U.S. DEPARTMENT OF ENERGY | Office of Science

DOE/SC-ARM-18-032

# Aerosol Vertical Profiling at Oliktok Point (AVPOP) Field Campaign Report

J Creamean
D Dexheimer
F Mei

December 2018

ARM

**DISCLAIMER**

This report was prepared as an account of work sponsored by the U.S. Government. Neither the United States nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the U.S. Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the U.S. Government or any agency thereof.

DOE/SC-ARM-18-032

# Aerosol Vertical Profiling at Oliktok Point (AVPOP) Field Campaign Report

J Creamean, Colorado State University
Principal Investigator

D Dexheimer, Sandia National Laboratories
F Mei, Pacific Northwest National Laboratory
Co-Investigators

December 2018

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

# Acronyms and Abbreviations

| | |
|---|---|
| AAF | ARM Aerial Facility |
| AMF | ARM Mobile Facility |
| ARM | Atmospheric Radiation Measurement |
| ASR | Atmospheric System Research |
| AVPOP | Aerosol Vertical Profiling at Oliktok Point |
| CPC | condensation particle counter |
| DTS | distributed temperature sensing |
| ICARUS | Inaugural Campaigns for ARM Research using Unmanned Systems |
| LBS | launched balloon system |
| PNNL | Pacific Northwest National Laboratory |
| POPEYE | Profiling at Oliktok Point to Enhance YOPP Experiments |
| SLWC | supercooled liquid water |
| SNL | Sandia National Laboratories |
| TBS | tethered balloon system |

# Contents



# Figures



# Tables

# 1.0 Summary

Aerosols are an important component of the atmospheric system through their various impacts on climate. Notably, the largest uncertainty of the energy budget (i.e., radiative forcing estimate) is the aerosol indirect effect. Aerosol-induced microphysical modifications influence cloud lifetime and albedo. However, constraining aerosol-cloud impacts in climate models, specifically in regions such as the Arctic, remains a significant challenge due to limited observations.

The efficacy of an aerosol to impact the arctic energy budget largely depends on its concentration, composition, and source. While ground-based measurements will provide a consistent, high-resolution time series of aerosol observations, the arctic atmosphere can be stratified, and thus what is observed on the ground may not be representative of the aerosol aloft. A key gap in arctic aerosol research is routine vertical profiling of abundance and source characterization. Previous work outside of the Arctic has focused on using launched or tethered balloon systems (LBS and TBS, respectively) to measure vertical profiles of aerosol size distributions and has demonstrated the utility of such observations (e.g., Hofmann et al. 1989; Hofmann 1993; Iwasaka et al. 2003; Kim et al. 2003; Tobo et al. 2007). More specifically, particle spectrometers have also been deployed via TBS systems (de Boer et al. 2018; Greenberg et al. 2009; Maletto et al. 2003; Renard et al. 2016; Wehner et al. 2007; Siebert et al. 2004) affording information on aerosol layer locations and evolution by means of multiple profiles. Filter samples for post-processing of aerosol composition and ice nucleation properties have also been conducted in mid-latitudes (Creamean et al. 2018). However, while these studies present novel measurements of aerosol vertical profiling via balloon systems, few exist to date in the Arctic.

The U.S. Department of Energy (DOE) Atmospheric Radiation Measurement (ARM) user facility TBS is composed of a variety of winches, balloons, and instrumentation that flies within ARM's Restricted Airspace (R-2204) at the third ARM Mobile Facility (AMF3) at Oliktok Point, Alaska (Figure 1). The system payload comprises instruments that can simultaneously collect in situ data on horizontal winds, ice microphysics, turbulence, thermodynamic state, aerosols, and the cloud-top environment (https://www.arm.gov/capabilities/instruments/tbs). Recent campaigns at AMF3 have involved the use of the ARM helikite, which is a balloon-kite hybrid that uses lighter-than-air principles to obtain its initial lift and a kite to achieve stability and dynamic lift. Additional information on the specifications of the helikite TBS can be found in the ARM TBS handbook (Dexheimer 2018).

