Supplement to

Global VOC emissions quantified from inversion of TROPOMI spaceborne formaldehyde and glyoxal data

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This supplement contains 4 figures and 2 tables which support the main manuscript.

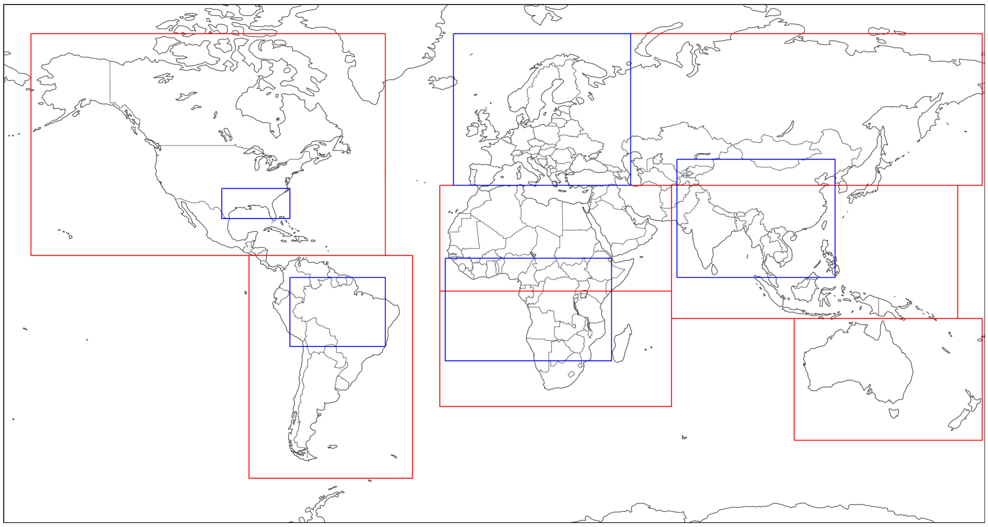

Figure S1. Eight regions (outlined in red) used for the calculation of the bottom-up and top-down emissions of Table 4 in the main text. North America: 13-75°N, 40-170°W, South America: 60°S-13°N, 30-90°W, Northern Hemisphere Africa: 0-37°N, 20°W-65°E, Southern Hemisphere Africa: 0-40°S, 20°W-65°E, North Asia: 37-75°N, 50-179°E, South Asia: 10°S-37°N, 65-170°E, Oceania: 10-50°S, 110-179°E and Europe: 37-75°N, 15°W-50°E (in red overlayed with blue). Blue boxes corespond to regions for the time series in main text Fig. 4: Southeast US: 26-36°N, 75-100°W, Amazonia: 20°S-5°N, 40-75°W, Equatorial Africa: 25°S-12°N, 18°W-43°E, Southeast Asia: 5-45°N, 67-125°E and Europe: 37-75°N, 15°W-50°E.

