atmospheric potassium concentration estimated from our analysis [$\sim 50 \text{ ng m}^{-3}$ for particles in the size range of 0.1 to 1 μm , (11) supplementary text S1.5] is consistent with previous measurement results [18 to 220 ng m^{-3} for particles $< 2 \mu\text{m}$ (16)]. Several studies show that active biota, such as plants and fungi, can efficiently release salts into the air (15, 16, 27–30). In particular, the active wet discharge of fungal spores is accompanied by the emission of aqueous droplets that contain potassium, chloride, and carbohydrates as the main osmolytes (11, 16) (supplementary text S2.1). STXM and light micrographs of our samples indicate a high abundance of fungal spores in the coarse particle fraction ($> 1 \mu\text{m}$, fig. S6), which supports the idea of fungal emissions as a plausible source for the observed potassium-rich particles.

SEM images show that the biogenic salt particles in the early morning samples consist of a

strongly electron-scattering salt core embedded in a thin organic coating (Fig. 1, E and F). However, potassium salt cores are not present in particles collected during the daytime. Instead, many particles show an inorganic microgranular material distributed over the entire particle (fig. S8, A and B). The phase separation observed in our samples follows the same pattern and dependence on oxygen-to-carbon ratio as reported in recent studies of liquid-liquid phase separation in organic and mixed organic-inorganic aerosol particles (31–33): $OA_{hydroxy}$ particles with high atomic ratios of oxygen to carbon ($O:C \approx 0.9$ to 1.0) showed no phase separation, whereas OA_{acid} and OA_{mixed} particles with $O:C$ ratios around 0.5 to 0.7 showed internal structures with a COOH-rich core and a C-OH-rich shell (table S4 and fig. S8). These observations indicate a pronounced influence of aqueous processing in deliquesced aerosol particles and cloud or fog droplets on the growth and aging of SOA particles, that is, the formation and evaporation of aqueous droplets in which multiphase chemical reactions can produce secondary organic matter and the inorganic salt seeds can undergo cyclic dissolution and recrystallization. SOA formation by multiphase rather than gas-phase chemistry might also contribute to a suppression of new particle formation (11) (supplementary text S2.3 and S2.4).

