Reply to review comments from reviewer #2

“Artic spring and summertime aerosol optical depth baseline from long-term observations and model reanalyses, with implications for the impact of regional biomass burning processes” by Xian et al. takes a multi-sensor/dataset approach to characterizing Arctic aerosols climatologically and their trends over the past almost two decades. These results are interpreted geographically, seasonally, as well as by aerosol species and instrument sensors.

In general, my recommendation to the editor is minor revisions for this publication. While I am not familiar with all the literature out there on Arctic aerosols, this study seems to be quite comprehensive, which provides value in characterizing Arctic aerosols from many different angles across the entire region. However, there were a few scientific and presentation matters that should be addressed prior to publication.

Reply: We thank for the reviewer’s comments, which we think helps to improve the clarity and presentation of the manuscript.

For the AERONET data, I wonder about how the availability of AERONET data plays out when using a 6-hour averaging interval. AERONET data is primarily a daytime measurement, therefore it is affected by the changing of daylight. For example, if there are more measurements closer to summer solstice because of daylight hours, does that impact the results? I am not sure how that would play out on the results here but see Appendix B of “The Diurnal Variation of the Aerosol Optical Depth at the ARM SGP Site” by Balmes et al. (2021, Earth and Space Science; doi.org/10.1029/2021EA001852) which showed that the changing of the season affected the diurnal cycle of AOD when considering AERONET measurements. Since AERONET is the basis for much of the comparison in this study, the averaging interval should be carefully considered to ensure the conclusions are not artifacts of data availability.

Reply: AERONET data is more available during summer than in springtime due to longer daylight. This is reflected in the difference of the total number of observations for JJA and MAM in Table 1. We expect some impact of summer vs spring sampling on the annually-averaged diurnal variation of the AOD if there is baseline AOD change between the two seasons (e.g. much higher summer AOD than spring AOD as shown in Appendix B of Balmes et al. (2021)). However diurnal variation of the AOD is not the focus of this manuscript, nor is the annual-mean diurnal cycle (actually, spring- and summer-averaged diurnal cycles would help avoid those spring vs summer sampling influences on the annually-averaged diurnal cycle). Nevertheless, we performed resampling of AERONET AOD data to demonstrate that our result is changed little by 6hrly vs daily sampling. Most of the Arctic AERONET sites have stable numbers of observations between 6-18hr local time (i.e., magnitude of the number of observations are stable between 6-18hr, while it drops at some earlier or later hours): so we generated AERONET daily AOD statistics with data restricted to 6-18hr local time. A supplemental table was produced to enable a direct comparison of Table 1 with the

6hrly statistics. The following text is added in section 2.4 AERONET AOD data introduction:

"To explore the potential impact of different temporal sampling on the result (e.g., Balmes et al., 2021), we generated AERONET daily AOD statistics (Table S1) to enable a direct comparison of Table 1 with the 6hrly statistics. In general, the mean and median of MAM or JJA AODs (including total, FM and CM AODs) at the ten AERONET sites change very slightly (mostly 0.00, or <=0.01). As expected, the standard deviation is smaller for the daily AOD case than for 6hrly AOD (due to temporal averaging)."

Table S1. Analogous table to Table 1 but using daily AOD statistics. The AERONET daily AOD statistics was generated with data restricted to 6-18hr local time when there are stable numbers of observations (i.e., magnitude of the number of observations are stable between 6-18hr, while it drops at some earlier or later hours).

