Supplemental Information

New insights into urban ethanol and oxygenated volatile organic compound sources from combined flux tower and mobile measurements

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Table S1: Summary of meteorological conditions (temperature and relative humidity, RH) during the mobile sampling campaign. Rain was not reported during hours of data collected on these dates. Meteorology data collected at the Oakland airport (located south of the mobile sampling domain) was downloaded from https://mesonet.agron.iastate.edu/request/download.phtml (last access: July 3, 2026).

Date	Temperature (°C)	RH (%)
11/5/21	15.4	73
11/8/21	14.3	55
11/10/21	16.3	77
11/12/21	17.9	77
11/15/21	14.5	82
11/16/21	15.9	80
1/18/22	11.2	82
1/24/22	12.3	71
1/26/22	9.7	84
1/31/22	11.6	82
2/3/22	12.8	59
2/4/22	13.2	58

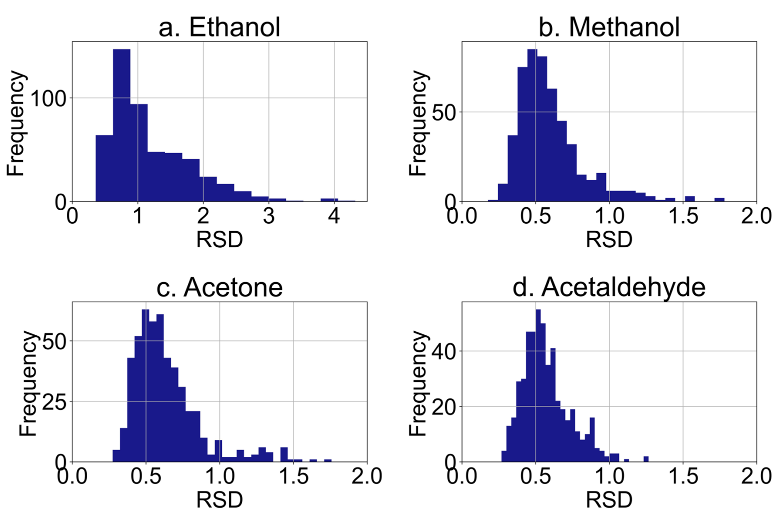

Figure S1: Histogram of the relative standard deviation (RSD = ratio of standard deviation to mean) of daily means in each grid cell.

