MANAGING AIR EMISSIONS FROM CONFINED FEEDING OPERATIONS IN ALBERTA

Ambient Air Quality Measurement Around Confined Feeding Operations in Alberta



Government of Alberta



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AMBIENT AIR QUALITY MEASUREMENT AROUND CONFINED FEEDING OPERATIONS IN ALBERTA

Alberta Agriculture and Rural Development

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Contents

Acronyms and Abbreviations

AAQM	Ambient air quality measurement
AAQO	Ambient Air Quality Objective
AEW	Alberta Environment and Water
AMD	Air Monitoring Directive
AOPA	*Agricultural Operation Practices Act* and Regulations
AQM	Air quality measurement
ARD	Alberta Agriculture and Rural Development
CASA	Clean Air Strategic Alliance
CFO	Confined feeding operation
CH_4	Methane
GPS	Global positioning system
H_2S	Hydrogen sulphide
IQR	Interquartile range
MDS	Minimum distance separation
NH_3	Ammonia
NMHC	Non-methane hydrocarbon
PM	Particulate matter
QA	Quality assurance
QC	Quality control
TSP	Total suspended particulates
VOC	Volatile organic compound
ppb_v	Parts per billion by volume
$\mu g\ m^{-3}$	Micrograms (of NH_3, H_2S, PM or VOC) in one cubic metre of air
α	Alpha, statistical level of significance

Executive Summary

In fulfillment of the mandate outlined in the Clean Air Strategic Alliance (CASA) Confined Feeding Operation (CFO) strategic plan, an ambient air quality measurement (AAQM) plan was developed in 2008 and the associated AAQM study implemented in 2009.

AAQM Study Objectives

The AAQM study had two objectives. The primary objective was to measure ambient air concentrations of five air quality parameters-of-interest at the category one minimum distance separation (MDS), along the path of the prevailing bi-directional wind, both upwind and downwind of a beef cattle, a dairy cattle, a poultry and a swine CFO in Alberta. The five parameters-of-interest were: ammonia (NH_3); hydrogen sulphide (H_2S); particulate matter with an aerodynamic diameter of 2.5 μm or less ($PM_{2.5}$); total suspended particulates (TSP); and volatile organic compounds (VOCs).

The study's secondary objective was to compare ambient air concentrations of the five parameters-of-interest to existing (October 2007) and proposed Alberta Ambient Air Quality Objectives (AAQOs).

Study Methodology

The AAQM study was conducted over a 14-month period. Owing to the immense scope of the study, the measurements were conducted intermittently for a minimum of 2 weeks (per measurement period) at only one of the four CFOs before relocating to the next CFO on the schedule at the end of the measurement period. A total of 18 measurement periods were completed over the course of the 14-month study.

A pair of mobile stations that housed gas analyzers and other instruments was used to conduct the measurements at each CFO. One station was located upwind of the respective CFO while the other was located downwind. In 15 of the 18 measurement periods, the mobile stations were aligned with respect to the prevailing bi-directional wind. However, for logistic reasons the stations were realigned with respect to the next most frequently occurring bi-directional wind in the remaining three measurement periods.

Electrical power supply to the mobile stations was provided using portable diesel generators. The gas analyzers were calibrated at the beginning of each measurement period and then verified at the end of the period to enhance measurement accuracy and reliability. Daily zero and span checks were also conducted on the gas analyzers. The mobile stations were usually visited and inspected at least once a week in each measurement period.

In general, ambient air concentrations of the air quality parameters-of-interest were measured continuously and then averaged on a 1-minute basis. Again, owing to the immense scope of the

study, specific VOCs that may potentially be found in CFO emissions were not identified nor were their ambient concentrations measured specifically. Rather, the concentrations of the suite of potential VOCs in CFO emissions were assumed to constitute the concentration of non-methane hydrocarbons (NMHCs), a composite mixture that included the concentrations of other volatile non-CFO related hydrocarbons minus methane. Thus, the concentration of NMHCs in the ambient air was measured during the study.

Data from each mobile station were frequently polled and checked on a daily basis. At the end of the 14-month study period, the data were statistically analyzed. Upwind and downwind concentrations were compared in order to determine if the CFOs significantly contributed to higher downwind ambient air concentrations of the respective air quality parameters-of-interest at the 5% level of significance ($\alpha = 0.05$). In addition, 1-hour, 24-hour and 3-day average concentrations of the respective air quality parameters-of-interest were compared to the provincial AAQOs, as indicated in the study's secondary objective.

Results and Conclusions

Note, because the measurements were only conducted intermittently around four CFOs over the 14-month period, the study results presented in this report are limited in scope, are site-specific, are not considered to be representative of the CFO industry in Alberta and therefore, cannot be extrapolated in time or space to signify the quality of the air around any or all CFOs in Alberta.

The results of the study indicate that the CFOs significantly contributed to higher downwind NH_3 concentrations over the entire duration of the study. Similarly, it appears that the CFOs contributed to significantly higher downwind concentrations of H_2S, $PM_{2.5}$, TSP and VOCs (NMHCs), 72%, 44%, 72% and 61% of the time, respectively, during the 14-month study period. The mean 1-minute average downwind NH_3, H_2S, $PM_{2.5}$, TSP and NMHC concentrations ranged between 5.45 ppb and 89.0 ppb, 0.06 ppb and 0.92 ppb, 4.16 $\mu g\ m^{-3}$ and 29.3 $\mu g\ m^{-3}$, 7.86 $\mu g\ m^{-3}$ and 94.6 $\mu g\ m^{-3}$, and 0.00 ppb and 49.3 ppb, respectively.

Over the 14-month study period there were no exceedances of the 1-hour and 24-hour NH_3 AAQOs. For H_2S, one exceedance of the 1-hour average AAQO was recorded, but there was no exceedance of the 24-hour AAQO.

For $PM_{2.5}$, 24 exceedances of the 1-hour average AAQO seemed to result from emissions that came from the direction of the CFOs. However, it is uncertain if the CFOs caused or were solely responsible for these exceedances. Some reasons for this uncertainty included: the presence of other sources of $PM_{2.5}$ emissions such as paved and unpaved roads or cultivated cropland between the upwind and downwind stations; and periods of time when the wind or PM analyzers malfunctioned, failed or were inoperable following interrupted power supply to either mobile station. There were no exceedances of the 24-hour average AAQO for $PM_{2.5}$.

With regards to TSP, six exceedances of the 24-hour average AAQO were recorded. Again, similar to $PM_{2.5}$ and for the same reasons it is uncertain how much, if any, CFO emissions contributed to these exceedances.

Potentially, of all the air quality parameters-of-interest to this study, the highest number of possible AAQO exceedances related to NMHC. A total of 401 possible exceedances could be attributed to the CFOs over the 14-month study period. However, this result is highly uncertain primarily because CFO-related VOCs that may potentially have constituted some part of the suite of NMHCs measured upwind and downwind of the CFOs were not specifically identified nor measured. In other words, it is impossible to ascertain if any VOCs that might have been emitted by the CFOs were present in the suite of NMHCs measured at the mobile stations, but if they were, then what their respective concentrations were.

In essence, the results of this study suggest the possible presence of CFO-related VOCs in the air downwind of the CFOs. Thus, more extensive work should be conducted in the future to determine what, if any, VOCs exist in CFO emissions in Alberta. Once this is accomplished, then the downwind concentrations of specific VOCs may be targeted, measured and compared to their respective AAQOs. Future work will also have to account for the possible contributions of secondary sources of VOCs that are located along the path of the wind between the upwind and downwind monitoring stations.

1. Introduction

In March 2008, Alberta's Clean Air Strategic Alliance (CASA) released a strategic plan developed by the Confined Feeding Operation (CFO) multi-stakeholder project team (CASA 2008). The strategic plan identified emissions-of-concern, CFOs of primary interest relative to the emissions-of-concern, and knowledge gaps related to how much the CFOs-of-interest emit, what effect the emissions-of-concern from the CFOs-of-interest might have on ambient air quality, and potential beneficial management practices to mitigate social and environmental impacts.

Six emissions-of-concern were identified by the CFO project team. Five of the emissions were classified as priority substances namely, ammonia (NH_3), hydrogen sulphide (H_2S), volatile organic compounds (VOCs), particulate matter (PM) and bioaerosols/pathogens. The sixth emission-of-concern, odour, was classified as a priority issue.

Of the different types of CFOs, only those associated with dairy cattle, beef cattle, swine, sheep and poultry were recognized in the strategic plan as being of primary interest to the CFO project team. The respective livestock industry commodity groups in Alberta, except the sheep industry, were represented on the CFO project team and were instrumental to the development of the strategic plan.

In one of its 10 recommendations, the CASA CFO strategic plan recommended the development of a plan to guide the monitoring of ambient air concentrations of NH_3, H_2S, PM and VOCs around CFOs in Alberta. A monitoring study plan (Appendix A) entitled, "Ambient Air Quality Measurement Around Confined Feeding Operations in Alberta: Ambient air quality measurement plan" was completed and approved by a multi-stakeholder advisory group in 2008.

1.1 Objectives of the Ambient Air Quality Measurement Study

Two objectives were outlined in the CFO ambient air quality measurement (AAQM) plan. The primary objective of the AAQM study was to determine ambient air concentrations of NH_3, H_2S, PM and VOCs at the category one minimum distance separation (MDS), both upwind and downwind of beef cattle feedlot, dairy cattle, swine and poultry CFOs in Alberta.

The secondary objective of the study was to compare ambient concentrations of NH_3, H_2S, PM and VOCs measured at each CFO MDS-1 to provincial thresholds, i.e., Alberta Ambient Air Objectives (AAQOs - October 2007 issue) and to a proposed 24-hour AAQO for NH_3.

2. Scope of the Ambient Air Quality Measurement Study

The AAQM study plan addressed specifics pertaining to the four emissions-of-concern, the types and number of CFO sites where measurement activities would be conducted, site selection criteria, scheduling of field and other activities, identification of equipment to be utilized and methodologies for measurement of air quality and meteorological parameters, quality assurance and quality control procedures, data quality objectives, and data acquisition, management and transfer, among other facets of the plan.

It is also important to note the limitations of the AAQM study as specified in the plan. Measurements were only conducted around four different CFOs. This implies that the study and its results are site-specific and cannot be extrapolated in time or space to represent the quality of the air, with respect to the four emissions-of-concern, around any or all CFOs in Alberta.

2.1 Confined Feeding Operations

As outlined in the AAQM plan, four CFOs located within Alberta, i.e., a beef cattle feedlot, a dairy cattle CFO, a swine CFO and a poultry CFO, were randomly selected to participate in the study with the consent of their owners. The number of livestock on each CFO conformed to the "size class eligibility" criteria specified in the AAQM plan.

In light of the confidentiality agreement between Alberta Agriculture and Rural Development (ARD) and the participating CFOs, the particulars of the participating CFOs, such as, business name, location, CFO type, etc., and certain other aspects of the study that could be used to identify the participating CFOs, are not divulged in this report.

2.2 Air Quality Parameters

Concentrations of the four priority substances outlined in the AAQM plan were measured during the study. Brief descriptions related to the parameters-of-interest measured in the study are presented below.

Ammonia

NH_3 was measured using a continuous measurement analyzer (Thermo Scientific 17i, Thermo Fisher Scientific Inc., Franklin, MA). In fulfillment of the secondary objective of the AAQM study, both 1-hour average and 24-hour average (proposed) NH_3 concentrations were compared to their corresponding AAQOs, i.e., 2,000 ppb (1,400 μg m^{-3}) and 286 ppb (200 μg m^{-3}), respectively.

Hydrogen Sulphide

H_2S was measured using a continuous measurement analyzer (Thermo Scientific 450i, Thermo Fisher Scientific Inc., Franklin, MA). In fulfillment of the study's secondary objective, 1-hour average and 24-hour average H_2S concentrations were compared to their corresponding AAQOs, i.e., 10 ppb (14 μg m^{-3}) and 3 ppb (4 μg m^{-3}), respectively.

Particulate Matter

Two categories of PM, namely (i) particles with an aerodynamic diameter of 2.5 μm or less ($PM_{2.5}$) and (ii) total suspended particulates (TSP), were measured using a continuous measurement analyzer (Model 190, Grimm Aerosol Canada Inc., Laval, QC). The analyzer was capable of measuring 31 different sizes (aerodynamic diameter) of PM, ranging from 0.25 μm to 32 μm or greater.

In fulfillment of the study's secondary objective, 1-hour average and 24-hour average $PM_{2.5}$ concentrations were compared to their corresponding AAQOs, i.e., 80 μg m^{-3} and 30 μg m^{-3}, respectively. Similarly, 24-hour average TSP concentrations were compared to their corresponding 24-hour AAQO, i.e., 100 μg m^{-3}.

Volatile Organic Compounds

Although acetic acid and phenol were identified as VOCs common to various livestock types in the AAQM plan, measurement of specific VOCs was considered to be too exorbitant. Alternatively, as stated in the AAQM plan, non-methane hydrocarbons (NMHCs) were measured to provide an indication of the possible presence of VOCs in the ambient air. A methane (CH_4) and NMHC analyzer (Model 55C, Thermo Environmental Instruments Inc., Franklin, MA) was used to continuously measure the concentration of NMHCs. Note that the minimum detectable limit of the analyzer as specified by the manufacturer was 0.02 ppm.

To fulfill the study's secondary objective, 1-hour average, 24-hour average and 3-day average concentrations of specific NMHCs possibly emitted by the CFOs (Schiffman et al. 2001) were compared to their corresponding AAQOs.

2.3 Meteorological Parameters

Four meteorological parameters were measured during the study. Initially, wind speed and wind direction were measured continuously with ultrasonic anemometers (Model 8100, R. M. Young Company, Traverse City, MI). About five months into the study the ultrasonic anemometers were replaced with mechanical anemometers (Model 200-05305, R. M. Young Company, Traverse City, MI) that were more sensitive to measuring wind direction at lower wind speeds.

Ambient air temperature and relative humidity were also measured continuously using temperature and relative humidity sensors (Model 225-HMP50YA, NovaLynx Corporation, Auburn, CA).

2.4 Measurement Locations

The distance between each upwind and downwind measurement location and the corresponding CFO was derived using the MDS formula for the category one land zoning and residential type classification in the *Agricultural Operation Practices Act* and Regulations - AOPA (GOA 2005). In addition, the orientation of the upwind and downwind measurement locations relative to each CFO was aligned with respect to the prevailing bi-directional wind (Fig. 1). The prevailing bi-directional wind was determined from wind rose plots based on hourly wind data collected between 2000 and 2007 from a provincial meteorological station in closest proximity to the CFOs.

Two mobile air monitoring stations containing the various analyzers and sensors used to measure concentrations of the air quality parameters and meteorological parameters were set up along the path of the bi-directional wind, i.e., with one station located on either side of the respective CFO. As stated in the AAQM plan, both stations were set up in accordance with the guidelines outlined in AMD (1989).

2.5 Measurement Period

Concentrations of the air quality parameters and meteorological parameters at the category one MDS (MDS-1), were measured over the span of 14 months both upwind and downwind of the four CFOs. Since only two custom-fabricated mobile monitoring stations were available for the study, the measurements relative to each CFO were staggered such that measurements were conducted for a minimum period of 2 weeks before the mobile stations were relocated to the next CFO. Each CFO was visited a total of four or five times over the course of the study, totalling 18 measurement periods in 14 months.

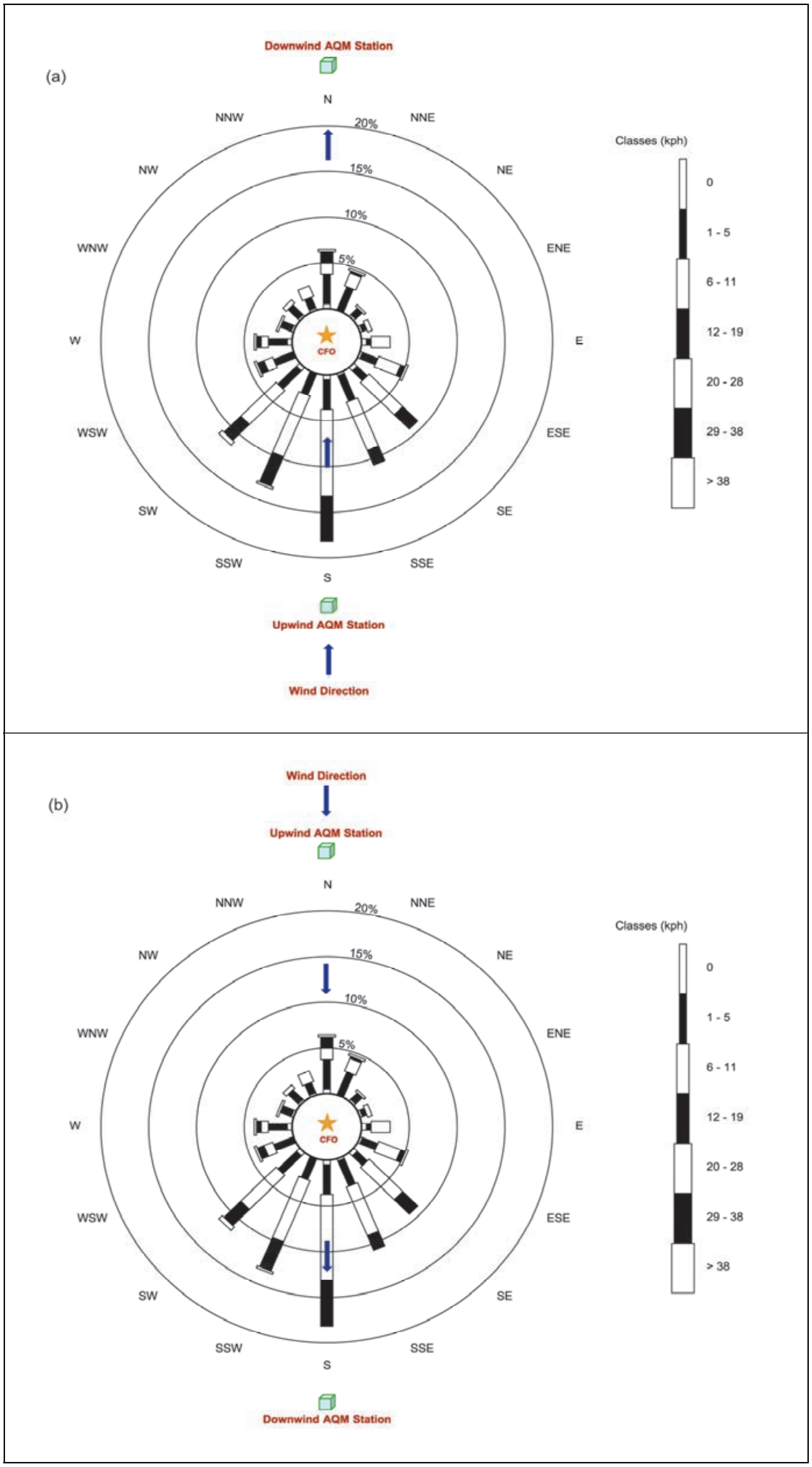

Figure 1. Illustration of upwind and downwind orientation of two mobile air monitoring stations with respect to a CFO and the prevailing bi-directional wind (a) wind from south (b) wind from north.

3. Study Description and Methodologies

The AAQM study commenced in summer 2009. A description of the various activities and milestones achieved over the course of the study is presented in the following sections.

3.1 Training

Staff from ARD were trained to conduct ambient air quality monitoring activities by R&R Environmental Devices Ltd. Attributes and scientific principles governing the operation of the various analyzers and their measurements were discussed during the theoretical component of the program. During the practical component of the program, ARD staff conducted a series of hands-on calibrations of the analyzers to be used in the AAQM study.

3.2 Setup

Prior to commencing field measurements, the two custom-fabricated mobile monitoring stations, including analyzers, dataloggers, data acquisition software, remote communication devices, and other apparatus housed within the stations, were inspected and tested by Alberta Environment and Water (AEW) air monitoring staff.

3.2.1 Instrumentation Specialist

Initially, R&R Environmental Devices Ltd. was contracted to oversee the setup, start-up calibration, daily checks, shut-down calibration verification, and general operation of the two custom-fabricated mobile monitoring stations at the first CFO on the schedule, and the setup and start-up calibration at the second CFO on the schedule. In addition, the services of R&R Environmental Devices Ltd. were retained on a monthly basis to attend to troubleshooting emergencies over the 14-month study period.

Later on in the study, the services of R&R Environmental Devices Ltd. were extended to include the shut-down calibration verification of the mobile stations prior to moving to the next CFO on the schedule and start-up calibration immediately after moving to that CFO.

3.2.2 Data Management Specialist

Aurora Atmospherics Inc. was contracted to provide data management services over the course of the study. A quality assurance plan developed by Aurora Atmospherics Inc. was implemented and used to verify data with respect to data collection, data validation, data processing, analyzer calibration, and daily zero and span checks in compliance with the 1989 Air Monitoring Directive (AMD 1989) and 2006 Amendments to the 1989 Air Monitoring Directive (AMD 2006). Furthermore, and where applicable, the measured concentrations of the air quality parameters were corrected for baseline shifts with respect to the calibration data and daily zero and span responses of the analyzers.

3.3 Field Activities

As noted in section 2.4, one of the two custom-fabricated mobile monitoring stations was aligned on either side of a CFO along the path of the prevailing bi-directional wind. This orientation was used to site the mobile stations in 15 of the 18 measurement periods. For logistical reasons, the stations were realigned with respect to the next most frequently occurring bi-directional wind in three of the 18 measurement periods.

The orientation of the monitoring stations with respect to each CFO and distance (MDS-1) of the stations from the CFOs were determined with the aid of a global positioning system (GPS) device (GPSMAP 76, Garmin International Inc., Olathe, KS). The locations of both stations were marked and the Universal Transverse Mercator (UTM) coordinates recorded. In addition, the proximity of the mobile stations to obstructions such as trees, elevation of such obstructions, and view from the mobile stations to the N, S, E and W, were documented in accordance with AMD (1989).

Once the stations were situated on either side of a CFO, the analyzers in both stations were calibrated prior to commencing ambient measurements of the air quality and meteorological parameters. After a period of data collection that lasted for 2 weeks or longer, calibration of the analyzers were verified and the mobile stations were relocated to the MDS-1 on either side of the next CFO on the schedule.

3.3.1 Electricity Supply

It was impossible to locate the mobile stations in accordance with the requirement outlined in the AAQM plan for these locations to be in close proximity to electricity distribution systems, i.e., either relative to the respective CFOs, their neighbours or via the installation of transformers and distribution lines. Therefore, as indicated in the *Risk Management* section of the plan, diesel generators were selected as the alternative source of electricity to power the mobile stations.

Two winterized diesel generators with accompanying fuel tanks were run continuously during each 2-week (or longer) measurement period. At the end of each measurement period, maintenance services such as replacement of oil filter were performed on the generators. Based on advice from the instrumentation specialist, among other experts, the generators were located approximately 100 m from the mobile stations and were oriented such that they were not situated along the path of the prevailing bi-directional wind.

3.3.2 Calibration

As part of the QA and QC procedures implemented, the NH_3, H_2S, and CH_4 and NMHC analyzers in each mobile station were calibrated after the stations and diesel generators were situated on either side of one of the four participating CFOs. Calibration activities typically lasted for about 12 hours per mobile station. Thus the gas analyzers in only one of the two mobile stations were calibrated per day.

During the calibration process, a gas dilution calibrator (Model 2010, Sabio Instruments Inc., Georgetown, TX) with an in-built ozone (O_3) generator was used to control the flow of filtered, neutral (zero) air and predetermined concentrations of nitric oxide (NO), nitrogen dioxide (NO_2) and NH_3 to the NH_3 analyzer. Similarly, a second gas dilution calibrator (GDC/MFC 201, R&R Environmental Devices, Edmonton, AB) was used to control the flow of filtered zero air and predetermined concentrations of H_2S, and mixtures of CH_4 and propane (C_3H_8) to their respective analyzers. Certified gases (NO, NH_3, H_2S, and a CH_4/C_3H_8 mix) obtained from a retail supplier in Alberta were used to calibrate the analyzers during the study. The O_3 generator in the Sabio Instruments Inc. gas dilution calibrator and the certified NO gas were used to generate NO_2 gas that was used during the NH_3 analyzer calibration process.

Upon completing the calibration process in each mobile station, span and zero checks were performed on the calibrated analyzers and the readings were logged. At the end of the 2-week (or longer) measurement period, calibration verification was performed and ultrafine particulate matter filters used to filter the inlet ambient air flow to the NH_3, H_2S, and CH_4 and NMHC analyzers during the measurement period were replaced with new ones. Calibration records for each station were regularly shared with the instrumentation and data management specialists over the course of the 14-month study.

The PM analyzers were designed to calibrate automatically by the manufacturer and did not require manual calibration. The performance of the analyzers was verified by the manufacturer at the end of the 14-month AAQM study. Calibration certificates specifying details of the manual recalibration process performed by the manufacturer were issued and shared with the instrumentation and data management specialists.

3.3.3 Data Collection and Storage

Each mobile monitoring station was set up to draw ambient air via an inlet port mounted above the roof of the station. The air flowed into an air manifold located inside the station, through the ultrafine particulate matter filters and finally to the respective NH_3, H_2S, and CH_4/NMHC analyzers. The inlet air port was mounted according to the specifications outlined in AMD (1989). Outlet air from all the analyzers was redirected into a separate air manifold and then exhausted outside the station.

Ammonia

The NH_3 analyzer in each mobile monitoring station measured and recorded ambient air concentrations of NO, NO_2, nitrogen oxides (NO_x), NH_3 and total nitrogen (N_t) in ppb on a 90-second averaging time basis. Output from the analyzer was retrieved by a datalogger (ESC 8832, Environmental Systems Corporation, Knoxville, TN), and averaged on a 1-minute basis prior to data storage.

Hydrogen Sulphide

The H_2S analyzer in each mobile monitoring station measured and recorded ambient air concentrations of H_2S in ppb on a 60-second averaging time basis. Output from the analyzer was retrieved and averaged by the datalogger in the station on a 1-minute basis prior to data storage.

Non-Methane Hydrocarbons

The CH_4 and NMHC analyzer in each mobile monitoring station measured and recorded ambient air concentrations of NMHC in ppm on a 70-second measurement cycle. Output from the analyzer was retrieved and averaged by the datalogger in the station on a 1-minute basis prior to data storage.

Particulate Matter

The PM analyzer in each mobile monitoring station was installed with a separate sampling inlet pipe that was connected directly to the analyzer. At temperatures below freezing, moisture condensation was observed to interfere with the measurements. This problem was resolved by wrapping heat tape around the inlet pipe to keep the pipe warm thereby minimizing the effects of condensation on the measurements. $PM_{2.5}$ and TSP concentrations were measured in µg m^{-3} on a 6-second basis. Output from the analyzer was retrieved and averaged by the datalogger in the station on a 1-minute basis prior to data storage.

Wind Speed and Direction

Wind speed and direction at each mobile monitoring station location were measured on a 1-second basis. Output from the sensor was retrieved by the dataloggers at the same frequency, and averaged on a 1-minute basis prior to data storage.

Ambient Air Temperature and Relative Humidity

Temperature and relative humidity at each mobile monitoring station were measured on a 1-second basis (NovaLynx 2005). Output from the sensors was retrieved by the dataloggers in the station at the same frequency and averaged on a 1-minute basis prior to data storage.

Data Storage

Data stored by the dataloggers were retrieved remotely by the data management specialist every 15 minutes. Data were also continuously downloaded to computers housed within the mobile monitoring stations and backed up on a weekly basis. In addition, data were backed up at the end of each measurement period prior to calibration verification. Backup copies of the downloaded data were stored on remote computer systems.

3.3.4 Periodic Checks

Gas Analyzers

Zero and span checks were conducted on the NH_3, H_2S, and CH_4 and NMHC analyzers in each mobile monitoring station daily. Output from the zero and span checks was stored by the dataloggers in the station, and retrieved and reviewed daily by the data management and instrumentation specialists.

Mobile Monitoring Stations

A member of the study team regularly visited each mobile station at least once a week to download data, check the performance of the analyzers and other instruments, check and if necessary adjust the indoor air temperature to the targeted temperature (22^{o}C), refill the generator fuel tanks and conduct a general inspection of the stations and their immediate surroundings. In addition, a member of the study team toured the area around the respective CFO, travelled along the closest gravel or paved roads to the N, E, S and W of the CFO, and stopped at the four intersections that cornered the CFO to record observations that might provide insight into the nature of air quality measurement data.

In addition, members of the study team visited the stations to troubleshoot problems when the need arose. All problems encountered during the study were resolved expeditiously.

3.4 Data Analyses

Two different series of data analyses were conducted in fulfillment of the objectives of the AAQM study.

3.4.1 Downwind Air Quality versus Upwind Air Quality

The intent of this series of analyses was to assess if each CFO significantly contributed to elevated downwind ambient air concentrations at the 95% confidence level (α = 0.05). Datasets containing 1-minute average concentrations and 15-minute average concentrations of NH_3, H_2S, NMHC, $PM_{2.5}$ and TSP that corresponded to each measurement period were analyzed by Air Resource Specialists Inc. The 15-minute average concentrations were examined to partially account for the time taken by a parcel of air to travel from the upwind mobile monitoring station to the downwind station, and to smoothen noisy instrument (analyzer) output readings.

Each analysis per measurement period included:

- An examination of the upwind and downwind concentrations of the air quality parameters that corresponded to the direction of the incident wind as it flowed across each CFO from the upwind station to the downwind station.

- An examination of the composite upwind and composite downwind ambient air concentrations. Composite datasets were generated by combining concentrations that corresponded to all upwind flow at either station over the course of the measurement period and all downwind flow at either station over that same time period, respectively.

- The treatment of all upwind datasets as independent distributions relative to their corresponding downwind datasets. Observations from both datasets were not paired because it was uncertain if the observations from both datasets could be accurately and precisely paired without bias.

- Tests for normality using statistical software (SigmaPlot 12, Systat Software Inc., Chicago, IL) as well as the creation of distribution plots and box plots.

- Non-parametric Mann-Whitney rank sum comparison tests (SigmaPlot 12, Systat Software Inc., Chicago, IL) to test for significant differences between each upwind dataset versus its corresponding downwind dataset. If the normality tests alluded to above indicated a normally distributed dataset then a parametric t-test (SigmaPlot 12, Systat Software Inc., Chicago, IL) was also performed on the respective dataset.

3.4.2 AAQM Study Concentrations versus Provincial AAQOs

As indicated in section 2.2, datasets containing 1-hour average concentrations and 24-hour average concentrations measured at each mobile station, and corresponding to all wind directions, were compared to Alberta AAQOs with respect to the parameters-of-interest to this study. Specifically, exceedances were marked for further review when the incident wind flowed from the upwind station, across the respective CFO, to the downwind station. The wind direction range used to determine potentially eligible exceedances associated with a CFO was determined relative to the spatial geometry of that CFO. This included the total area inclusive of and between all livestock housing facilities, manure storage facilities and other potential sources of emissions at the CFOs. If the corresponding wind direction was in alignment with the upwind station, the CFO and the downwind station, and an AAQO exceedance was recorded, the upwind and downwind 1-hour average or 24-hour average concentrations at the two stations were compared to determine if a potential upwind secondary source of emissions may have contributed to or been responsible for the exceedance.

For VOCs (NMHCs), the 1-hour, 24-hour or 3-day NMHC concentration averages were compared to the AAQOs of select NMHCs (Table 1). Prior to the comparison, the units of the measured concentrations were converted from ppm to ppb by multiplying each reading obtained from the original dataset by 1,000. The NMHCs listed in Table 1 are VOCs reported to be found in emissions from swine CFOs (Schiffman et al. 2001).