sites	latitude	longitude	elevation (m)	region	MAM (mean|median|std)				MAM FMF		JJA (mean|median|std)				JJA FMF	
					total AOD	FM AOD	CM AOD	n	mean	median	total AOD	FM AOD	CM AOD	n	mean	median
Hornsund	77.0N	15.6E	12	Svalbard	0.10|0.09|0.05	0.07|0.06|0.04	0.03|0.02|0.03	215	0.72	0.76	0.08|0.06|0.07	0.06|0.04|0.07	0.02|0.01|0.02	302	0.76	0.81
Thule	76.5N	68.8W	225	Greenland	0.09|0.07|0.05	0.06|0.06|0.03	0.03|0.01|0.04	324	0.76	0.81	0.07|0.05|0.08	0.06|0.04|0.08	0.01|0.01|0.02	464	0.85	0.87
Kangerlussuaq	67.0N	50.6W	320	Greenland	0.07|0.06|0.03	0.05|0.04|0.02	0.02|0.02|0.02	295	0.69	0.72	0.07|0.05|0.05	0.05|0.04|0.04	0.01|0.01|0.02	476	0.77	0.82
Ittoqqortoormiit	70.5N	21.0W	68	Greenland	0.06|0.06|0.03	0.04|0.04|0.02	0.02|0.01|0.03	193	0.72	0.78	0.06|0.04|0.04	0.05|0.03|0.04	0.01|0.01|0.02	369	0.80	0.84
Andenes	69.3N	16.0E	379	Norway	0.09|0.07|0.06	0.05|0.04|0.04	0.03|0.02|0.04	226	0.67	0.72	0.08|0.06|0.05	0.06|0.05|0.05	0.02|0.01|0.02	331	0.75	0.79
Resolute_Bay	74.7N	94.9W	35	Canada	0.10|0.09|0.05	0.07|0.06|0.03	0.03|0.02|0.03	173	0.72	0.74	0.07|0.05|0.09	0.06|0.04|0.09	0.02|0.01|0.02	371	0.78	0.83
Barrow	71.3N	156.7W	8	Alaska	0.12|0.09|0.10	0.08|0.06|0.07	0.04|0.02|0.06	158	0.69	0.74	0.09|0.06|0.09	0.07|0.05|0.09	0.02|0.01|0.02	335	0.79	0.82
Bonanza_Creek	64.7N	148.3W	353	Alaska	0.11|0.07|0.09	0.06|0.04|0.07	0.04|0.02|0.04	297	0.64	0.65	0.18|0.09|0.27	0.16|0.06|0.26	0.02|0.02|0.02	445	0.78	0.82
Tiksi	71.6N	129.0E	17	Siberia	0.09|0.10|0.03	0.07|0.07|0.02	0.03|0.02|0.02	13	0.73	0.78	0.13|0.08|0.19	0.11|0.07|0.18	0.02|0.01|0.02	139	0.81	0.85
Yakutsk	61.7N	129.4E	119	Siberia	0.15|0.11|0.15	0.11|0.08|0.13	0.04|0.02|0.06	517	0.73	0.77	0.17|0.09|0.23	0.14|0.07|0.23	0.02|0.01|0.03	748	0.81	0.84

An additional scientific issue I wonder about is that the CALIOP data only considers AODs greater than zero. Do other studies do this with CALIOP data? While there are instrument sensitivity limitations that preclude detecting all aerosols, leaving out when AOD=0 will artificially increase the mean AOD to a value not actually observed by the instrument. It is well documented that CALIOP cannot detect all aerosols and clouds and several of studies are cited in this reference, however, perhaps it would be more representative of the data to also include figures and data if AOD=0 is considered for CALIOP. Another option is the Level 3 AOD product which attempts to overcome the sensitivity issue. This data product is mentioned in the discussion but perhaps more discussion or a supplementary figure showing the various CALIOP AOD results from different data products and thresholds would be more representative of the instrument and data products.

Reply: We have now included more discussions in section 6 about the CALIOP AOD data used in the study and provided a supplemental figure (Fig. S4; also attached at the end of this reply document for your convenience) to help the comparison between the analysis with AOD=0 retained and removed. The artificial AOD value of zero is known by the CALIOP developing team and we are also well aware of the issue. We are hesitated to include AOD=0 into our study because those air columns with AOD=0 from

CALIOP actually represent air columns where CALIOP are blind to aerosol particles. Based on the paper first authored by Travis Toth (Toth et al., 2018), who is a coauthor of this paper, those air columns could have corresponding AOD (532 nm) of 0 to 0.1 or higher based on AERONET data. Giving the relative low mean AODs over or near the Arctic region, adding those air columns may likely introduce a low bias in climatological mean of AOD over the study region.

Toth T.D., J.R. Campbell, J.S. Reid, J.L. Tackett, M.A. Vaughan, and J. Zhang, Minimum Aerosol Layer Detection Sensitivities and their Subsequent Impacts on Aerosol Optical Thickness Retrievals in CALIPSO Level 2 Data Products, Atmos. Meas. Tech., 11, 499-514, https://doi.org/10.5194/amt-11-499-2018, 2018.