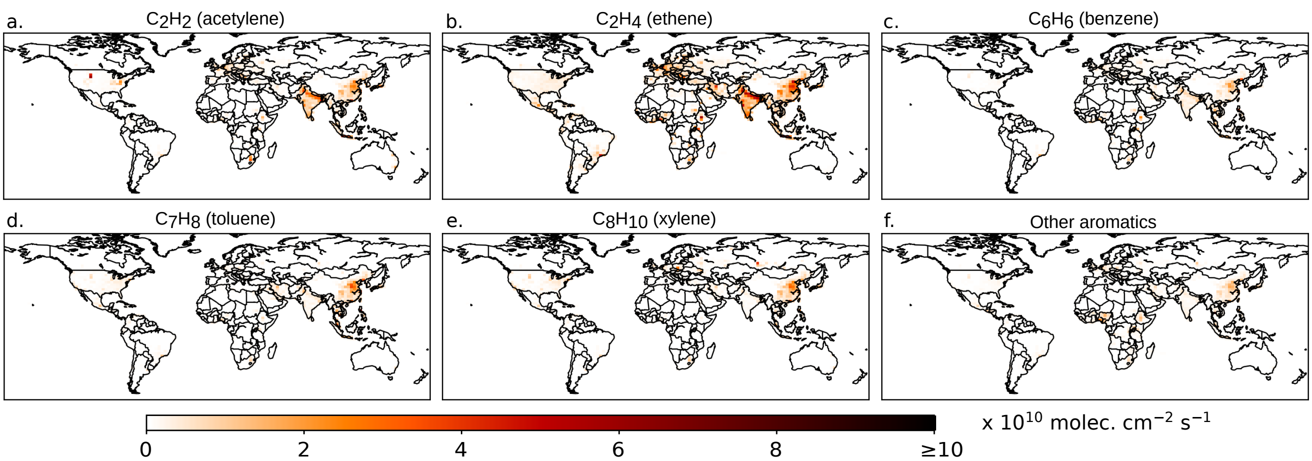

Figure S2. Distribution of a priori glyoxal precursor emission fluxes of anthropogenic origin based on the CAMS-GLOB-ANT inventory, averaged over 2021.

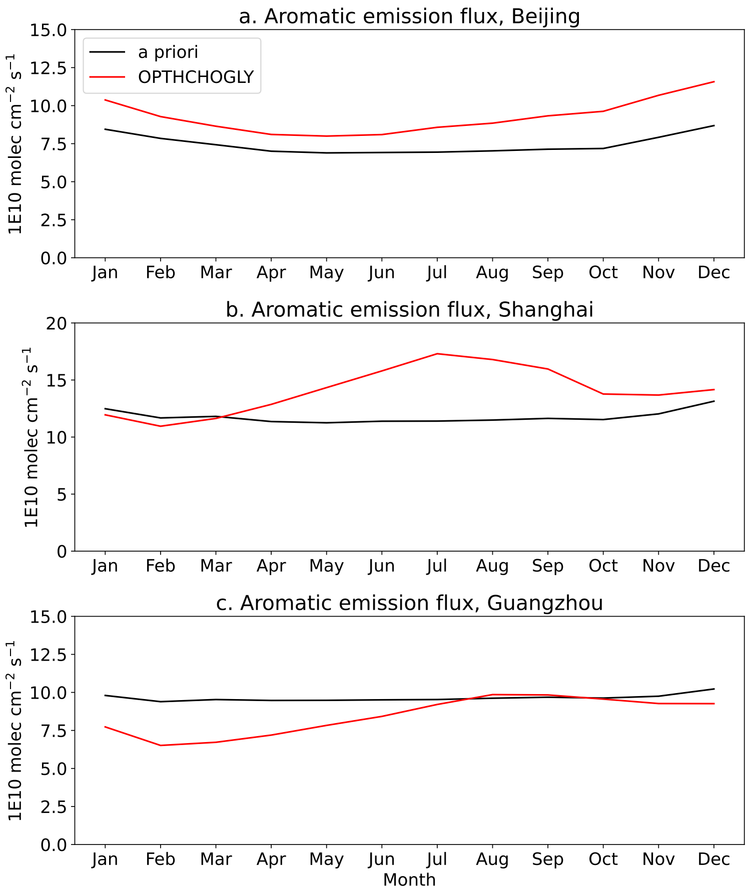

Figure S3. Time series for 2021 of anthropogenic aromatic emission flux from CAMS-GLOB-ANT (a priori) and from the OPTHCHOGLY inversion which is constrained by TROPOMI HCHO and CHOCHO data (a posteriori) for a. the Jing-Jin-Ji area around Beijing (115–117.5°E, 38–40°N); b. the Yangtze River Delta around Shanghai (120–122.5°E, 30–32°N); and c. the Pearl River Delta around Guangzhou (112.5–115°E, 22–24°N).

Table S1. Observed CHOCHO mixing ratios (pptv) from in situ measurement campaigns at 17 rural sites (between 1988 and 2018), and simulated values from a priori and optimized (OPTHCHOGLY) model (2021). Ind.: Index in main text Fig. 11. Country: ISO country code. Lat.: latitude. Long.: longitude. Month: start and end month. Time: start and end local time of measurement. Obs.: Observed. A priori: a priori model. Optimized: Optimized model. Different rows for the Sierra Nevada Mountains campaign correspond to different years. At Tomakomai, measurements were performed at 22 and 38 m above ground level. Some subsets of the observations are listed for different times of the month: [1]late October, [2]early October, [3]mid-October.

