Community-level Odour Monitoring in High River, Alberta

NRCB | Natural Resources Conservation Board

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Contents

NRCB

Acronyms used in this report

AAQG	Ambient air quality guideline
AAQO	Ambient air quality objective
AOPA	*Agricultural Operation Practices Act*
AQHI	Air quality health index
CFO	Confined feeding operation
CRAZ	Calgary Region Airshed Zone
FAO	Farmers' Advocate Office
FIDO	Frequency, intensity, duration, and offensiveness
H_2S	Hydrogen sulphide
HR	High River
MDS	Minimum distance separation
NH_3	Ammonia
NRCB	Natural Resources Conservation Board
OI	Odour index
PAML	Portable air monitoring laboratory
PM	Particulate matter
RSC	Reduced sulphur compounds
SAR	*Standards and Administration Regulation*
SOP	Standard operating procedure
TRS	Total reduced sulphur
VOC	Volatile organic compounds

Summary

The residents of High River and surrounding area have collectively logged over 4,500 odour complaints to the Natural Resources Conservation Board (NRCB) since July of 2022.

Odour is considered a nuisance issue under the *Agricultural Operation Practices Act* (AOPA), the provincial legislation that regulates confined feeding operations (CFOs) in Alberta. Under AOPA, nuisance odours can be dealt with by a Practice Review Committee formed by the Farmers' Advocate Office (FAO) under Part 1 of AOPA, which concerns nuisance issues, or by the NRCB who administer Part 2 of AOPA, which concerns manure management and the permitting and compliance of CFO facilities. Nuisance odours can be challenging to address given that some degree of odour from livestock operations is expected and considered a result of generally accepted agricultural practice. Confirming whether an operation is creating an inappropriate disturbance through odour requires, in part, an understanding of the source, frequency, intensity, duration, and offensiveness (FIDO) of odours.

In 2022, NRCB inspectors conducted in-person site visits in response to the odour complaints and attempted to respond in person during odour events to assess the FIDO criteria of the odours. However, these efforts were challenged with the timing of the odour complaints, the proximity of NRCB inspectors to the townsite, and competing demands on NRCB inspector workloads to effectively address the volume of complaints. In response to these complaints, the NRCB worked with the operation to address a source of odour on their operation, which was identified as the catch basin on the southeast section of the operation.

Complaints against the operation continued (albeit at a reduced level) after management of the identified odour source. In response, the NRCB put in motion a monitoring and evaluation plan to:

i. assess the frequency, intensity and duration of odours through continuous monitoring of odorous compounds (targeting ammonia, reduced sulphur, and volatile organic compounds that are commonly used indicators of livestock odours);
ii. identify the likely sources and their relative contribution of odours experienced in High River;
iii. conduct site-specific assessments of identified odour sources to better understand the facilities or practices that are producing more odours in an effort to target management practices; and,
iv. validate the effect of management practices conducted at the odour sources on reducing the odours experienced by the community.

This report focuses on objectives i) and ii) of the NRCB monitoring and evaluation plan. Community-level monitoring was conducted between May and September of 2023, and intermittently in periods between May and October in 2024. Site-specific assessments, in accordance with objective iii) were conducted in 2024, but are not reported here; this phase is ongoing at the time of writing this report, and the results of this work will be reported separately. This report is intended to summarize the methodologies and monitoring results obtained from the community-level monitoring stations and is not intended as an expert report.

The continuous monitoring data was analyzed separately for the full data set and during odour events (defined as periods in which complaints were registered by the NRCB) to assess the differences between the concentration and likely source of odorous compounds at the times when the residents

found the air quality offensive. It was observed that the majority of the peak concentrations of odorous compounds measured in the community were sourced from the direction of three CFOs, which are southwest-to-west of the community. However, high concentrations of odorous compounds were observed from the direction of other sources, indicating other sources in the region. Notably, reduced sulphur compounds are sourced from directions north-to-northeast of High River. Indeed, 62% of the ambient air quality guideline (AAQG) exceedances for odour management, defined as 5 ppb(v) of total reduced sulphur (TRS), occurred when the winds were blowing from north-to-northeast directions. However, the offensiveness of odours linked to these TRS exceedance events appeared to be higher when TRS was sourced from the direction of CFOs as evidenced by the number of complaints received during these exceedance events.

The continuous monitoring data demonstrates a strong correlation between community complaints and concentrations of ammonia. An ammonia deposition study was completed in 2023 to assess the spatial magnitude and confirm the likely sources of ammonia in the High River area. The result of this study shows that livestock operations are the majority source of ammonia. However, these results show only a time-integrated snapshot of ammonia deposition and cannot be used to assess the FIDO of regional odours.

An odour source profiling study was completed in an effort to verify the impact of odour sources on the community. Odour profiles, defined by an analysis of over 100 volatile organic compounds and 19 reduced sulphur compounds, were characterized for livestock and municipal wastewater sources. Two community samples were collected during active odour events to confirm the utility of the method in odour source attribution. One community sample was observed to be most similar to feedlot odour sources, and the other was observed to be most similar to municipal wastewater odours. However, the strength of this evidence is weak given the high diversity of compounds that exist in replicate samples of odour sources, and the relatively low overall similarity between the community samples and odour source profiles.

Taken together, these results demonstrate that the majority of odours experienced in the High River area are sourced from livestock operations, and the community was confirmed to be impacted to a minor extent by odours from other types of operations in the region. The continuous monitoring data collected at the community location is helpful in confirming odour sources, understanding the relative magnitude of odorous compound concentrations, and establishing a baseline for validating the effect of management practices on reducing odour impacts on the community.

Odour complaints in High River, Alberta and surrounding areas

Beginning in July 2022, a number of complaints about livestock odour have been received by the Natural Resources Conservation Board (NRCB) of Alberta from the residents of High River and surrounding areas (“residents”). A total of 4,562 odour complaints from the residents of Foothills County involving 10 operations have been logged by the NRCB between July 1, 2022 and October 17, 2024, which is the terminal date of the assessment period covered in this report. Of these odour complaints, 4,545 (99.6%) were directed toward a specific operation: Rimrock Feeders, which is located on legal land location SE-05-019-29-W4. A detailed breakdown of the number of complaints registered against this feedlot since 2009 is presented in Table 1.

Table 1 Number of complaints per month in each year contained in the NRCB CFO database directed toward the confined feeding operation located on SE-05-019-29-W4.

Month	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
January			2	1	3	1	1	1					1	3	59	64
February					1			1						1	54	91
March				1	1	2								1	85	55
April													4	2	18	138
May				4		1		1			sold		7		176	401
June				1								1	4	4	208	153
July		1											1	68	225	404
August						1							1	121	252	202
September			2	1		1						20	3	98	300	228
October	1		27				2					9	3	53	473	98
November		1	3									3	3	22	349	
December		9	6				1					2		11	139	
Total	**1**	**11**	**40**	**8**	**5**	**6**	**4**	**3**	**0**	**0**	**0**	**35**	**27**	**384**	**2338**	**1834**

Western Feeders
Not in operation
Rimrock Feeders

NRCB process for odour management

Livestock confined feeding operations (CFO) in Alberta are regulated under the *Agricultural Operation Practices Act* (AOPA) [1]. Part 1 of AOPA concerning nuisance issues such as odour, dust, noise, and smoke is administered by Practice Review Committees, assisted by the Farmers’ Advocate Office (FAO)[2]. The NRCB administers Part 2 of AOPA concerning manure management and the permitting and compliance processes for CFOs. All new and expanding operations are required to apply for NRCB permits, provided they meet threshold requirements for livestock numbers[3]. As of 2004, all operations that were previously approved under a municipal development permit were considered

[1] Agricultural Operation Practices Act. 2022. Government of Alberta, Edmonton, AB.
[2] Fair process for landowners and producers. Farmers’ Advocate Office, Edmonton, AB.
[3] Municipalities and the *Agricultural Operation Practices Act* (AOPA). 2014. The Standard: Environmental standards for Alberta’s livestock industry.

permits under AOPA ("deemed permits")[4], and the NRCB was assigned responsibility of enforcing the permit conditions that were contained in the municipal permit.

Livestock odours are addressed in AOPA primarily through manure management requirements and the application of minimum distance separation (MDS) standards prescribed in the *Standards and Administration Regulation* (SAR)[5]. The MDS approach is applied at the permitting stage for new or expanding operations. Application of MDS requirements attempts to mitigate the effect of nuisance odours from livestock production on neighbouring residences by ensuring suitable setbacks between the operation and residences. The MDS is calculated using a formula that considers the number and type of livestock, the type of manure (liquid or solid), and the type of neighbouring residential developments or zoned land. There are four categories of residences that are considered based on their sensitivity to nuisance odours, ranging from residences on land zoned for agricultural operations (least sensitive) to residences on land zoned for large-scale residential developments, such as towns (most sensitive). An operation can proceed where residences exist within the MDS if the operation owns the residence, or the resident waives the application of the MDS in writing. Many municipalities have a reciprocal MDS provision where residences are restricted from locating within an MDS of a CFO to mitigate conflicts that may arise between new residences and existing CFOs.[6]

The NRCB also addresses nuisance odours through compliance actions taken against operations that are thought to be creating an inappropriate disturbance. The SAR does not include technical requirements for nuisance odour. An NRCB inspector may issue an enforcement order if, in their opinion, a person is creating an inappropriate disturbance. When an odour complaint is received, NRCB inspectors work toward determining the source of the odour, whether the odour is the result of non-compliance with the technical rules in the SAR, and whether the odour is creating an inappropriate disturbance or would be considered normal for an agricultural operation[7]. Complaints regarding nuisance odours can be challenging to address given that some degree of odour from livestock operations is considered accepted agricultural practice. Confirming whether an operation is creating an inappropriate disturbance requires an understanding of the source as well as the frequency, duration, intensity, and offensiveness (FIDO) of odours.

The NRCB Compliance and Enforcement Policy[8] describes the guiding principles, general investigation process, enforcement ladder, and compliance options used by the NRCB. Nuisance issues, such as odours, may initiate complaint-driven compliance actions, which are described in the policy. Odour investigations include an assessment of the FIDO criteria of the odour. Cases in which odours are linked to generally accepted agricultural practice will be recorded in the NRCB database and communications with all parties will occur, but no management action will be initiated. For cases in which odour complaints are not readily linked to generally acceptable agricultural practice, additional investigation and focused studies may be conducted by the NRCB to understand the FIDO criteria of the odour and what management actions can be taken to mitigate odours. Parties aggrieved by agricultural nuisances may also submit an application to the Minister for a case to be reviewed by a Practice Review Committee under Part 1 of AOPA, who will make

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[4] Grandfathering (Deemed Permit) Operational Policy 2023-1. 2023. NRCB, Edmonton, AB.

[5] Standards and Administration Regulation. 2020. Government of Alberta, Edmonton, AB.

[6] Confined feeding operations: Examining the role of municipal government in land use planning. 2022. Oldman River Regional Services Commission, ORRSC Periodical – Spring 2022.

[7] Complaints. Natural Resources Conservation Board, Edmonton, AB.

[8] Compliance and Enforcement, Operational Policy 2016-8. 2021. NRCB, Edmonton, AB.

recommendations to the Minister on whether an operation is following generally accepted agricultural practice.

Objectives of the community-level monitoring investigation in High River

In response to the odour complaints registered by the residents of High River and surrounding areas, the NRCB initiated a focused study to better understand the odours impacting the residents and what, if any, management actions may be needed to address the odour concerns. The specific objectives of the investigation are to:

1. Assess the frequency, intensity, and duration of odorous compounds being experienced by the residents of High River through air quality monitoring.
2. Identify and confirm the likely source(s) of odours impacting the residents of High River.
3. Investigate the practices being conducted by the source operation(s) to determine management requirements to mitigate odours.
4. Validate the efficacy of management practices on reducing the frequency, intensity and duration of odorous compounds experienced at the community.

This report details the community-level monitoring studies completed by the NRCB during the 2023 and 2024 assessment periods, which are intended to meet objectives 1 and 2 stated above. Site-specific investigations, per Objective 3, were conducted on odour sources throughout 2024; however, this work is ongoing at the time of this report and the results will be reported separately. This report will describe the scope and details of the assessment and the methods and results of continuous air quality monitoring, air deposition monitoring across the High River area, and odour profiling completed to confirm odour sources.

Odour monitoring methods

Odour is complex to assess and quantify as it is based on human perception of airborne odorous compounds. Investigation actions for odour generally begin with site-specific assessments conducted by regulatory inspectors, who complete standard odour assessment protocols. Next phases of complex odour investigations can include olfactory methods that employ trained human panellists to characterize odours. Grab samples collected in the field can be sent to a laboratory where human panels, made up of trained individuals, assess odours under controlled conditions. Another tool used are field olfactometers, which allow trained personnel to assess odour intensity on-site by diluting odour-affected air with filtered air to give a quantitative measure of odour strength. Although these methods are best suited to evaluating the characteristics and strength of odour based on human perception, they are difficult to implement owing to the need for trained human assessors and limited scope of application over space and time.

Chemical-based analysis offers an alternative approach to monitoring odours other than through human perception by trained assessors. These methods can broadly be categorized into those that analyze specific or sets of compounds collected in grab samples and those that use continuous analyzers that target specific indicators. In the grab sample approach, air samples are collected at a specific point in time, typically near the odour source or in areas of concern and transported to a laboratory for analysis. The labs analyze these samples for a wide variety of odour-associated compounds according to standard analytical protocols. These analyses are particularly useful providing a detailed snapshot of odour profiles. However, similar to human perception methods, they are difficult to implement at scale. Continuous analyzers offer a more dynamic approach by targeting specific indicator parameters in real time and allow for pairing with wind data to enable an assessment of likely sources on the landscape. These analyzers continuously measure the concentrations of odour-related compounds, such as hydrogen sulfide, ammonia, and specific volatile organic compounds (VOCs), providing comprehensive data on odourant concentrations and trends over time. However, the trade-off with these devices is that they measure only a select few parameters and assumptions have to be made regarding human perception (offensiveness). Advancements in this technology have led to the development of electronic noses, which attempt to mimic human perception of odour by analyzing a number of odorous compounds and integrating these signals into an odour index. This technology is still in its infancy but offers promise.

At the beginning of the NRCB's response to complaints, inspectors conducted site visits following operational protocols to investigate odour sources. However, delays in response time, owing to complaints being logged after an odour event occurred or travel time needed by the NRCB inspector to arrive at the odour complaint location, often led to futile outcomes for the odour assessments. Given the frequency and magnitude of complaints recorded by the NRCB from the High River area, the NRCB opted to move to chemical-based methods, particularly continuous monitoring technologies that can be used to assess the spatial and temporal scope of odorous compounds. Further detail on the monitoring methods is provided in this report. All of the methods described in this report were new to the NRCB. As such, standard operating procedures (SOPs) had to be developed as part of the investigation. Consequently, the analysis and interpretation of results were challenged by procurement processes, equipment troubleshooting and repairs, and the need to develop data management systems and data analytical processes.

Scope of the NRCB odour impact assessment

The odour impact assessment was conducted through community-level monitoring that occurred in May 12 – September 23, 2023 and May 23 – October 17, 2024. The focus of the 2023 assessment period was on continuous air quality monitoring within the town of High River. The results of this phase of the assessment enabled the confirmation of potential sources contributing to odours in the community, an evaluation of odour-associated compounds against established Ambient Air Quality Objectives and Guidelines (AAQOs and AAQGs)[9], and the validation of potential source locations through a spatial ammonia deposition survey. The 2024 assessment included continuous air quality monitoring that was conducted intermittently at a different community-level monitoring location, balanced against equipment use at other locations for site-specific assessments, and also included an odour profiling study to determine the feasibility of these methods to confirm source impacts on the community.

During the two assessment periods, a total of 4,345 hours of continuous monitoring data were collected and 1,452 complaints were registered by residents of the High River area (Figure 1). The registered complaints were used to identify odour events, where the hour a complaint or complaints were logged initiated an odour event, and the preceding and following hour were identified as being part of the odour event. In this way, most complaints were consolidated into combined blocks of hours representing a cohesive odour event. In total, 1,510 hours of the total assessment hours (~35% of the data records in both 2023 and 2024) were considered as odour events.

[9] Alberta ambient air quality objectives and guidelines 2024. Government of Alberta.

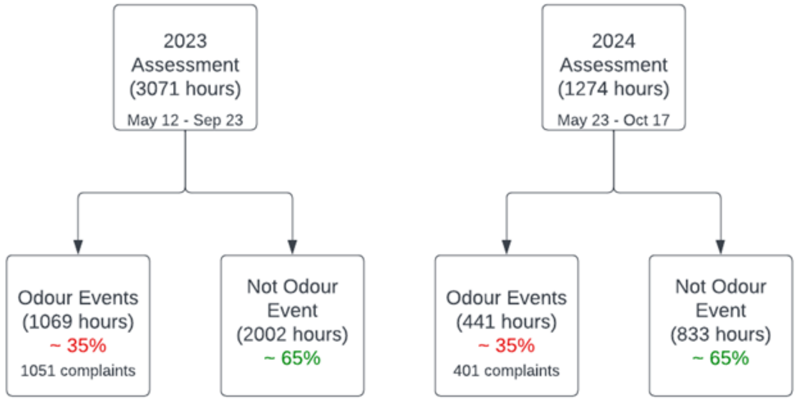

Figure 1 Breakdown of the total number of assessment hours, the number of hours defined as odour events, and the number of complaints registered in each assessment year.

Continuous air quality monitoring for odours

Odorous compound monitoring

Initial air quality monitoring was completed in collaboration with the Calgary Region Airshed Zone (CRAZ), who had deployed a Portable Air Monitoring Laboratory (PAML) in High River in December 2022 until December 2023[10]. The PAML initially included only air quality parameters used to assess and report on the Air Quality Health Index (AQHI) and did not focus on odorous compounds. The NRCB worked with CRAZ and Alberta Environment and Protected Areas to install a total reduced sulphur (TRS) analyzer in the PAML, effective January 19, 2023. TRS was chosen as a parameter because it was under consideration as the target of the Alberta Ambient Air Quality Guideline (AAQG) for odour management. The AAQG for TRS (30-min average of 5 ppb) was published in July 2024[11].

The NRCB purchased a continuous air quality analyzer (CTair) from Scentroid[12], an experienced odour-assessment company that offers contracted services and monitoring equipment for monitoring odour impacts. Initially, a single unit was procured to test the sensitivity and specificity of the unit for measuring odorous compounds experienced in High River, and likely sourced from livestock operations. This unit was co-located with the CRAZ PAML from May 12, 2023 to September 20, 2023. The unit was then moved later in 2023 to focus on site-specific assessments. A second CTair unit was received in September 2023, and a third CTair unit was received March 2024, to support site-specific odour assessments. The sensors installed in the new units were slightly different and based on lessons learned from the deployment of the first CTair. Details of the sensors included in the CTair units are provided in Table 2. Information on the deployment location, time periods, and sensors available at the time of deployment are provided in Table 3.