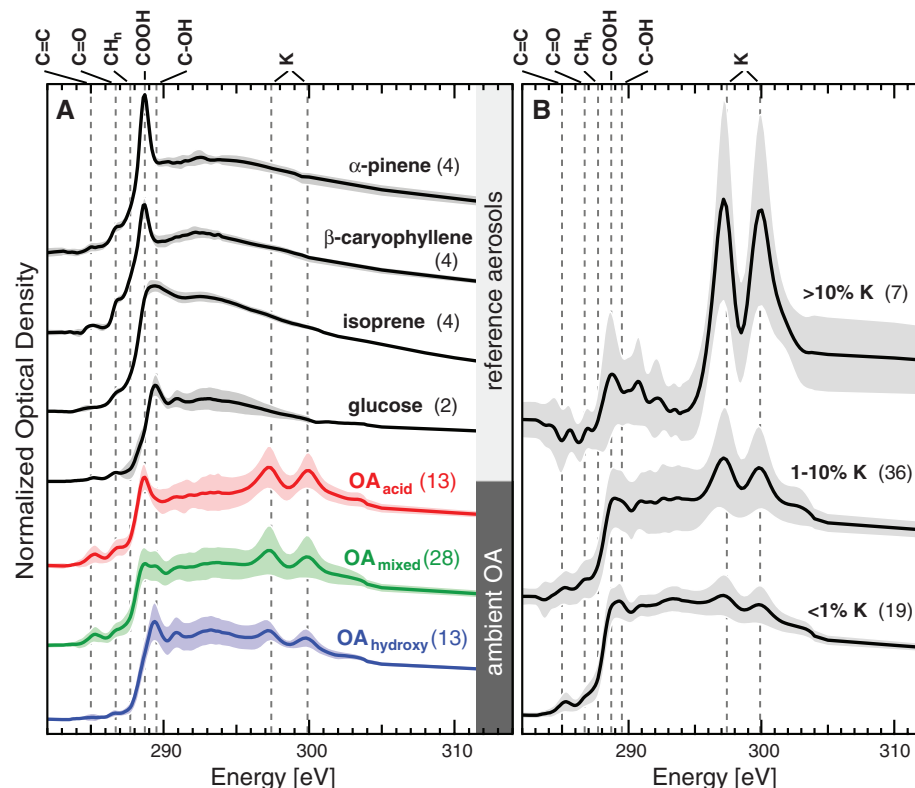


Fig. 2. (A) NEXAFS spectra of (i) laboratory-generated SOA from terpene and isoprene oxidation; (ii) glucose as carbohydrate reference compound from spray-drying of aqueous solution; and (iii) OA_{acid} , OA_{mixed} , and $OA_{hydroxy}$ particles from the Amazon. (B) NEXAFS spectra for Amazonian organic aerosol particles with different potassium (K) mass fractions. Solid lines and shaded areas represent mean spectra and standard deviations. Numbers of analyzed particles are given in parentheses. Vertical lines indicate resonant absorption of organic functional groups and potassium (table S3).

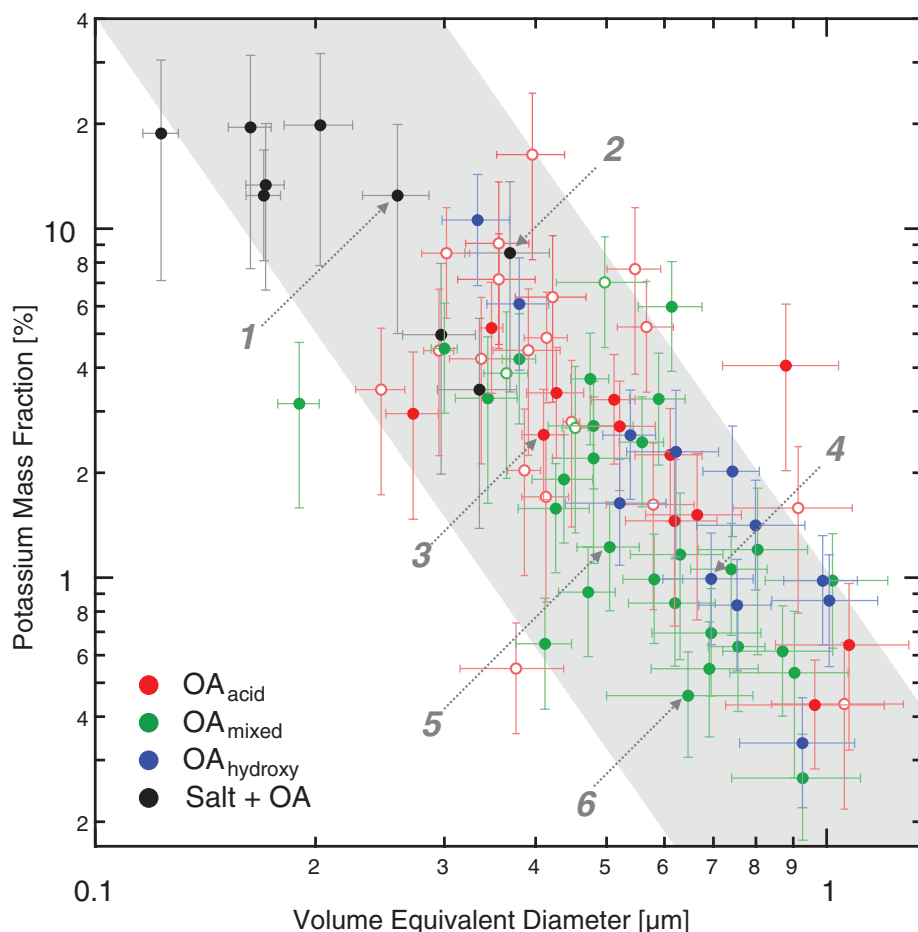
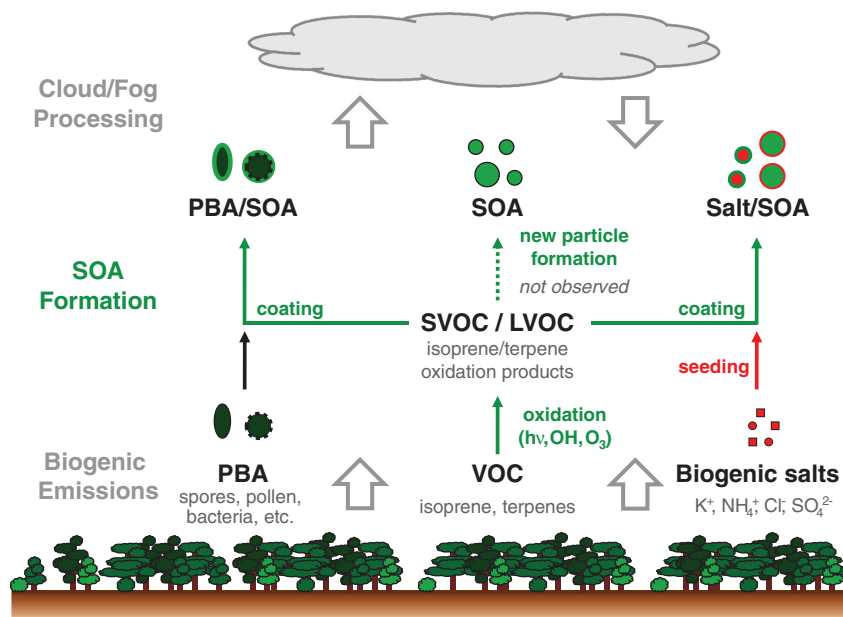