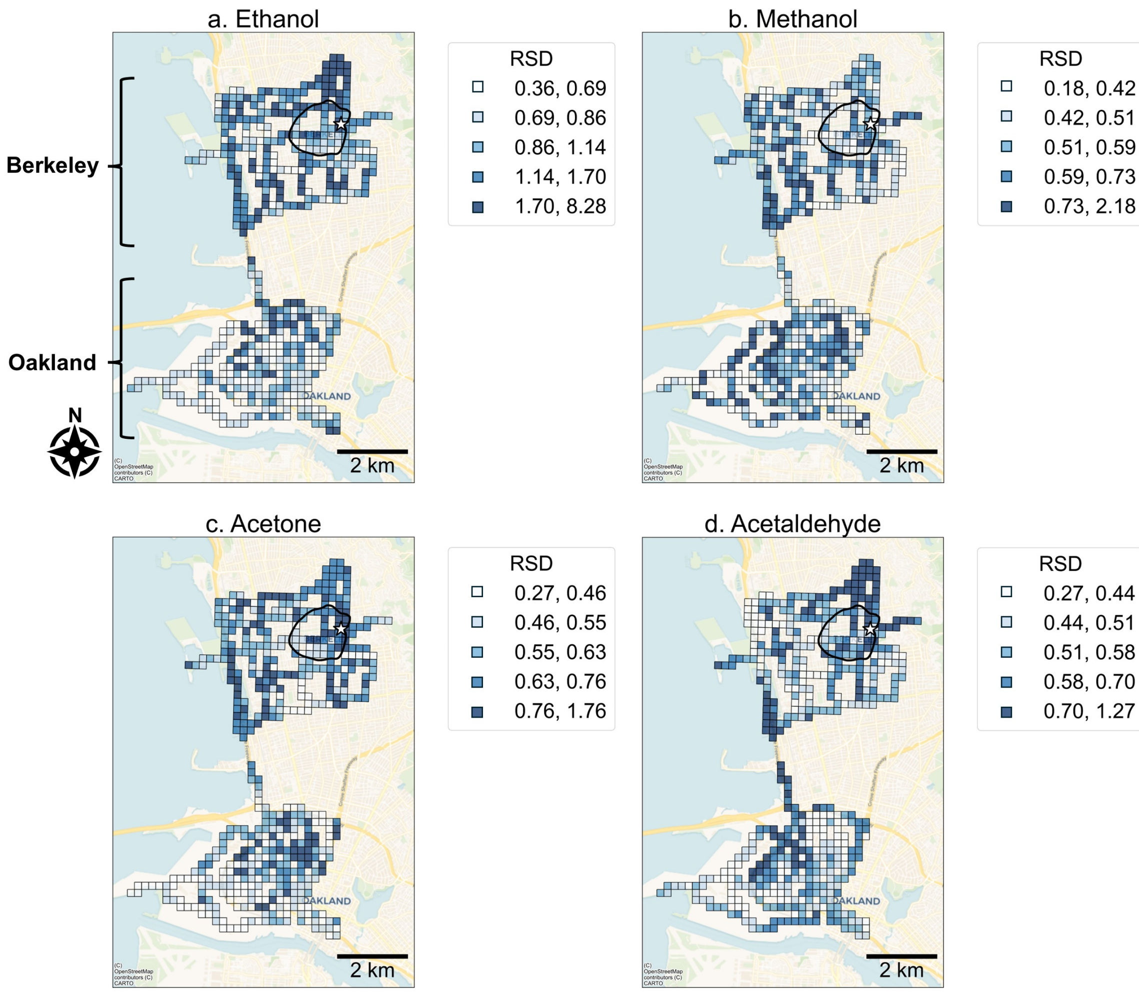

Figure S2: Relative standard deviation (RSD = ratio of standard deviation to mean) of daily means in each grid cell. Areas with high RSD reflect regions with episodic emissions. Map data courtesy of OpenStreetMap contributors, distributed under the Open Data Commons Open Database License v1.0.

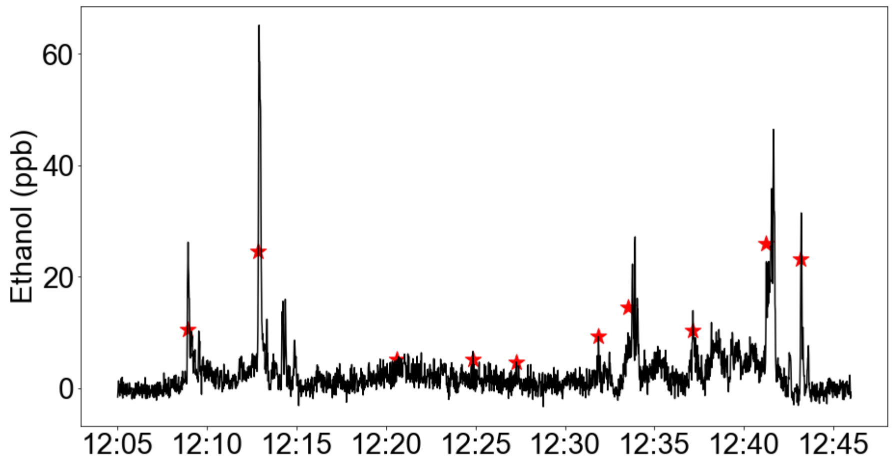

Figure S3: Example time series of ethanol mixing ratio versus local time showing where spikes were detected in the time series. Background-subtracted data is shown. Red stars indicate spikes.