Ind.	Site	Country	Lat.	Long.	Month	Time	Obs.	A priori	Optimized	Reference
1	Sierra Nevada Mts	USA	38.90	239.37	8-9	00-24	50	32	63	Huisman et al. (2011)
2	Sierra Nevada Mts	USA	38.90	239.37	9	00-24	30	26	48	Huisman et al. (2011)
3	Sierra Nevada Mts	USA	38.90	239.37	8-9	06-21	27	32	63	Spaulding et al. (2003)
4	Sierra Nevada Mts	USA	38.90	239.37	6-7	00-24	56	32	57	DiGangi et al. (2012)
5	San Nicolas Isl.	USA	33.25	240.48	9	00-24	100	20	35	Grosjean et al. (1996)
6	Central Rocky Mts	USA	39.10	254.90	8	00-24	30	14	37	DiGangi et al. (2012)
7	Georgia	USA	32.53	277.87	7-8	14-17	18	52	65	Lee et al. (1995)
8	Georgia	USA	32.53	277.87	6	14-17	83	40	51	Lee et al. (1995)
9	Pinnacles	USA	38.62	281.65	9	00-24	44	30	48	Munger et al. (1995)
10	Manacapuru	BRA	-3.30	299.40	9	00-24	17	47	57	Thayer et al. (2015)
11	Manacapuru	BRA	-3.30	299.40	10	00-24	8	46	55	Thayer et al. (2015)
12	Anadia	PRT	40.42	351.60	8	00-24	40	23	39	Cerqueira et al. (2003)
13	Tabua	PRT	40.32	351.95	8	00-24	150	24	40	Cerqueira et al. (2003)
14	Goldlauter[1]	DEU	50.64	10.76	10	23-13	20	10	12	Müller et al. (2005)
15	Goldlauter[2]	DEU	50.64	10.76	10	19-11	10	10	12	Müller et al. (2005)
16	Goldlauter[3]	DEU	50.64	10.76	10	22-04	5	10	11	Müller et al. (2005)
17	Pabstthum	DEU	52.85	12.94	7	00-24	38	28	41	Moortgat et al. (2002)
18	Wangdu	CHN	38.70	115.14	6	00-24	50	45	56	Min et al. (2016)
19	Borneo Rainforest	MYS	4.98	117.84	4-5	00-24	385	40	111	MacDonald et al. (2012)
20	Borneo Rainforest	MYS	4.98	117.84	6-7	00-24	328	39	111	MacDonald et al. (2012)
21	Yangtze River Delta	CHN	32.56	119.99	5-6	00-24	100	51	57	Liu et al. (2020)
22	Tomakomai (22 m)	JPN	42.73	141.52	9	09-22	25	12	21	Ieda et al. (2006)
23	Tomakomai (38 m)	JPN	42.73	141.52	9	09-22	28	13	22	Ieda et al. (2006)
24	Moshiri	JPN	44.30	142.20	8	00-24	18	14	25	Matsunaga et al. (2004)
25	Cape Grim	AUS	-40.68	144.69	8-9	00-24	7	2	4	Lawson et al. (2015)

Table S2. Observed CHOCHO mixing ratios (pptv) during in situ measurement campaigns at 20 urban sites, and calculated values from the a priori and optimized (OPTHCHOGLY) model. Ind.: Index in main text Fig. 11. Country: country code. Lat.: latitude. Long.: longitude. Month: start and end month. Time: start and end local time of measurement. Obs.: Observed. A priori: A priori model. Optimized: Optimized model. Different rows for the PKU campaigns correspond to different years. Some subsets of the observations are listed for different times of the day or month: [1]Jun 29, midday, and [2]evening; [3]Jun 30, midday, and [4]evening; [5]Jul 20, morning, [6]midday, [7]afternoon, and [8]evening; [9]Jul 6, morning, [10]midday, [11]afternoon, and [12]evening; [13]Sep 22, early morning, and [14] late morning. MIT = Massachusetts Institute of Technology, USP = Universidade de São Paulo, CETESB = Companhia Ambiental do Estado de São Paulo, HKUST = Hong Kong University of Science and Technology, PKU = Peking University, CRAES = Chinese Research Academy of Environmental Sciences.

