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Assessing Fog Oil Deposition to Simulated Plant Surfaces during Military Training

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Abstract: Fog oil is used as a battlefield obscurant during military operations. A smoke-like aerosol is emitted from mobile generators by volatilizing standard grade fuel #2 and blowing it through a heated manifold. In this study we monitored fog oil aerosol deposition to environmental surfaces during training. This project had two goals: to assess fog oil aerosol deposition (as total petroleum hydrocarbon, TPH) to environmental media and to quantify whether glass membrane fiber filters are a suitable proxy for plant surfaces. In support of these goals we exposed glass membrane fiber filters and collectors simulating plant surfaces (silk flowers and polypropylene leaves) to fog oil training. Samplers were deployed during winter and summer events. In the summer, TPH concentrations on leaves, flowers, and filters were strongly correlated, though flowers and leaves consistently yielded TPH concentrations 60% higher than filters. In the winter, TPH concentrations on polypropylene leaves and silk flowers were not correlated with concentrations measured on glass membrane filters. TPH concentrations measured during the winter were 100 times lower than in the summer. We attribute the winter anomalies to the presence of a low-level inversion at the ground surface that could have affected fog oil aerosol transport and deposition.

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Terminology / Abbreviations

DRO	diesel range organics
GC	gas chromatography
GC-FID	gas chromatography-flame ionization detection
GC-MS	gas chromatography-mass spectrometry
PAH	polycyclic aromatic hydrocarbon
RRO	residual range organics
RT	retention time
SGF2	Standard Grade Fuel Number 2
SPE	solid phase extraction
TPH	total petroleum hydrocarbons

Preface

This report was prepared by Dr. Thomas A. Douglas, Biogeochemical Sciences Branch, Cold Regions Research and Engineering Laboratory (CRREL), Engineer Research and Development Center (ERDC); Dr. Jerome B. Johnson, Terrestrial and Cryospheric Branch, CRREL; Charles M. Collins, Biogeochemical Sciences Branch, CRREL; Dr. C. Michael Reynolds, Biogeochemical Sciences Branch, CRREL; Karen L. Foley, Biogeochemical Sciences Branch, CRREL; Lawrence B. Perry, Biogeochemical Sciences Branch, CRREL; Arthur Gelvin, Engineering Resources Branch, CRREL; and Susan E. Hardy, Biogeochemical Sciences Branch, CRREL. The report was reviewed for technical merit by Beth Astley and Marianne Walsh, both of CRREL.

Members of the Chemical Platoon, Headquarters-Headquarters Company, 172nd Support Battalion, Fort Wainwright, Alaska, provided the aerosol generation for this study.

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1 Background

The U.S. Army maintains an active role in assessing the potential environmental impacts associated with military training exercises. One training activity includes the use of smoke-like obscurants, such as fog oil, as a force multiplier designed to confuse enemy sensors and reduce enemy command and control capabilities. To minimize the potential negative environmental effects of fog oil obscurant operations, we need to understand the deposition, fate, and consequence of products generated by fog oil. Seasonal controls on fogging may be significant. If managers can reliably predict the nature and concentrations of fog oil deposition following training in different environmental conditions, they can more successfully monitor and mitigate the effects of this component of Army training.

Fog Oil Properties

Standard Grade Fuel Number 2 (SGF2), otherwise known as fog oil, is the most common obscurant used in military operations. SGF2 aerosol is also well suited for use as a tracer of atmospheric motions and dispersion because it meets many of the prerequisites for a tracer outlined by Johnson (1983). Foremost in these requirements is the fact that SGF2 aerosol is conservative in nature because of its low evaporation rate (Lowry et al. 1951). SGF2 is a refined petroleum product in the middle distillate range, like mineral oil or SAE 20 grade motor oil, with a density of 0.9 g/mL, a flash point of 160°C, and a boiling point of 300°C.

A dense, grey to white, suspended, smoke-like plume of aerosols is generated as a result of vaporization of liquid SGF2 in a pulse jet mechanical generator. SGF2 vapors leave the aerosol generator at an elevated temperature. Upon ejection the vaporized oil cools and condenses after traveling approximately 1 m to form a fine oil aerosol that produces a dense white smoke plume. The oil droplets in the aerosol range from 0.9 to 1.9 μm in diameter (Driver et al. 1993). Generators are usually mounted on a vehicle and can be operated either in the static position with the vehicle parked or as a mobile generator with the vehicle in motion. Generators consume an average of roughly 150 L of SGF2 per hour, with maximum and minimum rates of 95 and 190 L per hour, respectively.

Most of the research on SGF2 has focused on the environmental impact associated with the deposition and fate of SGF2 oils and fog oil aerosol deposited on vegetation (Shinn et al. 1987), avian wildlife (Albers and Heinz 1983, Getz 1996, Driver 2002, Driver et al. 2002), and aquatic wildlife (Poston et al. 1986, 1988). The most common environmental risk associated with the use of SGF2 aerosol for training is the potential coating of plant or other biological surfaces with a thin layer of coalesced oil droplets. This coat of oil is postulated to affect soil and plant respiration processes and could inhibit photochemical reactions. These potential negative effects of aerosols on ecosystem properties could be attributed to deposition of atmospheric contaminants (i.e., soot from coal burning, diesel exhaust, or wood smoke) or anthropogenic aerosols (sulfate or black carbon). Aerosol concentrations measured on filter surfaces used as passive collectors are generally assumed to accurately represent particle deposition of these atmospheric aerosols (Jaffrezo et al. 1994, Bergin et al. 1994, 1995).

