Greenpeace Research Laboratories Technical Report

Trace gas observations Croatia 2026

July 2026 (Corrected September 2026)

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Correction

On 16th September 2026 it was identified that the wind direction data calculated by software provided with the measurement instrument was incorrect. Calculated wind directions were found to be inconsistent with the raw measured Northerly and Easterly wind components. The wind direction data have been revised by manually calculating wind directions from the raw Northerly and Easterly measurements.

Revision of the data does not impact the conclusions of the report. Rather, the corrections strengthen the interpretation that the industrial facilities are sources contributing to the measured pollutant concentrations. A corrigendum is available and the following changes were made to the text:

- Gas Facility Molve East: The revised wind directions are now consistent with the Gas Facility contributing to pollution at the measurement sites
- Gathering Station IVA-1, Ivanić-Grad: The revised wind directions suggest winds were less frequent from the north and west, not the south and east.
- Underground Gas Storage (UGS) facility Okoli south: The revised wind directions suggest that pollution from the facility may have affected sites 1 and 2, and were not more likely to affect Site 2 than Site 1.
- Underground Gas Storage (UGS) facility Okoli north: The revised wind directions no longer suggest that the Background location may have been influenced by air from the direction of the industrial facility.

Introduction

Observations of atmospheric pollutants were made in the vicinity of upstream and midstream hydrocarbon facilities in Croatia during June 2026. The facilities visited

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included sites for fossil gas gathering, processing, production, storage, and regasification and distribution. Operations at such sites are associated with the emission of atmospheric pollutants including green-house gases and local air pollutants. These include[1]:

- Emissions from engines and other powered processes on the site, such as particulate matter (PM), carbon monoxide (CO), carbon dioxide (CO_2), and nitrogen oxides (NO, NO_2)
- Emissions from the venting of condensate and from storage tanks, such as volatile organic compounds (VOCs) including methane (CH_4)
- Emissions from fossil gas capture, flaring and venting. Such as particulate matter (PM), carbon monoxide (CO), carbon dioxide (CO_2), nitrogen oxides (NO, NO_2), sulphur dioxide (SO_2) and volatile organic compounds (VOCs) including methane (CH_4)
- Fugitive leaks from equipment including pumps, valves and connectors. Such as methane and other trace constituents of the produced fossil gas.

Once released into the atmosphere the emitted greenhouse gases (CO_2 and CH_4) contribute to anthropogenic warming of the atmosphere. The emitted local air pollutants (PM, CO, NO, NO_2, SO_2, and VOCs) can directly cause a deterioration in local air quality and contribute to the formation of secondary air pollution as a result of chemical reactions in the presence of sunlight[2]. These local air pollutants are relevant for public health and can cause damage to plants including crops[3].

Here we analyse measured concentrations of CH_4, CO, $PM_{2.5}$, SO_2 and total VOCs using a mobile instrument designed for the detection of trace gases and suspended particulate matter. The objective of the campaign is to utilize high-resolution mobile sensing to investigate each facility's possible contribution to atmospheric pollution.

Methodology

Instrumentation

Air quality monitoring was conducted using the Sniffer 4D V2 system (Soarability). The Sniffer 4D is a compact, high-precision mobile instrument designed for the detection of trace gases and suspended particulate matter. The unit utilized in this study was equipped with sensors for CO, SO_2, NO_2, O_3 (Electrochemical), $PM_{1.0}$, $PM_{2.5}$, PM_{10} (Light scattering), VOCs (Photoionisation) and CH_4 (Tunable Diode Laser Absorption

[1] A Kibble, T Cabianca, Z Daraktchieva, T Gooding, J Smithard, G Kowalczyk, N P McColl, M Singh, L Mitchem, P Lamb, S Vardoulakis and R Kamanyire. Review of the Potential Public Health Impacts of Exposures to Chemical and Radioactive Pollutants as a Result of the Shale Gas Extraction Process. Centre for Radiation, Chemical and Environmental Hazards Public Health England Chilton, Didcot Oxfordshire OX11 0RQ

[2] Megaritis, A.G., Fountoukis, C., Charalampidis, P.E., Pilinis, C. and Pandis, S.N., 2013. Response of fine particulate matter concentrations to changes of emissions and temperature in Europe. *Atmospheric Chemistry and Physics*, *13*(6), pp.3423-3443.

[3] Koolen, C.D. and Rothenberg, G., 2019. Air pollution in Europe. *ChemSusChem*, *12*(1), pp.164-172.

Spectroscopy, TDLAS). Alongside these were integrated sensors for air temperature, humidity, and atmospheric pressure and an external sensor for wind speed and direction. Full technical specifications can be found at https://sniffer4d.eu/.

Initial setup and acclimatization

All measurements began at an background location where the instrument was prepared for use away from the hydrocarbon facilities being investigated and in an upwind location where possible.

Ambient conditions during sampling fell within the calibrated temperature range of the Sniffer 4D system. The system operating guidelines do not require manual field zeroing or background software calibrations under such circumstances and these were not undertaken.

However, to ensure instrument stability the system underwent a period of environmental acclimatisation upon arrival at each location. The device's sensors typically reach full acclimatization within 5 to 10 minutes of being powered on and exposed to ambient air. For additional confidence, the device was powered on and in ambient air and allowed to operate for 20 minutes, by which time successful stabilization was indicated by the integrated status LED display. Data from this initial 20-minute acclimatization period is excluded from the final analysis.

Electrochemical sensors, in particular for NO_2, can be sensitive to changes in environmental conditions, or cross-sensitive to other pollutant species. Best practice is to co-locate electro chemical sensors in the field with reference grade instruments in order to generate a local calibration. It was not possible to undertake a co-location study as part of the field work owing to a lack of local reference grade air quality monitoring. Particulate matter concentrations can be influenced by many sources including hydrocarbon processing, but also road traffic construction, and agriculture among others. Therefore, the analysis that follows focuses on data CH_4, CO, SO_2 and VOCs.

Table 1. Details of field measurement locations

No.	Location	Coordinates	Date	Facility type
1	Gas Facility Molve East	46.090°N, 17.068°E	1 June 2026	Separation of gas, condensate, and produced water
2	CPS Molve	46.109°N, 17.003°E	1 June 2026	Central gas processing station
3	Fractionation facilities Ivanić Grad	45.718°N, 16.395°E	2 June 2026	Fossil gas processing and fractionation plant
4	Gathering Station IVA-1, Ivanić-Grad	45.688°N, 16.401°E	2 June 2026	Gathering station
5	LNG Terminal Krk, Omišalj	45.200°N, 14.534°E	3 June 2026	Floating Storage and Regasification Unit (FSRU) and maritime terminal
6	Rijeka Refinery, Urinj	45.285°N, 14.532°E	3 June 2026	Large-scale crude oil refining facility
7	Underground Gas Storage (UGS), Okoli south	45.586°N, 16.524°E	4 June 2026	Underground fossil gas storage facility
8	Underground Gas Storage (UGS), Okoli north	45.594°N, 16.520°E	4 June 2026	Underground fossil gas storage facility

Sampling design

The campaign evaluated eight distinct infrastructural target locations across Croatia (Table 1). Upon arriving at each background location the acclimatisation procedure was completed. Immediately following acclimatisation, a 30-minute static measurement was recorded at the same upwind location. These data are used to provide a baseline to use in comparison with observations made at the sites of interest.

Once the acclimatisation was complete and background measurement had been taken, up to 3 distinct measurements were made at locations close to the facilities being investigated. The sampling locations were strategically positioned downwind of each facility to optimally intercept potential emission plumes (Appendix 1). These locations are described as 'Industrial sites' in the analyses. At each background site and Industrial site, the Sniffer 4D was mounted on a tripod at a height of 1.10 meters for a static sampling period of approximately 30 minutes in most cases, though monitoring was conducted for longer periods at some locations.

Results

Comparison of data collected at background and industrial sites indicate that there were several instances of elevated pollutant concentrations at some of the industrial settings.

Results are presented below for all cases where elevated concentrations of a pollutant were observed at one of the industrial sites. Site locations and wind direction data are presented separately in Appendix 1.

Concentrations of pollutants from industrial facilities vary significantly with weather conditions and emission rates, and so it was not expected that elevated concentrations would be observed during all of the sampling periods and at all of the locations. It remains possible that greenhouse gas and local air pollutant emissions do occur at facilities where elevated pollution concentrations were not observed during this investigation.

Gas Facility Molve East

CO and SO_2 concentrations were low except at Site 1 where measurements were very variable. The highest SO_2 concentrations were observed towards the beginning of measurement at Site 1. The results suggest that this location was being influenced by gasses from a combustion source (Figure 1, 2 and 3). An active gas flare was observed at the site. Wind data at this site suggested very low wind speed, and directions consistent with the Gas Facility contributing to pollution at the industrial sites. Concentrations of CH_4 and VOCs were low at all sites.

