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Investigating the vertical extent of the 2023 summer Canadian wildfire impacts with satellite observations

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Table S1: Number of monthly ACE-FTS occultations measurements taken between 40 and 70° N over the measurement period 2004 – 2022.

Year	May	June	July	August	September
2023	278	87	353	20	151
2022	293	95	269	21	164
2021	316	93	354	24	163
2020	308	89	302	25	160
2019	315	115	288	42	164
2018	321	117	326	41	171
2017	318	112	327	35	173
2016	301	109	330	28	160
2015	254	98	260	43	146
2014	256	81	236	38	151
2013	215	66	244	33	151
2012	284	92	252	32	152
2011	290	82	275	30	157
2010	296	82	274	23	154
2009	304	70	309	12	80
2008	274	61	280	1	150
2007	240	43	219	0	91
2006	255	50	226	0	103
2005	361	68	306	3	149
2004	35	31	193	10	100

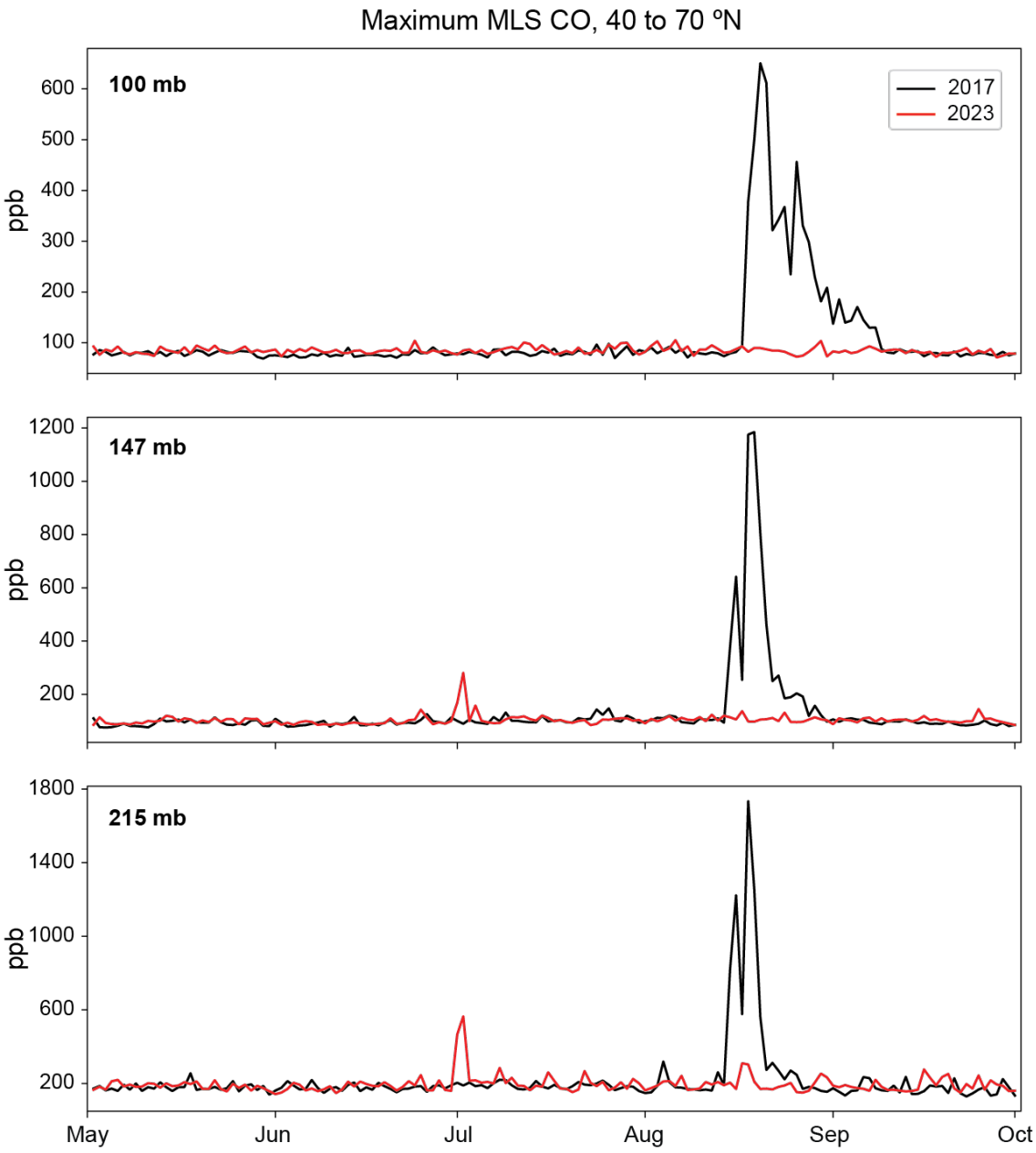

Figure S1: Carbon monoxide data from MLS. The maximum CO at three different levels in the lower stratosphere are shown for 2017 (black) and 2023 (red). The stratospheric impact of the 2017 Pacific Northwest Event is evident, while the 2023 Canadian wildfires show a small perturbation in July only up to 147 mb.

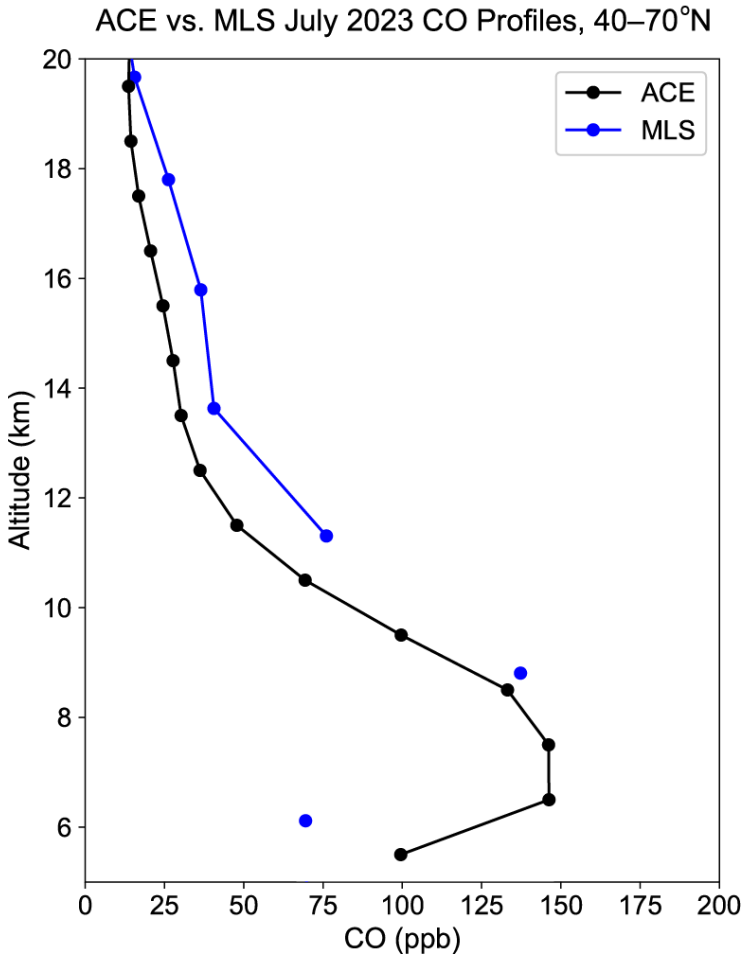

Figure S2: Comparison between MLS and ACE-FTS CO profiles. The average July 2023 values between 40 and 70 °N for MLS data are shown here in blue, and the average of every ACE occultation measurement taken between the same latitude range is shown in black. The MLS data is connected up to the lowest point of recommended use (215 hPa), and the remaining data is plotted as isolated points. The ACE data has higher vertical resolution and better signal lower in the atmosphere.