The diameter of fog oil aerosol droplets is within the range of environmental concern for anthropogenic aerosols in the accumulation mode size fraction (diameters between 0.1 and 2.5 μm). Aerosols including sulfate and black carbon can travel thousands of kilometers in this size range (Pacyna et al. 1984). As such, fog oil could serve as a proxy for the dispersion and deposition of these and perhaps other common aerosol environmental contaminants. Knowing the spatial and temporal loading rates of atmospheric aerosols is paramount to accurately monitoring and modeling aerosol deposition. As a consequence, it is possible that our work in assessing the deposition of fog oil aerosol to passive sample media has applicability to other environmental monitoring programs for aerosols.

Monitoring Hydrocarbon Deposition to Natural Surfaces

An important objective of any environmental monitoring campaign is to be able to extend the results from one specific field case to many others. In the case of fog oil deposition a major environmental monitoring goal is to estimate the deposition of the fog oil aerosol to natural plant surfaces over a range of field conditions. Leaves and needles have myriad shapes, sizes, and orientations that govern their presentation as a potential receptor for aerosol deposition or retention. A detailed understanding of the deposition rates of fog oil aerosol to different sample media morphologies should

allow us to extrapolate the results from a given test at one site to testing at other locations.

An important initial evaluation in this study was to identify low-cost yet effective field sampling protocols. The concept was to optimize the trade-off between the number of sample types and deployment locations and the analytical cost per sampling device. Leaves and needles provide the most obvious sample media in support of environmental monitoring in the boreal forest of the Alaskan Interior. However, analytical methods commonly used to determine concentrations of hydrocarbons and oils cannot accurately distinguish natural plant oils on plant surfaces from fog oil aerosol. As a consequence, it is difficult to estimate the deposition of fog oil to leaf plant surfaces using gas chromatographic (GC) techniques. We therefore used glass membrane fiber filters, silk flowers, and polypropylene leaves in this investigation because they provided sample media that represented a range of deposition surfaces, could be readily deployed, and could be used in both winter and summer conditions. The silk flowers and polypropylene leaves were selected for their ability to represent the morphologies of different plant types. As such, they were used as proxies to evaluate the effectiveness of the glass membrane fiber filters as passive collectors of fog oil aerosol.

2 Objectives

The principal objective of this study was to develop and implement a monitoring program to determine the deposition rate and fate of fog oil from obscurant plumes produced during military training. The monitoring program was required under the terms of the permit issued by the Alaska Department of Environmental Conservation to U.S. Army Alaska allowing the use of obscurants on military training lands in Alaska. A second objective was to determine whether glass membrane filters are an acceptable proxy for measuring petroleum hydrocarbon deposition to leaf and flower surfaces.

3 Approach

We first developed and tested simple methods for collecting and characterizing fog oil residues deposited from a vehicle-mounted fog oil generator. We then developed and implemented methodologies to characterize the amount of fog oil residues deposited from a plume during four training events involving multiple vehicle-mounted generators (Table 1). These training events were conducted in March and July 2001 and January and September 2002. The field sampling was augmented with an investigation of fog oil evaporation over time. In addition, petroleum hydrocarbon concentrations were measured from snow samples obtained along heavily used roadways in Fairbanks, Alaska, to place the hydrocarbon values associated with training in perspective.

Table 1. Fog oil training events.

Event	Date	Location	Description	Average deposition (mg/m ²)*
1	26 Mar 2001	Bear Drop Zone Fort Greely	Late winter / early spring (-3°C) Moving sources 700 gal. (2650 L) fog oil used ~ 10–20 min exposure time Snow samples taken	24.7 (filter) 41.6 at north end 5.12 at south end
2	3 Jul 2001	Firebird Landing Zone Fort Wainwright	Summer (19–21°C) Moving sources 960 gal. (3633 L) fog oil used Three exposure times (77, 57, 49 min)	3.5 (filter)
3	31 Jan 2002	Firebird Landing Zone Fort Wainwright	Winter (-15°C) Stationary sources 200 gal. (760 L) fog oil used Two exposure times for filters (93, 68 min) Synthetic flowers and leaves used (93 min)	10.4 (filter) 14.1 (leaf) 7.3 (flower)
4	12 Sep 2002	Firebird Landing Zone Fort Wainwright	Late summer / early fall (10–15°C) Stationary sources 111 gal. (420 L) fog oil used One exposure time (110 min) Synthetic flowers and leaves used	48.4 (filter) 77.1 (leaf) 85.5 (flower)

*Deposition is reported as TPH in milligrams divided by the surface area of the sample collector.

4 Methods and Materials

Chemical Platoon, HHC 172nd Infantry Brigade (Separate), on Fort Wainwright, Alaska, has twelve M157A2 fog oil aerosol generators, with two mounted on each of six High Mobility Multi Wheeled Vehicles (HMMWV). The generators can be operated in either a static position with the vehicle parked or as a mobile generator with the vehicle in motion. Each generator consumes roughly 40 gallons (151 L) of fog oil per hour, with maximum and minimum rates ranging from 25 to 50 gallons (95 to 190 L) per hour, respectively.

Prior to field use, we obtained the fog oil mixes that are used in support of training in Alaska. These include a standard fog oil and, for use at temperatures below -18°C (0°F), a 70:30 fog oil:diesel fuel mix.

We first observed a fogging exercise on 21 and 22 February 2001 at Firebird Landing Zone in the Yukon Maneuver Area on Fort Wainwright. This was the first time many of the Chemical Platoon personnel had used the generators in the field in winter conditions. Mechanical problems with the equipment precluded any meaningful production of fog oil aerosols. We spent the time observing the equipment and discussing standard operating procedures with the Chemical Platoon personnel. We did not collect any samples during this curtailed training exercise. A total of 150 gallons (568 L) of fog oil was used over the two days.

