RESULTS OF SO₂, NO_x, AND CO MONITORING AT MCMURDO STATION, ANTARCTICA

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ABSTRACT

This report presents the results of ambient air monitoring of carbon monoxide (CO), sulfur dioxide (SO₂), nitric oxide (NO), nitrogen dioxide (NO₂), and total oxides of nitrogen (NO_x) performed during the final weeks of the 1992-1993 austral summer in the vicinity of McMurdo Station, Antarctica. Commercially available, high sensitivity ambient air gas analyzers were used to continuously measure gas concentrations at two locations over a two and a three week time period respectively. Sampling site selection, sampling procedures and quality assurance procedures used for this effort were consistent with U.S. Environmental Protection Agency guidelines for local ambient air quality networks. CO, SO₂, and NO₂ concentrations measured were below the associated U.S. National Ambient Air Quality Standards. Carbon monoxide levels measured at both locations were near or below the instrument detection limit of 0.1 part per million (ppm). Hourly average SO₂ concentrations ranged from below the detection limit of 1 part per billion (ppb) to a single maximum hourly average value of 60 ppb. Hourly average NO₂ concentrations ranged from below the detection limit of 1 ppb to a single maximum hourly average value of 26 ppb. The impact on local air quality of ships docked at an ice pier was observed and quantified. The initial baseline effort demonstrated that site selection and sampling equipment performance were satisfactory, and provided useful data for assessing the impact of McMurdo operations on the local ambient air quality.

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Introduction

McMurdo Station (77°51' South 166°40' East) is the largest human community in Antarctica. It is a coastal station constructed on low ash and volcanic hills at the southern tip of Ross Island. McMurdo serves as the primary logistics and staging facility for airborne resupply of inland research stations and supports a wide variety of scientific research. The austral winter (March-September) population in 1992 was 257, and the austral summer (October-February) population exceeded 1,100. The station consists of over 100 structures, and numerous equipment laydown and storage areas. A nearby skiway airport and sea-ice runway serve fixed wing aircraft for flights to the Antarctica mainland, as well as flights to and from New Zealand. Emissions of atmospheric pollutants at or near McMurdo result from a variety of sources, including: boilers, furnaces, space heaters, electric generators, motor vehicle engines, incinerator, fugitive dust, petroleum storage tank vapors, aircraft operations, and ships. The major fixed air emission source is believed to be the electric generation plant. Tables 1 and 2 summarize the major source categories and estimated air pollutant/products of combustion emissions at McMurdo. There is also conjecture that Mt. Erebus, an active volcano located approximately 14 kilometers northeast of McMurdo, may contribute to local ambient air pollutant levels; the available meteorological data and elevation difference, however, suggest there is no continual, direct influence from Mt. Erebus on the ambient air quality at McMurdo¹. Effects of Mt. Erebus emissions have been observed in snow around Ross Island, and the SO₂ emissions from the volcano have been measured, therefore there is a possibility of occasional direct effects and effects from atmospheric recirculation.

A report on the National Science Foundation (NSF) implementation of a strategy to comply with environmental law in Antarctica (NSF 1989) established the need to assess the environmental impact of air emissions at McMurdo Station and other U.S. Stations. In addition, the recent Protocol on Environmental Protection to the Antarctic Treaty (NSF 1991) and implementation of interim incineration of selected solid wastes at McMurdo further underlined the need to implement an ambient air monitoring network. Incineration at McMurdo ceased on March 22, 1993. In 1992 an ambient air monitoring plan for McMurdo was prepared that established the objectives of the monitoring effort as: (1) to determine the highest concentrations of pollutants expected to occur in the area covered by the network, (2) to determine representative concentrations of selected air pollutants in areas of high population density (3) to determine the impact on ambient pollution levels of significant sources or source categories, and (4) to determine background levels of selected air pollutants (Lugar, 1992).

The objectives and performance criteria established for the monitoring network were consistent with the intent of U.S. EPA State and Local Air Monitoring Stations (SLAMS) objectives and network design (40CFR58, Appendix D). Quality assurance and quality control aspects of the monitoring effort were generally consistent with U.S. EPA sampling procedures, and the U.S. EPA Quality Assurance Handbook (US EPA 1977).

¹ Personal communication with Charles R. Stearns, Department of Atmospheric and Oceanic Sciences, Univ. of Wisconsin, Madison, WI, September 12, 1991.