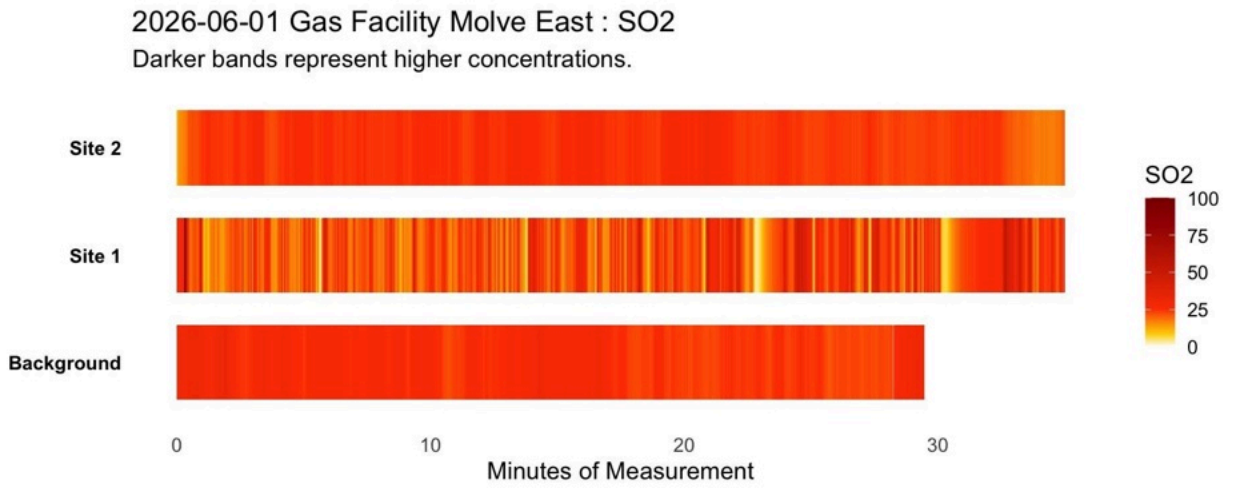


Figure 1. SO_2 observations at the Gas Facility Molve East Background, Site 1 and Site 2 locations (µg/m^3).

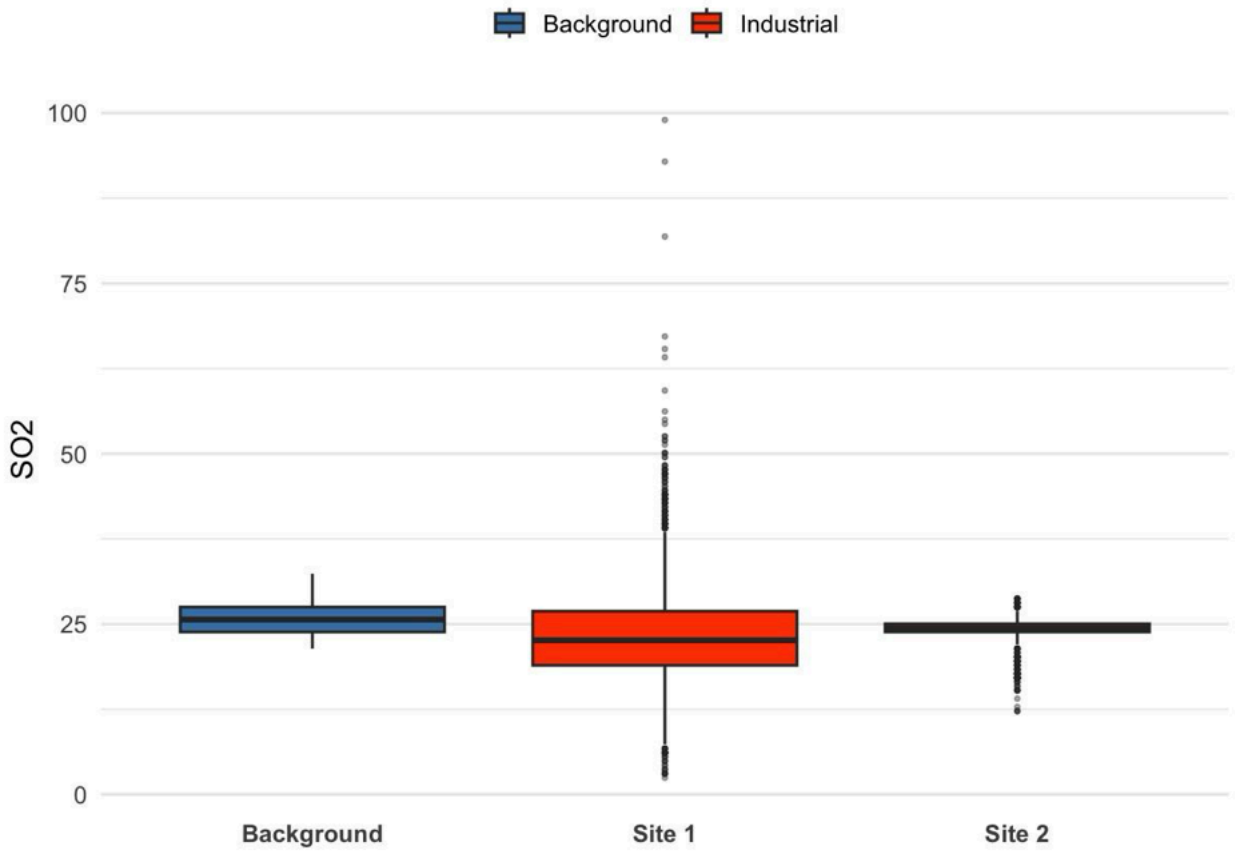


Figure 2. SO_2 observations at the Gas Facility Molve East Background, Site 1 and Site 2 locations (µg/m^3). Each box shows the 25th percentile, 75th percentile and median, with lines extending to 1.5 × the inter quartile range and outliers plotted individually beyond these.

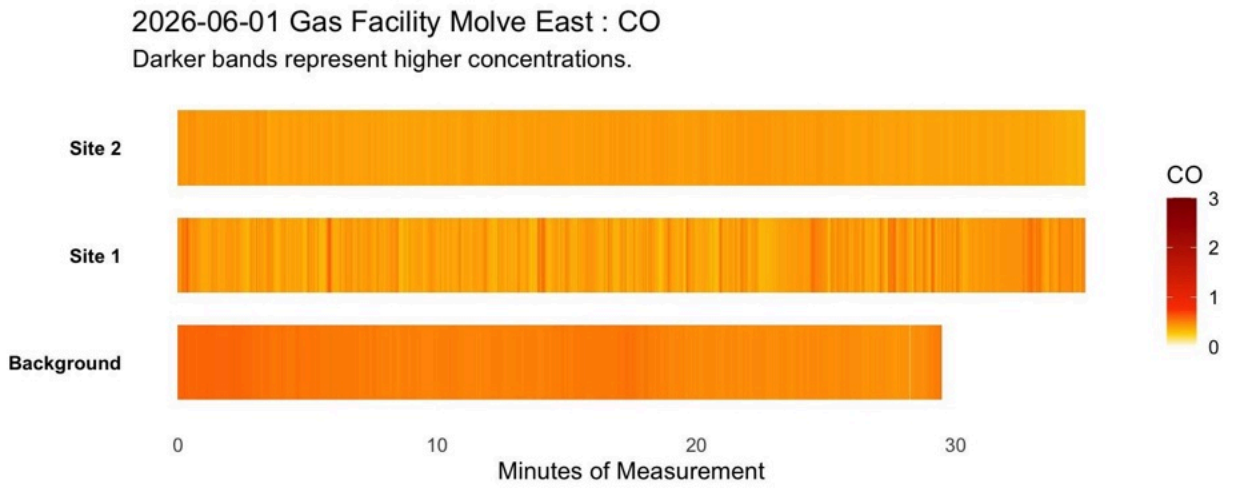


Figure 3. CO observations at the Gas Facility Molve East Background, Site 1 and Site 2 locations (mg/m^3).

CPS Molve

At CPS Molve results from the Background, Site 1 and Site 2 did not detect significant pollution enhancements in the industrial locations.

Fractionation facilities Ivanić Grad

At Fractionation facilities Ivanić Grad wind speeds were generally low and from the south and south-west (Appendix 1). This indicated that Site 2 was more likely to be affected by plumes of any air pollutants emitted from the facility than site 1. Large CH_4 and VOC enhancements were observed at Site 2 with some possible enhancements, close to the instrument detection limit, at Site 1 (Figure 4 and 5). There were no similar enhancements of combustion gases including CO and SO_2, suggesting that the observed CH_4 and VOCs may be linked to a vent or leak, rather than a combustion source.

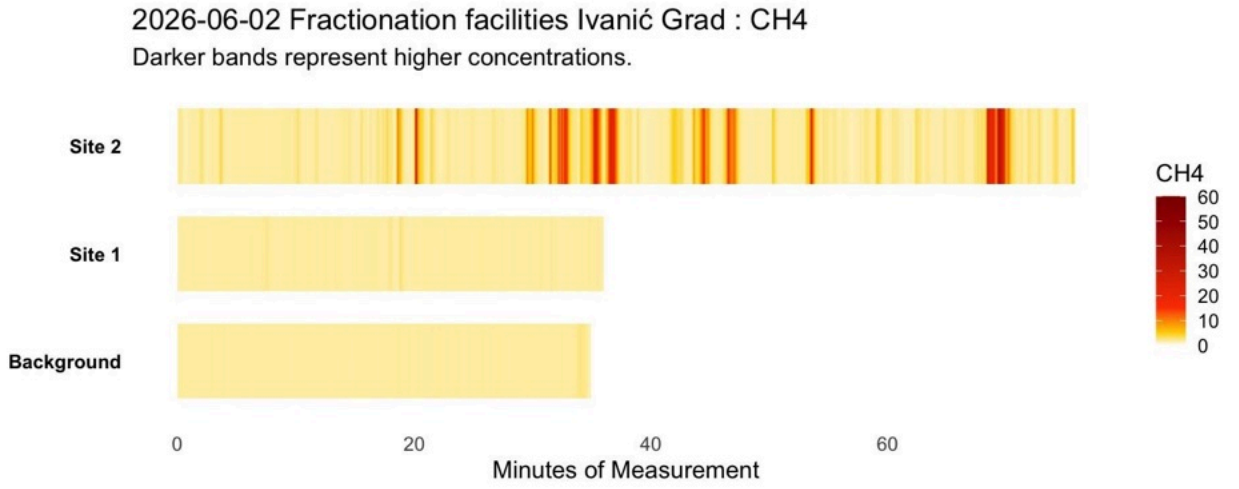


Figure 4. CH_4 observations at the Fractionation facilities Ivanić Grad Background, Site 1 and Site 2 locations (ppm).