**Figure 1**. The TBS payload ascending on the 17 May, 2018 flight. Photo: Darielle Dexheimer.

For the late May 2018 Aerosol Vertical Profiling at Oliktok Point (AVPOP; https://www.arm.gov/research/campaigns/amf2018avpop) campaign, we deployed instrumentation to address questions connecting several scientific foci related to the vertical structure of aerosols, including:

1. potential sources of aerosol in the arctic atmosphere
2. location of aerosol layers with respect to cloud
3. redistribution of aerosol through interaction with clouds, and
4. aerosol impacts on arctic cloud microphysics.

Such objectives are based on ongoing work and preliminary results from the Inaugural Campaigns for ARM Research using Unmanned Systems (ICARUS) flights from 2016 and 2017 whereby particle spectrometers (i.e., the Printed Optical Particle Spectrometer or POPS) and particle counters (i.e., condensation particle counter or CPC) were deployed on the Sandia National Laboratories (SNL) TBS system at Oliktok Point (AMF3). Several case studies are currently under evaluation by the DOE Atmospheric System Research (ASR) Oliktok Point Site Science Team, including TBS flights from the spring, summer, and fall for evaluation of aerosol vertical profiles during a wide range of seasons and cloud conditions. To comprehensively assess arctic aerosol sources, vertical distribution, and resulting impacts on clouds, additional profiling is needed to diversify the cases currently under investigation, specifically by providing additional cases where clouds are present during observational periods.

AVPOP involved deployment of a similar payload of instruments as ICARUS to afford additional cases to evaluate aerosol vertical distributions and possible aerosol-cloud interactions. The added aerosol measurements from AVPOP will address the scientific objectives above by providing additional key information and cases of aerosol vertical distribution for observational and modeling analyses of arctic aerosol sources and cloud microphysical impacts. Integrating such equipment is an added benefit that will leverage the planned flights and observations from previous ICARUS flights and the recent POPEYE (Profiling at Oliktok Point to Enhance YOPP Experiments) flights.

# 2.0 Results

AVPOP involved addition of 2 POPS (SN14 and SN18; Handix Scientific, LLC) and a CPC (3007; TSI, Inc.) from the ARM Aerial Facility (AAF) mentored by Pacific Northwest National Laboratory (PNNL) to the TBS deployment at Oliktok Point, Alaska during 13 flights on 14–18 May, 2018. The POPS measures particle size distributions in the 140nm–3.0µm range using a 405-nm laser. Flow rates were kept at 0.3L $min^{-1}$. Maximum partile concentration range within the 10% coincidence error is 1250$cm^{-3}$ (but when particle counts are less than 10$cm^{-3}$, uncertainty is > 30%) and it can operate in ambient temperatures of –40 to 35 °C. The CPC provides total particle number concentrations in the 10nm to > 1.0µm range at concentrations of 0 to 100000$cm^{-3}$. Deployment of both instruments in concert provides information on a large size range of aerosols, from nanometer-sized, newly formed particles from gas-phase precursors to accumulation-mode aged combustion aerosol to coarse mode aerosol such as sea salt and mineral dust.

Deployments were led by SNL and operated by SNL staff and ARM site technicians. Other deployed sensors include the SNL supercooled liquid water content sondes (SLWC; Anasphere, Inc.), distributed temperature sensing (DTS; Oryx + DTS-XR by Sensornet, Ltd. and XT DTS by Silixa, Ltd.) sensors, tethersondes (SmartTether™; Anasphere, Inc.), and 1-2 iMet packages (InterMet iMet-1-RSB radiosondes; International Met Systems, Inc.). Thus, several other atmospheric state parameters were measured in concert with the aerosol number concentrations and size distributions. Additionally, AMF3 measurements were available to guide flight patterns, namely radars to determine cloud base and top in near-real time and surface meteorology for temperatures and winds. Table 1 provides a synopsis of flight dates and times, the number of flights, and field notes from Darielle Dexheimer on TBS flight patterns and cloud/wind conditions.