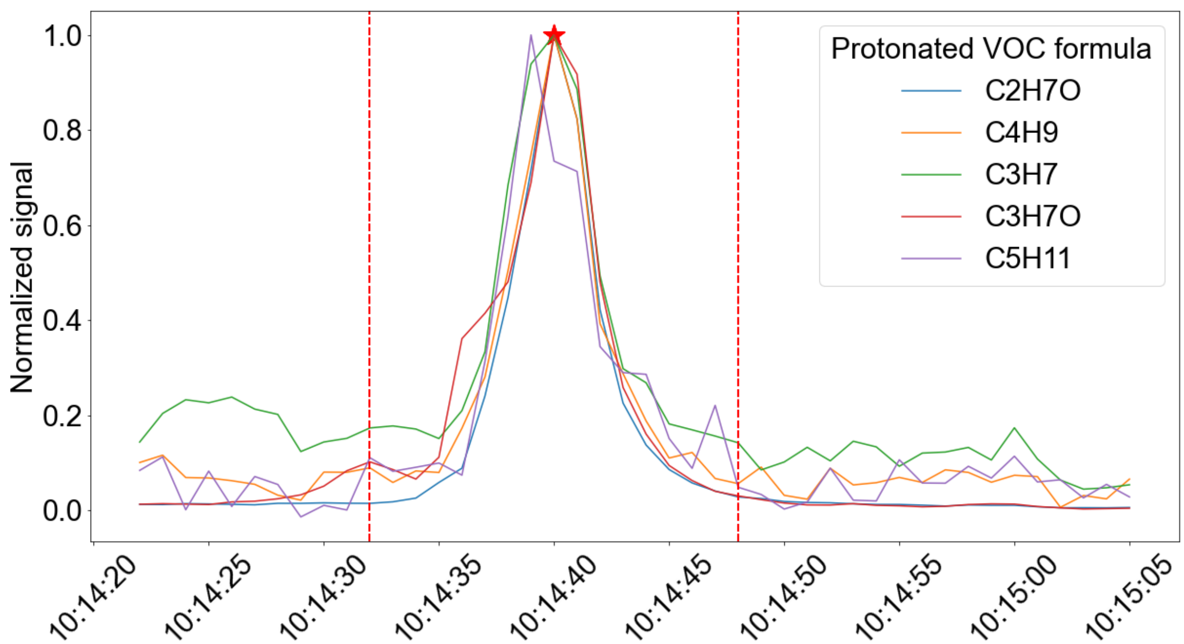

Figure S4: Example time series showing spike correlations. The normalized concentration of each VOC is plotted against local time. Data was normalized to the maximum concentration in the correlation window. The red star indicates the location of an ethanol (C2H7O) spike. The vertical dashed lines indicate the spike correlation window (±8 seconds around the spike). The VOCs in the plot had a correlation (R^2) above 0.85 with ethanol in the spike correlation window.