Ind.	Site	Country	Lat.	Long.	Month	Time	Obs.	A priori	Optimized	Reference
26	Los Angeles	USA	34.07	241.77	9	00-24	725	26	46	Grosjean et al. (1996)
27	Los Angeles	USA	34.14	241.88	5-6	15-16	190	21	38	Washenfelder et al. (2011)
28	Long Beach	USA	33.82	241.81	9	00-24	250	25	45	Grosjean et al. (1996)
29	Azusa	USA	34.14	242.08	9	00-24	950	24	44	Grosjean et al. (1996)
30	Claremont	USA	34.11	242.29	9	00-24	1175	23	43	Grosjean et al. (1996)
31	Las Vegas	USA	36.11	244.86	7-8	00-24	210	15	33	Jing et al. (2001)
32	Las Vegas	USA	36.11	244.86	11-2	00-24	140	8	13	Jing et al. (2001)
33	Mexico City	MEX	19.36	260.93	4	00-24	300	34	60	Volkamer et al. (2005)
34	Elizabeth	USA	40.66	285.78	3-5	00-24	780	20	25	Liu et al. (2006)
35	Elizabeth	USA	40.66	285.78	6-8	00-24	770	49	67	Liu et al. (2006)
36	Elizabeth	USA	40.66	285.78	9-11	00-24	550	25	34	Liu et al. (2006)
37	Elizabeth	USA	40.66	285.78	12-2	00-24	490	10	12	Liu et al. (2006)
38	MIT, Cambridge	USA	42.36	288.91	7	05-20	81	30	45	Sinreich et al. (2007)
39	USP, Sao Paulo[1]	BRA	-23.57	313.27	6	11-15	800	37	59	Grosjean et al. (1990)
40	USP, Sao Paulo[2]	BRA	-23.57	313.27	6	15-19	900	29	47	Grosjean et al. (1990)
41	USP, Sao Paulo[3]	BRA	-23.57	313.27	6	11-15	600	37	59	Grosjean et al. (1990)
42	USP, Sao Paulo[4]	BRA	-23.57	313.27	6	15-19	600	29	47	Grosjean et al. (1990)
43	USP, Sao Paulo[5]	BRA	-23.57	313.27	7	10-12	1300	31	52	Grosjean et al. (1990)
44	USP, Sao Paulo[6]	BRA	-23.57	313.27	7	12-14	1000	35	59	Grosjean et al. (1990)
45	USP, Sao Paulo[7]	BRA	-23.57	313.27	7	14-16	200	29	48	Grosjean et al. (1990)
46	USP, Sao Paulo[8]	BRA	-23.57	313.27	7	16-18	600	25	42	Grosjean et al. (1990)
47	CETESB, Sao Paulo[9]	BRA	-23.56	313.30	7	10-12	1100	32	52	Grosjean et al. (1990)
48	CETESB, Sao Paulo[10]	BRA	-23.56	313.30	7	12-14	700	36	59	Grosjean et al. (1990)
49	CETESB, Sao Paulo[11]	BRA	-23.56	313.30	7	13-15	700	32	53	Grosjean et al. (1990)
50	CETESB, Sao Paulo[12]	BRA	-23.56	313.30	7	15-17	200	26	43	Grosjean et al. (1990)
51	Rio de Janeiro	BRA	-22.90	316.80	5-11	08-11	152	21	33	Grosjean et al. (2002)
52	Salvador[13]	BRA	-12.99	321.47	9	08-10	150	16	23	Grosjean et al. (1990)
53	Salvador[14]	BRA	-12.99	321.47	9	09-11	1700	15	22	Grosjean et al. (1990)
54	Giesta	PRT	40.55	351.49	7-8	00-24	1540	21	35	Borrego et al. (2000)
55	Montelibretti	ITA	42.11	12.63	7	08-16	790	20	33	Possanzini et al. (2007)
56	Montelibretti	ITA	42.11	12.63	8	08-16	403	20	34	Possanzini et al. (2007)
57	Montelibretti	ITA	42.11	12.63	9	08-16	235	17	28	Possanzini et al. (2007)
58	Montelibretti	ITA	42.11	12.63	2	08-16	155	8	12	Possanzini et al. (2007)
59	Xi'an	CHN	34.22	109.01	6	00-24	70	55	82	Dai et al. (2012)
60	Xi'an	CHN	34.22	109.01	1	00-24	190	13	14	Dai et al. (2012)
61	Guangdong	CHN	22.73	112.93	1	00-24	100	31	32	Chang et al. (2019)
62	HKUST	HKG	22.33	114.26	12	00-24	1516	36	39	Ho et al. (2002)
63	PKU, Bejing	CHN	39.99	116.30	11	00-24	100	9	12	Shen et al. (2018)
64	PKU, Bejing	CHN	39.99	116.30	8	00-24	280	56	79	Qian et al. (2019)
65	PKU, Bejing	CHN	39.99	116.30	7-8	00-24	50	61	85	Qian et al. (2019)
66	PKU, Bejing	CHN	39.99	116.30	11	00-24	300	9	12	Qian et al. (2019)
67	PKU, Bejing	CHN	39.99	116.30	7	00-24	280	66	91	Rao et al. (2016)
68	PKU, Bejing	CHN	39.99	116.30	1-3	00-24	170	9	11	Rao et al. (2016)
69	CRAES, Bejing	CHN	40.04	116.41	7-8	07-19	680	80	111	Yang et al. (2018)