**Table 1**. Tethered balloon system flight details.

| Date | TBS Flight | Times (UTC) | Flight Pattern Field Notes |
|---|---|---|---|
| 14 May, 2018 | F01 | 19:26–19:59 | Ascended to 350m at 19:49. POPS SN18 in cloud 19:41–19:53. Could not lift second POPS or ascend to cloud top. |
| | F02 | 20:33–21:43 | Ascended to 400m at 20:50. POPS SN18 in cloud 20:41–21:34. Noticeable increase in POPS particle rate at cloud base on ascent (90 to 6 once in cloud). |
| | F03 | 23:35–00:10 | Ascended to 300m at 23:58. POPS SN18 in cloud 23:54–00:01. Noticeable increase in POPS particle rate at cloud base on descent. |
| | F04 | 00:16–00:40 | Ascended to 400m at 00:30. POPS SN18 in cloud 00:23–00:36 (cloud base ~190m). |
| 15 May, 2018 | F01 | 19:26–20:00 | Ascended to 308m at 19:50. POPS SN18 in cloud 19:43–19:53. Could not lift second POPS or ascend to cloud top. Cloud base 210 m. |
| | F02 | 21:00–21:26 | Ascended to 319m at 21:15. POPS SN18 in cloud 21:13–21:17. Cloud base 260m. |
| | F03 | 21:26–21:40 | Ascended to 220m at 21:33. Steep tether angle so began descent at 220m. Wind speed increased to 7.5m/s immediately below max altitude on descent. Cloud base 350m. |
| 17 May, 2018 | F01 | 17:00–17:40 | Ascended to 435m at 17:28. POPS SN14 in cloud 17:14–17:39. |
| | F02 | 18:08–19:18 | Ascended to 440m at 18:24. POPS SN14 in cloud 18:13–18:43. Attempted to loiter but could not maintain altitude due to heavy icing. Descended at 18:30. Held at 85m below cloud from 18:43–19:13. Cloud base increased from 90m to 130m while holding. |
| | F03 | 22:20–00:53 | Ascended to 650m at 23:37. Descended to 350m and held 00:2500:40. Had to cut hold short in order to retrieve before 5 pm local when operators leave site. |
| 18 May, 2018 | F02 | 17:25–17:55 | Ascended to 445m at 18:13. POPS SN14 in cloud 17:35 (~190m)–17:49 (~200m). Cloud base 190m, cloud top 430m. |
| | F03 | 18:01–18:25 | Ascended to 438m at 17:42. POPS SN14 in cloud 17:35 (~175m)–17:49 (~205m). |
| | F04 | 18:26–18:50 | Ascended to 435m at 18:38. POPS SN14 in cloud 18:31 (~180m)–18:36 (~180m). |

In general for flights on 14 May, cloud base and top was 150–200m and 400–600m, respectively. Surface temperatures were –2 to 2 °C and winds were easterly at < 4.5m $s^{-1}$. However, winds were forecasted to be > 10 m $s^{-1}$ on day prior, then 7–8m $s^{-1}$ on 14 May's forecast. The helikite flew due to forecasted higher wind speeds, but it has insufficient lift to fly more than one POPS or ascend above cloud top. Each flight ascended as high as possible. Not all POPS data were valid during this day (Figure 1).

On 15 May, cloud base increased from 210 to 360m over the course of the three flights. Clouds dissipated immediately after F03. Cloud top was observed at 400m consistently throughout the three flights. Surface temperatures warmed from –2 to 1 °C. Winds shifted from easterly to southeasterly over time, and were 4–5m $s^{-1}$, 5–6m $s^{-1}$, then 6–7 m $s^{-1}$ during F01, F02, and F03, respectively. The DTS fiber was damaged but repaired after F04 with the intent to fly during F04 (no aerosol instruments were planned for F04).

