

## Reply to Comments of Anonymous Referee # 3

This study presents the results of organic compounds measurements made during the summer of 2009 at Fairbanks site in central Alaska. Organic aerosols are a hot topic in aerosol science. Within that biomass burning is of particular interest since it is one of the main sources of organic aerosols. The authors have performed a lot of high-quality lab analysis. The data set is impressive. I think that the results are unique and will be of interest to many in the atmospheric science population. I recommend the manuscript for publication after the following comments are addressed.

Reply: We thank the reviewer for the positive comments and very careful reading of the manuscript. We have now taken all of them into account in the revised version of the manuscript. Please refer to the revised manuscript where we highlighted the changes in yellow. We provide here below a reply to the specific comments and modifications made in the revised manuscript.

Line 27-29: The authors concluded that forest fires and plant emissions are the crucial factors controlling the molecular composition of organic aerosols in central Alaska. Can authors discuss the contributions of biomass burning tracers and other tracer compounds to organic carbon and compare with previous studies in the revised version?

Reply: Based on the comment of reviewer, we have added a new table (Table 3) and discussed the contribution of tracer compound classes to OC in the revised manuscript as given below.

### “3.8 Contributions of compound classes to aerosol organic carbon

The contributions of each compound class to organic carbon (OC) in the Alaskan aerosols are given in Table 3. BB tracers accounted for 1.35 to 8.35 % (ave. 4.40 %) of OC. The contribution of anhydrosugars to OC was substantially high (ave. 4.26 %) than that of lignin and resin acids (ave. 0.14 %). This value from Fairbanks is notably higher than those reported in aerosol samples collected from a round-the-world cruise (ave. 0.15 %) (Fu et al., 2011), Gosan Jeju Island in Korea (ave. 0.29 %), Sapporo (ave. 0.44 %) and Chichijima (ave. 0.06 %) in Japan (Simoneit et al., 2004a), and Chennai in India (ave. 0.59 %) (Fu et al., 2010). The lipid compound classes in Fairbanks samples accounted for 1.16 to 45.8 % (ave. 12.4 %) of OC. *n*-Alkanoic acids contributed on average 7.48 % (0.67 to 15.9 %), which is much higher than those estimated in samples of round-the-world cruise (ave. 0.82 %), Sapporo (ave. 0.62 %) and Chichijima (ave. 0.78 %) (Simoneit et al., 2004a; Fu et al., 2011). The tracers of primary biological aerosol particles accounted for on average 0.85 % (0.17 to 1.50 %), among which comparable contributions of primary sugars (ave. 0.39 %) and sugar alcohols (ave. 0.46 %) to OC were found in Alaskan aerosols. Plastic burning tracer accounted for 0.02 to 1.07 % of OC (ave. 0.14 %), which is lower than those from Sapporo (ave. 1.1 %) and Chichijima samples (ave. 1.2 %) (Simoneit et al., 2004a) and tropical samples from India (ave. 4.50 %) (Fu et al., 2010). Biogenic SOA tracers contributed 0.18 to 3.99 % of OC (ave. 1.66 %), among which the contribution of isoprene-derived SOA tracers was high (ave. 1.28 %) followed by monoterpene (ave. 0.34 %) and sesquiterpene (ave. 0.03 %) SOA tracers. Other SOA tracers that contribute very less to OC include polyacids (ave. 0.08 %) and aromatic acids (ave. 0.02 %).

With the consideration of water-soluble dicarboxylic acids and related polar

compounds measured in the same sample sets as reported in Deshmukh et al. (2018), the total organic compounds identified in the Alaskan aerosols accounted for 6.37 to 59.2 % with a mean of 21.4 % of OC. This result indicates that a substantial portion of OAs studied in the Alaskan site can be identified at a molecular level.

**Table 3.** Contributions (%) of individual organic compound classes to organic carbon (OC) in PM<sub>2.5</sub> aerosols from central Alaska.<sup>a</sup>