Fig. 3. Size dependence of potassium mass fraction in Amazonian organic aerosol particles. Solid markers represent data from samples collected in this study (ATTO site, 2011), and open markers represent additional data from previously collected samples (ZF2 site, 2010) (11). Numbers and arrows identify individual particles from Fig. 1 (1, F; 2, E; 3 and 5, A; and 4 and 6, B). Shaded area illustrates idealized dilution of primary potassium content upon particle growth by condensation of secondary organic material (inverse third-order dependence on particle diameter) (11). Error bars indicate the estimated uncertainty in calculations of particle size and potassium mass content.

Fig. 4. Sources and processing of organic aerosol in pristine Amazonian boundary layer air. SOA formation by photooxidation of VOC and condensation of semi- and low-volatile organic compounds (SVOC/LVOC) on primary biological aerosols (PBA) that dominate the coarse particle fraction ($>1 \mu\text{m}$) (5, 6) and on biogenic salt particles that serve as seeds for organic particles dominating the accumulation size range (0.1 to $1 \mu\text{m}$).



Of the 77 Amazonian organic aerosol particles analyzed by STXM-NEXAFS, only 3 contained no detectable amount of potassium ($<2 \text{ fg}$). The near-ubiquitous presence of potassium suggests that biogenic salt particles emitted from active biota in the rainforest serve as initial seeds for the condensation of VOC oxidation products. This mechanism appears to dominate the formation of SOA particles in the accumulation size range in pristine Amazonian rainforest air (Fig. 4). It can explain why new particle formation events are not observed, even though the aerosol consists largely of secondary organic material formed from gas-phase precursors (11) (supplementary text S2.4). A major implication is that the number concentration of atmospheric aerosol particles in the accumulation size range is partly regulated by the primary emission of potassium-salt-rich particles from biota in the rainforest. Compared with smaller particles in the nucleation and Aitken size range ($<0.1 \mu\text{m}$), accumulation mode particles are by orders of magnitude more frequently activated as CCN (11) (supplementary text S2.3 and fig. S11B). Thus, the biological sources and emission rates of potassium-salt-rich particles have a direct influence on the initial droplet number and microphysical evolution of clouds over the rainforest, which in turn influence the dynamics of clouds and precipitation as well as their effects on the hydrological cycle and climate.