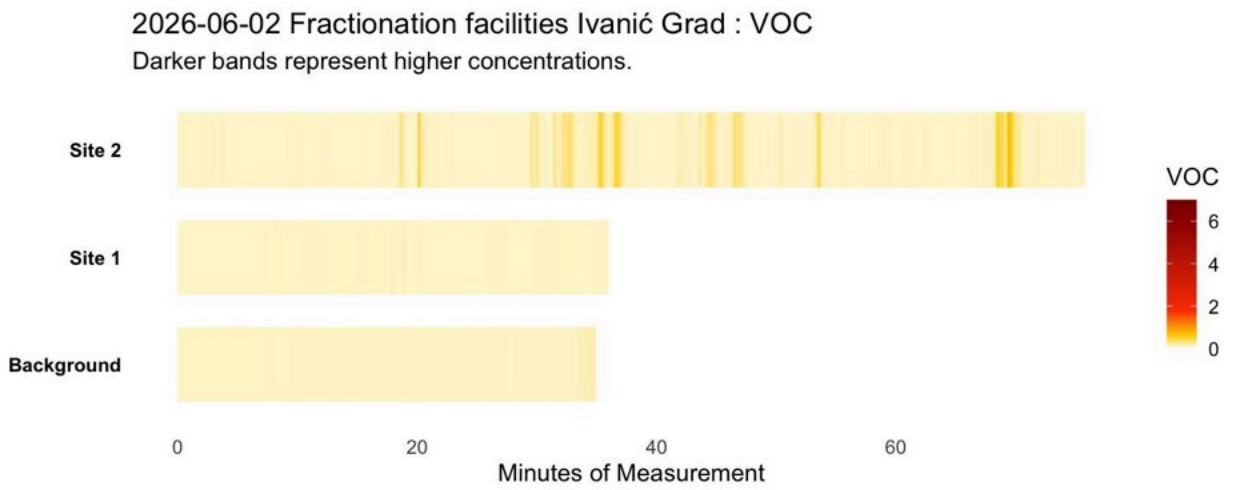


Figure 5. VOC observations at the Fractionation facilities Ivanić Grad Background, Site 1 and Site 2 locations (ppm[4]).

Gathering Station IVA-1, Ivanić-Grad

At Ivanić Grad's Gathering Station IVA-1 wind speeds were very low and there was no single dominant wind direction although winds were less frequent from the north and west. CH_4, VOC and CO concentrations were elevated at Site 1, with additional VOC enhancements at Site 2 (Figure 6, 7 and 8). An active flare was located close to Site 1 at a position between monitoring Site 1 and Site 2. An interpretation that emissions from the flare were impacting site 1 is consistent with the measurements made on site.

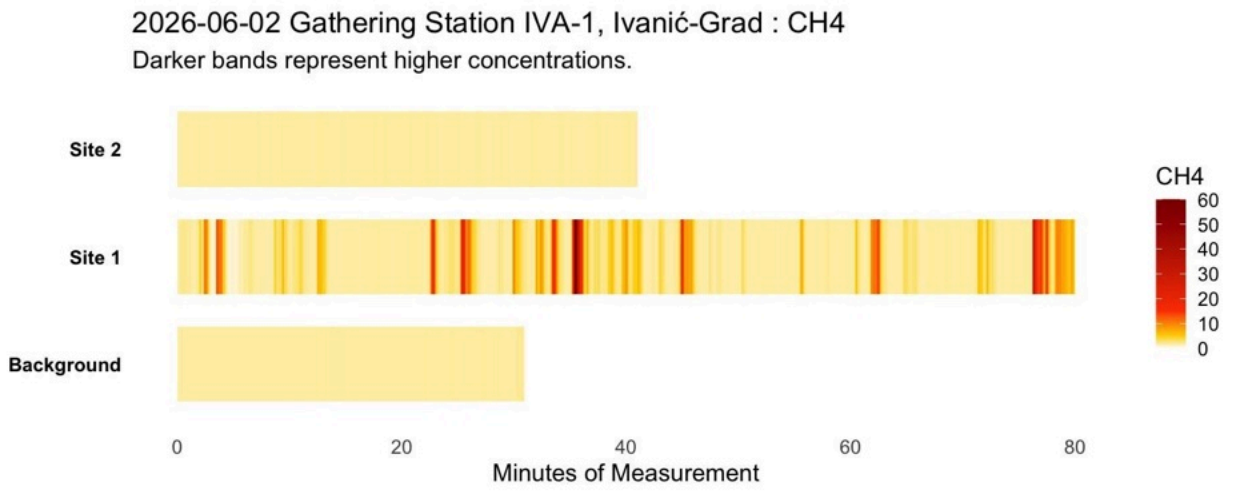


Figure 6. CH_4 observations at the Gathering Station IVA-1, Ivanić-Grad Background, Site 1 and Site 2 locations (ppm).

[4] Parts per million

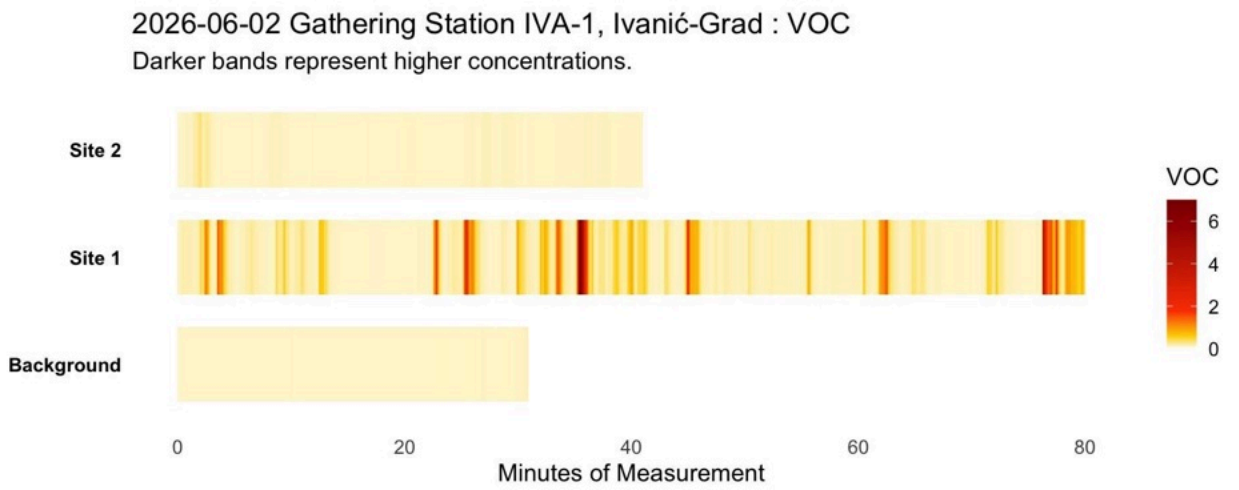


Figure 7. VOC observations at the Gathering Station IVA-1, Ivanić-Grad Background, Site 1 and Site 2 locations (ppm).

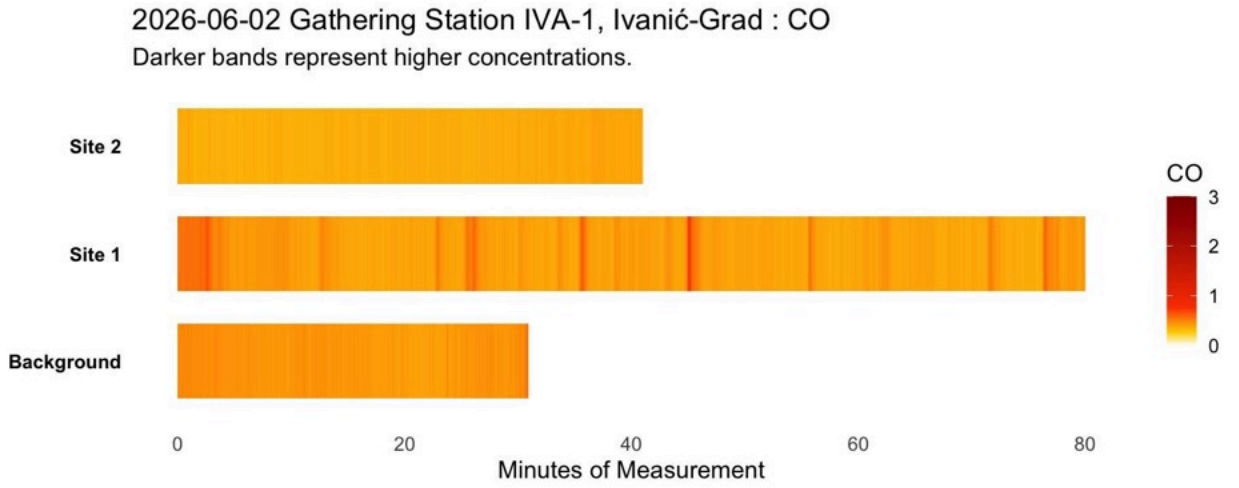


Figure 8. CO observations at the Gathering Station IVA-1, Ivanić-Grad Background, Site 1 and Site 2 locations (mg/m^3).