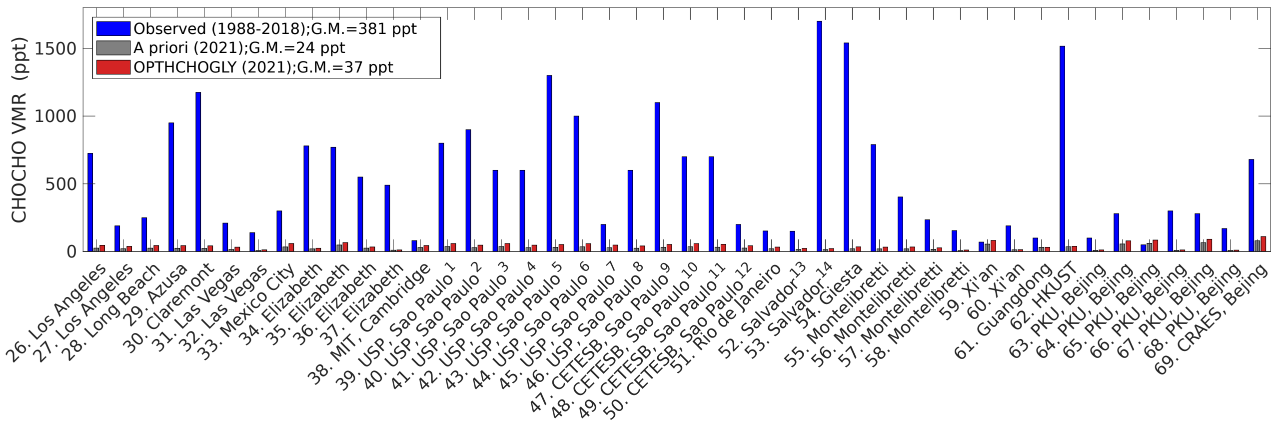

Figure S4. Observed CHOCHO concentrations during in-situ measurement campaigns at 20 urban sites, and CHOCHO concentrations from the a priori and optimized model for 2021. Numbering corresponds to the detailed entries in Table S2 and the locations on the map in main text Fig. 11. G.M.: geometric mean. Different bars for the PKU, Beijing campaign correspond to measurements in different years. Some subsets of the observations are listed for different times of the day or month: [1]Jun 29, midday, and [2]evening; [3]Jun 30, midday, and [4]evening; [5]Jul 20, morning, [6]midday, [7]afternoon, and [8]evening; [9]Jul 6, morning, [10]midday, [11]afternoon, and [12]evening; [13]Sep 22, early morning, and [14] late morning. MIT = Massachusetts Institute of Technology, USP = Universidade de São Paulo, CETESB = Companhia Ambiental do Estado de São Paulo, HKUST = Hong Kong University of Science and Technology, PKU = Peking University, CRAES = Chinese Research Academy of Environmental Sciences.

References

Borrego, C., Gomes, P., Barros, N. and Miranda, A. I.: Importance of handling organic atmospheric pollutants for assessing air quality, J. Chromatogr. A, 889, 271–279, https://doi.org/10.1016/S0021-9673(00)00230-2, 2000.

Cerqueira, M. A., Pio, C. A., Gomes, P. A., Matos, J. S. and Nunes, T. V.: Volatile organic compounds in rural atmospheres of central Portugal, Sci. Total Environ., 313, 49–60, https://doi.org/10.1016/S0048-9697(03)00250-X, 2003.

