FluxSense

MEASUREMENTS MAKE SENSE

Air Quality Data Collection for TRACER-AQ-2 Field Campaign in Houston

Contract No. R-22-0080

Monitoring Report

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Title: Air Quality Data Collection for TRACER-AQ-2 Field Campaign in Houston - Monitoring Report

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DISCLAIMER

Contents

Acronyms, Units and Definitions

Acronyms used in this report

95% CI	95% Confidence interval for the mean
BTEX	Sum of Benzene, Toluene, Ethyl Benzene and m- and p-Xylene
DOAS	Differential Optical Absorption Spectroscopy
EF	Emission factor
EPA	United States Environmental Protection Agency
FTIR	Fourier Transform InfraRed
HAP	Hazardous Air Pollutant
HHD EHD	Houston Health Department Environmental Health Division
HRVOC	Highly reactive VOC
IME	Indirectly Measured Emission, combining direct emission with concentration ratios
IQR	Interquartile Range
LIDAR	Light Detection and Ranging
MeDOAS	Mobile Extractive DOAS
MeFTIR	Mobile extractive FTIR
NMVOC	Non-methane volatile organic compound
SD	Standard deviation
SkyDOAS	Scattered Skylight DOAS
SOF	Solar Occultation Flux
TCEQ	Texas Commission on Environmental Quality
VOC	Volatile organic compound, used interchangeably for non-methane non-ethane VOC

Units

Air temperature	degrees C
Atmospheric Pressure	mbar
Relative Humidity	%
Wind direction	degrees North
Wind speed	m/s
Column	mg/m2
Concentration	µg/m3, ppbv@30C, 1atm
Flux, emissions	kg/h

Unit Conversions

1 lbs = 0.4536 kg
1 kg/h = 52.9 lbs/day
1 bbl = 159 l
1 bbl/day = 5.783 kg/h (crude oil)
1 (short) ton = 907.2 kg
1 kton/year = 104 kg/h
1 klbs/year=0.052 kg/h

Definitions

Alkane or **Alkanes** are considered, in this study, to be all non-methane non-ethane alkane species (e.g. C_3 and higher).

Highly reactive VOCs are defined by TCEQ to be ethylene, propylene, 1,3-butadiene and butenes for Harris County (https://www.tceq.texas.gov/airquality/stationary-rules/voc/hrvoc.html, 17 December 2020).

Emissions refers to emissions rate in mass per unit time.

Column or **Concentration** when applied to measurements in this survey refers to enhancement above a reference background.

Confidence Intervals are calculated for means of 4 or more measurements from Student's T distribution

1 INTRODUCTION

This report consists of measurement results and detailed information from a campaign conducted by FluxSense during September 2022 in support of the Air Quality Data Collection for TRACER-AQ-2 Field Campaign in Houston (Grant Number 582-18-81339). FluxSense Inc conducted this study on behalf of the University of Houston (UH) and the Texas Commission on Environmental Quality (TCEQ) with the objective to characterize emission fluxes and ambient pollutant concentrations near the Houston Ship Channel (HSC), Baytown, Texas City and other areas as agreed-upon with the TCEQ Project Manager. HRVOCs (ethylene and propylene) are the focus compounds, but emissions of other compounds like formaldehyde, NO_2 and alkanes are also reported. These additional compounds are particularly useful for historical comparison and examining trends for air quality within the Greater Houston region.

1.1 Background

FluxSense (Inc. and AB) and in cooperation with Chalmers University, has conducted emission measurement campaigns for VOCs, HRVOCs, SO_x, NO_x, in Houston since 2006 (Johansson et al. 2014, Mellqvist et al. 2010, Rivera et al. 2010) and formaldehyde since 2009. The first campaigns were in concert with the Second Texas Air Quality Study, and subsequently Air Quality Research Program (AQRP) administered by The University of Texas at Austin, and later the Houston Health Department (HHD). Typical findings from these previous studies were significant emissions of HRVOCs and alkanes with large discrepancies between measured emissions and reported inventories for VOCs and HRVOCs, and much smaller discrepancies for other gaseous emissions. The measurement also indicated a trend for HRVOCs (primarily ethylene and propylene) substantially decreasing from the first measurements and much of the emissions could be attributed to poorly combusting flares and that formaldehyde emissions were dominated by secondary formation from HRVOC precursors (Johansson et al. 2014).

1.2 Conditions and Measurements during the Field Campaign

A detailed summary of all measurement days conducted during the field campaign is given in Table 1. Measurements were conducted from 2 - 28 September. Weather conditions during the second half of September were more favorable for SOF and SkyDOAS methods which are the primary methods for emission measurement. A total of 20 measurement days were logged out of 26 days where personnel and instrumentation were in place. It Is to be noted that on 14 September there was no MeDOAS data collected due to a communication issue with the UV spectrometer. This issue was resolved and the MeDOAS was determind to be functioning properly for the subsequent measurement days.The wind lidar, deployed to provide the wind profile for flux measurements, was positioned daily according to the primary measurement target(s) as indicated in Table 1. For large-scale measurements a single position may be sub-optimal for parts, but the approach applied here for practical reasons.

Table 1 Summary of measurement days, meteorology and wind LIDAR postions. Days with no emission measurements but other activities are shown on a white background.

Date	Site/Areas	Operators	Sky Conditions	Wind	Temp	LIDAR Position and Comments
02-Sep	San Jacinto Battleground	AB, DR	Some high clouds with thicker low clouds moving in toward the afternoon	E 5 m/s	30°C	1 Monument Cir, La Porte, TX, 77571 (Battleground Monument) 29°45'02.8"N 95°04'49.3"W
05-Sep	Mont Belvieu	AB, DR	Partly cloudy	SW 5m/s	32°C	8700 N Hwy 146, Baytown, TX, 77523 (Walmart), 29°48'59.0"N 94°53'54.4"W
06-Sep	Mont Belvieu; Baytown	AB, DR	Partly cloudy and some rain in the morning clearing up in the afternoon,	SE 5 m/s	30°C	8700 N Hwy 146, Baytown, TX, 77523 (Walmart), 29°48'59.0"N 94°53'54.4"W; 4605 W Baker Rd, Baytown, TX, 77520 (TCEQ Site near ExxonMobil), 29°46'10.2"N 95°01'02.8"W; Had to move due to personnel access; 2510 J B Lefevre Rd, Baytown, TX, 77520 (Unidad Park), 29°44'01.8"N 94°59'52.3"W
07-Sep	W Ship channel; Lynchburg	AB, DR	Mostly sunny, stormy in the afternoon	NW-NE 4m/s	31°C	7005 TX-225, Deer Park, TX, 77536 (Love's Travel Stop), 29°42'31.1"N 95°05'30.3"W
08-Sep	Mont Belvieu; Texas city	BO, DR	Cloudy to the north clear down south	NE 5 m/s	28-31°C	10520 Interstate 10 Service Rd, Baytown, TX, 77523 (Freddy's), 29°49'12.8"N 94°53'49.7"W; 3620 Emmett F Lowry Expy, Texas City, TX, 77590 (Lowes), 29°23'46.5"N 94°57'07.2"W
09-Sep	San Jacinto Battleground	BO, AB	AM mostly sunny; cloudy in the afternoon	ENE 3 m/s in AM; SE 5m/s in PM	24-30°C	7005 TX-225, Deer Park, TX, 77536 (Love's Travel Stop), 29°42'31.1"N 95°05'30.3"W
10-Sep	Baytown	BO, AB	Difficult cloud coverage	N 4 m/s in AM, NNE 4 m/s in PM	25-29 °C	2510 J B Lefevre Rd, Baytown, TX, 77520 (Unidad Park), 29°44'01.1"N 94°59'49.0"W
11-Sep	Baytown	BO, DR	Clear in the AM but cloudy in the afternoon	NW 5-7 m/s	30-32 °C	2511 J B Lefevre Rd, Baytown, TX, 77520 (Unidad Park), 29°44'01.1"N 94°59'49.0"W
12-Sep	Mont Belvieu and ship channel	AB, DR	Clear in the AM but cloudy in the afternoon	NE 4 m/s in am, N 4 m/s in pm	24-29 °C	7005 TX-225, Deer Park, TX, 77536 (Love's Travel Stop), 29°42'31.1"N 95°05'30.3"W
13-Sep	Baytown; Lynchburg	BO, AB	Clouds in Baytown, clearer in Lynchburg	E 4 m/s	26-28 °C	7005 TX-225, Deer Park, TX, 77536 (Love's Travel Stop), 29°42'31.1"N 95°05'30.3"W

Date	Site/Areas	Operators	Sky Conditions	Wind	Temp	LIDAR Position and Comments
14-Sep	HSC (Houston Ship Channel)	AB, DR	Clear skies throughout ship channel, late afternoon interrupted by clouds	ENE 4 m/s	30-33 °C	2100 N Main St, Houston, TX, 77029 (Galena Park), 29°44'52.1"N 95°14'24.0"W; No MeDOAS data due to spectrometer communication issue
15-Sep	Channelview; Baytown	AB, DR	Clear in am but lots of cloud formation in late AM and early PM	NE 4-6 m/s	27-31 °C	1 Monument Cir, La Porte, TX, 77571 (Battleground Monument) 29°45'02.8"N 95°04'49.3"W; 10520 Interstate 10 Service Rd, Baytown, TX, 77523 (Freddy's), 29°49'12.8"N 94°53'49.7"W
16-Sep	Wind lidar test; no AQ measurements	None	Cloudy	ESE 4-6 m/s	30°C	504 S Virginia St, La Porte, TX 77571 (FluxSense AirBnB), 29°39'40.2"N 95°00'56.0"W; conducting measurements for comparison with airport wind measurements
17-Sep	Bayport; San Jacinto Battleground	AB, DR	Partly cloudy in Bayport and Battleground	ESE 4 m/s	28-33°C	504 S Virginia St, La Porte, TX 77571 (FluxSense AirBnB), 29°39'40.2"N 95°00'56.0"W
18-Sep	Channelview	AB, DR	Partly cloudy	E 2-3 m/s	25-34°C	5655 East Sam Houston Pkwy N, Houston, TX 77015 (Walmart) 29°48'28.8"N 95°09'55.2"W
19-Sep	Mont Belvieu	AB, DR	Cloudy	NE 4 m/s	29-32°C	N/A too cloudy for measurements
20-Sep	San Jacinto Battleground; Deer Park; Baytown	DR, JM	Mostly clear with interruptions above Hwy 330	E-SE 3 m/s	26-33°C	1 Monument Cir, La Porte, TX, 77571 (Battleground Monument) 29°45'02.8"N 95°04'49.3"W
21-Sep	Mont Belvieu; Channelview	DR, JM	Mostly clear	N 3 m/s in Mont Belvieu in AM; E 3 m/s in Channelview in PM	26-31°C	10520 Interstate 10 Service Rd, Baytown, TX, 77523 (Freddy's), 29°49'12.8"N 94°53'49.7"W; 13750 East Fwy, Houston, TX 77015 (Walmart), 29°46'12.4"N 95°10'36.6"W
22-Sep	HSC; San Jacinto Battleground	DR, JM	Clear skies in E ship channel, partly cloudy in W	N 4 m/s	24-32°C	125 W 3rd St, Deer Park, TX 77536 (Terrace Park), 29°42'30.9"N 95°07'31.5"W; rotated LiDAR 90° to N
23-Sep	HSC; Channelview	DR, JM	Partly cloudy	N 3 m/s in AM, ENE 4 m/s in PM	24-33°C	1107 Shaver St, Pasadena, TX 77506 (Walmart), 29°41'28.3"N 95°12'35.2"W
24-Sep	Baytown	DR, JM	Mostly clear	SSW 2-3 m/s in AM	24-32°C	2510 J B Lefevre Rd, Baytown, TX, 77520 (Unidad Park), 29°44'01.1"N 94°59'49.0"W

Date	Site/Areas	Operators	Sky Conditions	Wind	Temp	LIDAR Position and Comments
26-Sep	HSC; Baytown	DR, JM	Clear	N-NE 5 m/s	24-31°C	125 W 3rd St, Deer Park, TX 77536 (Terrace Park), 29°42'30.9"N 95°07'31.5"W; rotated LiDAR 90° to N
27-Sep	Bayport; Mont Belvieu and Baytown	AB, JM	Clear	NNE 5-10 m/s	18-27°C	504 S Virginia St, La Porte, TX 77571 (FluxSense AirBnB), 29°39'40.2"N 95°00'56.0"W; 2510 J B Lefevre Rd, Baytown, TX 77520, (Unidad Park), 29°44'01.3"N 94°59'49.4"W
28-Sep	Mont Belvieu	AB, JM	Clear	E 5 m/s in AM, ENE 4 m/s late afternoon	18-27°C	10520 Interstate 10 Service Rd, Baytown, TX, 77523 (Freddy's), 29°49'12.8"N 94°53'49.5"W

Figure 1 shows the distribution of total measurements on a daily basis for all direct flux measurements. The number of possible measurements depends on sky and wind conditions and area of focus. More measurements were possible on days in areas with a greater number of distinguishable sources, e.g. Lynchburg Ferry & La Porte. The percentage of measurements passing QAQC was typically higher for SOF and SkyDOAS on days with clear skies and not focused on large-scale measurements.

Figure 2 compares integrated wind profile from 10 - 300 m with the 100 m wind. For emission measurement in this report, the integrated profile 10 - 300 m was used. For concentration ratio measurements the integrated 0 - 50 m wind was used. This doesn't affect the integrated ratio but is used to indicate source direction and dispersion.

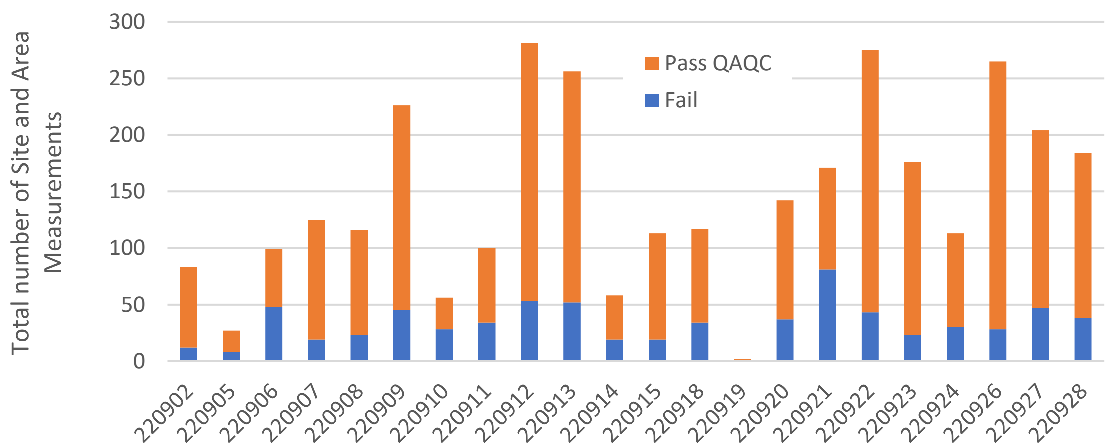


Figure 1 Number of Site and Area direct emission measurements per day. Total number of measurements depends on sky and wind conditions and area of focus. More measurements are made on days in areas with a greater number of distinguishable sources, e.g. Lynchburg Ferry & La Porte. QAQC criteria include parameters like wind speed, cloud interference, source interference, instrument performance.

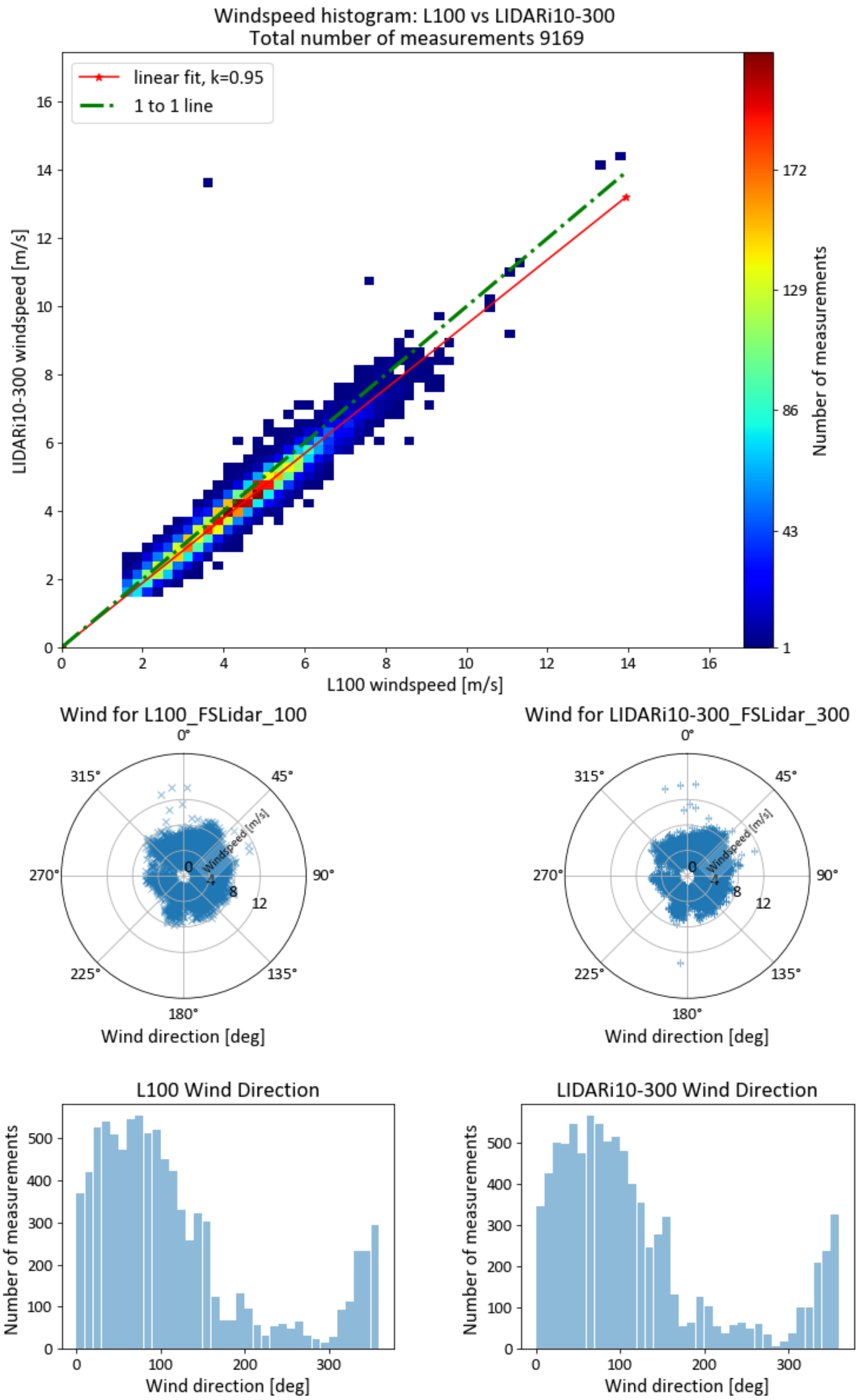


Figure 2 Example of wind speed data collected during the survey comparing the integrated 10 - 300 m (LIDARi10-300) winds to the 100 m (L100) measurement.