LNG Terminal Krk, Omišalj

At LNG Terminal Krk, Omišalj, very low wind speed and no dominant wind direction was detected. CH4 concentrations were low at all sites and there was no evidence of elevated pollution concentrations at the industrial sampling site.

Rijeka Refinery, Urinj

At Rijeka Refinery wind speeds were low and there was no dominant wind direction. The facility covers a wide area and each industrial sampling site was close to a

different section of the facility. Large CO enhancements were detected at Site 2 close to the western perimeter of the facility (Figures 9), possibly related to a local combustion source.

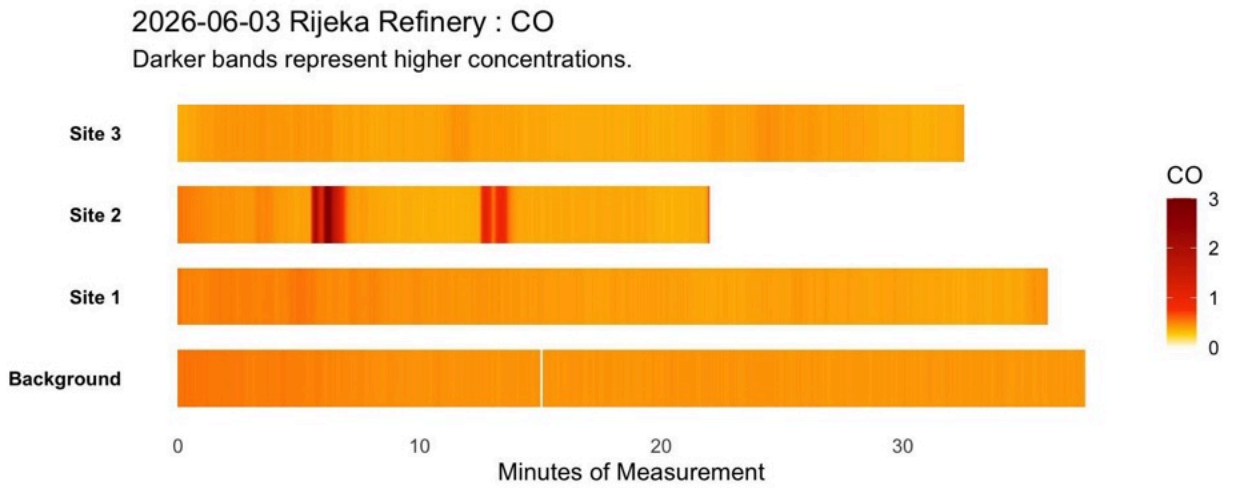


Figure 9. CO observations at the Rijeka Refinery Background, Site 1, Site 2 and Site 3 locations (mg/m^3).

Underground Gas Storage (UGS) facility Okoli south

At the Underground Gas Storage facility in the south of Okoli, wind data suggests that any emissions from the industrial facility may have affected sites 1 and 2. For most pollutants concentrations were low, but a possible VOC enhancement was detected at Site 2 (Figure 10).

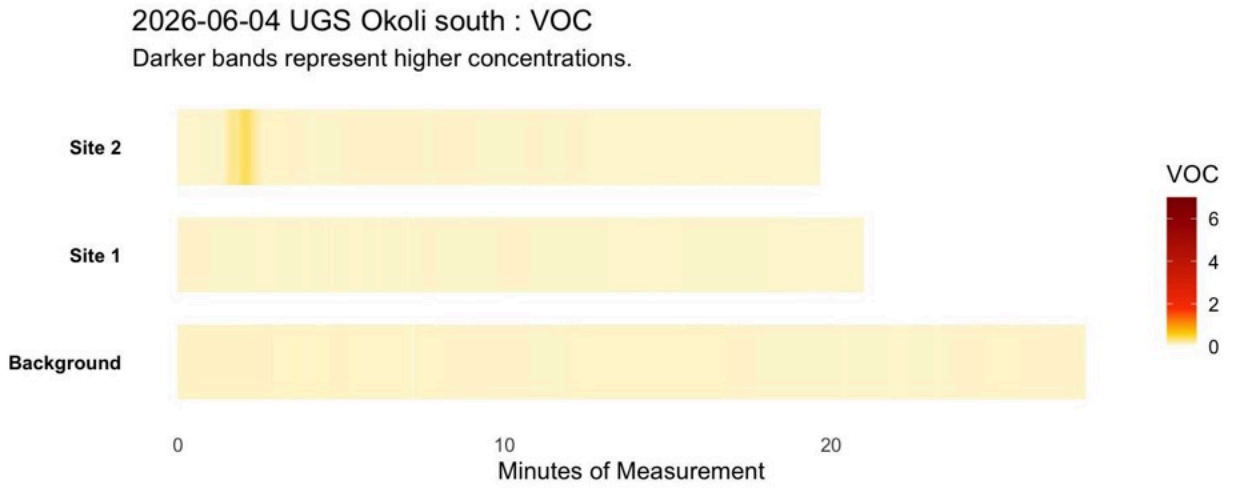


Figure 10. VOC observations at the Underground Gas Storage facility in the south of Okoli Background, Site 1 and Site 2 locations (ppm).

Underground Gas Storage (UGS) facility Okoli north

At the Underground Gas Storage facility in the north of Okoli, wind data suggests that both Site 1 and Site 2 may have been influenced by any air emissions occurring at the industrial facility.

Observations of CH_4 show enhancements at Site 1 with some possible enhancements at Site 2, at concentrations close to the limit of instrument detection (Figure 11).

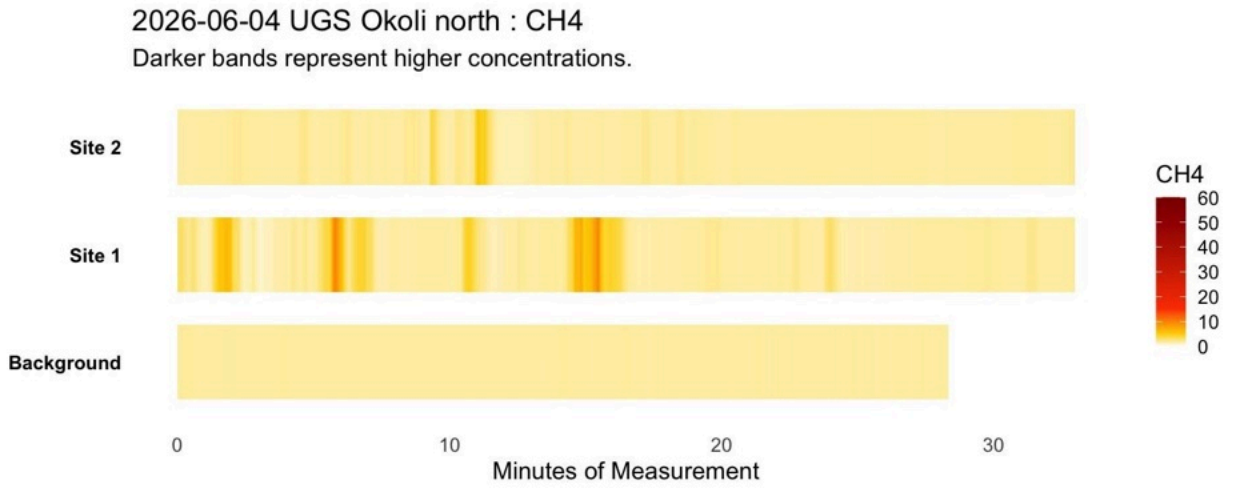


Figure 11. CH_4 observations at the Underground Gas Storage facility in the north of Okoli Background, Site 1 and Site 2 locations (ppm).

Discussion and Conclusion

A Sniffer4D mobile trace gas instrument was used to observe carbon monoxide and sulphur dioxide as well as methane and volatile organic compounds in air at upstream and midstream oil and gas facilities in Croatia.

When combined with analysis of wind direction data, the results provide strong evidence of local air pollutant and greenhouse gas emissions from several of the industrial sites visited.

Out of the eight sites visited:

- enhanced concentrations of **methane** were detected at **three** locations
    - Fractionation facilities Ivanić Grad,
    - Gathering Station IVA-1, Ivanić-Grad,
    - Underground Gas Storage facility Okoli north,
- enhanced concentrations of **VOCs** were detected at **three** locations,
    - Fractionation facilities Ivanić Grad,
    - Gathering Station IVA-1, Ivanić-Grad,
    - Underground Gas Storage facility Okoli south,
- enhanced concentrations of **carbon monoxide** were detected at **three** locations
    - Gas Facility Molve East,
    - Gathering Station IVA-1, Ivanić-Grad,
    - Rijeka Refinery, Urinj, and
- enhanced concentrations of **sulphur dioxide** were detected at **one** location
    - Gas Facility Molve East.