Sample Collection

Samples were collected during both winter and summer fog oil training exercises on 26 March 2001 at the Donnelly Training Area, Alaska, and on 3 July 2001, 31 January 2002, and 12 September 2002 in the Yukon Maneuver Area at Fort Wainwright, Alaska. Sample surfaces used in the study included surface snow, filter papers (52- by 52-cm filter pads), glass microfiber filters (7-cm-diameter binder-free borosilicate glass-membrane fiber filters with a $0.7\text{-}\mu\text{m}$ pore size), snow, vegetation, and synthetic plants.

Snow samples were collected during the first field sampling event. Surface, midlevel, and bottom snow samples were collected from the snow cover at each location within the grid area. Samples were collected over a known

surface area with a vertical thickness of 4 cm. Samples were also collected at locations upwind from the training area for use as controls. The snow was placed in precleaned 125-mL wide-mouth glass jars.

The large 52- by 52-cm filter papers (2704 cm² area) used in fogging event #1 had a foil backing to eliminate potential interference from oil residues that might have been present on the soil or snow prior to deployment of the filters (Fig. 1). These paper filters provided initial estimates of fog oil deposition, but background interferences associated with the paper filters and sorption of fog oil and solvent onto paper filters made the extraction tedious and increased the chances of error. To improve extraction efficiency, 7-cm-diameter Whatman[®] glass microfiber filters were used for the remaining fogging events. Because the glass microfiber filters were significantly smaller than the paper filters, an array of nine filters was stapled to a 21- by 28-cm cardboard backing at each sampling location (Fig. 2). Each array of nine filters gave a total of 350 cm² of filter surface area.



Figure 1. Filter papers (52 by 52 cm) on foil backing used for fogging event #1.



Figure 2. Arrays of nine 7-cm-diameter glass microfiber filters used for fogging events #2, #3, and #4. The arrays were used with synthetic vegetation, as shown above, in events #3 and #4.

The synthetic plant stalks were 0.75 m in height and included 0.5 m of polypropylene stem with 0.25 m of equally spaced silk flowers and polypropylene leaves (Fig. 2 and 3). The synthetic plants closely represent valerian (*Valeriana capitata*), a three-lobed, stem-leaved plant with a corolla of pistillate flowers that is found in semi-moist soils of subalpine meadows throughout Alaska and the western United States. The leaf and flower samples were pushed into the snow or gravel until the base of the leaf and flower region was even with the snow or ground surface. The silk flowers were sampled by removing the flowers and leaves from the stems. The silk flowers for each sample site were collected into one pre-cleaned glass sample jar while the leaves were placed in another jar.

Personnel wearing powder-free latex gloves collected samples into pre-cleaned glass jars. Filters were placed into 500-mL jars, and snow samples were placed into 125-mL jars. The jars were packed in bubble pack, placed in a cooler, and shipped back to CRREL for extraction and analysis by gas chromatography-flame ionization detection (GC-FID). All glassware used during collection and extraction was baked out in a furnace at 450°C for a minimum of 4 hours prior to use.



Figure 3. Silk flowers with polypropylene leaves and stems used in fogging events #3 and #4.

Filter Paper and Plant Sample Extraction

To effectively extract the oil from the larger 52- by 52-cm filter papers used in the first sampling event, we removed the filters and foil backing from the jars in the lab, placed them on a clean surface, and cut them into four strips. The filter strips were then placed on top of each other and loosely rolled into a tube shape and placed back in the sample jar. The goal was to reduce the likelihood of forming constricted areas where the solvent could not effectively extract oil. This process was not necessary with the smaller, 7-cm-diameter glass microfiber filters.

Hexane was used to extract the oil from the filter papers, silk flowers, and silk leaves. Each sample was extracted three times with 400 mL of hexane (when 52- by 52-cm filter pads were used) or 100–200 mL of hexane (when 7-cm-diameter glass microfiber filters were used), using sonication for 60 minutes. Samples were quantitatively transferred into a round-bottomed boiling flask and evaporated using a rotary evaporator set at 69°C and 120 rpm. After evaporation, the flasks were rinsed four times with three 2.0-mL washes of hexane and gently swirled, and the contents were transferred to a 10-mL glass sample tube using Pasteur pipettes. These were then evaporated to dryness under nitrogen. The samples were solubilized by the addition of two internal standards: 1.0 mL of 500-ppm 1-phenylhexane and 1.0 mL of 500-ppm alpha cholestane. A 100- μ L aliquot of the sample was transferred to a GC autosampler vial with mini-insert for analysis by gas chromatography-flame ionization detection (GC-FID). The remaining 1.9 mL was archived.

Snow Sample Solid Phase Extraction

Snow samples were allowed to thaw in the glass jars, a mark was made at the level of the meniscus, and the volume was determined using a graduated cylinder. The sample volume following snowmelt was typically 25–30 mL. We used a mini-extraction, solid phase extraction (SPE) method. The SPE tube (LC-18) was conditioned with 2.0 mL of hexane to elute any impurities, followed by a 5.0-mL addition of Milli-Q water to remove all the hexane. A 2.0-mL aliquot of the snow sample was transferred via Pasteur pipette to the SPE tube, where the sample was allowed to pass through the tube under a low vacuum at a flow rate of 2–5 mL/min. The tube was rinsed with five washes of 1.0 mL of hexane, and a 0.5- to 1.0-minute contact was maintained for each solvent wash. Samples were collected in culture tubes and evaporated to dryness in a nitrogen atmos-

phere. The samples were then solubilized to 2.0 mL by the addition of internal standards: 1.0 mL of 1-phenylhexane and 1.0 mL of alpha cholestane. A 100- μ L aliquot of the sample was transferred to an autosampler vial with a mini-insert for analysis by GC-FID. The results were recorded as concentrations of total petroleum hydrocarbons (TPH) in micrograms. Concentrations were related over the surface area represented by the sample and converted to milligrams, so that the final concentration is reported as total petroleum hydrocarbons in milligrams per square meter.