2 METHODS

2.1 Overview

This study employs an advanced mobile air pollution measurement lab equipped with four optical instruments for gas monitoring: SOF (Solar Occultation Flux), SkyDOAS (Differential Optical Absorption Spectroscopy), MeFTIR (Mobile extractive Fourier Transformed Infrared spectrometer) and MeDOAS (Mobile extractive White cell DOAS). The emissions measurement methodology is described breifly in the subsections below and has been applied in several international projects studying emissions to the atmosphere. Additional information on the measurement methods and instruments can be found at: www.fluxsense.com.

SOF and SkyDOAS both measure gas columns through the atmosphere by means of light absorption. SOF utilizes infrared light from the direct sun whereas SkyDOAS measures scattered ultraviolet light from the sky. SOF is considered Best Available Technique (BAT) for emission quantification of refinery VOC emissions in Europe since 2015 (European Commission, 2015) and a new European standard for refinery VOC emissions including the SOF method was published in the spring 2022 (European Committee for Standardization, 2022). MeFTIR and MeDOAS measure (typically) ground level concentrations (measurement vehicle roof height, approx. 3 m) of alkanes, ethylene, propylene, formaldehyde, methane and BTEX cmopounds (benzene, toluene, ethylbenzene, p-xylene, m-xylene) respectively.

Both concentrations and columns are shown as enhancements above the background level, i.e. the value relative to a reference outside the plume. This is generally the first measurement in the measurement series assuming a start outside of the source plume. This helps better visualize the contribution from the nearest sources. For species without significant background concentrations, the measured relative concentration approaches the absolute concentration. For other species such as methane, the background concentrations and columns can vary significantly especially near widespread sources such as in agricultural, wetlands or oil producing areas.

In order to calculate gas emissions, wind data (direction and magnitude) is required. Wind information for the survey is derived from a Zephir ZX300 LIDAR, probing wind speed and wind direction at multiple heights in the 10 – 300 m range above ground.

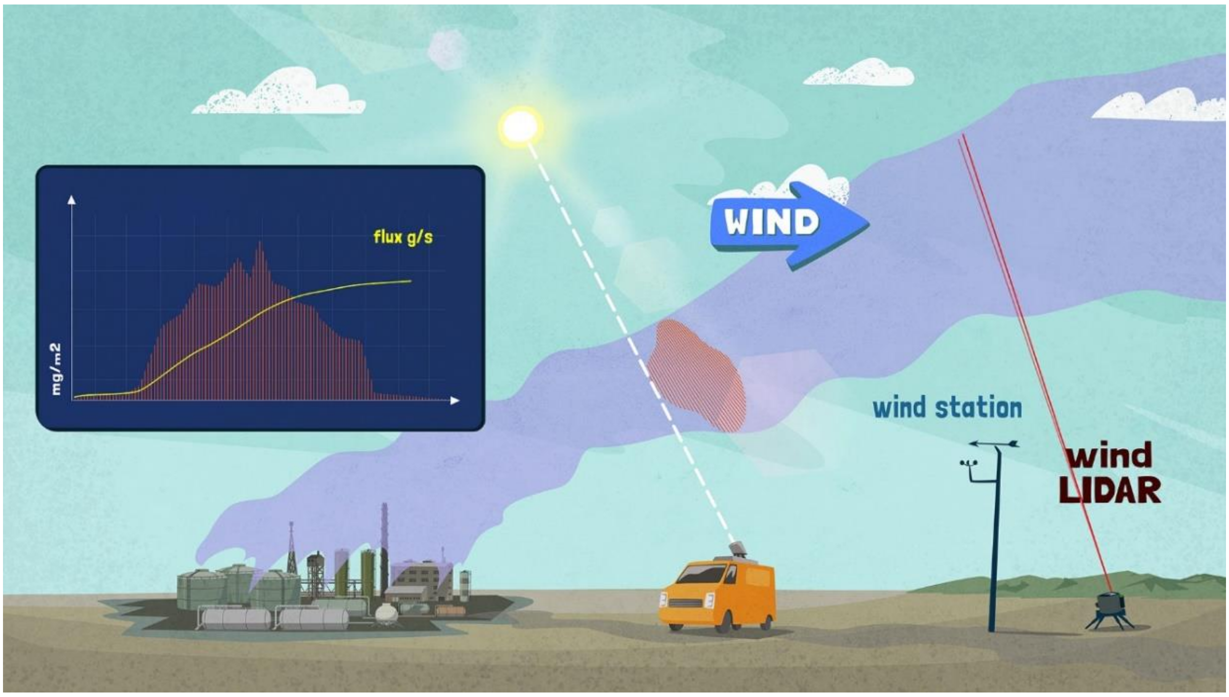


Figure 3 Methodology. The VOC mass (or other compound of interest) is integrated through the plume cross section by means of mobile solar and scattered skylight absorption spectroscopy (SOF and SkyDOAS) measurements. Gas emission rates (g/s) are then derived by combining the gas column (mg/m^2) measurements with wind speed and wind direction data measured by LIDAR and wind masts. Ground level concentrations (mg/m^3) are measured by mobile IR and UV absorption spectroscopy (MeFTIR and MeDOAS).

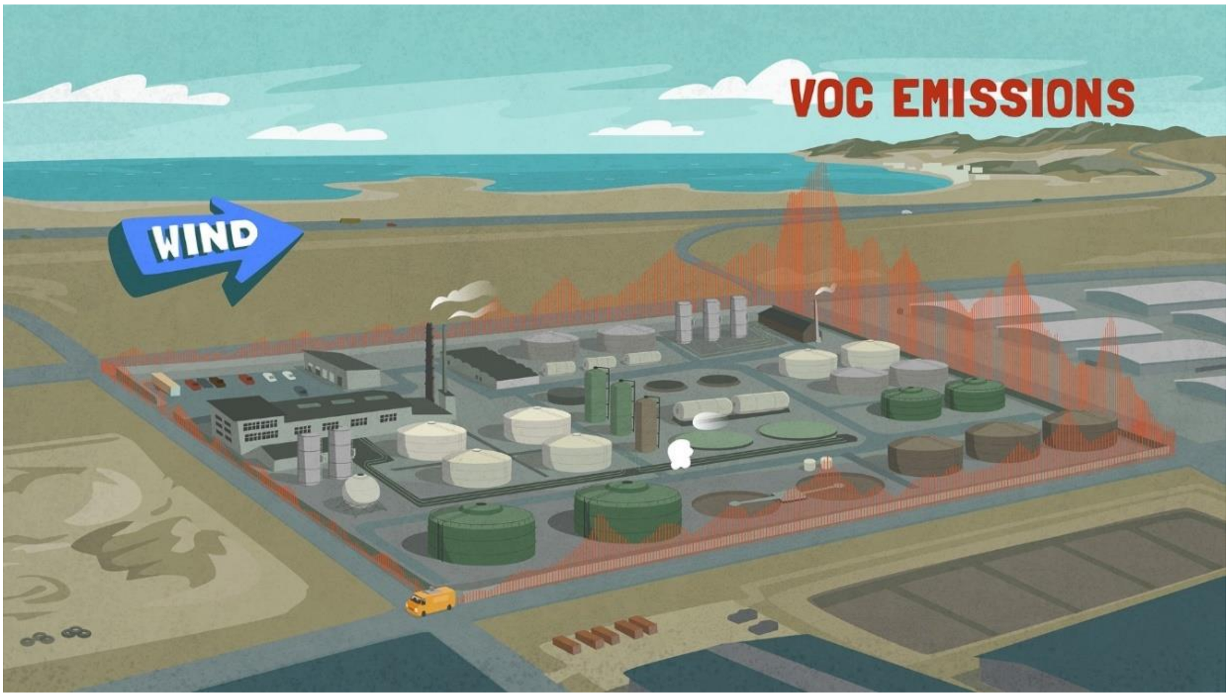


Figure 4 Schematic of SOF and SkyDOAS measurement where the vehicle is driven across the prevailing wind so that the solar beam or zenith sky light beam cuts through the emission plume while the sun is locked into the FTIR spectrometer by the solar tracking device on the roof. The VOC mass (or other compound of interest) is integrated through the plume cross section. Usually, the measurements are carried by encircling the individual sources, in order to remove the influence of the upwind (background) emissions.

Figure 5 Interior and exterior views of the mobile laboratory.

Table 2 Summary of the gas measurement techniques.

Method	SOF	SkyDOAS	MeFTIR	MeDOAS
Compounds	Alkanes: (C_nH_{2n+2}) Alkenes: C_2H_4, C_3H_6 NH_3	SO_2, NO_2, HCHO	CH_4, HCHO Alkanes: (C_nH_{2n+2}) Alkenes: C_2H_4, C_3H_6 NH_3	BTEX, Benzene
Detection limit column or conc	0.1-5 mg/m^2	0.1-5 mg/m^2	1-10 ppbv	0.5-3 ppbv
Wind Speed Tolerance	1.5-12 m/s	1.5-12 m/s		
Sampling Time Resolution	1-5 s	1-5 s	5-15 s	5-10 s
Measured Quantity [unit]	Integrated vertical column mass [mg/m^2]	Integrated vertical column mass [mg/m^2]	Mass concentration at vehicle height [mg/m^3]	Concentration at vehicle height [mg/m^3]
Derived Quantity [unit]	Mass Flux [kg/h]	Mass Flux [kg/h]	1) Alkane and methane mass concentration ratio of ground plume combined with SOF gives mass flux [kg/h] (indirect) and plume height information [m] 2) Alkane and CH_4 flux [kg/h] via tracer release	Combined with MeFTIR and SOF gives mass flux [kg/h] (indirect)
Complementary data	Vehicle GPS-coordinates, Plume wind speed and direction	Vehicle GPS-coordinates, Plume wind speed and direction	Vehicle GPS-coordinates Plume wind direction	Vehicle GPS-coordinates, Plume wind direction

2.2 Quality Assurance

The Quality Assurance - Quality Control (QAQC) protocols followed during the campaign and post processing are detailed in the submitted FluxSense Quality Assurance Method Report (QAMR, Samuelsson and Ericsson, 2022). Additionally all analysis was reviewed according to FluxSense internal review process which requires an additional control of all emissions and plume mass ratio measurements. As specified in the QAMR and in accordance with the review process, an independent audit (IA) was performed by Samuel Brohede reviewing the data collection, data analysis and data management and reporting steps.

2.3 Uncertainties and Error Budget

A summary of the typical performance of the measurements is presented in Table 3. Table 3 reports the total expanded uncertainty for the flux measurements which include possible systematic errors and was determined through a series of controlled gas release experiments. In addition, the statistical error is reported for all directly measured source emissions. The statistical error corresponds to the random error in the measurements and does not include possible systematic errors. For instance, systematic errors could include errors in wind speed due to the errors in estimated height of the plume or spectral calibration errors. The statistical error is given by the Confidence Interval (CI 95%) for the mean, $\bar{x}$, according to:

$$CI = \bar{x} \pm t_{.025} \frac{s}{\sqrt{N}}$$

Here t is Student's T distribution and s corresponds to sample standard deviation:

$$s_x = \sqrt{\frac{\sum_{i=1}^{N}(x-\bar{x})^2}{N-1}}$$

Statistical errors are not reported for the median which is typically used for ratio measurements. Instead, interquartile range is presented for the ratios.

Table 3 Estimated performance of applied measurement methods. Note that the total uncertainty includes systematic and random errors.

Measurement Parameter	Analysis Method	Total Uncertainty
SOF column concentrations, alkanes and alkenes	SOF spectral retrieval	±10%
SkyDOAS column concentrations: NO_2, SO_2, HCHO	DOAS spectral retrieval	±10%
MeFTIR concentrations: CH_4, VOC	MeFTIR spectral retrieval	±10%
MeDOAS or MWDOAS concentrations: BTEX, Benzene	DOAS spectral retrieval	±10%
SOF mass flux: Alkanes, Alkenes	SOF flux calculations	±30%-40%
SkyDOAS mass flux: NO_2, SO_2, HCHO	SkyDOAS flux calculations	±30%
Indirect mass flux (e.g. BTEX, Benzene, CH_4)	Concentration ratio times mass flux	±40%-70%

3 RESULTS

The results are presented for the focus species for all measured areas with sufficient number of measurements for statistics. Other noteworthy observations and complementary measurements are also included. Most of the measurement time was allocated to area and large-scale emissions measurements, however wherever possible, given road access and appropriate wind direction, emissions are attributed to smaller subdivisions containing a more limited number of facilities. During the analysis these areas are identified by the largest facility within them however for the purposes of this report these names have been replaced by identifiers indicated under the separate sub-headings.

3.1 Measured Areas, identification and delineation

Measured areas are primarily determined by available fenceline roads and prevailing wind conditions and are also influenced by the focus compounds for subdivision. Non-prioritized areas Channelview North, Bayport and Texas City were measured on one or few days, in some cases with very limited success due to wind direction and large inflow of VOC and other emissions. The Sectors of the HSC suitable for subdivision and attribution were determined only after the survey since this is largely dictated by the wind direction during measurements. Both the emission areas that were the focus of the measurement survey and the sectors of the HSC that were measured are shown in Figure 6. TPC (located on Pasadena just south of highway 225) was a goal for measurements, but the measurement days with southerly winds were in other prioritized locations and the measurements with easterly winds were impacted by background columns. Bayport and Texas City are shown in Figure 7 and Figure 8, respectively. Figure 9 shows the measurement paths that were driven during the survey.

Figure 6 Prioritized measurement areas for the survey with wind LIDAR positions. Areas prefaced with HSC are included in the total HSC measurements which are subdivided into the sectors demarcated by the black lines from Highway 225 south of the HSC to I-10 north of the HSC. The LIDAR was relocated once or twice daily to be near to the expected plume being measured. (Inset) Mont Belvieu – North, South, and East. Texas City and Bayport were also measured on occasion. Image mapped on Google Earth © 2022.

Figure 7 Bayport emissions areas, East highlighted. Image mapped on Google Earth © 2022.

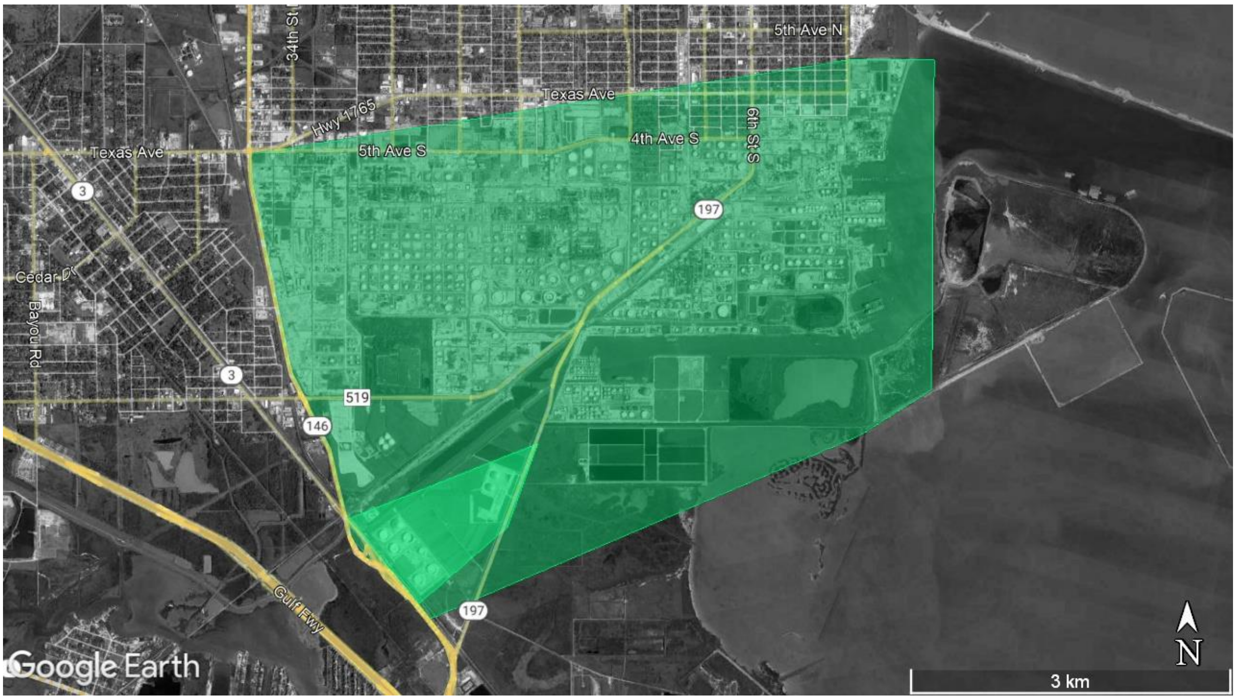


Figure 8 Texas City emissions areas, South Tanks highlighted. Image mapped on Google Earth © 2022.