Pollutant concentrations are significantly influenced by weather and emission rates, and these can vary with time. Consequently, it was not expected that elevated concentrations would be observed at all locations during the relatively short sampling periods. It is possible that greenhouse gases and air pollutants may be emitted at facilities where elevated concentrations were not detected.

Methane is a strong greenhouse gas, and emissions of methane are contributing to climate change. Some VOCs have direct health effects and many contribute to the formation of secondary air pollution. Carbon monoxide and SO_2 are combustion gases and are harmful to health. They are associated with burning fuel in flares, engines or other equipment. This interpretation is consistent with the data gathered at Gas Facility Molve East and at Gathering Station IVA-1 in Ivanić-Grad where flares were observed.

These observations, collected over relatively short time periods during just four days, represent a snapshot in time of air quality at upstream and midstream oil and gas facilities in Croatia. Nevertheless they provide strong evidence that such sites may be responsible for avoidable greenhouse gas emissions and worsened local air quality.

Appendix 1: Sample locations and wind data

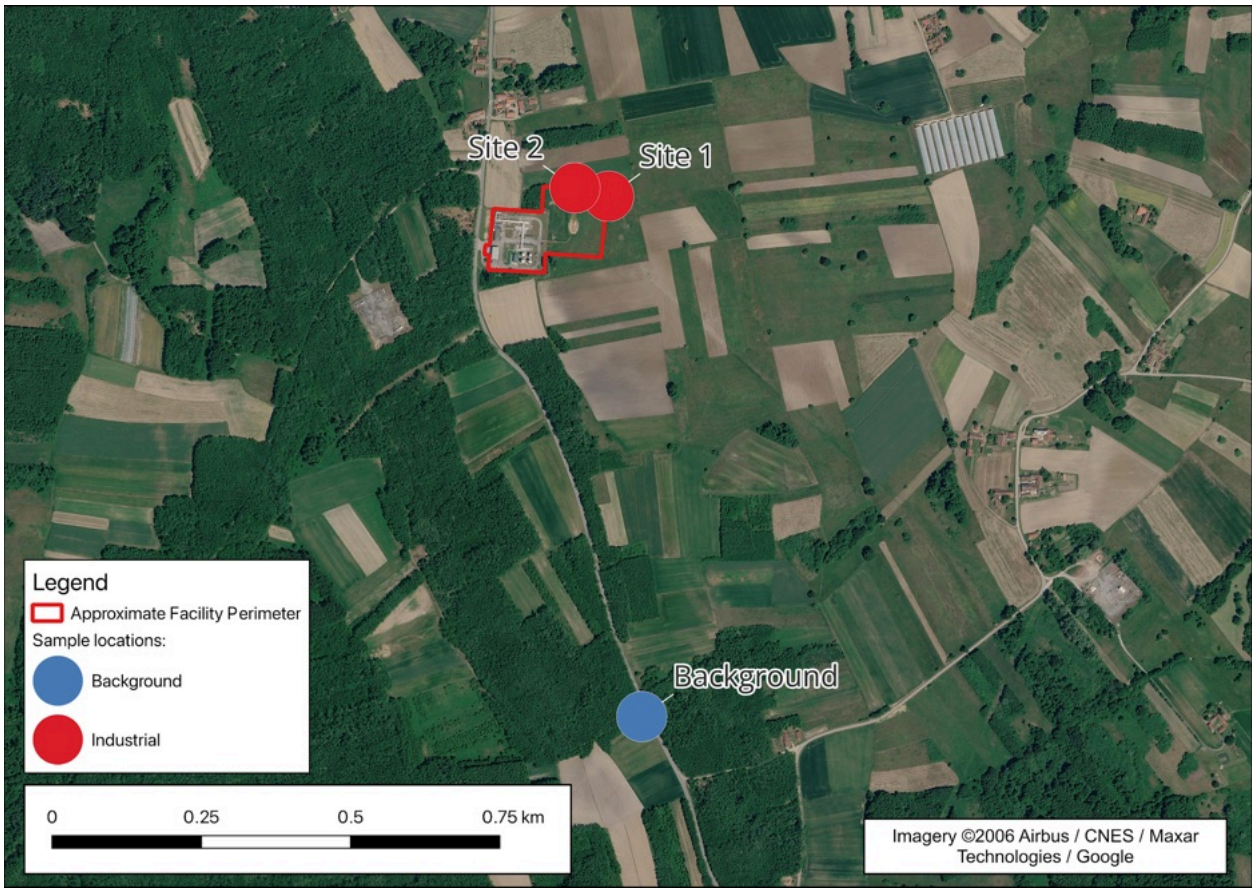


Figure A1. Location of the Background, Site 1 and Site 2 sample locations in Gas Facility Molve East.

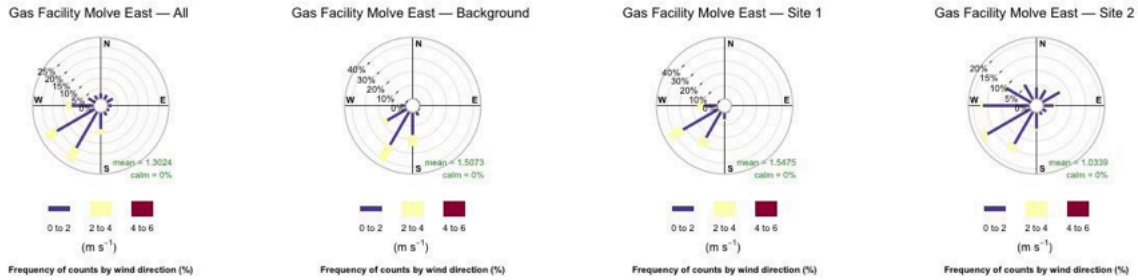


Figure A2. Wind observations during monitoring at background and industrial sites at Gas Facility Molve East.

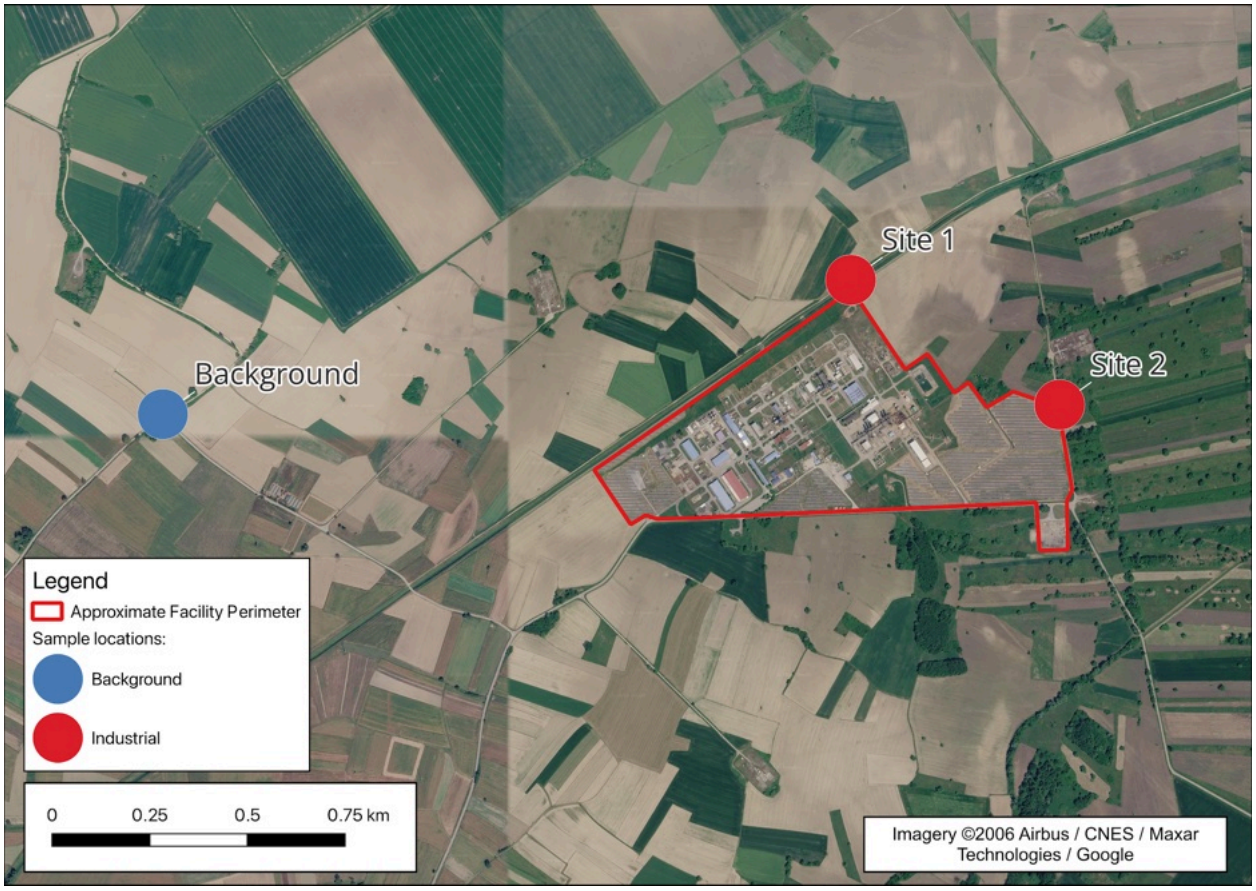


Figure A3. Location of the Background, Site 1 and Site 2 sample locations in CPS Molve.