Analytical methods

Gas chromatography followed a modified EPA Method (8015M) and guidelines of Alaska methods AK101, 102, and 103 (<http://www.state.ak.us/dec/eh/docs/lab/CS/manual.pdf>). A 1.0- μ L extract was analyzed with a 6890 GC (Agilent Technologies, formerly Hewlett Packard Co., Palo Alto California) equipped with a flame ionization detector (FID). The capillary column was a 25-m HP-1 (cross-linked methyl siloxane; internal diameter, 0.2 mm; film thickness, 0.33 μ m). The injector temperature was 250°C, and the detector temperature was 300°C. The carrier gas was hydrogen with a flow rate of 2.8 mL/min. Detector gases were 30 mL of hydrogen/min, 400 mL of air/min, and 30 mL of nitrogen/min. Fog oil was analyzed with the following heating program: an initial temperature of 60°C was held for 1 minute followed by a ramp at 6°C/min until temperatures reached 300°C, where they were held for 19.0 minutes. The total run time was approximately 60 minutes. Standards were made to determine the ranges of organics from C10–C36. A standard of C10–C28 was first analyzed to establish the range of retention times for the diesel range organics (DRO) (retention time = 7.1–31.4 min). Standards of fog oil from 10 to 50,000 μ g/mL were run for the range of residual oil (RRO, C25–C36; retention time = 31.4–60.0 min.). Sample quantities were based on comparison to a 5,000- μ g/mL fog oil standard. The calibration table included standards with retention times of 9.3 minutes for 1-phenylhexane and 35.5 minutes for alpha cholestane. Polycyclic aromatic hydrocarbon (PAH) 610 standards and diesel fuel #2 standards were also analyzed.

Fog Oil Concentration Calculations

Total petroleum hydrocarbon (TPH) concentrations for each sample were determined by summing the diesel range organic (DRO) and the residual range organic (RRO) fractions and correcting for the internal standard, filter blank, foil blank, and reagent blank. Filter areas were calculated and

final data were expressed as milligrams of fog oil per square meter of sample surface (mg/m^2). For the synthetic plant samples, the average surface areas of leaves and flowers were calculated by removing all the leaves and all the flowers from a single synthetic flower stem and measuring their surface area with a Win Rhizo™ root measuring system (Régent Instruments Inc. 2002). The surface area of each sample was used to calculate the milligrams of fog oil per square meter of surface area on the leaves and on the flowers.

5 Fog Oil Event #1 (26 March 2001)

The 26 March 2001 training exercise took place in the Ober training area at Bear Drop Zone, Fort Greely, near Donnelly Dome, Alaska. The area used was a road-track rectangle 1.3 by 0.3 km on a side (Fig. 4). The exercise started at 1615 at a temperature of -3°C and wind speeds of 1.5–2.5 m/s. The predominant wind direction was west-northwest. Fog oil generators were carried on HMMWVs moving counterclockwise around the track at varying speeds. One HMMWV continued generating fog oil while parked near the north corner (Fig. 5) for about 10 minutes. A total of approximately 700 gallons (2650 L) of fog oil was used during the training exercise. Exposure times for the samples are difficult to estimate because the vehicles were in a constant state of motion. However, the best estimated time frame for the test is 10–30 minutes.

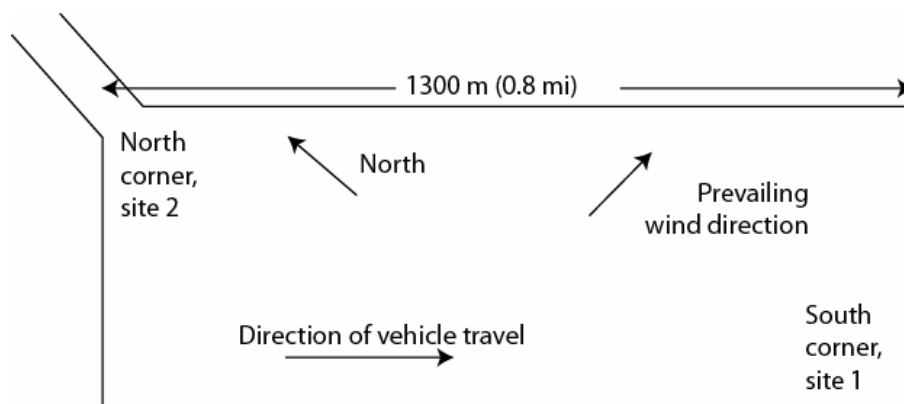


Figure 4. Road track used during event #1 (26 March 2001) winter obscuration training exercise. The north and south corner filter deployment sites are shown in the upper left and lower right corners of the drive track.

Before the exercise started, we placed sample collection filter pads, consisting of large filter papers (52 by 52 cm) with a foil backing, in a grid pattern at the north and south corners of the road track (Fig. 5 and 6). The locations of the collection pads were designed to maximize our ability to obtain representative fog oil samples given the layout of the site, the direction of prevailing winds, and the driving pattern of the vehicles. Filter pads and snow samples were collected after the fogging event.