The primary focus of the 2024 monitoring year was around site-specific assessments of emissions of odorous compounds. The continuous monitoring unit (CTair2) was deployed in July following warranty replacement (owing to issues identified during the winter period) and following the joint factory recalibration of all three units. The unit was then used throughout the summer for source-assessment purposes, then redeployed in late September of 2024 at the High River community

[10] Air quality monitoring comes to High River. December 1, 2022. Calgary Region Airshed Zone.
[11] Alberta ambient air quality objectives and guidelines 2024. Government of Alberta.
[12] Scentroid: Future of sensory technology.

station. The unit will henceforth be deployed at the community station to measure odorous compounds in the community.

Calendar plots showing the dates of the assessment periods, the range of complaints received by the NRCB, and measured concentrations of air quality parameters are provided in Figures A-1 and A-2 of Appendix A.

Table 2 Parameters included in the Scentroid CTair continuous air quality analyzers.

Sensor	Description	Units	Sensor type	Lower Det Limit	Upper Det Limit	Resolution
NH_3	Ammonia	ppm	Electrochemical	0.005	10	0.001
CS_2	Carbon disulphide	ppm	Electrochemical	1		
H_2S	Hydrogen sulphide	ppm	Electrochemical	0.007	3	0.001
TVOC	Total volatile organic compounds	ppm	Electrochemical	0.001	50	0.001
OI	Odour index		Proprietary calculation			
PM_1	Particulate matter <1 µm	µg / m³	Laser scattered	1	2000	1
$PM_{2.5}$	Particulate matter <2.5 µm	µg / m³	Laser scattered	1	2000	1
PM_{10}	Particulate matter <10 µm	µg / m³	Laser scattered	1	2000	1
PM_{100}	Particulate matter <100 µm	µg / m³	Laser scattered	1	20000	1

Table 3 Deployment schedule for the Scentroid CTair continuous air quality analyzers. Grey shading indicates out of service dates. Green shading indicates High River community-level monitoring periods. Dates not included have no data due to solar power issues with that unit during that period.

Monitoring unit	Deployment location	Date range	Sensors
CTair1	High River – Spray Park	May 15 – Sept. 20, 2023	NH_3, CS_2, TVOC, OI
	Source assessments	Oct. 5 – June 13, 2024	NH_3, CS_2, TVOC, OI, H_2S
	Factory recalibration	June 13 – July 15, 2024	
	Source assessments	July 17 – Oct. 17, 2024	NH_3, CS_2, H_2S, TVOC, OI, PM_1, $PM_{2.5}$, PM_{10}, PM_{100}
CTair2	Source assessments	Sept. 13 – Oct. 26, 2023	NH_3, H_2S, TVOC, OI, PM_1, $PM_{2.5}$, PM_{10}, PM_{100}
	Factory Repair	Oct. 26, 2023 – Jan 22, 2024	
	Source assessments	Jan. 22 – April 23, 2024	
	High River – West Boundary	May 23 – June 13, 2024	
	Factory recalibration	June 13 – July 15, 2024	
	High River – West Boundary	July 15 – July 25, 2024	
	Source assessments	July 25 – Sept. 25, 2024	
	High River – West Boundary	Sept. 25 – Oct. 17, 2024	
CTair3	Source assessments	April 23 – June 13, 2024	NH_3, H_2S, TVOC, OI, PM_1, $PM_{2.5}$, PM_{10}, PM_{100}
	Factory recalibration	June 13 – July 15, 2024	
	Source assessments	July 15 – Oct. 17, 2024	

Wind monitoring

Wind data used in the analysis was obtained from multiple sources. Wind speed and direction measured at 10 m height on the CRAZ PAML was used to support the 2023 community-level monitoring period. The NRCB installed a meteorological station that measures wind at 2 m height to support site-specific assessments. This station has been deployed approximately 550 m southwest of Rimrock Feeders since September 2023. A second meteorological station was procured for deployment on the High River – West Boundary monitoring location, beginning in spring of 2024. To mitigate against the effect of local anomalies on wind speed and direction, and to enhance the spatial resolution of the wind profiles to improve source attribution, an inverse-distance weighting (IDW) procedure was applied to wind data collected from the CRAZ PAML, the NRCB monitoring stations, and five regional meteorological stations with data accessible from the Alberta Climate Information Service[13] maintained by Alberta Agriculture and Irrigation (AGI). Details on the wind monitoring stations are provided in Table 4. In effect, the IDW procedure calculates average wind speed and direction, but is weighted such that the wind stations closest to the air quality measurement point have a higher influence on the average, and hence are better represented, than stations further away from the measurement point.

Table 4 Details on wind data collected from local and regional meteorological stations.

Station	Operator	Latitude	Longitude	Wind height (m)	Distance defined in IDW (km)	
					2023	2024
HR-PAML	CRAZ	50.592	-113.902	10	0.1	
HR-West Edge	NRCB	50.585	-113.907	2		
SW of Rimrock	NRCB	50.572	-113.995	2	8.6	6.4
Azure	AGI	50.512	-114.013	2	11.9	11.0
Blackie	AGI	50.546	-113.640	10	19.2	19.4
Black Diamond	AGI	50.707	-114.152	10	21.8	22.0
Priddis	AGI	50.869	-114.292	10	41.4	41.6
Stavely	AGI	50.183	-113.883	10	45.3	44.6

The weather station installed at the HR-West Edge site experienced a failure to its power supply, resulting in data not being available for the September – October 2024 assessment period. Subsequently, wind data from this site was not used as part of this analysis and this station was not included in the IDW procedure.

The wind profiles measured at the SW of Rimrock site and the IDW wind profile calculated from the stations are shown in Figures A-3 and A-4, respectively, of Appendix A. The wind profiles of the data partitioned by odour event are shown in Figure A-5. The wind profiles, termed wind roses, show the frequency of counts, as hourly averages. The concentric circles show the percentage of data that are represented by combinations of wind speed (in 2 m/s intervals) and direction (on 20° intervals). The cumulative proportion of each wind rose within each quadrant of wind direction are summarized in Table 5.

Altogether, the IDW wind profiles show reasonable comparability to the 2 m wind measured SW of Rimrock; an exact representation is not expected given that the IDW average is a regional estimate of wind speed and direction whereas the SW of Rimrock site is more influenced by localized conditions occurring upwind of the CFO. The wind data partitioned into the odour events shows a clear increase in cumulative wind direction from the southwest-to-northwest, and a reduction in cumulative wind from the southeast-to-northeast during complaint events. However, approximately 18-20% of wind was coming from SE-NE directions during odour events that occurred with the assessment periods.

[13] Alberta Climate Information Service.

Table 5 Cumulative percentage (%) of wind data within each quadrant of wind direction from the SW of Rimrock station, measured at 2 m height, the inverse-distance weighted (IDW) wind profile, and the wind data used for assessing odours during odour events.

Quadrant	2023			2024		
	SW of Rimrock	IDW Full	IDW Odour event	SW of Rimrock	IDW Full	IDW Odour event
NE	11	12	7	10	20	13
SE	26	28	11	14	15	7
SW	34	32	49	42	43	49
NW	29	28	33	34	22	31

Comparison to Ambient Air Quality Objectives and Guidelines (AAQO/AAQG)

The data collected from the community-level monitoring investigations were compared against the Alberta Ambient Air Quality Objectives and Guidelines (AAQO/AAQG)[14] for odorous compounds and particulate matter. Other air quality parameters measured in the PAML for calculating the AQHI were reported separately by CRAZ. Particulate matter was compared against the AAQOs given that CFOs can emit particulate matter. However, the detailed air quality assessments reported below were only conducted on odorous compounds and not particulate matter. A summary of the descriptive statistics and guideline exceedances for measured parameters that have AAQO or AAQG values are presented in Table 6.

No AAQO exceedances were observed for ammonia during the 2023 and 2024 assessment periods; the highest concentration measured for ammonia was 420 ppb in 2023 and 741 ppb in 2024. TRS measurements between February 1 and November 1, 2023 were compared against the 2024 AAQG odour management guideline as part of this assessment. There were 37 guideline exceedances during this period, representing 0.3% of the total number of 30-minute measurements. A detailed breakdown of the TRS guideline exceedances is presented in Table A-1 of Appendix A. The 37 TRS guideline exceedances occurred on 21 separate days; 10 days had consecutive exceedances of up to 2 hours. Of the 21 separate exceedance events, 8 occurred when the wind was blowing from a southwest-to-west direction (240° – 290°), approximating the direction of Rimrock Feeders, representing 38% of the exceedance events. The other 62% of the exceedance events occurred when the wind was blowing either from the N-NE (349° – 94°) or S (180°). However, the odours linked to TRS sourced from operations north-to-northeast of High River appears to be less offensive than odours linked to TRS sourced from southwest-to-west directions, as evidenced by the differences in the numbers of complaints received between these two directionalities. During the TRS guideline exceedances, there were 114 complaints registered during the 38% of TRS exceedance events linked to west-to-southwest sources in comparison to 34 complaints registered during the 62% of TRS exceedance events linked to north-to-northeast sources.

The particulate matter AAQO exceedances are believed to be linked to wildfire smoke events, as confirmed by AAQO exceedances for particulate matter occurring at regional air quality monitoring stations during the same time periods. A detailed breakdown of the particulate matter guidelines exceedances is presented in Table A-2 of Appendix A.

[14] Alberta ambient air quality objectives and guidelines 2024. Government of Alberta, Edmonton, AB.

Table 6 Summary of measured concentrations of odour-associated compounds and particulate matter compared to their respective Alberta Ambient Air Quality Objective (AAQO) or Guideline (AAQG).

Year	Parameter	Averaging Period	Unit	AAQO/ AAQG*	Summary Statistics					AAQO/AAQG Exceedances	
					n	mean	min	median	max	#	%
2023	NH_3	1 hour	ppb	2,000	3072	28	0	12	420	0	0
	TRS	30 min	ppb	5	12907	0.29	0.00	0.16	17.2	37	0.3
	$PM_{2.5}$	24 hour	µg/m³	29	269	10	0.3	6.1	129	18	6.7
2024	NH_3	1 hour	ppb	2,000	1264	77	0	44	741	0	0
	H_2S	1 hour	ppb	10	1264	0.080	0	0	7.1	0	0
	H_2S	24 hour	ppb	4	56	0.084	0	0.004	0.93	0	0
	$PM_{2.5}$	24 hour	µg/m³	28	56	15	1	3	148	8	14.3
	TSP	24 hour	µg/m³	100	56	32	5	19	195	4	7.1

* AAQO for NH_3 and H_2S (1 hour) are for odour perception.
AAQO for H_2S (24 hour) and $PM_{2.5}$ are for health effects.
AAQO for Total Suspended Particulate (TSP) are for pulmonary effects.
AAQG for TRS is the guideline for odour management.

Air Quality Assessments

Air quality data collected during the assessment periods was analyzed using the openair package (v2.18-2)[15] in R (v4.2.1). This package was used to graphically illustrate the monitoring data collected in High River, and to use statistical models to estimate average or peak concentrations over time or from combinations of wind speed and direction. The purpose of this analysis was to better understand the variability in air quality parameters over time, and to attribute the likely source of odours based on the directionality of odorous compounds with respect to their relationship to wind speed and direction.

Temporal variation in odorous compounds

The estimated mean odour index values and concentrations of odorous compounds are presented in Figures A-6 to A-9 in Appendix A. Only the 2023 data is presented in these figures because the 2023 assessment period was most contiguous and thought to best represent the temporal variation in parameter values.

These figures exhibit a clear diurnal pattern in the average odour index values and odorous compound concentrations. For all parameters, the average concentration tends to begin increasing at approximately 18:00 in the evening and remain elevated until approximately 6:00 in the morning with concentrations dropping to a trough at around 10:00 – 12:00. The effect of the increases in parameter concentration is correlated with the timing of complaints logged to the NRCB, which is illustrated in Figures A-1 and A-2. As shown, the number of complaints tend to increase substantively

[15] Openair: open source tools for air quality data analysis.

beginning at 18:00 until approximately 23:00 – 0:00, then rise again at approximately 6:00 – 9:00. The reduction in complaints logged between the hours of 0:00 – 6:00 is likely more indicative of the typical hours of sleep rather than a reduction of odorous compounds at High River. Diurnal patterns of odorants experienced downwind from beef cattle operations, where higher concentrations were observed in the mornings and evenings, have been reported elsewhere[16].

No differences in the hourly estimates of parameter concentrations are evident between the days of the week, showing the daily consistency of the parameters and a lack of response to typical human activity patterns (i.e., generally more work occurs during the weekdays). The only significant variation that exists on the days of the week is for TRS concentrations, which are significantly higher (as evidenced by non-overlapping 95% confidence intervals) on Mondays and Tuesdays compared with the other days of the week. It is unknown at the time of reporting why TRS would be higher on Mondays and Tuesdays than any other day.

Monthly variation in parameter values is also observed, where odour index (OI), ammonia, and VOCs are observed to increase between May and August (ammonia) or May through September (OI and VOCs). VOCs are not only emitted from human activities, but also naturally by plants. An increase in VOCs during the growing season would be expected in an agricultural region as plants grow larger and mature. Given that the odour index integrates the VOC signal, it is expected that the OI would increase concordantly. The pattern of ammonia increase, with subsequent decrease in September, may be illustrative of the temperature dependency of ammonia volatilization, where ammonia turns to gaseous form at a faster rate under warmer temperatures.

Source attribution of odorous compounds

The graphics presented in Figures A-10 to A-17 show five different outputs of the air quality analysis: (i) estimates of the maximum parameter value based on combinations of wind speed and direction over the assessment period; (ii) estimates of the maximum parameter value based on wind speed and direction during the conditions experienced during odour events; (iii) the probability of detecting parameter concentrations in the highest 10% of measured values according to wind speed and direction; (iv) the percentage contribution of each 10° wedge of wind direction to the overall weighted average of the parameter; and (v) the time series of measured values of each parameter over the assessment period. A summary of the directionality of the peak estimated maximums, highest measured values, and contribution to the weighted average is presented in Table 7.

The 2023 analysis shows a distinct hotspot of odour index, ammonia, TRS, and VOC concentration when the wind is blowing from the direction of Rimrock (southwest-to-west) toward High River. The estimated maximum values of these parameters are particularly evident in the dataset representative of the odour events, showing that the higher concentrations of these parameters sourced from the southwest direction was more objectionable than when sourced from other areas with higher estimated values (e.g., from the northwest). However, the odour event period, which was defined by registered complaints, also shows that objectionable odours were being experienced when the wind was blowing from other directions, such as the north (as shown by ammonia) and northwest (as shown by VOCs). Further, the graphics that present the probability of detecting the peak 10% of

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[16] Trabue et al. 2011. Identifying and tracking key odorants from cattle feedlots. Atmospheric Environment, 45(25): 4243-4251.

measured concentrations tend to show that high concentrations of ammonia, TRS, and OI were sourced from areas northeast of the monitoring stations.

Table 7 Summary of the wind speed and direction associated with the peak odour index or parameter concentrations based on estimated maximum values, probability of detecting the highest 10% concentrations and direction of the highest contribution toward the weighted average concentration over the assessment period.

Year	Parameter	Directionality of maximum values estimated from wind speed and direction				Directionality of highest probability of detecting the top 10% of measured data		Directionality of the highest contribution to the overall parameter average	
		All data		Odour events					
		Wind Direction	Wind speed (m/s)	Wind Direction	Wind speed (m/s)	Wind Direction	Wind speed (m/s)	Wind Direction (general)	Wind Direction (°)
2023	Odour index	SW – W NW	1 – 4 4 – 6	SW – W	1 – 4	W – NW	1 – 6	W	250 - 260°
	NH_3	SW – W	1 – 4	SW – W	1 – 4	N	4 – 10	W	250 - 260°
	TRS	SW – W	1 - 4	SW – W	1 – 4	SW NE	0 – 4 0 – 2	W	250 - 260°
	VOC	SW – W NW	1 – 4 4 – 6	SW – W	1 – 4	W – NW	1 – 6	W	250 - 260°
2024	Odour index	SW – W E	4 – 10 1 – 4	S – SW	4 – 5	SW	5 – 10	SW	210 - 220°
	NH_3	S – SW	1 – 5	S – SW	3 – 4	SW	6 – 8	SW	210 - 220°
	H_2S	N – NE	2 – 4	SW – W	0.5 – 1.5	NW – NE	3 – 6	N W	5 - 15° 250 - 260°
	VOC	SW	8 – 10	SW – W	3 – 5	SW – W	4 – 6 8 – 10	SW	240 - 250°

The results of the 2024 air quality analysis are admittedly weaker than the 2023 assessment period owing to the intermittent deployment of the air monitoring equipment at the community-level monitoring station. Nonetheless, an equivalent analysis was performed with the intermittent 2024 data in an effort to demonstrate the consistency in the results observed in 2023. A less clear representation of the air quality information is evident, but general trends in the directionality of the odour source are consistent with the 2023 assessment. However, three major departures from the 2023 assessment period are observed: (i) a substantively greater amount of ammonia is sourced from a more southerly direction, as evidenced in both the full data set and the odour events; (ii) a substantively greater amount of hydrogen sulphide (H_2S) is present from winds blowing from the north; and, (iii) substantively fewer VOCs are sourced from the northwest direction than the 2023 assessment period. Combined, these results are manifest in the differences exhibited in the odour index values between assessment periods. Regardless of these differences, the findings of the 2024 assessment period are consistent with the major findings of the 2023 assessment period, wherein a significant concentration of odorous compounds is evidently coming from westerly directions, likely sourced from livestock operations, and substantive concentrations of odorous compounds, particularly sulphur-based compounds, appear to be sourced from north of the community.

Taken together, these results illustrate three things: (i) complaints voiced by the community tend to correlate temporally with increasing concentrations of odorous compounds; (ii) the estimated maximum concentrations of odorous compounds and odour index values tend to occur when winds are blowing from the southwest (i.e., direction of Rimrock Feeders to the community); (iii) other sources exist on the landscape that appear to be contributing to peak odorous compound concentrations, particularly from areas north-to-northeast of the community.

It should be noted, however, that the peak concentrations modelled in this analysis tend to be low-to-middling. For instance, estimated peak concentrations of ammonia were modelled as ~120 ppb in 2023 and <600 ppb in 2024, whereas the AAQO for ammonia is 2,000 ppb. Further, the estimated peak concentration of TRS was ~1.9 ppb in 2023 (below the AAQG of 5 ppb for TRS) and the estimated peak concentration of H_2S was 0.22 ppb 2024 (below the AAQO of 10 ppb for H_2S). While these models show the directionality of the hotspots, it remains unknown how pertinent these models are to perceived odours, given that the model results are well below the published odour thresholds for these parameters. Nonetheless, these parameters are being used as indicator parameters of odour that may be derived from regional sources and are not necessarily intended to assess the magnitude of all odorous compounds in the area. The directionality of the odorous compounds identified in this analysis is useful for targeting odour sources.