Figure 9 Measurement paths during the survey (light green). (Inset) Texas City. Image mapped on Google Earth © 2022.

3.2 Area emission measurements and gas fluxes for ethylene, propylene and alkanes

Results are presented in tabular format summarized for the Houston Ship Channel and main areas and then subsequently for each area, highlighted sites and areas with distinct emissions.

3.2.1 Houston Ship Channel

HSC emissions were measured in their entirety (top-down) on a limited number of measurements, whereas subareas/sites typically have a larger number of measurement days and measurements. The limited number of measurements for the overall HSC run is due to the vast size of the HSC area and changing sky conditions, often turning cloudy for parts on many days at the plume location downwind of facilities.

Examples of measurements for HRVOCs and alkanes are shown in Figure 10 to Figure 13. Figure 10 shows the ethylene and propylene measurements combined overlaid on Google Earth, whereas Figure 11 and Figure 12 shows the corresponding measurements in an alternative representation with color coded measured columns (mg/m^2) for ethylene and propylene, respectively. Table 4 summarizes the emission measurements in the HSC by day. In the total HSC measurements, there were large variations between days for both ethylene and alkanes due to temporarily high emissions from some sectors.

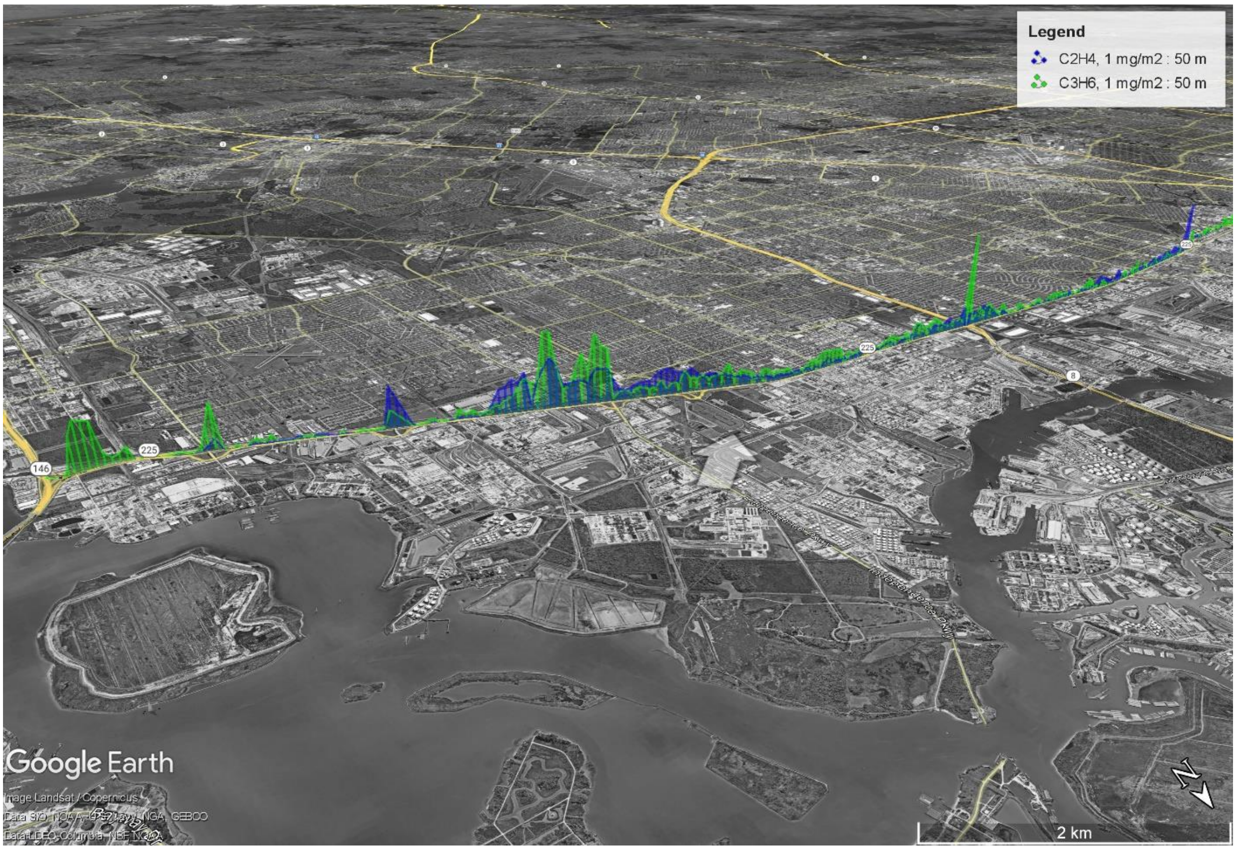


Figure 10. SOF ethylene (blue) and propylene (green) measurement at HSC, 27 September, about 11:00 AM. The apparent height of the overlay is proportional to the ethylene and propylene column, respectively. Wind direction (NE ~5 m/s) during the measurement is indicated with a white arrow. Image mapped on Google Earth © 2022.

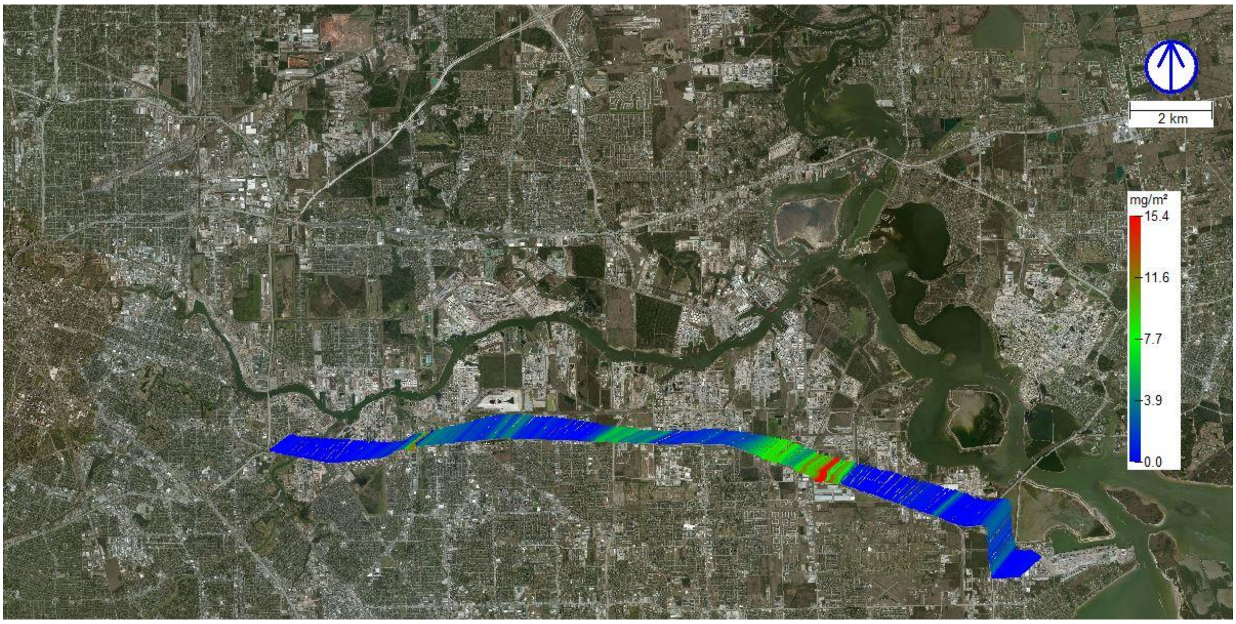


Figure 11 HSC SOF ethylene measurement, 27 September, 10:53 - 11:16. Marker size and color scale proportional to slant column in mg/m^2. Note color scale is logarithmic so smaller plumes are visible. Line from the marker points upwind in the direction of the source with length proportional to wind speed.

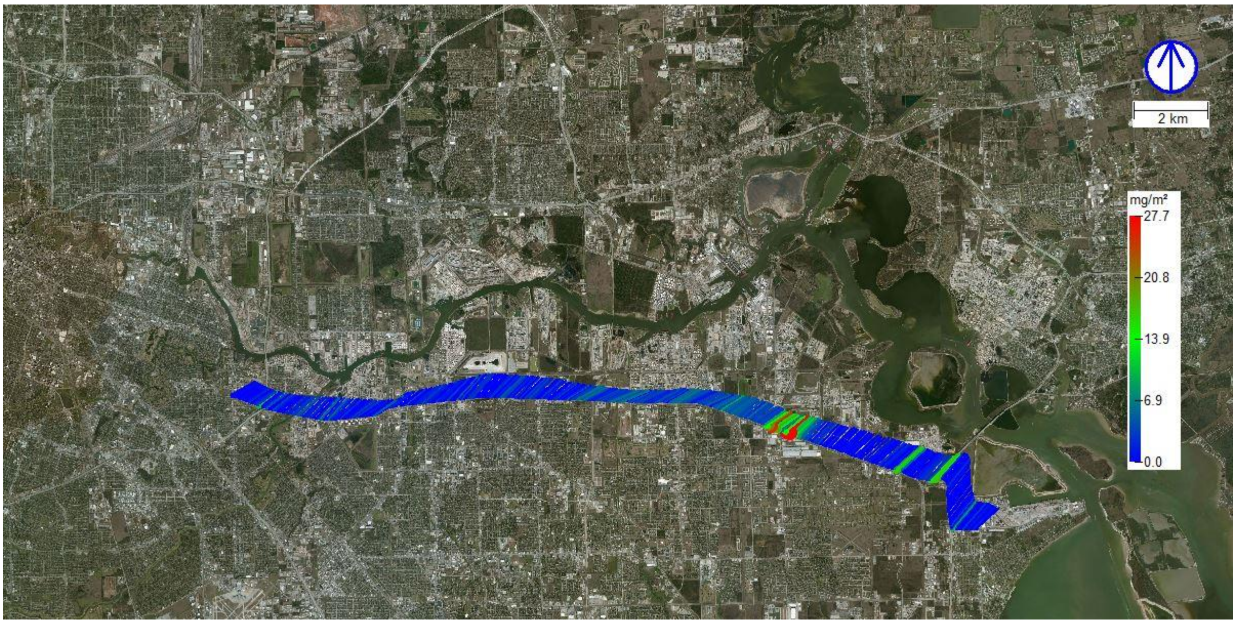


Figure 12 HSC SOF propylene measurement, 27 September, 10:53 - 11:16. Marker size and color scale proportional to slant column in mg/m^2. Line from the marker points upwind in the direction of the source with length proportional to wind speed.

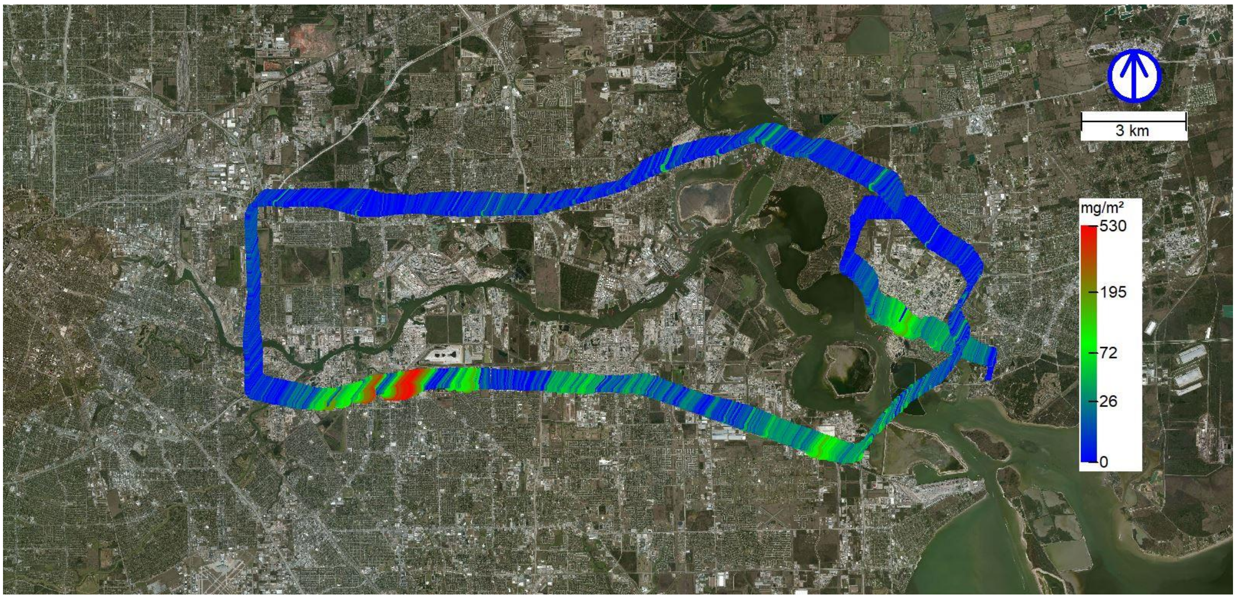


Figure 13 HSC SOF alkane measurement, 26 September, 11:39 - 13:03. Marker size and color scale proportional to slant column in mg/m^2. Note color scale is logarithmic so smaller plumes are visible. Line from the marker points upwind in the direction of the source with length proportional to wind speed.

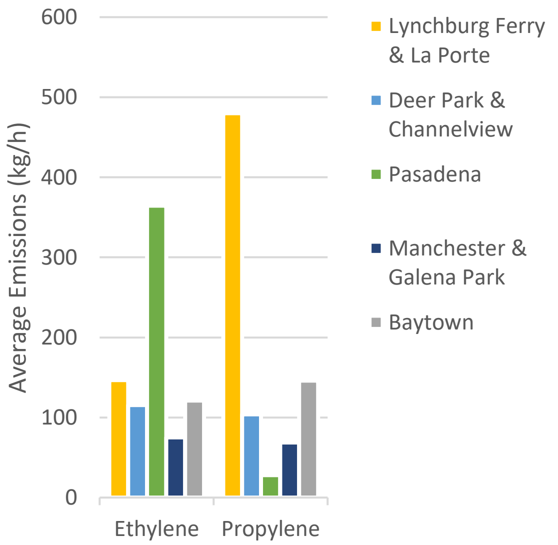
Table 4 Daily summary of VOC emission measurements for the Houston Ship Channel.

Gas	Date [YYMMDD]	Timespan [hhmmss - hhmmss]	N	Mean±95%CI (kg/h)	Wind Speed (m/s)	Wind Dir (deg)
C_2H_4						
	220907	115724-122248	1	1219	2.5	358
	220923	104335-111809	1	277	2.1	79
	220926	100047-103514	1	676	5.3	26
	220927	105738-114458	2	474	5.0-5.4	57-58
C_2H_4 Total			**5**	**624±449**	**2.1-5.4**	**26-358**
C_3H_6						
	220907	115358-122655	1	654	2.5	355
	220911	092339-093607	1	382	5.3	312
	220912	104800-134008	3	648	3.6-4.1	2-16
	220914	145713-154720	1	329	3.8	74
	220926	151013-171224	2	664	6.4-6.9	17-31
	220927	105327-114454	3	689	5.1-5.4	56-58
C_3H_6 Total		**092339-171224**	**11**	**609±111**	**2.5-6.9**	**2-355**
Alkanes						
	220912	111011-134246	2	15963	3.7-4.5	358-358
	220914	135211-141847	1	8026	3.7	85
	220922	125747-132251	1	24261	4.6	16
	220923	104855-124116	2	5114	2.2-2.6	77-79
	220926	115946-154216	3	20055	5.4-6.1	16-35
	220927	105625-114458	2	10683	5.1-5.4	57-58
Alkanes Total		**104855-154216**	**11**	**14179±5602**	**2.2-6.1**	**16-358**

Table 5 summarizes all large-scale measurements during the survey, both total HSC and by Sector. Emissions for areas within the HSC were highly variable during the survey. This was most pronounced for the alkane emission measurements with For the HSC and most areas, few measurements are available so mean emissions are easily affected by upset or activity related emissions. For individual areas the impacts are even greater, for example, ethylene emissions in the Pasadena sector, with one measurement over 1500 kg/h, has a standard deviation almost twice the mean. This is also the case for alkane emissions in the HSC, which were also impacted by temporarily high emissions in the Pasadena sector. As will be addressed in the sector sections, single sources could dominate the HSC for HRVOCs.

Table 5 Summary of VOC emission measurements within the Houston Ship Channel by sector for September 2022. *A few measurements may include some emissions from Baytown.