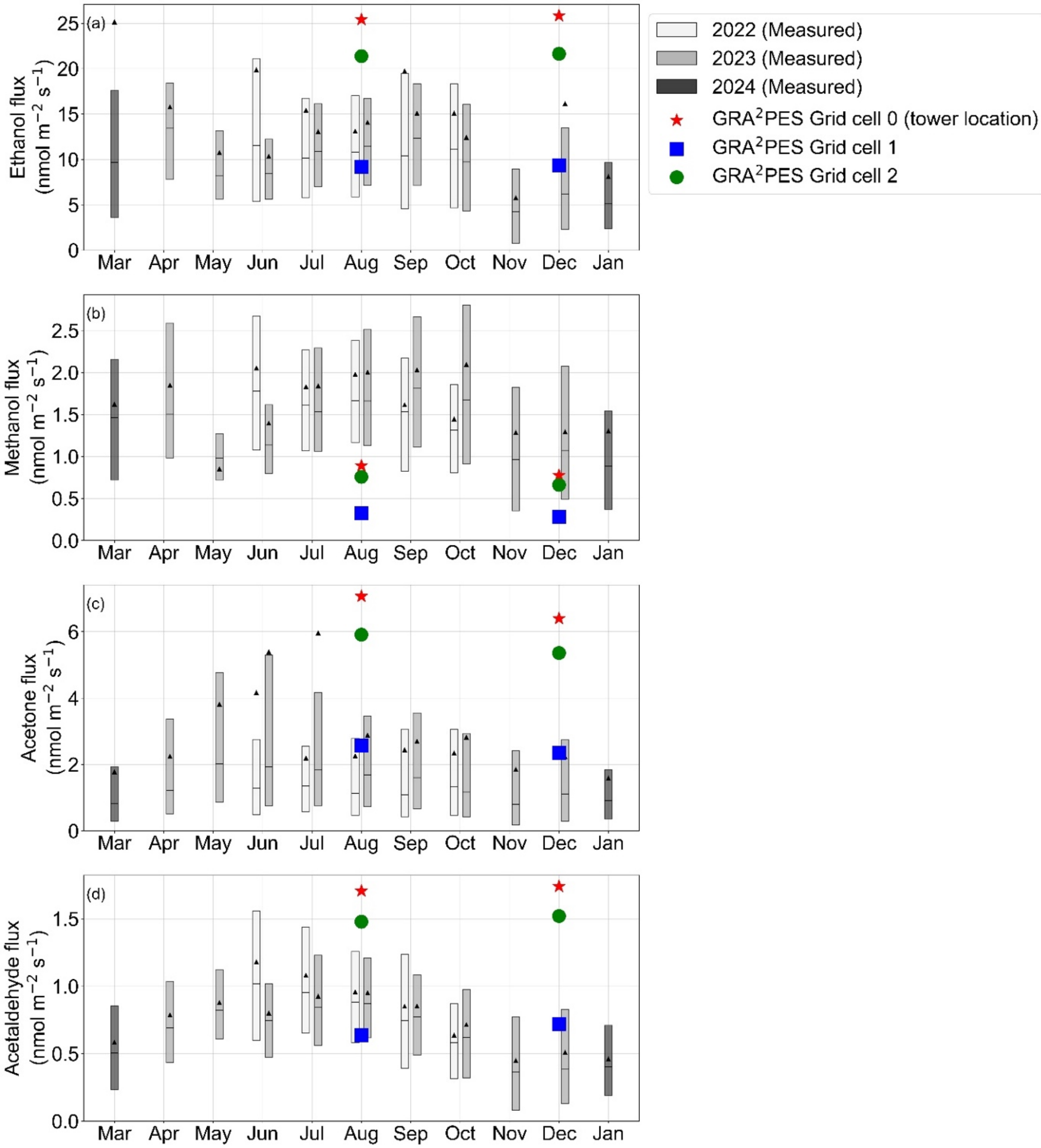

Figure S5: GRA^{2}PES emissions in August and December 2023 for each OVOC, (a) ethanol, (b) methanol, (c) acetone, and (d) acetaldehyde, overlayed on the monthly flux statistics. Boxes represent the interquartile range, horizontal lines within the boxes represent the median, and triangle icons represent the mean. The star icon represents GRA^{2}PES emissions for the grid cell containing the URBAN-EC flux tower. GRA^{2}PES differences from August to December were much lower than inventory vs. measurement comparisons, so only August was used in the analysis.