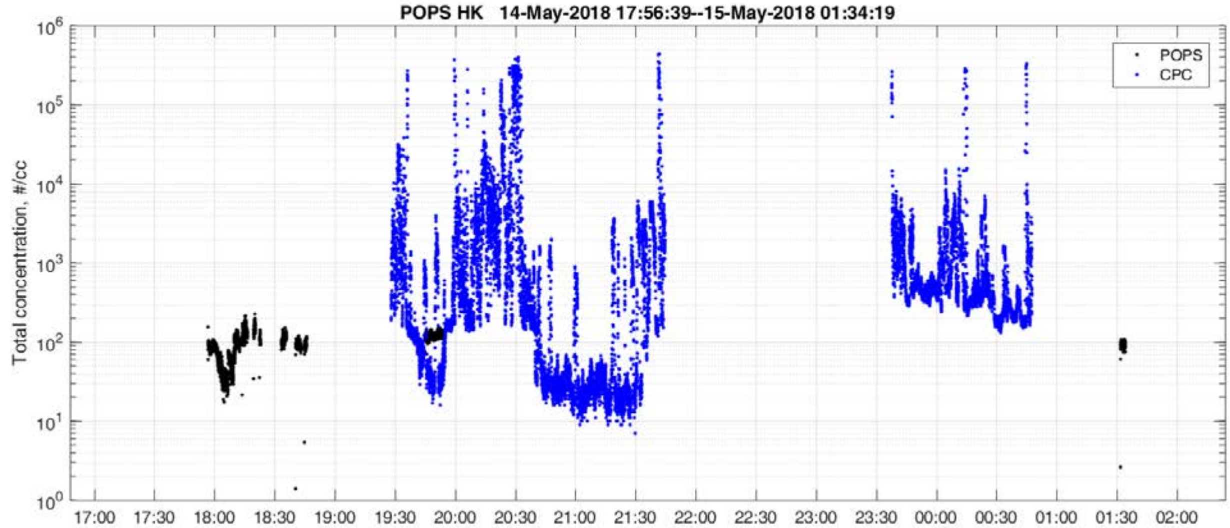


**Figure 2**. Time series of POPS (black markers) and CPC (blue markers) data from 14 May AVPOP flights.

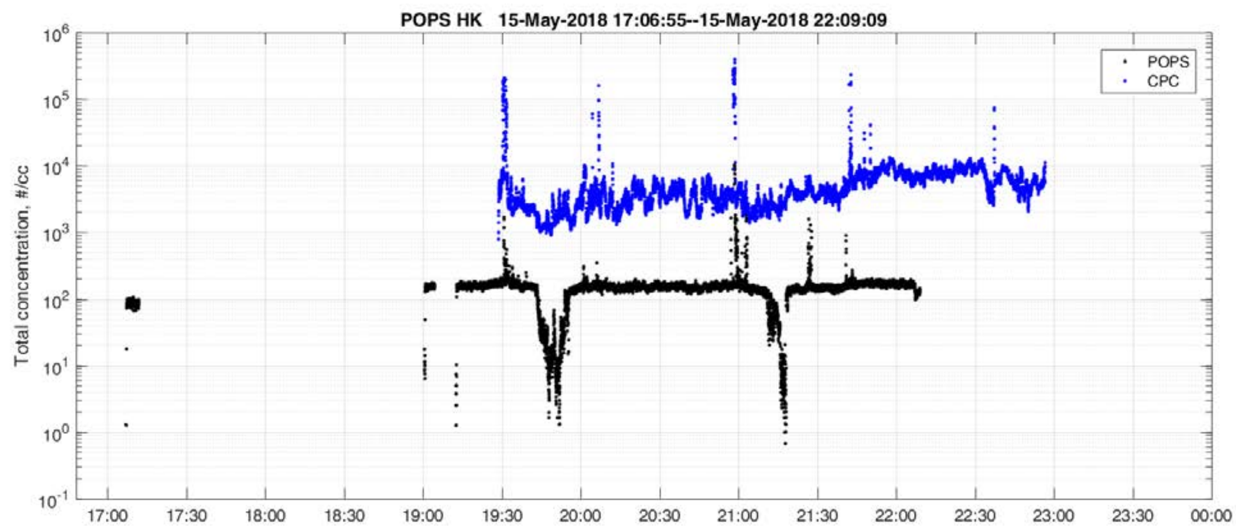


**Figure 3**. Same as Figure 2, but for flights on 15 May, 2018.

When the team was ready to launch for F04, winds started gusting > 8m $s^{-1}$ and the cloud layer had dissipated, thus flights were suspended for the remainder of the day.