Table 1. AAQOs for VOCs (NMHCs) potentially emitted by CFOs

VOC (NMHC)	AAQO Criteria	Threshold Concentration	
		(ppm)	(ppb_v)
Monoethylamine	1-h average	0.001	0.6
Ethylene oxide	1-h average	0.008	8
Benzene	1-h average	0.009	9
Acrylic acid	1-h average	0.020	20
Phenol	1-h average	0.026	26
	3-d average	0.040	40
Acetaldehyde	1-h average	0.050	50
Formaldehyde	1-h average	0.053	53

VOC (NMHC)	AAQO Criteria	Threshold Concentration	
		(ppm)	(ppb_v)
Cumene (isopropylbenzene)	1-h average	0.100	100
Acetic acid	1-h average	0.102	102
	24-h average	0.106	106
2-Ethylhexanol	1-h average	0.111	111
	24-h average	0.161	161
Ethylbenzene	1-h average	0.460	460
Toluene	1-h average	0.499	499
Xylenes	1-h average	0.529	529
Ethylene	1-h average	1.044	1,044
Methanol	1-h average	2.000	2,000
Acetone	1-h average	2.400	2,400
Isopropanol	1-h average	3.190	3,190
Dimethyl ether	1-h average	10.100	10,100

4. Results and Discussion

Results of the data analyses on the concentrations of the air quality parameters measured upwind and downwind of the four CFOs over the course of the 14-month study are discussed in the sections below. For each air quality parameter-of-interest and measurement period, the results as shown in Tables 2 to 11 portray the mean, minimum, median and maximum 1-minute average upwind and downwind concentrations, the outcome of the statistical comparisons between both datasets, and the mean, minimum, median and maximum 1-hour average concentrations at each mobile station regardless of wind direction. In addition, 15-minute time series plots and box plots are presented in Appendices C and D, respectively.

Furthermore, the 1-hour, 24-hour or 3-day average concentrations measured at the mobile stations were compared to the AAQOs of the respective air quality parameters-of-interest as described in section 3.4.2. The outcomes of these comparisons are also discussed in the following sections.

4.1 Ammonia

Table 2 shows the 1-minute average NH_3 concentrations measured upwind and downwind of the CFOs during the study. The mean 1-minute average upwind and downwind concentrations ranged between 1.64 ppb and 10.7 ppb, and 5.45 ppb and 89.0 ppb, respectively. The negative values of some of the minimum 1-minute average concentrations presented in Table 2 are indicative of the responses of the analyzers.

The results of the statistical comparison between the upwind and downwind 1-minute average NH_3 concentrations indicates that the downwind concentrations were significantly higher than the upwind concentrations in each measurement period as shown by the higher mean and median values. This suggests that the CFOs consistently contributed to higher downwind ambient air NH_3 levels at the MDS-1.

Table 3 shows the 1-hour average NH_3 concentrations measured at each mobile station with respect to all wind directions in each measurement period. The 1-hour average concentrations ranged between 0.00 ppb and 495 ppb, and 0.00 ppb and 390 ppb at mobile stations one and two, respectively. Despite the higher downwind NH_3 concentrations measured throughout the study, no exceedances of either the 1-hour average or proposed 24-hour average NH_3 AAQOs occurred during the study.

4.2 Hydrogen Sulphide

Table 4 shows the 1-minute average H_2S concentrations measured upwind and downwind of the CFOs during the study. The mean 1-minute average upwind and downwind concentrations ranged between 0.05 ppb and 0.55 ppb, and 0.06 ppb and 0.92 ppb, respectively. The negative

Table 2. NH_3 1-minute average ambient air concentrations upwind and downwind of CFOs

Measurement Period (#)	Measurement Location								Significant Difference?* (α = 0.05)
	Upwind				Downwind				
	Mean (ppb)	Minimum (ppb)	Median (ppb)	Maximum (ppb)	Mean (ppb)	Minimum (ppb)	Median (ppb)	Maximum (ppb)	
1	3.30	-3.84	2.70	26.0	50.2	-4.92	14.9	577	Y ($p < 0.001$)
2	6.08	-2.39	4.34	254	89.0	-2.24	30.5	1791	Y ($p < 0.001$)
3	3.16	-1.72	1.59	98.7	60.6	-1.00	29.9	537	Y ($p < 0.001$)
4	1.64	-17.3	1.28	18.7	62.5	-1.44	31.8	663	Y ($p < 0.001$)
5	8.02	-0.65	2.74	170	18.5	0.31	11.8	149	Y ($p < 0.001$)
6	5.84	1.99	4.68	820	13.5	0.46	8.47	538	Y ($p < 0.001$)
7	3.61	-2.13	2.42	45.4	25.8	-15.8	21.4	190	Y ($p < 0.001$)
8	3.51	-1.08	2.41	31.3	11.45	-0.19	9.54	83.0	Y ($p < 0.001$)
9	3.36	-114	1.67	173	17.8	-18.4	14.3	350	Y ($p < 0.001$)
10	8.01	-3.38	5.50	248	48.5	-0.64	30.1	599	Y ($p < 0.001$)
11	10.7	-2.53	8.02	225	40.7	-0.89	25.1	411	Y ($p < 0.001$)
12	4.94	-3.40	3.31	99.2	32.1	-35.0	21.2	750	Y ($p < 0.001$)
13	7.99	-35.8	4.18	809	23.9	-10.9	15.9	836	Y ($p < 0.001$)
14	4.47	-1.51	3.23	125	8.57	0.68	7.75	49.7	Y ($p < 0.001$)
15	6.39	1.51	6.22	18.9	8.51	-0.67	7.21	63.2	Y ($p < 0.001$)
16	8.05	-6.31	4.50	901	8.89	0.59	5.92	110	Y ($p < 0.001$)
17	3.16	-0.35	2.63	16.7	5.45	-1.55	3.62	32.3	Y ($p < 0.001$)
18	5.24	-1.83	3.48	56.7	6.33	-1.23	4.94	58.4	Y ($p < 0.001$)

*Y (yes) signifies a significant difference between upwind and downwind concentrations; N (no) signifies no significant difference between the two datasets.

Table 3. NH_3 1-hour average ambient air concentrations recorded at two mobile air monitoring stations

Measurement Period (#)	Mobile Station #1				Mobile Station #2			
	Mean (ppb)	Minimum (ppb)	Median (ppb)	Maximum (ppb)	Mean (ppb)	Minimum (ppb)	Median (ppb)	Maximum (ppb)
1	4.69	0.00	2.89	328	20.7	0.00	4.96	255
2	14.4	0.81	4.88	495	27.5	0.00	8.65	390
3	6.27	0.00	1.35	249	14.9	0.00	3.64	236
4	19.3	0.34	2.47	402	10.4	0.00	1.57	184
5	12.0	0.00	4.65	88.5	11.1	0.18	7.44	76.8
6	9.55	1.61	7.56	120	7.53	0.79	6.01	47.2
7	14.8	1.54	6.21	140	3.76	0.00	1.47	41.3
8	5.59	0.00	4.14	49.1	6.74	0.00	6.00	37.9
9	7.06	0.00	4.03	79.9	14.3	0.04	9.51	161
10	11.7	0.00	7.44	88.3	24.1	0.60	10.8	170
11	13.4	0.00	9.99	131	19.6	0.00	9.08	134
12	8.11	0.19	3.86	101	18.0	0.24	5.89	251
13	10.9	0.00	4.78	298	17.3	0.00	8.30	169
14	4.24	0.00	2.86	58.0	6.95	0.48	5.84	81.5
15	7.08	1.69	6.42	42.8	6.44	1.20	5.71	23.1
16	4.84	0.00	3.36	117	5.53	0.17	3.48	191
17	3.30	0.02	2.64	15.5	3.93	0.00	2.85	27.9
18	2.09	0.00	0.82	20.6	8.51	0.00	5.42	70.3

Table 4. H_2S 1-minute average ambient air concentrations upwind and downwind of CFOs

Measurement Period (#)	Measurement Location								Significant Difference?* (α = 0.05)
	Upwind				Downwind				
	Mean (ppb)	Minimum (ppb)	Median (ppb)	Maximum (ppb)	Mean (ppb)	Minimum (ppb)	Median (ppb)	Maximum (ppb)	
1	0.40	-0.56	0.40	1.21	0.18	-0.67	0.16	2.30	Y (p < 0.001)
2	0.05	-0.83	0.03	1.15	0.07	-0.78	0.06	1.77	Y (p < 0.001)
3	0.06	-0.64	0.05	1.62	0.32	-0.68	0.19	6.01	Y (p < 0.001)
4	0.50	-0.53	0.56	1.48	0.31	-0.56	0.23	2.96	Y (p < 0.001)
5	0.55	-0.66	0.55	3.59	0.47	-0.98	0.45	27.5	Y (p < 0.001)
6	0.12	-0.52	0.12	1.50	0.17	-0.72	0.14	2.49	Y (p < 0.001)
7	0.05	-0.81	0.04	1.06	0.06	-0.69	0.04	12.7	N (p = 0.203)
8	0.13	-0.56	0.02	1.73	0.57	-0.53	0.57	14.7	Y (p < 0.001)
9	0.06	-0.68	0.05	1.85	0.42	-0.69	0.14	114	Y (p < 0.001)
10	0.28	-0.56	0.25	9.08	0.36	-0.64	0.33	4.07	Y (p < 0.001)
11	0.20	-0.74	0.17	4.94	0.23	-0.83	0.19	3.18	Y (p < 0.001)
12	0.31	-0.79	0.13	9.67	0.36	-0.63	0.19	8.65	Y (p < 0.001)
13	0.23	-0.76	0.11	19.4	0.63	-0.43	0.57	9.66	Y (p < 0.001)
14	0.44	-0.38	0.46	1.30	0.32	-0.44	0.29	2.13	Y (p < 0.001)
15	0.21	-0.62	0.16	2.30	0.42	-0.54	0.24	30.2	Y (p < 0.001)
16	0.08	-0.63	0.06	1.28	0.42	-0.70	0.23	9.23	Y (p < 0.001)
17	0.20	-0.69	0.10	9.36	0.92	-0.39	0.58	16.3	Y (p < 0.001)
18	0.19	-0.66	0.16	7.34	0.34	-0.39	0.32	3.80	Y (p < 0.001)

*Y (yes) signifies a significant difference between upwind and downwind concentrations; N (no) signifies no significant difference between the two datasets.

values of some minimum 1-minute average concentrations presented in Table 4 are indicative of the responses of the analyzers.

In addition, the time series distribution plots presented in Appendix C suggest the presence of baseline shifts in the measurements by the H_2S analyzers at either mobile station in 10 of the 18 measurement periods. According to Air Resource Specialists Inc., baseline shifts are defined by the extended length of time instrument (analyzer) readings are elevated, typically greater than 24 hours, regardless of the upwind or downwind orientation of the respective monitoring station. Such baseline shifts may be ascribed to systematic error.

Statistically, there were significant differences between the upwind and downwind 1-minute average concentrations in 17 of the 18 measurement periods. However, in four of those 17 measurement periods, higher 1-minute averages were recorded at the upwind station as implied by the higher mean and median values. In the other 13 measurement periods, the downwind 1-minute average concentrations were higher than the upwind concentrations. Of these, baseline shifts appear to have occurred in six of the 13 measurement periods. However, it is uncertain what effect, if any, baseline shifts may have had on the significantly higher downwind concentrations in the 13 measurement periods. In general, the results suggest that the CFOs contributed to higher downwind H_2S levels 72% of the time over the 14-month study period.

Table 5 shows the mean, minimum, median and maximum 1-hour average H_2S concentrations measured at each mobile station with respect to all wind directions in each measurement period. The 1-hour average concentrations ranged between 0.00 ppb and 6.59 ppb, and 0.00 ppb and 22.8 ppb at mobile stations one and two, respectively.

A total of two exceedances of the 1-hour average AAQO for H_2S were recorded at mobile station two during the study. Upon further review, only one of the two exceedances seemed to have occurred as a result of emissions from the direction of the respective CFO. This exceedance occurred during measurement period nine when the downwind H_2S concentration was significantly higher than the upwind concentration, thus further supporting the notion that the exceedance was likely due to the CFO. There was no record of a specific or peculiar activity or event that may have triggered the exceedance, either at the CFO or in the vicinity of the CFO.

A comparison of the averaged 24-hour concentration measurements to the 24-hour average AAQO for H_2S signified that no exceedance of the latter AAQO occurred during the study.

4.3 Particulate Matter

4.3.1 Particles 2.5 μm in Size

Table 6 shows the 1-minute average $PM_{2.5}$ concentrations measured upwind and downwind of the CFOs over the 14-month period. The mean 1-minute average upwind and downwind

Table 5. H_2S 1-hour average ambient air concentrations recorded at two mobile air monitoring stations

Measurement Period (#)	Mobile Station #1				Mobile Station #2			
	Mean (ppb)	Minimum (ppb)	Median (ppb)	Maximum (ppb)	Mean (ppb)	Minimum (ppb)	Median (ppb)	Maximum (ppb)
1	0.45	0.14	0.45	0.81	0.16	0.00	0.13	0.76
2	0.05	0.00	0.02	0.49	0.09	0.00	0.05	0.72
3	0.08	0.00	0.03	0.78	0.12	0.00	0.05	1.46
4	0.07	0.00	0.03	0.56	0.63	0.35	0.62	1.29
5	0.65	0.30	0.63	2.63	0.31	0.00	0.25	3.80
6	0.12	0.00	0.09	0.71	0.24	0.00	0.17	2.02
7	0.05	0.00	0.00	1.55	0.11	0.00	0.05	0.68
8	0.15	0.00	0.01	6.59	0.56	0.19	0.50	1.74
9	0.14	0.00	0.08	4.75	0.22	0.00	0.09	22.8
10	0.23	0.00	0.19	2.90	0.45	0.00	0.40	8.82
11	0.17	0.00	0.13	1.06	0.21	0.00	0.18	1.05
12	0.24	0.00	0.07	3.97	0.27	0.00	0.12	2.26
13	0.19	0.00	0.06	2.48	0.71	0.33	0.62	2.70
14	0.51	0.23	0.48	1.18	0.14	0.00	0.12	0.69
15	0.11	0.00	0.07	2.97	0.25	0.00	0.15	4.81
16	0.13	0.00	0.01	5.53	0.08	0.00	0.00	2.55
17	0.17	0.00	0.06	4.74	0.61	0.00	0.43	3.76
18	0.08	0.00	0.00	2.16	0.46	0.21	0.44	2.04

Table 6. $PM_{2.5}$ 1-minute average ambient air concentrations upwind and downwind of CFOs

Measurement Period (#)	Upwind Mean ($\mu g\ m^{-3}$)	Upwind Minimum ($\mu g\ m^{-3}$)	Upwind Median ($\mu g\ m^{-3}$)	Upwind Maximum ($\mu g\ m^{-3}$)	Downwind Mean ($\mu g\ m^{-3}$)	Downwind Minimum ($\mu g\ m^{-3}$)	Downwind Median ($\mu g\ m^{-3}$)	Downwind Maximum ($\mu g\ m^{-3}$)	Significant Difference?* ($\alpha = 0.05$)
1	7.57	0.46	6.03	34.7	10.4	0.52	6.76	499	Y ($p < 0.001$)
2	7.57	0.24	4.28	36.1	8.50	0.41	4.99	81.4	Y ($p < 0.001$)
3	3.33	0.38	2.82	36.1	4.16	0.67	3.33	51.7	Y ($p < 0.001$)
4	4.10	0.54	3.21	57.0	4.18	0.63	3.31	27.1	N ($p = 0.086$)
5	5.80	0.12	1.77	90.3	5.75	0.17	1.92	67.7	Y ($p < 0.001$)
6	15.4	0.35	11.6	81.3	15.4	0.39	12.1	73.2	N ($p = 0.396$)
7	7.83	0.12	5.56	52.3	8.03	0.08	5.63	56.4	Y ($p < 0.001$)
8	28.1	0.12	4.03	588	29.3	0.18	3.83	600	N ($p = 0.092$)
9	6.13	0.12	4.30	256	5.95	0.11	4.44	76	N ($p = 0.514$)
10	15.9	0.61	12.0	100	17.7	0.75	13.3	123	Y ($p < 0.001$)
11	14.9	0.67	9.83	76.9	16.8	1.11	12.0	144	Y ($p < 0.001$)
12	7.16	0.62	6.50	81.5	8.88	0.92	7.53	205	Y ($p < 0.001$)
13	6.76	0.36	4.16	232	9.34	0.43	5.30	258	Y ($p < 0.001$)
14	5.04	0.36	4.91	43.2	5.17	0.40	4.90	44.6	N ($p = 0.446$)
15	19.5	1.58	19.0	124	19.8	1.83	19.4	97.3	N ($p = 0.187$)
16	5.99	0.12	5.23	35.3	5.88	0.19	5.45	84.6	N ($p = 0.435$)
17	13.8	1.10	12.1	58.5	14.4	1.21	12.3	60.0	N ($p = 0.146$)
18	20.1	0.62	15.3	205	19.1	0.50	15.4	68.4	N ($p = 0.375$)

*Y (yes) signifies a significant difference between upwind and downwind concentrations; N (no) signifies no significant difference between the two datasets.

concentrations ranged between 3.33 μg m^{-3} and 28.1 μg m^{-3}, and 4.16 μg m^{-3} and 29.3 μg m^{-3}, respectively.

Table 6 indicates significant differences between the upwind and downwind 1-minute average concentrations in nine of the 18 measurement periods over the 14-month study period. In eight (44%) of those nine periods, the downwind concentrations were higher than the upwind concentrations as implied by the higher mean, median and percentile values. Although a significant difference also existed between the upwind and downwind concentrations in the fifth measurement period, it is uncertain if the downwind concentrations were higher than the upwind concentrations since the mean and 90th percentile values were higher upwind, but the median, 10th percentile, 25th percentile and 75th percentile values were higher downwind. In other words, there is greater certainty that the downwind concentrations were significantly higher than the upwind concentrations 44% of the time over the course of the 14-month study.

Table 7 shows the mean, minimum, median and maximum 1-hour average $PM_{2.5}$ concentrations measured at each mobile station with respect to all wind directions in each measurement period. The 1-hour average concentrations ranged between 0.13 μg m^{-3} and 477 μg m^{-3}, and 0.19 μg m^{-3} and 510 μg m^{-3} at mobile stations one and two, respectively.

In comparison to the 1-hour and 24-hour average AAQOs for $PM_{2.5}$, a total of 1,350 exceedances and four exceedances, respectively, were recorded at the mobile stations relative to all wind directions. Of the 1,350 1-hour average $PM_{2.5}$ exceedances, 24 exceedances seemed to be attributable to the CFOs. However, it is highly uncertain if the CFOs were partially or wholly responsible for the exceedances for a couple of reasons.

First, there were periods of time during the 14-month study when wind direction or $PM_{2.5}$ concentrations were not measured at the upwind station either because calm (no wind) conditions prevailed, wind sensors malfunctioned, generator power supply was interrupted or a station was shutdown prior to the move to the next CFO. The wind sensors were observed to malfunction when frost or ice accumulated on the anemometers. All such interruptions to the data collection sequence were flagged and duly noted by the data management specialist in the dataset associated with the respective measurement period. Thus, because $PM_{2.5}$ concentration data were not available at certain times during the study it is impossible to ascertain if secondary sources of $PM_{2.5}$ emissions (situated upwind of the upwind mobile station) may have influenced the measurements at the downwind mobile station in those specific time periods.

Second, the mobile stations were situated in close proximity to gravel or paved roads, or cultivated cropland. Typically, these roads or cultivated fields were located between the CFO and the mobile stations which suggests that these secondary sources of emissions may have been partially or wholly responsible for the exceedances.

Table 7. $PM_{2.5}$ 1-hour average ambient air concentrations recorded at two mobile air monitoring stations

Measurement Period (#)	Mobile Station #1				Mobile Station #2			
	Mean (μg m^{-3})	Minimum (μg m^{-3})	Median (μg m^{-3})	Maximum (μg m^{-3})	Mean (μg m^{-3})	Minimum (μg m^{-3})	Median (μg m^{-3})	Maximum (μg m^{-3})
1	8.00	0.57	6.36	26.6	9.00	0.59	6.59	105
2	5.33	0.30	2.83	34.6	6.53	0.40	3.73	51.1
3	3.89	0.28	3.08	18.2	4.24	0.37	3.39	33.3
4	3.72	0.41	3.04	21.8	3.99	0.66	3.30	15.4
5	6.00	0.18	3.18	41.9	6.81	0.29	3.69	44.8
6	18.4	0.38	13.2	71.6	18.0	0.40	11.6	71.4
7	6.57	0.13	5.45	43.2	6.80	0.19	5.39	49.2
8	27.6	0.14	5.79	477	24.0	0.23	6.68	510
9	6.84	0.32	4.97	50.9	6.99	0.31	5.26	43.2
10	18.2	1.00	16.8	59.7	17.7	1.10	14.9	65.1
11	12.9	0.33	7.81	68.3	15.4	1.04	11.4	70.8
12	7.00	0.54	5.56	53.2	8.52	1.34	6.77	115
13	8.37	0.42	6.02	91.7	11.03	0.80	7.07	119
14	6.02	0.30	4.67	38.5	6.26	0.37	5.09	28.0
15	20.9	1.11	17.1	116	22.2	1.02	19.2	124
16	5.91	0.37	4.94	28.2	6.34	0.45	5.52	24.2
17	15.4	1.03	10.2	84.7	17.0	1.47	11.6	70.3
18	14.2	0.63	11.4	52.4	15.3	0.66	11.9	58.2

On the other hand, none of the four 24-hour average TSP AAQO exceedances could be attributed to the CFOs either because the wind direction between the two stations was out of range or the concentrations measured at the upwind station signified the presence of a potential secondary source of emissions located upwind of the upwind station.

4.3.2 Total Suspended Particulates

Table 8 shows the upwind and downwind 1-minute average TSP concentrations measured over the course of the 14-month study. The mean 1-minute average upwind and downwind concentrations ranged between 7.62 μg m^{-3} and 61.0 μg m^{-3}, and 7.86 μg m^{-3} and 94.6 μg m^{-3}, respectively.

The results of the statistical comparison between the upwind and downwind 1-minute average concentration datasets indicated significant differences between the two datasets in 13 of the 18 measurement periods during the study. As shown in Table 8, the corresponding mean and median 1-minute average concentrations in the 13 measurement periods were higher at the downwind location relative to the upwind location. Consequently, the results suggest that the downwind concentrations were significantly higher than the upwind concentrations approximately 72% of the time in the 14-month study period.

Table 9 shows the mean, minimum, median and maximum 24-hour average TSP concentrations measured at each mobile station with respect to all wind directions in each measurement period. The 1-hour average concentrations ranged between 0.40 μg m^{-3} and 248 μg m^{-3}, and 0.70 μg m^{-3} and 272 μg m^{-3} at mobile stations one and two, respectively.

During the study, a total of 45 exceedances of the 24-hour average TSP AAQO were recorded that corresponded to measurements taken at both air monitoring stations and all wind directions. Of these, six exceedances appeared to be attributable to the CFOs. Similar to the discussion in the previous section, it is uncertain if the CFOs were primarily responsible for the exceedances owing to the presence of paved and gravel roads or cultivated cropland in close proximity to the stations, and periods of time during which there were no recorded TSP concentration or wind direction data.

4.4 Volatile Organic Compounds

Table 10 shows the converted (ppb) 1-minute average NMHC concentrations that were measured upwind and downwind of the CFOs over the course of the 14-month study. The mean 1-minute average upwind and downwind concentrations ranged between -0.10 ppb and 21.0 ppb, and 0.00 ppb and 49.3 ppb, respectively. The negative values of the minimum 1-minute average concentrations presented in Table 10 are indicative of the responses of the analyzers. Furthermore, the time series distribution plots (Appendix C) signify that over the entire study period, higher NMHC concentrations seemed prevalent at mobile station two irrespective of the direction of the incident wind. Again, this raises the question of the possible influence of systematic error on the data obtained from that station.

Table 8. TSP 1-minute average ambient air concentrations upwind and downwind of CFOs

Measurement Period (#)	Measurement Location: Upwind				Measurement Location: Downwind				Significant Difference?* (α = 0.05)
	Mean (µg m^{-3})	Minimum (µg m^{-3})	Median (µg m^{-3})	Maximum (µg m^{-3})	Mean (µg m^{-3})	Minimum (µg m^{-3})	Median (µg m^{-3})	Maximum (µg m^{-3})	
1	12.8	0.55	7.78	185	35.6	0.67	11.7	1,000	Y (p < 0.001)
2	24.0	0.32	16.8	1,000	64.2	0.43	27.1	1,000	Y (p < 0.001)
3	13.4	0.34	6.16	600	52.3	0.76	12.5	1,000	Y (p < 0.001)
4	14.2	0.63	6.80	329	23.9	0.74	7.94	922	Y (p < 0.001)
5	7.62	0.12	2.14	115	7.86	0.12	2.74	215	Y (p < 0.001)
6	18.4	0.31	12.8	434	16.8	0.40	13.1	169	N (p < 0.796)
7	45.6	0.12	14.6	1,000	62.5	0.12	19.2	1,000	Y (p < 0.001)
8	44.1	0.12	9.53	1,000	49.2	0.20	11.9	1,000	Y (p < 0.001)
9	16.0	0.12	8.67	884	23.6	0.15	9.68	1,000	Y (p < 0.001)
10	17.5	0.55	13.0	328	25.0	0.77	18.6	364	Y (p < 0.001)
11	28.8	0.84	22.0	628	47.2	1.14	33.5	655	Y (p < 0.001)
12	27.8	0.58	13.0	1,000	54.2	1.38	26.1	1,000	Y (p < 0.001)
13	61.0	0.31	17.2	1,000	94.6	0.56	30.9	1,000	Y (p < 0.001)
14	18.7	0.31	8.12	160	18.9	0.42	8.68	252	N (p = 0.285)
15	21.5	1.53	20.3	135	22.2	1.88	21.0	130	Y (p = 0.011)
16	57.4	0.12	9.53	728	57.7	0.26	11.7	1,000	N (p = 0.237)
17	30.9	1.53	22.6	477	32.7	1.88	23.0	923	N (p = 0.486)
18	23.1	0.55	16.1	616	21.3	0.48	16.5	205	N (p = 0.406)

*Y (yes) signifies a significant difference between upwind and downwind concentrations; N (no) signifies no significant difference between the two datasets.

Table 9. TSP 24-hour average ambient air concentrations recorded at two mobile air monitoring stations

Measurement Period (#)	Mobile Station #1				Mobile Station #2			
	Mean (μg m^{-3})	Minimum (μg m^{-3})	Median (μg m^{-3})	Maximum (μg m^{-3})	Mean (μg m^{-3})	Minimum (μg m^{-3})	Median (μg m^{-3})	Maximum (μg m^{-3})
1	13.5	1.90	12.5	26.4	35.0	3.90	21.2	170
2	22.1	3.80	19.9	55.1	37.5	6.40	26.1	117
3	16.0	6.40	13.6	53.0	24.9	10.0	21.0	58.2
4	15.2	1.70	9.20	46.9	17.7	4.00	14.4	38.5
5	7.60	0.70	5.65	17.9	11.1	1.40	6.60	42.7
6	20.2	2.50	15.1	58.4	20.4	3.10	13.3	55.1
7	40.9	0.40	27.5	180	41.4	0.70	30.2	140
8	46.9	1.00	20.0	164	40.7	1.80	20.8	185
9	20.8	1.20	20.0	52.0	22.1	2.10	21.7	53.1
10	21.0	5.40	17.4	43.6	20.5	7.10	17.7	44.3
11	30.6	4.30	25.4	63.4	36.9	25.2	34.6	50.8
12	32.9	8.50	24.9	86.2	47.0	6.60	31.5	119
13	85.4	23.1	67.1	248	119	14.1	117	272
14	18.8	2.80	19.4	37.4	20.8	3.70	18.5	43.2
15	22.9	3.60	24.7	44.4	24.3	3.10	26.0	56.3
16	65.9	4.60	35.2	188	63.4	5.70	41.7	181
17	34.5	11.3	31.6	77.2	34.8	13.4	29.2	73.7
18	17.3	4.60	16.2	39.1	17.8	6.10	16.4	41.5

Table 10. NMHC 1-minute average ambient air concentrations upwind and downwind of CFOs

Measurement Period (#)	Measurement Location: Upwind				Downwind				Significant Difference?* ($p \leq 0.05$)
	Mean (ppb)	Minimum (ppb)	Median (ppb)	Maximum (ppb)	Mean (ppb)	Minimum (ppb)	Median (ppb)	Maximum (ppb)	
1	4.40	-1.00	0.00	0.28	15.3	-1.00	0.00	0.85	Y ($p < 0.001$)
2	0.40	-1.00	0.00	264	2.80	-10.0	0.00	887	Y ($p < 0.001$)
3	0.10	-21.0	0.00	306	0.40	-21.0	0.00	249	Y ($p < 0.001$)
4	1.20	-18.0	0.00	391	0.60	-20.0	0.00	192	N ($p = 0.078$)
5	0.20	-1.00	0.00	40.0	0.40	-1.00	0.00	100	N ($p = 0.089$)
6	16.8	-17.0	2.00	200	9.80	-1.00	0.00	241	Y ($p < 0.001$)
7	0.10	-21.0	0.00	76	0.20	-20.0	0.00	102	Y ($p < 0.001$)
8	0.20	-1.0	0.00	82.0	4.20	-19.0	0.00	281	Y ($p < 0.001$)
9	0.40	-12.0	0.00	200	2.50	-20.0	0.00	173	Y ($p < 0.001$)
10	21.0	-1.00	0.00	17,015	49.3	-2.00	0.00	264	Y ($p < 0.001$)
11	7.20	-18.0	0.00	141	10.6	-14.0	0.00	222	Y ($p < 0.001$)
12	0.00	-20.0	0.00	57	0.90	-19.0	0.00	159	Y ($p < 0.001$)
13	0.20	-1.00	0.00	116	1.30	-18.0	0.00	429	Y ($p < 0.001$)
14	1.20	-1.00	0.00	89.0	1.20	-1.00	0.00	121	Y ($p = 0.007$)
15	19.8	-13.0	0.00	170	4.70	-18.0	0.00	174	Y ($p < 0.001$)
16	-0.10	-16.0	0.00	14.0	0.00	-2.00	0.00	1.00	Y ($p < 0.001$)
17	3.90	-1.00	0.00	1,922	0.20	-13.0	0.00	49.0	N ($p = 0.718$)
18	11.0	-18.0	0.00	161	13.7	-1.00	0.00	161	N ($p = 0.320$)

*Y (yes) signifies a significant difference between upwind and downwind concentrations; N (no) signifies no significant difference between the two datasets.

The maximum 1-minute average concentrations recorded at the upwind station during the 10th measurement period was 17,015 ppb, suggestive of an outlier, considered to be a value greater than the 75th percentile plus three times the interquartile range (IQR) or less than the 25th percentile minus three times the IQR. When potential outliers were removed from the upwind and downwind datasets, the mean upwind 1-minute average concentration decreased to 0.00 ppb while the mean downwind concentration (49.3 ppb) and median values (0.00 ppb) remained the same.

Statistically, the upwind and downwind 1-minute concentrations were significantly different in 14 of the 18 measurement periods. In 11 of those 14 periods, the downwind concentrations were higher than the upwind concentrations as indicated by the higher mean values. All the corresponding upwind and downwind median values remained at 0.00 ppb. In two of the 14 measurement periods, the mean upwind concentrations were higher than the downwind concentrations suggesting the presence of sources of NMHC emissions upwind of the mobile stations. The median upwind value was also higher in one of those two measurement periods. Finally, in the 14th measurement period, although a significant difference existed between the upwind and downwind 1-minute averages, there was no clear distinction between the two datasets with respect to the mean, median, or percentile values. Ultimately, the results of the statistical comparison between the upwind and downwind NMHC concentrations suggest that the CFOs contributed to significantly higher downwind NMHC concentrations approximately 61% of the time over the course of the 14-month study.

Table 11 shows the mean, minimum, median and maximum 1-hour average NMHC concentrations measured at each mobile station with respect to all wind directions in each measurement period. The 1-hour average concentrations ranged between 0.00 ppb and 475 ppb, and 0.00 ppb and 248 ppb at mobile stations one and two, respectively.

Hypothetically, there were 4,278 possible AAQO exceedances of the VOCs listed in Table 1 during the study. Of these, it appears that 401 possible AAQO exceedances could be attributed to emissions from the CFOs. However, it is uncertain whether or not a 1-hour average, 24-hour average or 3-day average AAQO exceedance actually occurred during the study since none of the VOCs listed in Table 1 were measured specifically. In other words, it is impossible to determine if any one of the VOCs listed in Table 1 actually constituted part or all of the NMHCs measured at either station. Similarly, if one or more of the VOCs did constitute a fraction of the NMHCs measured, it is equally impossible to determine what the specific VOCs were, what their concentrations were, or if their concentrations were in excess of their respective AAQO(s).