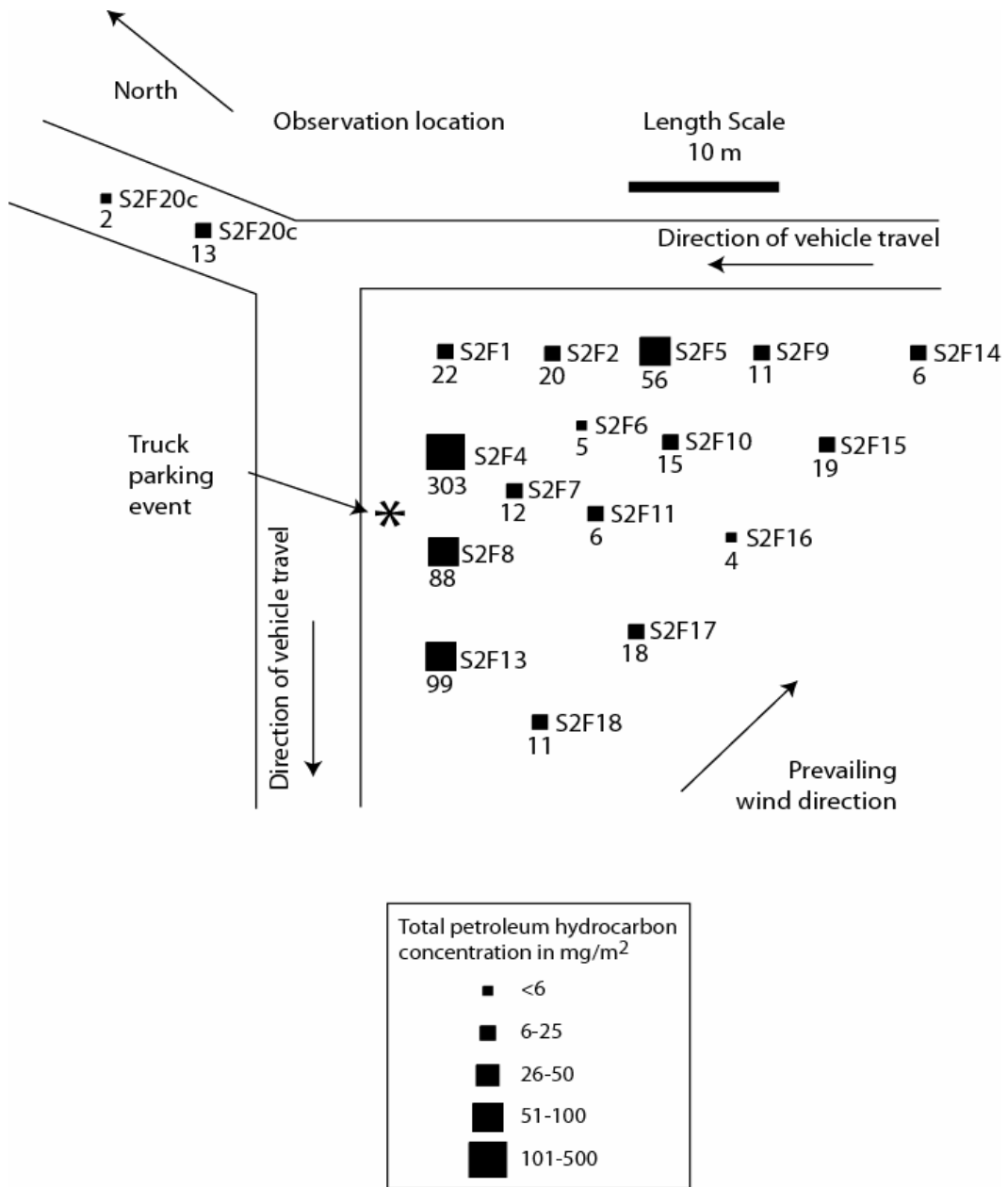


Figure 5. Event #1 (26 March 2001) north corner filter deployment grid, showing the location of the HMMWV that generated fog oil aerosol while parked for roughly 10 minutes. The marker size is proportional to the total petroleum hydrocarbon concentration. Numbers next to the markers with the S prefix are identification numbers for filters, while numbers without a prefix correspond to the TPH concentration.