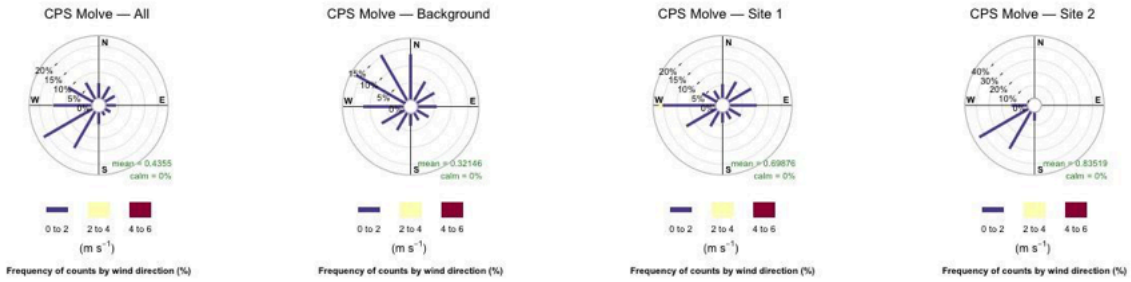


Figure A4. Wind observations during monitoring at background and industrial sites at CPS Molve.

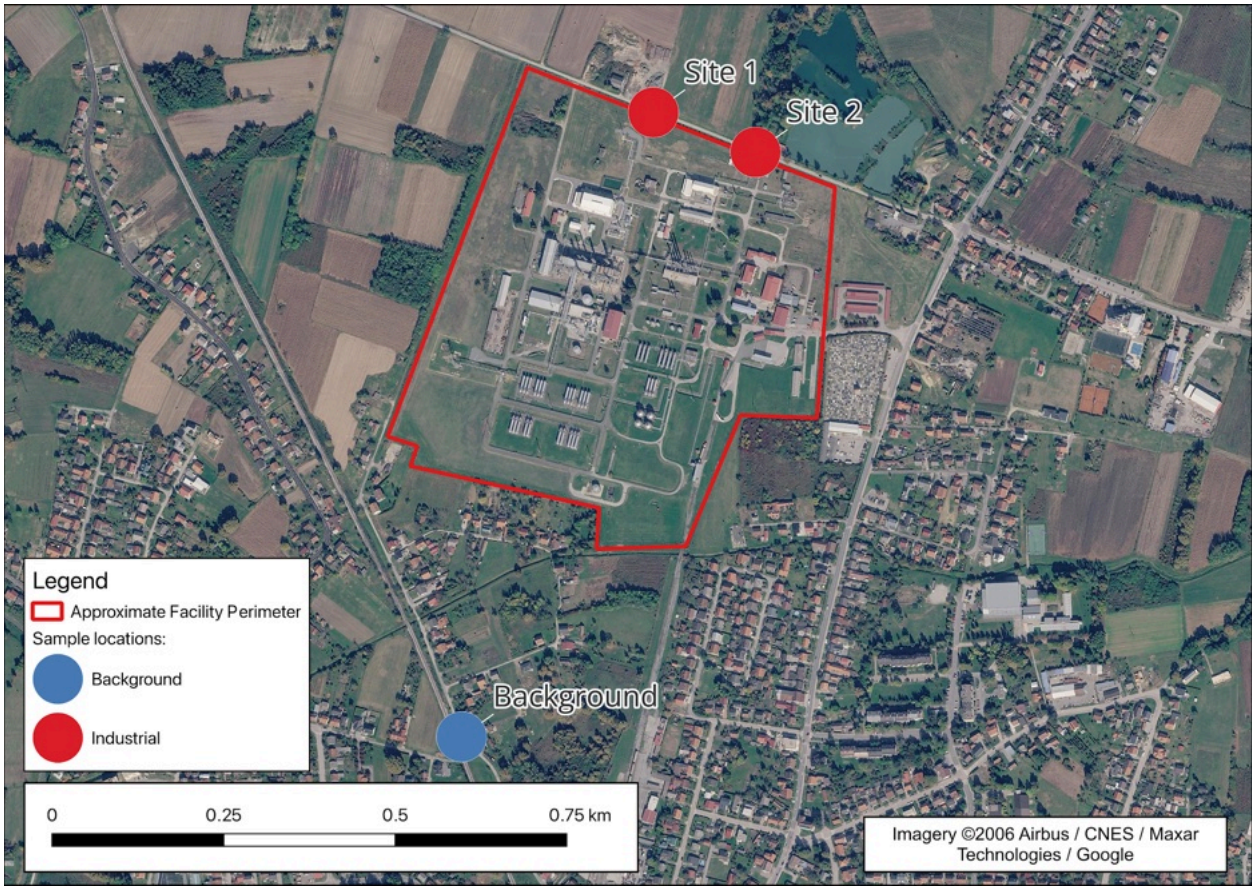


Figure A5. Location of the Background, Site 1 and Site 2 sample locations in Fractionation facilities Ivanić Grad

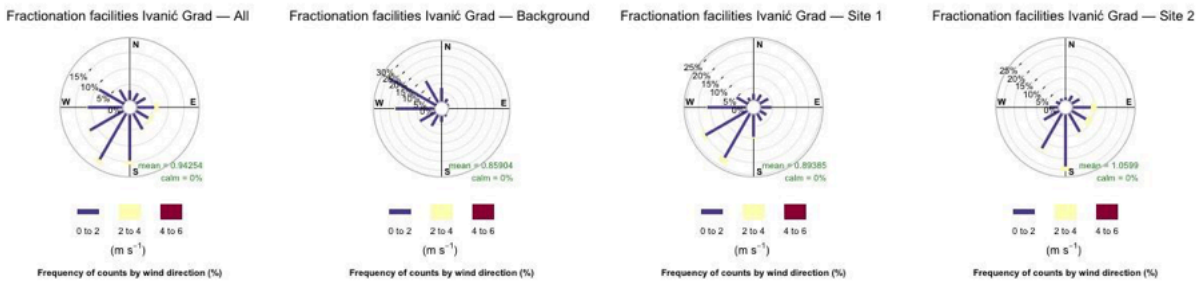


Figure A6. Wind observations during monitoring at background and industrial sites at Fractionation facilities Ivanić Grad

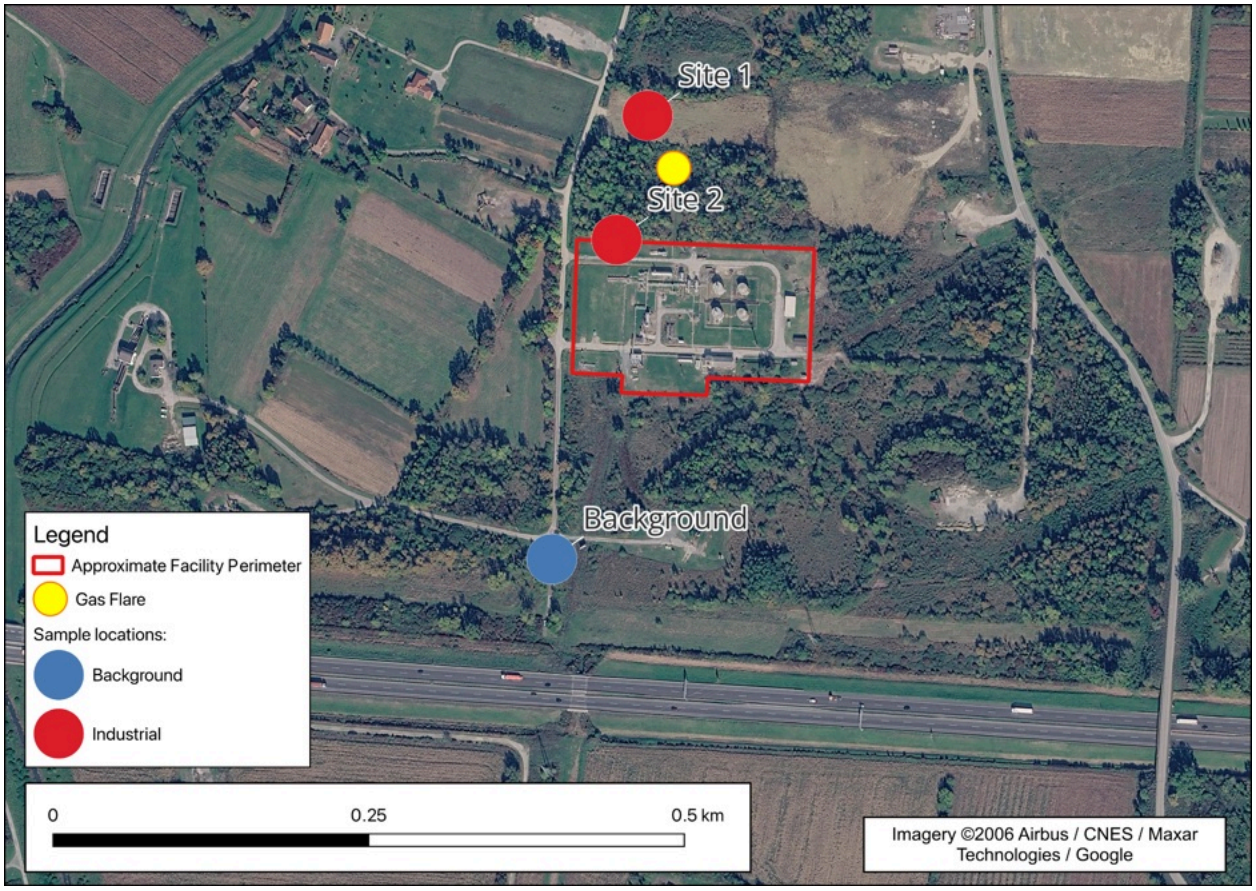


Figure A7. Location of the Background, Site 1 and Site 2 sample locations in Gathering Station IVA-1, Ivanić-Grad