Table 1. Comparison of Sources of Products of Combustion at McMurdo Station (thousands of pounds per year)

Compound Discharged	Electric Generation	Water Distribution	Space Heating	Surface Vehicles	Waste Incineration ¹	TOTAL
CO ₂	27207	14867	4460	6311	444	53291
H ₂ O	9069	5775	1732	2478	414	19468
SO ₂	17.1	9.5	2.9	0.14	0.19	29.8
NO _x	111.6	9.3	2.8	15.2	0.27	39.2
Part./HC	10.6	2.6	1.4	11.2	0.015	25.1
HCl	<1.0	<0.5	<0.1	<0.01	0.088	<1.6

1. after scrubber

Source: Pearson 1991.

Table 2. Estimated Annual Air Pollutant Emissions at McMurdo Station

Source Category	Annual Emission Basis		Pollutant Emission Rate (tons ^a /yr)				
	Units	Quantity	SO ₂	NO ₂	PM-10	HC	CO
Aircraft Operations							
LC-130 and C-130	LTOs ^b	328	0.6	2.9	0.4	8.9	14.0
C-141	LTOs	25	0.004	0.2	0.01	1.8	2.2
C-5B	LTOs	5 ^c	0.001	0.1	neg.	0.2	0.5
Subtotal			0.7	3.2	0.4	11.0	17.0
Internal combustion engines							
Diesel (stationary and mobile)	1000 gal ^d	1500	23.0	350.0	25.0	28.0	77.0
Gasoline (mobile)	1000 gal	150	0.4	7.7	0.5	15.0 ^e	300.0
External combustion							
Boilers, furnaces, etc.	1000 gal	1300	4.6	13.0	1.6 ^f	1.6 ^f	3.3
Open burning (landfill)	DISCONTINUED		0	0	0	0	0
Storage tanks (evaporation)							
JP-8						0.2	
Gasoline						7.2	
TOTAL McMurdo			29	374	28	63	398

- a. One ton equals 0.907 metric tons. English units are used in this table because regulatory emission limits and U.S. EPA emission factors are given in English units.
- b. Landing take-off cycles.
- c. Only two C-5B flights to McMurdo were reported for the 1989-90 summer season, but up to five flights per season would be typical.
- d. One gallon equals 3.785 liters.
- e. Sum of exhaust, evaporative, and crankcase emissions.
- f. Used emission factors from residential furnaces.

Source: NSF 1991.

Figure 1. Map of Ambient Air Monitoring Stations at McMurdo, Antarctica.

A variety of air pollutants, including many for which the U.S. EPA has established National Ambient Air Quality Standards, were selected for monitoring. Gaseous air pollutants selected for this baseline monitoring included sulfur dioxide (SO_2), nitrogen oxides ($\text{NO}/\text{NO}_2/\text{NO}_x$), and carbon monoxide (CO). Utilizing historical wind data, a sampling network consisting of three locations was selected for the gas monitoring. The locations were selected after field reconnaissance and were based on the objectives outlined in the monitoring plan, the availability of electrical power and other operational support, and location of major emission sources. The three sites selected were: 8-Site for the predominantly upwind location, Hut Point for the predominantly downwind site, and Central McMurdo, near building 155, as the "worst case urban" location (See Figure 1). The monitoring plan called for one set of continuous gas analyzers to be permanently located at Hut Point, and a second set of analyzers to be rotated on a biweekly basis between the Central McMurdo and 8-Site locations.

Methods

Each set of gas analyzers was housed in an insulated, temperature controlled weather shelter. The weather shelters provided the necessary room-temperature operating environment for the analyzers, and were designed to keep the internal shelter temperature as stable as possible, thereby optimizing the analyzer measurement stability. Each shelter also contained a zero air supply, gas calibration system, datalogger, calibration gas cylinders, electrical outlets, and internal lighting. Electricity (110 VAC) was provided to each shelter from nearby power lines. Due to the potential for unstable line power and occasional outages, each shelter also included a power sifter, two uninterruptible power supplies (UPS), and two surge protectors to minimize data loss and protect the monitoring system from damage. Each analyzer utilized a nominal 6.4 mm ID Teflon™ tubing for a sample inlet line and a 47 mm diameter Teflon™ inlet particulate filter. Each shelter had a single roof penetration for an inverted U-shaped PVC pipe assembly that housed a bundle of three inlet lines and provided protection of the inlet tube openings from blowing snow and dust.