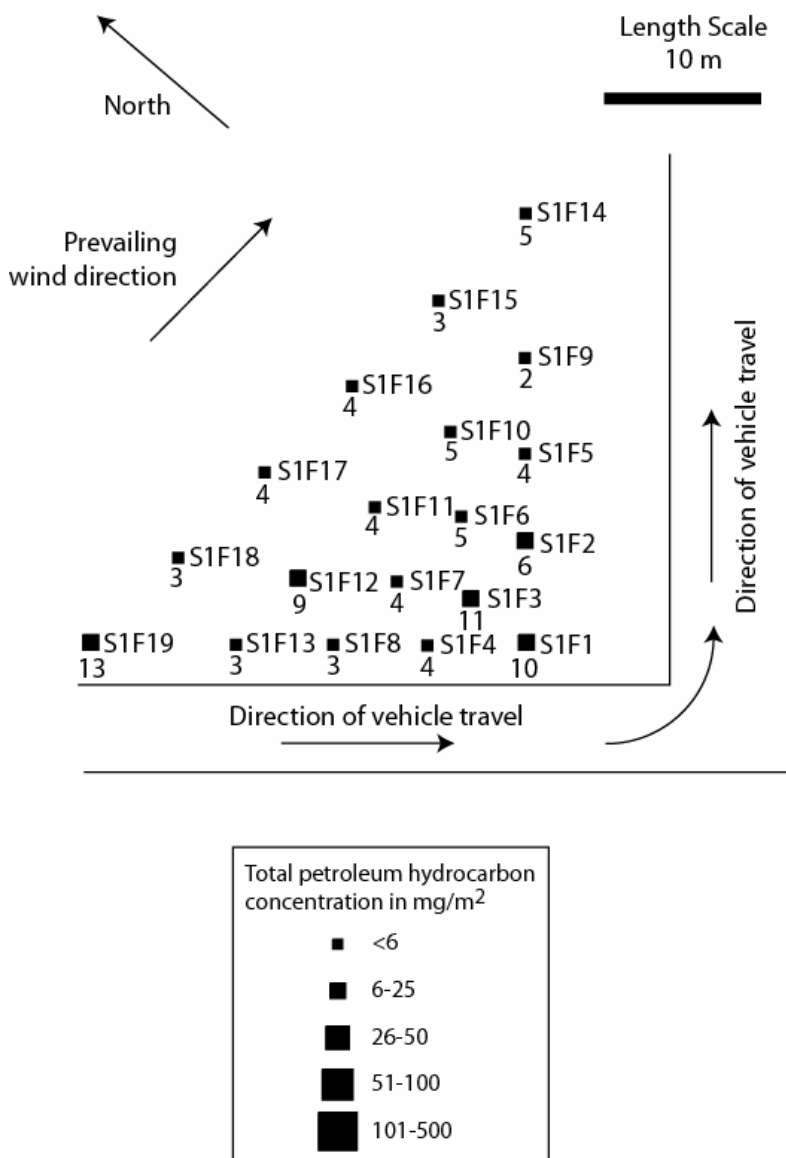


Figure 6. Event #1 (26 March 2001) south corner filter deployment grid. The size of the markers is proportional to the total petroleum hydrocarbon concentration. Numbers next to the markers with the S prefix are identification numbers for filters, while numbers without a prefix correspond to the TPH concentration.

Deposition to Snow

Snow samples, each collected from the top 4 cm of the snowpack, were collected after fogging at eight locations adjacent to filters at the north corner site and at control sites located upwind. Fog oil aerosol deposition should be concentrated at the snow surface as the oil droplets adhere to snow grains. Little fog oil would be expected to penetrate to more than a few centimeters depth through the top of the snowpack. Thus, our sample

included the surface 0.5 cm of the snowpack, where we would expect fog oil aerosol deposition, and the next 2 cm of snow, where we would expect to find little to no fog oil aerosol deposition.

Total petroleum hydrocarbon concentrations measured on filters at the north corner site ranged from 2.3 to 302.7 mg/m², while at the south corner site they ranged from 3.0 to 10.9 mg/m². TPH concentrations measured in snow at the north corner site ranged from 9.0 to 298.0 mg/m². At sample locations where both a snow sample and a filter sample were obtained, there was no apparent relationship between TPH concentrations on the filter pads and TPH concentrations from the surface snow (Table 2). At four of the sample locations the snow yielded higher TPH concentrations than was measured on the nearby filters, while at the other four locations the filter paper had greater values than the snow. This could be the result of either a different scavenging efficiency of fog oil by the snow surface compared to the filters or of exposure of the snow to petroleum hydrocarbons prior to the winter fog oil training exercise we monitored. The training area used for this test was utilized for vehicle maneuvers regularly throughout the winter.

The two control site filter samples yielded TPH concentrations of 2.3 and 12.7 mg/m², while the three control site snow samples had TPH concentrations ranging from 77.0 to 247.5 mg/m². These values from snow are alarmingly high because the control site was located upwind of the fogging area and had no visible fog oil deposition during the event we monitored. At some sample locations, there was a noticeable sheen of oil on the snow before the fogging event began, suggesting previous field exercises were responsible for the presence of petroleum in the snow. No previous fog oil training occurred during the winter at this site prior to our field test, so this oil was likely the result of other training exercises.

Table 2. Total fog oil on filter pads (0.27 m² filter area each) and snow samples during event #1 (26 March 2001).

Sample ¹	Fog oil on filter (µg)	Fog oil on foil (µg)	Total fog oil (µg)	Total fog oil (mg/m ²)	Snow sample# ¹	Total fog oil in snow (mg/m ²)
South corner						
S1F1	2,700	BDL	2,700	BDL		
S1F2	1,500	BDL	1,500	BDL		
S1F3	3,000	BDL	3,000	BDL		
S1F4	1,200	BDL	1,200	BDL		
S1F5	1,200	BDL	1,200	BDL		
S1F6	1,300	BDL	1,300	BDL		
S1F7	1,200	BDL	1,200	BDL		
S1F8	800	BDL	800	BDL		
S1F9	600	BDL	600	BDL		
S1F10	1,300	BDL	1,300	BDL		
S1F11	1,200	BDL	1,200	BDL		
S1F12	2,300	BDL	2,300	BDL		
S1F13	800	BDL	800	BDL		
S1F14	1,400	50	1,400	6		
S1F15	900	BDL	900	BDL		
S1F16	1,000	BDL	1,000	BDL		
S1F17	1,000	70	1,100	4		
S1F18	800	BDL	800	3		
S1F19	1,500	400	1,900	7		
North corner						
S2F1	6,000	BDL	6,000	BDL	S2S1	150
S2F2	5,000	301	5,300	20		
S2F3	2,400	229	2,600	10		
S2F4	73,800	8,041	81,800	300	S2S4	10
S2F5	14,200	758	15,000	60	S2S5	40
S2F6	1,300	BDL	1,300	BDL		
S2F7	3,100	BDL	3,100	BDL		
S2F8	23,100	635	23,800	90		
S2F9	3,100	BDL	3,100	BDL	S2S9	20
S2F10	4,000	BDL	4,100	BDL		
S2F11	1,700	86	1,800	7	S2S11	60
S2F12	8,200	495	8,700	32		
S2F13	25,100	1,713	26,800	100	S2S13	90.5
S2F14	1,600	BDL	1,600	BDL		
S2F15	4,900	233	5,200	19		
S2F16	1,200	BDL	1,200	BDL	S2S16	300
S2F17	4,400	495	4,900	18		
S2F18	2,800	BDL	2,800	BDL		
S2F19	37,400	736	38,100	140	S2S19	80
S2F20c	600	BDL	600	BDL		
S2F21c	2,400	1,030	3,400	13		
					S2S25c	250
					S2S28c	100
					S2S30c	70

¹ c = control site sample.

BDL= Below TPH detection limit of 50 µg/mL.