Sector	C_2H_4 (mean ± SD) [kg/h]	C_3H_6 (mean ± SD) [kg/h]	Alkanes (mean ± SD) [kg/h]
HSC	624 ± 361	609 ± 166	14179 ± 8339
HSC (sum of sectors)	**544**	**826**	**17597 ± 544**
Baytown	121 ± 55	146 ± 69	1428 ± 337
Lynchburg Ferry & La Porte*	147 ± 71	480 ± 319	2623 ± 1455
DeerPark & Channelview	116 ± 77	104 ± 44	2645 ± 1160
Pasadena	90 ± 52	28 ± 23	8389 ± 6236
Manchester & Galena Park	75 ± 36	69 ± 30	2512 ± 1478



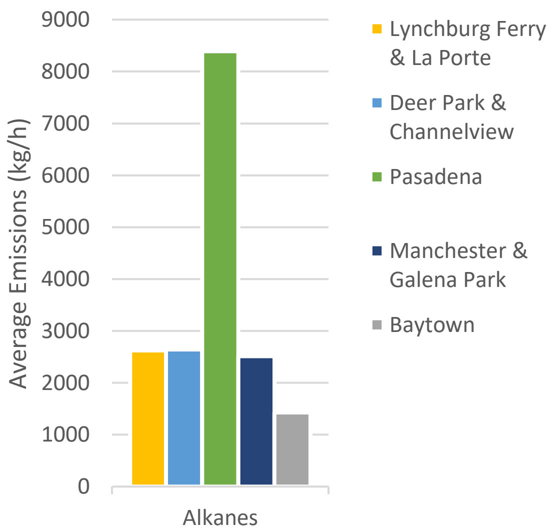


Figure 14 Average emissions by sector for the HSC, September 2022.

3.2.2 Baytown

Emissions from Baytown were more repeatable than other areas due to its isolation and the possibility of making box measurements to eliminate upwind sources. Ethylene emissions averaged just over 100 kg/h, and propylene 140 kg/h and alkane emissions about 10 times that, or over 1400 kg/h. No significantly larger anomalous emissions were noted during the survey. A summary of these measurements can be found in Table 6.

Table 6 Daily summary of VOC emission measurements for Baytown.

Gas	Date [YYMMDD]	Timespan [hhmmss - hhmmss]	N	Mean±95%CI (kg/h)	Wind Speed (m/s)	Wind Dir (deg)
C_2H_4						
	220906	144957-174331	3	78	4.5-4.9	146-153
	220907	121727-122322	1	51	2.7	12
	220912	143801-144308	1	270	3.7	330
	220913	104728-114235	2	140	3.4-3.8	92-128
	220914	160242-161558	1	147	3.8	64
	220915	112240-130544	5	134±61	4.9-6.1	70-94
	220922	093400-094519	1	109	3.6	348
	220924	121846-142018	3	130	3.3-5.1	143-155
	220926	150446-151412	1	109	5.8	10
	220927	154653-165323	3	93	4.1-4.3	34-56
C_2H_4 Total		**093400-174331**	**22**	**121±25**	**2.7-6.1**	**10-348**
C_3H_6						
	220906	124944-162348	5	154±121	4.8-6.4	146-191
	220910	103249-110029	1	207	4.6	16
	220911	091606-124642	5	181±84	3.0-5.5	313-343
	220912	143741-144207	1	240	3.7	334
	220913	104728-110015	1	60	3.8	92
	220914	160242-161558	1	186	3.8	64
	220922	094133-123803	3	126	3.0-4.5	337-358
	220924	110818-164711	6	93±22	3.1-5.1	132-160
	220927	154653-162849	2	174	4.0-4.3	50-56
C_3H_6 Total		**091606-164711**	**25**	**146±29**	**3.0-6.4**	**16-358**
Alkanes						
	220911	091606-120400	4	1526±271	4.5-5.5	313-340
	220915	124132-130330	1	1698	5.9	89
	220920	150523-151715	1	716	2.7	122
	220922	103825-123807	2	1284	3.0-4.6	338-358
	220924	113728-150912	7	1461±321	2.6-4.5	142-160
	220926	114452-151343	3	1467	5.3-5.8	4-351
Alkanes Total		**091606-151715**	**18**	**1428±168**	**2.6-5.9**	**4-358**

3.2.3 Lynchburg Ferry and La Porte

The Lynchburg Ferry and La Porte sector of the HSC contains numerous distinct and large sources of HRVOCs. However due to winds during the survey (often northeasterly), measurements of the entire sector may inevitably include some upwind emissions from the Baytown area. However enough measurements of individual sites exist to corroborate sector emissions with bottom-up approach. Table 7 summarizes sector emissions by day. Ethylene emissions were relatively stable and averaged around 150 kg/h, while propylene and alkanes were much more variable. Based on 26 measurements over 8 days, propylene emissions averaged 480 kg/h (±129 kg/h 95% CI).

Table 7 Daily summary of VOC emission measurements for Lynchburg Ferry and La Porte.

Gas	Date [YYMMDD]	Timespan [hhmmss - hhmmss]	N	Mean±95%CI (kg/h)	Wind Speed (m/s)	Wind Dir (deg)
C_2H_4						
	220902	121645-135954	3	113	4.0-4.6	95-105
	220907	130215-131949	1	119	3.4	63
	220909	160323-161207	1	109	4.0	102
	220912	085120-132212	4	125±121	3.5-4.2	7-358
	220913	092155-160908	7	139±45	3.0-4.0	44-96
	220922	090425-120316	4	151±77	3.2-5.2	331-358
	220923	103122-114105	3	96	2.0-3.0	34-89
	220926	100145-172320	3	263	5.3-7.1	21-29
	220927	101354-114132	3	175	4.9-5.2	36-59
C_2H_4 Total		**085120-172320**	**29**	**147±27**	**2.0-7.1**	**7-358**
C_3H_6						
	220902	121559-135859	5	765±435	4.0-4.7	92-105
	220907	130215-131322	1	228	3.0	58
	220912	112652-174429	8	674±236	3.5-4.9	6-359
	220913	094108-160706	4	278±117	2.9-4.0	33-93
	220922	090429-110738	3	285	3.1-4.3	331-343
	220923	103122-120753	2	155	2.0-2.3	41-62
	220926	100145-100914	1	247	5.3	29
	220927	102102-110426	2	257	5.0-5.6	39-59
C_3H_6 Total		**090429-174429**	**26**	**480±129**	**2.0-5.6**	**6-359**
Alkanes						
	220909	174323-174943	1	808	5.4	140
	220912	131311-132156	1	3638	4.3	6
	220913	092155-161101	4	1925±2331	3.0-4.1	49-93
	220922	125855-130738	1	2777	4.3	13
	220926	121129-172557	3	3210	5.0-8.5	37-56
	220927	105625-114224	2	3458	5.0-5.3	56-58
Alkanes Total		**092155-174943**	**12**	**2623±925**	**3.0-8.5**	**6-140**

Figure 15 indicates the locations of individual sites with measured emissions in the Lynchburg Ferry & La Porte Sector. Figure 16 summarizes the emissions for these sites. Lynchburg Ferry Site C was apparently the largest source of propylene emissions in the area, and La Porte B the largest ethylene source. The La Porte B source is thought to be venting of a gas tank. Summaries of these measurements by day are given in Table 8 through Table 12.

Figure 15 Individual sites with measured HRVOC emissions in the Lynchburg Ferry (cyan) & La Porte Sector (yellow). Image mapped on Google Earth © 2022.

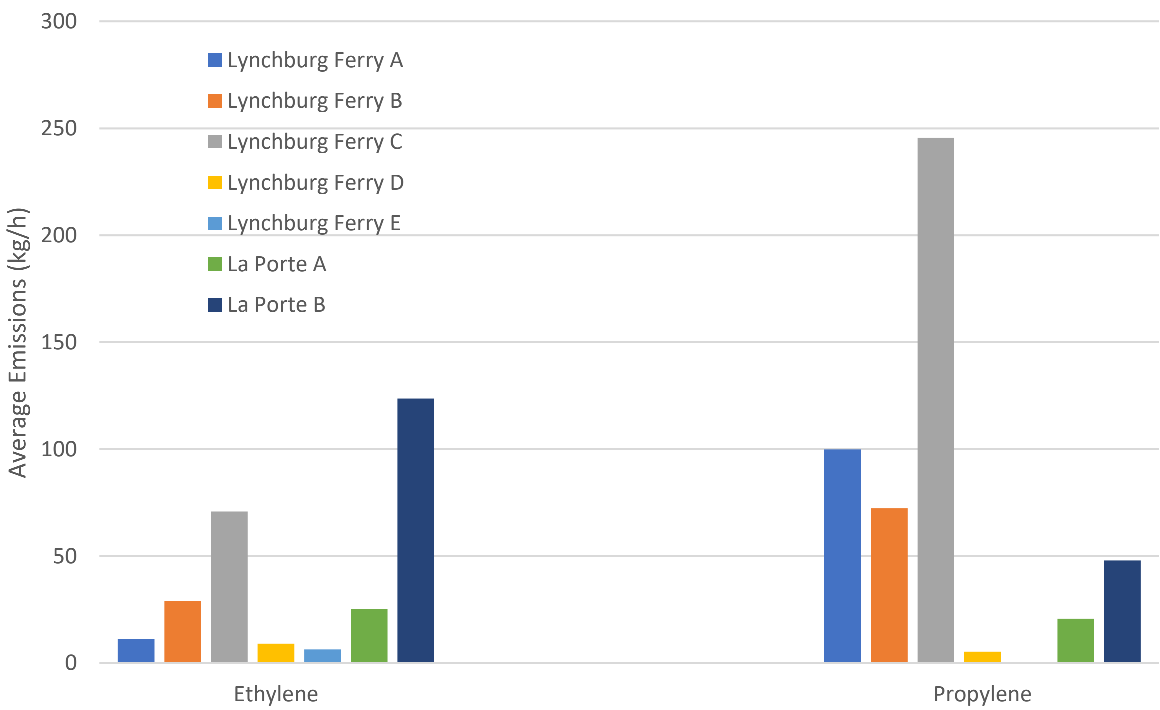


Figure 16 Ethylene and propylene emissions within the Lynchburg Ferry and La Porte Sector, September 2022.

Table 8 Daily summary of VOC emission measurements for Lynchburg Ferry A.

Gas	Date [YYMMDD]	Timespan [hhmmss - hhmmss]	N	Mean±95%CI (kg/h)	Wind Speed (m/s)	Wind Dir (deg)
C_2H_4						
	220902	121803-135737	3	20	4.1-4.7	95-105
	220907	130552-130727	1	3	2.8	51
	220909	092918-163407	6	7±6	2.1-4.6	65-137
	220913	094912-160702	4	11±7	2.8-4.1	58-95
	220920	104113-122005	6	9±5	1.6-2.5	22-349
	220922	152519-153611	4	17±11	3.7-4.9	16-357
C_2H_4 Total		**092918-163407**	**24**	**11±3**	**1.6-4.9**	**16-357**
C_3H_6						
	220902	121613-135841	4	168±305	4.2-4.7	95-104
	220909	092918-163400	6	71±28	2.1-4.6	65-136
	220913	093725-160702	8	98±37	2.5-4.4	34-95
	220920	104113-135426	9	99±49	1.6-2.7	23-352
	220922	145018-153611	5	85±22	3.2-4.9	15-357
C_3H_6 Total		**092918-163400**	**32**	**100±28**	**1.6-4.9**	**15-357**

Table 9 Daily summary of VOC emission measurements for Lynchburg Ferry B.

Gas	Date [YYMMDD]	Timespan [hhmmss - hhmmss]	N	Mean±95%CI (kg/h)	Wind Speed (m/s)	Wind Dir (deg)
C_2H_4						
	220902	121939-135646	5	42±15	4.0-5.2	91-107
	220907	130823-130945	1	23	3.3	70
	220909	092810-164727	8	25±13	2.1-5.7	58-148
	220913	093532-160546	9	26±10	2.4-4.7	27-96
C_2H_4 Total		**092810-164727**	**23**	**29±6**	**2.1-5.7**	**27-148**
C_3H_6						
	220902	130740-135646	2	200	4.6-5.2	91-107
	220909	092706-163509	6	44±13	2.1-4.5	65-140
	220913	093552-160505	7	60±73	2.4-4.3	26-96
C_3H_6 Total		**092706-163509**	**15**	**72±48**	**2.1-5.2**	**26-140**

Table 10 Daily summary of VOC emission measurements for Lynchburg Ferry C.

Gas	Date [YYMMDD]	Timespan [hhmmss - hhmmss]	N	Mean±95%CI (kg/h)	Wind Speed (m/s)	Wind Dir (deg)
C_2H_4						
	220907	131217-131312	1	10	3.9	71
	220909	092010-162202	4	35±38	1.9-3.9	65-99
	220912	173632-173729	1	49	4.8	45
	220913	093112-142254	4	48±33	2.7-4.0	52-97
	220914	123530-142028	2	231	3.7-4.5	62-83
C_2H_4 Total		**092010-173729**	**12**	**71±52**	**1.9-4.8**	**45-99**
C_3H_6						
	220902	121930-135505	3	572	4.2-5.1	96-108
	220909	092108-163718	5	108±72	2.0-4.2	66-148
	220912	085341-173918	3	610	3.9-5.3	16-43
	220913	093028-160131	4	87±4	3.2-4.0	30-97
	220914	123550-123743	1	130	4.5	63
	220923	103255-120126	4	86±78	2.0-3.1	33-89
C_3H_6 Total		**085341-173918**	**20**	**246±126**	**2.0-5.3**	**16-148**

Table 11 Daily summary of VOC emission measurements for La Porte A.

Gas	Date [YYMMDD]	Timespan [hhmmss - hhmmss]	N	Mean±95%CI (kg/h)	Wind Speed (m/s)	Wind Dir (deg)
C_2H_4						
	220902	131455-131735	1	30	4.9	93
	220913	134540-135124	1	20	3.4	63
	220920	122346-140103	2	26	2.3-2.4	82-100
C_2H_4 Total		**122346-140103**	**4**	**25±18**	**2.3-4.9**	**63-100**
C_3H_6						
	220913	131505-135023	2	19	3.5-3.7	63-68
	220920	135635-140126	1	24	2.2	101
C_3H_6 Total		**131505-140126**	**3**	**21**	**2.2-3.7**	**63-101**

Table 12 Daily summary of VOC emission measurements for La Porte B.

Gas	Date [YYMMDD]	Timespan [hhmmss - hhmmss]	N	Mean±95%CI (kg/h)	Wind Speed (m/s)	Wind Dir (deg)
C_2H_4						
	220907	121619-133645	6	297±325	2.5-4.0	1-85
	220909	095628-100816	4	4±6	1.8-3.0	55-72
	220912	113440-115030	2	26	3.4-3.7	16-354
	220913	125013-125147	1	12	3.3	64
	220922	115524-125944	2	30	4.2-5.4	22-358
	220923	103722-103838	1	19	1.8	38
	220926	095827-151508	3	167	5.0-6.7	9-346
	220927	114204-114333	1	29	5.6	51
C_2H_4 Total		**095628-151508**	**20**	**124±100**	**1.8-6.7**	**1-358**
C_3H_6						
	220907	132002-132114	1	28	4.0	70
	220909	095709-100806	4	105±129	1.8-2.9	55-72
	220912	085027-085108	1	8	4.1	23
	220913	142612-142756	1	6	3.5	65
	220914	142125-142350	1	15	3.6	80
	220920	165739-170221	2	0	1.4-1.5	143-170
	220927	105625-105742	1	49	5.7	51
C_3H_6 Total		**085027-170221**	**11**	**48±44**	**1.4-5.7**	**23-170**
Alkanes						
	220913	125009-125102	1	60	3.2	63
	220922	125839-130008	1	1038	4.1	23
	220926	133309-171544	4	1108±1549	6.3-6.8	13-34
Alkanes Total		**125009-171544**	**6**	**922±907**	**3.2-6.8**	**13-63**

3.2.4 Deer Park & Channelview

The Deer Park sector typically includes upwind emissions from Channelview although a few measurements may exclude these emissions. Ethylene and propylene emissions averaged just over 100 kg/h and alkane emissions over 2500 kg/h. Alkane emissions were the highest on the same day as the highest Pasadena alkane emissions.

Table 13 Daily summary of emission measurements for Deer Park & Channelview.

Gas	Date [YYMMDD]	Timespan [hhmmss - hhmmss]	N	Mean±95%CI (kg/h)	Wind Speed (m/s)	Wind Dir (deg)
C_2H_4						
	220907	120735-121139	1	117	2.0	357
	220912	111844-132957	3	211	3.1-4.9	5-353
	220922	091348-160120	6	95±63	3.1-4.6	4-348
	220923	102656-121151	4	40±47	2.2-2.5	18-100
	220926	100822-165833	3	155	4.9-7.1	27-29
	220927	110402-113520	2	125	5.0-5.0	57-61
C_2H_4 Total		**091348-165833**	**19**	**116±37**	**2.0-7.1**	**4-357**
C_3H_6						
	220912	111912-155011	4	66±40	3.1-4.9	6-354
	220922	091348-161330	6	130±47	3.0-4.6	3-343
	220923	102640-103126	1	77	2.3	18
	220926	100907-102152	1	114	4.9	28
	220927	110349-110801	1	116	5.0	61
C_3H_6 Total		**091348-161330**	**13**	**104±26**	**2.3-5.0**	**3-354**
Alkanes						
	220912	111832-133046	2	2577	3.1-4.8	5-355
	220922	100930-154514	3	3834	3.8-4.3	20-355
	220926	121806-170215	4	2361±988	5.0-7.1	25-38
	220927	110333-113544	2	1499	4.9-5.1	57-61
Alkanes Total		**100930-170215**	**11**	**2645±779**	**3.1-7.1**	**5-355**

3.2.5 Pasadena

The Pasadena sector had the most highly varying emissions for ethylene and alkanes. For ethylene this was due to a single upset emission so it was excluded from the sector statistics. For alkanes the anomalously high emissions were observed on two days, 22 and 26 September. Since the focus was on continued large-scale emission measurements there was no possibility to investigate the source at the time.