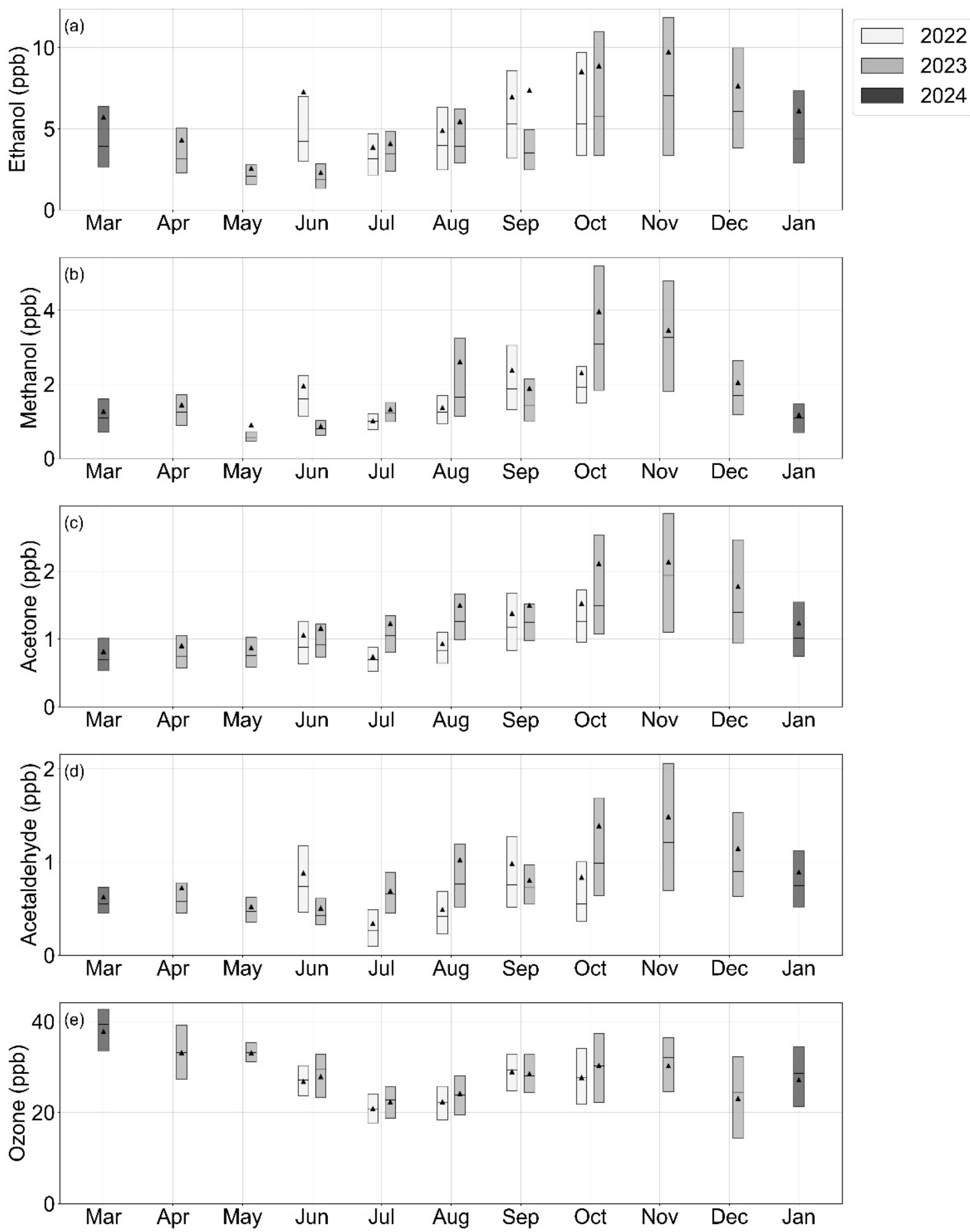

Figure S6: Daytime monthly box plot of mixing ratio for (a) ethanol, (b) methanol, (c) acetone, (d) acetaldehyde, and (e) ozone. Boxes represent the interquartile range, the horizontal line within the box represents the median, and the triangle icon represents the mean.

Table S2: Oxygenated VOC fluxes from this study compared to other urban VOC eddy covariance studies. For this study, Summer and Autumn are the averages of the 2022 and 2023 median fluxes, and Winter and is the median flux. For Acton et al., (2020) and Rantala et al., (2016), the median flux is presented. For Langford et al., (2010), the median fluxes from measurements collected in October are shown.

	Summer	**Winter**	**Autumn**	**Location**
Methanol flux (nmol m^{-2} s^{-1})				
This study	1.53	1.03	1.59	Berkeley, California, United States
Acton et al. 2020	6.40	1.12	-	Beijing, China
Rantala et al. 2016	1.22	0.51	-	Helsinki, Finland
Langford et al. 2010	-	-	8.16	London, United Kingdom
Ethanol flux (nmol m^{-2} s^{-1})				
This study	10.33	5.80	11.07	Berkeley, California, United States
Acton et al. 2020	3.00	0.57	-	Beijing, China
Rantala et al. 2016	0.31	0.58	-	Helsinki, Finland
Langford et al. 2010	-	-	-	London, United Kingdom
Acetone flux (nmol m^{-2} s^{-1})				
This study	1.54	1.01	1.33	Berkeley, California, United States
Acton et al. 2020	0.75	0.03	-	Beijing, China
Rantala et al. 2016	0.26	0.20	-	Helsinki, Finland
Langford et al. 2010	-	-	2.39	London, United Kingdom
Acetaldehyde flux (nmol m^{-2} s^{-1})				
This study	0.89	0.39	0.69	Berkeley, California, United States
Acton et al. 2020	1.43	0.04	-	Beijing, China
Rantala et al. 2016	0.21	0.12	-	Helsinki, Finland
Langford et al. 2010	-	-	3.79	London, United Kingdom

Table S3: Oxygenated VOC mixing ratios (ppb) from this study compared to other urban studies. For this study, Summer and Autumn are the averages of the 2022 and 2023 median mixing ratios, and Winter is the median mixing ratio. For Acton et al., (2020) and Rantala et al., (2016), the median is presented. For Langford et al., (2010), the median from measurements collected in October are shown.