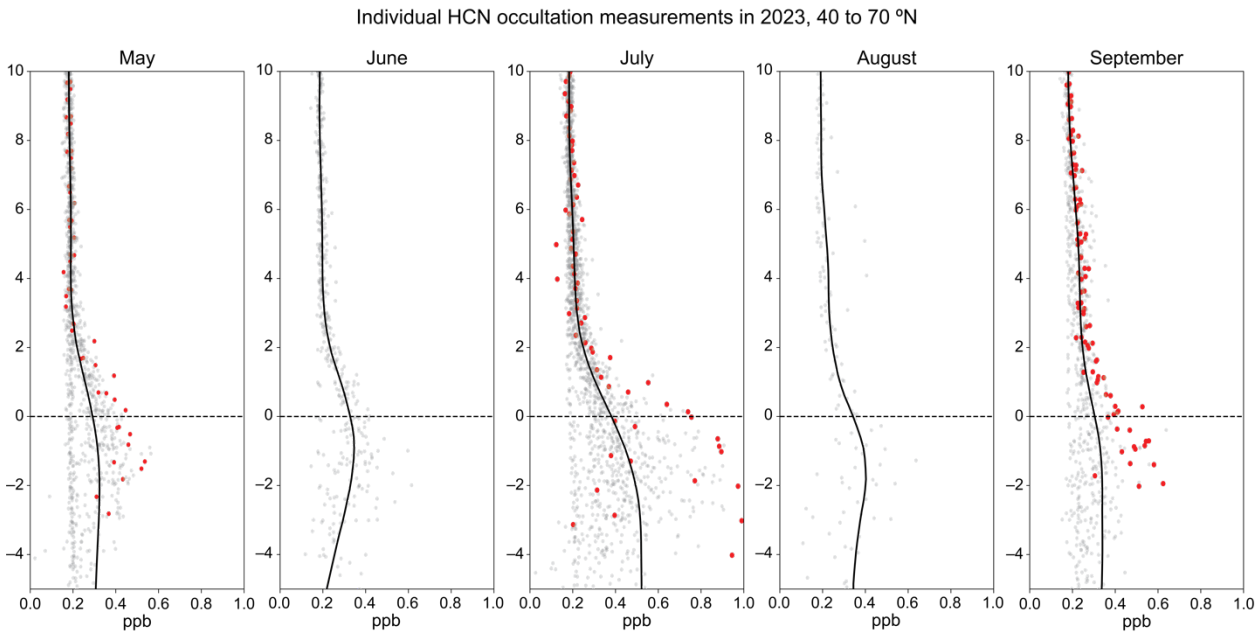

Figure S3: Individual ACE-FTS HCN measurements for May through September 2023. Each occultation is plotted relative to its self-consistent tropopause height calculated from concurrent temperature profiles. The average of these tropopause-adjusted occultations for each month is shown in black. Occultations highlighted in red exhibit both elevated HCN and aerosol extinction in the stratosphere (Fig. 3, Fig. S5). Other occultations that exhibit enhanced HCN in the stratosphere do not exhibit similarly high aerosol extinction measurements, complicating interpretation of stratospheric entry, as shown in Figure S4.