On 17 May, cloud base was 80–90m during F01, then increased to 130m during F02 and remaining flights. Cloud top was observed at 600m and descended to 550m over time. Surface temperatures were around –8°C and winds were 4–6 m $s^{-1}$ during F01 and F02 and decreased to 3–5m $s^{-1}$ for F03. Unfortunately, data were not recorded from the CPC during these flights.

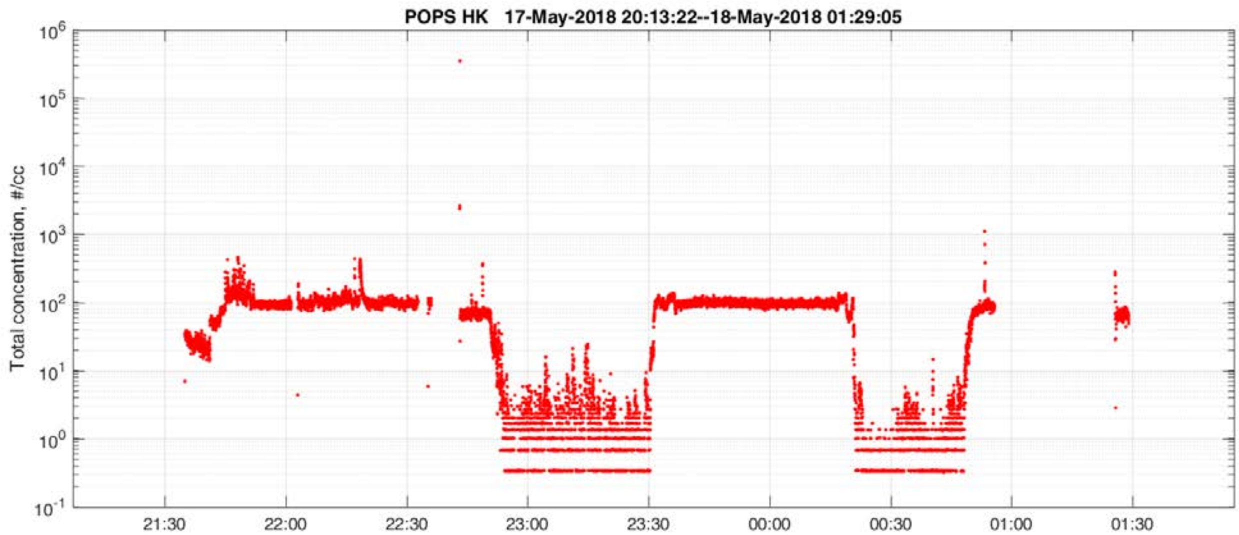


**Figure 4**. Same as Figure 2, but for flights on 17 May, 2018. POPS data are now shown as red markers. No CPC data were recorded this day.

On 18 May, cloud base and top resided at 170–210m and approximately 430m, respectively. Surface temperatures hovered around –8 °C and wind speeds were consistently at 4–6m $s^{-1}$.