Compound classes	Minimum	Maximum	Mean	Median	Standard deviation
<b>Biomass burning tracers</b>					
Anhydrosugars	1.32	8.12	4.26	3.64	2.13
Lignin and resin acids <sup>b</sup>	0.03	0.51	0.14	0.11	0.13
Subtotal	1.35	8.35	4.40	3.71	2.24
<b>Lipid compounds</b>					
<i>n</i> -Alkanes	0.05	8.53	1.55	0.98	2.19
<i>n</i> -Alkanols	0.40	21.3	3.32	1.82	5.47
<i>n</i> -Alkanoic acids	0.67	15.9	7.48	6.71	4.80
Subtotal	1.16	45.8	12.4	9.20	11.3
<b>Primary biological aerosols</b>					
Primary sugars	0.05	0.85	0.39	0.50	0.26
Sugar alcohols	0.07	0.95	0.46	0.33	0.33
Subtotal	0.17	1.50	0.85	0.74	0.56
<b>Phthalate esters</b>					
Phthalate esters	0.02	1.07	0.14	0.05	0.28
Aromatic acid	0.01	0.09	0.02	0.01	0.02
Polyacids	0.02	0.25	0.08	0.09	0.06
<b>Biogenic SOA tracers</b>					
Isoprene oxidation products	0.07	3.20	1.28	0.83	1.12
Monoterpene oxidation products	0.07	0.75	0.34	0.34	0.20
Sesquiterpene oxidation products	0.02	0.04	0.03	0.03	0.01
Subtotal	0.18	3.99	1.66	1.22	1.29
Dicarboxylic acids and related compounds <sup>a</sup>	1.15	2.97	1.90	1.87	0.58
<b>Total detected organic compounds</b>	<b>6.37</b>	<b>59.2</b>	<b>21.4</b>	<b>16.9</b>	<b>13.8</b>

<sup>a</sup>All the organic compounds quantified were converted to carbon contents and then divided by OC. See Deshmukh et al. (2018) for OC and dicarboxylic acids and related compounds. <sup>b</sup>The results of lignin and resin acids were combined due to the very low contribution of resin acid to OC.

Please see Table 3 and lines 623-649 in the revised manuscript.

Line 72-78: This is a piece of the limited information provided by authors about the previous studies over the Arctic. An in-depth discussion about the findings of earlier studies should be included in the revised manuscript.

Reply: Following the comment of reviewer, we have provided a thorough discussion on the outcomes of earlier studies over the Arctic region as follows.

“Although early Arctic explorers had noticed atmospheric haze (Nordenskiöld, 1883), the remote Arctic atmosphere was believed to be extremely clean. Pilots flying over the North American Arctic in the 1950s observed widespread haze that could be seen every winter and early spring (Mitchell, 1957). It took until the 1970s for scientists to realize that the haze was air pollution transported from the middle latitudes (Barrie, 1986). Over the past three decades there has been much research on the climate consequences of this pollution that is also present in summer. Surface air temperature has increased more than the global average over the past few decades and is predicted to warm by about 5 °C over a large part of the Arctic by the end of the twenty-first century (IPCC, 2001).

French et al. (2003) proposed that wildfire has contributed a substantial amount of carbon-based gas from 1950 to 1999 in the atmosphere of the boreal region of Alaska. Based on the modeling and in-situ observations of black carbon (BC) and soot during the FROSTFIRE campaign, Kim et al. (2005) revealed that BC and soot particles of 0.4 to 10 µm in radius can be transported to the Arctic and the whole area of Alaska in a very short time. The results of Kaplan and New (2006) delivered strong evidence that high-latitude ecosystems are sensitive to climate change due to the increase in concentrations of greenhouse gases. Iziomon et al. (2006) examined summertime aerosols based on column integrated and surface aerosol measurements at Barrow in the North Slope of Alaska between 1998 and 2003. They noticed high loadings of aerosols at least 8 days each summer and demonstrated that the pollution events with the highest aerosol loadings were associated with smoke from wildfires in northwest Canada. Stohl et al. (2006) explored the impact of boreal forest fire emissions on the light absorbing aerosol levels at the Barrow Arctic station. They proposed that boreal forest fires could result in elevated concentrations of light absorbing aerosols throughout the entire Arctic with an impact on the radiation transmission of the Arctic atmosphere. The results of Ward et al. (2012) based on Chemical Mass Balance modeling revealed that wood smoke was the major source of PM<sub>2.5</sub> particles mainly during the winter months at several locations in Fairbanks. Haque et al. (2016) found high contributions of isoprene oxidation products than monoterpene and sesquiterpene oxidation products to SOA formation in summer due to the more isoprene emissions and high levels of oxidants. They estimated isoprene-derived secondary organic carbon (SOC) nearly 5 times higher than SOA derived from monoterpene and nearly 2 times higher than sesquiterpene-derived SOA in central Alaska.”

Please see lines 69-77 and 84-106 in the revised manuscript.

Line 107: The authors mention that field blanks were analyzed. But how many field blanks were included in the analysis? This would be useful information to include.