In addition, uncertainty is also introduced by the fact that the minimum detectable limit of the CH_4/NMHC analyzer was 0.02 ppm (or 20 ppb), as noted earlier. A review of the datasets indicates that 1-minute average concentration measurements as low as 0.001 ppm (or 1 ppb) were recorded. Thus, it is uncertain if readings below 0.02 ppm were a true representation of the NMHC concentration in the ambient air or were the result of other influences, including instrument noise (systematic error).

Table 11. NMHC 1-hour average ambient air concentrations recorded at two mobile air monitoring stations

Measurement Period (#)	Mobile Station #1				Mobile Station #2			
	Mean (ppb)	Minimum (ppb)	Median (ppb)	Maximum (ppb)	Mean (ppb)	Minimum (ppb)	Median (ppb)	Maximum (ppb)
1	1.12	0.00	0.00	96.0	37.0	0.00	3.00	248
2	0.02	0.00	0.00	2.00	3.54	0.00	0.00	58.0
3	0.08	0.00	0.00	11.0	1.67	0.00	0.00	58.0
4	0.01	0.00	0.00	2.00	3.71	0.00	0.00	136
5	0.21	0.00	0.00	3.00	0.70	0.00	0.00	32.0
6	4.69	0.00	0.00	99.0	43.2	0.00	11.0	214
7	0.14	0.00	0.00	5.00	0.11	0.00	0.00	33.0
8	0.02	0.00	0.00	3.00	2.01	0.00	0.00	222
9	0.75	0.00	0.00	45.0	12.4	0.00	0.00	164
10	1.03	0.00	0.00	323	67.3	0.00	39.0	232
11	0.76	0.00	0.00	31.0	12.9	0.00	1.00	142
12	0.06	0.00	0.00	12.0	0.71	0.00	0.00	83.0
13	0.19	0.00	0.00	44.0	1.47	0.00	0.00	69.0
14	0.43	0.00	0.00	30.0	3.16	0.00	0.00	83.0
15	2.04	0.00	0.00	85.0	38.9	0.00	19.0	197
16	0.00	0.00	0.00	0.00	0.30	0.00	0.00	2.00
17	9.36	0.00	0.00	475	0.21	0.00	0.00	6.00
18	2.83	0.00	0.00	91.0	37.1	0.00	15.0	189

5. Conclusions and Recommendations

Following the 14-month study, 1-minute average concentrations of NH_3, H_2S, $PM_{2.5}$, TSP and NMHCs were obtained from a pair of mobile monitoring stations located at the MDS-1, both upwind and downwind of each of four CFOs. These 1-minute average data were used to determine 15-minute average, 1-hour average, 24-hour average and 3-day average data to facilitate the fulfillment of the study objectives.

The results of the study suggest that:

a. The CFOs contributed to significantly higher downwind ambient air NH_3 concentrations at the MDS-1 in comparison to the upwind concentrations. In other words, relative to the orientation of the mobile stations on either side of the CFOs, there were no other significant sources of NH_3 emissions on the upwind side of the CFOs.

b. Despite the significant contributions of the CFOs to the higher downwind NH_3 concentrations, no 1-hour average or 24-hour average AAQO exceedances occurred throughout the study.

c. The CFOs contributed to significantly higher downwind ambient H_2S concentrations 72% of the time during the study. This suggests that one or more secondary sources of emissions may have existed on the upwind side of the CFOs, and contributed to equivalent or higher ambient air concentrations 28% of the time.

d. H_2S emissions from one of the CFOs were the likely cause for a 1-hour average AAQO exceedance during the study. No 24-hour AAQO exceedance occurred during the study.

e. The CFOs may have contributed to significantly higher downwind ambient $PM_{2.5}$ concentrations 44% of the time during the study. However, the accuracy of this result is uncertain due to the possible influence of several other potential secondary sources of $PM_{2.5}$ emissions between and around the two mobile stations.

f. Twenty-four 1-hour average $PM_{2.5}$ AAQO exceedances that may be attributable to the CFOs were recorded during the study. Similar to (e) above, the accuracy of this result is uncertain not only for the reason provided above but also because of periods when data were unavailable due to interruptions at the mobile stations. No 24-hour AAQO exceedances were attributable to the CFOs.

g. TSP emissions from the CFOs may have been responsible for significantly higher downwind ambient concentrations 72% of the time during the study. Similar to the conclusion drawn in (e) above and for the reasons provided, the accuracy of this result is uncertain.

h. Six 24-hour average TSP AAQO exceedances attributable to the CFOs were recorded during the study. Again, for the reasons provided in (f) above, the accuracy of this outcome is uncertain.

i. The CFOs contributed to significantly higher downwind NMHC ambient concentrations 61% of the time during the study. It is possible but not certain that the NMHCs included CFO-related VOCs.

j. Although 401 possible VOC AAQO exceedances may have been caused by the CFOs, this result is highly uncertain due to the fact that CFO-related VOCs that may have constituted part or all of the NMHCs were not identified nor measured specifically.

Prospectively, the following recommendations are included to provide some insight and facilitate discussions or decision-making regarding studies of similar nature and intent.

i. Apparently, the performance of the analyzers and the effects of the source of power supply on the analyzer performance are critical to the outcome of AAQM studies. Potential risks associated with questionable instrument performance, noisy power supply and the influence of baseline shifts and other forms of systematic error on recorded measurements need to be better understood and accounted for.

ii. Where other secondary sources of the emissions-of-interest exist between the upwind or downwind air monitoring station and the primary (main) source of the emissions-of-interest, then the use of additional monitoring stations may have to be considered to help account for the effects of the secondary sources on the downwind measurements.

iii. Since potential VOC exceedances occurred during the study, studies should be conducted to investigate and identify VOCs found in emissions from different CFO sources and sub-sources in Alberta.

iv. As a follow-up to (c) above, studies should be conducted to measure ambient air concentrations of individual VOCs emitted by CFOs as listed in Alberta's AAQO. The emphasis should be on VOCs that pose the highest risk to human health, animal health or the environment.

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Appendix A

Ambient Air Quality Measurement Plan

AMBIENT AIR QUALITY MEASUREMENT AROUND CONFINED FEEDING OPERATIONS IN ALBERTA

AMBIENT AIR QUALITY MEASUREMENT PLAN

September 26, 2008

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Contents

Glossary

AAFC	Agriculture and Agri-Food Canada
AAQO	Ambient Air Quality Objective
AAQOSAC	Ambient Air Quality Objectives Stakeholder Advisory Committee
AENV	Alberta Environment
AHW	Alberta Health and Wellness
AMD	Air Monitoring Directive
AOPA	Agricultural Operation Practices Act and Regulations
AQM	Air Quality Measurement
ARD	Alberta Agriculture
CASA	Clean Air Strategic Alliance
CCME	Canadian Council of Ministers of the Environment
CD	Compact Disk
CFO	Confined Feeding Operation
CH_4	Methane
DQO	Data Quality Objective
EC	Environment Canada
EPEA	Environmental Protection and Enhancement Act
FID	Flame Ionization Detection
FOIP	Freedom of Information and Protection of Privacy
GC	Gas Chromatography
GPS	Global Positioning System
H_2S	Hydrogen Sulphide
ILWG	Intensive Livestock Working Group
INMS	Institute for National Measurement Standards
MDS	Minimum Distance Separation
NH_3	Ammonia
NMHC	Non-Methane Hydrocarbons
NRCB	Natural Resource Conservation Board
PAML	Purdue Applied Meteorology Laboratory
PAMZ	Parkland Airshed Monitoring Zone
PASZA	Peace Airshed Zone Association
PM	Particulate Matter
QA	Quality Assurance
QC	Quality Control

SAGE	Southern Alberta Group for the Environment
SOP	Standard Operating Procedure
SUI	Set-Up Instructions
THC	Total Hydrocarbons
TSP	Total Suspended Particulates
USEPA	United States Environmental Protection Agency
VOC	Volatile Organic Compound
ppb_v	Parts per Billion by Volume
$\mu g.m^{-3}$	Micrograms of NH_3, H_2S, PM or VOC in One Cubic Metre of Air

1. Introduction

In March 2008, the Clean Air Strategic Alliance (CASA) board of directors released a strategic plan developed by the Confined Feeding Operation (CFO) multi-stakeholder project team. In one of its ten recommendations, the plan recommended that Alberta Agriculture and Rural Development (ARD):

a. Develop, with input from all stakeholders, an ambient monitoring plan for ammonia (NH_3), hydrogen sulphide (H_2S), particulate matter (PM) and volatile organic compounds (VOCs) to determine current ambient levels around CFOs. The plan will include timelines, budget, methodology (with reference to the air monitoring directive) and, responsibilities.

b. Undertake ambient air monitoring of NH_3, H_2S, PM and VOCs around CFOs based on the above plan and beginning in 2008.

c. Submit a status report by March 31, 2009, with a final report on results to be submitted by March 31, 2010 to CFO project team stakeholders and the Alberta Ambient Air Quality Objectives Stakeholder Advisory Committee (AAQOSAC)[1].

As opposed to source emission measurement, ambient air measurement (AQM) implies the measurement of the concentration of a substance in the air at a given location or distance relative to the source or origin of the substance and, over a fixed time period, only after that substance has had the opportunity to disperse into the atmosphere. With regards to livestock operations, ambient AQMs are not conducted immediately in front of an air exhaust port of a livestock building where substances of interest have not had the opportunity to mix with the atmospheric or ambient air. Similarly, ambient AQMs are not conducted immediately above or around the perimeter of non-point sources of emissions, such as outdoor manure storage facilities, since the emitted substances would not likely have had the opportunity to disperse and mix with the ambient air.

1.1 Other Ambient AQM Studies in Alberta

Alberta Environment (AENV), Environment Canada (EC) and a few Airshed Zones in Alberta, such as, Parkland Airshed Monitoring Zone (PAMZ) and Peace Airshed Zone Association (PASZA), have measured ambient air quality around CFOs in Alberta in the past and, in some cases, continue to do so. However, it is important to note that the specific purposes and mandates of these other studies differ from those of this study. As such, it is not the intent of this study to replicate the other studies. Furthermore, although data obtained from the other studies will only be compared to data from this study out of interest, those data will not be used to validate the results of this study.

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[1] AAQOSAC is a working group established by AENV. The group hosts priority-setting workshops every 3 to 4 years to identify AAQOs priority substances for review and development.

2. AQM Objectives

The primary objective of this study is to determine current ambient air concentrations of NH_3, H_2S, PM and VOCs (acetic acid and non-methane hydrocarbons) at the minimum distance separation (MDS), upwind and downwind of beef feedlot, dairy cow, swine and poultry CFOs in Alberta.

The secondary objective of this study is to compare levels of NH_3, H_2S, PM and VOCs at specified location around the CFOs to Alberta ambient air quality objectives (AAQOs).

Alberta's AAQOs were developed under the Alberta Environmental Protection and Enhancement Act (EPEA). These objectives are equal to or more stringent than existing National Ambient Air Quality Objectives (CCME, 1999) and Canada Wide Standards (CCME, 2000). In circumstances whereby no National Ambient Air Quality Objectives or Canada Wide Standards exist, Alberta has developed its own objectives or adopted objectives from other jurisdictions. Air quality objectives are generally established for one-hour, 24-hour, and annual averaging periods and are based on an evaluation of scientific, social, technical, and economic factors.

AENV works with a variety of stakeholders, including other government departments, the scientific community, environmental organizations, industry and the general public to prioritize substances and to review AAQOs. Some uses of the AAQOs include: (1) comparisons to actual AQMs; (2) reporting on the state of Alberta's environment; (3) special ambient air quality surveys; (4) current air quality through the Air Quality Index; and (5) design of industrial facilities.

AAQOs for NH_3, H_2S, PM and VOCs are presented in the sections below.

2.1 Ammonia

Averaging Period	Limit		Comments
	($\mu g.m^{-3}$)	(ppb_v)	
1-hour	1,400	2,000	The 1-hour average AAQO for NH_3 is based on the odour perception of an unspecified percentage of the population.
24-hour	200	286	AENV has not established a 24-hour average AAQO for NH_3. However, such a limit has been proposed and is under review by AAQOSAC[2].

[2] Following a review of the AAQO for NH_3 by AAQOSAC, the committee did not recommend any changes to the 1-hour objective. However, a new 24-h objective was proposed relative to the health effects threshold of highly sensitive individuals reported by Holness et al. (1989).

2.2 Hydrogen Sulphide

Averaging Period	Limit (μg.m⁻³)	(ppb_v)	Comments
	$(\mu g.m^{-3})$	(ppb_v)	
1-hour	14	10	The 1-hour average AAQO for H_2S is based on the odour perception of an unspecified percentage of the population.
24-hour	4	3	The basis of the 24-hour average AAQO for H_2S is unspecified.

2.3 Particulate Matter

PM with particle sizes 2.5 microns ($PM_{2.5}$) or smaller and, total suspended particulates are of interest to this study.

2.3.1 Particle Sizes 2.5 Microns or Smaller

This is a measure of all particle sizes with an aerodynamic diameter of 2.5 μm or less.

Averaging Period	Limit		Comments
	$(\mu g.m^{-3})$	(ppb_v)	
1-hour	80		The 1-hour average AAQO for $PM_{2.5}$ or smaller is based on the Canada Wide Standard (2000). The Canada Wide Standard for $PM_{2.5}$ is intended to minimize the risks particulate matter can have on human health and the environment. It is a balance between achieving the best short-term health and environmental protection and the feasibility and costs of reducing the pollutant emissions that contribute to elevated levels.
24-hour	30		The 24-hour average AAQO for $PM_{2.5}$ or smaller is based on the Canada Wide Standard (2000).

2.3.2 Total Suspended Particulates

This is a measure of all particles suspended in the air, regardless of size.

Averaging Period	Limit		Comments
	$(\mu g.m^{-3})$	(ppb_v)	
24-hour	100		The 24-hour average AAQO for total suspended particulates (TSP) is based on pulmonary effects in an unspecified percentage of the population

2.4 Volatile Organic Compounds

Only a limited number of studies appear to have been conducted on VOCs emitted from livestock, livestock manure or livestock housing facilities. In one study, over 300 VOCs were identified in the emissions from swine operations (Schiffman et al., 2001). From the relatively few studies found, acetic acid and phenol seem to be two VOCs common to cattle, pigs and poultry (chickens) and, among VOCs with established AAQOs.

Individual VOCs are expensive to measure regardless of the measurement technique used. The original intent of this study was to measure only acetic acid (see appendix I for AAQOs) because its levels have been reported to be relatively high compared to other VOC emissions associated with cattle and pig activities (Shaw et al., 2007; McGinn et al., 2003; Schiffman et al., 2001). However, due to the limited financial resources available to conduct this study and the expense associated with the measurement of acetic acid using standardized integrated sampling and analysis methodologies, the multi-stakeholder advisory group responsible for developing the ambient AQM plan collectively agreed to limit the scope of the study to the measurement of non-methane hydrocarbons only.

2.4.1 Non-methane Hydrocarbons

Levels of total hydrocarbons and methane in the air will be measured and the difference in concentration between the two will be used to determine levels of non-methane hydrocarbons (NMHC). Although, the specific compounds that constitute the non-methane hydrocarbons will not be identified and therefore cannot be compared to any of the objectives, awareness of the total non-methane hydrocarbons will offer some perspective to the levels of non-methane hydrocarbons downwind from CFOs. Levels lower than any of the limits outlined in the AAQOs for various VOCs will signify that VOC emissions from CFOs are not a concern. If the levels are higher than some or all the VOCs listed in the objectives then additional studies may be warranted to identify and measure specific VOCs. Such studies are beyond the scope of this study.

2.5 Types of Livestock

There are four livestock CFO categories or commodity groups (AOPA, 2005a) of interest to this study. These commodity groups include beef (beef feedlot), dairy (dairy cow), swine (pig) and poultry (chicken or turkey) operations. They also rank as the highest number of livestock CFOs relative to all types of CFOs in Alberta. According to the Natural Resource Conservation Board (NRCB), the number of geese, duck, sheep, horse, goat, bison, cervid (deer-like) or wild boar CFOs in the province are very few. For instance, there is only one known bison CFO in Alberta. Therefore, concentrations of NH_3, H_2S, PM and VOCs will be measured in the air only around a beef feedlot CFO, a dairy cow CFO, a swine CFO and a poultry CFO.

3. Site Selection

Three site selection options were given due consideration by the multi-stakeholder advisory group. Of the three options, independent ambient AQMs around a few randomly selected CFOs in the province was chosen as the preferred option. The alternative options given due consideration by the group are presented in Appendix II of this document.

One of the benefits of the preferred approach is that background (benchmark) information relative to the individual CFOs can be obtained from the study. This will provide the opportunity to revisit these CFOs in the future in order to determine what, if any, impact new or alternate management practices or changes in production capacity, may have on ambient air quality. Hence, ambient air quality will be measured around one CFO per livestock commodity group in each season. In other words, within each climatic season, air quality will be measured around a total of four CFOs, one each from each of the four livestock commodity groups of interest to the study.

It is equally important to note that the AQM data that will be obtained based on the preferred site selection option would be extremely limited in its ability to statistically represent air quality around CFOs from the four livestock commodity groups in Alberta. Consequently, the data obtained with respect to this study will be specific to each CFO participating in the study and cannot be extrapolated to represent air quality around any other or all CFOs in Alberta.

3.1 Size Class Eligibility

Statistics Canada 2006 census of agriculture classifies farms participating in its survey into different size classes (Table 1). These classifications include farms with as few as one animal to as many as tens of thousands of animals per farm. However, it would not be worth the resources invested in the ambient AQM study if a farm with only one livestock animal on it, within any of the livestock commodity groups, were randomly selected as one of the CFOs short-listed for this study. This is because it is extremely unlikely (or only in rather unusual circumstances) that ambient air quality levels based on emissions relative to one or few animals would register at levels significantly above background levels. Also note that the census data does not distinguish between animals on mixed livestock farms or single commodity farms.

Hence, AOPA (2005b) was consulted to help identify CFOs of a certain animal capacity that are assumed to have an impact on ambient air quality greater than background levels. The "number of animals" classification outlined in AOPA (2005b) is presented in Table 2. It specifies the minimum number, or range of numbers, of animals for which a new or expanding CFO requires a registration or approval license in order to commence construction of an animal housing facility or manure storage facility, and subsequently, production at the licensed capacity. The size classes identified for the purpose of this study and the basis for selecting these size classes relative to the different livestock commodity groups are presented below.

Table 1. Livestock size classes adopted from Statistics Canada 2006 Census of Agriculture

Livestock Commodity Group	Animal Numbers in Each Size Class									
	#1	#2	#3	#4	#5	#6	#7	#8	#9	#10
Beef Cattle (Feeding Operations: Steers and Feeder Heifers)	Less than 65	65 - 134	135 – 274	275 - 699	700 - 1,000	1,001 - 5,000	5,001 - 10,000	10,001 - 15,000	15,001 - 20,000	More than 20,000
Dairy Cattle (Dairy Cows)	1 - 17	18 - 47	48 – 77	78 - 122	123 - 177	More than 177				
Poultry:										
Total Hens and Chickens	1 - 99	100 - 999	1,000 - 9,999	10,000 - 19,999	20,000 - 29,999	More than 29,999				
Turkey	1 - 49	50 - 249	250 - 999	More than 999						
Swine (Total Pigs)	1 - 77	78 - 272	273 - 527	528 - 1,127	1,128 - 2,652	2,653 - 4,684	More than 4,684			

Table 2. Number of animals associated with regulated CFOs (adapted from AOPA, 2005b)

CFO Livestock Commodity Group	Type	Number of Animals	
		Registration	Approval
Beef Cattle	Cows/Finishers (900+ lb)	150 - 349	More than 349
	Feeders (450 - 900 lb)	200 – 499	More than 499
Dairy Cattle	Lactating cows only[1]	50 – 199	More than 199
Poultry	Chicken - breeders[2]	1,000 - 15,999	More than 15,999
Swine	Farrow only (sows)	60 - 1,249	More than 1,249
	Feeders and Boars	500 - 3,299	More than 3,299
	Growers/Roasters	500 - 5,999	More than 5,999
	Weaners	500 - 8,999	More than 8,999

[1] Dries, heifers and calves are not counted.

[2] Among all poultry sub-categories, chicken breeders is the sub-category where the least number of animal are required in order to obtain either a registration or approvals license.

3.1.1 Beef Cattle

The 2008 estimate of cattle statistics (Statistics Canada, 2008) suggests that a predominance (approximately 72%) of steers and feeder heifers on feeding operations (beef feedlots) in Alberta are animals that weigh over 900 lbs (408 kg). Since the minimum number of animals in AOPA for beef cattle of this type and weight category is 150 (Table 2), only those CFOs that at any given time raise at least 150 steers and feeder heifers weighing over 900 lbs will be considered prospective CFOs to be selected for the intended AQM activity. According to Statistics Canada 2006 census of agriculture size class classification (Table 1), this corresponds to those CFOs that are in size classes 3 (note, the minimum requirement is 150 animals) to 10.

3.1.2 Dairy Cattle

AOPA (2005b) requires a CFO that is intending to milk a minimum of 50 cows to obtain a registration license (Table 2). Therefore, for the purposes of this study, CFOs with number of animals in size classes 3 (note, the minimum requirement is 50 animals) to 6 (Table 1) are eligible to be considered as prospective operations for the intended AQM activity.

3.1.3 Poultry

As shown in Table 2, the least number of birds required to grant poultry operations a license of registration by AOPA (2005b) is 1,000. Incidentally, this minimum requirement applies to most chicken and all turkey CFO sub-categories. According to Statistics Canada 2006 census of agriculture, 1,000 chickens or turkeys correspond to animal numbers in size class 3 for total hens and chickens and size class 4 for turkeys (Table 1). Therefore, for the purposes of this study, CFOs with number of hens or chickens in size classes 3 to 6 or, turkeys in size class 4 (for a total of 5 poultry size classes), will be considered eligible to participate in the intended AQM activity.

3.1.4 Swine

Unlike CFOs within the other three livestock commodity groups, swine operations vary considerably by type. AOPA (2005b) classifies swine operations into 6 types namely, farrow-to-finish, farrow-to-wean, farrow only, feeders/boars, roasters and weaners. Statistics Canada (2008) on the other hand classifies swine as, total hogs, breeding stock, boars (6 months and over), sows and bred gilts, all other hogs, under 20 kg, 20 to 60 kg and, over 60 kg. It does not indicate if the swine under the various classifications are all on the same farm or combinations of the various classes thereof or, if swine in the different classes are on separate farms.

According to AOPA (2005b), a CFO intending to raise sows on a farrow-only operation requires a registration license for a minimum of 60 sows (Table 2). Therefore, relative to Table 1, CFOs with swine in size classes 1 (note, the minimum requirement is 60 sows) to 3 (less than 500 sows) are only eligible to be considered as prospective operations for the intended AQM activity if the CFOs are farrow only operations. Otherwise, CFOs with swine in size classes 3 (note, the minimum requirement is 500 weaners, growers/roasters, feeders/boars or sows or, combinations thereof) to 7 (Table 1) are eligible to be considered as prospective operations for the intended AQM activity.

3.2 Randomization Process

Although, it is impossible to conduct a comprehensive scientific AQM survey (see Appendix I) due to the magnitude of the financial and other resource implications, effort will be made to keep the CFO selection process unbiased, transparent and fair, i.e., similar to the tenets upon which a scientific study would be based. Therefore, prospective CFOs short-listed to participate in the AQM activity shall be picked at random from a set of CFOs, who by nature of their type, size or location, meet certain pre-defined criteria established by this study. A Microsoft Excel random generator software program will be used to facilitate the randomization process.

3.2.1 Ranking by Size Class

Eligible size classes associated with each livestock commodity group (section 3.1.) will be ranked randomly until every eligible size class within each commodity group has been ranked in order of selection.

3.2.2 Ranking by Region

The region where the AQM activity will be conducted shall be determined randomly. CFOs in Alberta are allocated to four regions by the NRCB namely, Central region, North Central region, Peace region and Southern region. Through randomization, each region shall be ranked in order of first, second, third and fourth pick.

3.2.3 Ranking by Eligible Counties

A number of counties exist within each NRCB-defined region. In order to be considered eligible, a county must have CFOs in all the eligible size classes within all the livestock commodity groups (section 3.2.1). The eligible counties within each region shall be ranked in order of randomization, i.e., from the county randomly picked first to the county randomly picked last.

3.2.4 Ranking by Eligible CFOs

Eligible CFOs within each eligible size class (section 3.2.1) and in each eligible county shall be identified and ranked in order of randomization. Note that under this second site selection option, mixed livestock CFOs will not be eligible to participate in the AQM activity. This is because when more than one livestock commodity is raised on a CFO it is extremely difficult to separate the impacts of the different commodity groups on ambient air quality levels.

3.3 CFO Selection Process

The selection process will be conducted in four stages as shown in Fig. 1. In the first stage of the process, the eligible size class ranked first will be identified. Next, the region ranked first will be identified. In the third stage, the eligible county ranked first within that region will be identified. Finally, eligible CFOs within the size class, region and county ranked first will be listed in order of ranking.

Each of the CFOs identified in the fourth stage of the selection process shall be assessed for their suitability relative to participation in the AQM activity. The assessment will be based on:

- Willingness of the CFO operator to cooperate.
- Geography of the land surrounding the CFO.
- Road access to the intended AQM location.
- Access to electrical power.

Hence, if a CFO is ranked first but fails to meet the criteria outlined above then the next CFO listed in the order of ranking shall be assessed for its suitability until the list has been exhausted. If the latter is the case, then the list of CFOs for the size class ranked second but still within the region and county ranked first, will be assessed for their suitability. If all CFOs by size class by region by county matches prove unsuitable then the search shall proceed to the next size class in order of ranking and so on until all four CFOs, one from each livestock commodity group, are found within the same county.

3.4 Confidentiality and Anonymity

The information collected from CFOs eligible to participate or participating in this ambient AQM study will be subject to the provisions of the Freedom of Information and Protection of Privacy (FOIP) Act. Consequently, information gathered regarding the related NRCB-region, county and, CFO-specific information such as, type, name, specific location, address, telephone number, number of animals or other information that could be used to identify a CFO eligible to participate or one that is participating in the AQM activity shall be kept in strictest confidence by Alberta Agriculture and Rural Development.

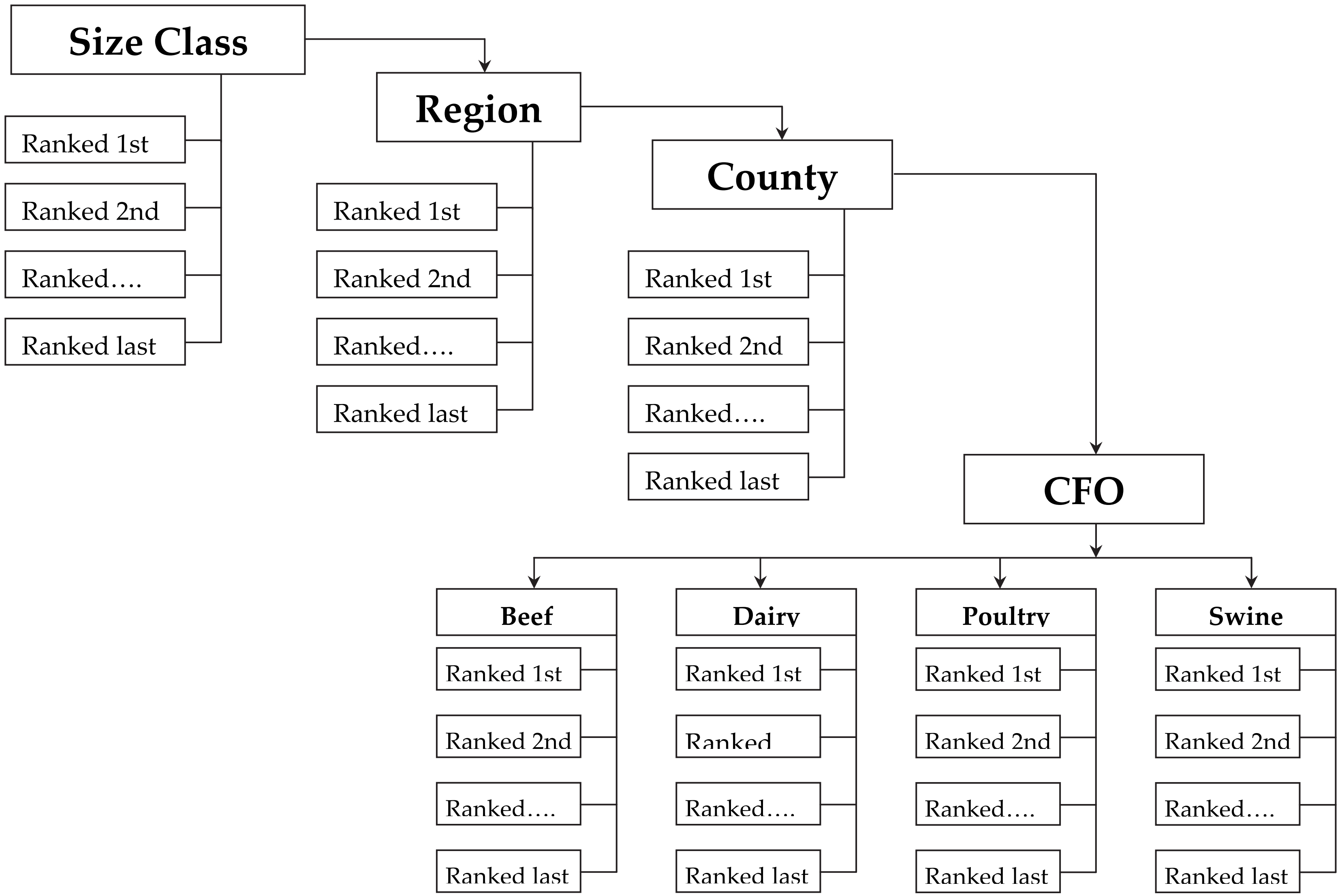

Figure 1. CFO randomized selection process flowchart

Such information shall not be released in any report or documentation associated with this study. Confidential information may only be shared with other provincial and federal government agencies, the CFO industry sector and, non-government or non-CFO-industry personnel such as, private consultants that participate in the AQM activity and affected neighbouring land owners, at the discretion of Alberta Agriculture and Rural Development and with the consent of the CFO owner or a bona fide representative.

In order to participate in the study, a CFO owner or a bona fide representative will be required to sign a FOIP consent form. Among other items, the form will identify which government agencies and CFO industry groups will have access to the private information. Such agencies or groups will still be governed by the provisions of the FOIP Act and will not share information without the consent of the CFO operator. Furthermore, the government agencies, industry groups, private consultants and affected neighbours identified in the consent form will be required to sign an information sharing agreement.

3.5 Location of Monitoring Activity

The primary mandate of this study is to conduct AQM activities around CFOs. AQM equipment shall be located upwind and downwind of manure collection areas (buildings or outdoor feedlot pens) or manure storage facilities, as defined by AOPA (2005a). Similar to the nuisance-related regulations stipulated by AOPA (2005c), manure application sites are exempt from conducting any AQM activities since these sites typically tend to vary from year to year.

3.5.1 Bearing

Due to the limited resources available for this study, ambient AQM activities shall be conducted upwind and downwind from the point closest to a manure collection area (animal housing facility) or manure storage facility in the direction of the prevailing wind. The direction of the prevailing wind, in any given area, shall be determined based on a minimum of 10 years worth of the most recent meteorological data recorded by provincially or federally-owned and operated meteorological stations in closest proximity to the respective CFOs.

3.5.2 Distance

The distance between the point closest to a manure collection area or manure storage facility on each CFO eligible to participate in this study and each AQM site will be determined as a function of the MDS for a category 1 land zone and residential type, as specified in AOPA (2005c). Although AMD (1989) prescribes a site selection process using geographic coverage factors, the application of the latter is limited by the lack of dispersion data that is specific to CFOs in Alberta.