Deposition Versus Exposure Time

Three to five HMMWVs, each carrying two fog oil generators, participated in the exercise. About half of the time only one of the two fog oil generators was working on each HMMWV. During the exercise, the HMMWVs drove around the road track in a counterclockwise direction at varying speeds (Fig. 4). Because of windy conditions, a fog oil cloud covered the filter pads only when the fog oil generators were on the immediate upwind side of the sampling area. We set up an observation post at the north corner and estimated that the fog covered filter pads for between 15 and 20 seconds per vehicle pass. The counterclockwise travel direction appeared to result in a longer period of fog oil cloud coverage for the north corner filters than for the south corner filters because of the difference in time between deceleration and acceleration at the corners and the prevailing wind direction. The time of deceleration on the upwind side of the south corner was significantly shorter than the time of acceleration on the upwind side of the north corner. It is difficult to estimate the exposure times, however, because the aerosol source was in a constant state of motion, except for the time one HMMWV was parked near the north corner. The presumed longer exposure time for filters at the north corner site resulted in higher fog oil deposition than for the south corner site filters (Fig. 5, 6, and 7). The highest fog oil deposition (300 mg/m^2) occurred on filter S2F4, which was immediately downwind of the location where a HMMWV had parked for about 10 minutes with its fog oil generator running while the driver examined the vehicle (Fig. 5). This parked vehicle event at the north corner added an additional 10 minutes of exposure to a narrow band defined by the line of filters S2F2–S2F4 (Fig. 5).

Deposition Versus Distance from the Fog Oil Source

In addition to the correlation of fog oil deposition with exposure time, there was also an apparent correlation between fog oil concentrations and distance from the fog oil generator source at the north corner site (Fig. 5 and 7). In the north corner, the highest fog oil concentrations are those closest to the upwind side of the road and concentrations decrease exponentially with distance from the road (Fig. 7). The south corner site does not show a similar correlation of fog oil magnitude with distance from the road. This may be a result of shorter exposure times caused by the rapid deceleration of the HMMWVs as they approached the south corner (Fig. 6).

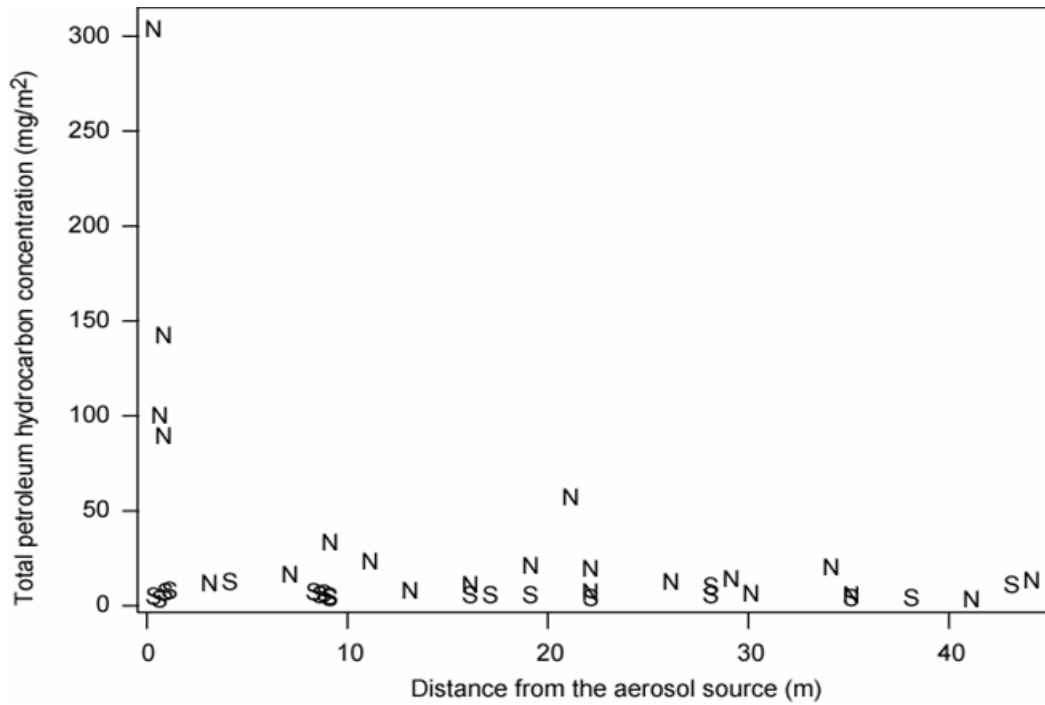


Figure 7. Total petroleum hydrocarbon deposition concentration measured on filters as a function of distance from the fog oil aerosol source for event #1 (26 March 2001). N represents north corner filters and S represents south corner filters.

6 Fog Oil Event #2 (3 July 2001)

The 3 July 2001 summer fog oil exercise conducted at the Firebird Landing Zone in the Yukon Maneuver Area, Fort Wainwright, Alaska, was more extensive than the winter training event and the sampling program was more detailed. The Firebird Landing Zone runs northeast to southwest for 1.5 km at the top of a linear shaped hill. Fog was produced for a total of 77 minutes spread over three hours. Five HMMWVs, each carrying two fog oil generators, participated in the exercise, although not all ten generators were operating all the time. The HMMWVs started out in a static position (Fig. 8) and then began several mobile "racecourse" patterns adjacent to and across the airstrip to try to provide a continuous smog plume. Two of the tracks were across the airstrip, and the third track was located northwest of the airstrip (Fig. 8). A set of 0.035-m² round microfiber filters was deployed prior to the commencement of fogging, a second set was deployed 20 minutes into the fogging event, and a smaller third set was deployed 28 minutes into the event. Total exposure times were 77 minutes for the first set, 57 minutes for the second set, and 49 minutes for the third set. The generators used a total of 960 gallons (3633 L) of fog oil.