Passive ammonia samplers

Passive samplers were used to assess the spatial scale of odour-associated compounds in the region of High River. Passive samplers are small, simple devices that do not require power and work by collecting pollutants that deposit on the sampler over time. They provide a time-integrated average concentration of the target indicator. Because they integrate time periods occurring over hundreds of hours, the results cannot readily be integrated with wind profiles to estimate the likely sources. However, their simplicity allows for them to be applied at large spatial scales to assess multiple locations at the same time to get a regional picture of pollutant concentrations.

In this study, passive ammonia samplers were used because ammonia was found to be highly correlated with odour index values and indicative of potential odour sources in a preliminary evaluation of the continuous monitoring data. Passive ammonia samplers were obtained from Bureau Veritas analytical laboratory in Edmonton, Alberta, and were deployed following the laboratory's SOPs at the dates and locations detailed in Table 8. The samplers were deployed at approximately 1.2 – 1.5 m aboveground, affixed to a fencepost, chain link fence, or other structure. The two samplers deployed in the townsite were placed on top of the CRAZ PAML (NR#8) and on the fence line of the town water reservoir (NR#9).

During the deployment period, the majority of wind was blowing from the SW – NW; approximately 33% of the wind came from directions of 230° - 310°. The highest average ammonia concentrations (50 – 75 ppb) during the deployment period occurred when the winds were from the SW to N (230° - 20°). However, the greatest contribution toward the total, weighted average ammonia during the deployment event was from winds blowing from the W (250 – 270°). Further detail on the wind profile and directionality of ammonia concentrations are presented in Figure A-22 of Appendix A.

Over the course of the deployment, one of the samplers (NR#5) was broken by cattle grazing in the field along the fence line. The sampler was collected and analyzed, regardless. However, a rain event was experienced a few days before sample collection, and it is likely that the sampler was exposed to precipitation and the ammonia was washed out. All other samples were successfully deployed.

Table 8 Deployment details for the passive ammonia samplers used in the study. Two of the 14 samplers were used for quality assurance/quality control (QA/QC).

Sampler ID	Latitude	Longitude	Installation date	Retrieval date	Hours Deployed	Target (Direction to HR)	Ammonia concentration (ppb)
NR #1	50.4845	-114.1787	July 19, 2023	Aug. 2, 2023	335.9	Background (SW)	1.6
NR #2	50.5332	-114.0706			335.8	Small CFO (SW)	4.3
NR #3	50.6690	-114.1400			335.8	Background (NW)	4.0
NR #4	50.6014	-114.0477			335.9	Large CFO (W)	41.1
NR #5	50.5767	-113.9609			335.9	Target CFO (W)	<0.1*
NR #6	50.6304	-113.9723			335.9	Landfill (NW)	4.6
NR #7	50.6162	-113.8818			333.0	Industrial (N)	3.9
NR #8	50.5919	-113.9016			334.8	Town – spray park	11.4
NR #9	50.5821	-113.8748			337.4	Town – downtown	6.6
NR #10	50.5431	-113.8794			332.8	Background (S)	3.5
NR #11	50.5574	-113.7601			335.7	Background (SE)	2.6
NR #12	50.6170	-113.7601			335.5	Background (NE)	2.7
NR #13	QAQC – Duplicate, deployed with NR#4						45.9
NR #14	QAQC – Trip blank						<0.1

A spatial graphic of the measured concentrations of ammonia is presented in Figure 2. Concentrations of ammonia between the sample locations was interpolated through an inverse-distance weighting procedure in a geospatial program (QGIS, v. 3.26.3). The loss of ammonia concentration information from the location of the compromised sampler (NR#5) is evident in the graphic. The lost sampler was expected to have high concentrations of ammonia; it is reasonable to assume that the concentrations from this sampler would have been similar to NR#4, which was placed adjacent to other CFOs northwest of this sampler and Rimrock. Nonetheless, it is still evident that the highest concentrations of ammonia are within the proximity of confined feeding operations, and that the second and third highest concentrations observed are within the Town of High River. It stands to reason that the area of the livestock operations is associated with substantially greater ammonia deposition, and that ammonia deposited in High River was likely carried by the prevailing winds from this area.

Although a time-integrated, spatial correlation between ammonia deposition adjacent to CFOs and within High River is apparent in these results, this method is not directly interpretable toward the frequency, intensity, duration, or offensiveness of odours in High River. However, this information confirmed that the majority source of ammonia in the area is from livestock operations, rather than other potential sources in the region. The NRCB used these results to inform the scope of the site-specific assessments, which are not included in this assessment report.

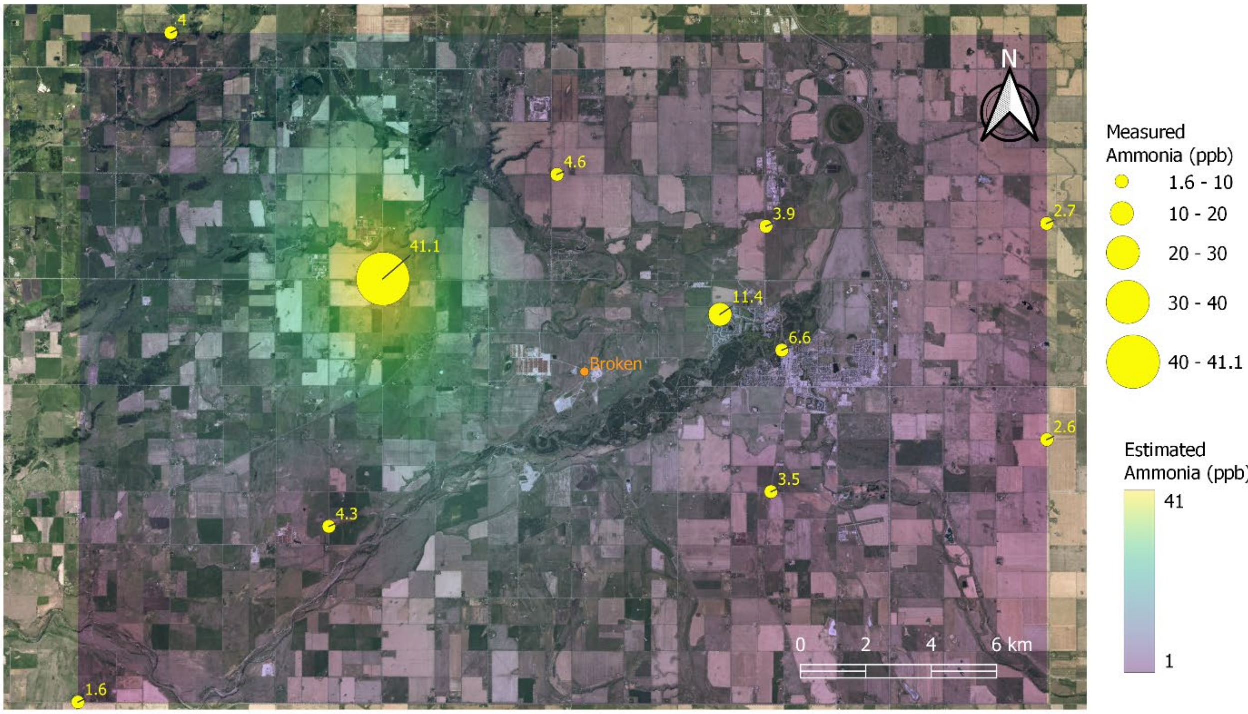

Figure 2 Spatial representation of the measured (yellow circles) and inverse-distanced weighted estimates (gradient) concentrations of ammonia. The location of the broken passive sampler is identified with an orange circle.

Odour source profiling

A total of 10 grab samples were collected for odour profile analysis. The location identifier, intent of the sample, target location, and date of collection for each sample is detailed in Table 9. The collected grab samples were submitted to InnoTech Alberta laboratory in Vegreville, AB for analysis. The odour profiling suite used by InnoTech consists of 102 volatile organic compounds (VOC) and 19 reduced sulphur compounds (RSC); the analytes measured by InnoTech are presented in Table A-3 of Appendix A. In total, 51 unique compounds were detected among the samples collected in the High River area: 5 RSCs and 46 VOCs. The total number of each class of compound detected in each sample is summarized in Table 9. The specific compounds and measured concentrations of each compound for each sample are presented in Table A-4 of Appendix A.

The wind profiles for the day of sampling and time of sampling are presented in Figures A-18 and A-19 of Appendix A. On April 13, 2024, the wind was predominantly blowing from the west to northwest; approximately 35% of the wind was from the southwest (210° – 270°) and 32% was from the NW (270° – 330°) with a daily average of 2.0 m/s. At the time of sampling, 88% of the wind was from a westerly direction (250° – 310°) with an average speed of 2.5 m/s. On April 24, 2024, the majority of the wind was blowing from a westerly direction, where 68% of the wind was blowing from the SW – W directions (210° – 290°), with a daily average wind speed of 2.7 m/s. At the time of sampling, 100% of the wind was blowing from a SW-W direction (230° – 290°) with an average of 3.4 m/s.

The similarity of the odour profiles was estimated using multivariate statistical techniques. In brief, the chemical concentration data for each sample was standardized using the Hellinger transformation and the profiles were then compared using hierarchical cluster analysis (Figure 3 and Figure A-20) and principal components analysis (Figure A-21). The Hellinger transformation was chosen for the multivariate analysis because it is resilient against high-magnitude concentrations found in source samples compared against more dilute samples in community samples, is not overly distorted by the absence of parameters that may occur in some samples compared with others, and enables a linear comparison of parameter concentrations between samples.

Table 9 Summary of sample locations, target odours, date and time of sample collection, and number of compounds detected.

Sample Code	Location	Target odour	Date of sampling	Sample duration	No. VOC detected	No. RSC detected
Upwind	Rural upwind	Background	Feb. 29, 2024	11:57 – 12:23	12	
FL1-Pens-1	Feedlot 1	Pens	Feb. 29, 2024	11:18 – 11:44	18	1
FL1-Pens-2	Feedlot 1	Pens	June 7, 2024	14:36 – 14:55	22	3
FL1-Manure	Feedlot 1	Manure pile	Feb. 29, 2024	11:41 – 12:08	21	2
FL2-Pens	Feedlot 2	Pens	Feb. 29, 2024	13:06 – 13:32	13	1
FL2-Compost	Feedlot 2	Compost pile	Feb. 29, 2024	13:00 – 13:26	13	
Lift station 1	High River lift station	Municipal wastewater	Feb. 28, 2024	14:25 – 14:52	19	5
Lift station 2	High River lift station	Municipal wastewater	June 7, 2024	11:44 – 12:11	23	1
Community 1	64 St./Longview Trail		April 13, 2024	20:45 – 21:11	31	
Community 2	Riverside Green NW		April 24, 2024	20:37 – 21:10	10	2

The results of the hierarchical cluster analysis are shown in Figure 3. The Hellinger distance is a dissimilarity metric, so values of 0 are perfectly similar and values of 1 are perfectly dissimilar (i.e., not at all similar). The results show two primary clusters of odour profiles, which are driven by perfect dissimilarity: one cluster includes one of the lift station samples and one of the feedlot pen samples, both of which are sources where duplicate samples were collected. The other cluster contains all of the other odour profiles.

The two main clusters can be further separated into two clusters each, for a total of four clusters. The one cluster partitions the first lift station (Lift station 1) sample and the second sample collected from Feedlot #1 pens (FL1-pens 2); these odour profiles have a dissimilarity of over 80% (i.e., are less than 20% similar). The other cluster partitions at about 60% dissimilarity (~40% similarity) into samples collected from pens of two different feedlots (FL1-pens 1, FL2-pens) and a manure pile of Feedlot #1 (FL1-manure). The other cluster contains samples collected from a compost pile of Feedlot #2 (FL2-pens) and the second lift station sample (Lift station 2). The community samples appear within these clusters. The first community sample (Community 1) is most similar to the odour profiles representing the feedlot samples, whereas the second community sample (Community 2) is most similar to the cluster with the lift station and compost pile.

The highest similarity in odour profiles was observed in the pens of the two separate feedlots collected on the same day (FL2 pens and FL1 pens-1), with a dissimilarity of approximately 17% (~83% similar). The community sample (Community 2), while clustering with these odour profiles, was approximately 50% dissimilar (~50% similar) to the feedlot profiles. The second community sample (Community 1) exhibits approximately 40% dissimilarity (~60% similar) to the second lift station sample (Lift Station 2), and approximately 60% dissimilarity (~40% similar) to the cluster containing the feedlot samples.

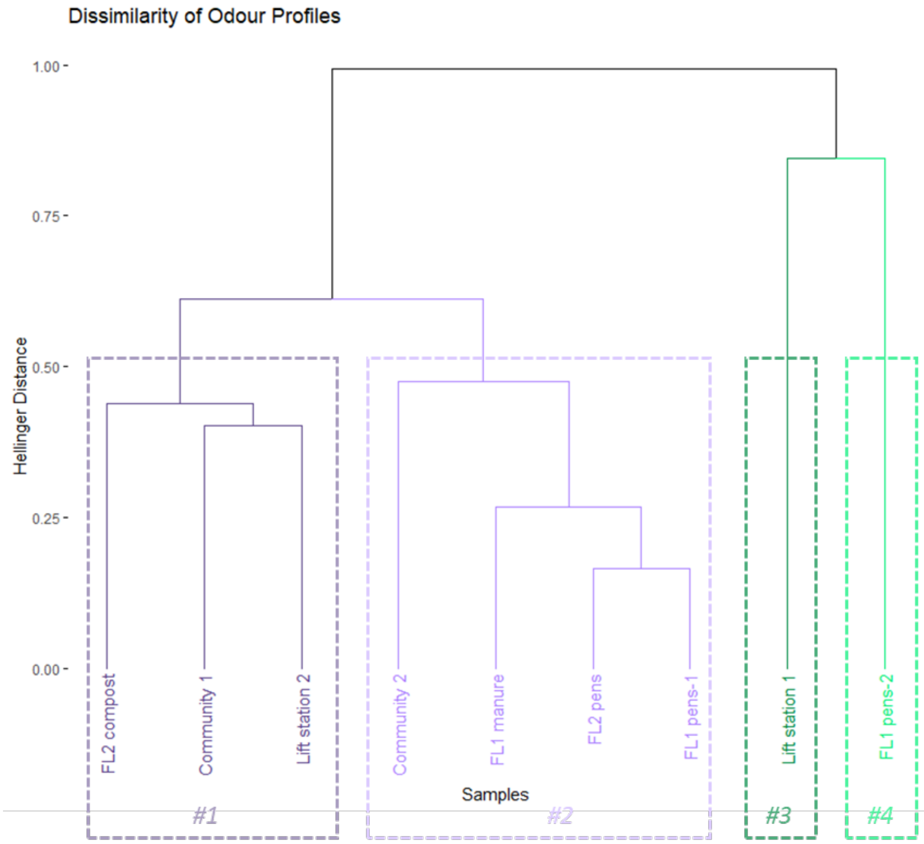

Figure 3 Hierarchical cluster analysis of odour profile samples collected in the High River region.

The influence of the various chemical compounds on the Hellinger distance between the odour profiles samples is projected in Figure A-21 in Appendix A. The cluster with the first community sample (Community 1) and the lift station (Lift station 2) appear to be influenced strongly by organic compounds associated with petroleum hydrocarbons (e.g., octane, hexane, xylene). The first lift station sample (Lift station 1), and to a limited extent the second Feedlot #1 sample (FL1-pens 2), are influenced by reduced sulphur compounds; the first lift station is strongly influenced by these compounds. The second community sample (Community 2) and the two feedlot pen profiles appear to cluster mostly due to their lack of influence by petroleum hydrocarbons or reduced sulphur compounds; however, they are influenced to a limited extent by products of manure digestion, such as alcohols and ketones.

Important limitations on the results

Taken together, these results demonstrate that the community odours are affected to a certain extent by both livestock odours as well as municipal and/or industrially generated odours. However, the results from this study should be treated with caution. The ability to link the odour samples are limited by the analytical suite that is used by the contracted laboratory, where most of the chemical parameters that are analyzed for are targeted toward industrial operations, combustion sources, and high-intensity effluent sources (e.g., wastewater treatment plants). The laboratory does not analyze for many of the compounds that would be more prevalent in manure sources, likely as an artefact of the typical application of these methods for municipal or industrial odour assessments. Further, the odour source profiles show highly divergent results when collected from the same sources. Such high variability in source odour profiles requires that several replicate samples of each odour source be collected to build a source sample library that captures the variability in source profiles, which was not conducted here.

Consequently, the weight of this evidence is limited given the high degree of variability observed in the duplicate source profiles, and the relatively low similarity observed between the community samples and the odour source profiles. The utility of this technique holds promise, but significant sampling and analytical effort would be required to produce results that can provide definitive results of the impact of specific odour sources on the community.

Conclusions

The purpose of the 2023 and 2024 community-level monitoring investigation was to identify the likely source(s) and temporal and spatial variation of odorous compounds in High River and surrounding areas. The intent of collecting this information was to inform site-specific odour evaluations that would be used to define what, if any, management actions could be applied to mitigate odours sourced from livestock operations. The NRCB will continue to provide community-level monitoring in the High River region to measure odorous compounds in the community.

The following can be concluded from this study:

1. Odour complaints are consistently registered by the NRCB, likely demonstrating an ongoing effect of odour on the community of High River.
2. The evidence does not support that the compounds measured exist at concentrations that are likely to have deleterious impacts to physical health, aside from the few instances of particulate matter exceedances that were associated with wildfire smoke events.
3. Odorous compounds appear to be strongly linked to sources that occur in southwesterly direction of High River; predominantly in the direction of Rimrock.
4. Other sources exist in the region and appear to emit odorous compounds at concentrations that equal or exceed those sourced from the direction of Rimrock; however, the frequency of odour events associated with these sources is lower owing to the prevailing wind directions.
5. Distributed, intermittent sources of odour are evident in the data collected, wherein high parameter values were sourced from the NW direction in 2023 and southerly direction in 2024. It is possible that these sources are linked to manure spreading events, or other practices that lead to intermittent, non-stationary odour emission.

The NRCB has acted on a preliminary assessment of these results to inform its approach toward investigation and compliance procedures that have occurred throughout 2024. The site-specific assessments are ongoing, and the results will be reported separately. The results from that concurrent phase of investigation are intended to establish a site-specific baseline and measure the efficacy of management practices targeted toward odour mitigation. Community-level monitoring will continue at High River in an effort to validate the effect of management practices on reducing the concentration of odorous compounds being detected at the community.