Our expanded discussion regarding this aspect in section 6 reads
"Often artificial AOD value of zero are observed over the Arctic in CALIOP V4.2 L2 and L3 data, resulted partially from algorithmically setting altitude bins with retrieval filled values in the aerosol profile to zero, as these represent undetectable levels of faint aerosol (i.e.,Toth et al., 2016; 2018). With AOD=0 values retained in the CALIOP V4.2 L2 data analysis (same processing in CALIOP V4.2 L3), the climatological seasonal mean AOD magnitude is much smaller (about half) than that shown in Fig. 3 and the AOD trends are slightly smaller than those in Fig. 9, although the spatial patterns of the seasonal AOD and trends are similar to those obtained with AOD data after removing the AOD=0 values (Fig. S4). After removing the pixels with filled and zero values, CALIOP AOD seasonal spatial AOD distributions are similar to those from MODIS and MISR. "

Below are minor comments I had and typos I found while reviewing:
Minor Comments:

The title is really long. Perhaps it should be shortened for brevity.
Reply: We think the current title represent the essence of the study and express the important implications for biomass burning processes, which we are really reluctant to remove.

Lines 138-139: "We define the Arctic/high-Arctic as regions north of 60°N/70°N, and sub-Arctic as regions between 60°N-70°N." It took me a second read through to understand this correctly. Since it is a definition sentence, it seems worth it to make it two sentences or edit it for clarity.
Reply: We have revised the statement to "We define the Arctic and the high-Arctic as regions north of 60°N and 70°N respectively. The lower-Arctic is defined as regions between 60°N-70°N.". We also changed all "sub-Arctic" to "lower-Arctic".

Data section: there is quite a lot of data used in this section so it leaves the reader a little overwhelmed to read through as well as to reference later on in the paper. Perhaps a table listing all the data described would be a useful summary to reference?
Reply: We have added the following table in the Appendix A and appended in the first paragraph of the data section "A summary of the datasets is provided in Appendix A."

Products	Data	resolution	time
MODIS (Moderate Resolution Imaging Spectroradiometer) C6.1L3	550nm AOD	1°x1° monthly	2003-2019
MISR (Multi-angle Imaging SpectroRadiometer) V23	558nm AOD	1°x1°, monthly	2003-2019
CALIOP (Cloud-Aerosol Lidar with Orthogonal Polarisation) V4.2L2	532nm AOD	2°x5°, monthly	2006-2019
AERONET (AErosol RObotic NETwork) V2L3	SDA total, FM, CM AOD at 550nm	6hrly, monthly	2003-2019
MAN (Marine Aerosol Network) Level2	SDA total, FM, CM AOD at 550nm	6hrly, monthly	2003-2019
MERRA-2 (Modern-Era Retrospective Analysis for Research and Applications, v2)	Total and speciated AOD at 550nm	0.5°lat x0.63°lon, monthly	2003-2019
CAMSRA (Copernicus Atmosphere Monitoring Service Reanalysis)	Total and speciated AOD at 550nm	0.7°x0.7°, monthly	2003-2019
NAAPS-RA v1 (Navy Aerosol Analysis and Prediction System reanalysis v1)	Total and speciated AOD at 550nm	1°x1°, 6hrly, monthly	2003-2019
MRC (Multi-Reanalysis-Consensus)	Total and speciated AOD at 550nm	1°x1°, monthly	2003-2019
FLAMBE (Fire Locating and Modeling of Burning Emissions) v1.0	BB smoke emission flux	1°x1°, monthly	2003-2019

Note: These are final form of data used in the result section. Some pre-processing and quality-control were applied to remote sensing data as described in the data section.

Figure 1: "Warm colors represent fine mode and cool colors represent coarse mode." I think this should be more explicit to avoid confusion, e.g., "warm colors (red, orange, and pink) … cool colors (green and blue)"
Reply: Revised.

Line 765: "(i.e. the square …" should have a comma after the i.e
Reply: Corrected.

Line 989-997 and throughout: I think "95% percentile mark" should be "95$_{th}$ percentile mark"? 95% percentile sounds redundant
Reply: Revised accordingly.

Figure 16: I think there may be a typo in the caption as it says 12 September 2012 after August 5, 2021?
Reply: Thanks for capturing this typo. It is corrected.

Line 1078: "black colors, respectively"
Reply: Revised.

Line 1124: figures should be capitalized
Reply: Revised.