Our findings support the hypothesis that the Amazonian rainforest ecosystem can be regarded as a biogeochemical reactor in which the formation of clouds and precipitation in the atmosphere are triggered by particles emitted from the biosphere. The connection between biogenic particle emissions and cloud properties in the tropical rainforest ecosystem appears even stronger and more direct than previously assumed (6, 34). In view of the large impact of tropical rainforests on biogeochemistry and climate, the biological

activity and diversity of particle-emitting organisms seem likely to play important roles in Earth history and future global change.

References and Notes

- J. L. Jimenez *et al.*, *Science* **326**, 1525 (2009).
- M. Hallquist *et al.*, *Atmos. Chem. Phys.* **9**, 5155 (2009).
- S. Solomon, *IPCC 4th Assessment Report* (Cambridge Univ. Press, Cambridge, 2007).
- M. O. Andreae, *Science* **315**, 50 (2007).
- S. T. Martin *et al.*, *Rev. Geophys.* **48**, RG2002 (2010).
- U. Pöschl *et al.*, *Science* **329**, 1513 (2010).
- Q. Chen *et al.*, *Geophys. Res. Lett.* **36**, L20806 (2009).
- D. V. Spracklen *et al.*, *Atmos. Chem. Phys.* **6**, 5631 (2006).
- R. Weigel *et al.*, *Atmos. Chem. Phys.* **11**, 9983 (2011).
- A. M. L. Ekman *et al.*, *Geophys. Res. Lett.* **35**, L17810 (2008).
- Materials and methods are available as supplementary materials on Science Online.
- A. V. Tivanski, R. J. Hopkins, T. Tyliczszak, M. K. Gilles, *J. Phys. Chem. A* **111**, 5448 (2007).
- S. F. Maria, L. M. Russell, M. K. Gilles, S. C. B. Myneni, *Science* **306**, 1921 (2004).
- M. Claeys *et al.*, *Science* **303**, 1173 (2004).
- J. L. Goatley, R. W. Lewis, *Plant Physiol.* **41**, 373 (1966).
- W. Elbert, P. E. Taylor, M. O. Andreae, U. Pöschl, *Atmos. Chem. Phys.* **7**, 4569 (2007).
- M. O. Andreae, *Science* **220**, 1148 (1983).
- J. Li, M. Posfai, P. V. Hobbs, P. R. Buseck, *J. Geophys. Res.* **108**, 8484 (2003).
- http://sigma.cptec.inpe.br/queimadas/v_anterior/dados_ant/dp_anteriores.html.
- <http://firefly.geog.umd.edu/firemap> [accessed 23 March 2012].
- P. Artaxo, H. C. Hansson, *Atmos. Environ.* **29**, 393 (1995).
- M. O. Andreae, P. J. Crutzen, *Science* **276**, 1052 (1997).
- P. Artaxo, W. Maenhaut, H. Storms, R. Vangrieken, *J. Geophys. Res.* **95**, 16971 (1990).
- A. Worobiec *et al.*, *Atmos. Environ.* **41**, 9217 (2007).
- D. R. Lawson, J. W. Winchester, *J. Geophys. Res.* **84**, 3723 (1979).
- D. R. Lawson, J. W. Winchester, *Geophys. Res. Lett.* **5**, 195 (1978).
- G. E. Nemeryuk, *Sov. Plant Physiol.* **17**, 560 (1970).
- G. Crozat, *Tellus* **31**, 52 (1979).
- W. Beauford, J. Barber, A. R. Barringer, *Science* **195**, 571 (1977).
- W. Beauford, J. Barber, A. R. Barringer, *Nature* **256**, 35 (1975).
- A. K. Bertram *et al.*, *Atmos. Chem. Phys.* **11**, 10995 (2011).
- M. Song, C. Marcolli, U. K. Krieger, A. Zuend, T. Peter, *Atmos. Chem. Phys.* **12**, 2691 (2012).
- A. Zuend, J. H. Seinfeld, *Atmos. Chem. Phys.* **12**, 3857 (2012).
- S. S. Gunthe *et al.*, *Atmos. Chem. Phys.* **9**, 7551 (2009).