Reply: We included 3 field blanks that were collected during the campaign. We have added this information in the revised manuscript.

Please see line 138 in the revised manuscript.

Line 136 and 137: Do the authors correct the concentrations of reported organic compounds for recoveries. It should be mentioned in section 2.3.

Reply: We did not correct the concentrations of reported organic compounds for their recoveries. We provided this information in the revised manuscript.

Please see line 168 in the revised manuscript.

Line 172-175: Hennigan et al. (2010) proposed the degradation of levoglucosan by hydroxyl (OH) radical. How does it affect the concentration level of levoglucosan during summertime in central Alaska?

Reply: Hennigan et al. (2010) and other studies such as Hoffmann et al. (2009) and Gensch et al. (2018) investigated that the hydroxyl (OH) radicals and photochemical processing during long-range atmospheric transport mostly induce the oxidation of levoglucosan in the atmosphere. Therefore, we propose that the levoglucosan degradation could be insignificant if the sampling site is close to the source region. The backward air mass trajectories during the sampling campaign indicated that the Alaskan PM<sub>2.5</sub> aerosols were mainly associated with the local and regional biomass burning. Hence, we consider that the levoglucosan degradation may not be an important factor to control the low levels of biomass burning tracers in the samples collected at the beginning and end of the campaign. The emission strength of biomass burning source and a wet deposition might be the major factors to control the temporal variations of levoglucosan in the Alaskan samples. Therefore, we have added following discussion for the possible degradation of levoglucosan in the Alaskan atmosphere during the campaign.

“The chemical reaction of anhydrosugars could also influence their concentrations in the atmosphere. Although previous studies have reported that levoglucosan can remain stable in the atmosphere for around 10 days with no substantial degradation (Fraser and Lakshmanan, 2000; Schkolnik and Rudich, 2006), recent findings (Hoffmann et al., 2009; Hennigan et al., 2010; Gensch et al., 2018) reported significant chemical reactivity of levoglucosan and have raised a question over the stability of levoglucosan in the atmosphere. Hennigan et al. (2010) carried out a smog chamber experiment and reported the lifetime of atmospheric levoglucosan to be 0.7 to 2.2 days when exposed to  $1 \times 10^6$  molecules of OH cm<sup>-3</sup>. This lifetime is within the range of 0.5 to 3.4 days predicted by Hoffmann et al. (2009) using the Spectral Aerosol Cloud Chemistry Interaction Model. Lai et al. (2014) found that the atmospheric lifetime of levoglucosan ranged from 1.2 to 3.9 days by the control experiment integrating OH in a flow reactor under different environmental conditions and different mixing states. Nevertheless, Bai et al. (2013) reported an atmospheric lifetime of levoglucosan to be 26 days under the different variables along with OH level of  $2 \times 10^6$  molecules cm<sup>-3</sup> that is much longer than other predictions.

It is notable from the above discussion that the degradation of levoglucosan is mostly induced by the oxidation reaction with OH radicals and photochemical aging during long-range transport. Therefore, the degradation of levoglucosan could be insignificant if the receptor site is close to the source region. As discussed previously, anhydrosugars detected in Alaskan aerosols during the campaign were originated from local and regional BB, we consider that the degradation of anhydrosugars may not be important to contribute the low levels of BB tracers in the samples collected at the beginning and end of the campaign.”

Please see lines 236-257 in the revised manuscript.

Line 211-222: The authors compared the L to M ratios in Fairbanks PM<sub>2.5</sub> samples with few studies reported for L to M ratios in specific burning materials. I suggest discussing the differences in L to M ratios in Alaskan aerosols and aerosol samples collected over the Arctic region and other locations.

Reply: We thank the reviewer for this suggestion. We added the following sentences towards the comparison of L to M ratios in Alaskan samples with aerosol samples collected over the Arctic region and other locations.