Table 14 Daily summary of emission measurements for Pasadena. *Upset emission excluded from sector statistics

Gas	Date [YYMMDD]	Timespan [hhmmss - hhmmss]	N	Mean±95%CI (kg/h)	Wind Speed (m/s)	Wind Dir (deg)
C_2H_4						
	220907	120231-120735	1	50	2.6	4
	220912	120817-133843	2	99	3.5-4.4	20-359
	220922*	131121-131920	1	1737	4.9	20
	220926	152803-164948	2	100	6.0-6.9	22-36
C_2H_4 Total		**120231-164948**	**5**	**90±64**	**2.6-6.9**	**4-359**
C_3H_6						
	220912	111414-164150	4	27±42	3.6-5.0	20-360
	220927	110801-111345	1	34	5.2	53
C_3H_6 Total		**110801-164150**	**5**	**28±28**	**3.6-5.2**	**20-360**
Alkanes						
	220907	112856-113424	1	5737	3.3	345
	220912	111349-133835	2	8518	3.6-4.9	0-359
	220922	131154-135359	2	16986	3.5-4.9	20-349
	220926	122301-164900	4	7666±8461	5.6-6.9	21-41
	220927	110756-113145	2	2437	5.2-5.2	53-56
Alkanes Total		**110756-164900**	**11**	**8389±4189**	**3.3-6.9**	**0-359**

3.2.6 Manchester & Galena Park

Within the Manchester & Galena Park sector, no distinct source of HRVOCs were expected or observed and the sector was not prioritized, so there are fewer measurements here than for the other sectors. The results are summarized in Table 15. Alkane emissions in this sector averaged 2512 kg/h (±1058 kg/h 95% CI).

Table 15 Daily summary of emission measurements for Manchester & Galena Park.

Gas	Date [YYMMDD]	Timespan [hhmmss - hhmmss]	N	Mean±95%CI (kg/h)	Wind Speed (m/s)	Wind Dir (deg)
C_2H_4						
	220907	120101-120308	1	55	3.0	354
	220912	121928-134318	2	105	4.0-4.1	19-333
	220923	091218-091806	1	70	2.7	349
	220926	153339-153801	1	41	5.5	356
C_2H_4 Total		**091218-153801**	**5**	**75±45**	**2.7-5.5**	**19-356**
C_3H_6						
	220912	122008-134447	2	69	3.9-4.0	17-333
	220927	111345-111731	1	68	5.3	61
C_3H_6 Total		**111345-134447**	**3**	**69**	**3.9-5.3**	**17-333**
Alkanes						
	220907	113424-113826	1	1287	2.9	342
	220912	111011-134535	2	1098	3.8-4.7	10-334
	220922	131859-135705	2	4808	3.6-4.9	22-353
	220926	122809-153809	3	2539	5.5-6.1	15-355
	220927	111349-112514	2	2201	5.3-5.9	62-63
Alkanes Total		**111011-153809**	**10**	**2512±1058**	**2.9-6.1**	**10-355**

3.2.7 Mont Belvieu

Mont Belvieu is separated geographically from the HSC (approximately 10 km to the Baytown fenceline) and generally has no significant upwind emission plumes to contend with in measurements. Table 16 summarizes measurements of the Mont Belvieu area by day. Ethylene and propylene emissions were relatively invariant, i.e. the 95 % CI for the means were within 20% of the respective mean. Alkane emissions were subject to more variability but less than in the HSC Sectors. Overall ethylene emissions averaged 235 kg/h and propylene emissions 172 kg/h.

Emissions in Mont Belvieu were further subdivided into North, East and South areas, however only the North area has sufficient measurements for adequate statistics at this time.

Figure 17 shows a SOF measurement of ethylene and propylene emissions at Mont Belvieu on the morning of 21 September. Winds were from the north, and the aggregated emissions from the different site areas at Mont Belvieu were measured south of the area on I-10.

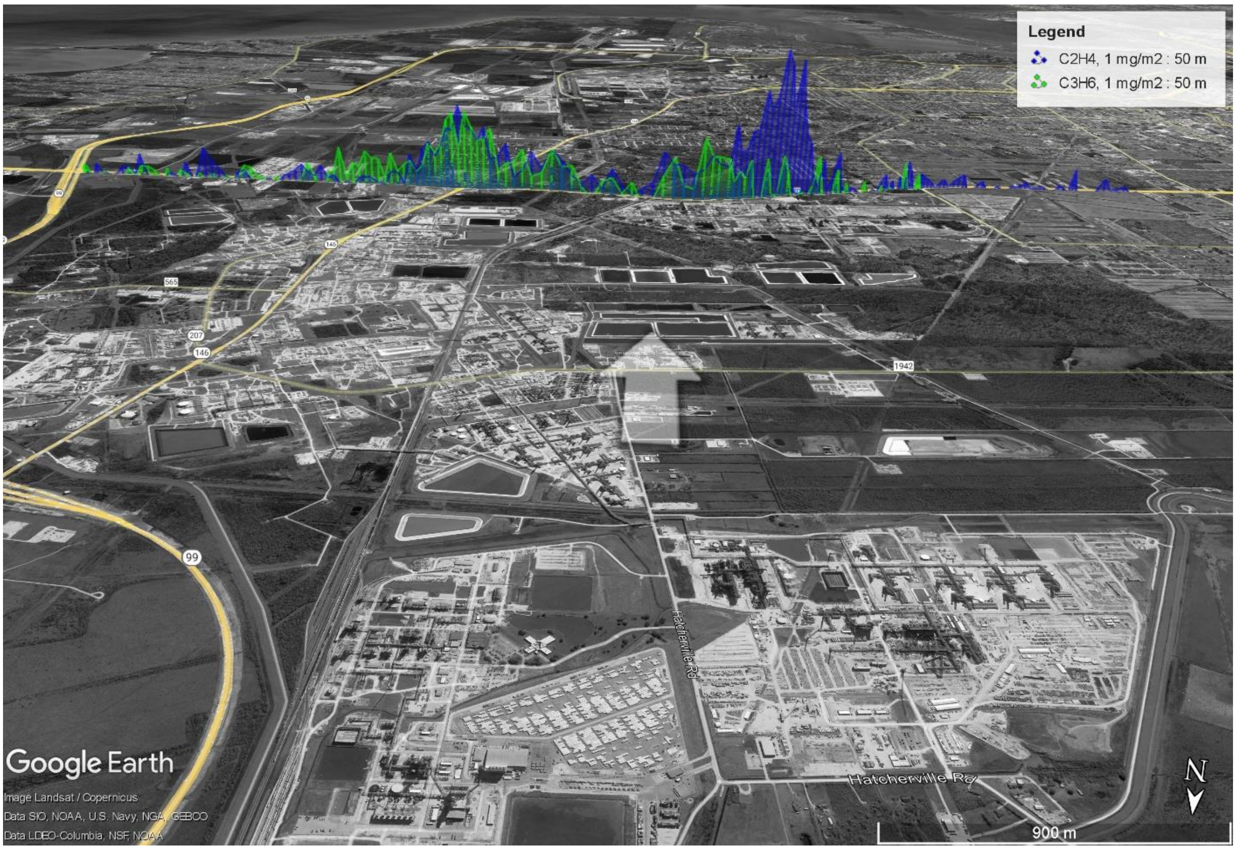


Figure 17. SOF ethylene (blue) and propylene (green) measurement at Mont Belvieu, 21 September, about 09:15 AM. The apparent height of the overlay is proportional to the ethylene and propylene column, respectively. Wind direction (North) during the measurement is indicated with a white arrow. Image mapped on Google Earth © 2022.

Table 16 Daily summary of emission measurements for Mont Belvieu.

Gas	Date [YYMMDD]	Timespan [hhmmss - hhmmss]	N	Mean±95%CI (kg/h)	Wind Speed (m/s)	Wind Dir (deg)
C_2H_4						
	220912	092645-104519	5	212±76	3.6-4.0	25-39
	220921	091607-101416	3	237	2.6-2.7	14-356
	220927	124930-151905	3	312	4.8-6.3	35-57
	220928	094346-172349	10	223±31	3.1-5.0	5-82
C_2H_4 Total		**091607-172349**	**21**	**235±30**	**2.6-6.3**	**5-356**
C_3H_6						
	220912	092717-104455	4	220±53	3.8-4.0	33-39
	220921	091607-101416	3	178	2.6-2.8	8-347
	220927	124930-144001	2	136	4.5-6.3	45-57
	220928	162009-165453	3	126	3.4-5.2	16-31
C_3H_6 Total		**091607-165453**	**12**	**172±33**	**2.6-6.3**	**8-347**
Alkanes						
	220912	092645-104507	4	1872±254	3.9-4.0	31-39
	220921	103434-104239	1	714	2.6	38
	220927	124930-143807	2	1124	3.0-6.3	0-57
	220928	124836-170826	7	1347±523	3.4-5.2	11-349
Alkanes Total		**092645-170826**	**14**	**1420±305**	**2.6-6.3**	**0-349**

Table 17 Daily summary of emission measurements for Mont Belvieu - North.

Gas	Date [YYMMDD]	Timespan [hhmmss - hhmmss]	N	Mean±95%CI (kg/h)	Wind Speed (m/s)	Wind Dir (deg)
C_2H_4						
	220921	110339-111233	1	98	2.3	47
	220927	134831-141232	2	51	5.2-5.3	40-61
	220928	100323-141536	4	106±99	3.9-4.7	51-80
C_2H_4 Total		**100323-141536**	**7**	**89±49**	**2.3-5.3**	**40-80**
C_3H_6						
	220921	110335-111116	1	43	2.3	47
	220927	134836-145541	3	62	4.7-5.3	40-61
	220928	102953-141540	6	83±32	3.8-4.8	51-68
C_3H_6 Total		**102953-145541**	**10**	**73±19**	**2.3-5.3**	**40-68**
Alkanes						
	220921	105326-111619	2	221	2.1-2.6	57-68
	220927	120232-145239	3	153	2.8-4.6	0-50
	220928	110810-125919	3	295	3.8-5.6	56-68
Alkanes Total		**105326-145239**	**8**	**223±95**	**2.1-5.6**	**0-68**

3.2.8 Channelview North (of I-10)

Measurements of the facilities in the north of Channelview (North of I-10) were made on either the nearby fenceline, on Sheldon Rd, or on I-10. A summary of days measurements is given in Table 18. Emissions of ethylene and propylene averaged under 100 kg/h, with one outlier propylene emission over 200 kg/h measured on I-10.

Table 18 Daily summary of emission measurements for Channelview North.

Gas	Date [YYMMDD]	Timespan [hhmmss - hhmmss]	N	Mean±95%CI (kg/h)	Wind Speed (m/s)	Wind Dir (deg)
C_2H_4						
	220912	105335-105813	1	41	4.2	36
	220918	104308-164149	5	70±67	1.4-5.9	86-139
	220921	143806-145113	2	88	2.8-2.9	105-117
	220922	102147-102658	1	101	3.7	360
	220923	141046-142757	2	81	3.4-3.6	91-116
C_2H_4 Total		**102147-164149**	**11**	**75±26**	**1.4-5.9**	**36-360**
C_3H_6						
	220912	105247-125047	2	67	2.3-4.1	5-35
	220918	145122-145934	1	31	4.7	137
	220922	102243-102618	1	212	3.6	359
	220923	135932-142720	2	59	3.7-5.0	90-119
C_3H_6 Total		**102243-145934**	**6**	**82±70**	**2.3-5.0**	**5-359**
Alkanes						
	220912	105126-110018	1	469	4.1	37
	220918	103841-131640	3	117	2.0-3.4	86-131
	220923	140926-142249	2	477	3.4-3.7	84-114
Alkanes Total			**6**	**295.7±231.6**	**2.0**	**37 - 131**

3.2.9 Channelview (HSC)

Within the HSC Channelview area, emissions were regularly observed from Site A, several barge mooring sites and a shipyard area, that also includes barge mooring (Figure 18). The area boundaries are not exact and upwind emissions from other moored barges are possible. Alkane emissions were on the order of a few hundred kilograms per hour (Table 19).

Figure 18 Measured emission sources in the HSC Channelview area. Image mapped on Google Earth © 2022.

Table 19 Daily summary of emission measurements for HSC Channelview.

Site / *Gas*	Date [YYMMDD]	Timespan [hhmmss - hhmmss]	N	Mean±95%CI (kg/h)	Wind Speed (m/s)	Wind Dir (deg)
Moored barges						
Alkanes						
	220914	173415-173737	1	79	3.5	91
	220915	111443-112043	1	22	6.4	81
	220923	125051-131753	8	487±184	2.6-4.4	57-130
Alkanes Total		**111443-173737**	**10**	**400±192**	**2.6-6.4**	**57-130**
Channelview Site A						
Alkanes						
	220914	172008-173307	2	278	4.2-4.3	81-89
	220915	111302-115311	4	249±222	5.3-6.2	75-94
	220923	125900-131006	4	121±40	2.4-2.8	37-109
Alkanes Total		**111302-173307**	**10**	**204±78**	**2.4-6.2**	**37-109**
Shipyard						
Alkanes						
	220915	115439-123005	3	287	4.8-5.6	67-85
	220923	132626-133029	1	69	2.7	88
Alkanes Total		**115439-133029**	**4**	**232±281**	**2.7-5.6**	**67-88**

3.2.10 Texas City

Although initially on the list of objects or the survey, Texas City was not prioritized as the campaign progressed and was measured on only single afternoon on 8 September. VOC emissions are summarized in Table 20. Figure 19 shows a SOF measurement of ethylene and propylene on Hwy 146 west of the site.

Table 20 Daily summary of VOC emission measurements for Texas City.

Gas	Date [YYMMDD]	Timespan [hhmmss - hhmmss]	N	Mean±95%CI (kg/h)	Wind Speed (m/s)	Wind Dir (deg)
C_2H_4	220908	135507-164254	7	50±13	2.6-3.6	32-86
C_3H_6	220908	135612-171436	8	161±104	2.4-3.5	32-120
Alkanes	220908	155340-164937	3	1056	3.2-3.9	63-87

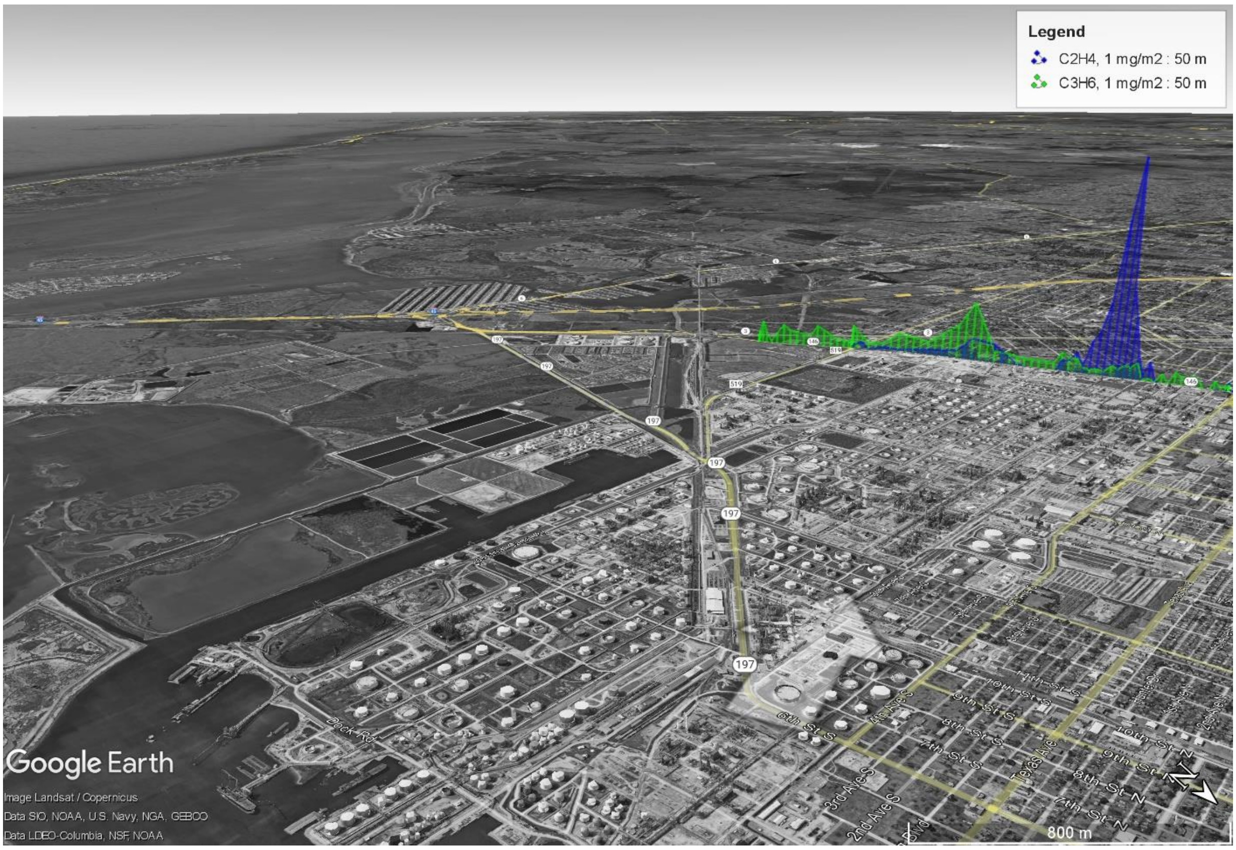


Figure 19. SOF ethylene (blue) and propylene (green) measurement at Texas City, 8 September, about 2:10 AM. The apparent height of the overlay is proportional to the ethylene and propylene column, respectively. Wind direction (Northeast) during the measurement is indicated with a white arrow. Image mapped on Google Earth © 2022.