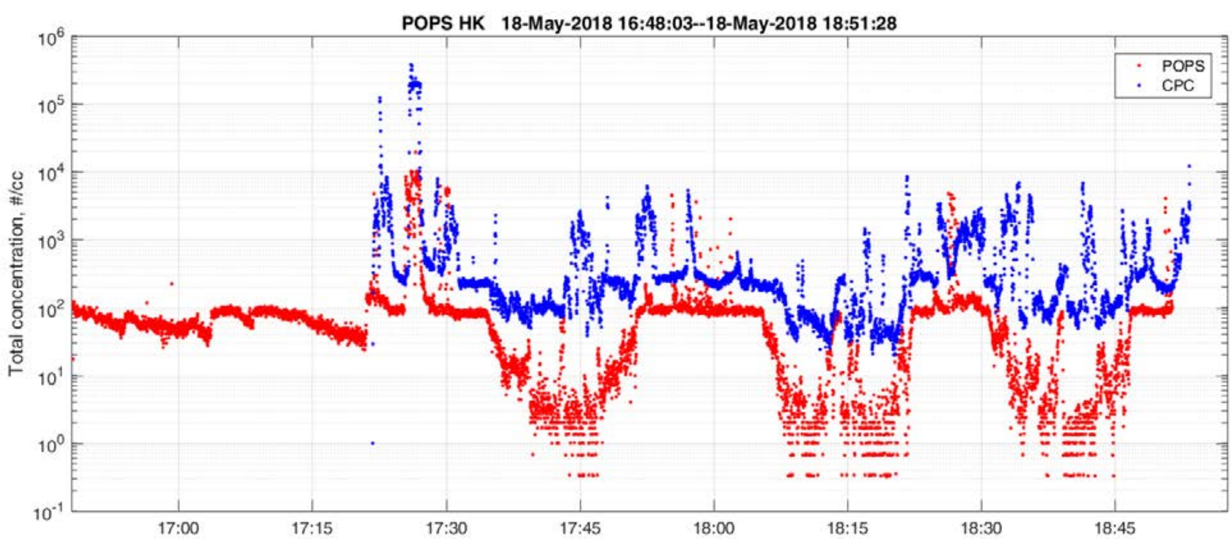


**Figure 5**. Same as Figure 2, but for flights on 18 May, 2018. POPS data are now shown as red markers. CPC data are still shown as blue markers.

Data from all of the TBS instrumentation for AVPOP can be found in the ARM External Data Center. As discussed earlier, the Oliktok Point Site Science team will continue to use data from ICARUS (2016–2017), AVPOP (spring 2018), and the more recent POPEYE (summer 2018; data not yet available) to assess vertical distributions of aerosols and aerosol-cloud interactions in the arctic atmosphere. The number of cases is increasing given the recent and ongoing TBS deployments at Oliktok Point; thus we welcome the scientific community to use these data for further aerosol distribution and aerosol-cloud observational investigations and to guide modeling parameterizations.

# 3.0 Publications and References

We have published nothing to date, but data from AVPOP will be incorporated into publications in preparation regarding specified cases from ICARUS. A future publication summarizing all TBS flights from ICARUS, AVPOP, and POPEYE is planned.

**References Cited**

Creamean, JM, KM Primm, MA Tolbert, EG Hall, J Wendell, A Jordan, PJ Sheridan, J Smith, and RC Schnell: 2018. "HOVERCAT: a novel aerial system for evaluation of aerosol–cloud interactions." *Atmospheric Measurement Techniques* 11(7): 3969–3985, https://doi.10.5194/amt-11-3969-2018

de Boer, G, M Ivey, B Schmid, D Lawrence, D Dexheimer, F Mei, J Hubbe, A Bendure, J Hardesty, MD Shupe, A McComiskey, H Telg, C Schmitt, SY Matrosov, I Brooks, J Creamean, A Solomon, DD Turner, C Williams, A Maahn, B Argrow, S Palo, CN Long, R-S Gao, and J Mather. 2018. "A Bird's-Eye View: Development of an Operational ARM Unmanned Aerial Capability for Atmospheric Research in Arctic Alaska." *Bulletin of the American Meteorological Society* 99(6): 1197–1212, https://doi.10.1175/bams-d-17-0156.1

Dexheimer, D. 2018. Tethered Balloon System (TBS) Instrument Handbook, Sandia National Laboratories.