“Fine et al. (2001, 2002, 2004) presented the concentrations of BB tracers in fine particles derived from the burning of several wood species collected from the United States. Based on their data, we calculated the L/M ratios to be 3.4 to 6.7 for softwood burning and 10.7 to 83.4 for hardwood burning. Our values from the Alaskan aerosol (2.2 to 6.8) are well within the range of L/M ratios for softwood burning from the United States. The ratios in Alaskan aerosol samples are comparable to those for marine aerosols collected from the Arctic Ocean (ave. 3.5) (Fu et al., 2013), South China Sea (6.4) and western North Pacific (ave. 4.6) (Fu et al., 2011). Our values are also similar to those found in aerosol samples collected at Montana in the USA (4.6) (Ward et al., 2006), Vienna (4.1 to 6.4) and Salzburg (5.4 to 5.7) sites in Austria (Caseiro et al., 2009) and Moitinhos in Portugal (ave. 3.5) (Pio et al., 2008), where BB was dominated by burning of softwoods but lower than the ratios estimated in aerosol samples collected at Chennai in India (ave. 11.2) (Fu et al., 2010), Karachi in Pakistan (ave. 17.5) (Sahid et al., 2016), Lumbini in Nepal (ave. 15.1) (Wan et al., 2017), Morogoro in Tanzania (9 to 13) (Mkoma et al., 2013), Chiang Mai in Thailand (14.1 to 14.9) (Tsai et al., 2013) and Rondonia in Brazil (ave. 14.2) (Claeys et al., 2010), where hardwoods and crop residues were the major sources of biomass burning. Our results and above comparison imply that softwood is most likely biomass burned in central Alaska during the campaign.”

Please see lines 280-297 in the revised manuscript.

Line 569-573: There is a minimal discussion of the implications of the results in the context of Arctic climate. The manuscript would benefit from referring to any existing literature on the contribution of biomass burning to the aerosol burden. Such a discussion would significantly improve the manuscript.

Reply: As suggested we now refer to a few relevant references and made a detailed discussion about the implications of the result in the perspective of Arctic climate. We added the following sentences in the revised manuscript.

“The Arctic is a critical region on the Earth with a significant warming and high sensitivity to climate forcing due to a strong effect on an albedo-sea ice feedback system. Our results substantiated that forest fires and plant emissions are important factors controlling the organic chemical composition of fine aerosol particles in central Alaska. The results of Hegg et al. (2009) and Warneke et al. (2009) validate that BB causes a more efficient transport and deposition of BC aerosol in Arctic snow, causing a strong climate forcing in high latitudes. Based on in-situ measurements in the Arctic and a transport model of carbon monoxide (CO), Warneke et al. (2010) proposed that BB plumes transported to the Arctic in spring in 2008 were more than double the Arctic atmospheric burden in other seasons. Biogenic emissions from boreal forest largely increase during the summertime growing season. The year-round measurements conducted at Fairbanks by Haque et al. (2016) have shown that SOA derived from biogenic VOC emissions dominated organic chemical composition of total suspended particles during summer in central Alaska. The measurements of Ward et al. (2012) and Wang and Hopke (2014) demonstrate that Arctic air pollution could be so severe that the city of Fairbanks has been labeled as a serious nonattainment area by the United States Environmental Protection Agency.

It is worth therefore to note from the above discussion that the Fairbanks exemplifies many of the problems of pollution in the Arctic regions. The local and regional BB episodes in warmer season enhanced the atmospheric levels of OAs in central Alaska. Because residence time of fine particles is relatively long in the atmosphere, we propose that OAs of PM<sub>2.5</sub> at Fairbanks can be subjected to long-range transport to the Arctic causing a significant influence on the air quality and climate in the Arctic region. Although we studied the aerosol samples collected in 2009, further research is needed to characterize the seasonal and interannual trends of OAs using more recent aerosol samples to better evaluate their current impact in the Arctic atmosphere.”

Please see lines 671-695 in the revised manuscript.

Table 1: I would suggest adding median values for the concentrations of compounds groups presented in the table. A separate table showing the list of all organic compounds detected together with their concentration levels in all PM<sub>2.5</sub> aerosol samples of Fairbanks would be useful for the readers.

Reply: We added the median values for the compound groups given in Table 1. We now provided a Table S1 in the supplement with information on the list of all organic compounds measured and their concentrations in all PM<sub>2.5</sub> aerosol samples collected during the campaign.

Please see Table 1 in the revised manuscript and Table S1 in the supplement.