4. Time

The specific time periods and length of time the AQM activity will be conducted upwind and downwind of the CFOs participating in this study are presented in the sections below.

4.1 Seasonal Effects

Seasonal variations in the emissions of the four substances are of interest because they will provide a temporal distribution of emissions relative to the different climatic patterns in the year. This suggests that should levels of any of the substances exceed the AAQOs in any given season then particular attention can be paid to reducing such in a cost-effective manner within that time period.

According to the schedule presented by INMS (2008) the following are considered the official start and end dates in 2008 and 2009 for winter, spring, summer and autumn (fall) in Alberta. The dates presented below coincide with the proposed AQM period.

Season	Start Date	End Date
Fall (2008)	September 22, 2008	December 21, 2008
Winter (2008/2009)	December 21, 2008	March 20, 2009
Spring (2009)	March 20, 2009	June 20, 2009
Summer (2009)	June 20, 2009	September 22, 2009
Fall (2009)	September 22, 2009	December 21, 2009

4.2 Seasonal AQM Period

Within each season, levels of the four substances of concern shall be measured continuously for a minimum of 15 days at specified locations upwind and downwind of a CFO participating in the study. At the end of each AQM period, the measurement equipment will be relocated to the next CFO participating in the study where AQM activity will resume, and so on. CFOs from the four livestock commodity groups will be randomly ranked to determine the order of measurement.

4.3 Schedule of Activities

The tentative schedule of activities is presented in the following sections. It is described as tentative because procurement of equipment, completion of contractual agreements or other matters beyond the control of this study may delay the commencement of the AQM activity. Should a delay occur, the next available date, as specified in section 4.3.2, will be targeted as the date AQM activity will commence and so on.

4.3.1 General Activities

Year	Month	Activity
2008	August	Commence site selection process Equipment and contractual procurement
	September	Identify specific locations for measuring ambient air quality around each prospective CFO in each season. Sign agreements with CFOs that will participate in study. Locate source of electrical power and where applicable, initiate discussions with company supplying power to the area. Sign contract with ambient AQM specialist. Commence setup and calibration of gas and PM analyzers and, other measurement equipment.
	October	Commence ambient AQM around CFOs. Commence data acquisition and analysis.
	December	Prepare project status report. Continue ambient AQM around CFOs and data acquisition and analysis.
2009	January	Submit status report to Minister of ARD for approval. Continue ambient AQM around CFOs and data acquisition and analysis.
	March	Multi-stakeholder advisory group meeting Submit status report to CASA CFO project team and AAQOs Stakeholder Advisory Committee. Continue ambient AQM around CFOs and data acquisition and analysis.
	December	Conclude ambient AQM around CFOs and data acquisition and analysis. Prepare project final report.
2010	January	Submit status report to Minister of ARD for approval.
	March	*Final multi-stakeholder advisory group meeting* *Submit status report to CASA CFO project team and AAQOs Stakeholder Advisory Committee.*

4.3.2 AQM Activities

Ambient AQM activities will include, setting up AQM stations and meteorological stations upwind and downwind of each CFO site, calibrating gas and PM analyzers prior to measurement of ambient air concentrations, connecting measurement devices to data logger, disconnecting apparatus at the end of each measurement period, calibrating gas and PM analyzer, dismantling meteorological stations and, transportation of mobile measurement units. Activities will also include data retrieval and analysis.

As mentioned previously, a minimum of 15 days has been assigned to AQM and data collection at each site between October 2008 and December 2009. An additional 7 days (minimum) has been assigned for assembling, disassembling and transporting the AQM stations. The targeted start and end dates for AQM and data collection are presented below.

Site #	Year	Start Date	End Date	Season
1	2008	Oct. 15	Oct. 30	Fall
2		Nov. 06	Nov. 23	Fall
3		Dec. 01	Dec. 16	Fall
4	2008/2009	Dec. 23	Jan. 07	Winter
1	2009	Jan. 14	Jan. 29	Winter
2		Feb. 05	Feb. 22	Winter
3		Mar. 02	Mar. 17	Winter
4		Mar. 24	Apr. 08	Spring
1		Apr. 15	Apr. 30	Spring
2		May 07	May 24	Spring
3		Jun. 01	Jun. 16	Spring
4		Jun. 23	Jul. 08	Summer
1		Jul. 15	Jul. 30	Summer
2		Aug. 06	Aug. 23	Summer
3		Aug. 31	Sep. 15	Summer
4		Sep. 23	Oct. 08	Fall
1		Oct. 15	Nov. 01	Fall
2		Nov. 09	Nov. 24	Fall
3		Dec. 01	Dec. 16	Fall

5. Methodologies and Equipment

The methodologies and equipment outlined in this section of the report are in accordance with and meet the requirements of the Air Monitoring Directive, 1989 (AMD, 1989) and the 2006 Amendments to the Air Monitoring Directive, 1989 (AMD, 2006).

5.1 AQM Site

Each AQM site will include an AQM station and a meteorological station. Within each season, a GPS (global positioning system) device will be used to orient the sites in the direction of the prevailing wind, i.e., both upwind and downwind from each CFO participating in the study and at the AOPA-defined MDS for category one land zone and residential type.

5.1.1 AQM Station

The AQM station will be situated and set up in accordance with the criteria and requirements established in AMD (1989). In addition, site selection, location and, documentation guidelines published by AAQD (2004) will complement AMD (1989).

5.1.2 Meteorological Station

The meteorological station will be situated and set up in accordance with the criteria and requirements outlined in AMD (1989).

5.2 Instrumentation

Continuous ambient AQM systems employed for measuring concentrations of NH_3, H_2S, PM ($PM_{2.5}$ and TSP), NMHC and wind parameters shall be used in accordance with AMD (1989) and, standard operating procedures (SOPs) developed by AENV. The SOPs include information on measurement principles, range and sensitivity, equipment and apparatus, interferences, precision and accuracy, site requirements, installation requirements, operational requirements (including any of the following: set up, daily requirements, analyzer test parameters, inlet filter change, maintenance, data collection, multipoint calibration, analyzer audit, sampling frequency, sample collection frequency, sample transportation), calibration, applicable documents, literature references, revision history and approval.

The AQM systems shall operate continuously at each site in each season, collecting real time data that will be stored by data acquisition systems. For H_2S and NH_3 measurement systems, data collection will be interrupted by regular zero and single point upscale response checks as well as full multipoint calibrations.

5.2.1 Ammonia

Ambient air NH_3 concentrations shall be measured using a continuous measurement system that operates based on principles of catalytic thermal oxidation, chemiluminescence and infrared light detection. Details of this technique and setup instructions for NH_3 analyzers are presented in AENV SOP-008 and SUI-008, respectively. Also see AENV SOP-037 for measurement of oxides of nitrogen and United States Environmental Protection Agency (USEPA) reference method RFNA-1289-074.

5.2.2 Hydrogen Sulphide

Ambient air H_2S concentrations shall be measured using a continuous measurement system that operates based on the principles of thermal oxidation and pulsed fluorescence. The specifics of the measurement system and setup instructions are presented in AENV SOP-010 and SUI-010a, respectively. Also see SOP-021 for measurement of sulphur dioxide (SO_2), section 1.1 of Appendix A-10 (AMD, 1989) and USEPA reference method EQSA-0486-060.

5.2.3 Particulate Matter

Ambient air PM concentrations of $PM_{2.5}$ and TSP shall be measured using a particulate mass concentration measurement system that functions based on the principle of orthogonal light scattering. The specifics of this measurement system are presented in AENV SOP-014.

Although this measurement technique does not correspond to the procedure outlined by AMD (1989) and USEPA reference method RFPS-0498-117 for measurement of fine particulate matter ($PM_{2.5}$), continuous measurement systems are gaining recognition. Currently, several comparisons between continuous measurement systems for measuring $PM_{2.5}$ and the USEPA reference method are in progress under the direction of USEPA.

5.2.4 Methane and Non-Methane Hydrocarbons

Ambient air CH_4 and NMHC concentrations shall be measured using a continuous measurement system that operates based on the gas chromatography (GC) coupled with the flame ionization detection (FID) principle. See AENV SOP-023 for the specifics of this system.

5.2.5 Wind Parameters

A sonic anemometer will be used to measure wind speed and wind direction in accordance with section II-C (L) and section 2 of Appendix A-10 of AMD (1989) and, AENV SOP-017.

5.2.6 Ambient Air Temperature and Relative Humidity

An air temperature and relative humidity probe will be used to measure both parameters. Ambient air monitoring program methods AQ02/01/14.00M and AQ02/01/15.00M developed by Metro Vancouver (previously Greater Vancouver Regional District) and deemed acceptable by AENV will be used as guides for the installation and utilization of the probe. Purdue Applied Meteorology Laboratory (PAML) SOP-W1 will also be used as a guide for measuring ambient air temperature and relative humidity.

5.3 Documents

AMD
AMD (1989) and AMD (2006) may be obtained from AENV website.

AENV SOPs, Check Sheets and Equipment Setup Instructions
AENV SOPs, check sheets and equipment setup instructions may be obtained by contacting:

Monitoring Program Delivery
Environmental Assurance
Alberta Environment
McIntyre Centre, 4946 89 Street
Edmonton, AB T6E 5K1
Tel: 780-427-7888

USEPA Reference Methods
USEPA reference methods may be obtained from the USEPA website: Check http://www.epa.gov/ttn/amtic/files/ambient/criteria/reference-equivalent-methods-list.pdf

Greater Vancouver Regional District Ambient Air Monitoring Program Methods
Ambient Air Monitoring Program Methods may be obtained by contacting:

Air Quality Policy and Management Division
Policy and Planning Department
Metro Vancouver
Tel. 604-432-6375
Fax: 604-436-6970

PAML
SOP may be obtained by contacting:

Dr. Robert H. Grant
Agronomy
Purdue University
West Lafayette, IN
47907 U.S.A.

5.4 CFO Activity Records

Activity records will be kept by CFOs participating in the study. These data will provide details of livestock production activities carried out at the CFO over the course of each AQM period. Information gathered from such records will be used to validate ambient AQMs conducted at the pre-defined locations. An activity data sheet will be created and distributed to the participating CFOs.

6. Quality Assurance and Quality Control

The AQM specialist contracted to coordinate the AQM activity for this project will be required to develop a quality assurance and quality control (QA/QC) plan in accordance with the guidelines set out in AMD (1989) and AMD (2006). The plan will be submitted to AENV for review.

In addition, the specialist will document all methodologies and procedures used to conduct the AQM activity.

7. Data Quality Objectives

Data Quality Objectives (DQOs) are qualitative and quantitative statements derived from study objectives that will specify tolerance limits on decision errors. These statements will be used as the basis for establishing the quantity and quality of data needed to support the decision. The DQOs are then used to develop a scientific and resource-effective data collection design. The DQOs for the air quality and meteorological parameters monitored in this study are presented in terms of accuracy, precision and data availability criteria in Table 3.

Table 3. DQOs for air quality and meteorological parameters

Parameter	Accuracy	Precision	Operating Range	Data Availability	Minimum Detectable Limit
H_2S	n/a	± 1.0 ppb	0.1 ppm	75% of reported averaging period	0.5 ppb
NH_3	n/a	± 0.4 ppb	2 ppm	75% of reported averaging period	1 ppb
$PM_{2.5}$	n/a	1 µg m^{-3}	n/a	75% of reported averaging period	1 particle per litre
TSP	n/a	1 µg m^{-3}	n/a	75% of reported averaging period	1 particle per litre
NMHC	±2% of measured value	± 2% of measured value	20 ppm methane 20 ppm NMHC 40 ppm THC	75% of reported averaging period	0.02 ppm methane
Wind speed	±1% ±0.05 m s^{-1} from 0 to 30 m s^{-1} ±3% for 30 to 40 m s^{-1}	n/a	40 m s^{-1}	75% of reported averaging period	0.01 m s^{-1}
Wind direction	±2° from 1 to 30 m s^{-1} ±5° from 30 to 40 m s^{-1}	n/a	360°	75% of reported averaging period	0°
Temperature	±0.2 @ 20 °C ±0.4 @ 60 °C ±0.5 @ -40 °C	n/a	60 °C	75% of reported averaging period	-39.2 °C
Relative Humidity	At 20 °C: ±2% from 0 to 90% ±3% from 90 to 100%	±0.05% RH/°C	100%	75% of reported averaging period	0.8%

[1] The values presented in this table are designated for the purposes of this study only.

8. Data Acquisition and Transfer

Air quality and meteorological parameters will be measured at one second intervals or less at each AQM location and one minute averages will be stored by a data acquisition system. To minimize the risk of losing data, personal computers will be programmed to retrieve data daily from each data acquisition system. In addition, manual data retrieval will occur on a weekly basis or as determined by the data storage capacity of the data acquisition systems and, at the end of each AQM period at each site. Data will also be backed-up to portable digital storage devices such as CDs or other electronic devices on a weekly basis and at the end of each AQM period. All the data collected over each AQM period at each site will be forwarded to ARD for processing.

On a daily basis, meteorological and air quality data will be checked to determine proper operation of the equipment. This check may be done in person or by remote polling. Prior to submitting data to ARD, the AQM specialist shall review the data for anomalies and shall flag such data accordingly.

9. Data Analysis and Archiving

Data received from each site will be analyzed and compared to the AAQOs outlined in section 2 of this AQM plan. Wind direction data will be analyzed to help determine potential sources of emissions. Furthermore, the data analysis methods and results will be peer reviewed by ambient air quality specialists in AENV and other organizations.

10. Reporting

A project interim report and final report will be prepared and submitted to CASA CFO project team, among others, in March 2009 and March 2010, respectively. The reports may include but are not limited to any of the following:

Executive Summary
An executive summary describing the ambient AQM study, its objectives, methodologies, results, conclusions and recommendations will be included in the final report.

Introduction
This section of the report will provide details of the study mandate and its objectives similar to what was presented in sections 1 and 2 of this AQM plan. In addition, background information on the study may be obtained from the CFO project team report to the CASA board of directors.

Study Description and Methodologies
This section will include details of the site selection process, the AQM period, AQM frequency, equipment used to measure concentrations of the substances-of-interest and their setup procedures. It will also include a detailed description of the methodologies and procedures used to conduct the measurements, for data acquisition, storage and finally processing. Reference will be made to quality assurance and quality control (QA/QC) procedures that were followed in the conduct of the study. Details of the QA/QC procedures will be documented in the appendices of the report.

Results and Discussion
The results of the AQM data analysis procedures will be presented in this section of the report. It will include tabulated and graphical information specifying the maximum, minimum, 1-h averages and 24-h averages for each seasonal AQM period at each measurement site.

A discussion of the relationship between the results and specific events suspected to be responsible for distinguishable temporal changes in the data patterns will be included in the report. The results will also be compared to AAQOs presented in section 2 of this AQM plan.

Conclusion and Recommendations
Conclusions drawn from the study will be presented in this section of the report. This section will also include recommendations, some of which will be based on the outcome of a project closure and lessons learned process conducted upon completion of the first draft of the final report. The environmental monitoring (measurement) report formats outlined in chapter 3.1 of the 2006 Amendments to the Air Monitoring Directive, 1989 (AMD 2006) may be used as a reference to draft the interim and final report of this study.

Bibliography
The report will include a bibliography section referencing all cited information.

Appendices

Other pertinent information, such as the QA/QC procedures, will be presented in the appendices of the report. Raw data will be copied to a CD and will accompany the report as an attachment.

11. Resource Requirement

Human and financial resources will be required to accomplish this study. The specific requirements are detailed in the following sections.

11.1 Personnel

Personnel from the following organizations will be required to implement and complete the project:

Role	Organization	Number of Personnel
Project Manager	ARD	1
Site Selection Team	ARD	3
	AENV	1
	NRCB	1
	ILWG	As needed
Mobile AQM Station Fabrication and Instrumentation	ARD	3
	AENV	1
Assembly (setup) and Disassembly at AQM Sites	ARD	2
	AQM Specialist	1
	Electricity Supplier	Work Crew
Equipment Calibration	ARD	2
	AQM Specialist	1
Relocation of AQM and Meteorological Stations	ARD	2
Data Collection, Recording and Transfer	ARD	2
	AQM Specialist	1
Data Analysis	ARD	1
	AENV	1
	†EC	1
Reporting	ARD	1
Report Review	AENV	1
	†EC	1
	AAFC	1
	AHW	1

[1]Environment Canada's (EC) participation is dependent upon resource availability.

11.2 Finance

Project cash and in-kind cost estimates are presented in the sections below.

11.2.1 Cash Estimate

Item	Per Unit	Total Cost
AQM Specialist (contract)	$25,000/CFO	$100,000
Gas and PM Analyzers	$100,000/AQM station	$200,000
Electricity Supply (from power grid)	$6,250/AQM station/site	$50,000
Maintenance	$20,000/AQM station	$40,000
Travel		$5,000
User fee		$5,000
Supplies and Miscellaneous Expenses		$5,000
Total cash		**$405,000**

11.2.2 In-kind Support

Item	Per Unit	Total Cost
Human Resources (ARD, AENV, NRCB, ILWG)		$125,000
Meteorological Station	$5,000/station	$10,000
Total in-kind		**$135,000**

12. Risk Management

Risk mitigation measures will be applied in the event any or all the following should occur.

Lack of CFO Participation or Cooperation
CFO owners may not be willing to participate or cooperate in the study. In order to prevent this from occurring, prior effort should be made to provide open communication and clarity regarding the purpose of the study. Details of the study will be distributed to owners or bona fide representatives of CFOs that qualify to participate in the study. FOIP consent forms will specify details of the study pertaining to confidentiality and anonymity. Communication and facilitation by ILWG members will also be essential. Incentives should also be provided to CFO owners or bona fide representatives who consent to participate in the study.

Exorbitant Cost of Rural Electrification
The estimated cost of acquiring a transformer and power lines to supply power to the two AQM stations at each site in each season can be exorbitant (see section 10.2.1). Therefore it is imperative that during the site selection process, the ability of a CFO to supply power at a metered rate is considered as criteria for determining if a CFO is suitable for participating in the AQM activity.

The use of generators will be considered as a last resort. Whereby a generator is required at any site then a generator will be used at that site for the entire duration of the study.

Exorbitant Cost of Continuous AQM Analyzers
Whereby the total cost of analyzers for each AQM station is above the budget provided by ARD, then a strategically defined combination of continuous measurement analyzers and, passive and integrated samplers will be used. In this case, only ambient air quality levels measured using the continuous measurement analyzers will be compared to AAQOs.

Concentrations measured using passive and integrated samplers will be averaged for the length of time each sample was collected and then integrated to determine the predicted 1-h or 24-h average. The passive and integrated samplers will be set up to only measure substances when the wind is in the corresponding direction and will be completely sealed off from the ambient air otherwise.

Limited Budget
The budget presented in this document already far exceeds what ARD indicated was available to meet the mandates of the CASA CFO strategic plan recommendations. Therefore, if ARD cannot access additional funds to conduct this project then the scope of the project will be narrowed down considerably. If this were to occur, then under extreme circumstances:

i. The number of CFOs participating in the study could be reduced from four to one.

ii. The number of substances measured could be reduced from four to one, in other words ammonia.

Hence, a reduction in the project scope relative to (i) and (ii) above could reduce the estimated cash requirement by approximately 80% or $385,000.

Delayed Commencement Date of AQM Activity

The schedule in section 4.3.2 is tentative because of anticipated delays in the procurement of equipment and contractual agreements. Should such or any other delays occur, the start date for the AQM activity would be moved up to the next start date listed on the schedule. For instance, if the AQM activity cannot start on October 15, 2008 then the next targeted date to commence the AQM activity will be November 6, 2008 for site #1.

Interruptions to AQM Activity Schedule

Interruptions due to natural or other circumstances may occur. Once the interruption has been resolved, AQM activities will resume at the respective site, or the next site, in accordance with the schedule presented in section 4.3.2 of the AQM plan.

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Appendix I. Volatile Organic Compounds: Acetic Acid

Ambient Air Quality Objectives

Averaging Period	Limit		Comments
	($\mu g.m^{-3}$)	(ppb_v)	
1-hour	250	102	The 1-hour average AAQO for acetic acid was adopted from the State of Texas, U.S.A.

Instrumentation

Acetic acid is measured as an integrated sample. Integrated samples can be collected using Tedlar™ bags, canisters or adsorbent tubes and a portable sampling pump in accordance with AENV SOP-015, USEPA Compendium Method TO-15 or USEPA Compendium Method TO-17. Alternate continuous measurement techniques such as the FTIR technique are not recognized by environmental protection agencies in Alberta and the USEPA.

Appendix II. Alternative Site Selection Options

The following options were given due consideration by a multi-stakeholder advisory group established to develop the ambient AQM plan.

Option 1: Comprehensive Scientific Survey

This section addresses the number of CFOs that ought to be measured within each livestock commodity group in order to provide scientifically representative, and therefore, unbiased AQM information relative to the CFO industry in Alberta. To achieve this purpose, a statistical sample size was determined relative to the population of CFOs within each commodity group in the province with the intent to randomly select CFOs short-listed for the AQM activity from this population.

Statistics Canada performs a census of agriculture in Canada at the provincial and municipal levels every five years. The most recent census of agriculture was conducted in 2006. Therefore, along with information gathered from Statistics Canada's 2006 census of agriculture, and the expert assistance of statisticians with the Statistics and Development Unit, Alberta Agriculture and Rural Development, sample sizes for CFOs from the five commodity groups were determined relative to the 95%, 90% and 80% confidence levels with a permissible error (accuracy) within 5% of the desired value of the population parameter of interest.

It is important to note that certain assumptions were made in deciding what categories of livestock animals specified in Statistics Canada's 2006 census of agriculture were most likely to be considered CFOs in Alberta. Information presented in AOPA (2005b) was used to guide the identification of livestock categories or sub-categories that would fit the definition of CFOs (AOPA, 2005a). Where necessary, data specific to a livestock commodity group was purchased from Statistics Canada. In addition, those sub-categories that were assumed to have a greater impact on ambient air quality based on their size or animal units (AOPA, 2005b) were taken into consideration.

Sample Size

Table 1 shows the statistical survey sample sizes at 95%, 90% and 80% confidence and 5% error for the different livestock commodity groups. The survey sample sizes were determined by the Statistics and Development Unit, Alberta Agriculture and Rural Development in accordance with procedures outlined by McCall Jr. (1982).

Cost

Conservatively, costs could range from a minimum of about $41 million to over $450 million for capital cost items alone in order to accomplish AQM activities of such capacity in a single year.

Table 1. Statistical survey sample sizes required to generate data representative of ambient air quality around CFOs in Alberta.

CFO Livestock Commodity Group Classification		Total Number of Farms Reporting in Alberta[1]	Sample Size[2]		
AOPA	Statistics Canada		95%	90%	80%
Beef Cattle	Feeding Operations: Steers and feeder heifers	797	259	202	136
Dairy Cattle	Dairy cows	1,107	285	217	143
Poultry	Total hens and chickens	3,935	350	253	158
	Turkeys	652	242	191	131
Swine	Pigs (total)	1,576	309	231	149

1 This data was obtained from Statistics Canada, 2006 Census of Agriculture. It does not distinguish between farms with only one type of livestock animal versus mixed livestock farms.

2 Note: Lower confidence levels produce less reliable survey results. Therefore, a confidence level of 95% is normally recommended.

Option 2: Grid AQM in an Area with a High Concentration of CFOs

According to NRCB, there are areas of the province where high concentrations of CFOs exist relative to other areas of the province. The second site selection option for this study is based on identifying areas where CFOs are highly concentrated within a 10 km by 10 km square centred at a rural hamlet, village or town and measurement of ambient air quality within and around this 100 km^2 area.

Objectives

The objectives of this option were not discussed in detail. However, it will be extremely difficult to compare 1-hour and 24-hour averages to the limits listed in Alberta AAQOs as required by Alberta Environment. Rather, an objective of this site selection option could be to determine the potential impact the spatial distribution of CFOs may have on ambient air quality in a given area. Again, note that such data would not be representative of all areas in the province with high concentrations of CFOs, even if the number of CFOs were the same, but would be specific to the given area under observation.

Types of Livestock

The types of livestock under consideration will be all inclusive, ranging from beef cattle to wild boar, according to types of CFOs defined by AOPA (2005b). It may also include residences, livestock seasonal feeding and bedding sites, equestrian stables, auction markets, racetracks or exhibition grounds, all of which are not considered to be CFOs by AOPA (2005a). In addition, mixed livestock farms and non-livestock industrial sources of emissions may also be located within the given area of interest.

AQM Sites
The 10 km by 10 km square area of interest will be divided into twenty-five, 2 km by 2 km, grid areas. At each intersecting grid point, a series of passive and integrated samplers will be located for a total of 36 sampling points. Two mobile continuous AQM stations will also be located at opposite ends of the 10 km by 10 km square area along the same bearing. The location of the mobile AQM stations will vary from season to season or monthly.

Data Analysis
Isopleths will be developed to show the spatial distribution of ambient concentrations of the substances of interest across the given area.

Cost
Conservatively, if passive and integrated samples (3 per grid point) are collected once a week for a year, then the cost of laboratory analysis could be as high as $1.9 million while the capital cost for equipping the continuous AQM mobile stations could be as high as $0.3 million, totalling $2.2 million.

Appendix III. Assumptions

The following assumptions were made:

1. The minimum number of animals required to obtain a registration license by schedule 2 of AOPA (2005b) are sufficient to cause emissions that can have an impact on ambient air quality greater than background levels.

2. The livestock commodity group sub-categories listed in AOPA (2005b) and selected for this study have a greater impact on ambient air quality than other sub-categories within the same group.

3. Number of animals in Statistics Canada's size classes 3 and over will have significantly greater impacts on ambient air quality than background levels. However, this is not the case for size classes 1 and 2, except for farrow only swine operations.
4. Acetic acid is a common type of VOC that is emitted in concentrations higher than most other VOCs emitted from CFOs within the four livestock commodity groups selected for this study.

Appendix B

QA/QC Procedures

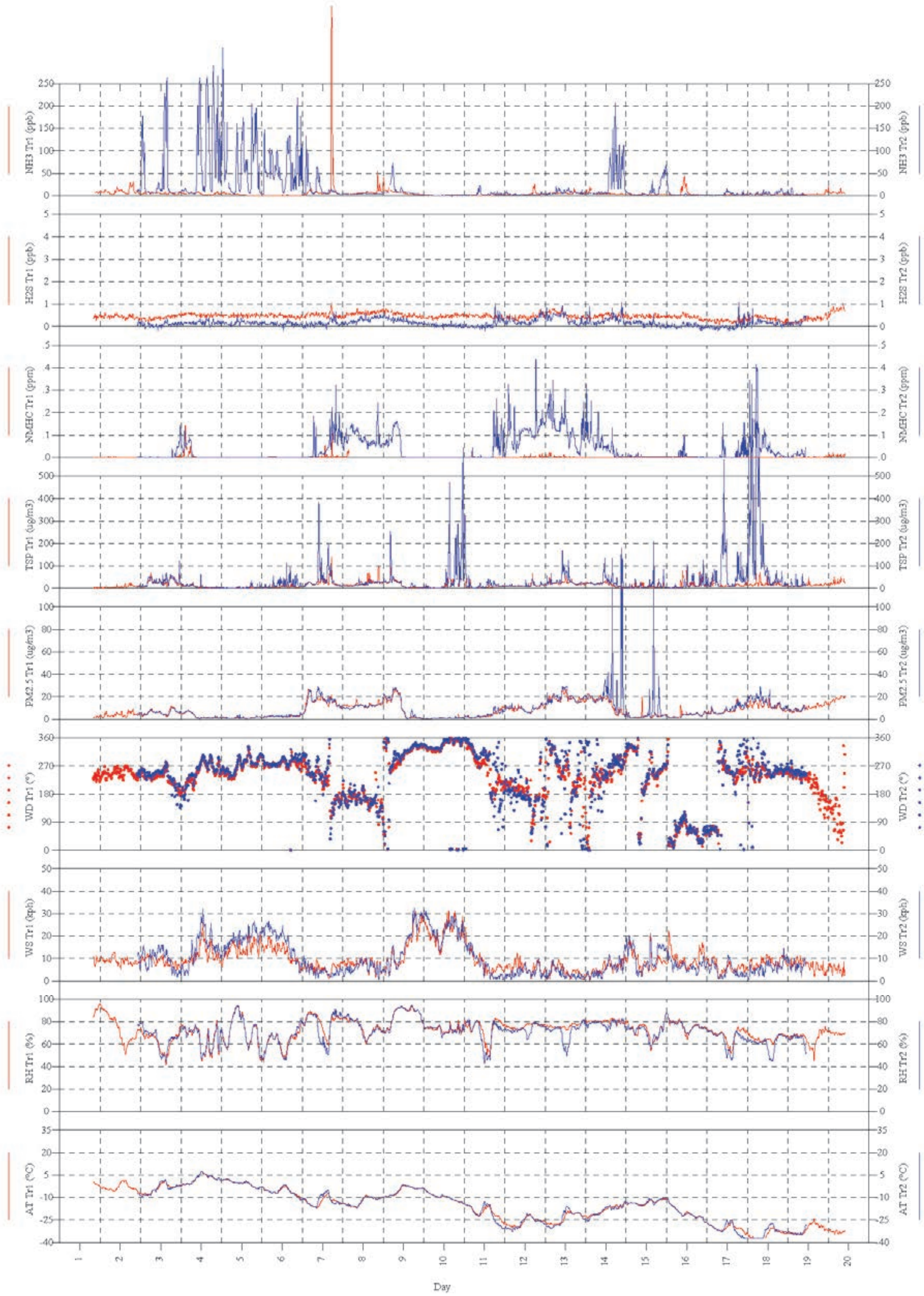
The QA/QC procedures applicable to this study are not outlined in this section. Although ARD received a copy, the procedures utilized for this study are the intellectual property of Aurora Atmospherics Inc. Aurora Atmospherics Inc. developed these procedures prior to conducting the AQM study. They have utilized these procedures in the past and continue to use them in other ambient air quality monitoring projects similar to the AQM study. Consequently, ARD cannot copy, share or distribute the Aurora Atmospheric Inc. QA/QC procedures without the prior written consent of Aurora Atmospherics Inc.