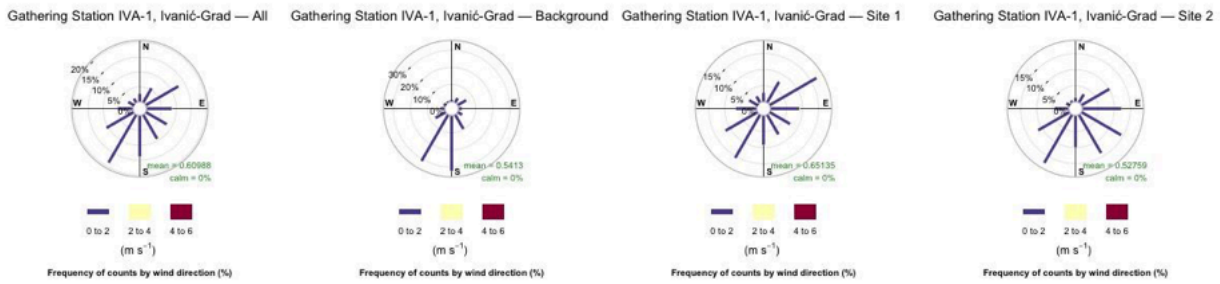


Figure A8. Wind observations during monitoring at background and industrial sites at Gathering Station IVA-1, Ivanić-Grad

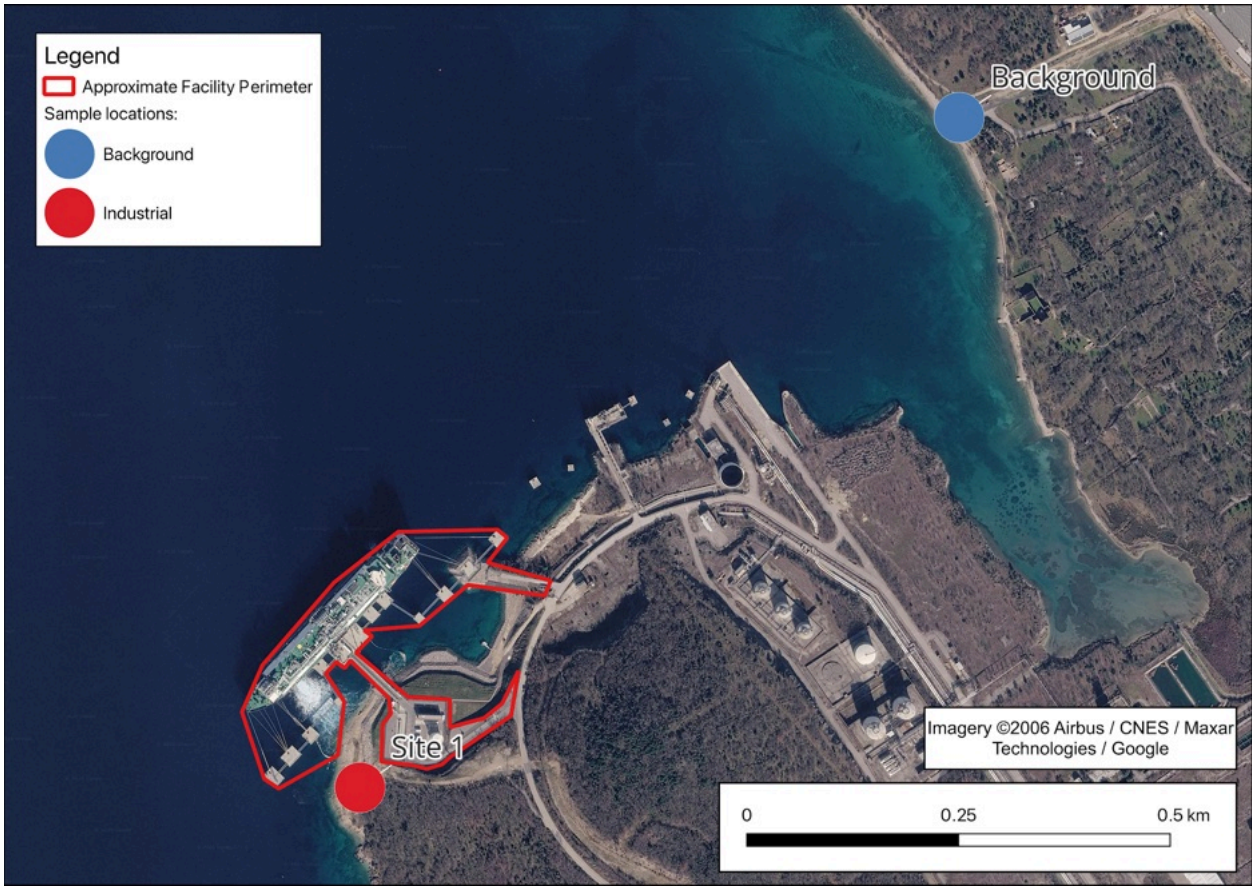


Figure A9. Location of the Background, Site 1 and Site 2 sample locations LNG terminal Krk

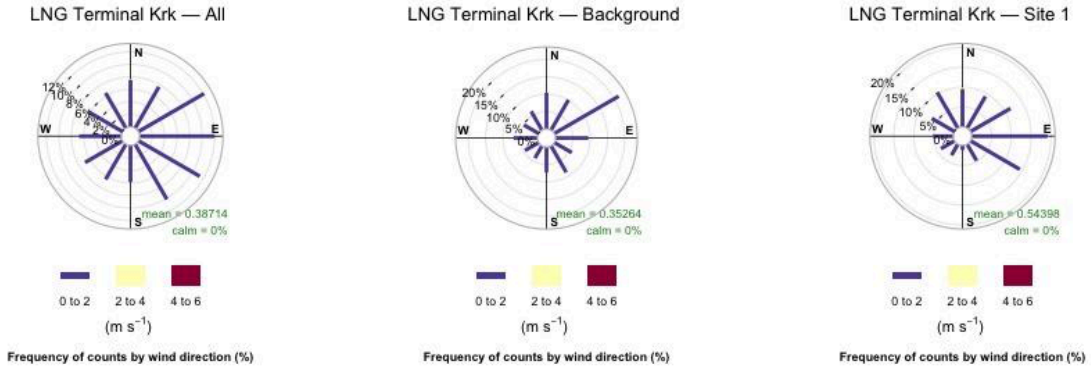


Figure A10. Wind observations during monitoring at background and industrial sites at LNG Terminal Krk



Figure A11. Location of the Background, Site 1 and Site 2 sample locations in Rijeka Refinery

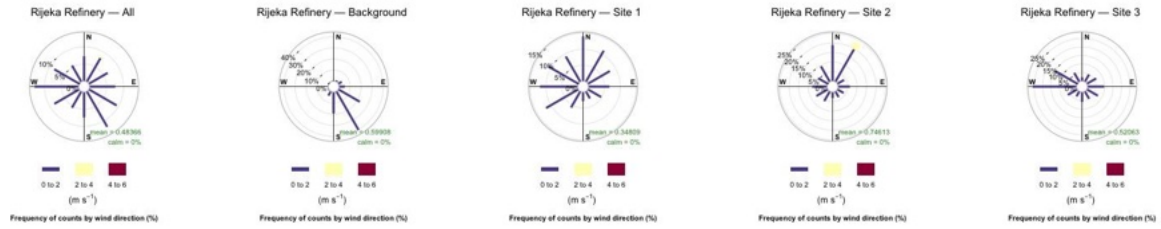


Figure A12. Wind observations during monitoring at background and industrial sites at Rijeka Refinery