3.3 Formaldehyde and NO_2 emissions measurements and gas fluxes

Observed emissions of formaldehyde in the Greater Houston area are mostly secondary, i.e. a product of photochemically degraded HRVOC emissons. With the exception of a few primary sources in the HSC and Mont Belvieu, emissions measurements and interpretation are complicated by transport time, upwind plumes and chemistry involved. In contrast to the other emission measurements, the source area of the HCHO emissions is less certain since the contributing primary HRVOC emissions may originate in a different area.

3.3.1 Houston Ship Channel

Figure 20 and Figure 21 show examples of SkyDOAS measurements for formaldehyde and NO_2, respectively. As can be seen in Figure 20 a large background of HCHO comes in from the east-northeast. This could be from Mont Belvieu or plumes from the HSC returning. Results are assigned according to the area upwind of the measurement. Measurements are summarized in Table 21.

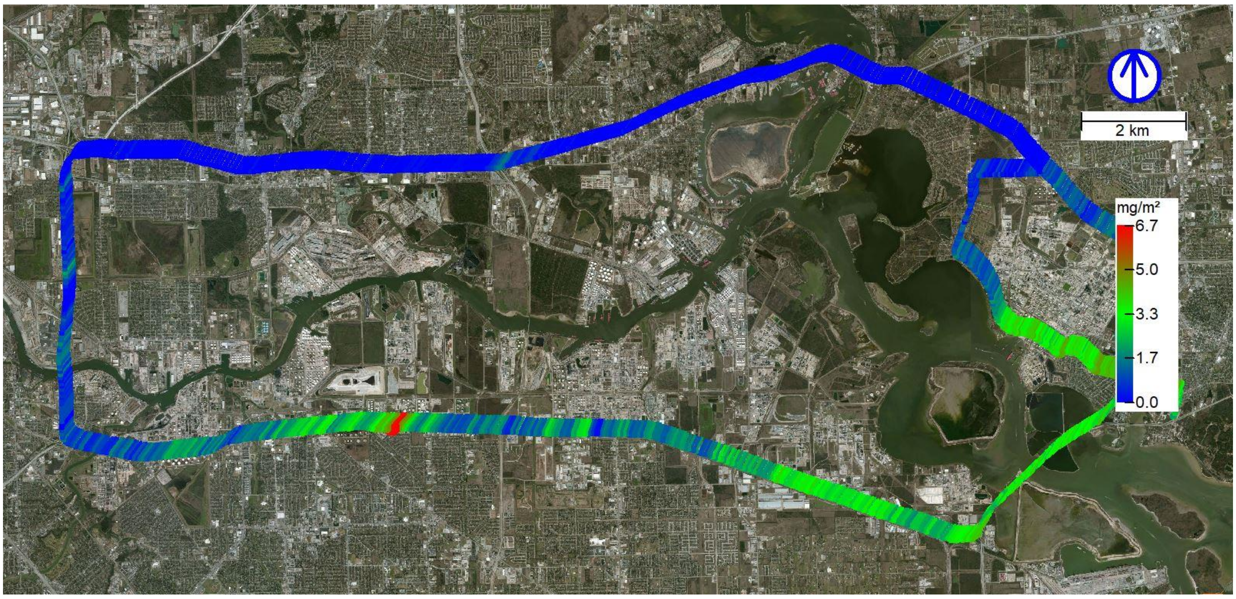


Figure 20 HSC SkyDOAS HCHO measurement, 26 September, 11:39 - 13:03. Marker size and color scale proportional to vertical column in mg/m^2. Line from the marker points upwind in the direction of the source with length proportional to wind speed.

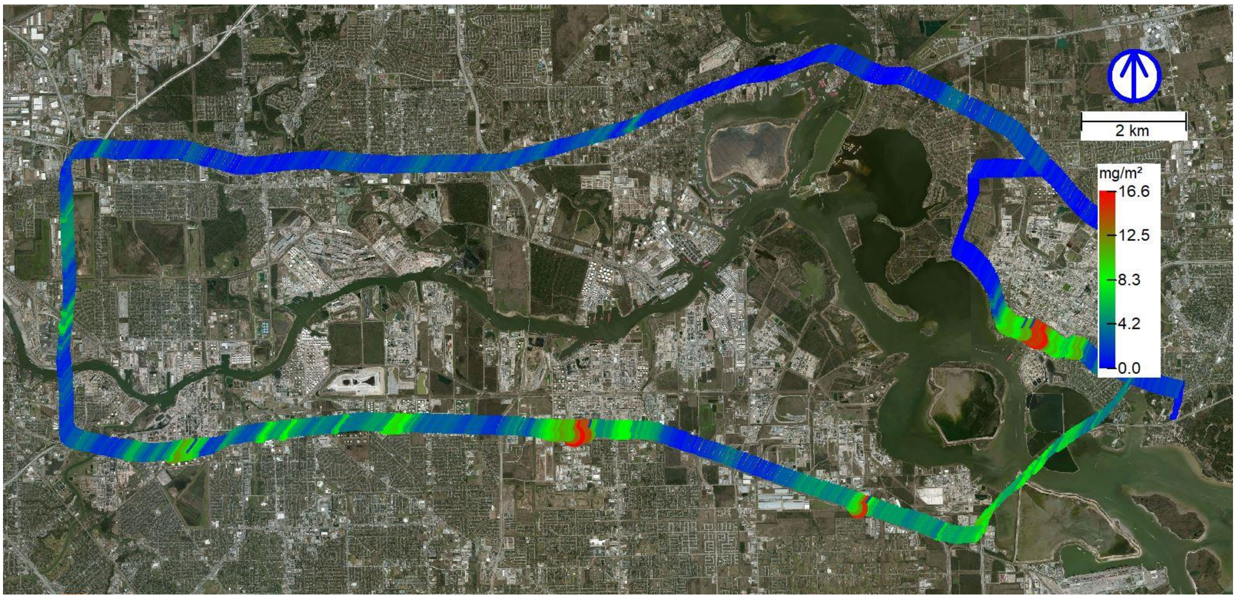


Figure 21 HSC SkyDOAS NO_2 measurement, 26 September, 11:39 - 13:03. Marker size and color scale proportional to vertical column in mg/m^2. Line from the marker points upwind in the direction of the source with length proportional to wind speed.

Table 21 Daily summary of formaldehyde and NO_2 emission measurements for HSC.

Gas	Date [YYMMDD]	Timespan [hhmmss - hhmmss]	N	Mean±95%CI (kg/h)	Wind Speed (m/s)	Wind Dir (deg)
HCHO						
	220912	130825-134441	1	242	3.7	359
	220914	131711-164958	3	750	3.7-3.9	70-73
	220926	120953-141204	2	610	5.5-5.9	26-36
	220927	105625-114253	2	433	5.1-5.4	58-58
HCHO Total			**8**	**572±221**	**3.7-5.9**	**26-359**
NO_2						
	220912	110459-134433	3	1014	3.7-4.4	2-359
	220914	134731-154820	2	1325	3.8-3.8	72-83
	220923	115433-150509	2	1307	2.6-4.3	77-124
	220926	115941-140344	2	1453	5.4-5.9	26-35
	220927	105633-114730	2	1148	5.1-5.4	56-58
NO_2 Total		**105633-154820**	**11**	**1228±233**	**2.6-5.9**	**2-359**

Sector based emissisons are summarized in Table 22. Noteworthy the formaldehyde to NO_2 ratio is considerably lower for the Manchester & Galena Park sector compared to the others, plausibly reflecting the comparably lower emissions of HRVOCs in this sector.

Table 22 Summary of formaldehyde and NO_2 emissions by HSC Sector, campaign aggregate.

Site / *Gas*	Timespan [hhmmss - hhmmss]	N	Mean±95%CI (kg/h)	Wind Speed (m/s)	Wind Dir (deg)
HSC					
HCHO	105625-164958	8	572±221	3.7-5.9	26-359
NO_2	105633-154820	11	1228±233	2.6-5.9	2-359
Baytown					
HCHO	085810-174533	34	71±22	2.5-7.3	5-358
NO_2	085930-174625	41	235±42	2.3-7.3	8-358
Lynchburg Ferry & La Porte					
HCHO	090438-175459	28	81±18	1.9-6.2	0-342
NO_2	090625-173345	30	248±42	2.0-7.1	7-358
DeerPark & Channelview					
HCHO	091358-154900	11	75±46	2.3-7.1	14-354
NO_2	091346-163121	19	284±56	2.0-7.1	3-356
Pasadena					
HCHO	102343-164254	8	90±59	3.2-6.3	19-357
NO_2	094538-164254	16	242±40	2.5-6.3	1-359
Manchester & Galena Park					
HCHO	103123-135824	4	27±33	2.9-6.1	18-338
NO_2	091302-153839	14	276±91	2.5-6.1	0-353

Most of the sectors in the south of the HSC had some, apparently primary, emissions of formaldehyde. These and the subdivision of sites in Lynchburg Ferry and La Porte are summarized in Table 23.

Table 23 Summary of formaldehyde and NO_2 emissions by site.

Site / *Gas*	Timespan [hhmmss - hhmmss]	N	Mean±95%CI (kg/h)	Wind Speed (m/s)	Wind Dir (deg)
Lynchburg Ferry A					
HCHO	103144-135850	9	15±8	1.9-4.7	25-204
NO_2	092848-162633	16	25±9	1.7-4.8	17-356
Lynchburg Ferry B					
HCHO	100528-135647	4	12±11	3.9-5.2	88-107
NO_2	125725-171217	2	19	4.7-4.8	91-135
Lynchburg Ferry C					
HCHO	093225-102110	3	4	3.6-4.0	82-97
NO_2	091716-092104	1	101	1.9	68
Lynchburg Ferry D					
HCHO	093501-160435	6	5±2	3.8-5.1	63-108
La Porte A					
NO_2	131605-143830	3	104	3.3-3.7	66-91
Deer Park West					
HCHO	101759-162931	6	29±15	2.4-6.2	16-348
NO_2	160927-161427	1	152	3.7	348
Pasadena (Flare Jefferson Rd)					
HCHO	094726-162703	10	23±12	2.5-6.4	5-358

Many more individual sites could be analyzed for NO_2 emissions based on the measurements, however this is outside the scope of the current report. Figure 22 shows the average formaldehyde and NO_2 emissions measured from the Lynchburg Ferry and La Porte sites.

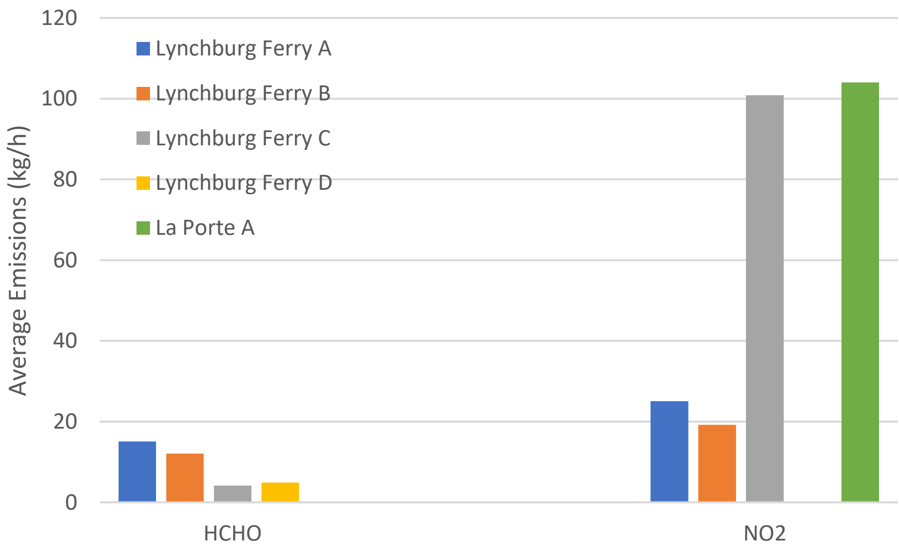


Figure 22 Formaldehyde and NO_2 emissions from sites in Lynchburg Ferry and La Porte.

3.3.2 Mont Belvieu

Like with the VOC measurements, Mont Belvieu's isolation makes measurements relatively easier with less interference from other sites to consider.

Table 24 Daily summary of HCHO and NO_2 emission measurements for Mont Belvieu.

Gas	Date [YYMMDD]	Timespan [hhmmss - hhmmss]	N	Mean±95%CI (kg/h)	Wind Speed (m/s)	Wind Dir (deg)
HCHO						
	220912	094721-104255	3	47	3.9-4.1	28-38
	220921	091609-104235	4	39±20	2.3-2.9	19-356
	220926	110103-115425	2	225	5.2-5.5	29-37
	220927	115122-152307	5	129±63	4.6-6.6	21-54
	220928	150045-172210	5	88±24	3.5-5.2	6-354
HCHO Total		**091609-172210**	**19**	**96±31**	**2.3-6.6**	**6-356**
NO_2						
	220912	093031-104439	2	170	3.9-4.0	25-33
	220921	091633-104119	5	134±22	2.3-2.9	18-357
	220927	115822-143622	3	199	4.6-6.3	50-54
	220928	104530-172106	6	182±56	3.1-5.4	7-354
NO_2 Total		**091633-172106**	**16**	**169±23**	**2.3-6.3**	**7-357**

3.4 Benzene and other aromatic emissions measurements and gas fluxes

Concentration ratios for benzene/alkanes and BTEX/alkanes were measured in parallel with the emission measurements and assigned areas based on the nearest upwind fenceline. This method of emissions determination is best applied to smaller more isolated facilities where sources can be more equidistant from the measurement location. For certain source areas where stronger BTEX point sources were observed closer to the measurement vehicle, care was taken not to unduly influence the measurements. One such example is presented in Figure 23. A strong point source of benzene exists in the port area so the port portion of the fenceline measurement is excluded for southerly winds.

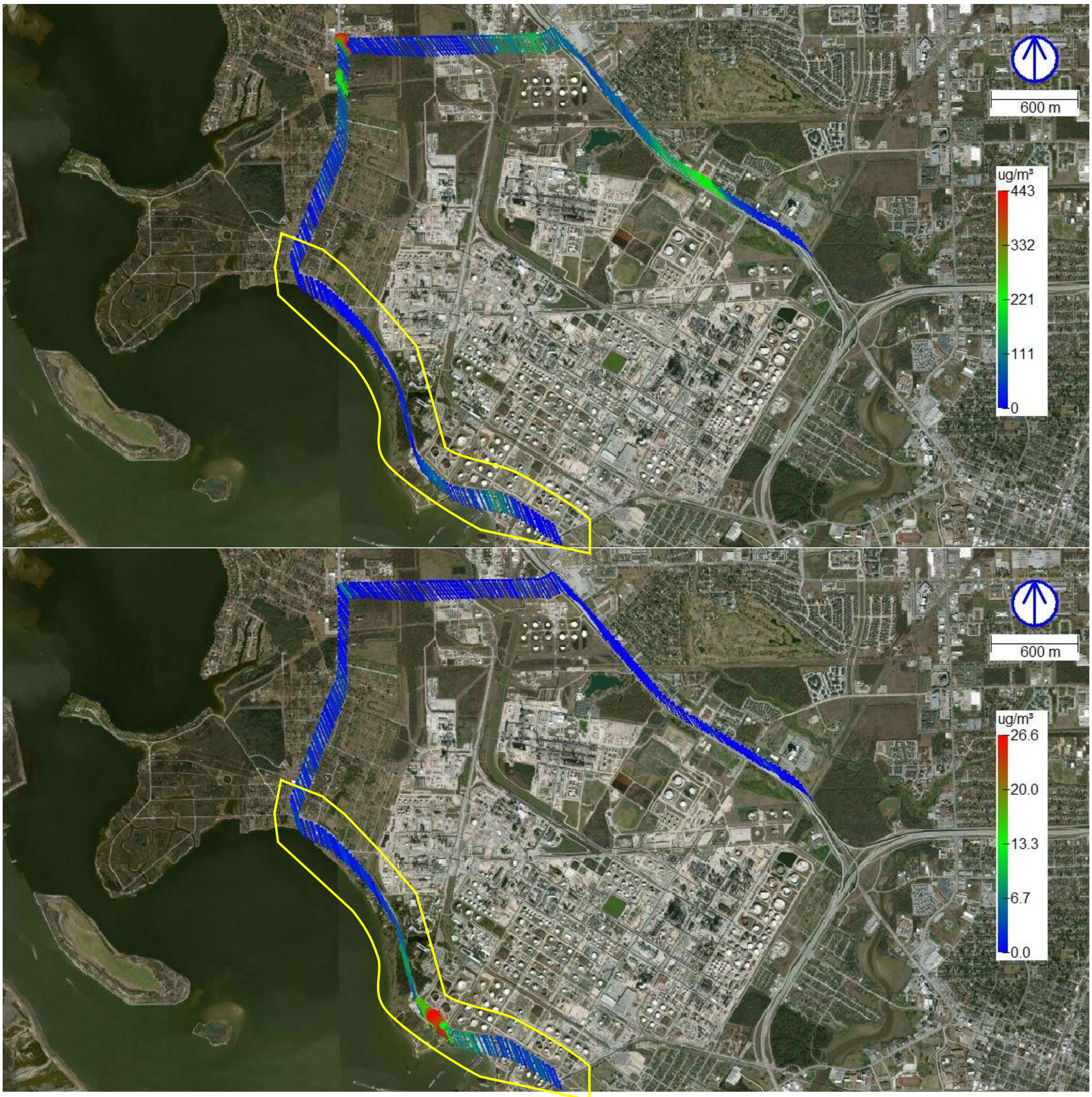


Figure 23 Extractive measurements of alkane (top) and benzene (bottom) concentrations at Baytown Facility fenceline. Color scale and marker size proportional to concentration and line points upwind in direction of the source. Yellow ringed area exluded from total facility indirect flux measurements with southerly winds. The mass ratio of BTEX/alkanes for the source in the port is about 0.5.