The gas analyzers, gas calibration systems, and zero air supplies were manufactured by Thermo Environmental Inc. All analyzers were calibrated using a Matheson NBS traceable certified gas standard, a Model 111 Zero Air Supply, and Model 146 Gas Calibration System. Multipoint calibration curves were prepared for all instruments during start-up of the monitoring program, and again just prior to the conclusion of the monitoring period. Additional zero and span checks were performed periodically. Additionally, a recalibration was performed once on the Hut Point analyzers during the three-week operating period.

SO_2 was continuously monitored using a Model 43S High Sensitivity Pulsed Fluorescence SO_2 Analyzer. Although this instrument does not have a U.S. EPA designation as a compliance monitor, it is identical to the EPA designated Model 43A in most respects (U.S. EPA Equivalent Method to 40CFR50 Appendix A). The principal difference in the Model 43S is its improved sensitivity (lower detectable limit of 0.1 ppb SO_2), and associated lower operating ranges (minimum range of 10 ppb, maximum range of 200 ppb). The Model 43S was selected because the ambient SO_2 levels at McMurdo were suspected to be in the ppb range or lower.

$\text{NO}/\text{NO}_2/\text{NO}_x$ was continuously measured using a Model 42S Chemiluminescence Low Level $\text{NO}-\text{NO}_2-\text{NO}_x$ Analyzer. This instrument does not have a U.S. EPA designation as a reference method monitor, however it is very similar to the EPA designated Model 42; the main difference being the

improved sensitivity of the Model 42S (minimum detectable limit of 50 parts per trillion). Data was collected in accordance with U.S. EPA Reference Method described in 40CFR50 Appendix F.

CO was measured continuously using a Model 48 Gas Filter Correlation (GFC) Ambient CO Analyzer. This instrument is designated by the U.S. EPA as a Reference Method (40CFR50 Appendix C), and holds designation reference method number RFCA-0981-054. It is not available in a more sensitive model as are the SO₂ and NO_x analyzers, and has a minimum detectable limit of 0.1 parts per million (ppm).

The datalogger used in each shelter was an Environmental Systems Corporation ESC 8800 Data Logger, programmed to perform hourly averaging and storage of the analyzer outputs. In addition, a multichannel chart recorder was used in each shelter to provide additional real-time record of the analyzer output during calibration, span and zero checks, and initial operation.

Due to delays in equipment procurement and delivery, the gas analyzers arrived at McMurdo late in the summer season, and were operated for a limited time. The Hut Point analyzers were placed into continuous operation between 23JAN93 and 25JAN93, and ran approximately three weeks until shutdown on 16FEB93 and 17FEB93. The Central McMurdo/8-Site set of analyzers were only operated at the Central McMurdo location due to time constraints. The Central McMurdo analyzers were placed into continuous operation between 30JAN93 and 01FEB93, and ran approximately two weeks until their shutdown on 17FEB93.

Results

The concentrations of SO₂, NO₂, and CO measured in the McMurdo locale during this initial monitoring effort were below all applicable U.S. National Ambient Air Quality Standards (NAAQS). SO₂, NO, NO₂ and NO_x were continuously measured at both Hut Point and Central McMurdo in the low parts per billion (ppb) concentration range. CO levels at both locations were near or below the 0.1 ppm level of detection. The localized impact of vehicle and ship emissions on the ambient concentration of SO₂ and NO_x were observed at Hut Point. No prominent evidence of any direct effect of SO₂ emissions from Mt. Erebus were observed during this initial monitoring effort. Table 3 provides a summary of the Central McMurdo and Hut Point average hourly gas concentration data and associated NAAQS for the gaseous air pollutants measured. A graphical presentation of hourly average concentration of CO, SO₂, NO₂, NO, and NO_x measured at Central McMurdo and Hut Point are provided on Figures 2 through 11. Note that the data presented on these figures has been screened to remove data associated with analyzer calibration, analyzer or datalogger downtime or malfunction, and any other conditions resulting in erroneous or suspect data. Ambient gas concentrations were measured only at Hut Point and Central McMurdo locations. The planned alternating of the shelter and instruments between Central McMurdo and the predominantly upwind 8-site was canceled due to time constraints.