Appendix C

Time Series Distribution Plots

(15-minute Average)

Measurement Period #1



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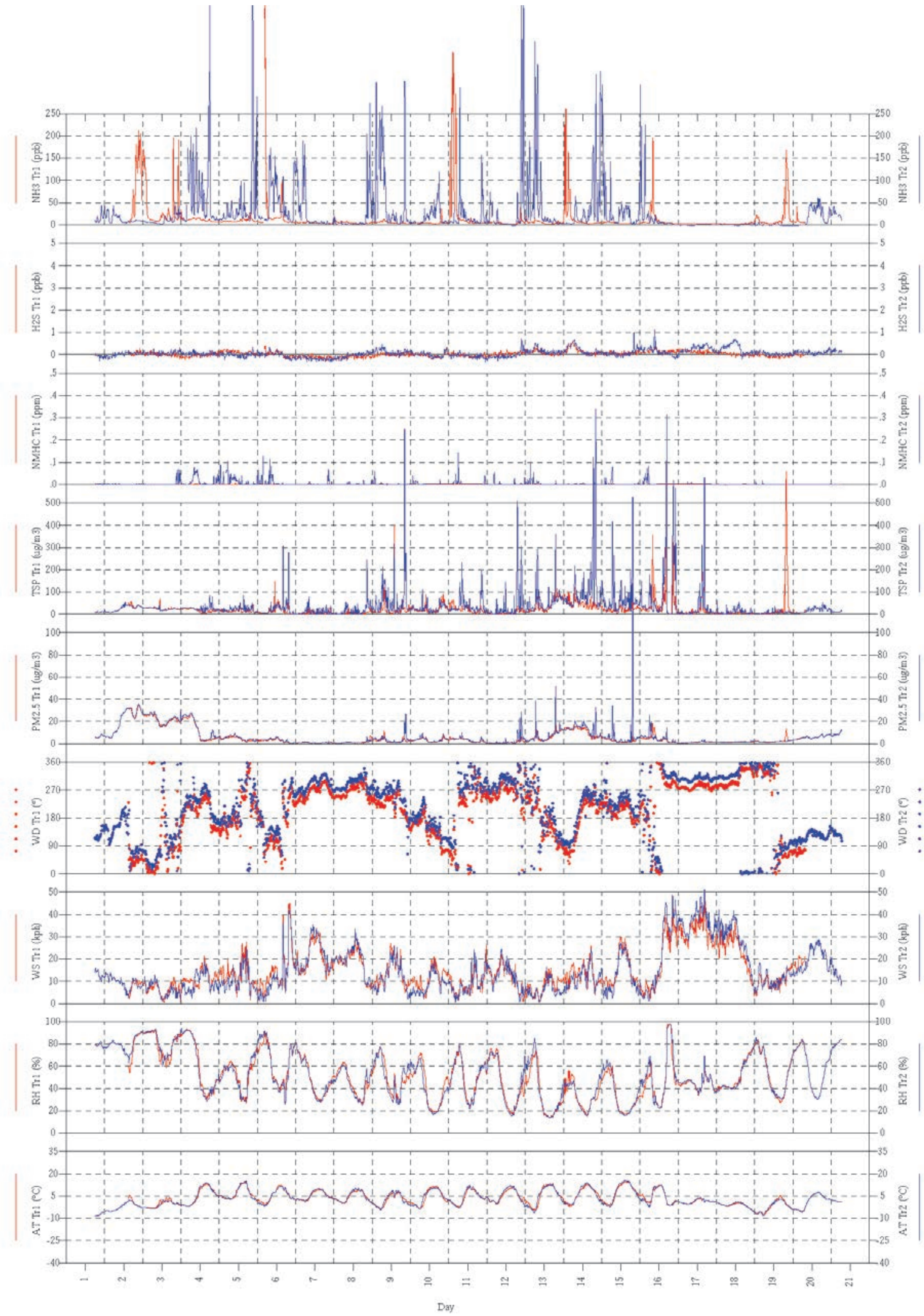

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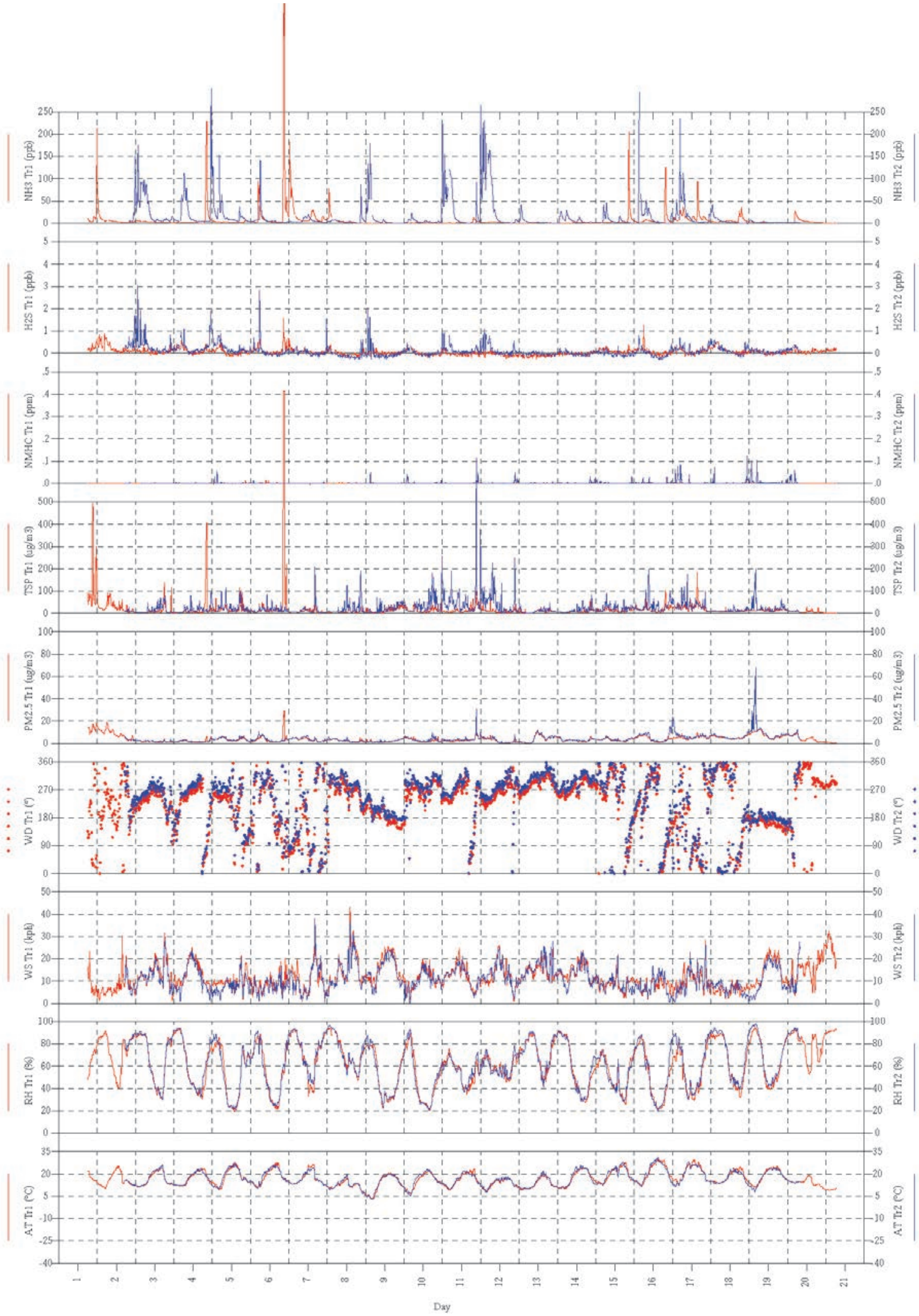

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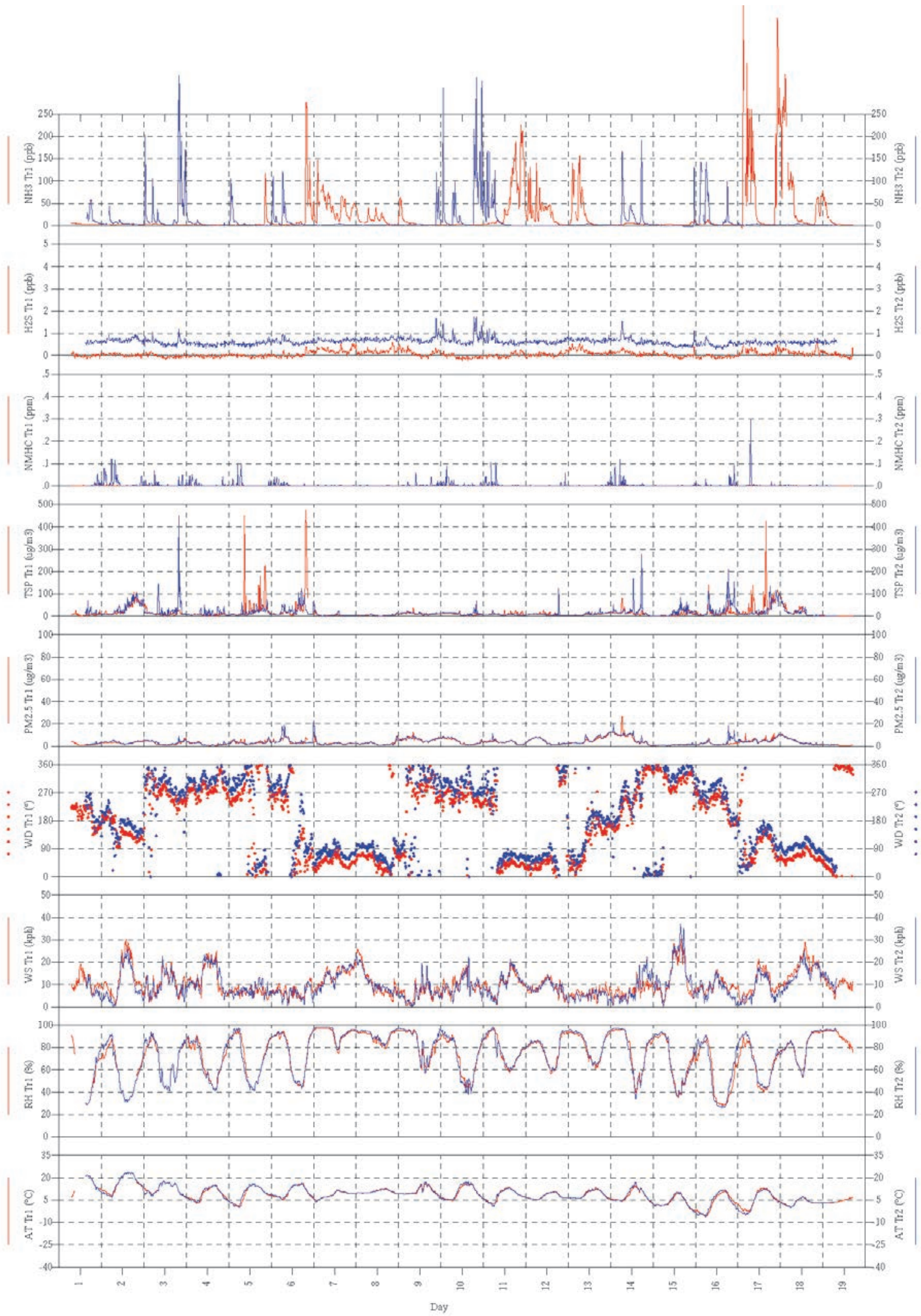

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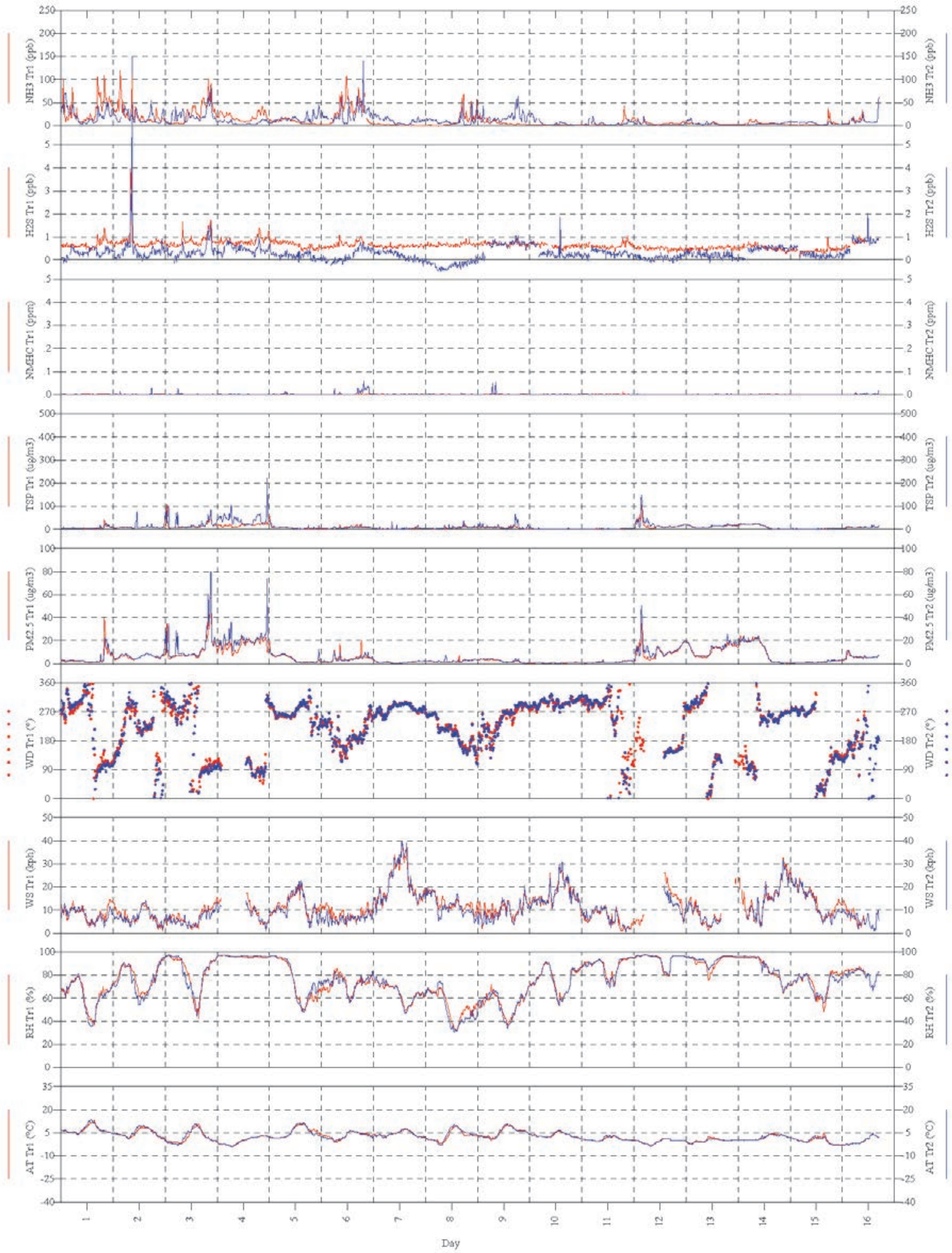

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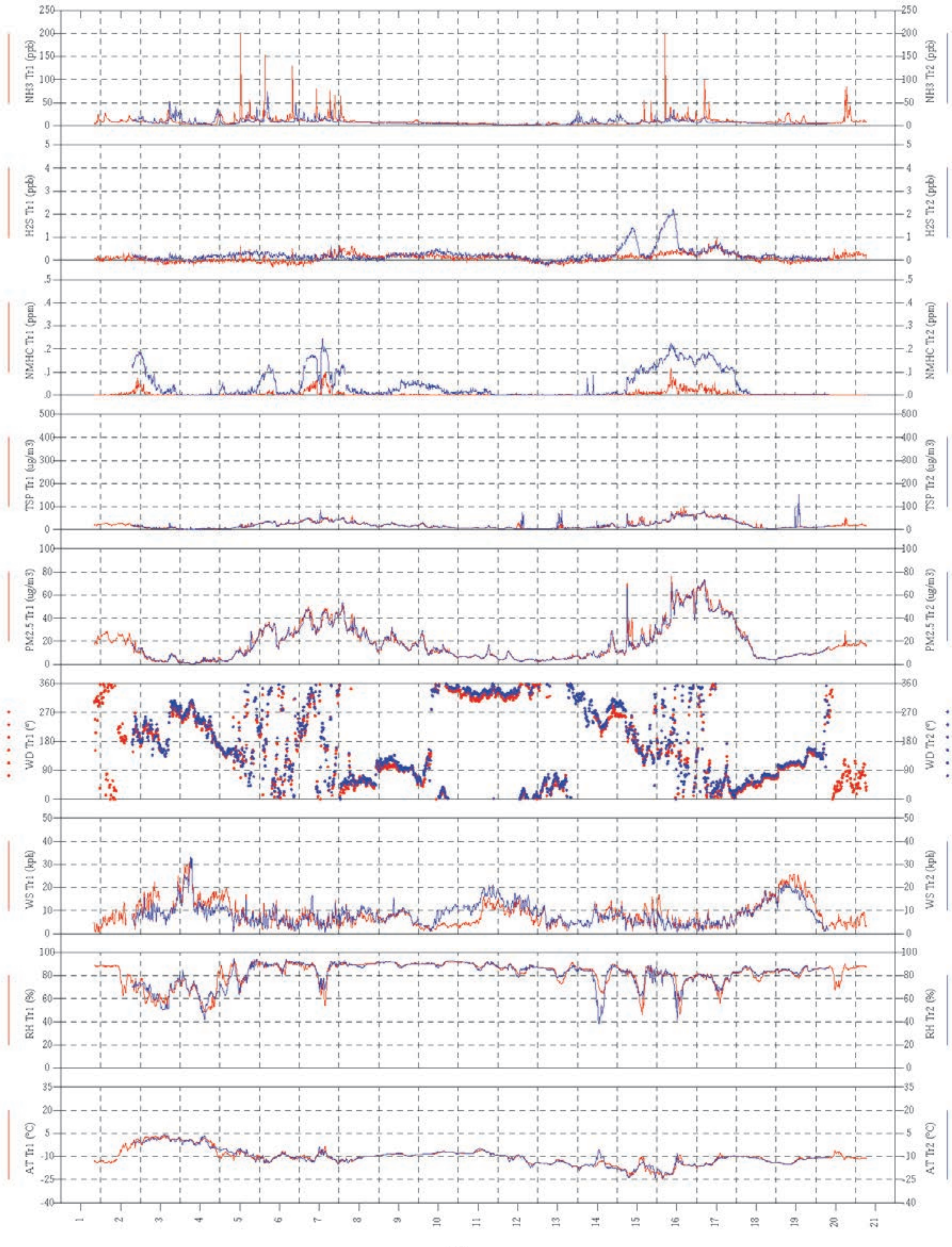

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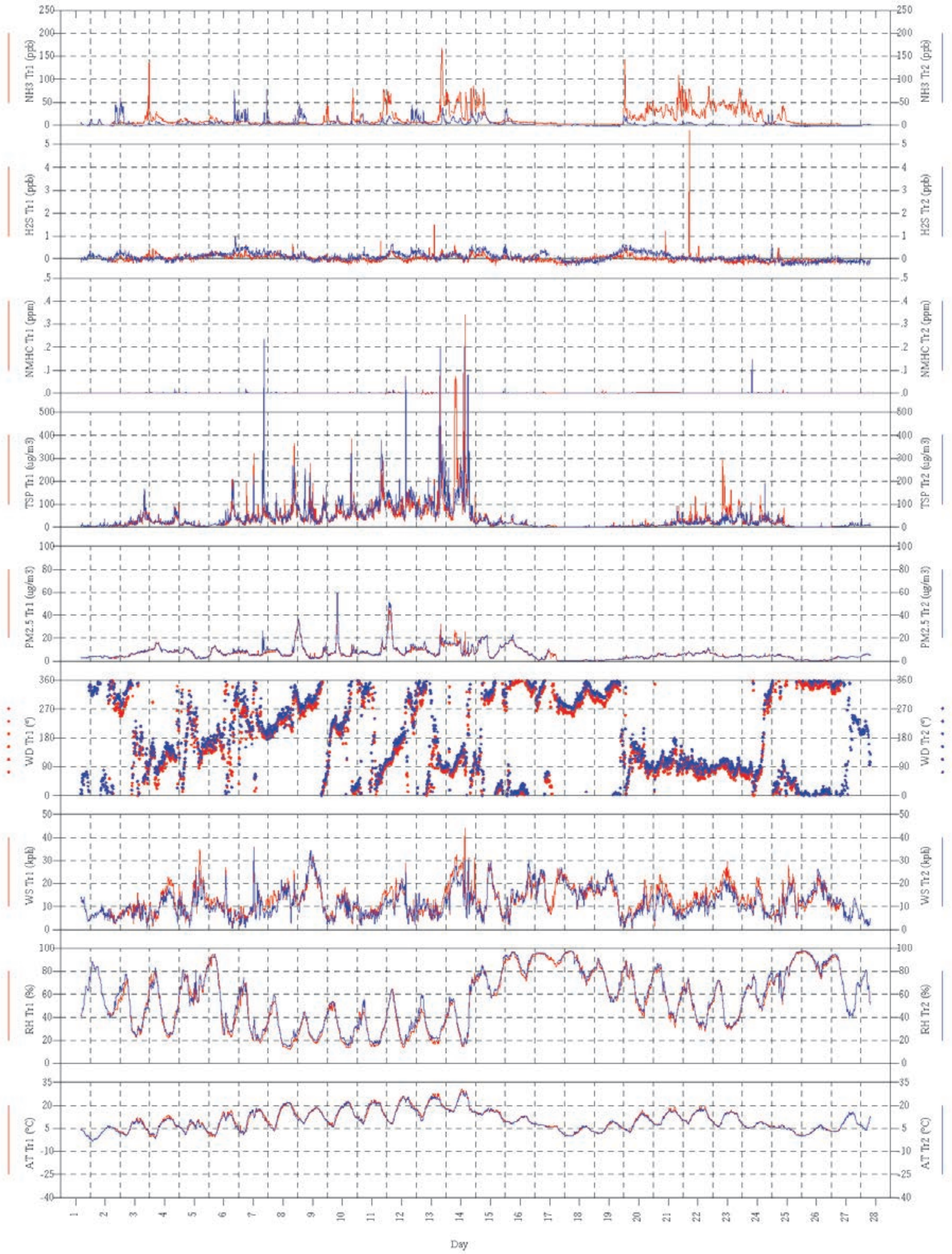

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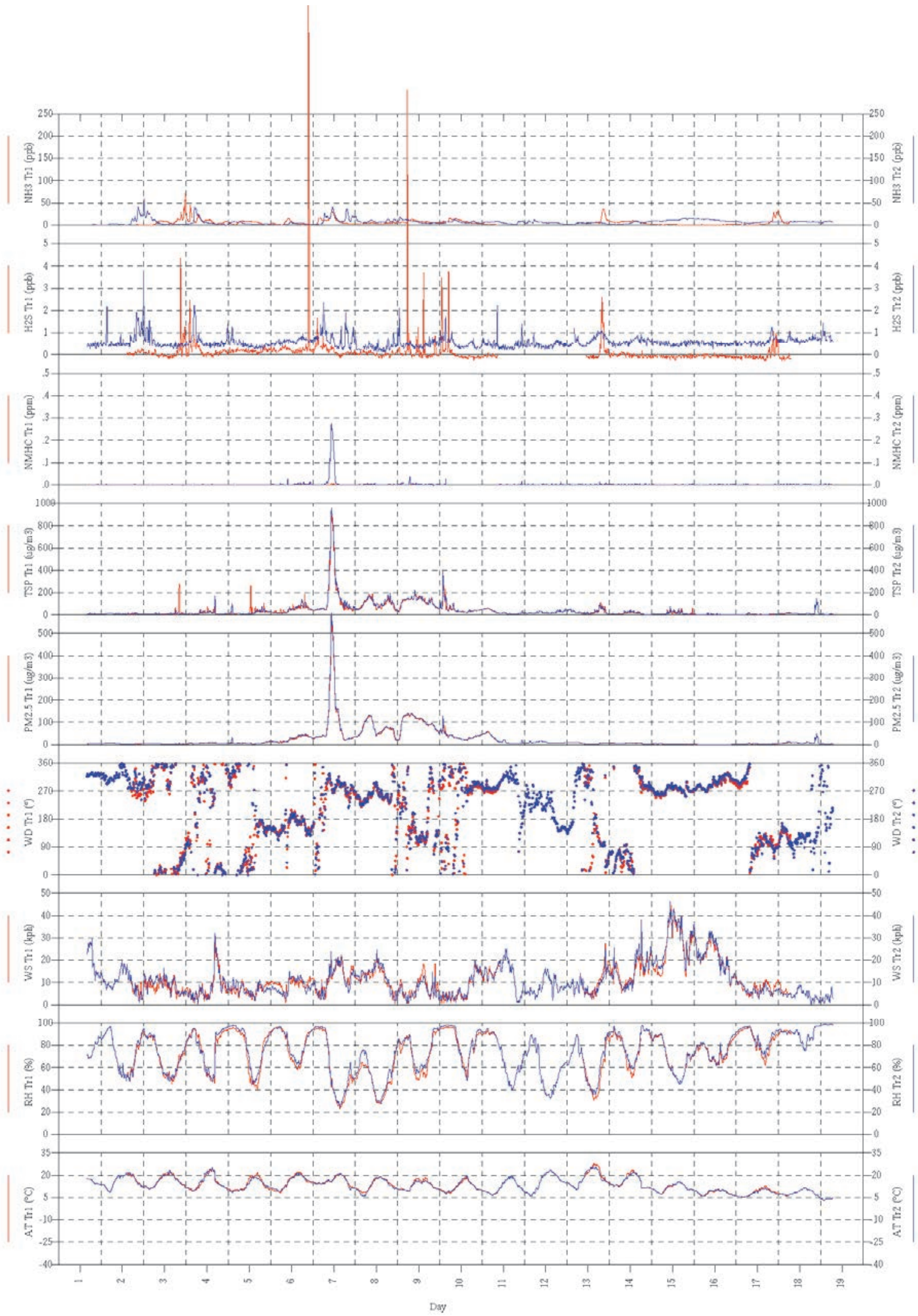

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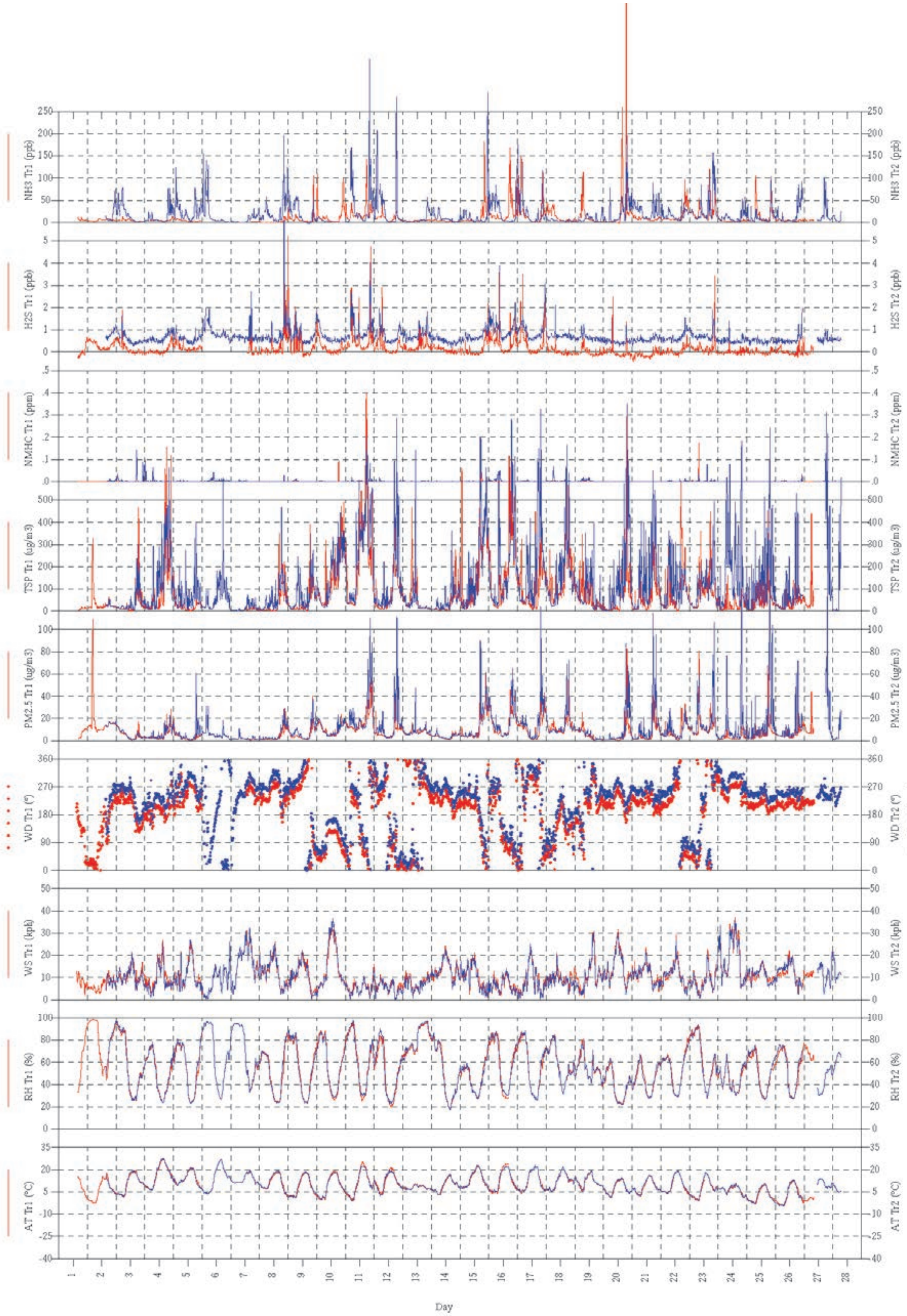

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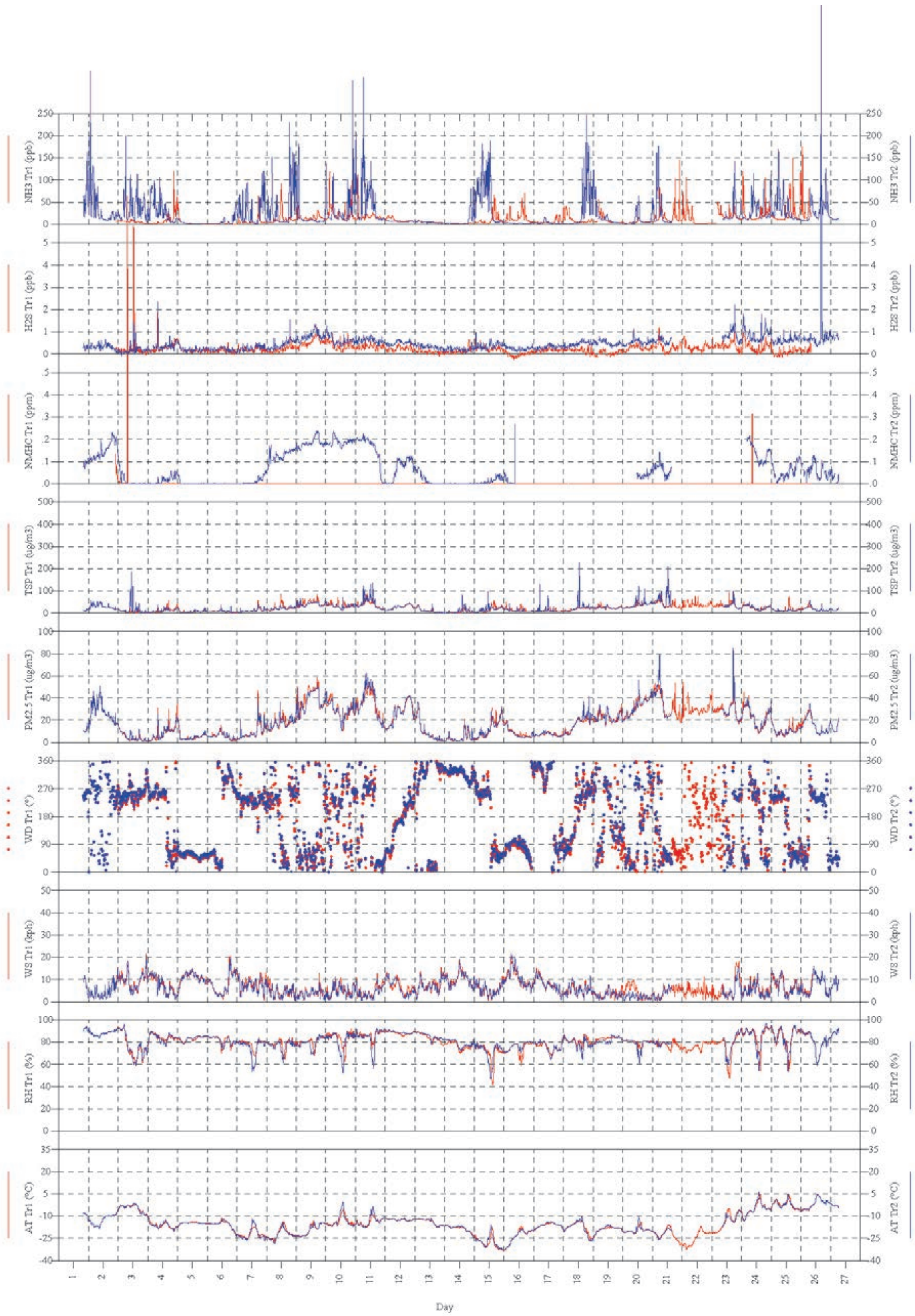