In this section the ratios measured are reported for all areas with the caveat that the sources of aromatics may not be co-located with the main source of alkane emissions. If the distance to the sources are negligibly different and the same dispersion factor can be assumed, the data can be used to determine aromatic emissions.

Once the ratios and alkane emission fluxes have been determined, emissions of benzene and BTEX are determined by the median ratios and the mean alkane emission. For the ratios the median is used because it is a much more robust measure of central tendency.

3.4.1 Houston Ship Channel

Table 25 and Table 25 summarize mass concentration ratio measurements and emissions for benzene (benzene/alkane x 100%) and BTEX (BTEX/alkane x 100%), respectively, for selected sources including the main sectors of the HSC. The reason that emissions for only a few sources can be presented at this time differ. For some areas with significant BTEX emissions, no alkane emission was available for determination. This is likely because the site could not be well isolated in the alkane emission measurements (e.g. Tidal Road) but can be examined with further analysis. For other sources with primarily alkene emissions (e.g. Lynchburg Ferry) the alkane emissions may not be significant and the ratio to alkanes are less certain and should be analyzed with respect to alkenes. For all sites the emissions are determined assuming the same dispersion for aromatic emissions as alkane emissions (i.e. coincident emission weighted upwind distance from the measurement), which is likely not met in all instances, and the impact of this mismatch increase with shorter plume transport distances to the measurement location. Areas where aromatic emission sources were suspected to be close to the measurement location are noted in the table.

Figure 24 shows an example of concentration mapping data from MeDOAS showing benzene in the HSC area. Winds were blowing from the northeast. The figure is a composite of several measurements from the 12, 23 and 26 September.

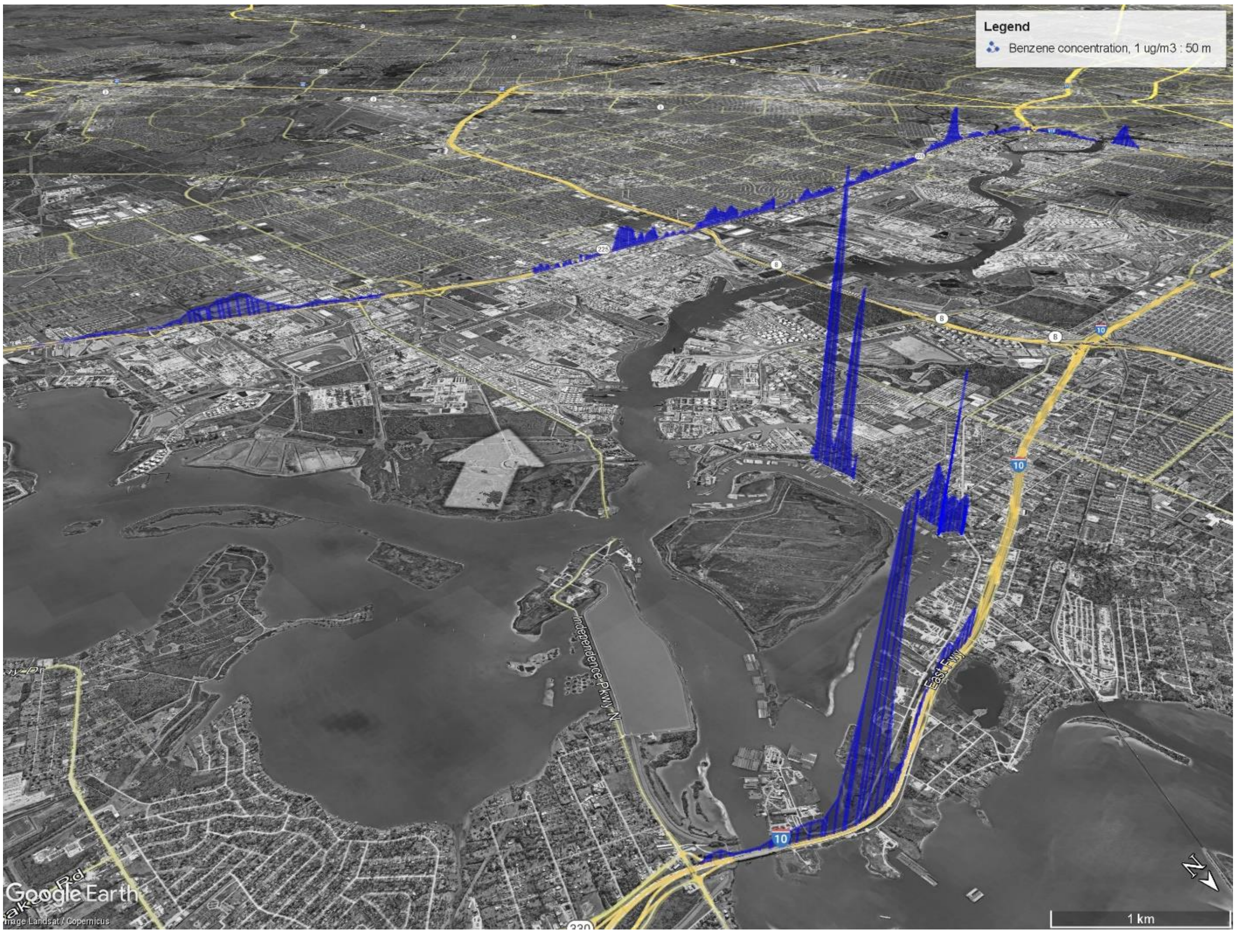


Figure 24. Example of concentration mapping data from MeDOAS showing benzene (blue) in the HSC area. Winds from the northeast as indicated by the white arrow. Composite of several measurements from the 12, 23 and 26 September. Image mapped on Google Earth © 2022.

Table 25 Summary of benzene mass concentration ratio (benzene/alkane x 100%) measurements and emissions for selected sources. Areas with consistently high ratios are shown in bold as sources for further investigation. For some sources alkane emissions were not available or are insufficient for emissions determination. TBD = source area known but exact source uncertain. Blank cells indicate that emissions could not be determined at the time of this report. *Aromatic source is likely closer to fenceline than bulk alkane emission. [1]Alkane emissions from B only. [2] Note that Pasadena alkane emissions showed large variability (compare Table 14). ** Evident aromatic source but likely located closer to fenceline than bulk alkane emission and require further assessment.

Site or Sector	N	Mean (%)	SD (%)	Median (%)	Benzene Emission (kg/h)
Baytown	54	1.7	1.3	1.6	23.5
Baytown Port	**7**	**4.7**	**5.5**	**3.2**	**-**
La Porte	10	0.1	1.1	0.4	2.2
La Porte B	11	0.2	0.4	0.1	0.7
La Porte TBD	**12**	**4.1**	**8.8**	**1.6**	**-**
Lynchburg Ferry	30	1.3	1.8	1	-
Lynchburg Ferry A	12	0.4	0.8	0.3	-
Lynchburg Ferry B-D-E1	16	0	0.4	0.1	0.5
Tidal Road	6	8.8	5.4	7.4	-
Tidal Road A	**3**	**16.4**	**16.1**	**15.4**	**-**
Deer Park**	**23**	**5.7**	**2.8**	**5.8**	**-**
DeerPark West TBD	2	11	10	11	-
Pasadena2	13	0.9	0.7	0.6	52
Manchester	15	1.1	0.9	0.7	18.3
I10-Shipyard TBD (winds from north)	**12**	**3.5**	**2.6**	**3.7**	**-**
Channelview	3	1.1	0.2	1.1	-
Channelview (Moored Barges)	-	-	-	-	-
Channelview Site A	**12**	**8.1**	**10.9**	**4.5**	**9.2**
Channelview (Shipyard)	5	2.9	2.7	3.9	9.1
Channelview (North of I10)*	2	3.4	2.2	3.4	10.2
MtBelvieu North	12	0.6	0.3	0.6	1.4
MtBelvieu East	6	1	0.8	1.3	-
MtBelvieu South	14	0.5	0.3	0.5	-
Bayport East	**5**	**5.4**	**4.9**	**5.4**	**19.8**
TexasCity*	13	2.1	1.9	1.4	14.9
TexasCity SouthTanks	4	0	1.3	0.3	-

Table 26 Summary of BTEX mass concentration ratio (benzene/alkane x 100%) measurements and emissions for selected sources. Areas with consistently high ratios are shown in bold as sources for further investigation. For some sources alkane emissions were not available or are insufficient for emissions determination. TBD = source area known but exact source uncertain. Blank cells indicate that emissions could not be determined at the time of this report. *Aromatic source is likely closer to fenceline than bulk alkane emission. [1]Alkane emissions from B only. [2] Note that Pasadena alkane emissions showed large variability (compare Table 14). ** Evident aromatic source but likely located closer to fenceline than bulk alkane emission and require further assessment.

Site or Sector	N	Mean (%)	SD (%)	Median (%)	BTEX Emission (kg/h)
Baytown	45	14.6	17.9	8.3	118.7
Baytown Port	**11**	**53.4**	**31.9**	**40.8**	**-**
La Porte	9	30.5	57.5	10.5	61.7
La Porte B	12	2.1	1.9	2.1	19.2
La Porte TBD	**13**	**8.4**	**5**	**8.5**	**-**
Lynchburg Ferry	32	8.2	9.1	6.3	-
Lynchburg Ferry A	12	9.8	8.7	8	-
Lynchburg Ferry B-D-E1	17	1.9	1.6	1.5	8
Tidal Road	5	17.1	8.1	15.2	-
Tidal Road A	**3**	**30.7**	**32.4**	**25.3**	**-**
Deer Park**	26	14	7.3	12.2	-
DeerPark West TBD	2	26.6	11.1	26.6	-
Pasadena2	15	4.8	4	3.5	294.5
Manchester	14	6.7	5.8	5.1	128.5
I10-Shipyard TBD (winds from north)	**14**	**9.9**	**5.7**	**11.5**	**-**
Channelview	10	14.8	7.6	13.5	-
Channelview (Moored Barges)	5	7.6	3	8.7	34.7
Channelview Site A	**11**	**28.6**	**27.5**	**17**	**34.6**
Channelview (Shipyard)	5	8.3	4.1	10	23.2
Channelview (North of I10)*	7	13.7	8.9	13.6	40.2
MtBelvieu North	14	5.3	2.6	5.5	12.2
MtBelvieu East	6	14.4	6.2	14.8	-
MtBelvieu South	13	7.4	6.3	6.9	-
Bayport East	**6**	**45.5**	**33.7**	**49.5**	**182.1**
TexasCity*	14	11.7	3.2	12.6	132.9
TexasCity SouthTanks	11	7	2.5	7.1	-

3.4.2 Other notable measurements

As noted earlier significant aromatic sources exist in the Channelview area (Figure 25), Deer Park West (Figure 26),Tidal Road (Figure 27), and Bayport East.

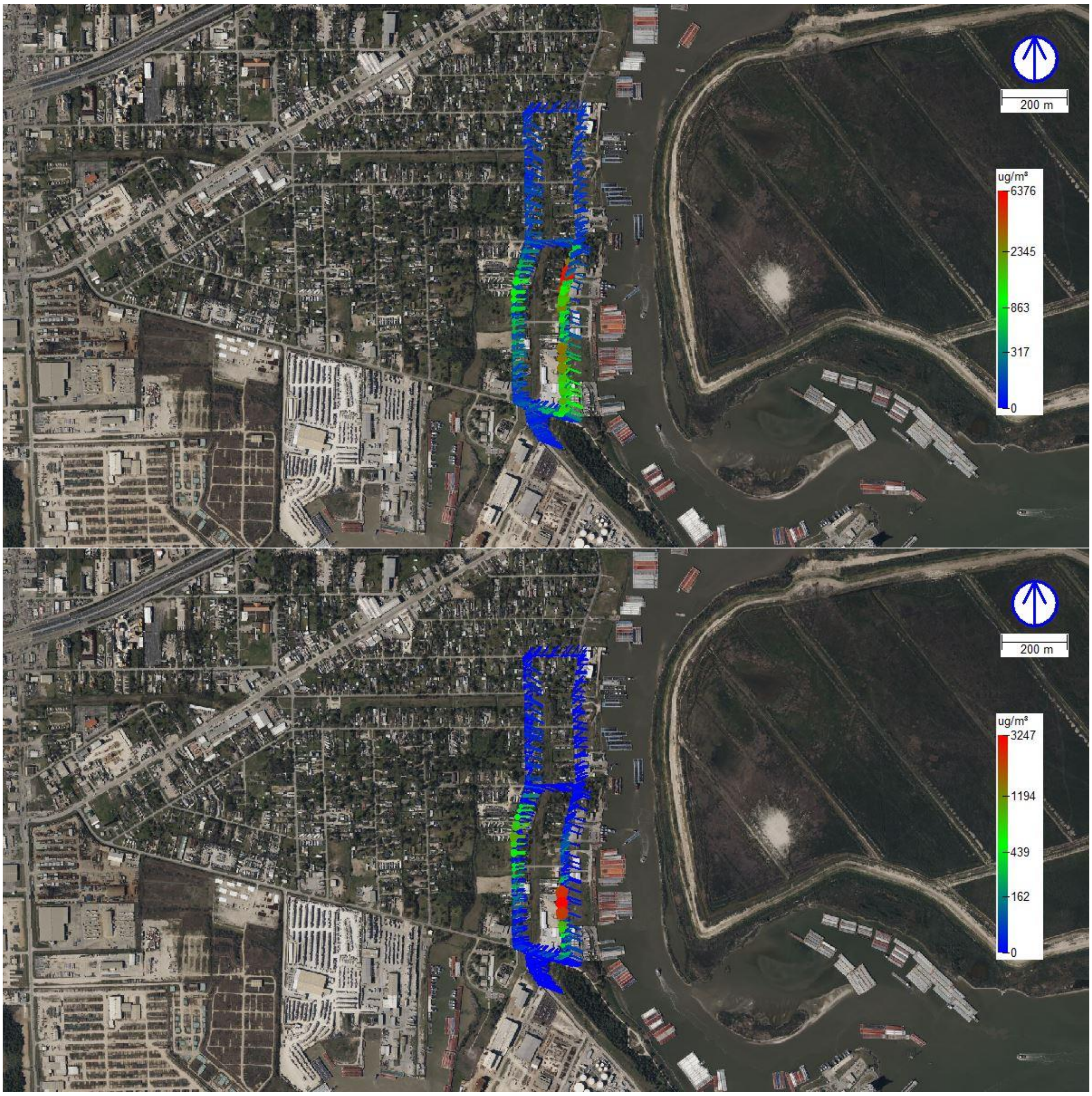


Figure 25 Extractive measurements of alkane (top) and benzene (bottom) concentrations in the Channelview area. Color scale and marker size proportional to concentration and line points upwind in direction of the source. Note: Color scale is logarithmic.

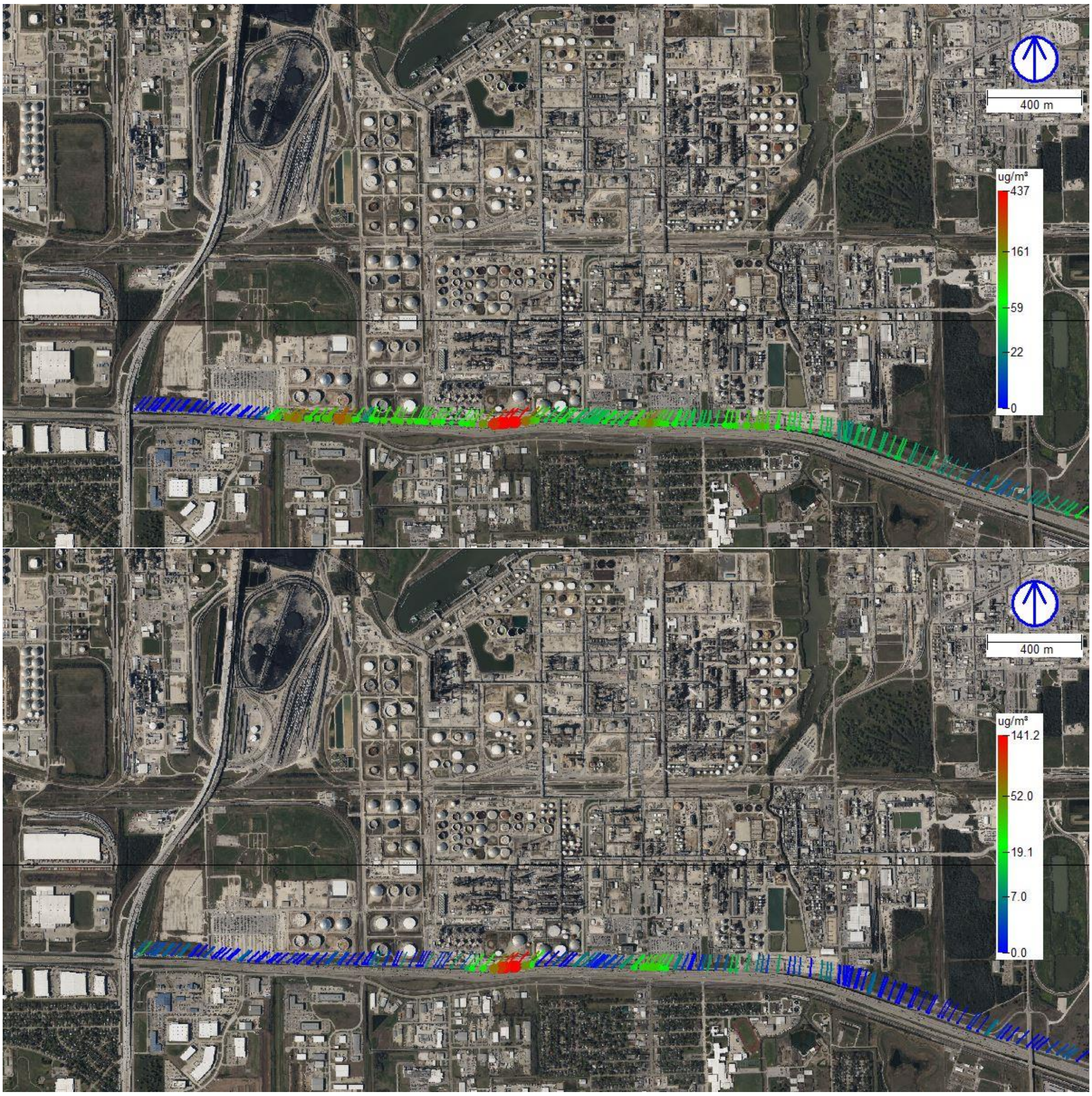


Figure 26 Extractive measurements of alkane (top) and BTEX (bottom) concentrations of the Deer Park area. Color scale and marker size proportional to concentration and line points upwind in direction of the source. Note: Color scale is logarithmic.