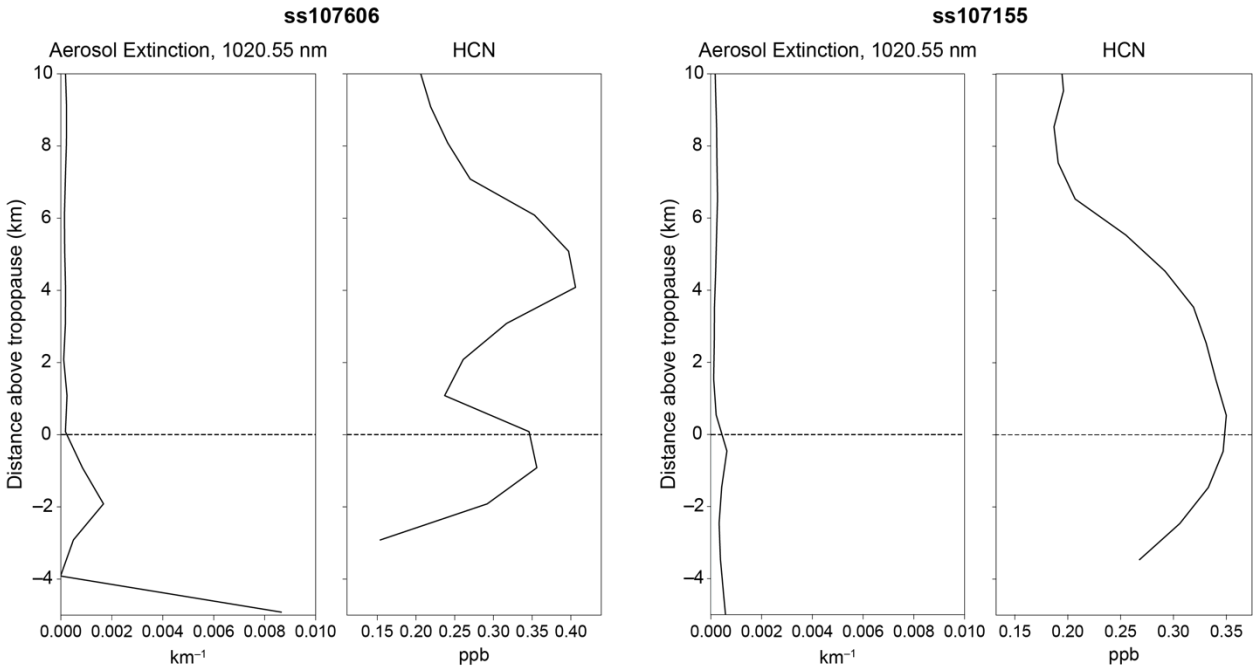

Figure S4. Example occultations with enhanced HCN volume mixing ratios that do not exhibit similarly enhanced aerosol extinction. These measurements cannot be confidently attributed to fresh smoke since they do not measure aerosols in addition to gaseous biomass burning products. HCN has a long lifetime, and tropical observations indicate a seasonal source likely due to global biomass burning and upward transport into the stratosphere (Pumphrey et al., 2008). This source implies that enhanced HCN alone does not indicate a fresh biomass-burning plume but rather a more diffuse wildfire influence. Thus, the presence of simultaneous aerosol extinction and HCN VMR enhancement is important for identifying recent smoke influences.