Line 1134: Does the parenthesis starting "(e.g. …" go all the way to line 1139? I think this should be rewritten, very challenging to make sense of a 5 line parentheses
Reply: We have broken this into two sentences to make it easier to read.

Line 1134 and 1143: should have a comma after e.g. I think this might be an issue throughout for i.e. and e.g. so check throughout the text

Reply: Thanks! This is corrected throughout the text.

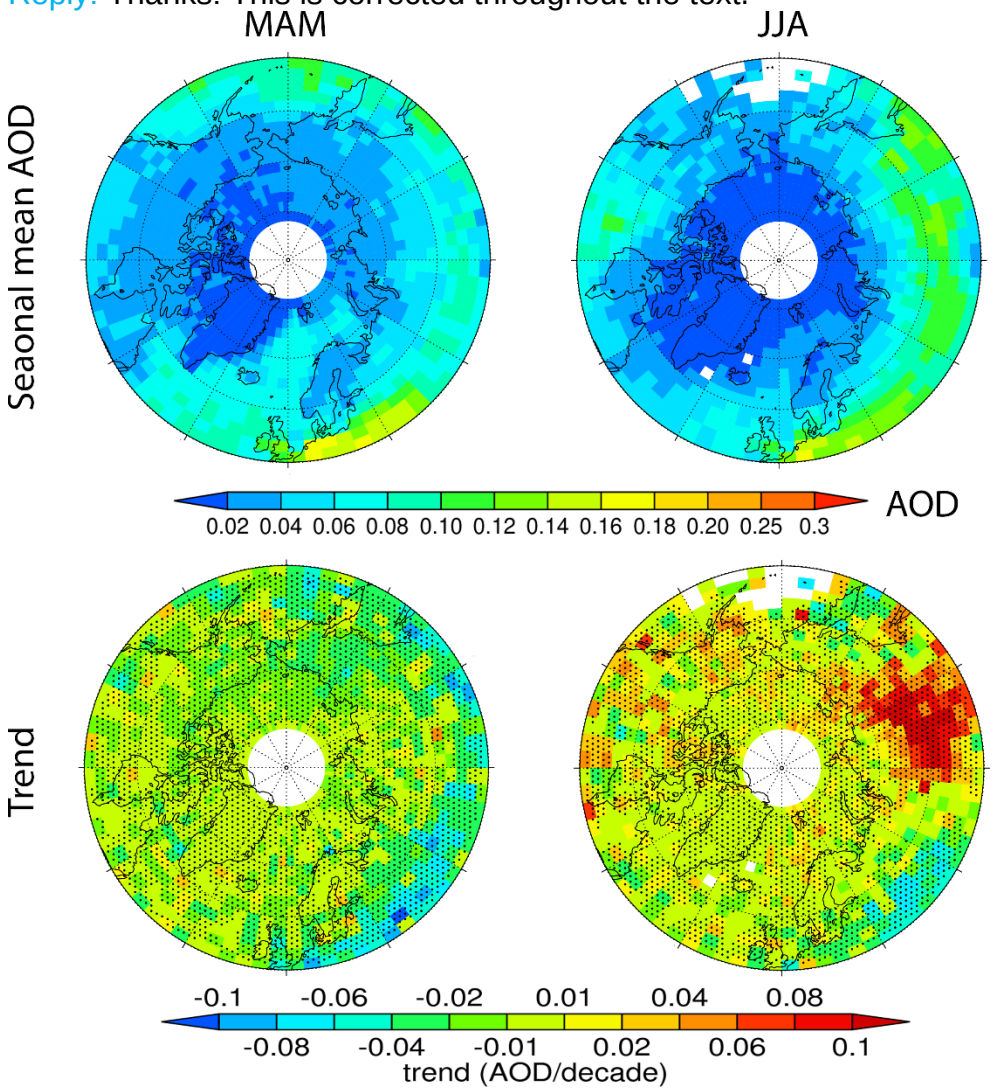

Figure S4. CALIOP mean climatological MAM (upper-left) and JJA (upper-right) AOD at 532 nm (2006-2019) and AOD trends (lower) derived with AOD=0 values retained in the CALIOP V4.2 L2 data analysis, to compare with CALIOP AOD seasonal climatology and trends derived with AOD=0 values removed in Fig. 3 and Fig. 9. White area means lack of data.