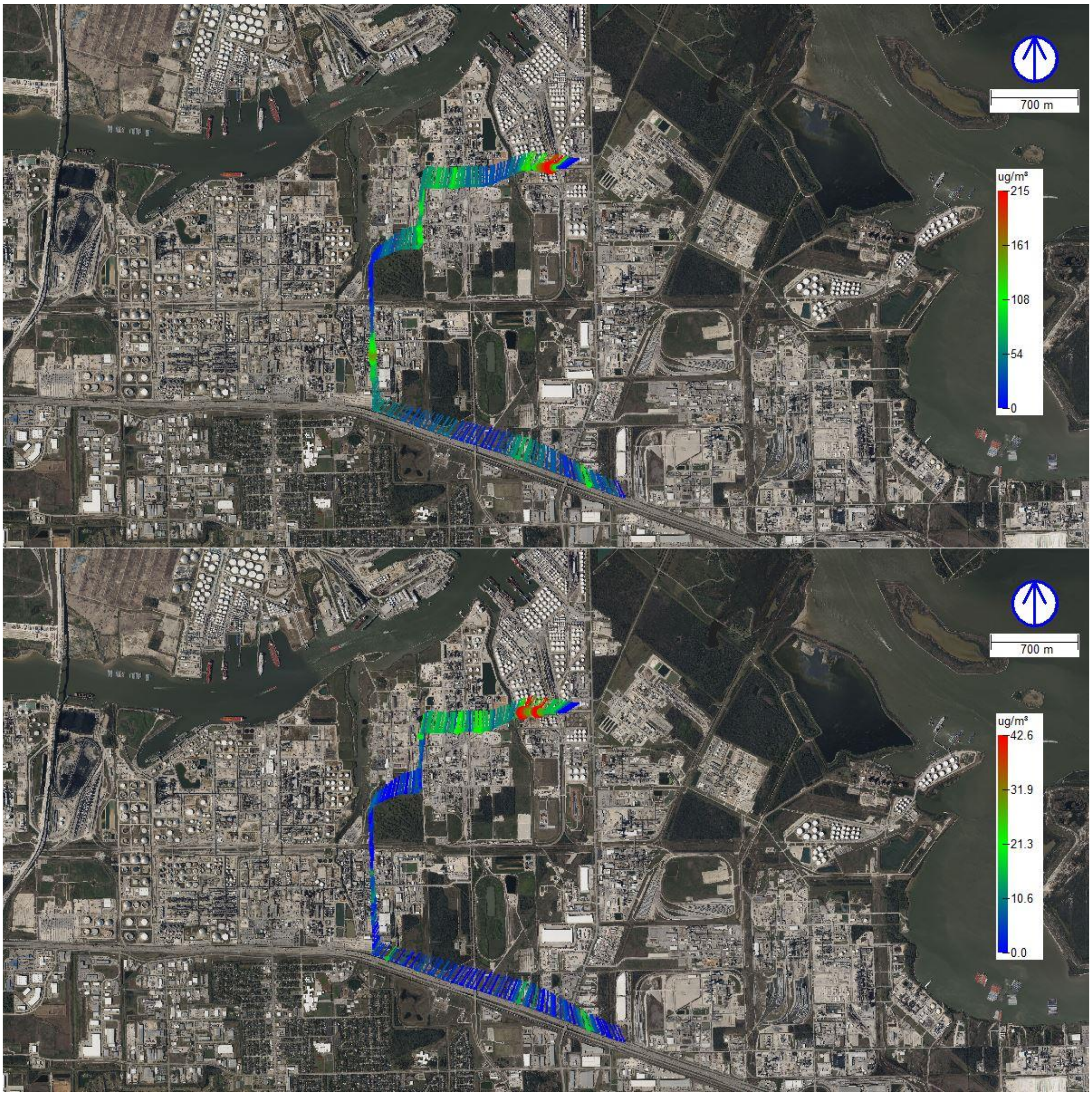


Figure 27 Extractive measurements of alkane (top) and BTEX (bottom) concentrations of the Tidal Road area. Color scale and marker size proportional to concentration and line points upwind in direction of the source.

3.5 Intercomparison with other mobile and stationary measurements

Measurements were made at the same location as the UH Mobile Lab on one occasion (17 September) at Lynchberg Ferry (Figure 28) and during an additional day (27 September) for mobile comparision in Baytown and Mont Belvieu. Example of time-series from is shown in Figure 29 for a few selected compounds and the 2 extractive instruments. Winds were from the southeast so no nearby plumes were captured during the measurement. Column measurements were not available due to cloudiness. Data intercomparison will be further assessed when all data sets are made available.

Figure 28 Location of mobile lab intercomparison, 17 September. Winds were from the southeast so there were likely no immediately nearby sources. Image mapped on Google Earth © 2022.

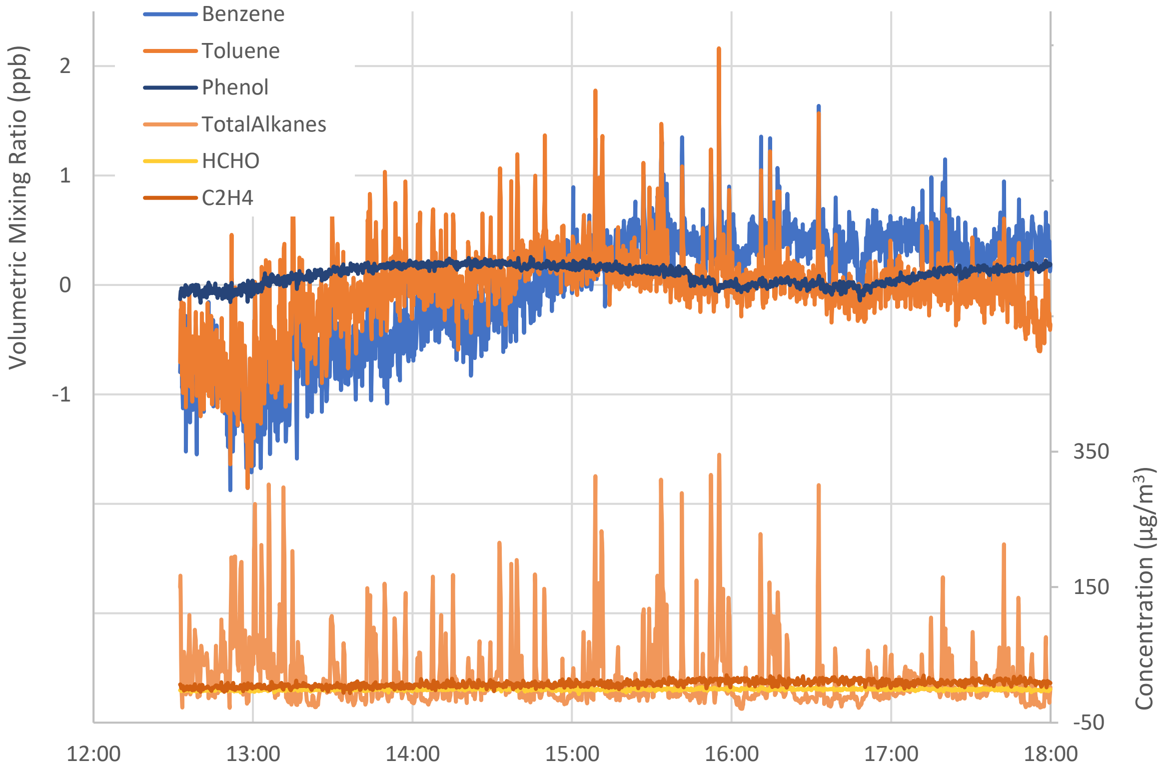


Figure 29 Example of time-series data during intercomparison for a few selected compounds. Benzene, toluene and phenol volumetric mixing ratios from the MEDOAS instrument are shown on the upper left axis and alkanes, formaldehyde and ethylene concentrations from MEFTIR are shown on the lower right axis.

3.6 Mapping of ambient pollutant concentrations

Some examples of noteworthy observations are highlighted here, however, it is more pertinent to examine the digital data and maps provided. A total of 21 compounds are continuously measured with a time resolution of between 4.5 to 8 seconds. This serves to be able to pinpoint ground level sources for a variety of species. An example of this digital data is shown in Figure 30 showing BTEX sources in both the south and north of the HSC. These data can also be combined with SOF or SkyDOAS data to give a first order estimate of plume height.

Figure 30 Example of concentration mapping data from MeDOAS showing benzene (blue, max 20 ppb) and Toluene (orange, max 18 ppb), in the Deer Park & Pasadena area and north of HSC, 09:39 - 17:57, 26 September. Winds from the east-northeast. Image mapped on Google Earth © 2022.

4 DISCUSSION

Emissions around Houston Ship Channel and Mont Belvieu

Total large-scale fugitive ozone precursor (HRVOC) emissions from the HSC area averaged 624 ± 449 kg/h (mean ± 95% CI) ethylene and 609 ± 111 kg/h propylene over the campaign time frame. Excluding a large temporary emission for ethylene in Pasadena, the mean emissions were down to 475 ± 259 kg/h. Ethylene emissions were not significantly different than in a study in October-November 2020 (553 kg/h), however, propylene emissions are higher (400 kg/h in the 2020 study). As time duration, spatial coverage and scope of the surveys were different these figures are provided for reference, and differences between the surveys should be expected in the detailed measurements. Most of the alkene emissions in the HSC originate from the area to the south and east of Lynchburg Ferry. Alkane emissions at HSC were highly variable due to a number of perceived upset emissions, showing significant emissions of on average 14180 kg/h and 17600 kg/h in a top-down (all HSC in one run) and bottum-up (sector by sector) measurement approach, respectively.

Measurements and emissions from the TPC facility south of 225 were not completed to satisfaction largely due to the lack of suitable winds for the available roads.

HRVOC emissions in Mont Belvieu were comparably less variable than for HSC, with 95% CI for the means within 20% of the mean, both for ethylene (235 kg/h) and propylene (172 kg/h). Formaldehyde observations in northeast HSC during northeasterly winds showed the impact of HRVOCs emissions from Mont Belvieu being degraded along plume transport, forming a significant HCHO plume as it approached HSC.

Bayport, Texas City and Channelview North Facilities

Texas City was included in the initial agenda for the study areas but along the project propagation other targets was prioritized higher, with limited temporal coverage left for Texas City. The single measurement day showed it likely to be a significant source of HRVOCs and aromatics. Bayport was measured on occasion but likewise was not a priority for the survey. The Bayport East area produced strong BTEX plumes, however there were few emission measurements of alkanes from which the BTEX emissions could be determined with certainty.

Mapping of ambient pollutant concentrations and notable observations

Ground level concentration mapping with the mobile laboratory was carried out in parallel with emission measurements. In addition to the HRVOC precursors and formaldehyde, targeted measured species also included aromatics e.g. BTEX, acetaldehyde, 1,3-butadiene, as well as various alkanes, and methane.

As would be expected with secondary production of formaldehyde, the highest ground-level concentrations were observed during the day when there is rapid formation from HRVOC precursor emissions due to photolysis, even though vertical atmospheric mixing is much higher in the day. Several primary sources were suspected in the Lynchburg Ferry area along Independence Parkway. Other primary sources were noted in Pasadena, Deer Park and Mont Belvieu. Detection of primary emission sources should be more apparent at night with no secondary formation and less vertical mixing. During this survey no evening or nighttime measurements were conducted.

Persistent and significant BTEX sources were found in the Channelview area south of the I-10. One source has been regularly noted since at least 2013. Notable in 2022 were several additional sources, likely moored barges, in the area also contributing. Benzene concentrations over several hundred ppb were observed in the nearby residential neighborhood.

Comparisons with previous measurements

Due the limited duration of the surveys and corresponding statistical uncertainties, trends or differences between years are for the most part not statistically significant. Formaldehyde emissions should be seen as indicative rather than an absolute quantitative measure due to the chemistry involved and the uncertain transport time from different sources.

Table 27 Historic and current emissions ± standard deviation (kg/h) measured with SOF and SkyDOAS for different sites, as reported after the measurement campaigns. Results from earlier campaigns and Emission inventory data for 2013 [Johansson, 2014] are also shown. Updated inventories are available but are not within the scope of this report. 2020 Data: [Offerle, 2021].

Area / Species	**2009 (kg/h)**	**2011 (kg/h)**	**2013 (kg/h)**	**2013 Emission Inventories (kg/h)**	**2020 (kg/h)**	**2022 (kg/h)**
HSC						
Ethylene	614 ± 284	612 ± 168	475 ± 79	53	553 ± 271	624 ± 361
Propylene	642 ± 108	563 ± 294	394 ± 245	48	400 ± 217	609 ± 166
Alkanes	10522 ± 2032	11569 ± 2598	13934 ± 4321	818	10591 ± 1807	14179 ± 8339
NO_2	-	1830 ± 330	2242 ± 684	1103	1192 ± 557	1228 ± 347
CH_2O	-	-	-	--	757 ± 245	572 ± 264
Mont Belvieu						
Ethylene	444 ± 174	545 ± 284	271 ± 33	29	253 ± 115	235 ± 67
Propylene	303 ± 189	58	220 ± 115	21	148 ± 49	171 ± 47
Alkanes	1575 ± 704	1319 ± 280	2854 ± 1212	146	1017 ± 729	1341 ± 1484
NO_2	168 ± 39	305 ± 29	245 ± 102	138	63.6 ± 16.9	169 ± 43
CH_2O	-	-	-	-	43.4 ± 29.1	54 ± 68

Important (larger) sources need to be studied in detail over longer periods if the objective is to discern appropriate emission reduction measures. Many of the larger propylene emissions in previous surveys were apparently from flaring and poor combustion efficiency. This still appears to be the case. This conclusion is based on the direction to the source of the emissions as well as the source behaviour.

Total HSC alkane emissions were measured on five days averaging around 14 tons/h but were widely varying due to temporary or upset emissions, see see Figure 31.

Figure 31 SOF Alkane measurement showing temporary or upset emissions from an unknown source in the west of the HSC, 26 September, approximately 12:30 PM when the dominant plumes were passed. The apparent height of the blue overlay is proportional to the alkane column. Wind direction (NE) during the measurement is shown with a white arrow. Image mapped on Google Earth © 2022.

Emissions of NO_2 are generally closer to reported values because reported values are more closely tied to actual measurements.

Suggestions for future work

In this large scale campaign there was limited time available to investigate particular point or area sources, with the scope of covering multiple large areas with sufficient statistics requiring a large fraction of the time. This is particularly of interest since a large number of upset or temporary emissions were observed, as in Figure 31, for which a source could not be identified. It should be noted that none of these upsets corresponded to emission events reported to TCEQ (https://www2.tceq.texas.gov/oce/eer/, searched date 21 Dec 2022) with start or stop times within the survey period. This should be seen as a call to more frequent monitoring to determine if such emissions occur with regularity and how much they contribute to the annual emissions. Focused and frequent measurements at particular site areas would help to identify source locations and their temporal emission pattern. On site access for refined leak search and source attribution would improve this even further. Thermal emission gas measurements of flare exhaust would be another approach to further understand flaring impact on observed variabilities in emissions and sources of HRVOCs and formaldehyde.

Formaldehyde emissions are more result of the chemistry, so-called secondary emissions, from HRVOCs than primary direct emissions from incomplete combustion or HCHO production. Understanding the spatial and diurnal formaldehyde distribution with both primary and secondary production and impact by HRVOC emissions and photochemistry would benefit from chemical transport modelling.

Extractive measurements showed occasional high (> 100 ppb) concentrations of aromatic species within residential neighborhoods during daytime measurements. Nighttime concentrations could be considerable if the emissions were constant. Intensified mobile concentration mapping accompanied by the network of fixed monitoring stations in the HSC area would improve understanding of source locations and potential exposure levels in communities.

5 References

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