Appendix A

Tables

Figures

Table A-10 Summary of total reduced sulphur (TRS) measured in High River between February 1 and October 31, 2023 that exceeded Alberta AAQG odour management guidelines (2024) of 30-min average of TRS ≤ 5 ppb(v). Exceedances occurring when wind was from the direction of Rimrock Feeders are highlighted.

Date of TRS guideline exceedances	Time range of exceedance	No. exceedances	Avg. TRS	Wind speed	Wind direction	Complaints*	
	(24:00)		(ppb)	(m/s)	(°)	± 3 hr	Total of day
February 25, 2023	23:00	1	5.1	1.4	349	0	0
April 30, 2023	6:00	1	5.0	1.2	***246***	0	0
May 11, 2023	0:00 - 1:30	3	5.9	1.6	***253***	4	10
May 13, 2023	4:00 - 5:30	3	7.7	1.5	***248***	6	8
May 15, 2023	23:30	1	5.3	2.0	***248***	17	3
May 16, 2023	0:00	1	7.3	1.9	***252***	16	28
June 10, 2023	6:00	1	6.0	0.8	39	0	1
June 22, 2023	21:00	1	6.1	0.1	***274***	8	5
July 18, 2023	20:00 - 20:30	2	4.9	1.0	4	9	10
July 24, 2023	3:30 - 5:00	4	7.0	0.4	20	0	0
July 30, 2023	6:30 - 7:00	2	11.1	0.3	356	2	3
August 10, 2023	6:30	1	6.1	0.1	94	1	3
August 11, 2023	7:00 - 7:30	2	8.5	0.5	35	5	15
August 30, 2023	1:00	1	7.0	0.7	323	5	11
September 3, 2023	4:30	1	6.2	0.6	180	3	10
September 23, 2023	3:30 - 4:30	3	7.7	0.3	25	1	3
October 5, 2023	18:00 - 18:30	2	8.7	1.5	78	1	4
October 15, 2023	18:30 - 19:30	2	7.5	2.1	***288***	60	69
October 16, 2023	3:00 - 4:30	3	5.8	0.3	51	6	26
October 19, 2023	3:00	1	5.2	1.5	***279***	3	33
October 20, 2023	10:00	1	5.3	2.1	85	1	3
Total		**37**				**148**	**245**

*Complaints are calculated as the sum of complaints recorded 3-hours preceding and following a TRS guideline exceedance (± 3 hr) and the total complaints recorded on the calendar day of the guideline exceedance (Total of day).

Table A-11 Summary of Alberta Ambient Air Quality Objective (AAQO) exceedances for particulate matter ($PM_{2.5}$) and total suspended particulate (TSP) in High River compared against nearby monitoring stations in Calgary-Southeast and Airdrie. Guideline exceedances are indicated by red, bold numbers.

Assessment Year	Date	NRCB*		CRAZ**			
		HR-CTair	HR-CTair	High River - Spray Park	Calgary SE	Airdrie	
		TSP	$PM_{2.5}$	$PM_{2.5}$	$PM_{2.5}$	$PM_{2.5}$	
		100	**29**	**29**	**29**	**29**	AAQO (µg/m^3)
2023	May 16, 2023			**113**	**185**	**126**	
	May 17, 2023			**129**	**201**	**128**	
	May 18, 2023			**53**	**64**	**31**	
	May 19, 2023			**39**	**29**	**48**	
	May 20, 2023			**79**	**149**	**192**	
	May 21, 2023			17	**51**	**81**	
	May 22, 2023			**34**	**51**	**52**	
	June 11, 2023			**42**	**53**	**40**	
	June 12, 2023			12	21	17	
	June 13, 2023			22	17	18	
	June 14, 2023			6	11	18	
	June 15, 2023			**49**	**88**	**63**	
	June 16, 2023			**61**	**37**	21	
	July 13, 2023			**46**	**83**	**64**	
	July 14, 2023			**43**	**60**	**46**	
	July 15, 2023			**45**	**59**	**41**	
	July 16, 2023			**40**	**62**	**44**	
	August 17, 2023			**43**	**61**	**35**	
	August 31, 2023			**32**	**39**	**29**	
	September 3, 2023			**29**	**49**	**61**	
	September 4, 2023			**81**	**139**	**94**	
	September 5, 2023			**49**	**73**	**47**	
2024	July 18, 2024	54	**29**		15	16	
	July 19, 2024	61	**36**		21	15	
	July 20, 2024	66	**40**		18	17	
	July 21, 2024	68	**42**		19	13	
	July 22, 2024	**129**	**94**		**36**	**33**	
	July 23, 2024	**195**	**148**		**50**	**38**	
	July 24, 2024	**157**	**117**		**122**	**41**	
	July 25, 2024	**184**	**136**		**50**	26	

* NRCB monitoring data was collected with particle analyzers in the CTair unit. This analyzer has not been assessed against the criteria described in the Alberta Air Monitoring Directive (2016) [17].

** CRAZ monitoring data was collected with equipment and procedures that meet the Alberta Air Monitoring Directive (2016), and are considered most accurate and representative of ambient air quality conditions.

[17] Alberta ambient air quality objectives and guidelines 2024. Government of Alberta, Edmonton, AB.

Table A-12 List of analytes and their detection limits for the odour source profiling work. Analyses were completed by InnoTech Alberta (Vegreville).

Volatile organic compounds (VOC)		Reduced sulphur compounds (RSC)
1,1,1-Trichloroethane	Freon-11	2,5-Dimethylthiophene
1,1,2,2-Tetrachloroethane	Freon-113	2-Ethylthiophene
1,1,2-Trichloroethane	Freon-114	2-Methylthiophene
1,1-Dichloroethane	Freon-12	3-Methylthiophene
1,1-Dichloroethylene	Hexachloro-1,3-butadiene	Butyl mercaptan
1,2,3-Trimethylbenzene	Isobutane	Carbon disulphide
1,2,4-Trichlorobenzene	Isopentane	Carbonyl sulphide
1,2,4-Trimethylbenzene	Isoprene	Dimethyl disulphide
1,2-Dibromoethane	Isopropyl alcohol	Dimethyl sulphide
1,2-Dichlorobenzene	Isopropylbenzene	Ethyl mercaptan
1,2-Dichloroethane	m,p-Xylene	Ethyl sulphide
1,2-Dichloropropane	m-Diethylbenzene	Hydrogen sulphide
1,3,5-Trimethylbenzene	m-Ethyltoluene	Isobutyl mercaptan
1,3-Butadiene	Methyl butyl ketone	Isopropyl mercaptan
1,3-Dichlorobenzene	Methyl ethyl ketone	Methyl mercaptan
1,4-Dichlorobenzene	Methyl isobutyl ketone	Pentyl mercaptan
1,4-Dioxane	Methyl methacrylate	Propyl mercaptan
1-Butene/Isobutylene	Methyl tert butyl ether	tert-Butyl mercaptan
1-Hexene/2-Methyl-1-pentene	Methylcyclohexane	Thiophene
1-Pentene	Methylcyclopentane	
2,2,4-Trimethylpentane	Methylene chloride	
2,2-Dimethylbutane	n-Butane	
2,3,4-Trimethylpentane	n-Decane	
2,3-Dimethylbutane	n-Dodecane	
2,3-Dimethylpentane	n-Heptane	
2,4-Dimethylpentane	n-Hexane	
2-Methylheptane	n-Nonane	
2-Methylhexane	n-Octane	
2-Methylpentane	n-Pentane	
3-Methylheptane	n-Propylbenzene	
3-Methylhexane	n-Undecane	
3-Methylpentane	Naphthalene	
Acetone	o-Ethyltoluene	
Acrolein	o-Xylene	
Benzene	p-Diethylbenzene	
Benzyl chloride	p-Ethyltoluene	
Bromodichloromethane	Styrene	
Bromoform	Tetrachloroethylene	
Bromomethane	Tetrahydrofuran	
Carbon disulfide	Toluene	
Carbon tetrachloride	trans-1,2-Dichloroethylene	
Chlorobenzene	trans-1,3-Dichloropropylene	
Chloroethane	trans-2-Butene	
Chloroform	trans-2-Pentene	
Chloromethane	Trichloroethylene	
cis-1,2-Dichloroethene	Vinyl acetate	
cis-1,3-Dichloropropene	Vinyl chloride	
cis-2-Butene		
cis-2-Pentene		
Cyclohexane		
Cyclopentane		
Dibromochloromethane		
Ethanol		
Ethyl acetate		
Ethylbenzene		

Table A-13 Concentrations of the volatile organic compounds (VOC) and reduced sulphur compounds (RSC) detected in the odour profile source investigation.

Class	Parameter	Upwind	Feedlot #1			Feedlot #2		Lift Station		Community	
			Pens-1	Pens-2	Manure	Pens	Compost	1	2	1	2
	1,2,4-Trimethylbenzene				0.05						
	1,3,5-Trimethylbenzene									0.08	
	1,3-Butadiene				0.06						
	1-Butene/Isobutylene				0.16						
	1-Pentene				0.06						
	2,2,4-Trimethylpentane								0.03		
	2,3-Dimethylpentane								0.03	0.04	
	2-Methylhexane		0.06							0.06	
	2-Methylpentane		0.08	0.03	0.47	0.06	0.04	0.05	0.03	0.12	
	3-Methylhexane	0.05	0.07				0.03	0.05	0.02	0.09	
	3-Methylpentane							0.03	0.05	0.19	
	Acetone	1.7	3.4	18.6	10.1	2.6	1.7	1.8	2.5	2.2	3.4
	Benzene				0.07			0.06			
	Benzyl chloride			0.4					0.4		
	Bromoform			0.05					0.06		
	Carbon tetrachloride	0.06	0.06	0.04	0.07	0.06	0.06	0.06	0.04	0.05	0.06
	Chloromethane	0.8	0.8	0.62	0.78	0.74	0.8	0.75	0.6	0.44	0.65
	Cyclohexane									0.17	
	Dibromochloromethane	0.1	0.1		0.1	0.1		0.1			
	Ethanol	0.9	36.8	18.6	75.3	25.7	2.4	7.8	18.6	37.6	17.5
	Ethylbenzene							0.05		0.15	
	Freon-11	0.26	0.27	0.22	0.26	0.25	0.27	0.26	0.21	0.21	0.22
	Freon-113	0.08	0.08		0.08	0.07	0.08	0.07			0.06
VOC	Freon-12	0.62	0.64	0.53	0.61	0.58	0.65	0.63	0.55	0.45	0.53
	Hexachloro-1,3-butadiene			0.4					0.4		
	Isobutane	0.06	0.12	0.16	0.11	0.06	0.11	0.3	0.53	0.62	0.14
	Isopentane	0.07	0.13	0.37	0.09	0.1	0.13	0.23	0.33	0.22	
	Isoprene			0.07						0.04	
	Isopropyl alcohol		0.7	0.7	0.9					0.5	
	Isopropylbenzene									0.07	
	m,p-Xylene									0.21	
	Methyl ethyl ketone			0.6	1.2						
	Methyl tert butyl ether	0.05	0.05		0.05	0.05	0.05	0.05			
	Methylcyclopentane								0.06	0.26	
	m-Ethyltoluene									0.09	
	n-Butane		0.35	0.44		0.13	0.24	0.63	0.92	0.91	0.27
	n-Heptane			0.06					0.05	0.1	
	n-Hexane			0.04					0.03	0.14	
	n-Nonane									0.12	
	n-Octane			0.04						0.14	
	n-Pentane		0.07	0.15				0.06	0.05	0.13	
	o-Ethyltoluene										0.06
	o-Xylene									0.07	
	Toluene		0.07		0.07			0.06	0.04	0.06	
	trans-1,3-Dichloropropylene			0.03					0.03		
	trans-2-Butene									0.91	
	Carbon disulphide		0.21	0.27	0.08	0.11		1.32			
	Carbonyl sulphide			1.4				5.2	1.4		1
RSC	Dimethyl disulphide				1.4			3.4			
	Hydrogen sulphide			4.7				8.4			2.4
	Methyl mercaptan							2			
Count		**12**	**19**	**24**	**22**	**14**	**13**	**24**	**24**	**31**	**12**

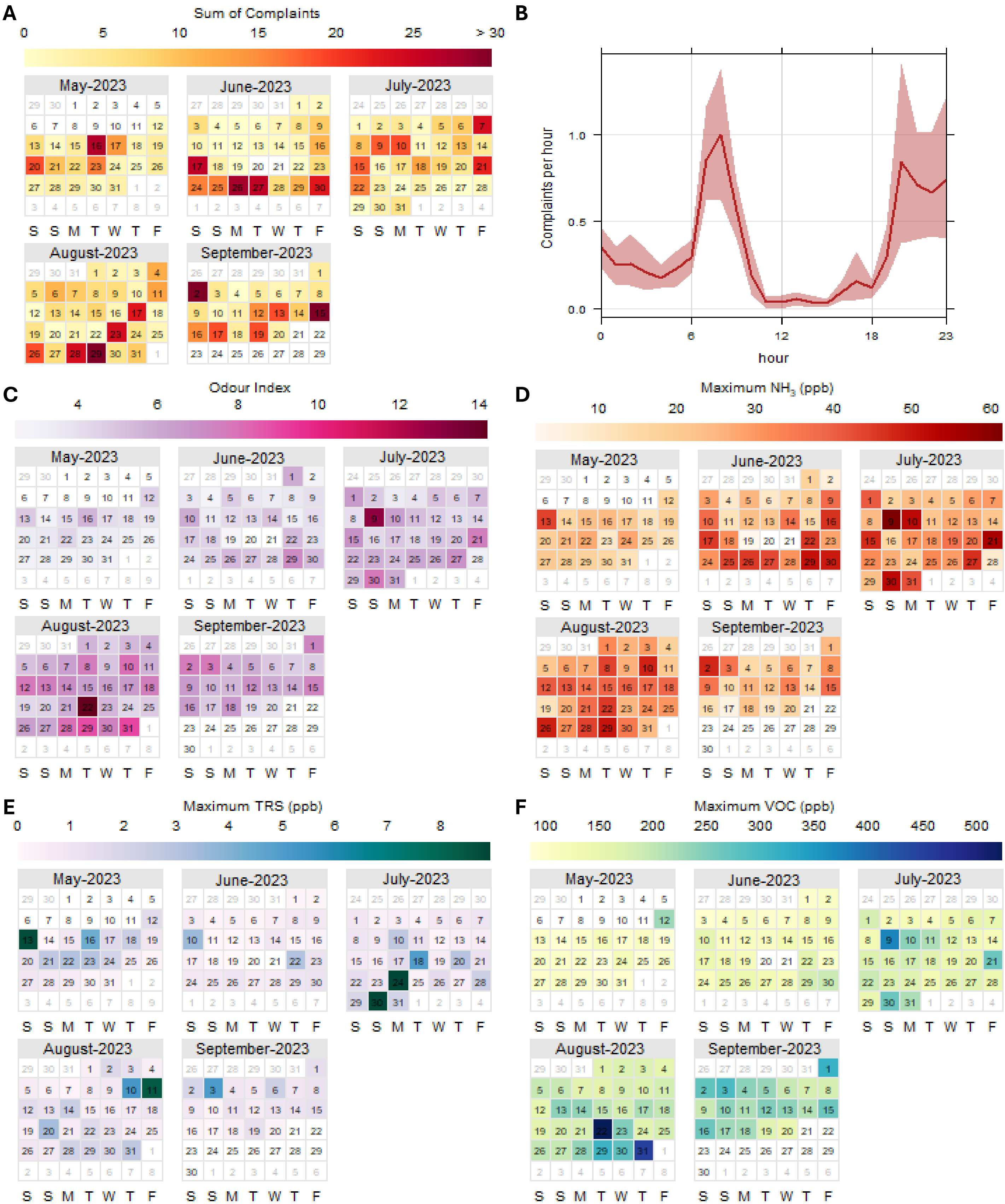

Figure A-4 Daily number of complaints (A), time of complaints (B), odour index (C), and concentrations of ammonia (NH_3) (D), total reduced sulphur (TRS) (E), and total volatile organic compounds (VOC) (F) for the 2023 community-level odour monitoring period.

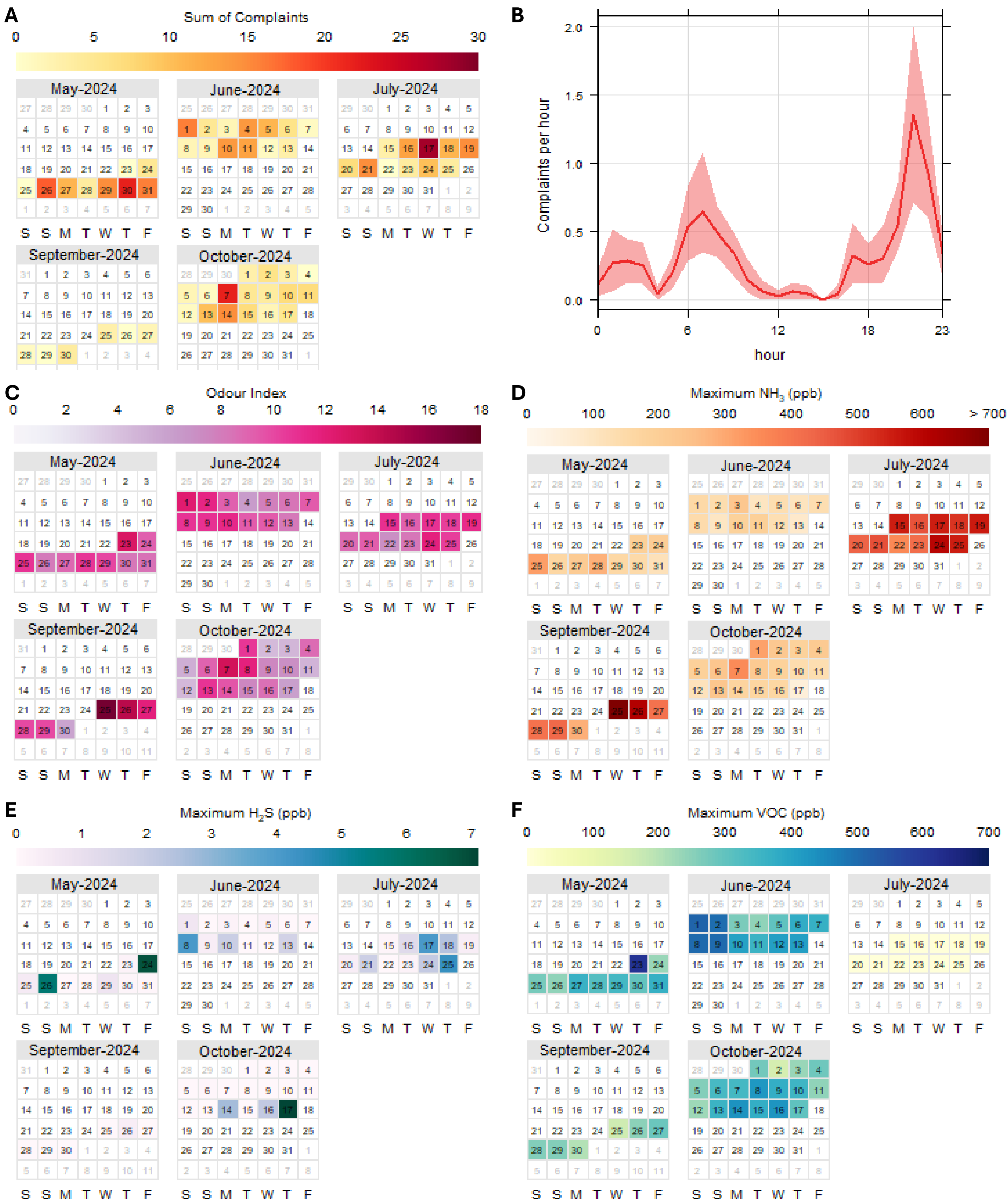

Figure A-5 Daily number of complaints (A), time of complaints (B), odour index (C), and concentrations of ammonia (NH_3) (D), hydrogen sulphide (H_2S) (E), and total volatile organic compounds (VOC) (F) for the 2024 community-level odour monitoring period.