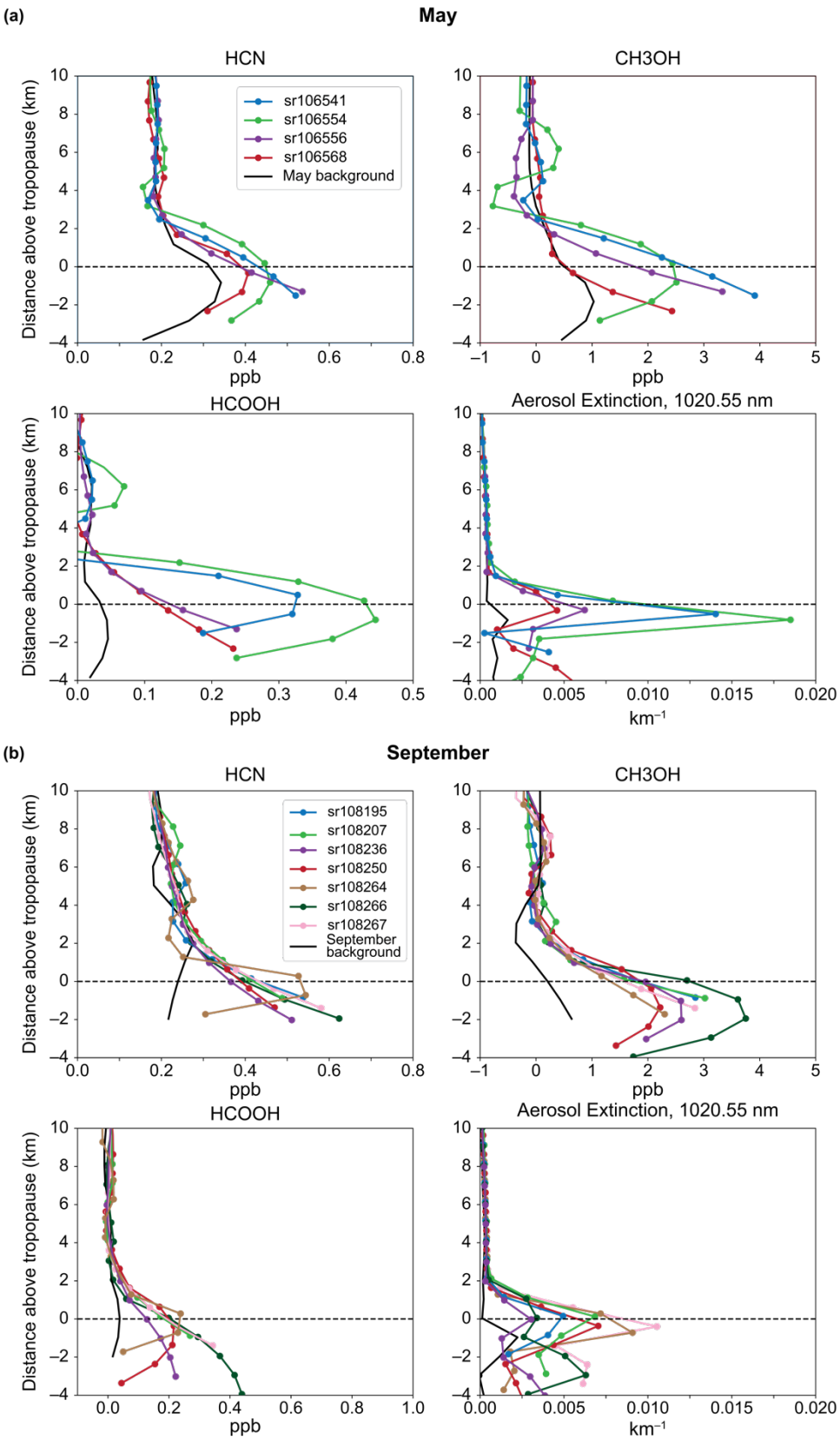

Figure S5. Tropopause-relative profiles for (a) May and (b) September 2023 occultations that exhibit enhanced wildfire product VMRs and aerosol extinction in the lower stratosphere. Background profiles with no smoke from similar locations, sr106467 (May) and sr108161 (September), are plotted for reference.