The localized impact of ship emissions and cargo handling activities at the ice pier were observed at Hut Point from analysis of wind direction, continuous concentration measurements (chart recorder output), and hourly average concentration data for NO_x gases and SO₂. During the time period when the Research Vessel (R/V) Akademik Federov was docked at the ice pier the average NO₂ concentration at Hut Point was 5.6 ppb. After the departure of the R/V Akademik Federov, the

Figure 2.

Central McMurdo Hourly Avg. CO Concentration
McMurdo, Antarctica 30JAN93 – 17FEB93

Figure 3.

Central McMurdo Hourly Avg. SO₂ Concentration
McMurdo, Antarctica 01FEB93 – 17FEB93

Figure 4.

Central McMurdo Hourly Avg. NO₂ Concentration
McMurdo, Antarctica 30JAN93 – 17FEB93

Central McMurdo Hourly Avg. NOx Concentration
McMurdo, Antarctica 30JAN93 - 17FEB93

Figure 5.

Figure 6.

Hut Point Hourly Average CO Concentration
McMurdo, Antarctica 23JAN93 – 17FEB93

Central McMurdo Hourly Avg. NO Concentration
McMurdo, Antarctica 30JAN93 - 17FEB93

Figure 7.

Figure 8. Hut Point Hourly Average SO₂ Concentration
McMurdo, Antarctica 23JAN93 - 16FEB93

Figure 9. Hut Point Hourly Average NO₂ Concentration
McMurdo, Antarctica 25JAN93 - 17FEB93

Figure 10.

Hut Point Hourly Average NO Concentration
McMurdo, Antarctica 25JAN93 - 17FEB93

Hut Point Hourly Average NOx Concentration
McMurdo, Antarctica, 25JAN93 - 17FEB93

Figure 11.

Table 3. Summary of SO₂, NO, NO₂, NO_x and CO Monitoring Results at McMurdo Station, Antarctica

Pollutant	Central McMurdo (2-week avg.)	Hut Point (3-week avg.)	U.S. National Air Quality Standard	Background	Urban
SO ₂	< 1 ppb	< 1 ppb	Annual Average: 80 µg/m ³ (30.1 ppb) 24-hr. max: 365 µg/m ³ (139.3 ppb) 3-hr. max.: 500 ppb (1300 µg/m ³)	0.2 ppb ^a 0.3 - 1.1 ppb ^b (Antarctica) 0.02 - 0.2 ppb ^c (Antarctic area) 0.5 - 1.2 ppb ^d (King George/ Penguin Islands)	2.7 - 23 ppb ^e (international) 8.0 - 12 ppb ^f (U.S.)
NO ₂	4.6 ppb	5.9 ppb	Annual Average: 100 µg/m ³ (52.4 ppb)	0.5 - 4.0 ppb ^a	22 - 28 ppb ^f (U.S.)
NO	4.7 ppb	11.0 ppb	None	0.2 - 2.0 ppb ^a	
NO _x	9.2 ppb	16.7 ppb	None	31 ppb annual mean @ Syowa Station, Antarctica ^c	40 - 80 ppb ^g
CO	0.2 ppm	< 0.1 ppm	8-hour avg.: 10 mg/m ³ (8.6 ppm) 1-hour max.: 40 mg/m ³ (34.9 ppm)	100 ppb ^a 40-70 ppb @ South Pole ^h	1.1 - 1.6 ppm ^f (U.S.)

Sources:

- a. Robinson and Robbins 1969
- b. Sterns 1976
- c. Nguyen Ba Cuong et al. 1974
- d. Molski et al. 1981

- e. OECD 1991
- f. U.S. EPA 1992
- g. Wark and Warner 1976
- h. Khalil and Rasmussen 1989

following four-day NO_2 average dropped to 2.9 ppb. NO , and NO_x levels responded similarly (See Figures 9, 10, & 11). A similar correlation was observed during the period of time the resupply ship, Merchant Vessel (M/V) Greenwave was docked at the ice pier, with NO_2 concentrations averaging 10.3 ppb during the six-day ship loading activities; dropping to 3.1 ppb for the 4 days after the M/V Greenwave's departure (See Figures 4, 5, & 6).

Although the gas monitoring data set for the austral summer season was considerably smaller than originally planned, the effort did prove useful in assessing the analyzer and shelter performance, determining the range of pollutant concentrations present, providing information to optimize future analyzer-specific QA/QC requirements, and provided useful data for assessing the impact of McMurdo operations on the local air quality.

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