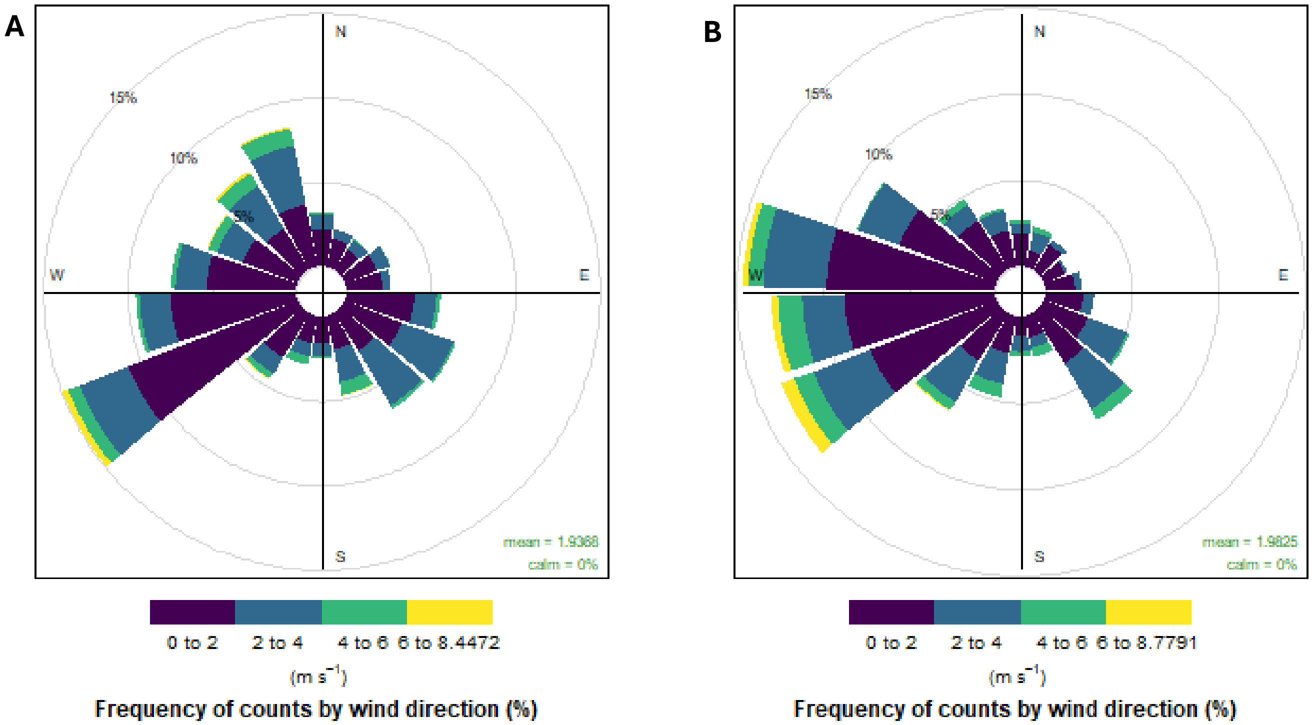

Figure A-6 Wind roses of the NRCB wind monitoring station placed west of Rimrock Ffeeders from the 2023 (A) and 2024 (B) community-level odour monitoring periods.

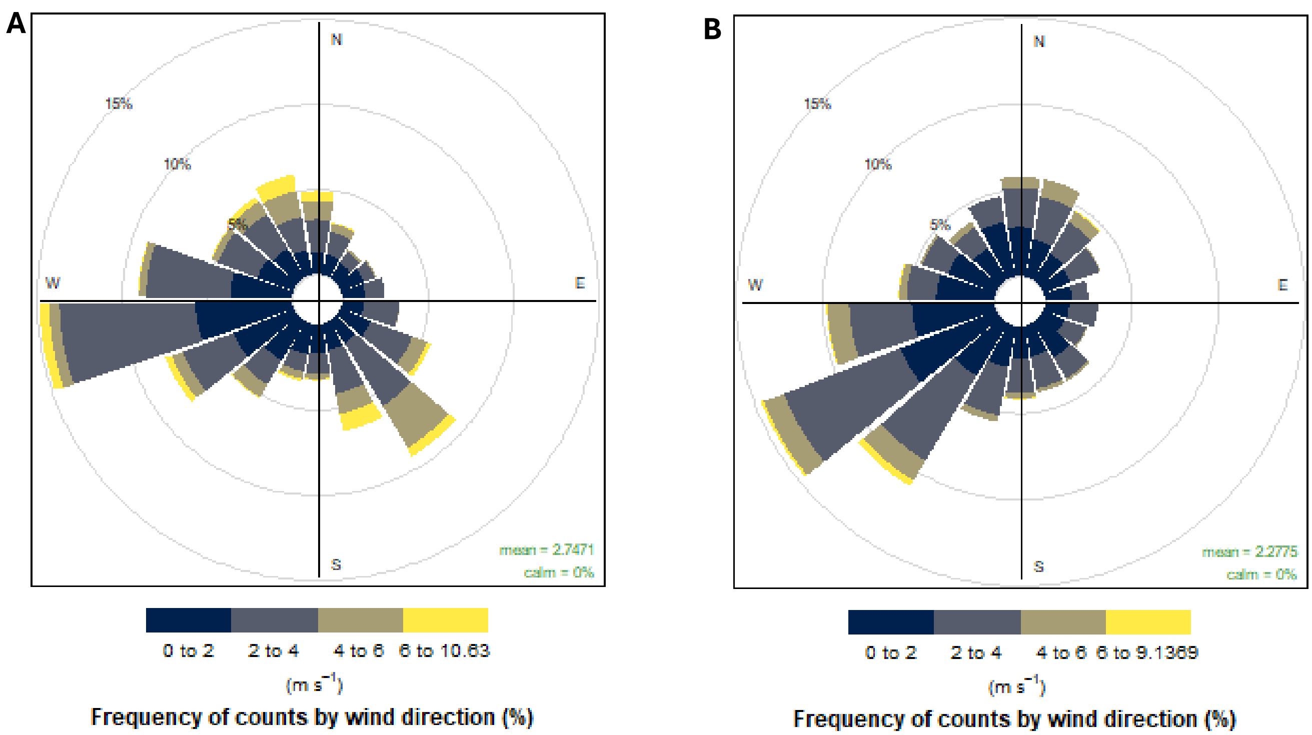

Figure A-7 Wind roses of the inverse-distance weighted wind estimates from the 2023 (A) and 2024 (B) community-level odour monitoring periods.

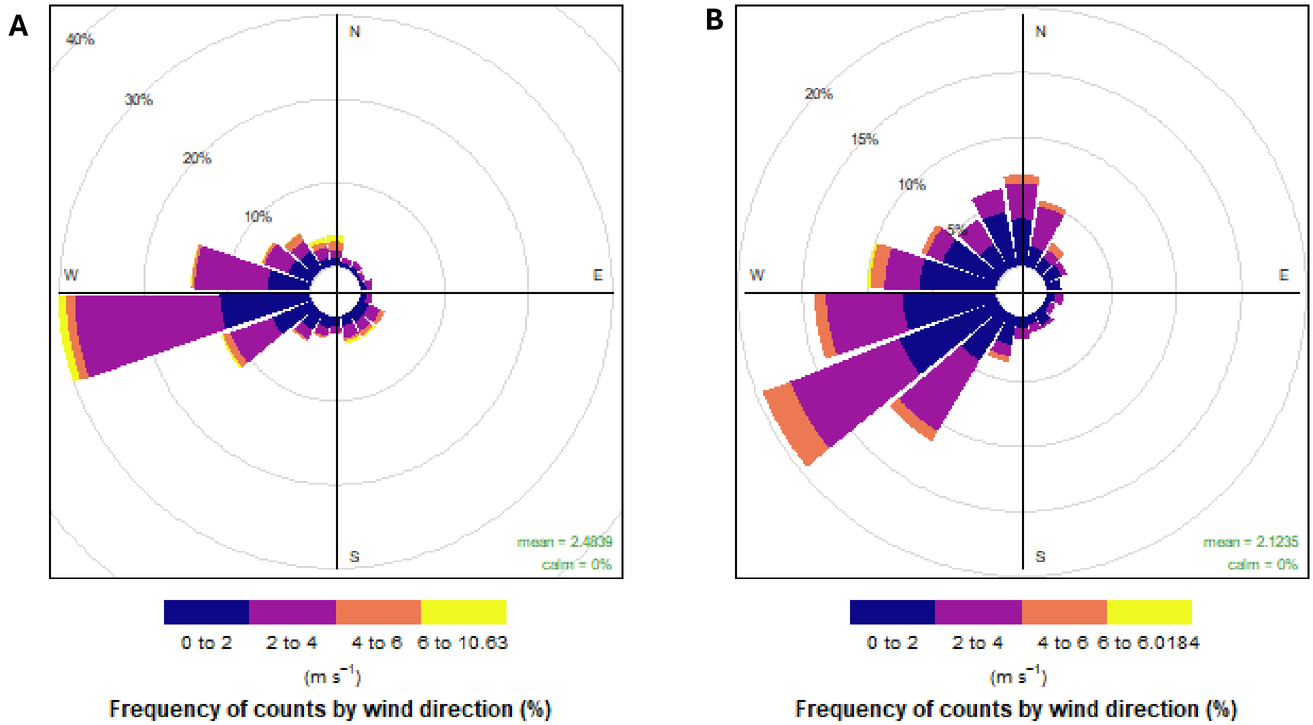

Figure A-8 Wind roses of the inverse-distance weighted wind estimates from the odour events that occurred during the 2023 (A) and 2024 (B) community-level odour monitoring periods.

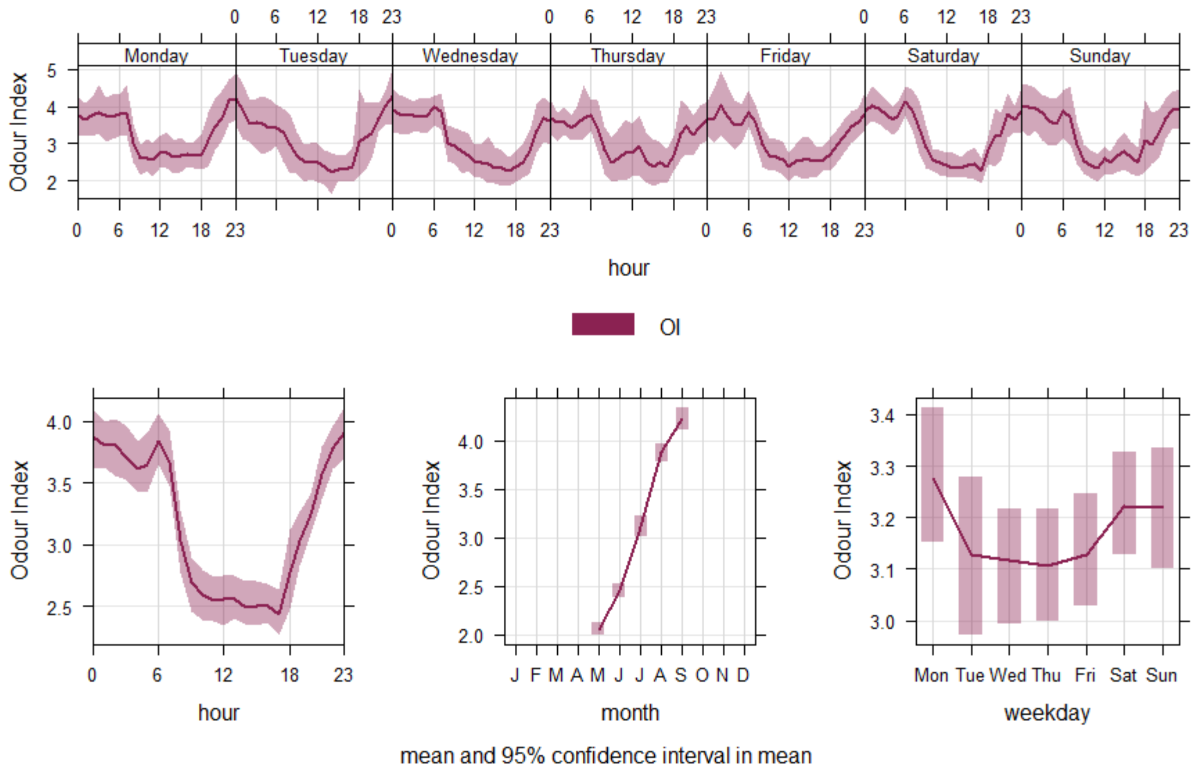

Figure A-9 Time series analysis of odour index values measured during the 2023 community-level odour monitoring period. Illustrated are the mean odour index and 95% confidence interval estimated according to the time and day of the week, hour of the day, month, and day of the week.

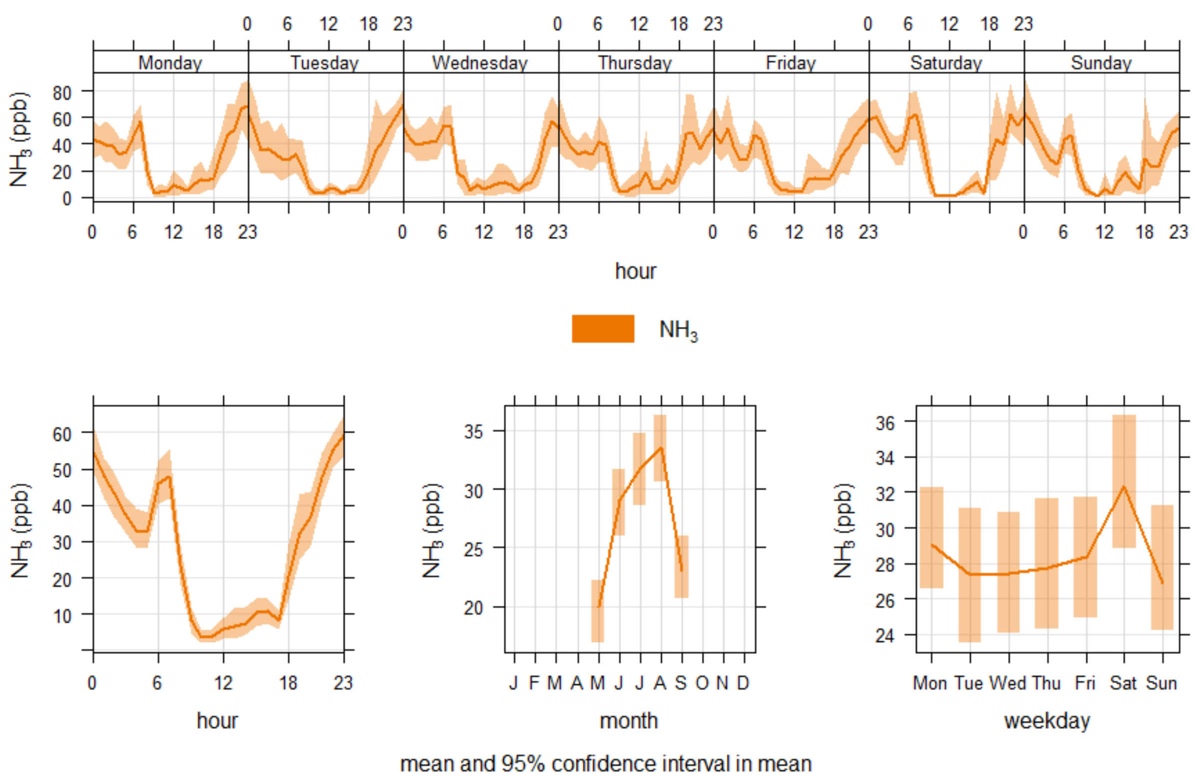

Figure A-10 Time series analysis of concentrations of ammonia (NH_3) measured during the 2023 community-level odour monitoring period. Illustrated are the mean concentrations of NH_3 and 95% confidence interval estimated according to the time and day of the week, hour of the day, month, and day of the week.

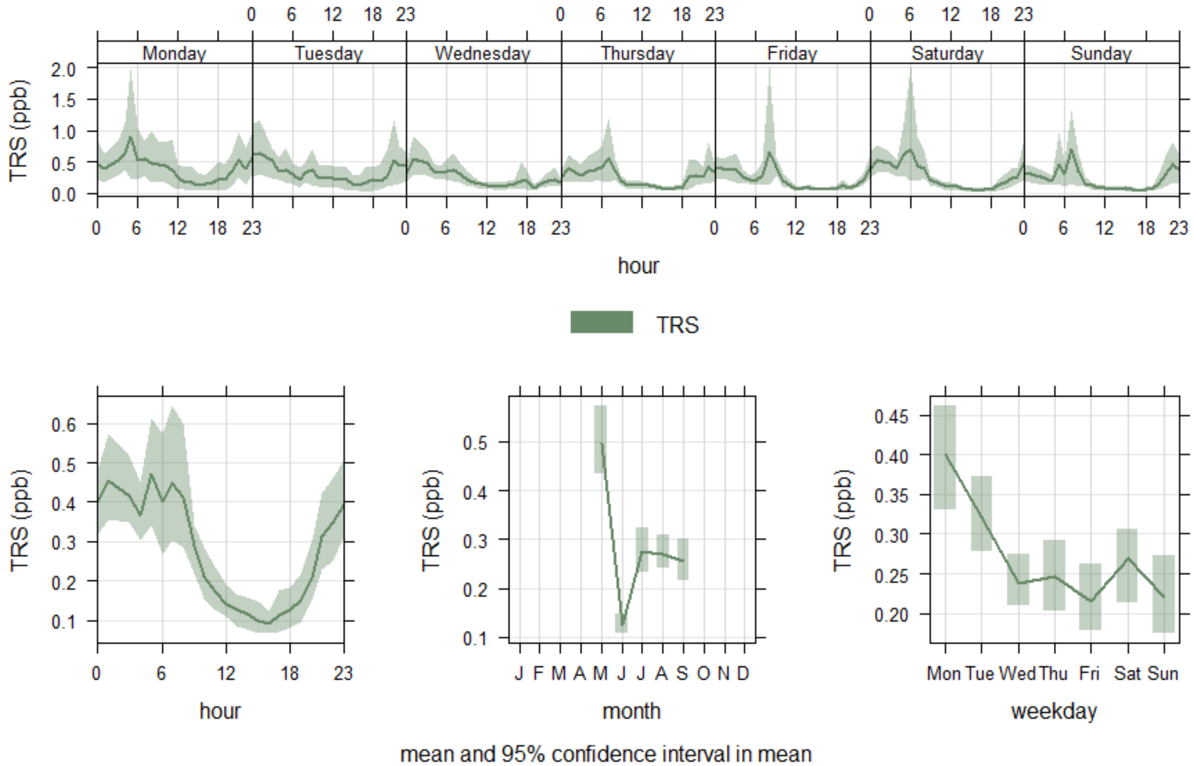

Figure A-11 Time series analysis of concentrations of total reduced sulphur (TRS) measured during the 2023 community-level odour monitoring period. Illustrated are the mean concentrations of TRS and 95% confidence interval estimated according to the time and day of the week, hour of the day, month, and day of the week.