Acknowledgments: This work has been supported by the Max Planck Society, the Max Planck Graduate Center, the Geocycles Cluster Mainz (Landesexzellenzcluster Rheinland-Pfalz),

and the European Community (PEGASOS, FP7-265148). The Harvard Environmental Chamber was supported by the Office of Science, Office of Basic Energy Sciences (BES), U.S. Department of Energy (DOE), grant no. DE-FG02-08ER6452, and the U.S. NSF under grant no. 0925467. The Advanced Light Source is supported by the Director, Office of Science, BES, of the U.S. DOE under contract no. DE-AC02-05CH11231. We thank the Helmholtz-Zentrum Berlin for the allocation of synchrotron radiation beamtime at BESSY II. We thank the Instituto Nacional de Pesquisas da Amazônia (INPA), Manaus, and the ATTO team under the Brazilian coordinator, A. O. Manzi, for their collaboration and field support. We also thank G. R. Carmichael and the Center for Global and Regional Environmental Research at the University of Iowa for support in the Weather Research and Forecasting (WRF) model simulations. We gratefully acknowledge R. Ditz, I. Trebs, X. Chi, J. A. Huffman, J. Kesselmeier, J. Schöngart, M. Kuwata, T. Tyliczszak, J. Huth, G. Schütz, E. Goering, M. Bechtel, J.-D. Förster, and T. Behrendt for support and helpful discussions.

Supplementary Materials

www.sciencemag.org/cgi/content/full/337/6098/1075/DC1
Materials and Methods
Supplementary Text
Figs. S1 to S12
Tables S1 to S9
References (35–106)

12 April 2012; accepted 23 July 2012
10.1126/science.1223264

Radiative Absorption Enhancements Due to the Mixing State of Atmospheric Black Carbon

Christopher D. Cappa,^{1*} Timothy B. Onasch,^{2,3*} Paola Massoli,² Douglas R. Worsnop,^{2,4} Timothy S. Bates,⁵ Eben S. Cross,^{3†} Paul Davidovits,³ Jani Hakala,⁴ Katherine L. Hayden,⁶ B. Tom Jobson,⁷ Kathryn R. Kolesar,¹ Daniel A. Lack,^{8,9} Brian M. Lerner,^{8,9} Shao-Meng Li,⁶ Daniel Mellon,^{1‡} Ibraheem Nuaaman,^{6,10} Jason S. Olfert,¹¹ Tuukka Petäjä,⁴ Patricia K. Quinn,⁵ Chen Song,¹² R. Subramanian,¹³ Eric J. Williams,⁸ Rahul A. Zaveri¹²

Atmospheric black carbon (BC) warms Earth's climate, and its reduction has been targeted for near-term climate change mitigation. Models that include forcing by BC assume internal mixing with non-BC aerosol components that enhance BC absorption, often by a factor of ~2; such model estimates have yet to be clearly validated through atmospheric observations. Here, direct in situ measurements of BC absorption enhancements (E_{abs}) and mixing state are reported for two California regions. The observed E_{abs} is small—6% on average at 532 nm—and increases weakly with photochemical aging. The E_{abs} is less than predicted from observationally constrained theoretical calculations, suggesting that many climate models may overestimate warming by BC. These ambient observations stand in contrast to laboratory measurements that show substantial E_{abs} for BC are possible.

Black carbon (BC) in the atmosphere has a strong effect on global and regional climate, with some estimates suggesting that the positive (warming) radiative forcing by BC is second only to CO₂ (1), making it an important near-term climate mitigation target (2, 3). Quantification of the warming caused by BC in global climate models depends explicitly on the mixing state assumed for particles (internal versus external) and, for internal mixtures, the assumed influence of coatings on the magnitude of BC absorption (4–6). Optical properties of internally mixed BC-containing particles can be calculated in various ways, all of which indicate substantially greater absorption than for an equivalent exter-

nal mixture—the absorption by internally mixed BC is “enhanced” because the coatings act as a lens (7). Model estimates of BC radiative forcing are increased by up to a factor of 2 for internally versus externally mixed BC (4, 5), and many models that use external mixtures simply multiply BC absorption by a scaling factor (8) to account for the theoretical absorption enhancement (E_{abs}). However, the magnitude of E_{abs} has not been determined for real atmospheric particles (9, 10), which is crucial as more models describe aerosol distributions as combinations of internal and external mixtures (11).