Chang, D., Wang, Z., Guo, J., Li, T., Liang, Y., Kang, L., Xia, M., Wang, Y., Yu, C., Yun, H., Yue, D. and Wang, T.: Characterization of organic aerosols and their precursors in southern China during a severe haze episode in January 2017, Sci. Total Environ., 691, 101–111, https://doi.org/10.1016/j.scitotenv.2019.07.123, 2019.

Dai, W. T., Ho, S. S. H., Ho, K. F., Liu, W. D., Cao, J. J. and Lee, S. C.: Seasonal and diurnal variations of mono- and di-carbonyls in Xi'an, China, Atmos. Res., 113, 102–112, https://doi.org/10.1016/j.atmosres.2012.05.001, 2012.

DiGangi, J. P., Henry, S. B., Kammrath, A., Boyle, E. S., Kaser, L., Schnitzhofer, R., Graus, M., Turnipseed, A., Park, J.-H., Weber, R. J., Hornbrook, R. S., Cantrell, C. A., Maudlin Iii, R. L., Kim, S., Nakashima, Y., Wolfe, G. M., Kajii, Y., Apel, E. C., Goldstein, A. H., Guenther, A., Karl, T., Hansel, A. and Keutsch, F. N.: Observations of glyoxal and formaldehyde as metrics for the anthropogenic impact on rural photochemistry, Atmos. Chem. Phys., 12, 9529–9543, https://doi.org/10.5194/acp-12-9529-2012, 2012.

Grosjean, D., Miguel, A. H. and Tavares, T. M.: Urban air pollution in Brazil: Acetaldehyde and other carbonyls, Atmos. Environ., 24, 101–106, https://doi.org/10.1016/0957-1272(90)90015-M, 1990.

Grosjean, E., Grosjean, D., Fraser, M. P. and Cass, G. R.: Air Quality Model Evaluation Data for Organics. 2. C 1 -C 14 Carbonyls in Los Angeles Air, Environ. Sci. Technol., 30, 2687–2703, https://doi.org/10.1021/es950758w, 1996.

Grosjean, D., Grosjean, E. and Moreira, L. F. R.: Speciated Ambient Carbonyls in Rio de Janeiro, Brazil, Environ. Sci. Technol., 36, 1389–1395, https://doi.org/10.1021/es0111232, 2002.

Ho, S. S. H. and Yu, J. Z.: Feasibility of Collection and Analysis of Airborne Carbonyls by On-Sorbent Derivatization and Thermal Desorption, Anal. Chem., 74, 1232–1240, https://doi.org/10.1021/ac015708q, 2002.

Hoque, H. M. S., Irie, H. and Damiani, A.: First MAX-DOAS Observations of Formaldehyde and Glyoxal in Phimai, Thailand, J. Geophys. Res. Atmos., 123, 9957–9975, https://doi.org/10.1029/2018JD028480, 2018.

Huisman, A. J., Hottle, J. R., Galloway, M. M., DiGangi, J. P., Coens, K. L., Choi, W., Faloona, I. C., Gilman, J. B., Kuster, W. C., De Gouw, J., Bouvier-Brown, N. C., Goldstein, A. H., LaFranchi, B. W., Cohen, R. C., Wolfe, G. M., Thornton, J. A., Docherty, K. S., Farmer, D. K., Cubison, M. J., Jimenez, J. L., Mao, J., Brune, W. H. and Keutsch, F. N.: Photochemical modeling of glyoxal at a rural site: observations and analysis from BEARPEX 2007, Atmos. Chem. Phys., 11, 8883–8897, https://doi.org/10.5194/acp-11-8883-2011, 2011.

Ieda, T., Kitamor, Y., Mochida, M., Hirata, R., Hirano, T., Inukai, K., Fujinuma, Y. and Kawamura, K.: Diurnal variations and vertical gradients of biogenic volatile and semi-volatile organic compounds at the Tomakomai larch forest station in Japan, Tellus B: Chem. Phys. Meteorol., 58, 177, https://doi.org/10.1111/j.1600-0889.2006.00179.x, 2006.