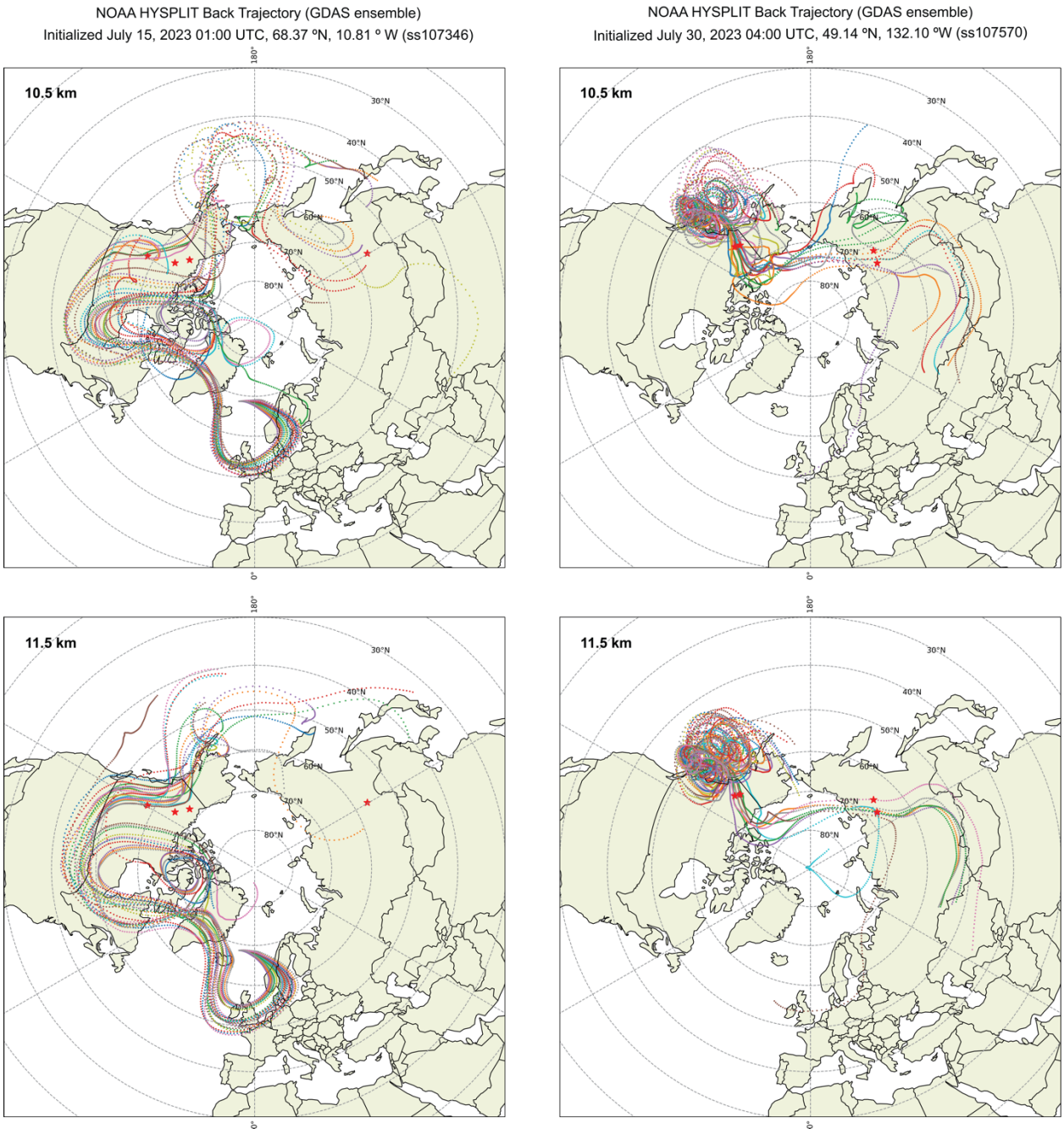

Figure S6: NOAA HYSPLIT back-trajectory ensembles run on GDAS 1-degree meteorology. All of the trajectories were initialized from ACE measurement locations and times and run backwards for 315 hours. Launch altitudes were varied to cover a range of where elevated VMRs and aerosol extinction values were measured. Red stars indicate locations of reported pyroCbs up to two weeks before the ACE measurement time. Trajectories from the only two occultations that pass near reported pyroCbs are shown here.

A trajectory initialized from ss107346 (left panel) at 11.5 km reaches 57.95 ºN, -120.7 ºW at 18:00 UTC on July 5th 2023, near a reported pyroCb at 58.2 ºN, 120.46 ºW around 01:00 UTC on July 6th 2023. Trajectories initialized from ss107570 (right panel) at 11.5 km pass near two reported pyroCbs: 1) trajectory point 67.6º N, 130.2 ºW at 20:00 UTC July 21st near a reported pyroCb at 67.4 ºN, 130.1 ºW around 23:40 UTC July 22nd and 2) trajectory point 62.7 ºN, 133.7 ºW at 22:00 UTC July 24th near a reported pyroCb at 63 ºN, 133.8 ºW around 02:40 UTC July 24th. These times and locations do not exactly coincide, but suggest the possible influence of fires in the region on measured atmospheric composition.

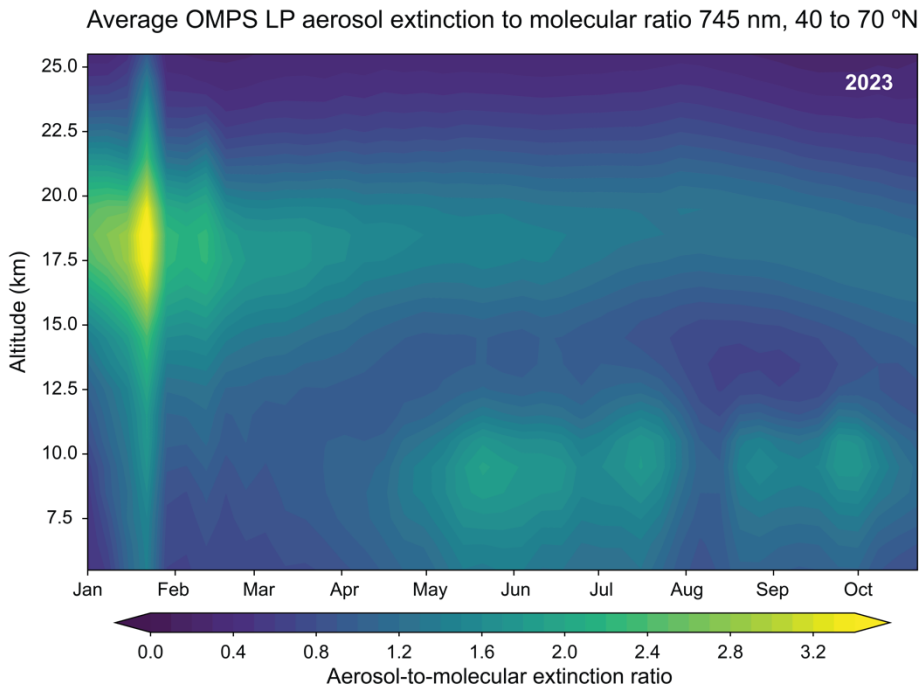

Figure S7. OMPS aerosol-to-molecular extinction ratio averaged between 40 and 70 ºN. The evolution of vertical aerosol distribution over 2023 shows two clear features: a large aerosol burden around 18 km present from the start of the year (not wildfires) and an increase in upper tropospheric aerosol burden starting in May 2023 (wildfires).

References

Pumphrey, H. C., Boone, C., Walker, K. A., Bernath, P., and Livesey, N. J.: Tropical tape recorder observed in HCN, Geophys. Res. Lett., 35, L05801, https://doi.org/10.1029/2007GL032137, 2008.