In this study, direct measurements of E_{abs} and average mixing state for BC in the atmo-

sphere around California are reported from two field campaigns: the 2010 CalNex study and the Carbonaceous Aerosols and Radiative Effects Study (CARES). The CalNex measurements were made onboard the R/V *Atlantis*, whereas the CARES measurements were made at a ground site in the Sacramento urban area (fig. S1) (12). Our observations indicate that the E_{abs} for ambient particles around large urban centers do not vary much with photochemical aging, are significantly less than predicted from traditional core-shell Mie theory, and are in contrast to laboratory experiments, suggesting that the warming by BC may be overestimated in climate models. Further, they indicate a role for absorption by non-BC aerosol components [brown carbon (BrC)] (13) in urban environments at short visible wavelengths.

¹Department of Civil and Environmental Engineering, University of California, Davis, CA 95616, USA. ²Aerodyne Research, Billerica, MA 01821, USA. ³Department of Chemistry, Boston College, Boston, MA 02467, USA. ⁴Department of Physics, University of Helsinki, Helsinki FI-00014, Finland. ⁵National Oceanic and Atmospheric Administration (NOAA) Pacific Marine Environmental Laboratory, Seattle, WA 98115, USA. ⁶Air Quality Research Division, Environment Canada, Toronto M3H 5T4, Canada. ⁷Department of Civil and Environmental Engineering, Washington State University, Pullman, WA 99164, USA. ⁸NOAA Earth System Research Laboratory, Boulder, CO 80305, USA. ⁹Cooperative Institute for Research in Environmental Sciences, University of Colorado, Boulder, CO 80309, USA. ¹⁰Centre for Atmospheric Chemistry, York University, Toronto M3J 1P3, Canada. ¹¹Department of Mechanical Engineering, University of Alberta, Edmonton T6G 2R3, Canada. ¹²Atmospheric Sciences and Global Change Division, Pacific Northwest National Laboratory, Richland, WA 99354, USA. ¹³RTI International, Research Triangle Park, NC 27709, USA.

*To whom correspondence should be addressed. E-mail: cdcappa@ucdavis.edu (C.D.C.); onasch@aerodyne.com (T.B.O.)
†Present address: Massachusetts Institute of Technology, Cambridge, MA 02139, USA.
‡Present address: PCME, St. Ives PE27 3GH, UK.

Biogenic Potassium Salt Particles as Seeds for Secondary Organic Aerosol in the Amazon

Christopher Pöhlker, Kenia T. Wiedemann, Bäbel Sinha, Manabu Shiraiwa, Sachin S. Gunthe, Mackenzie Smith, Hang Su, Paulo Artaxo, Qi Chen, Yafang Cheng, Wolfgang Elbert, Mary K. Gilles, Arthur L. D. Kilcoyne, Ryan C. Moffet, Markus Weigand, Scot T. Martin, Ulrich Pöschl, and Meinrat O. Andreae

Science, 337 (6098), • DOI: 10.1126/science.1223264

Salty Origins of Fresh Water

Cloud droplets above the Amazonian rain forest form mostly around organic aerosols, but the source of the aerosols has been a mystery. Pöhlker *et al.* (p. 1075) report that particles rich in potassium salts emitted by Amazonian vegetation can act as the seeds for the growth of organic aerosol particles that function as condensation nuclei for water droplets. These specks of biogenic salts provide a surface for the condensation of low- or semi-volatile organic compounds formed by the atmospheric oxidation of isoprene and terpenes, molecules produced in great abundance by many kinds of Amazonian plants.

View the article online

<https://www.science.org/doi/10.1126/science.1223264>

Permissions

<https://www.science.org/help/reprints-and-permissions>

Use of this article is subject to the [Terms of service](#)