Jing, L., Steinberg, S. M. and Johnson, B. J.: Aldehyde and Monocyclic Aromatic Hydrocarbon Mixing Ratios at an Urban Site in Las Vegas, Nevada, J Air Waste Manag Assoc., 51, 1359–1366, https://doi.org/10.1080/10473289.2001.10464352, 2001.

Lawson, S. J., Selleck, P. W., Galbally, I. E., Keywood, M. D., Harvey, M. J., Lerot, C., Helmig, D. and Ristovski, Z.: Seasonal in situ observations of glyoxal and methylglyoxal over the temperate oceans of the Southern Hemisphere, Atmos. Chem. Phys., 15, 223–240, https://doi.org/10.5194/acp-15-223-2015, 2015.

Lee, Y., Zhou, X. and Hallock, K.: Atmospheric carbonyl compounds at a rural southeastern United States site, J. Geophys. Res., 100, 25933–25944, https://doi.org/10.1029/95JD02605, 1995.

Liu, W., Zhang, J., Kwon, J., Weisel, C., Turpin, B., Zhang, L., Korn, L., Morandi, M., Stock, T. and Colome, S.: Concentrations and Source Characteristics of Airborne Carbonyl Compounds Measured Outside Urban Residences, J Air Waste Manag Assoc., 56, 1196–1204, https://doi.org/10.1080/10473289.2006.10464539, 2006.

Liu, J., Li, X., Li, D., Xu, R., Gao, Y., Chen, S., Liu, Y., Zhao, G., Wang, H., Wang, H., Lou, S., Chen, M., Hu, J., Lu, K., Wu, Z., Hu, M., Zeng, L. and Zhang, Y.: Observations of glyoxal and methylglyoxal in a suburban area of the Yangtze River Delta, China, Atmos. Environ., 238, 117727, https://doi.org/10.1016/j.atmosenv.2020.117727, 2020.

MacDonald, S. M., Oetjen, H., Mahajan, A. S., Whalley, L. K., Edwards, P. M., Heard, D. E., Jones, C. E. and Plane, J. M. C.: DOAS measurements of formaldehyde and glyoxal above a south-east Asian tropical rainforest, Atmos. Chem. Phys., 12, 5949–5962, https://doi.org/10.5194/acp-12-5949-2012, 2012.

Matsunaga, S., Mochida, M. and Kawamura, K.: Variation on the atmospheric concentrations of biogenic carbonyl compounds and their removal processes in the northern forest at Moshiri, Hokkaido Island in Japan, J. Geophys. Res., 109, 2003JD004100, https://doi.org/10.1029/2003JD004100, 2004.

Min, K.-E., Washenfelder, R. A., Dubé, W. P., Langford, A. O., Edwards, P. M., Zarzana, K. J., Stutz, J., Lu, K., Rohrer, F., Zhang, Y. and Brown, S. S.: A broadband cavity enhanced absorption spectrometer for aircraft measurements of glyoxal, methylglyoxal, nitrous acid, nitrogen dioxide, and water vapor, Atmos. Meas. Tech., 9, 423–440, https://doi.org/10.5194/amt-9-423-2016, 2016.

Moortgat, G. K., Grossmann, D., Boddenberg, A., Dallmann, G., Ligon, A. P., Turner, W. V., Gäb, S., Slemr, F., Wieprecht, W., Acker, K., Kibler, M., Schlomski, S. and Bächmann, K.: Hydrogen Peroxide, Organic Peroxides and Higher Carbonyl Compounds Determined during the BERLIOZ Campaign, J. Atmos. Chem., 42, 443–463, https://doi.org/10.1023/A:1015743013107, 2002.

Müller, K., van Pinxteren, D., Plewka, A., Svrcina, B., Kramberger, H., Hofmann, D., Bächmann, K. and Herrmann, H.: Aerosol characterisation at the FEBUKO upwind station Goldlauter (II): Detailed organic chemical characterisation, Atmos. Environ., 39, 4219–4231, https://doi.org/10.1016/j.atmosenv.2005.02.008, 2005.