	Summer	**Winter**	**Autumn**	**Location**
Methanol mixing ratio (ppb)				
This study	1.18	1.38	1.97	Berkeley, California, United States
Acton et al. 2020	26.39	19.29	-	Beijing, China
Rantala et al. 2016	3.88	1.13	-	Helsinki, Finland
Langford et al. 2010			12.3	London, United Kingdom
Ethanol mixing ratio (ppb)				
This study	3.41	5.20	4.20	Berkeley, California, United States
Acton et al. 2020	-	-	-	Beijing, China
Rantala et al. 2016	0.79	0.82	-	Helsinki, Finland
Langford et al. 2010	-	-	-	London, United Kingdom
Acetone mixing ratio (ppb)				
This study	0.93	1.18	1.28	Berkeley, California, United States
Acton et al. 2020	3.67	2.57	-	Beijing, China
Rantala et al. 2016	1.70	0.79	-	Helsinki, Finland
Langford et al. 2010	-	-	1.49	London, United Kingdom
Acetaldehyde mixing ratio (ppb)				
This study	0.54	0.83	0.75	Berkeley, California, United States
Acton et al. 2020	3.50	4.59	-	Beijing, China
Rantala et al. 2016	0.50	0.43	-	Helsinki, Finland
Langford et al. 2010	-	-	3.35	London, United Kingdom

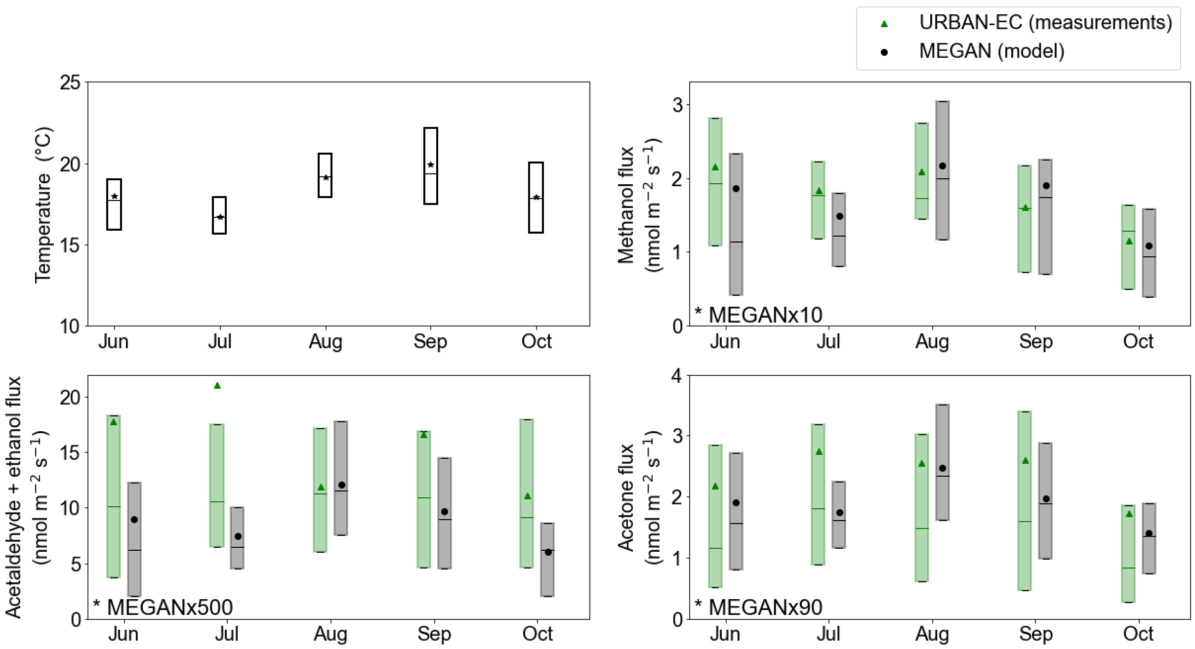

Figure S7: Biogenic volatile organic compound (BVOC) emissions from MEGAN (model) compared to URBAN-EC (measurements). BVOC emissions were estimated for June through October 2022 and compared with flux tower observations. For each month, MEGAN results are shown in black, and measurements are shown in green. MEGAN results are multiplied by a scaling factor, indicated in each panel, so they could be plotted with the observations. Top left: Measured temperature. Top right: Methanol flux. Bottom left: acetaldehyde + ethanol flux. Bottom right: acetone flux.