Greenberg, JP, AB Guenther, and A Turnipseed. 2009. "Tethered balloon-based soundings of ozone, aerosols, and solar radiation near Mexico City during MIRAGE-MEX." *Atmospheric Environment* 43(16): 2672–2677, https://doi.org/10.1016/j.atmosenv.2009.02.019

Hofmann, DJ, JM Rosen, JW Harder, and JV Hereford. 1989. "Balloon-borne measurements of aerosol, condensation nuclei, and cloud particles in the stratosphere at McMurdo Station, Antarctica, during the spring of 1987." *Journal of Geophysical Research: Atmospheres* 94(D9): 11253–11269, https://doi:10.1029/JD094iD09p11253

Hofmann, DJ. 1993. "Twenty years of balloon-borne tropospheric aerosol measurements at Laramie, Wyoming." *Journal of Geophysical Research: Atmospheres* 98(D7): 12753–12766, https://doi:10.1029/93JD00466

Iwasaka, Y, G-Y Shi, Z Shen, YS Kim, D Trochkine, A Matsuki, D Zhang, T Shibata, M Nagatani, and HJW Nakata. 2003. "Nature of Atmospheric Aerosols over the Desert Areas in the Asian Continent: Chemical State and Number Concentration of Particles Measured at Dunhuang, China." *Water, Air and Soil Pollution: Focus* 3(2): 129–145, https://doi.10.1023/a:1023282221749

Kim, YS, Y Iwasaka, G-Y Shi, Z Shen, D Trochkine, A Matsuki, D Zhang, T Shibata, M Nagatani, and HJW Nakata. 2003. "Features in Number Concentration-Size Distributions of Aerosols in the Free Atmosphere over the Desert Areas in the Asian Continent: Balloon-Borne Measurements at Dunhuang, China." *Water, Air, and Soil Pollution: Focus* 3(2): 147–159, https://doi.10.1023/a:1023234305819

Maletto, A, IG McKendry, and KB Strawbridge. 2003. “Profiles of particulate matter size distributions using a balloon-borne lightweight aerosol spectrometer in the planetary boundary layer.” *Atmospheric Environment* 37(5): 661–670, https://doi.10.1016/S1352-2310(02)00860-9

Renard, JB, F Dulac, G Berthet, T Lurton, D Vignelles, F Jegou, T Tonnelier, M Jeannot, B Coute, R Akiki, N Verdier, M Mallet, F Gensdarmes, P Charpentier, S Mesmin, V Duverger, JC Dupont, T Elias, V Crenn, J Sciare, P Zieger, M Salter, T Roberts, J Giacomoni, M Gobbi, E Hamonou, H Olafsson, P Dagsson-Waldhauserova, C Camy-Peyret, C Mazel, T Decamps, M Piringer, J Surcin, and D Daugeron. 2016. “LOAC: a small aerosol optical counter/sizer for ground-based and balloon measurements of the size distribution and nature of atmospheric particles – Part 2: First results from balloon and unmanned aerial vehicle flights.” *Atmospheric Measurement Techniques* 9(8): 3673–3686, https://doi.10.5194/amt-9-3673-2016

Siebert, H, F Stratmann, and B Wehner. 2004. “First observations of increased ultrafine particle number concentrations near the inversion of a continental planetary boundary layer and its relation to ground-based measurements.” *Geophysical Research Letters* 31(9), https://doi.10.1029/2003gl019086

Tobo, Y, D Zhang, Y Iwasaka, and G Shi. 2007. “On the mixture of aerosols and ice clouds over the Tibetan Plateau: Results of a balloon flight in the summer of 1999.” *Geophysical Research Letters* 34(23), https://doi:10.1029/2007GL031132

Wehner, B, H Siebert, F Stratmann, T Tuch, A Wiedensohler, T Petaja, M Dal Maso, and M Kulmala. 2007. “Horizontal homogeneity and vertical extent of new particle formation events.” *Tellus B-Chemical and Physical Meteorology* 59(3): 362–371, https://doi.10.3402/tellusb.v59i3.16996

www.arm.gov

U.S. DEPARTMENT OF ENERGY

Office of Science