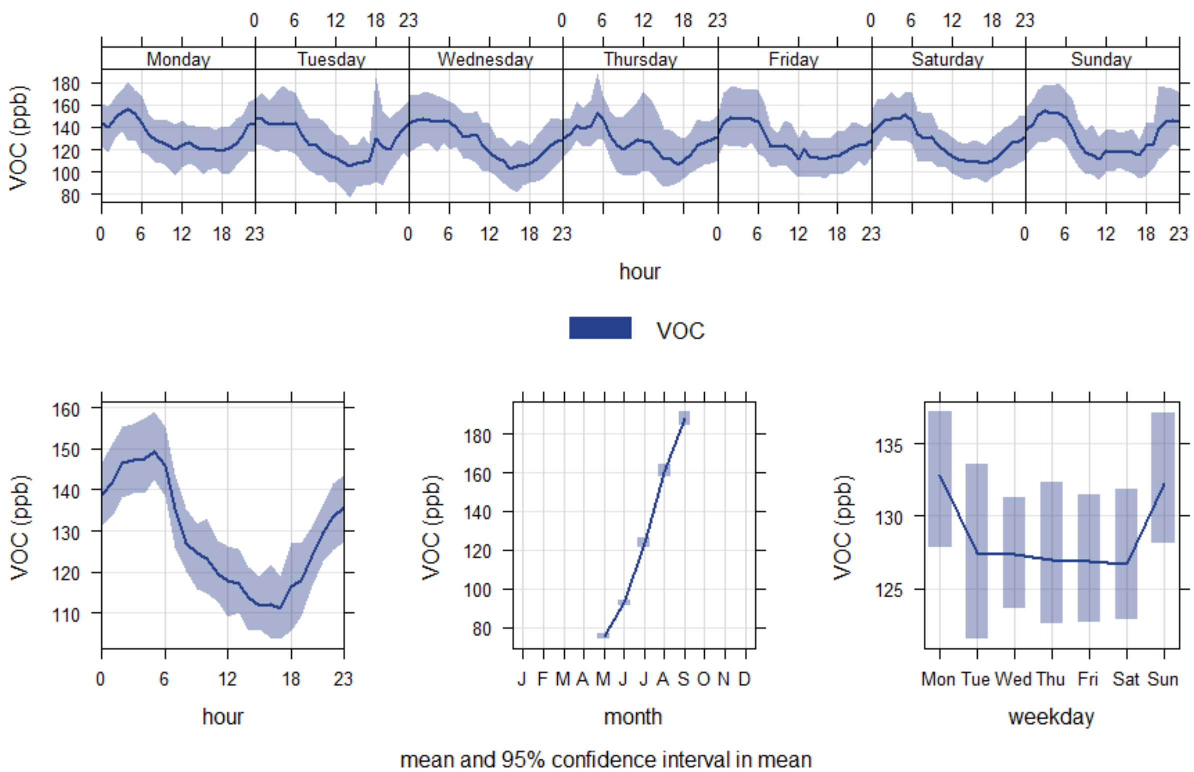

Figure A-12 Time series analysis of concentrations of total volatile organic compounds (VOC) measured during the 2023 community-level odour monitoring period. Illustrated are the mean VOC concentrations and 95% confidence interval estimated according to the time and day of the week, hour of the day, month, and day of the week.

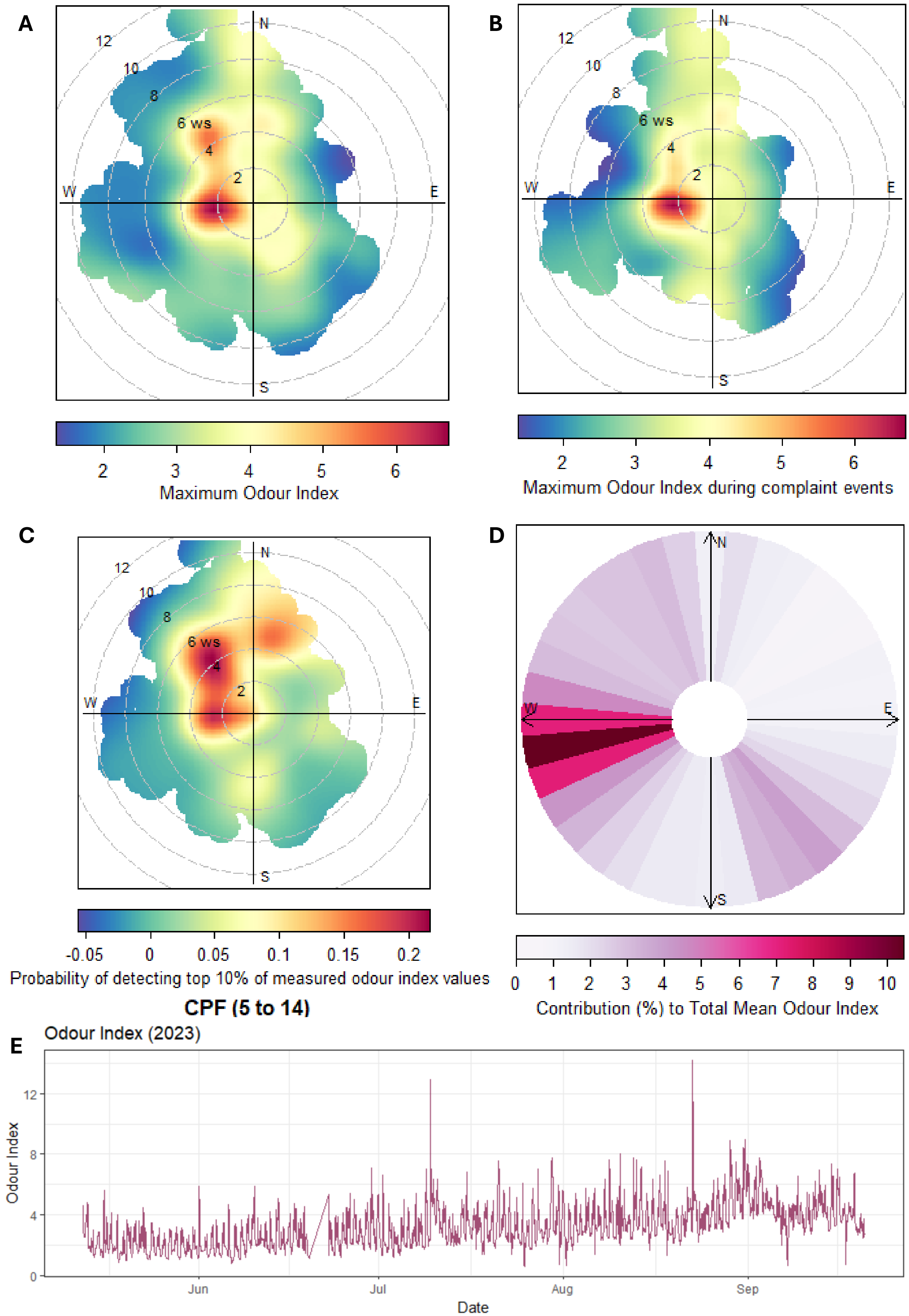

Figure A-13 Odour index values during the 2023 community-level odour monitoring period. (A) Estimated maximum odour index by wind speed and direction. (B) Estimated maximum odour index during complaint events. (C) Probability of detecting the top 10% of odour index values by wind speed and direction. (D) Contribution of odour index from each wind direction to the overall mean odour index. (E) Time series plot of measured odour index values.

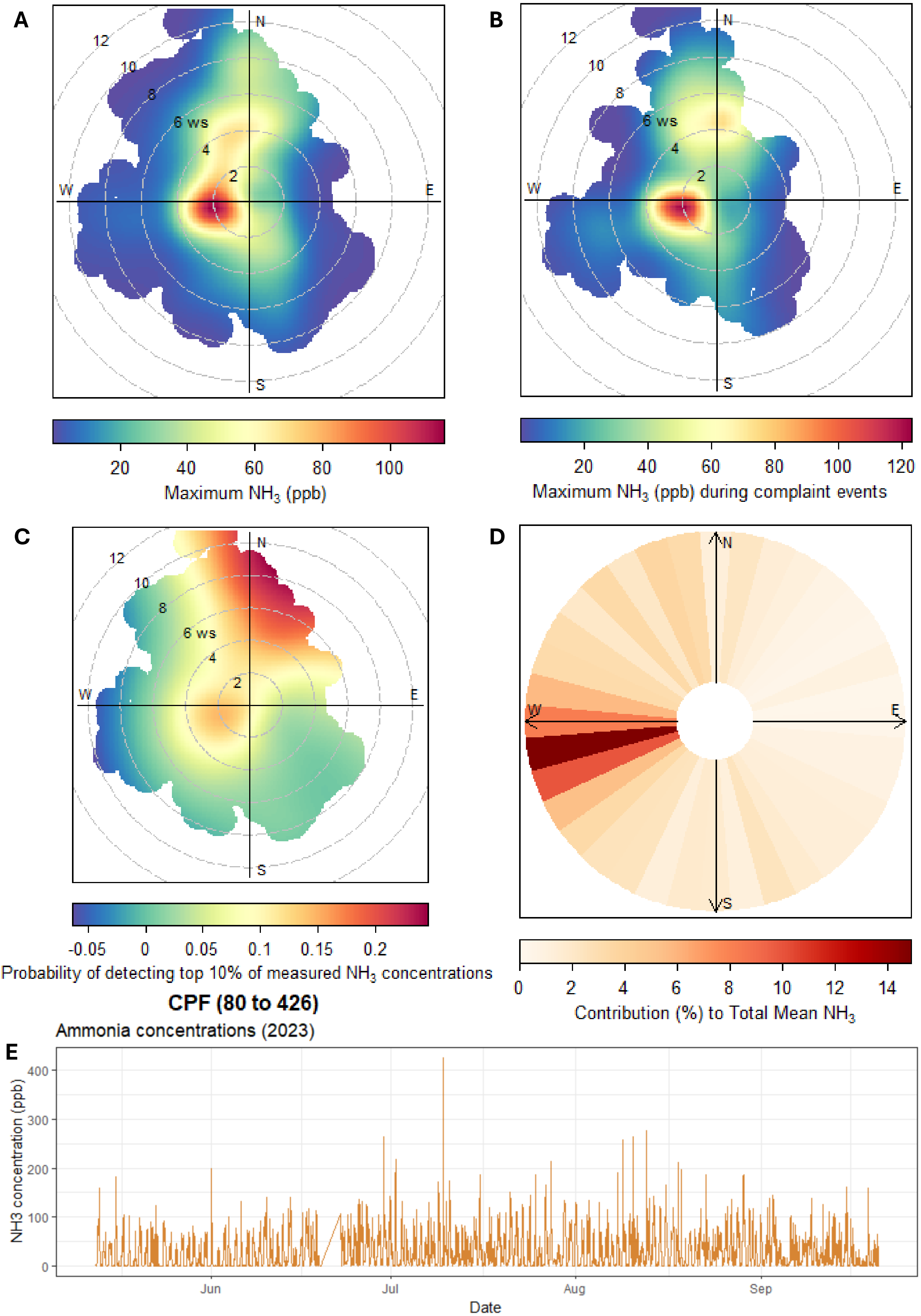

Figure A-14 Concentrations of ammonia (NH_3) during the 2023 community-level odour monitoring period. (A) Estimated maximum NH_3 by wind speed and direction. (B) Estimated maximum NH_3 during complaint events. (C) Probability of detecting the top 10% of NH_3 concentrations by wind speed and direction. (D) Contribution of each wind direction to the overall mean NH_3 concentration. (E) Time series plot of measured NH_3 concentrations.

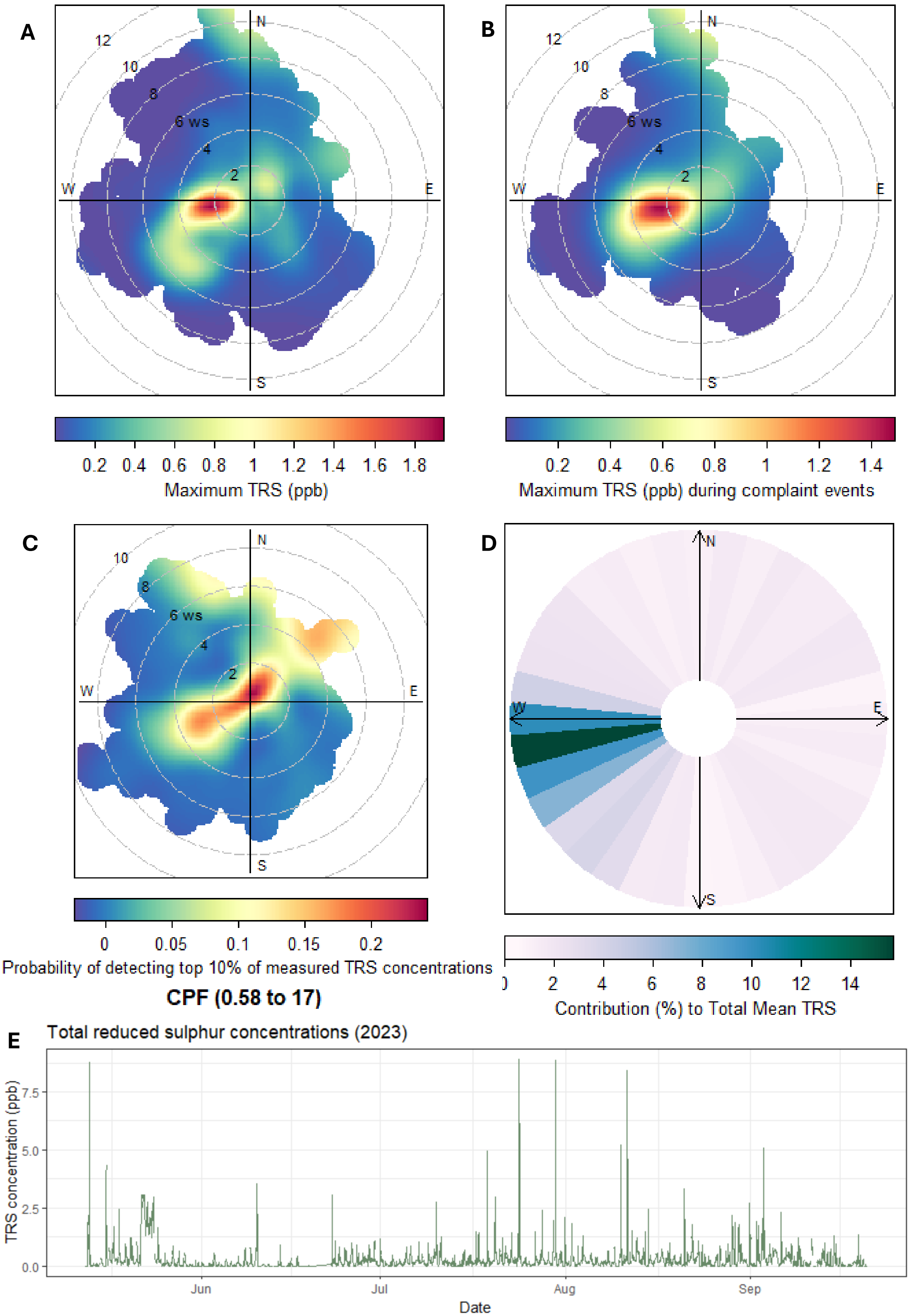

Figure A-15 Concentrations of total reduced sulphur (TRS) during the 2023 community-level odour monitoring period. (A) Estimated maximum TRS by wind speed and direction. (B) Estimated maximum TRS during complaint events. (C) Probability of detecting the top 10% of TRS concentrations by wind speed and direction. (D) Contribution of each wind direction to the overall mean TRS concentration. (E) Time series plot of measured TRS concentrations.