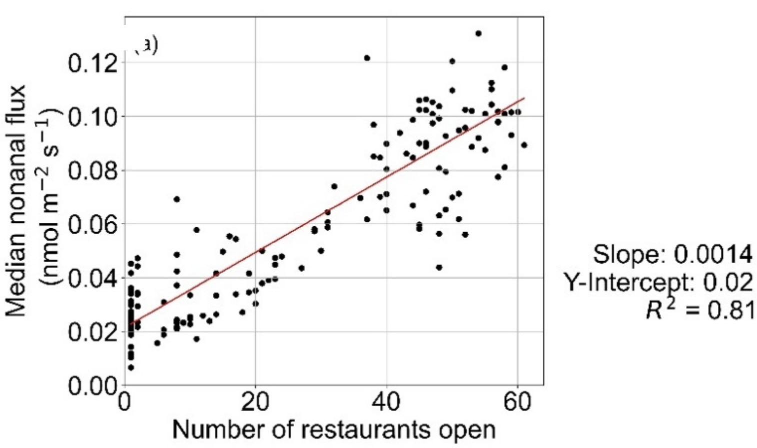

Figure S8: Nonanal flux versus number of restaurants open. Each point represents an hourly median flux for a given day of the week. For example, one data point is the 15:00-16:00 median for Tuesdays. The results of the linear fit (slope, y-intercept, and R^2) are shown.

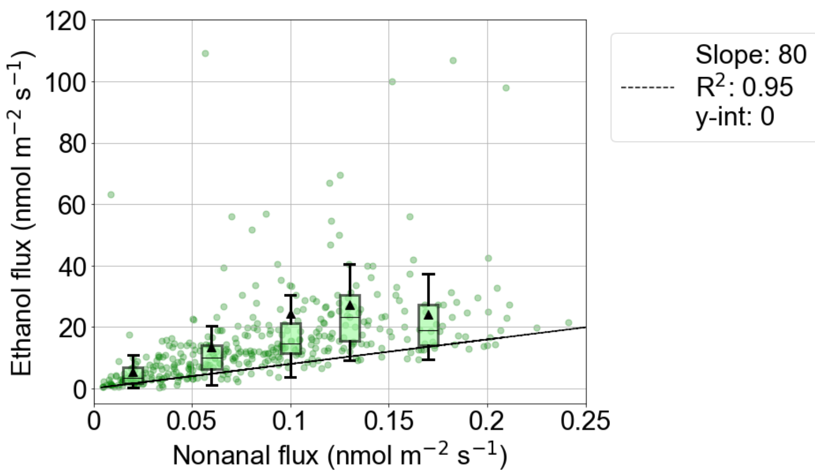

Figure S9: Ethanol flux versus nonanal flux. Data points represent 30-minute averaging intervals influenced by cooking emissions. Boxes represent ethanol fluxes binned by nonanal fluxes and are plotted against the median nonanal flux in each bin. Boxes represent the interquartile range, the horizontal line within the box represents the median, and the triangle icon represents the mean. The linear fit is through the 10th percentile of ethanol fluxes for each bin.

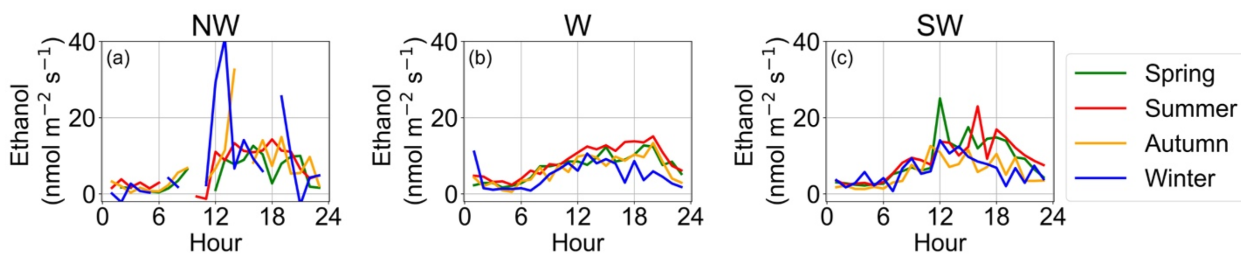

Figure S10: Median diurnal profile of Ethanol flux for each wind sector: (a) Northwest, (b) West, and (c) Southwest. Data is split by season: spring (green), summer (red), autumn (gold), winter (blue). Data from the NW was sparser than data from the W and SW, as evidenced by the noise in (a).