## References

- Bai, J., Sun, X., Zhang, C., Xu, Y., and Qi, C.: The OH-initiated atmospheric reaction mechanism and kinetics for levoglucosan emitted in biomass burning, *Chemosphere*, 93, 2004-2010, 2013.
- Barrie, L. A.: Arctic air pollution: an overview of current knowledge, *Atmos. Environ.* 20, 643-663, 1986.
- Caseiro, A., Bauer, H., Schmidl, C., Pio, C. A., and Puxbaum, H.: Wood burning impact on PM<sub>10</sub> in three Austrian regions, *Atmos. Environ.*, 43, 2186-2195, 2009.
- Claeys, M., Kourtchev, I., Pashynska, V., Vas, G., Vermeylen, R., Wang, W., Cafmeyer, J., Chi, X., Artaxo, P., and Andreae, M.: Polar organic marker compounds in atmospheric aerosols during the LBA-SMOCC 2002 biomass burning experiment in Rondonia, Brazil: sources and source processes, time series, diel variations and size distributions, *Atmos. Chem. Phys.*, 10, 9319-9331, 2010.
- Deshmukh, D. K., Haque, M. M., Kawamura, K., and Kim, Y.: Dicarboxylic acids, oxocarboxylic acids and  $\alpha$ -dicarbonyls in fine aerosols over central Alaska: implications for sources and atmospheric processes, *Atmos. Res.*, 202, 128-139, 2018.
- Fine, P. M., Cass, G. R., and Simoneit, B. R. T.: Chemical characterization of fine particle emissions from fireplace combustion of wood grown in the northeastern United States, *Environ. Sci. Technol.*, 35, 2665-2675, 2001.
- Fine, P. M., Cass, G. R., and Simoneit, B. R. T.: Chemical characterization of fine particle emissions from the fireplace combustion of woods grown in the Southern United States, *Environ. Sci. Technol.*, 36, 1442-1451, 2002.

- Fine, P. M., Cass, G. R., and Simoneit, B. R. T.: Chemical characterization of fine particle emissions from the fireplace combustion of woods types grown in the Midwestern and Western United States, *Environ. Eng. Sci.*, 21, 387-409, 2004.
- Fraser, M.P., Lakshmanan, K.: Using levoglucosan as a molecular marker for the long-range transport of biomass combustion aerosols, *Environ. Sci. Technol.*, 34, 4560-4564, 2000.
- French, N. H. F., Kasischke, E. S., and Williams, D. G.: Variability in the emission of carbon-based trace gases from wildfire in the Alaskan boreal forest, *J. Geophys. Res.*, 108, No. D1, 8151, doi:10.1029/2001JD000480, 2003.
- Fu, P. Q., Kawamura, K., and Miura, K.: Molecular characterization of marine organic aerosols collected during a round-the-world cruise, *J. Geophys. Res.*, 116, D13302, doi:10.1029/2011JD015604, 2011.
- Fu, P. Q., Kawamura, K., Chen, J., Charriere, B., and Sempere, R.: Organic molecular composition of marine aerosols over the Arctic Ocean in summer: contributions of primary emission and secondary aerosol formation, *Biogeosciences*, 10, 653-667, 2013.
- Fu, P. Q., Kawamura, K., Pavuluri, C. M., Swaminathan, T., and Chen, J.: Molecular characterization of urban organic aerosol in tropical India: contributions of primary emissions and secondary photooxidation, *Atmos. Chem. Phys.*, 2663-2689, 2010.
- Gensch, I., Sang-Arlt, X.F., Laumer, W., Chan, C.Y., Engling, G., Rudolph, J., and Kiendler-Scharr, A.: Using  $\delta^{13}\text{C}$  of levoglucosan as a chemical clock, *Environ. Sci. Technol.*, 52, 11094-11101, 2018.
- Haque, M. M., Kawamura, K., and Kim, Y.: Seasonal variations of biogenic secondary organic aerosol tracers in ambient aerosols from Alaska, *Atmos. Environ.*, 130, 95-104, 2016.
- Hegg, D. A. et al.: Source attribution of black carbon in Arctic snow, *Environ. Sci. Technol.*, 43, 4016-4021, 2009.
- Hennigan, C.J., Sullivan, A.P., Collett, J.L., and Robinson, A.L.: Levoglucosan stability in biomass burning particles exposed to hydroxyl radicals, *Geophys. Res. Lett.*, 37, L09806, doi:10.1029/2010GL043088, 2010.
- Hoffmann, D., Tilgner, A., Iinuma, Y., and Hermann, H.: Atmospheric stability of levoglucosan: a detailed laboratory and modeling study, *Environ. Sci. Technol.*, 44, 694-699, 2009.
- IPCC: Climate change 2001: the scientific basis. Contribution of Working Group I to the third assessment report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, 2001.
- Iziomon, M. G., Lohmann, U., and Quinn, P. K.: Summertime pollution events in the Arctic and potential implications, *J. Geophys. Res.*, 111, D12206, doi:10.1029/2005JD006223, 2006.
- Kaplan, J. O. and New, M.: Arctic climate change with a 2°C global warming: timing, climate patterns and vegetation change, *Climate Change*, 79, 213-241, 2006.
- Kim, Y., Hatsushika, H., Muskett, R. R., and Yamazaki, K.: Possible effect of boreal wildfire soot on Arctic sea ice and Alaska glaciers, *Atmos. Environ.*, 39, 3513-3520, 2005.
- Lai, C., Liu, Y., Ma, J., Ma, Q., and He, H.: Degradation kinetics of levoglucosan initiated by hydroxyl radical under different environmental conditions, *Atmos. Environ.*, 91, 32-39, 2014.
- Mitchell, J. M.: Visual range in the polar regions with special reference to the Alaskan Arctic, *J. Atmos. Terr. Phys. Spec. Suppl.*, 195-211, 1957.
- Mkoma, S. L., Kawamura, K., and Fu, P. Q.: Contributions of biomass/biofuel burning to organic aerosols and particulate matter in Tanzania, East Africa, based on analyses of