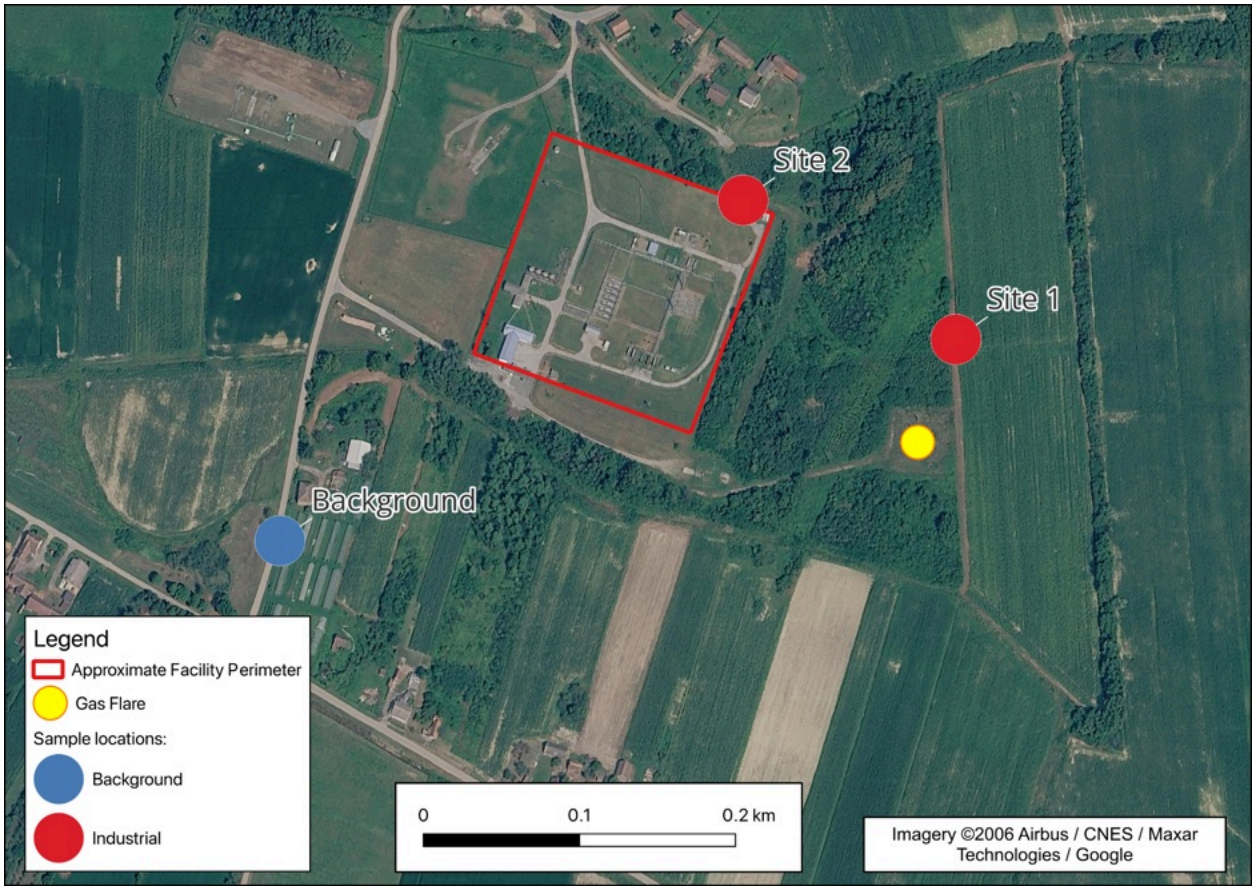


Figure A13. Location of the Background, Site 1 and Site 2 sample locations at Underground Gas Storage (UGS), Okoli south

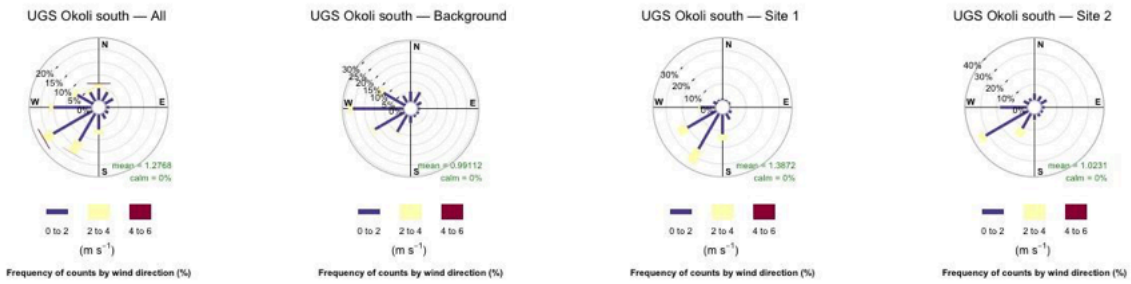


Figure A14. Wind observations during monitoring at background and industrial sites at Underground Gas Storage (UGS), Okoli south

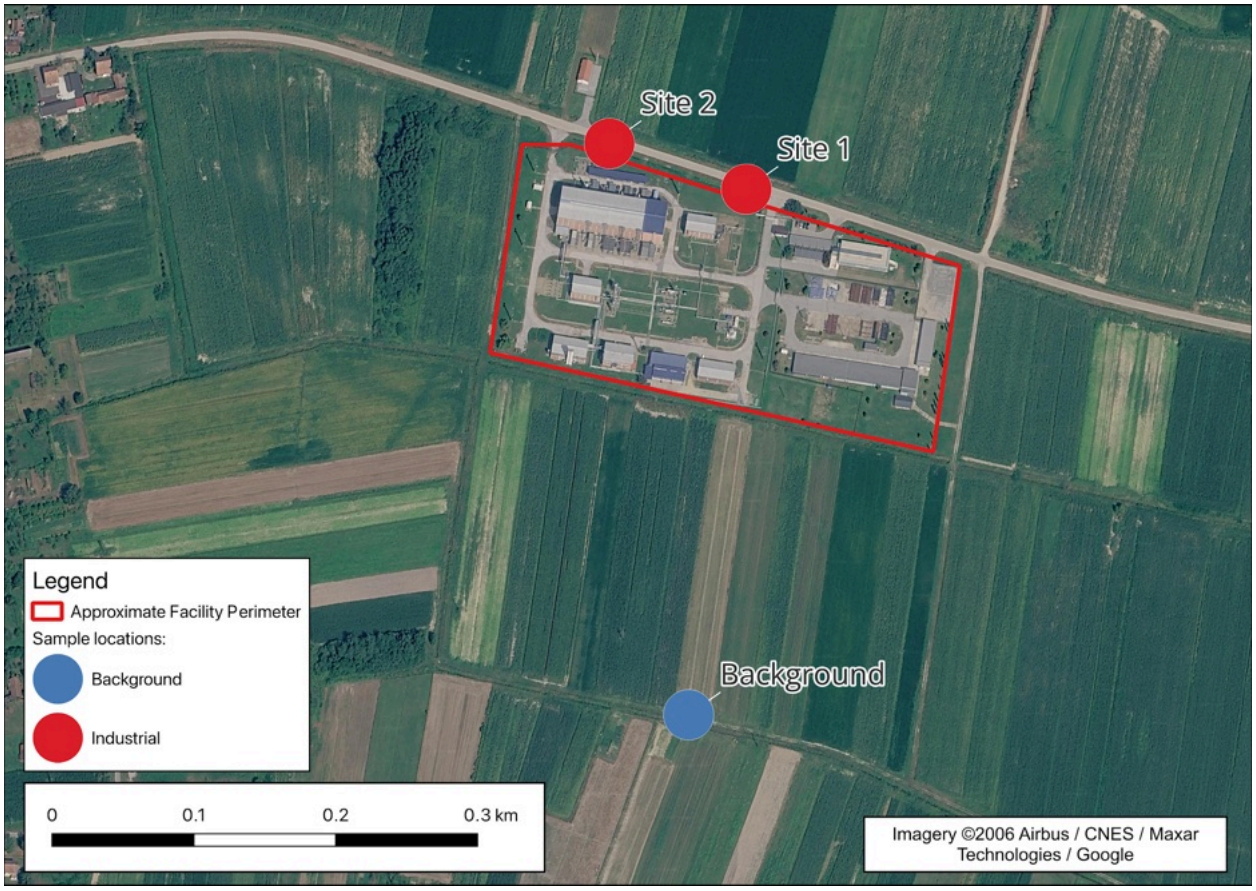


Figure A15. Location of the Background, Site 1 and Site 2 sample locations at Underground Gas Storage (UGS), Okoli north

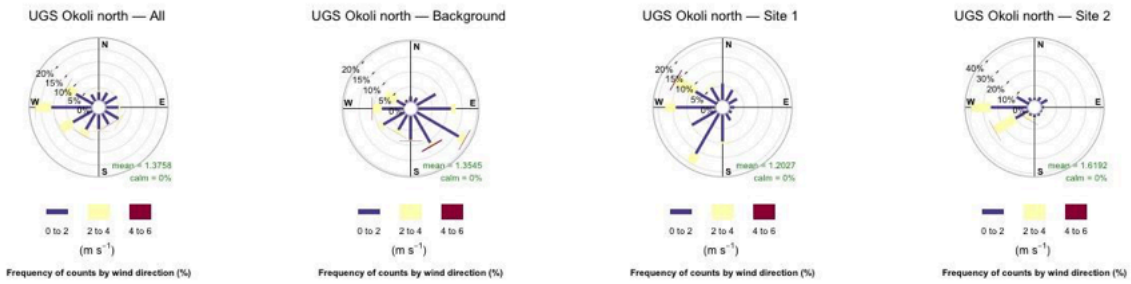


Figure A16. Wind observations during monitoring at background and industrial sites at Underground Gas Storage (UGS), Okoli north[5]

[5] Windrose plots produced using 'openair', Carslaw, D. C. and K. Ropkins, (2012) openair --- an R package for air quality data analysis. Environmental Modelling & Software. Volume 27-28, 52-61.