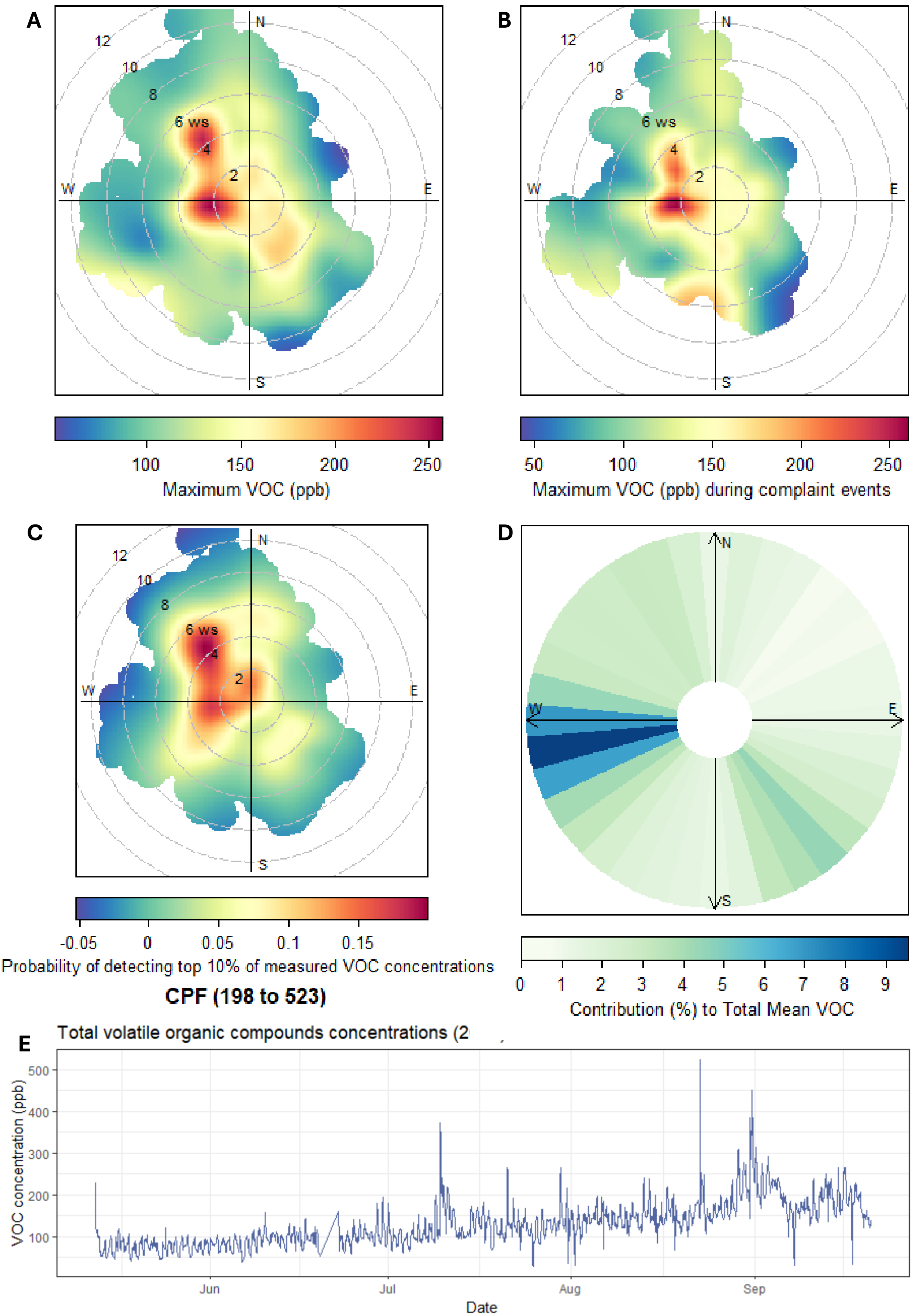

Figure A-16 Concentrations of total volatile organic compounds (VOC) during the 2023 community-level odour monitoring period. (A) Estimated maximum VOC by wind speed and direction. (B) Estimated maximum VOC during complaint events. (C) Probability of detecting the top 10% of VOC concentrations by wind speed and direction. (D) Contribution of each wind direction to the overall mean VOC concentration. (E) Time series plot of measured VOC concentrations.

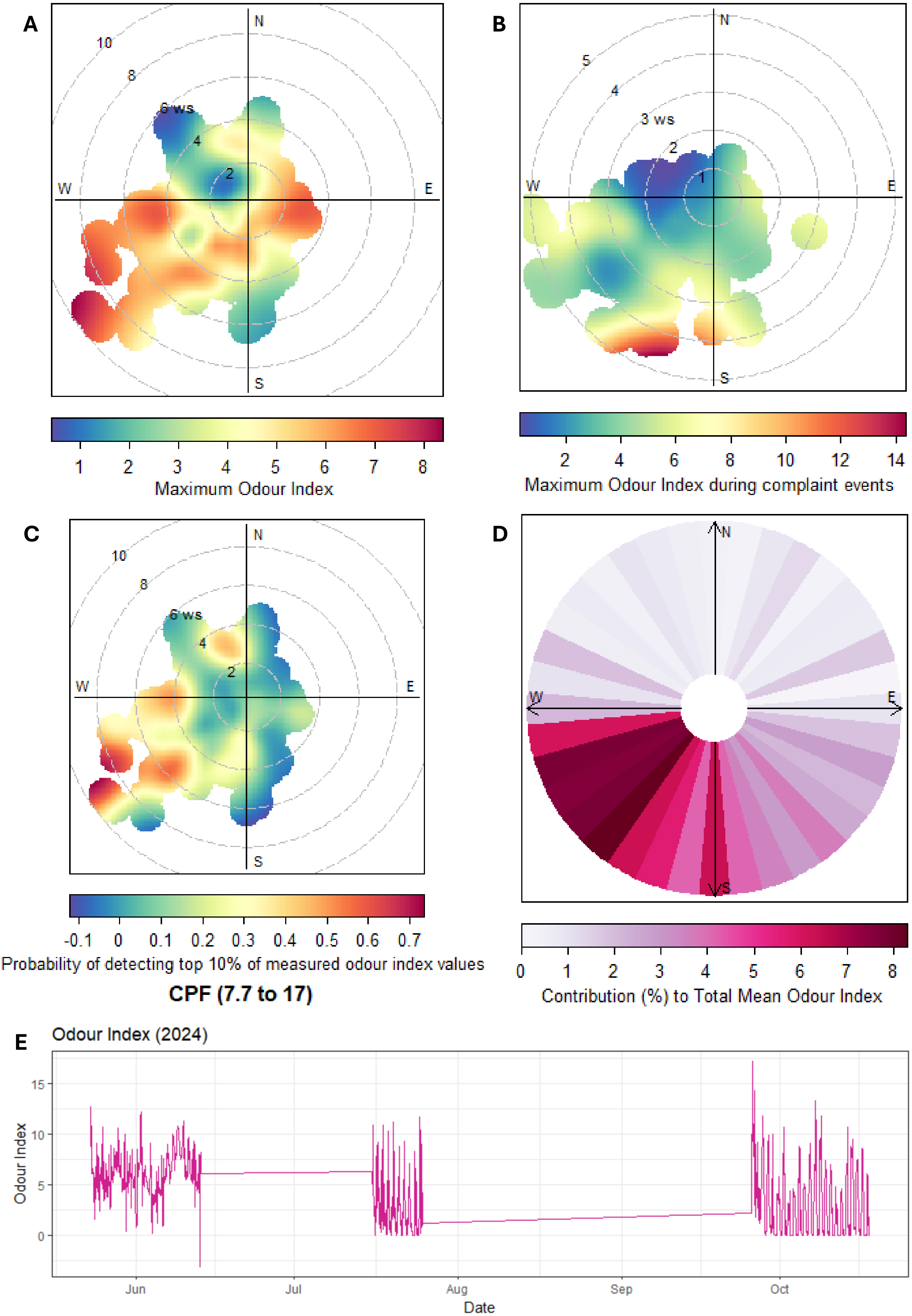

Figure A-17 Odour index values measured during the May-June 2024 community-level odour monitoring period. (A) Estimated maximum odour index by wind speed and direction. (B) Estimated maximum odour index values during complaint events. (C) Probability of detecting the top 10% of odour index values by wind speed and direction. (D) Contribution of each wind direction to the overall mean odour index. (E) Time series plot of measured odour index values.

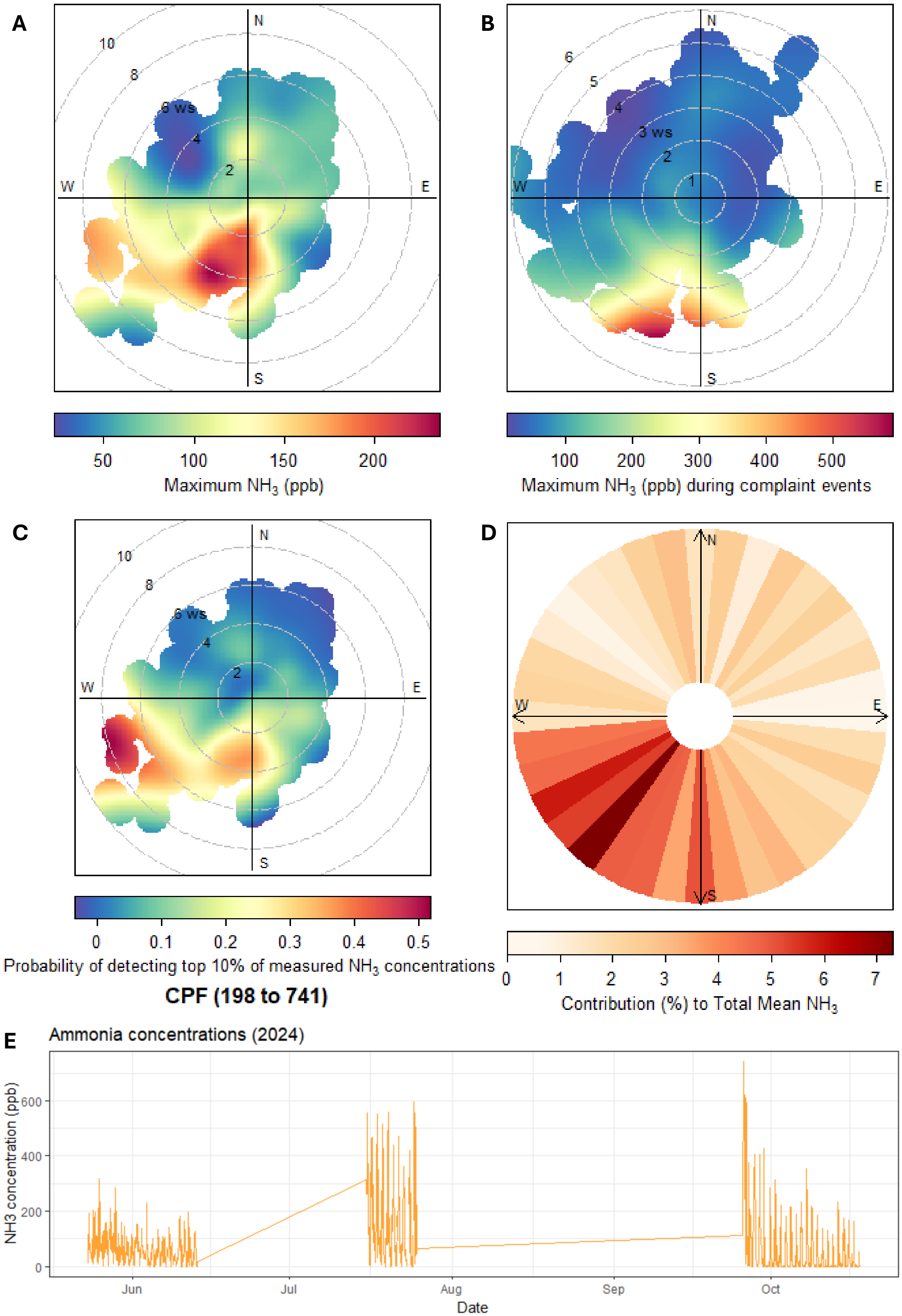

Figure A-18 Concentrations of ammonia (NH_3) measured during the 2024 community-level odour monitoring period. (A) Estimated maximum NH_3 by wind speed and direction. (B) Estimated maximum NH_3 during complaint events. (C) Probability of detecting the top 10% of NH_3 concentrations by wind speed and direction. (D) Contribution of each wind direction to the overall mean NH_3 concentration. (E) Time series plot of measured NH_3 concentrations.

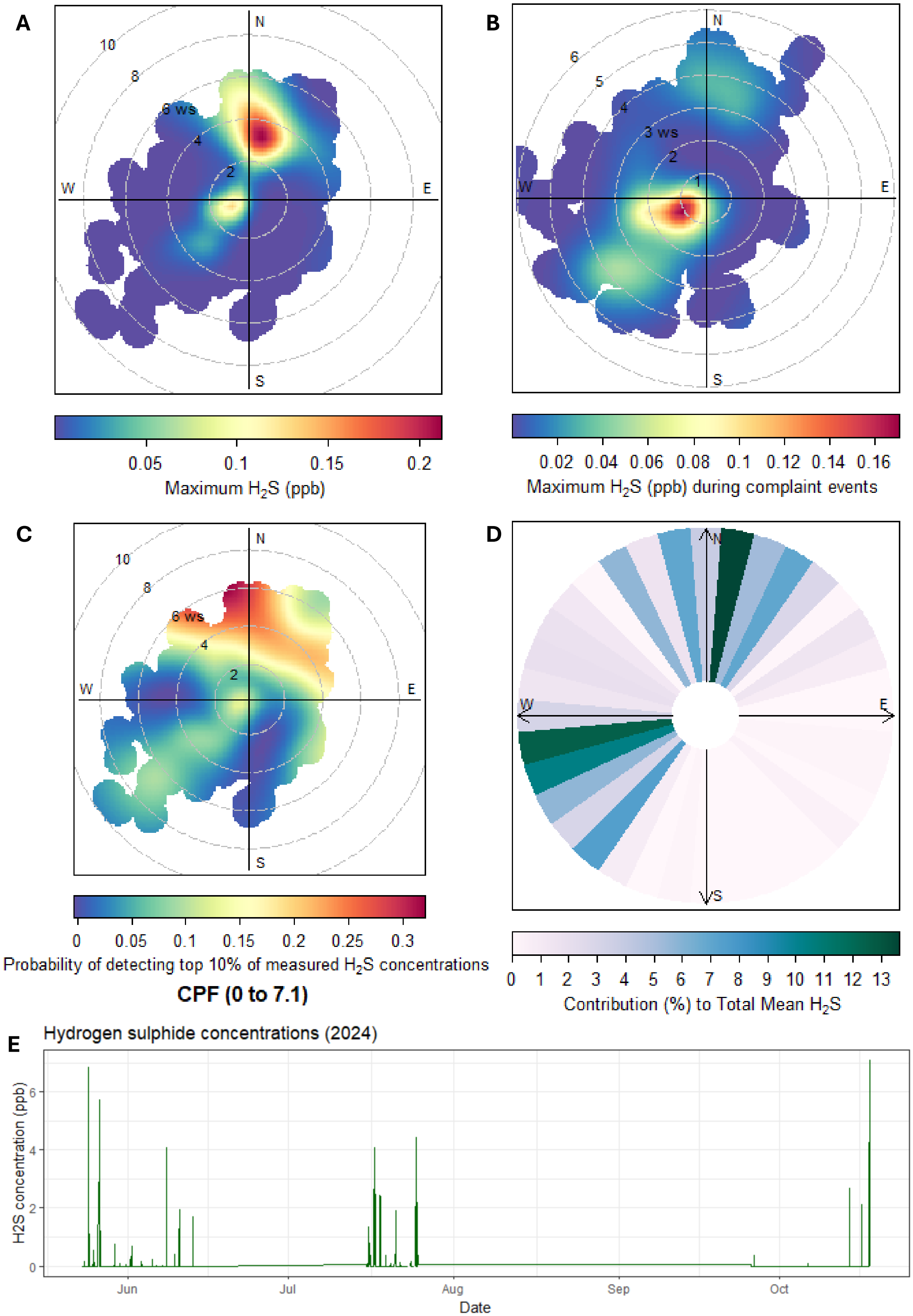

Figure A-19 Concentrations of hydrogen sulphide measured during the 2024 community-level odour monitoring period. (A) Estimated maximum H_2S by wind speed and direction. (B) Estimated maximum H_2S during complaint events. (C) Probability of detecting the top 10% of H_2S concentrations by wind speed and direction. (D) Contribution of each wind direction to the overall mean H_2S concentration. (E) Time series plot of measured H_2S concentrations.

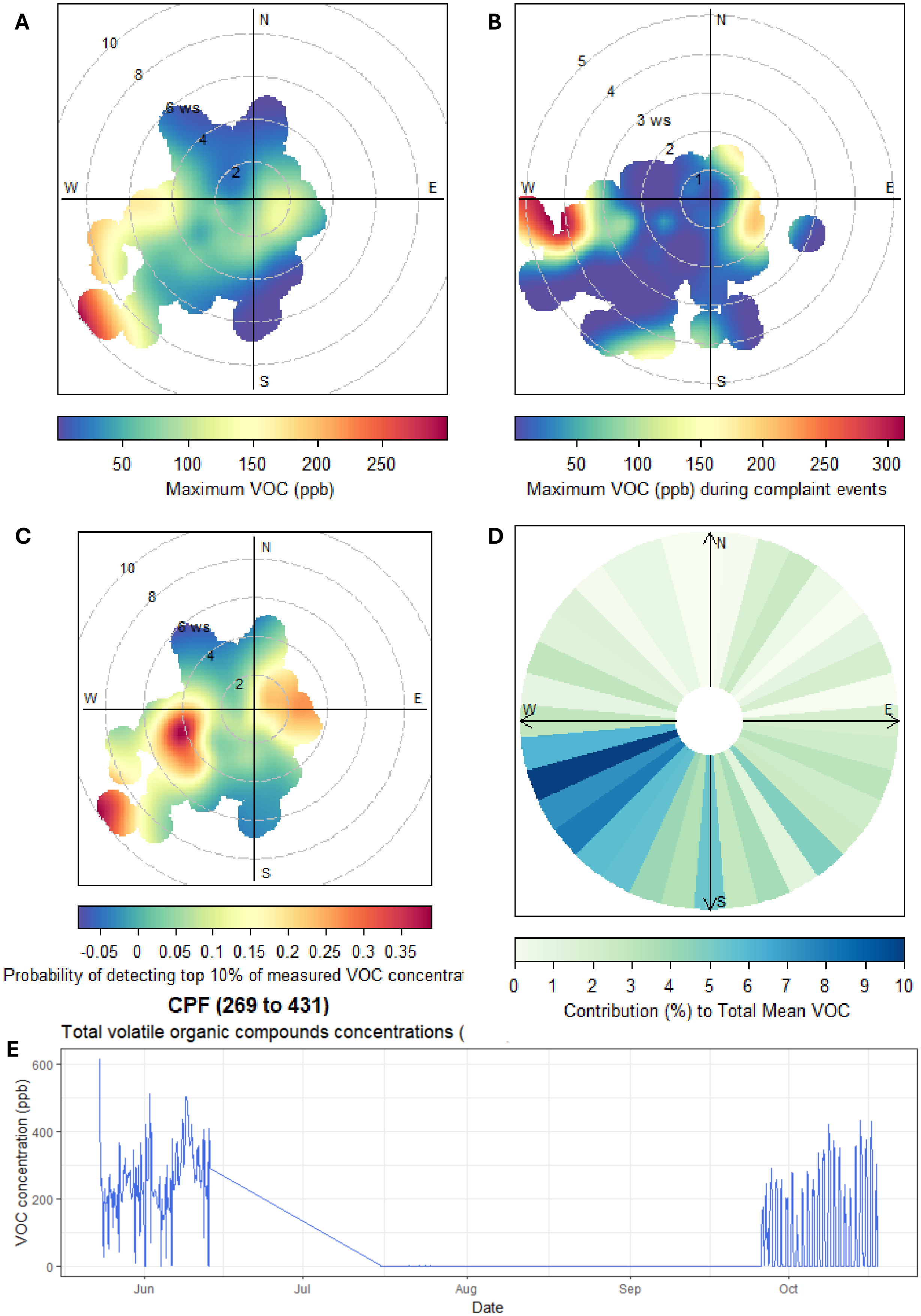

Figure A-20 Concentrations of total volatile organic compounds (VOC) during the May-June 2024 community-level odour monitoring period. (A) Estimated maximum VOC by wind speed and direction. (B) Estimated maximum VOC during complaint events. (C) Probability of detecting the top 10% of VOC concentrations by wind speed and direction. (D) Contribution of each wind direction to the overall mean VOC concentration. (E) Time series plot of measured VOC concentrations.