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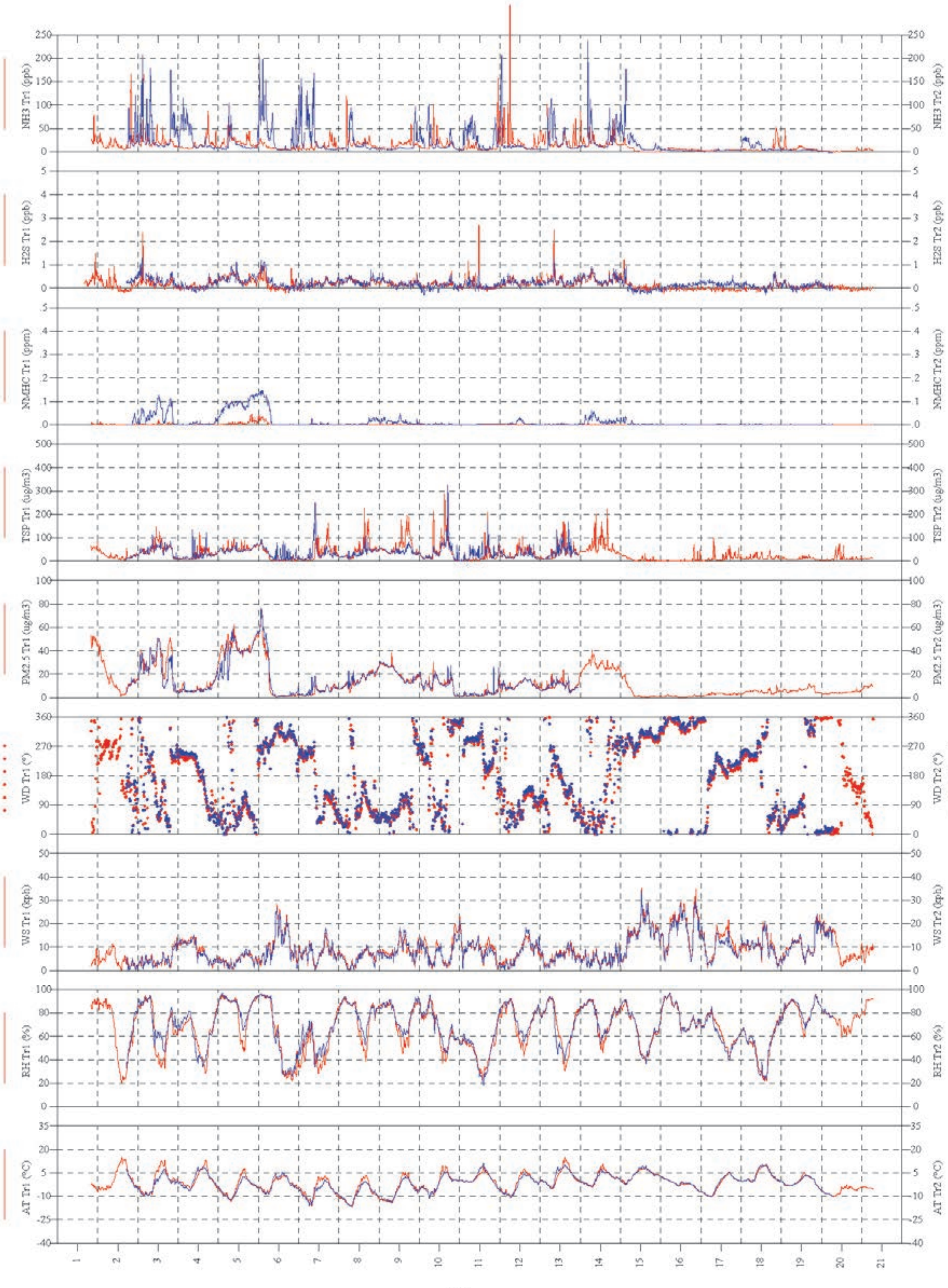
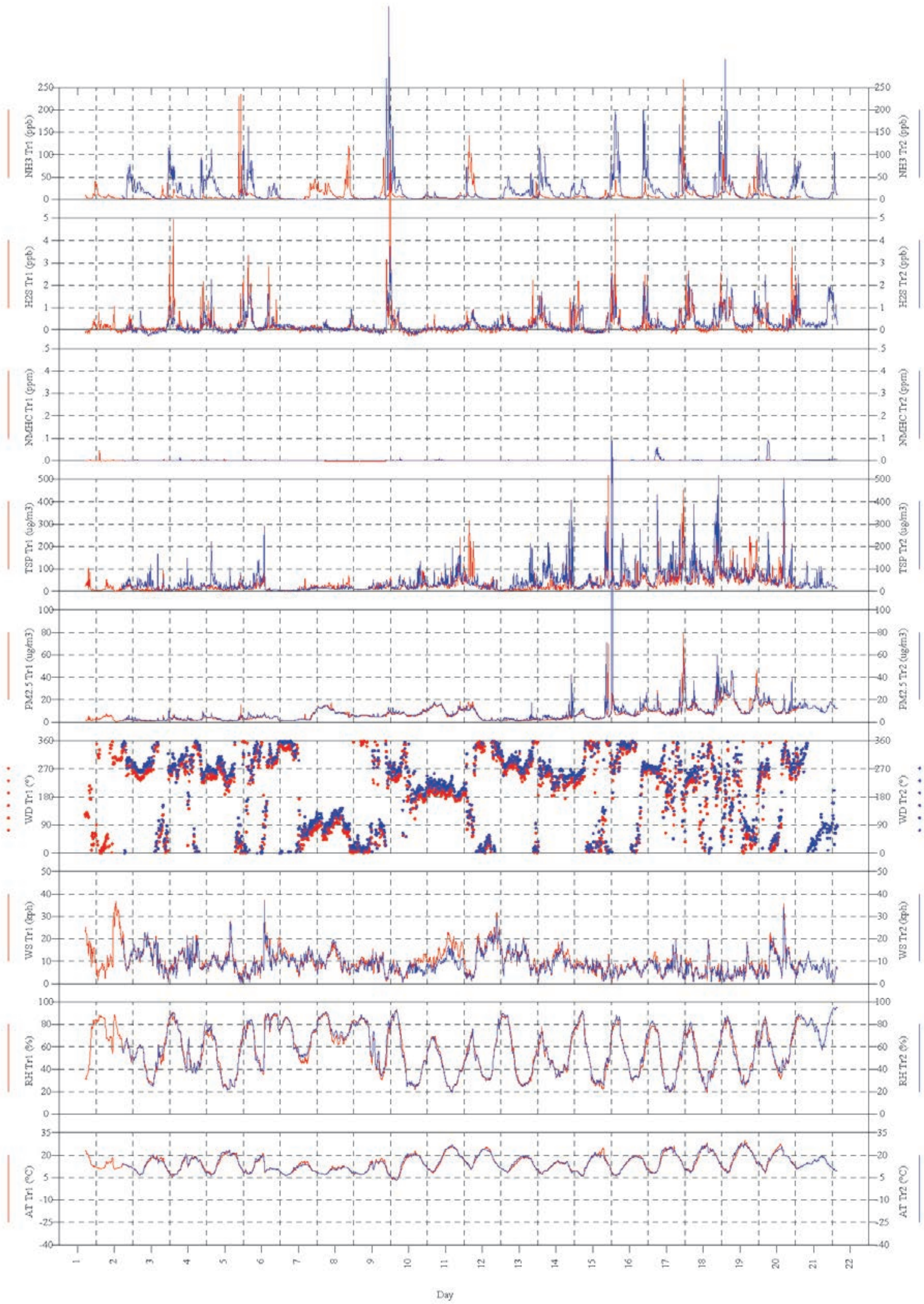


Measurement Period #12



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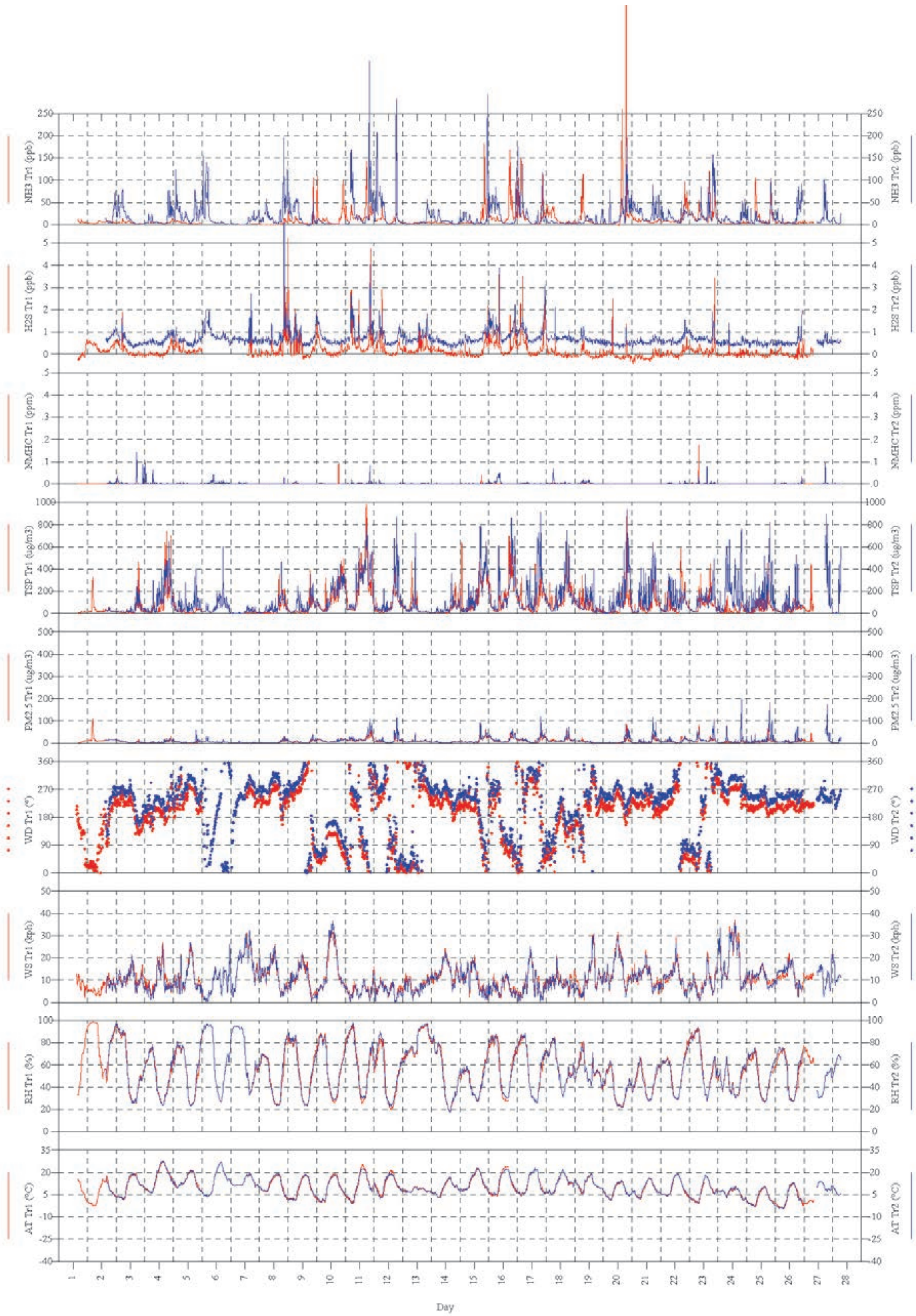

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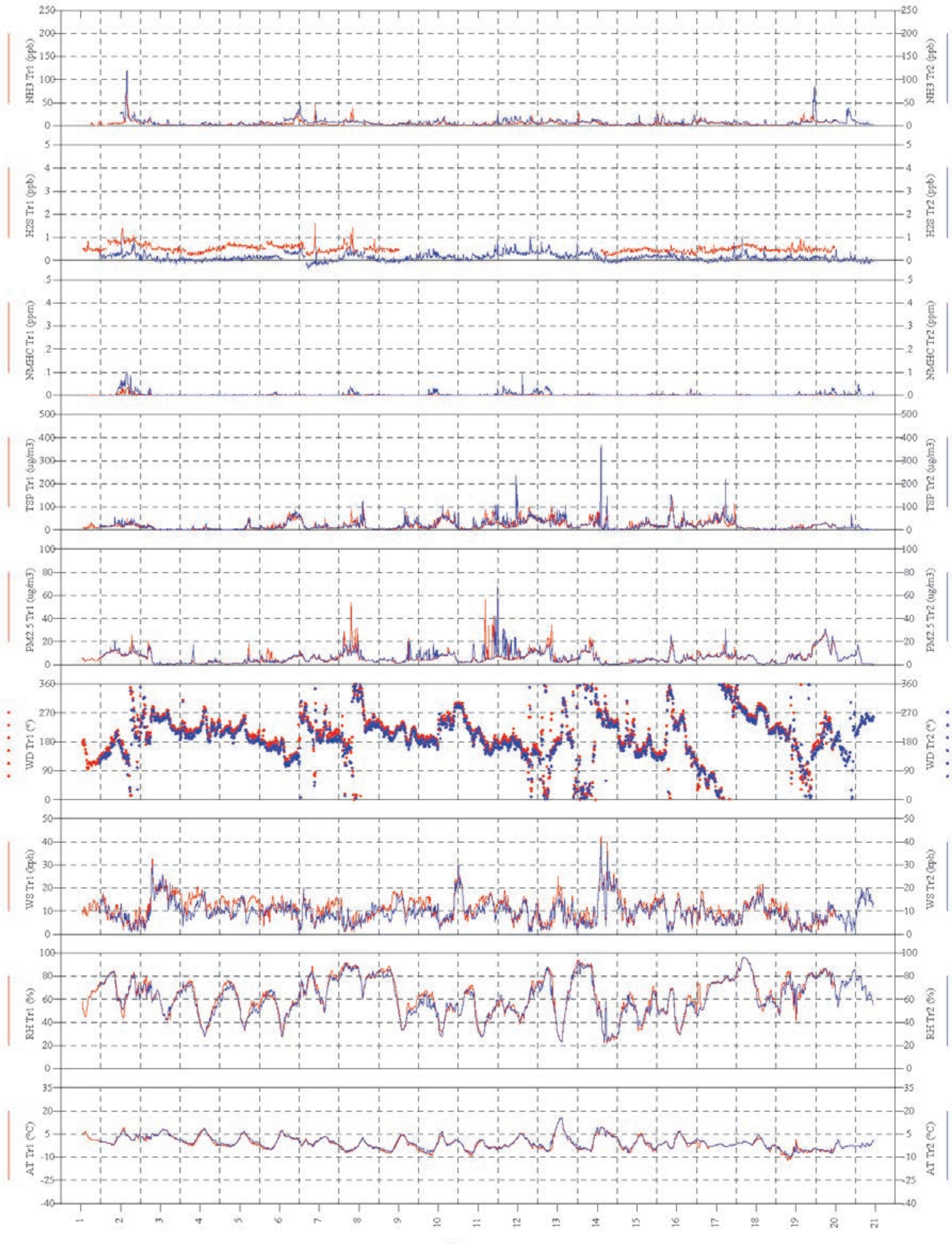

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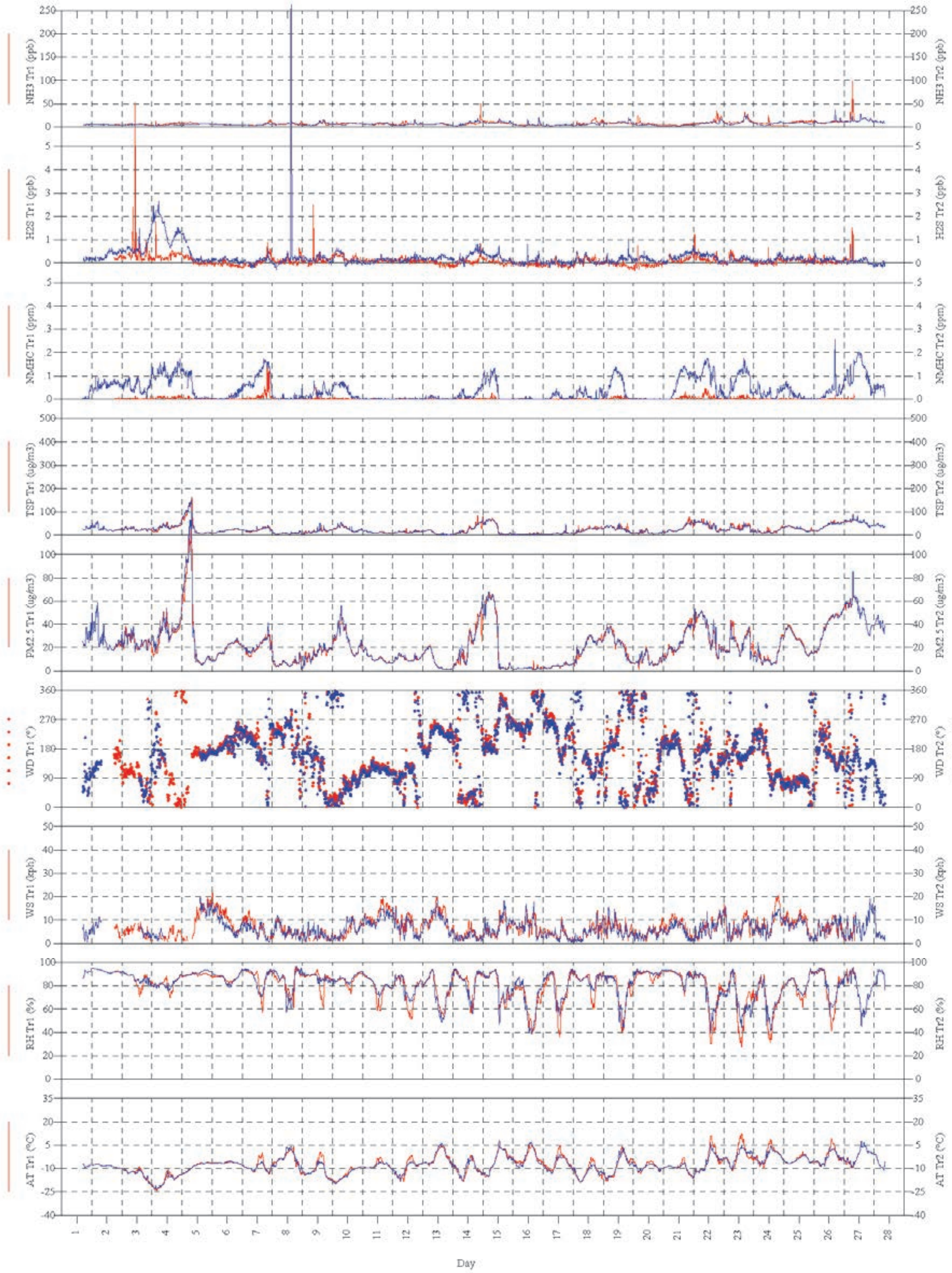

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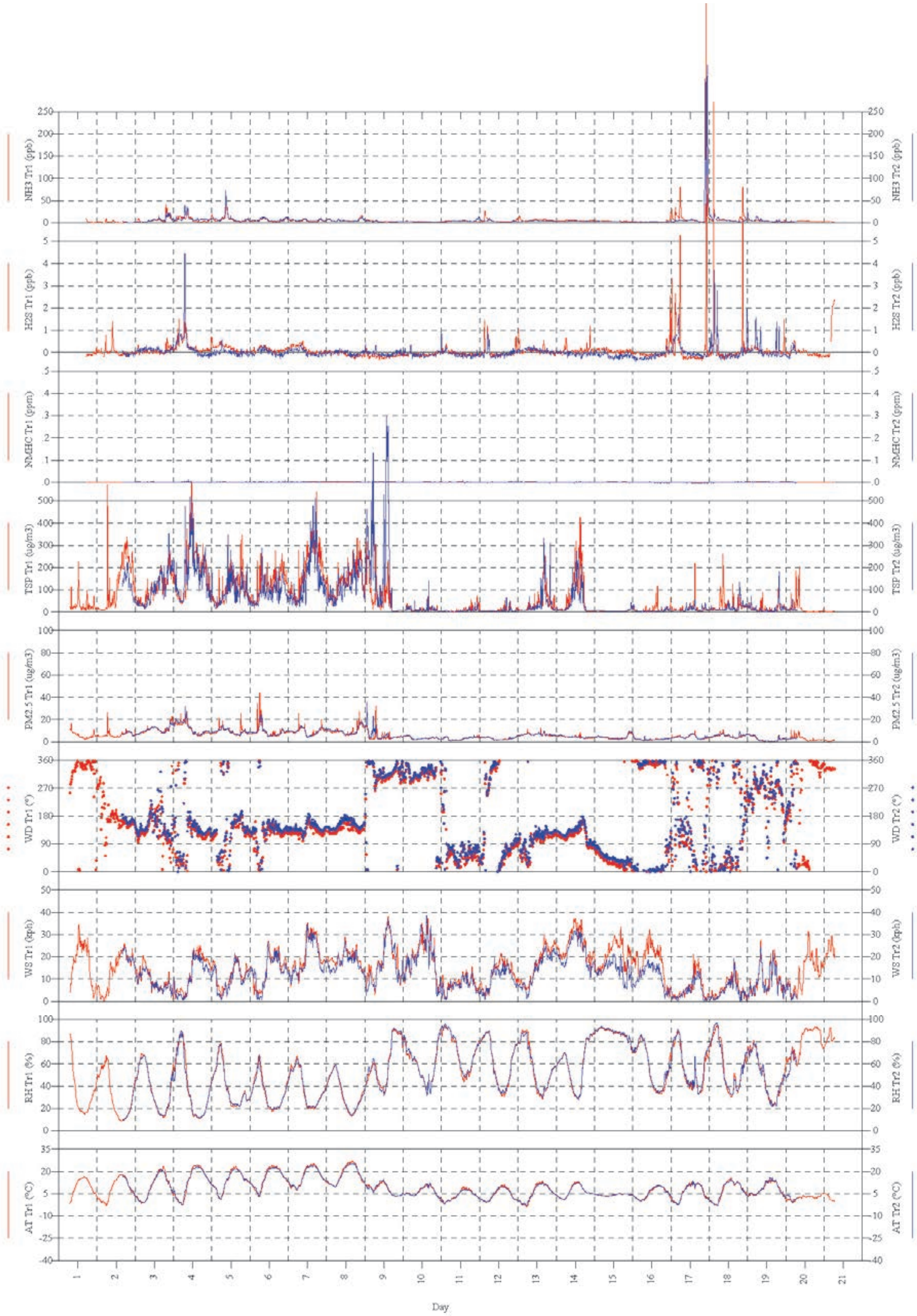

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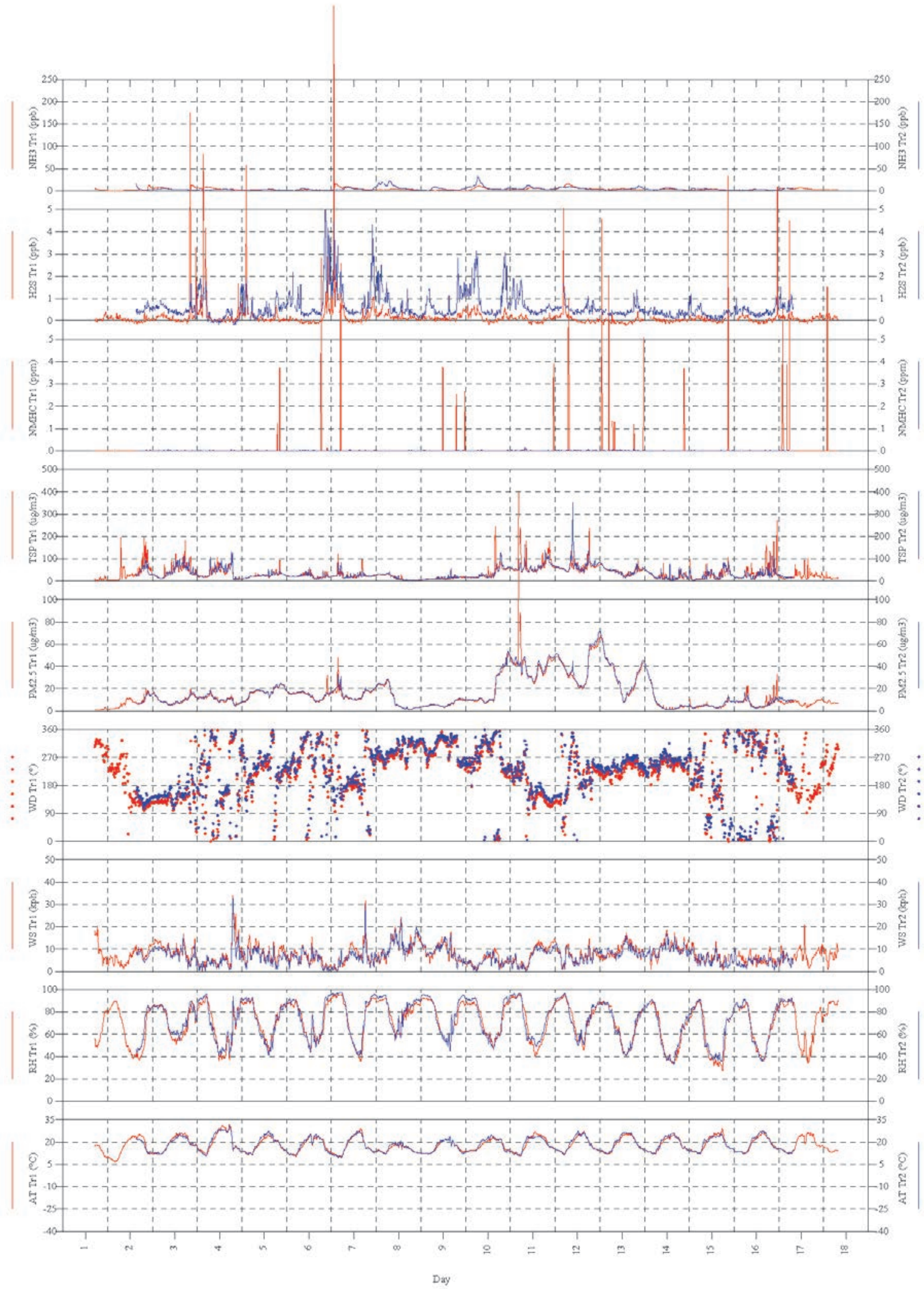

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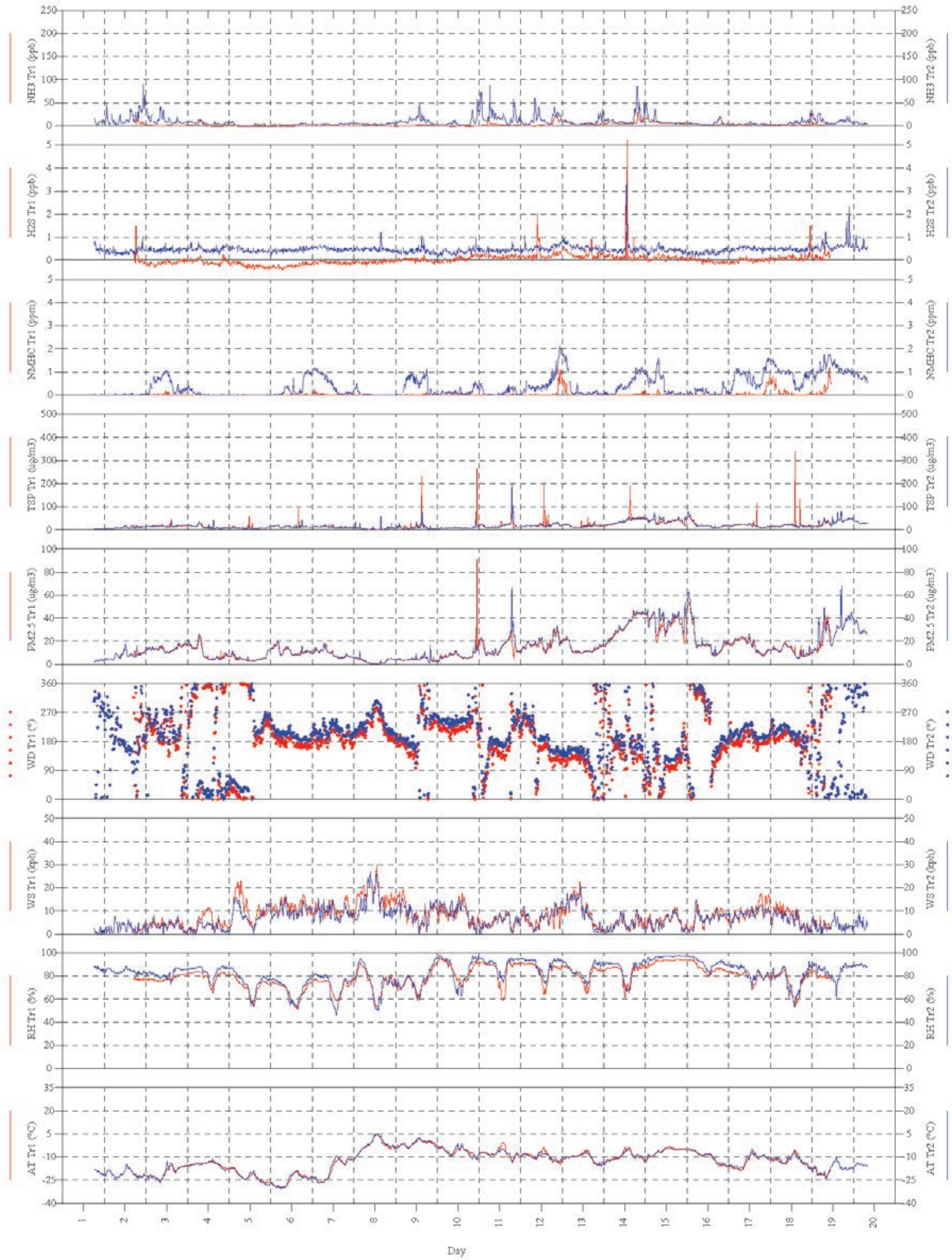

Appendix D

Box Plots

(15-minute Average)

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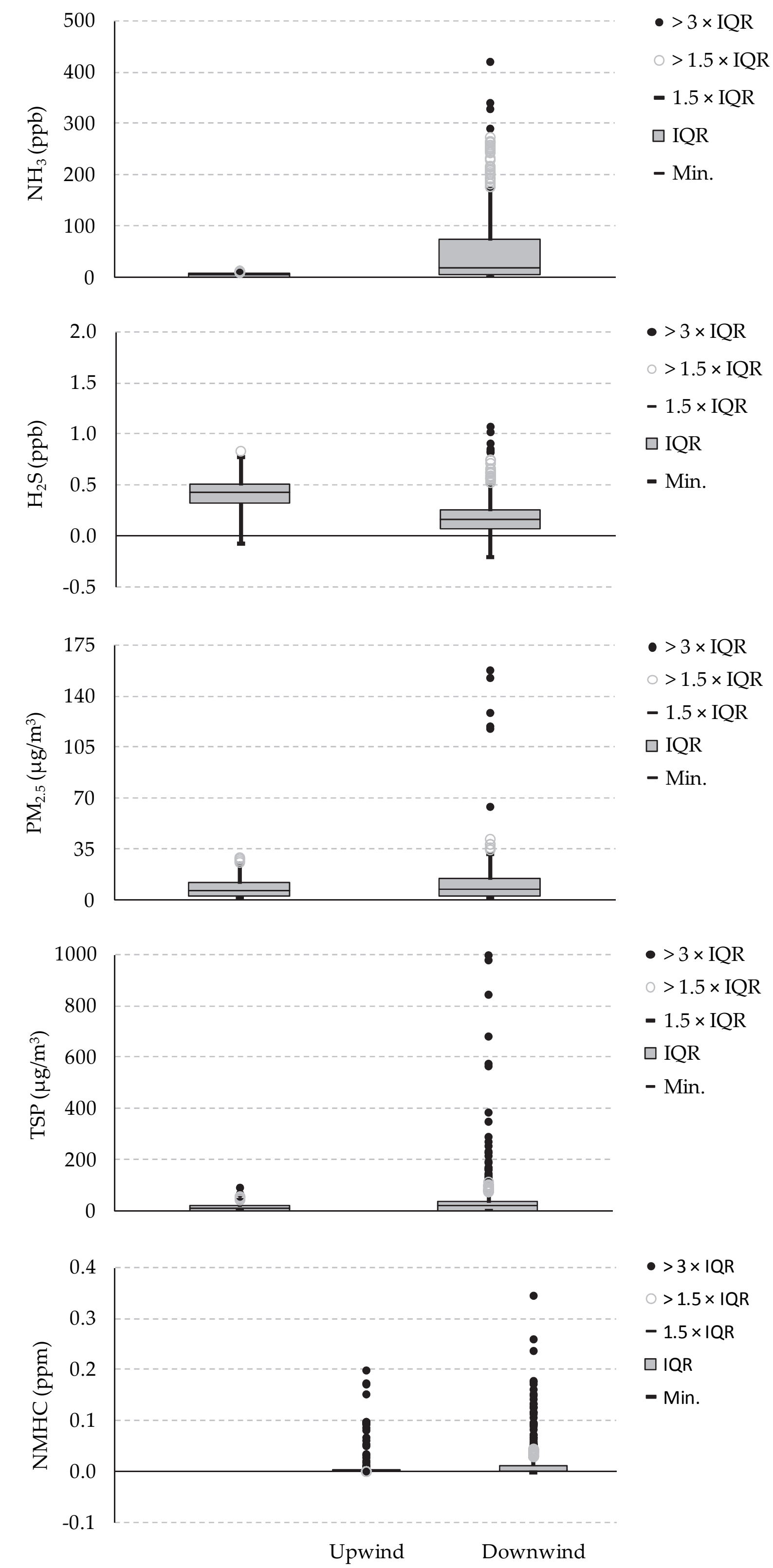