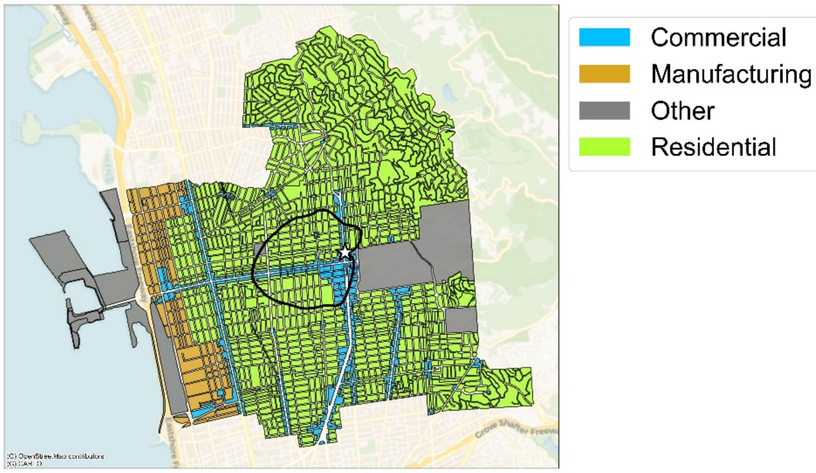

Figure S11: Berkeley zoning data with the flux footprint. Map data is courtesy of OpenStreetMap contributors, distributed under the Open Data Commons Open Database License v1.0.

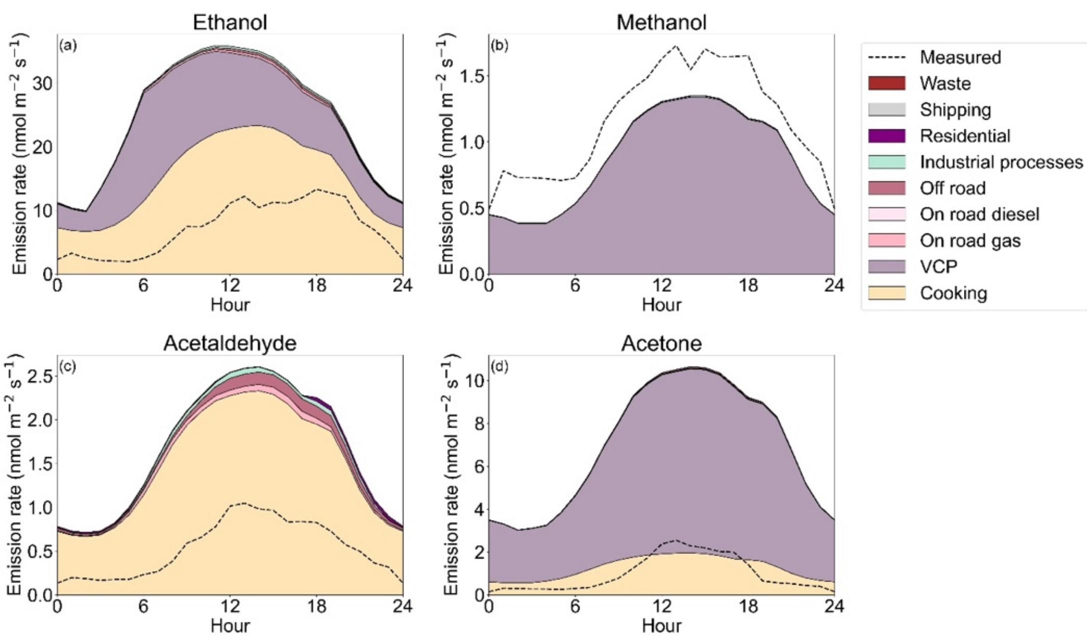

Figure S12: Diurnal profile of GRA^{2}PES emissions for August 2023 (colors) and flux tower observations (campaign median, dashed line) for (a) ethanol, (b) methanol, (c) acetaldehyde, and (d) acetone. The legend shows relevant GRA^{2}PES source categories.

References

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Rantala, P., Järvi, L., Taipale, R., Laurila, T. K., Patokoski, J., Kajos, M. K., Kurppa, M., Haapanala, S., Siivola, E., Petäjä, T., Ruuskanen, T. M., and Rinne, J.: Anthropogenic and biogenic influence on VOC fluxes at an urban background site in Helsinki, Finland, Atmospheric Chem. Phys., 16, 7981–8007, https://doi.org/10.5194/acp-16-7981-2016, 2016.