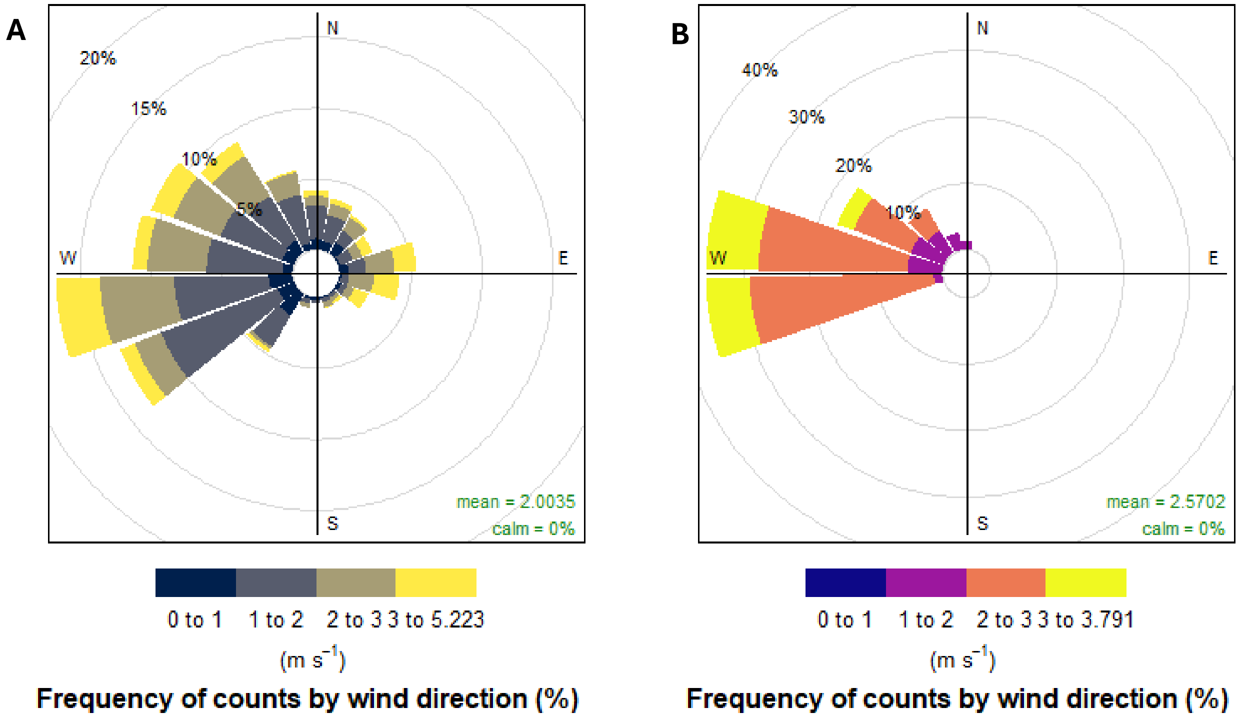

Figure A-21 Wind roses of wind conditions experienced during the community odour profiling conducted on April 13, 2024 (Community #1 sample) including the wind rose of the whole day (A) and during the sampling period (B).

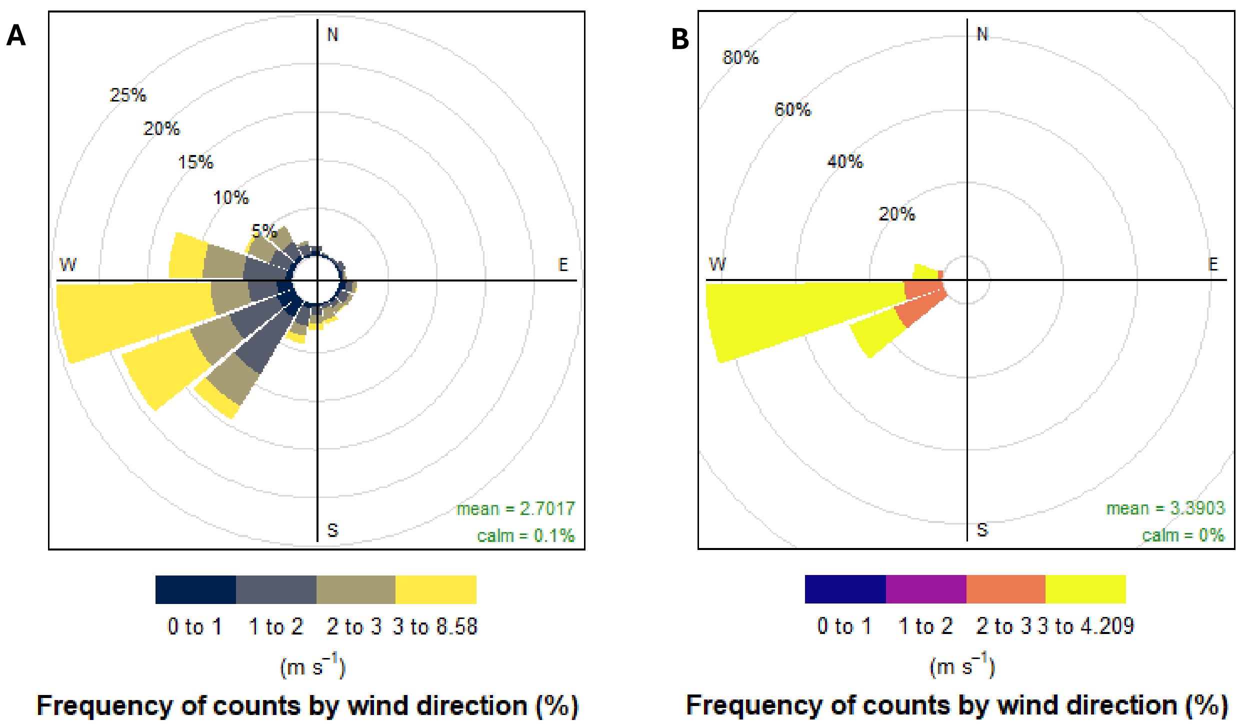

Figure A-22 Wind roses of wind conditions experienced during the community odour profiling conducted on April 24, 2024 (Community #2 sample) including the wind rose of the whole day (A) and during the sampling period (B).

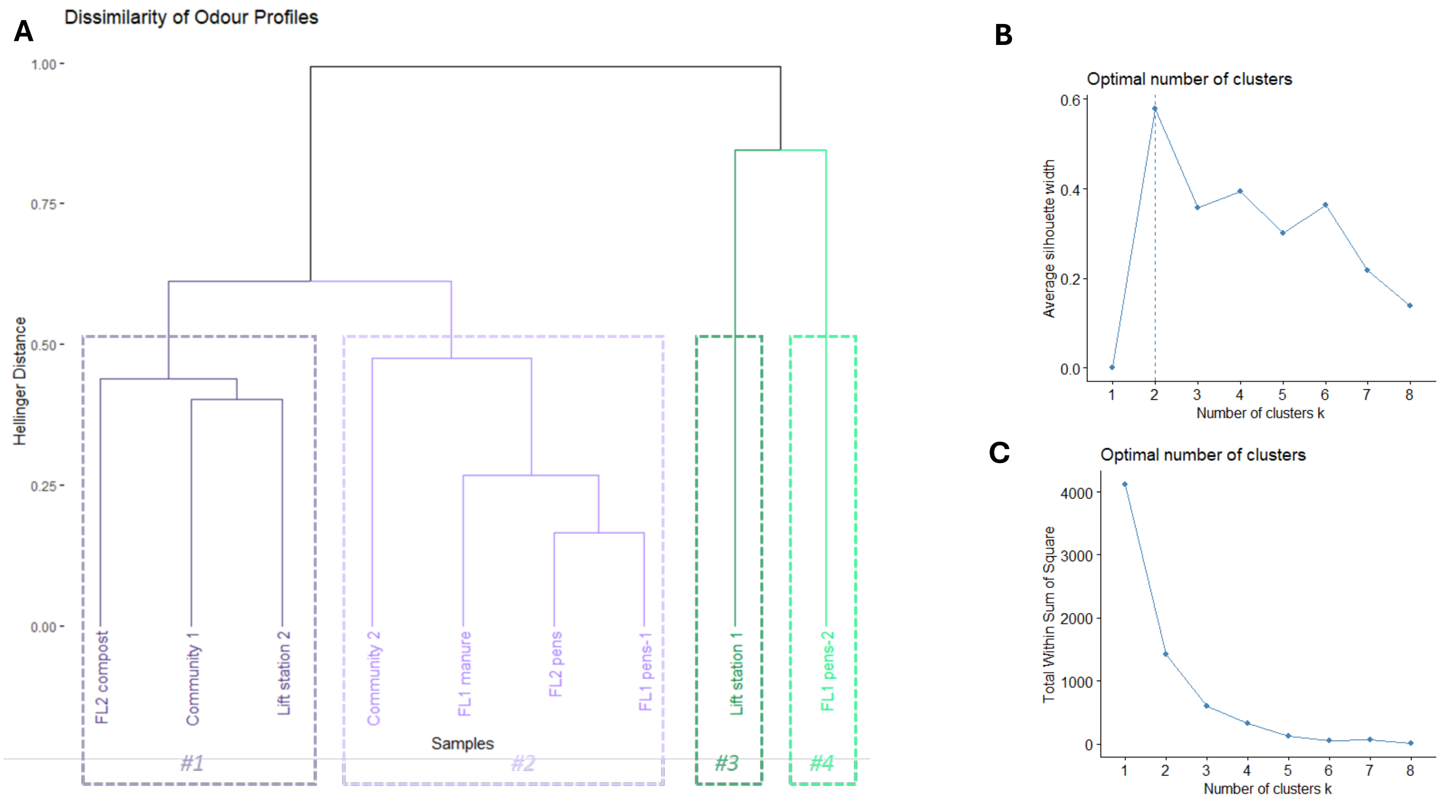

Figure A-23 Hierarchical Cluster Analysis showing the similarity of odour source profiles (A). Clusters indicate groups of sources with similar odour characteristics. Optimal number of plots were determined using silhouette analysis (B) and weighted sums of squares (C).

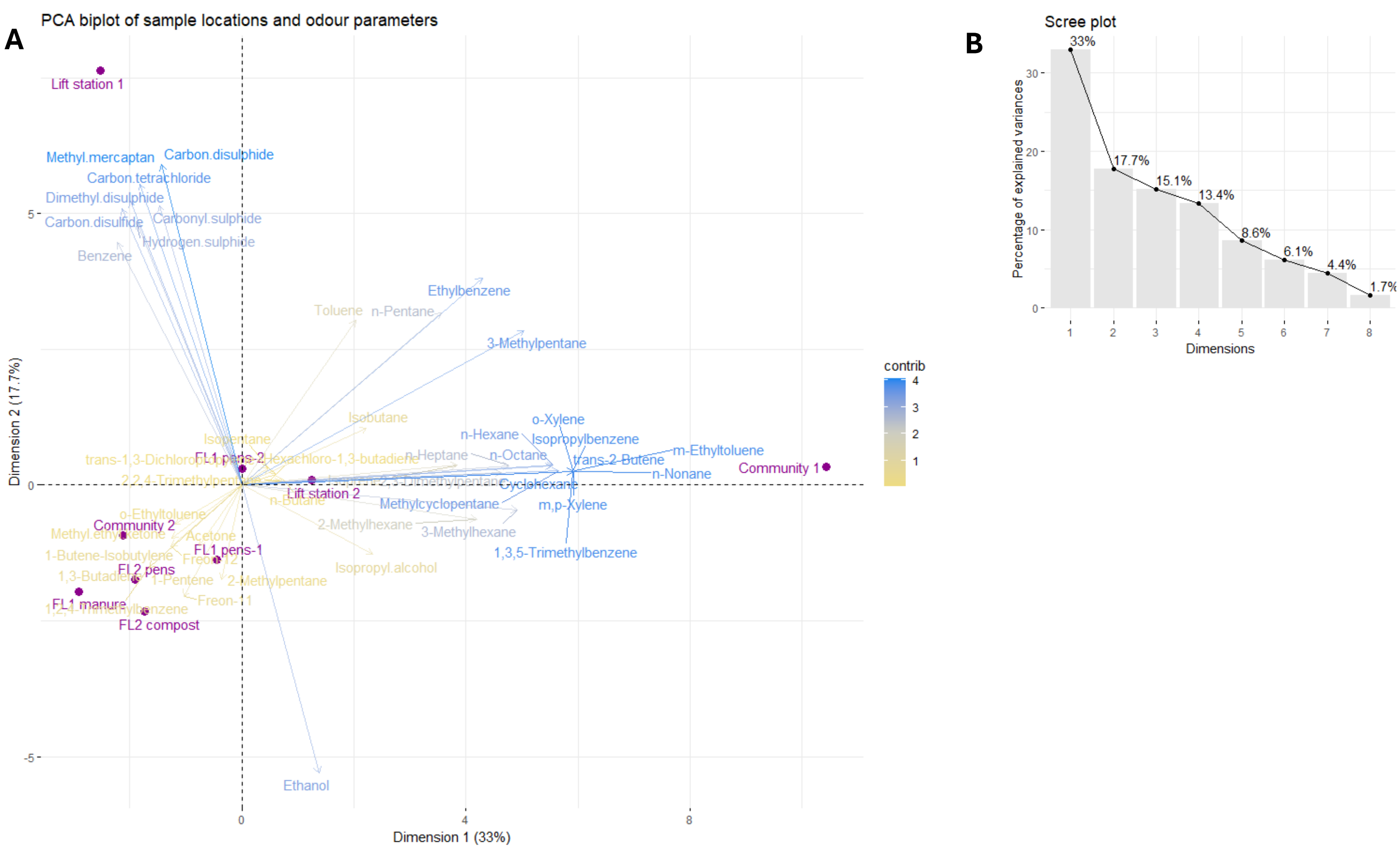

Figure A-24 Principal Component Analysis (PCA) illustrating odour parameters and sample locations (A). Arrows represent odour parameters; their contribution toward the projection is illustrated by colour. Points indicate sample locations based on odour profile similarities. Scree plot showing the explained variance of each dimension for the first eight dimensions of the PCA (B).

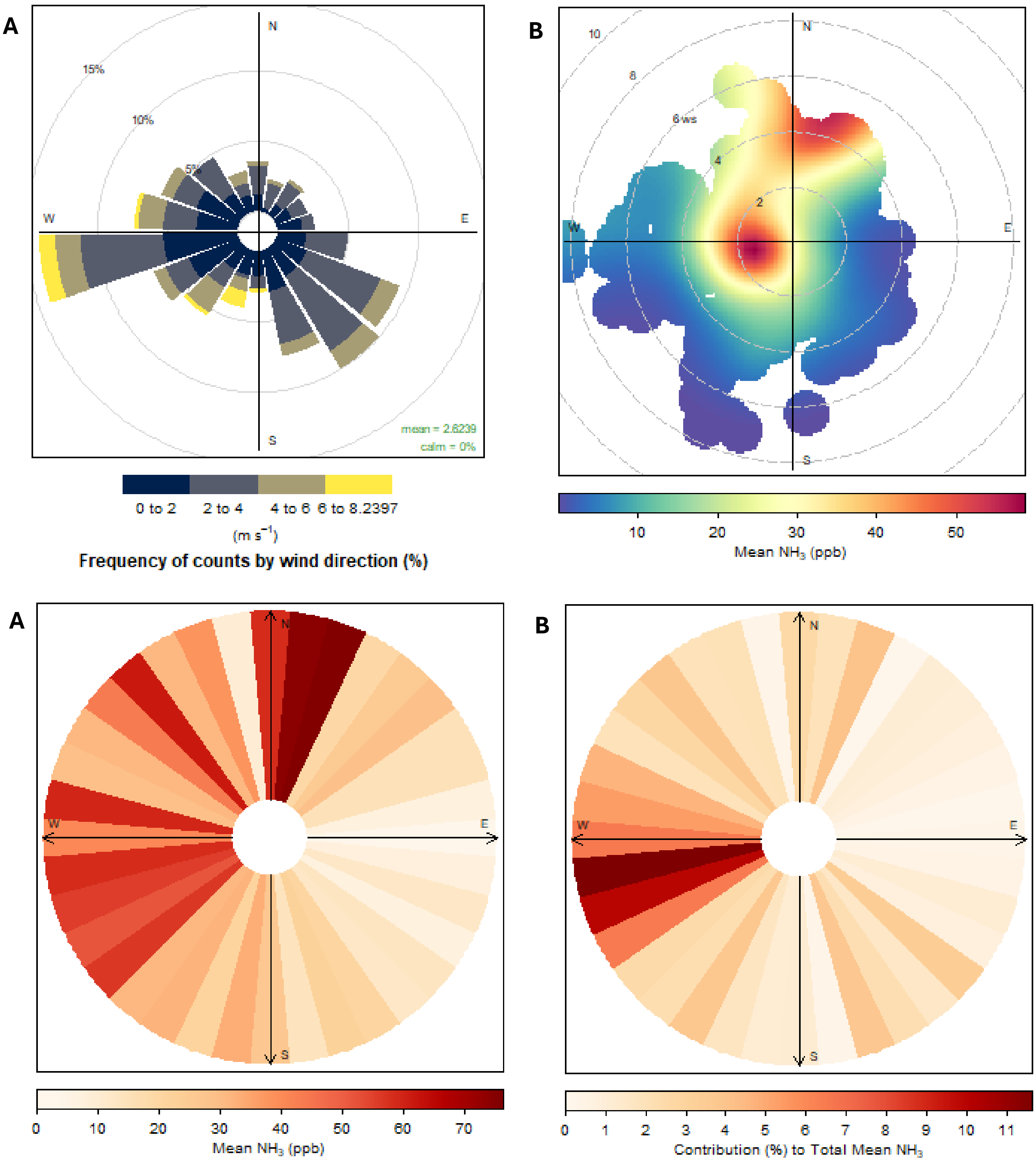

Figure A-25 Wind conditions and ammonia (NH_3) concentrations experienced during the deployment of the passive ammonia samplers. (A) Wind rose illustrating the frequency of wind speed and direction. (B) Estimated mean concentration of NH_3 based on wind speed and direction. (C) Mean NH_3 concentration from each segment of wind direction. (D) Contribution of each wind direction to the overall mean NH_3 concentration.