Müller, J.-F., Stavrakou, T., Oomen, G.-M., Opacka, B., De Smedt, I., Guenther, A., Vigouroux, C., Langerock, B., Aquino, C. A. B., Grutter, M., Hannigan, J., Hase, F., Kivi, R., Lutsch, E., Mahieu, E., Makarova, M., Metzger, J.-M., Morino, I., Murata, I., Nagahama, T., Notholt, J., Ortega, I., Palm, M., Röhling, A., Stremme, W., Strong, K., Sussmann, R., Té, Y. and Fried, A.: Bias characterization of OMI HCHO columns based on FTIR and aircraft measurements and impact on top-down emission estimates, EGUsphere, https://doi.org/10.5194/egusphere-2023-2456, 2024.

Munger, J. W., Jacob, D. J., Daube, B. C., Horowitz, L. W., Keene, W. C. and Heikes, B. G.: Formaldehyde, glyoxal, and methylglyoxal in air and cloudwater at a rural mountain site in central Virginia, J. Geophys. Res., 100, 9325–9333, https://doi.org/10.1029/95JD00508, 1995.

Possanzini, M., Tagliacozzo, G. and Cecinato, A.: Ambient Levels and Sources of Lower Carbonyls at Montelibretti, Rome (Italy), Water Air Soil Pollut., 183, 447–454, https://doi.org/10.1007/s11270-007-9393-1, 2007.

Qian, X., Shen, H. and Chen, Z.: Characterizing summer and winter carbonyl compounds in Beijing atmosphere, Atmos. Environ., 214, 116845, https://doi.org/10.1016/j.atmosenv.2019.116845, 2019.

Rao, Z., Chen, Z., Liang, H., Huang, L. and Huang, D.: Carbonyl compounds over urban Beijing: Concentrations on haze and non-haze days and effects on radical chemistry, Atmos. Environ., 124, 207–216, https://doi.org/10.1016/j.atmosenv.2015.06.050, 2016.

Shen, H., Chen, Z., Li, H., Qian, X., Qin, X. and Shi, W.: Gas-Particle Partitioning of Carbonyl Compounds in the Ambient Atmosphere, Environ. Sci. Technol., 52, 10997–11006, https://doi.org/10.1021/acs.est.8b01882, 2018.

Sinreich, R., Volkamer, R., Filsinger, F., Frieß, U., Kern, C., Platt, U., Sebastián, O. and Wagner, T.: MAX-DOAS detection of glyoxal during ICARTT 2004, Atmos. Chem. Phys., 7, 1293–1303, https://doi.org/10.5194/acp-7-1293-2007, 2007.

Spaulding, R. S., Schade, G. W., Goldstein, A. H. and Charles, M. J.: Characterization of secondary atmospheric photooxidation products: Evidence for biogenic and anthropogenic sources, J. Geophys. Res., 108, 2002JD002478, https://doi.org/10.1029/2002JD002478, 2003.

Thayer, M., Keutsch, F. N. and Dorris, M. R.: Field campaign data: ambient HCHO and CHOCHO, https://www.arm.gov/research/campaigns/amf2014goamazon, 2015.

Volkamer, R., Molina, L. T., Molina, M. J., Shirley, T. and Brune, W. H.: DOAS measurement of glyoxal as an indicator for fast VOC chemistry in urban air, Geophys. Res. Lett., 32, 2005GL022616, https://doi.org/10.1029/2005GL022616, 2005.

Washenfelder, R. A., Young, C. J., Brown, S. S., Angevine, W. M., Atlas, E. L., Blake, D. R., Bon, D. M., Cubison, M. J., De Gouw, J. A., Dusanter, S., Flynn, J., Gilman, J. B., Graus, M., Griffith, S., Grossberg, N., Hayes, P. L., Jimenez, J. L., Kuster, W. C., Lefer, B. L., Pollack, I. B., Ryerson, T. B., Stark, H., Stevens, P. S. and Trainer, M. K.: The glyoxal budget and its contribution to organic aerosol for Los Angeles, California, during CalNex 2010: GLYOXAL BUDGET FOR LOS ANGELES, J. Geophys. Res., 116, https://doi.org/10.1029/2011JD016314, 2011.

Yang, X., Xue, L., Wang, T., Wang, X., Gao, J., Lee, S., Blake, D. R., Chai, F. and Wang, W.: Observations and Explicit Modeling of Summertime Carbonyl Formation in Beijing: Identification of Key Precursor Species and Their Impact on Atmospheric Oxidation Chemistry, J. Geophys. Res. Atmos., 123, 1426–1440, https://doi.org/10.1002/2017JD027403, 2018.