- ionic species, organic and elemental carbon, levoglucosan and mannosan, *Atmos. Chem. Phys.*, 13, 10325-10338, 2013.
- Nordenskiöld, A. E.: Nordenskiöld on the inland ice of Greenland, *Science*, 44, 732-738, 1883.
- Pio, C. A., Legrand, M., Alves, C. A., Oliveira, T., Afonso, J., Caseiro, A., Puxbaum, H., Sanchez-Ochoa, A., and Gelencser, A.: Chemical composition of atmospheric aerosols during the 2003 summer intense forest fire period, *Atmos. Environ.*, 42, 7530-7543, 2008.
- Schkolnik, G., Rudich, Y.: Detection and quantification of levoglucosan in atmospheric aerosols: a review, *Anal. Bioanal. Chem.*, 385, 26-33, 2006.
- Shahid, I., Kistler, M., Mukhtar, A., Ghauri, B. M., Cruz, C. R., Bauer, H., and Puxbaum, H.: Chemical characterization and mass closure of PM<sub>10</sub> and PM<sub>2.5</sub> at an urban sites in Karachi - Pakistan, *Atmos. Environ.*, 128, 114-123, 2016.
- Simoneit, B. R. T., Kobayashi, M., Mochida, M., Kawamura, K., Lee, M., Lim, H. J., Turpin, B. J., and Komazaki, Y.: Composition and major source of organic compounds of aerosol particulate matter sampled during the ACE-Asia campaign, *J. Geophys. Res.*, 109, D19S10, doi:10.1029/2004JD004598, 2004a.
- Stohl, A. et al.: Pan-Arctic enhancements of light absorbing aerosol concentrations due to North American boreal forest fires during summer 2004, *J. Geophys. Res.*, 111, D22214, doi:10.1029/2006JD007216, 2006.
- Tsai, Y. I., Sopajaree, K., Chotruska, A., Wu, H. C., and Kuo, S. C.: Source indicators of biomass burning associated with inorganic salts and carboxylates in dry season ambient aerosol in Chiang Mai Basin, Thailand, *Atmos. Environ.*, 78, 93-104, 2013.
- Wan, X. et al.: Organic molecular tracers in the atmospheric aerosols from Lumbini, Nepal, in the northern Indo-Gangetic Plain: influence of biomass burning, *Atmos. Chem. Phys.*, 17, 8867-8885, 2017.
- Wang, Y. and Hopke, P.K.: Is Alaska truly the great escape from air pollution? Long term source apportionment of fine particulate matter in Fairbanks, Alaska, *Aerosol Air Qual. Res.*, 14, 1875-1882, 2014.
- Ward, T. J., Hamilton, R. F., Dixon, R. W., Paulsen, M., and Simpson, C. D.: Characterization and evaluation of smoke tracers in PM: results from the 2003 Montana wildfire season, *Atmos. Environ.*, 40, 7005-7017, 2006.
- Ward, T., Trost, B., Conner, J., Flanagan, J., and Jayanty, R. K. M.: Source apportionment of PM<sub>2.5</sub> in a subarctic airshed - Fairbanks, Alaska, *Aerosol Air Qual. Res.*, 12, 536-543, 2012.
- Warneke, C et al.: An important contribution to springtime Arctic aerosol from biomass burning in Russia, *Geophys. Res. Lett.*, 37, L01801, doi:10.1029/2009GL041816, 2010.
- Warneke, C. et al.: Biomass burning in Siberia and Kazakhstan as an important source for haze over the Alaskan Arctic in April 2008, *Geophys. Res. Lett.*, 36, L02813, doi:10.1029/2008GL036194, 2009.