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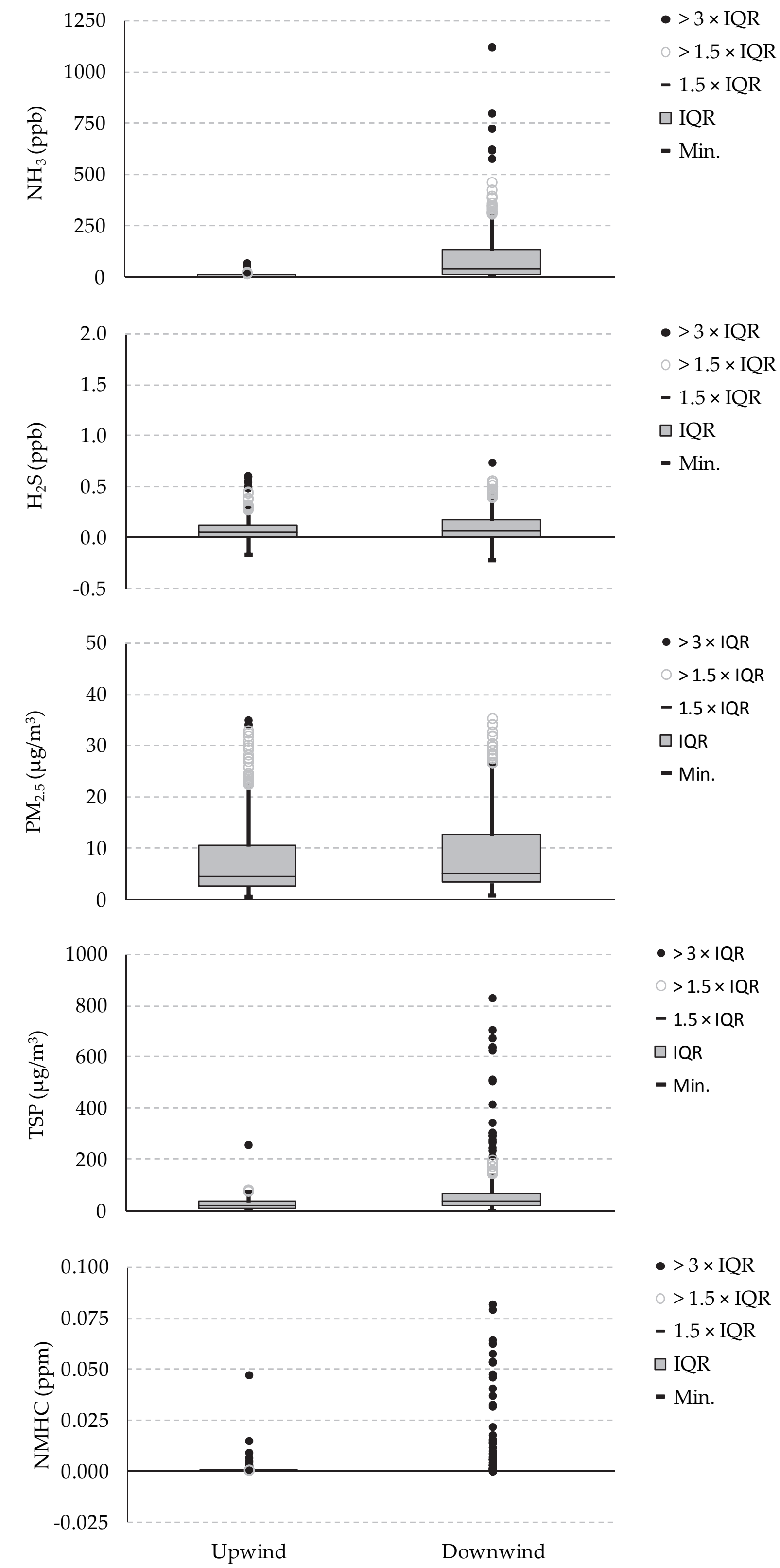
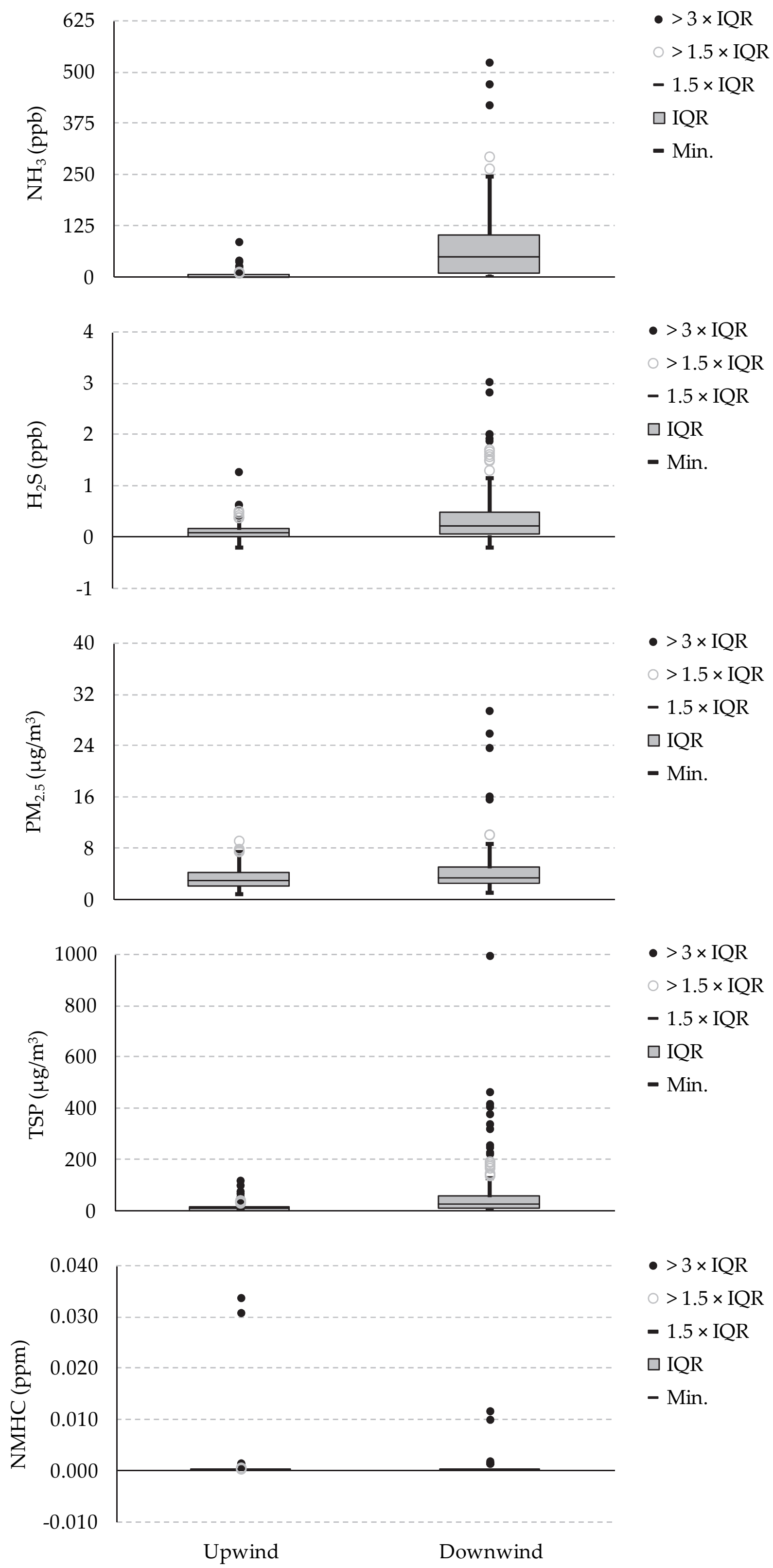
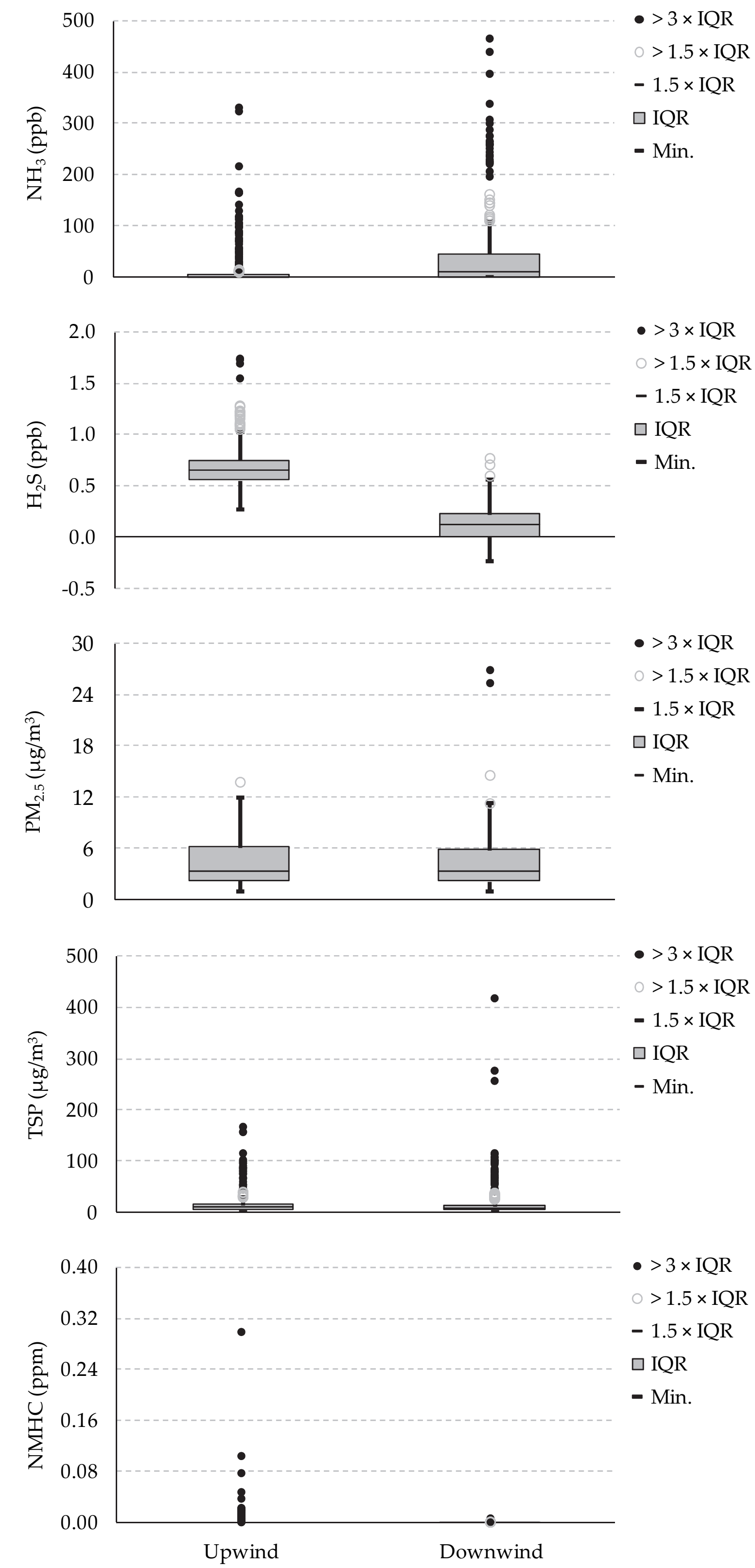


Measurement Period #3



Measurement Period #4



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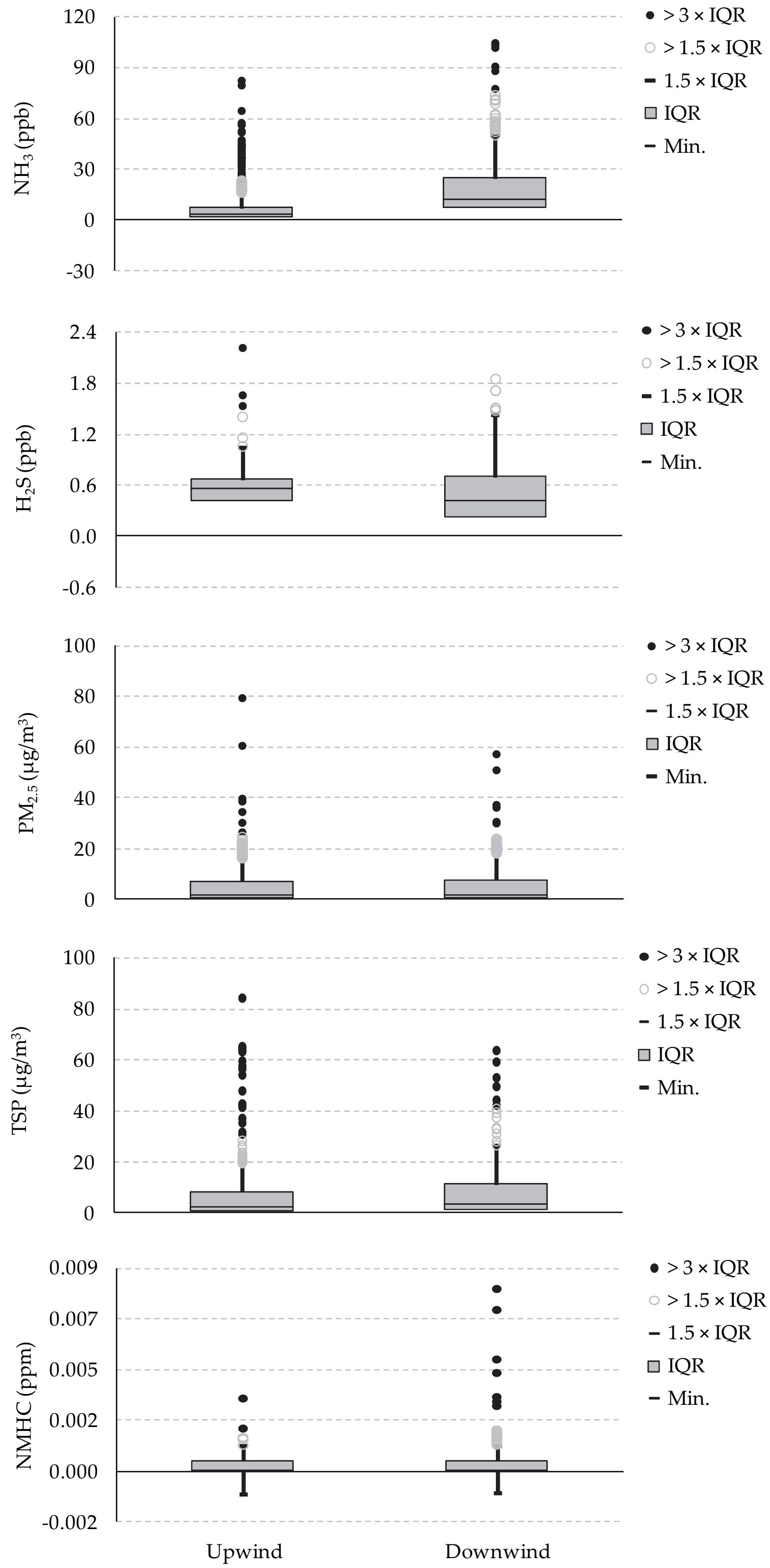

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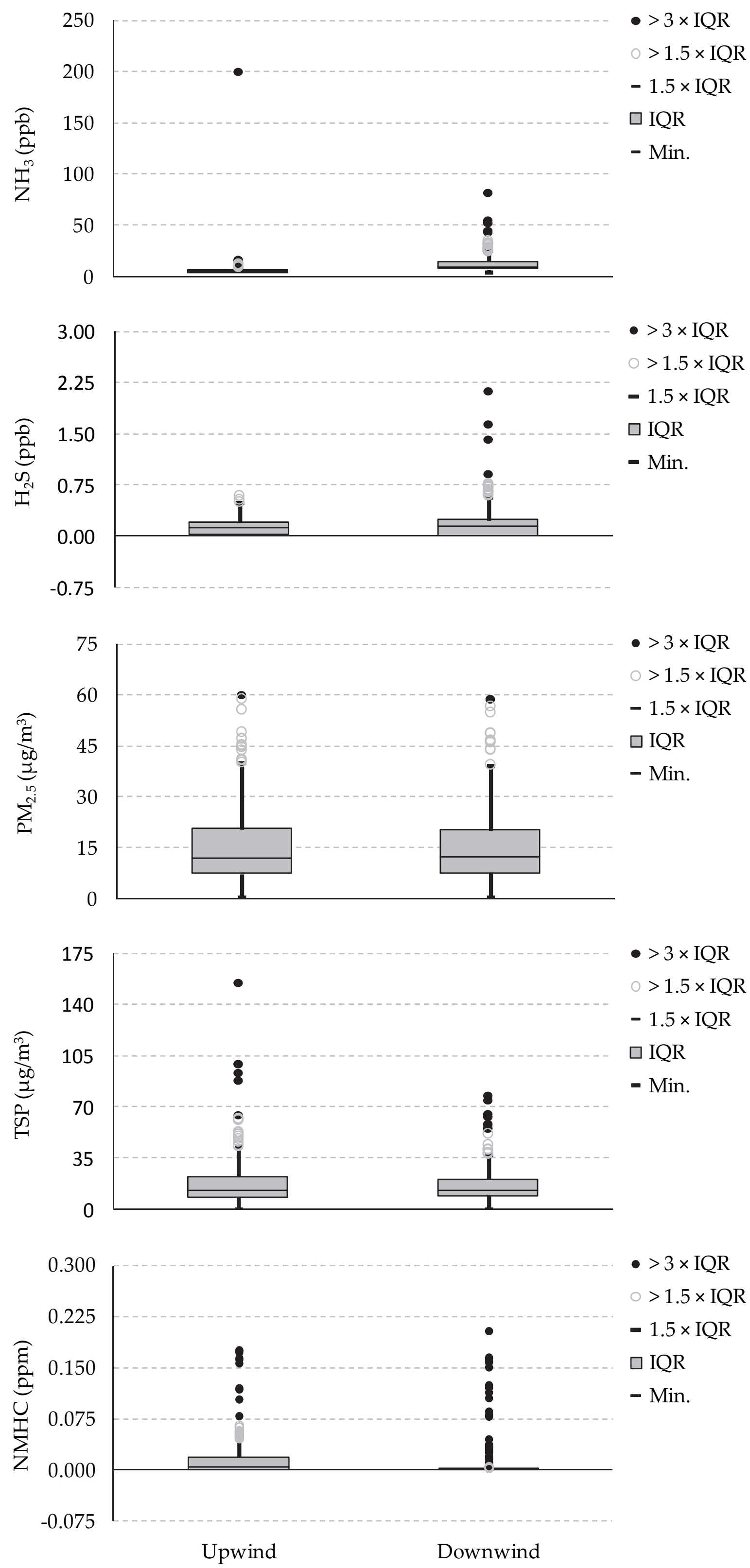

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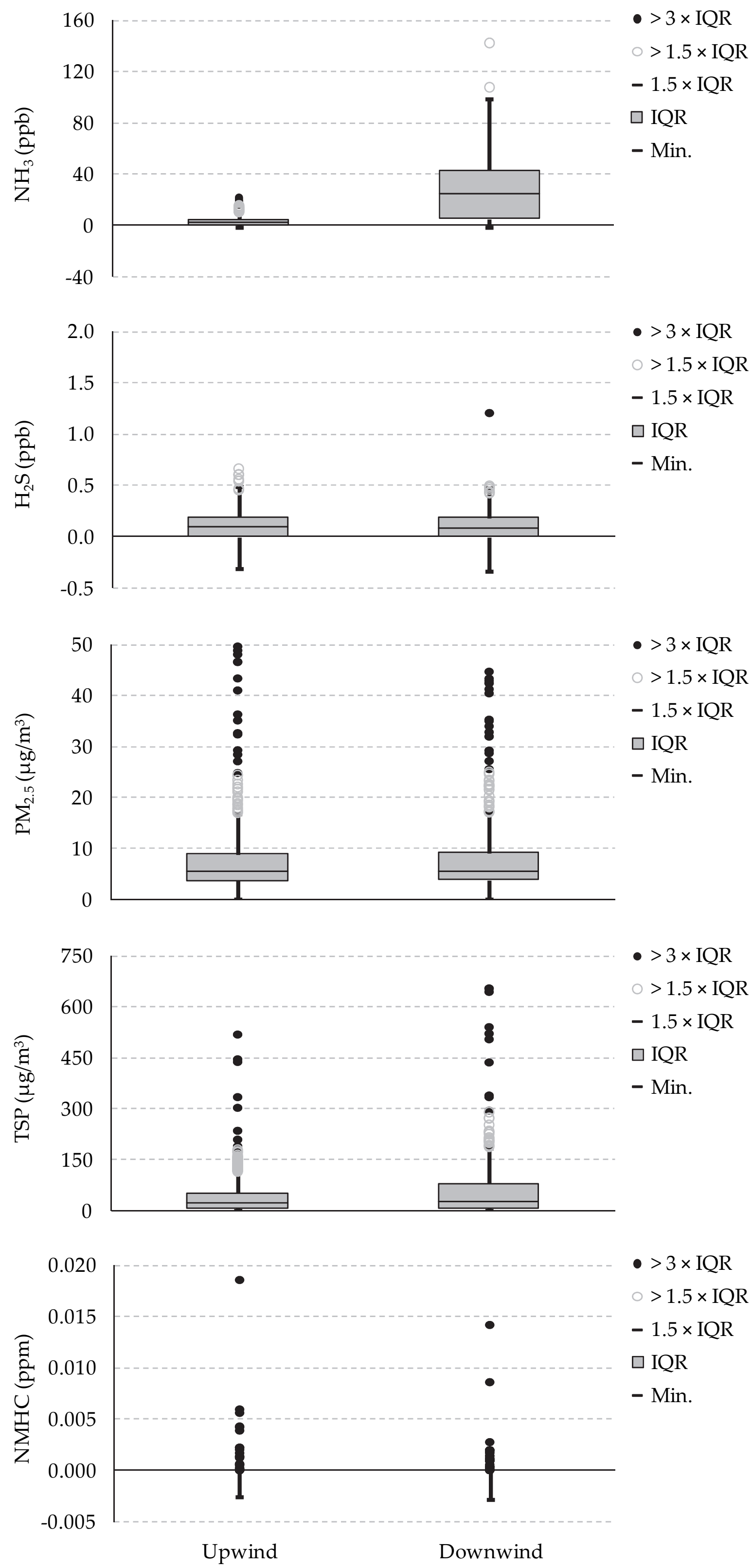

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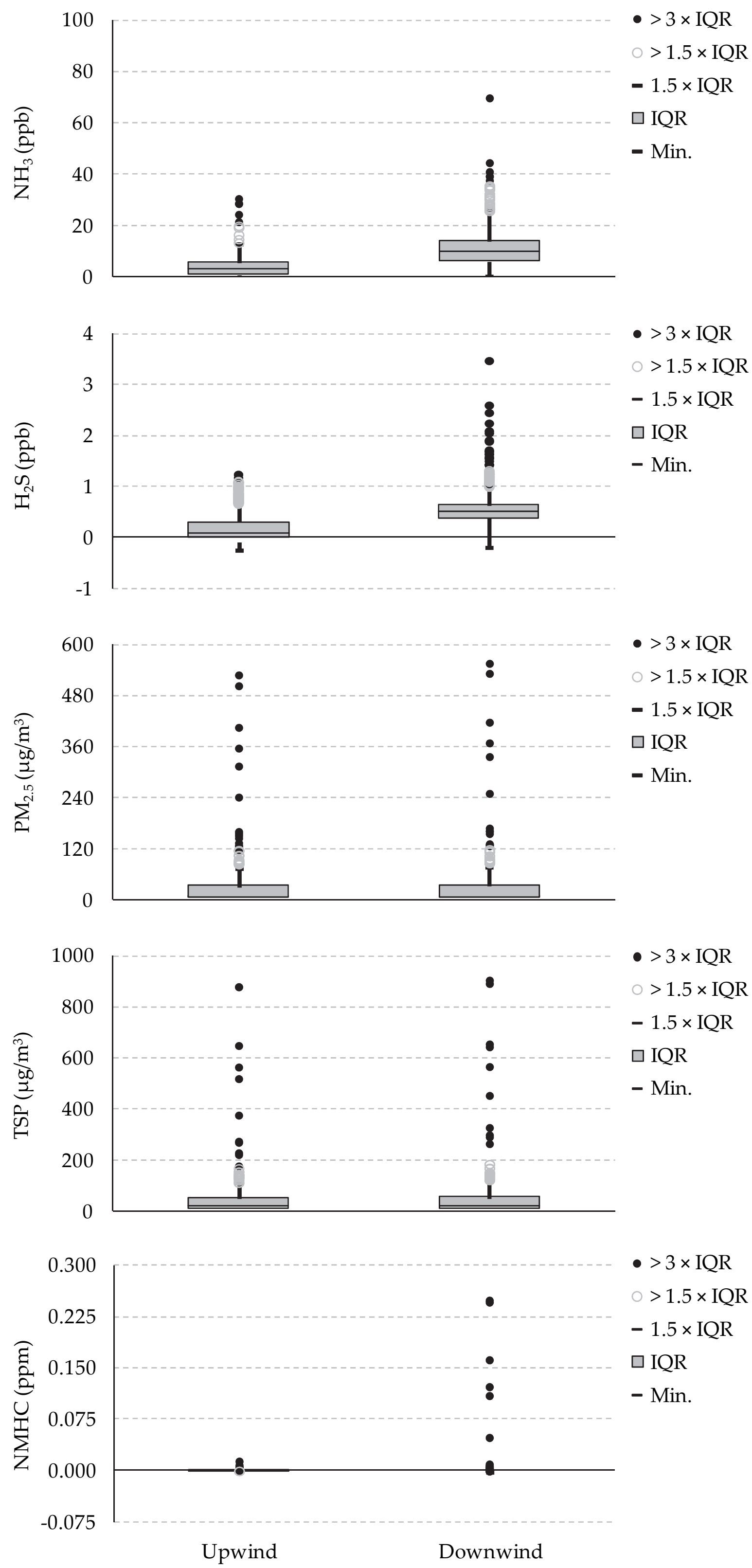

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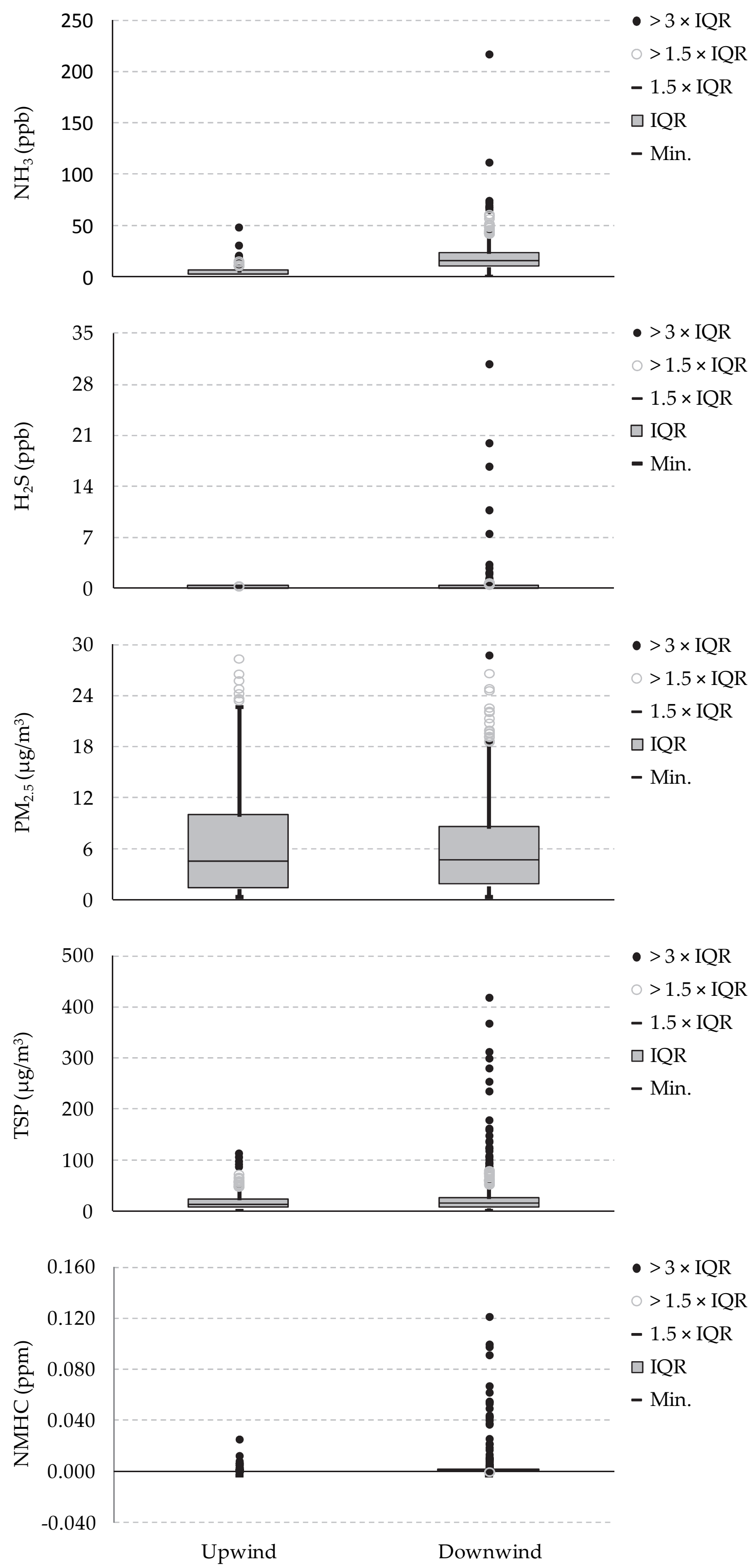

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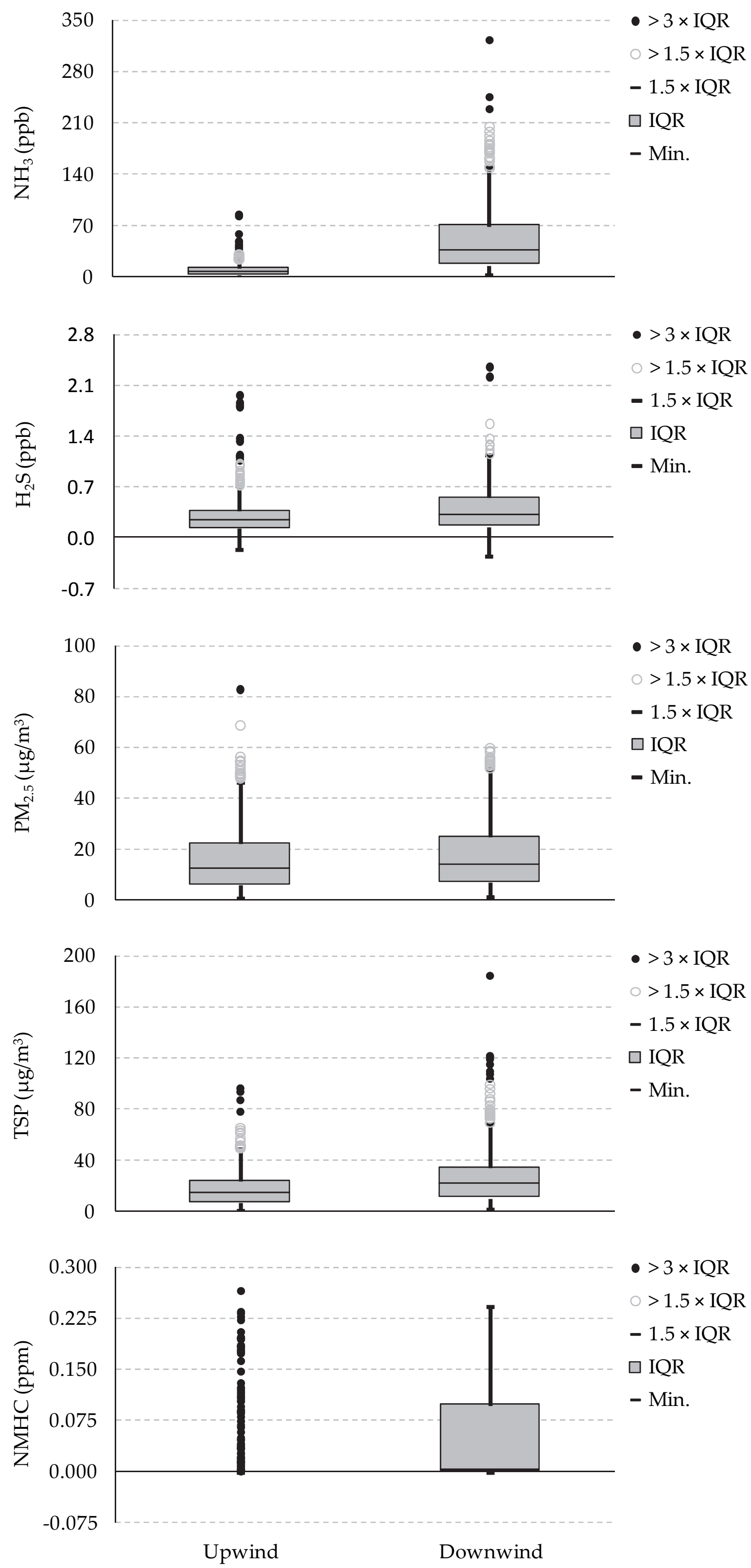

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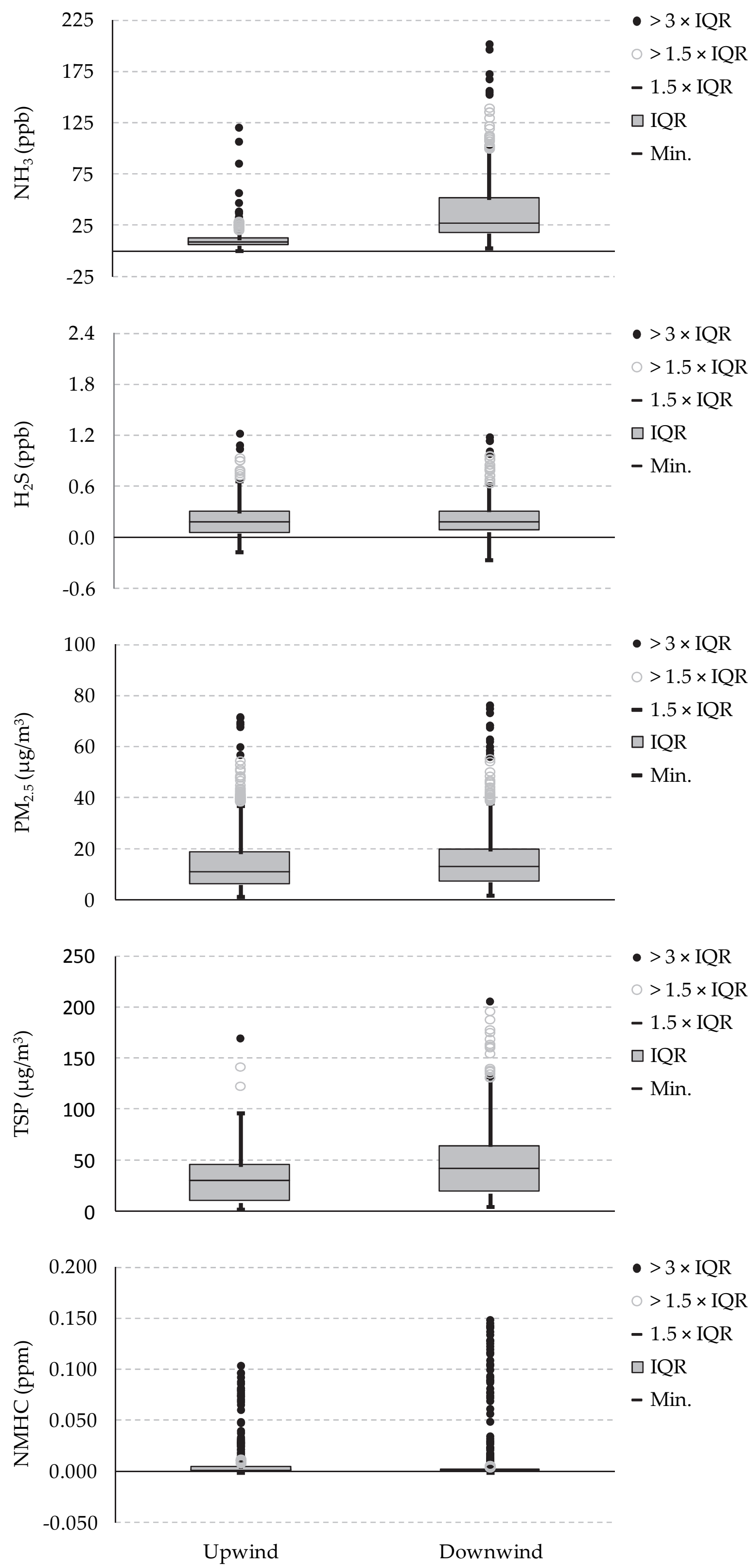

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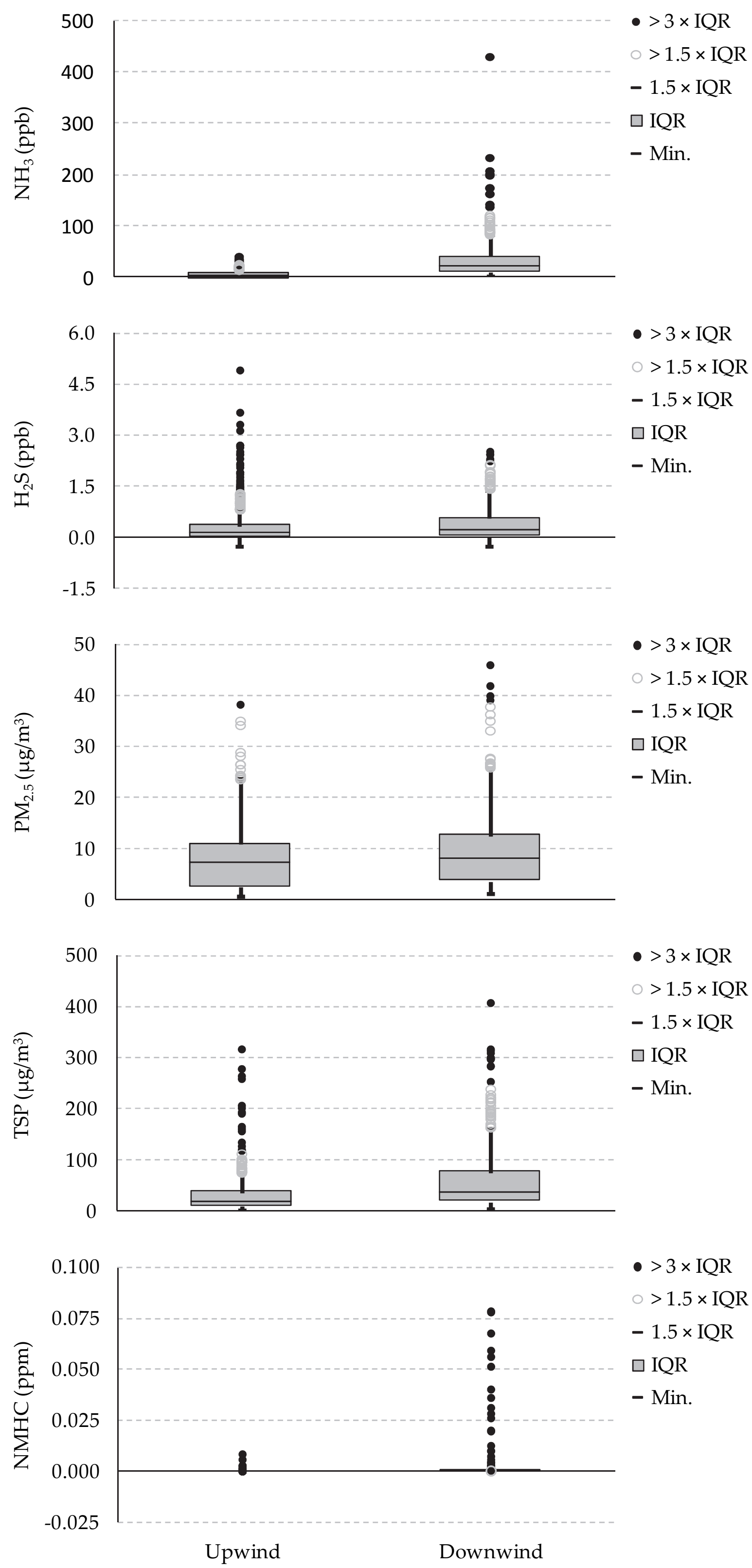

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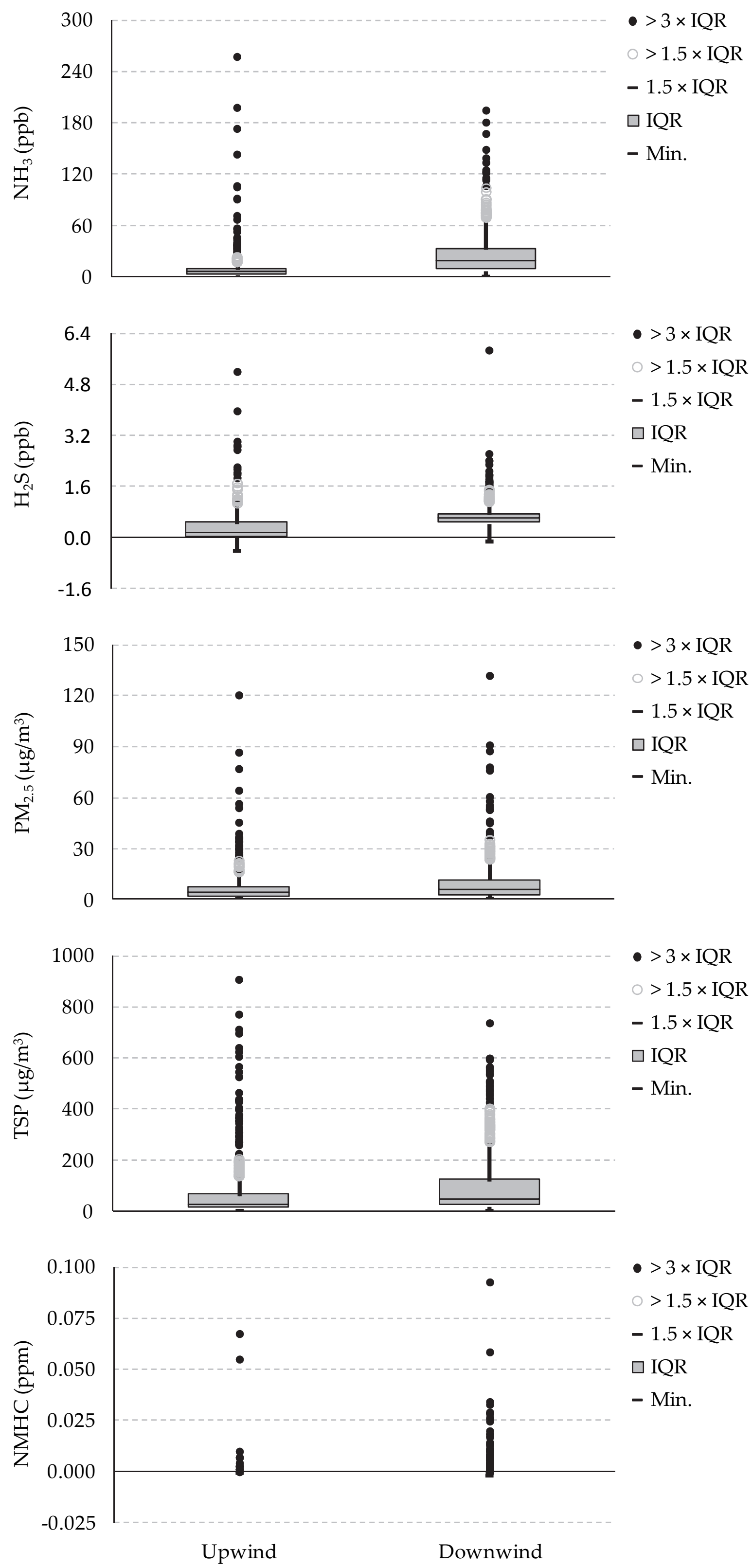

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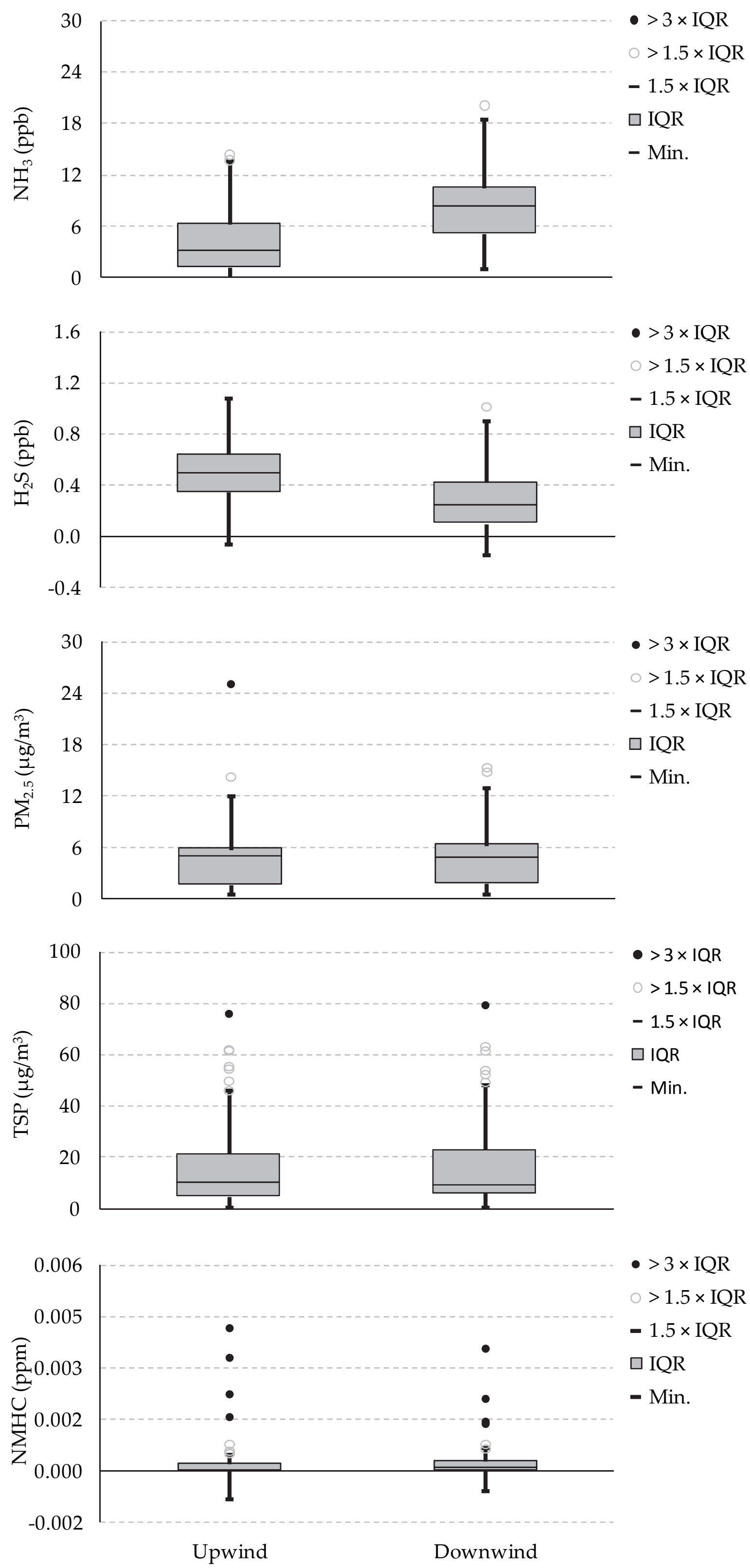
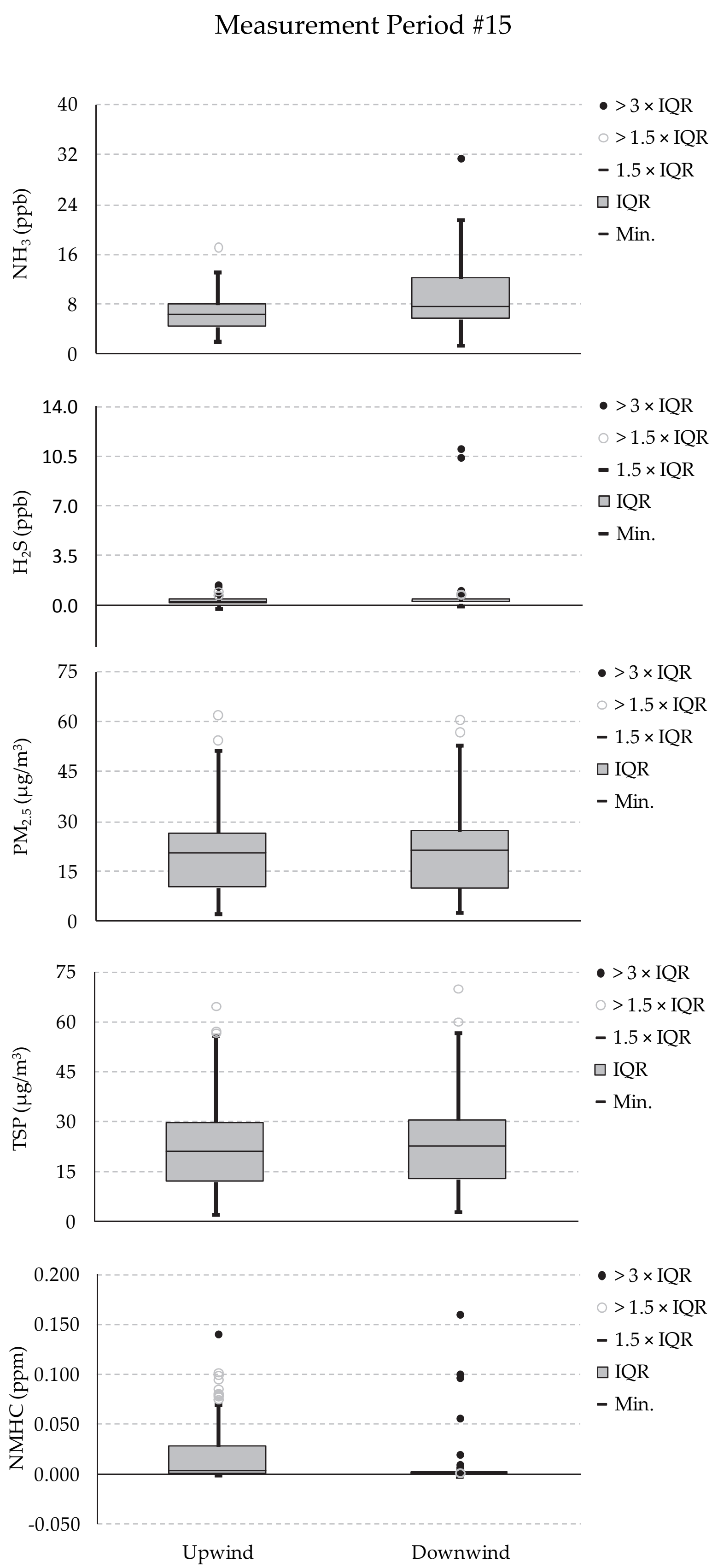
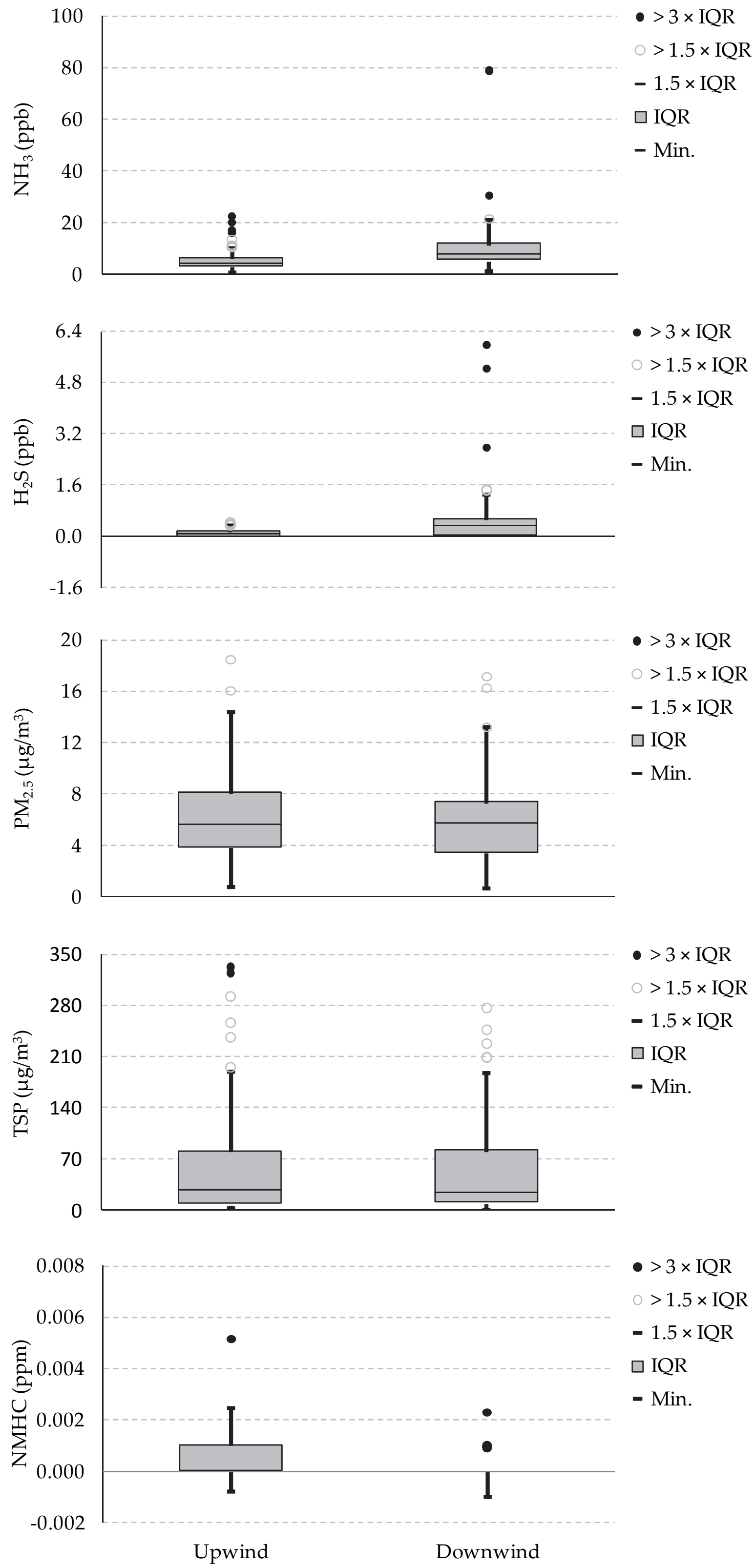




Measurement Period #15
NH3 (ppb)
40
32
24
16
8
0
H2S (ppb)
14.0
10.5
7.0
3.5
0.0
PM2.5 (µg/m3)
75
60
45
30
15
0
TSP (µg/m3)
75
60
45
30
15
0
NMHC (ppm)
0.200
0.150
0.100
0.050
0.000
-0.050
Upwind
Downwind
> 3 × IQR
> 1.5 × IQR
1.5 × IQR
IQR
Min.

Measurement Period #16



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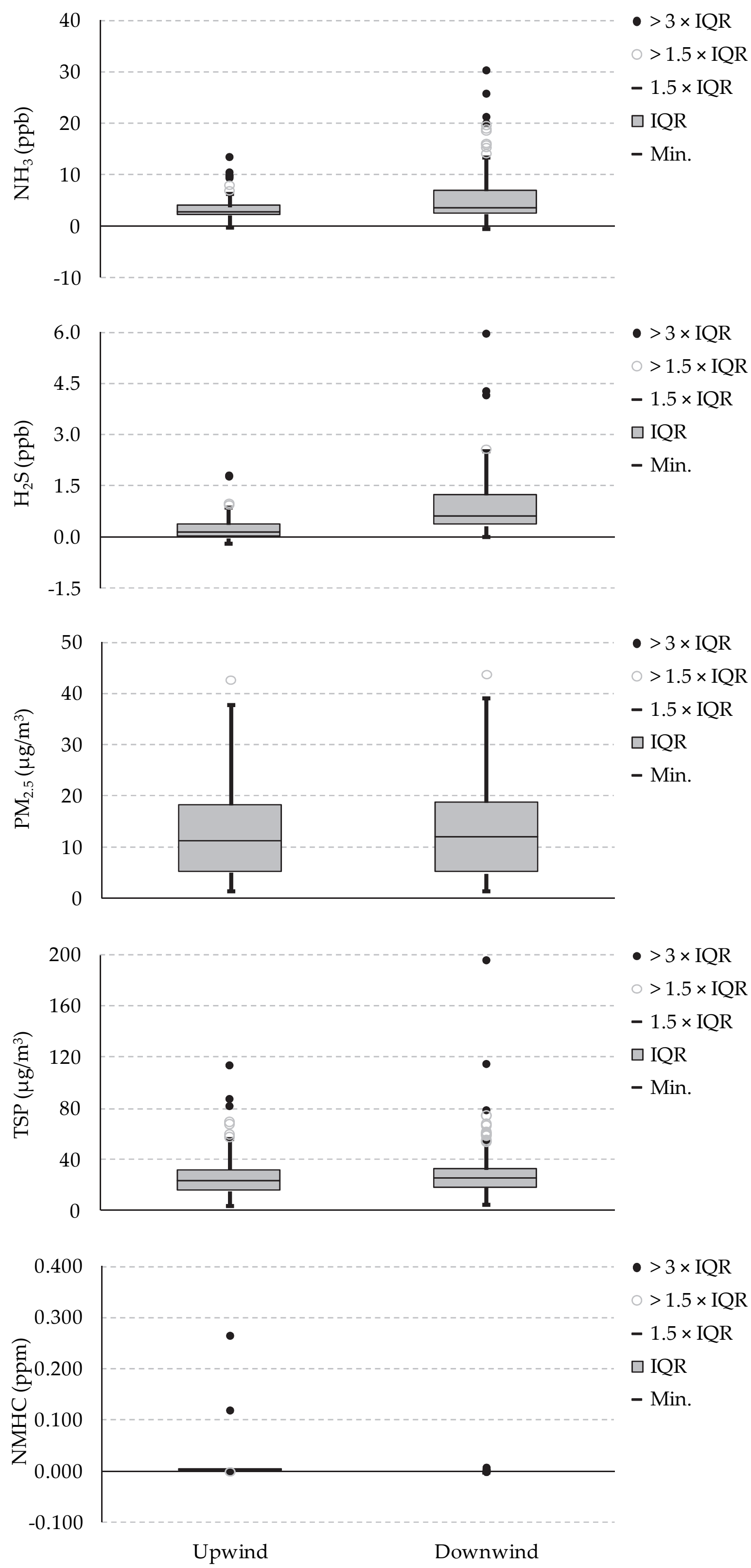
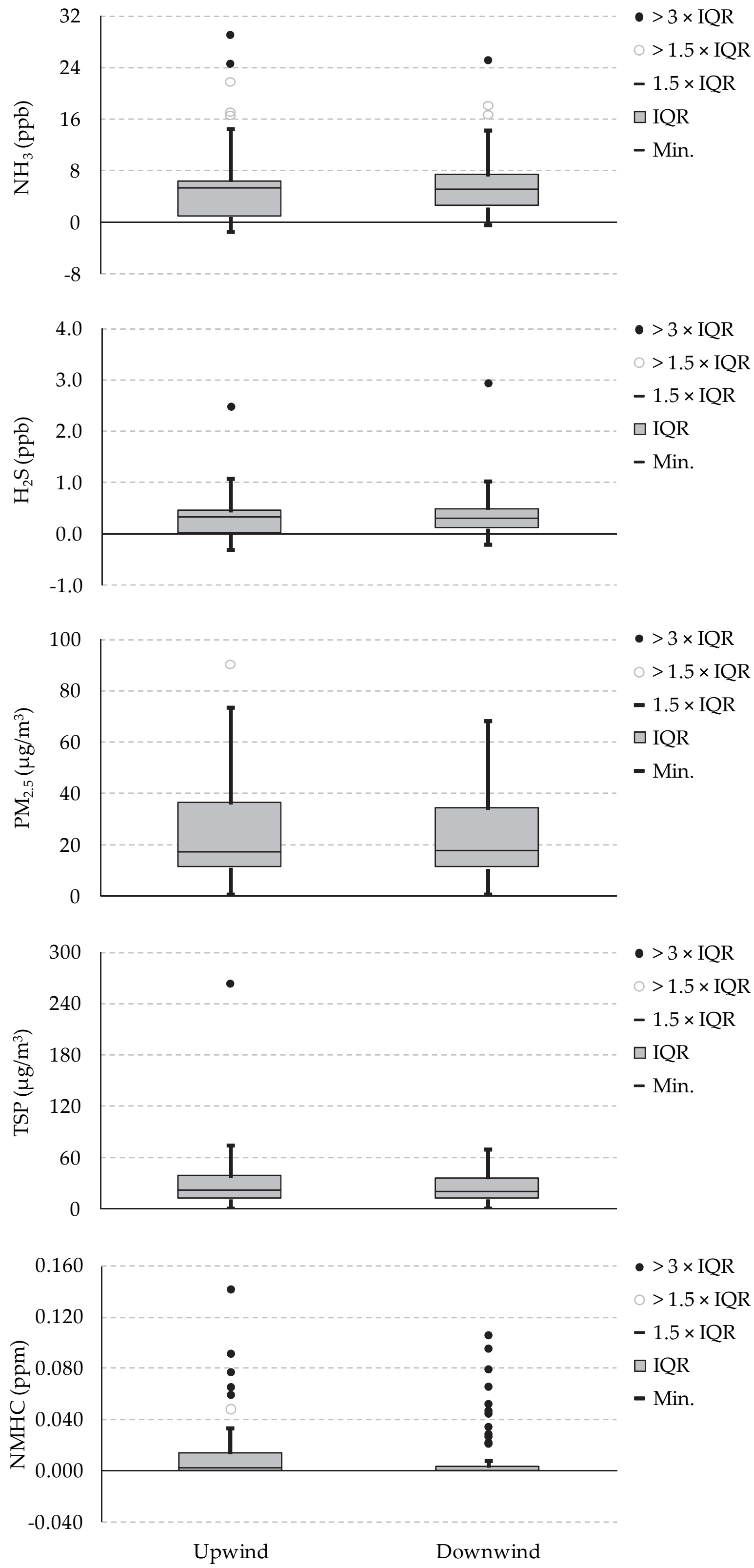


Measurement Period #18



Alberta