The fog oil sample arrays were laid out along the edges of the airstrip and among the vegetation about 15 m northeast from the edge of the airstrip downwind from the location of the vehicles. The sample arrays along the edges of the airstrip were placed flat on the ground. Four towers were also placed across the runway, with sample arrays placed perpendicularly to the ground at 1- and 2-m elevations (4–11, Fig. 8). The location of the collection pads was designed to maximize our ability to obtain consistent fog oil sample collection given the topography of the Firebird Landing Zone, the direction of prevailing winds, the locations of the fog oil aerosol generators, and the driving patterns of the drivers. Filter samples from locations downwind from the fog oil generators were collected at the conclusion of the training exercise (Fig. 8).

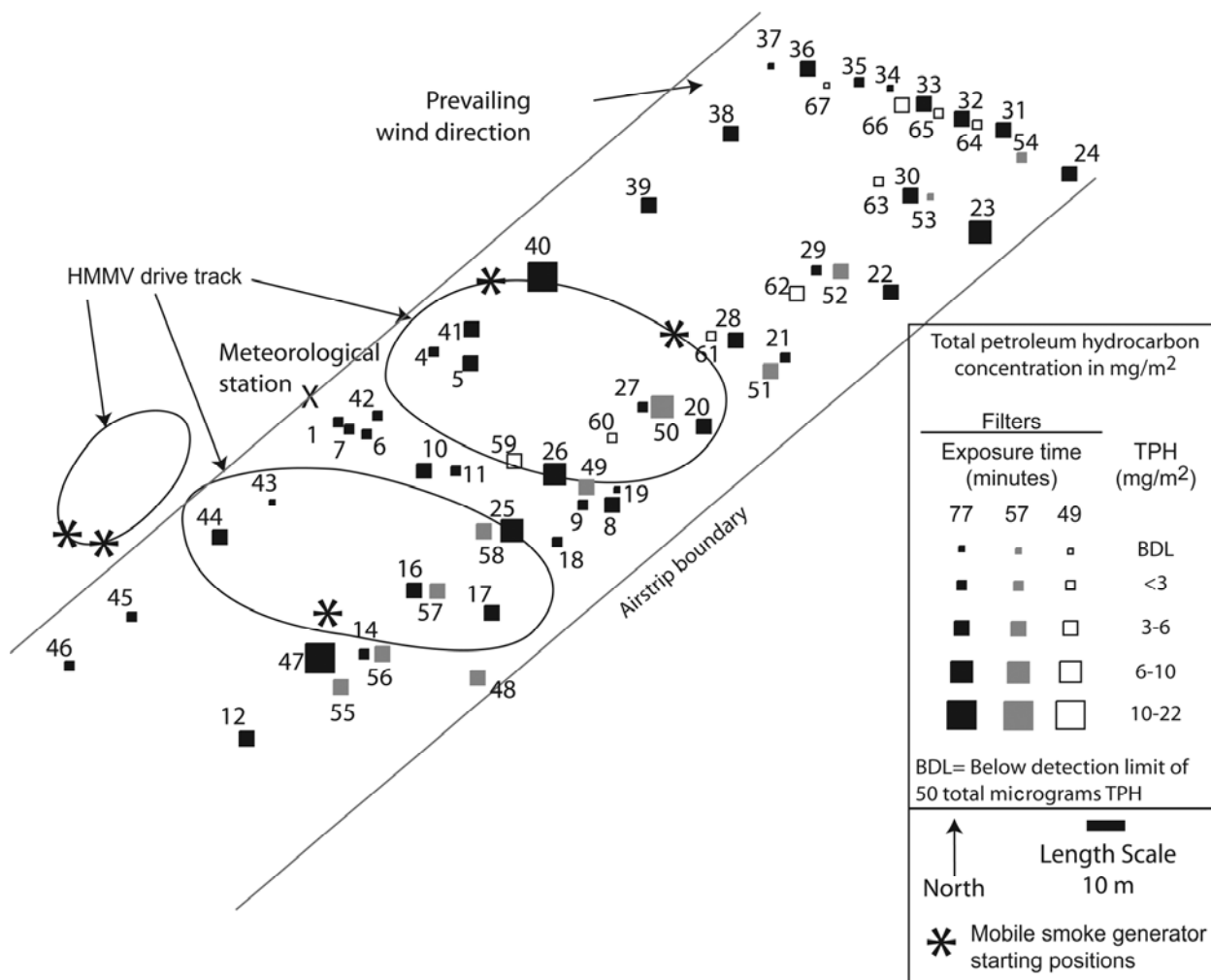


Figure 8. Site map for event #2 summer exercise (3 July 2001). Marker size is proportional to the total petroleum hydrocarbon concentration. The numbers are identification numbers for the filter samples in Table 3.

Deposition Versus Distance from the Source and Exposure Time

TPH deposition was nearly uniform over the training areas for the filters with exposure times of 77 and 49 minutes, with no discernible relationship between TPH concentration and distance from the source (Table 3 and Fig. 8, 9). However, TPH deposition for the filters exposed for 57 minutes was strongly related to distance (Fig. 9). If we interpret the deposition magnitude at S50 as an anomalous value, then the differences between the deposition for the three exposure times were insignificant. However, if the relatively high deposition measured at S50 is accurate and the trend of decreasing deposition with distance from the fogging source for the 57-minute exposure is valid, then a complex set of conditions is acting that we do not understand.

Table 3. Total fog oil on filters (surface area 0.035 m²) for exposure times of 77, 56, and 49 minutes during event #2 (3 July 2001).

Sample	Total fog oil on filter (µg)	Total fog oil (mg/m ²)	Sample	Total fog oil on filter (µg)	Total fog oil (mg/m ²)
Exposure time: 77 minutes			Exposure time: 57 minutes		
1	68	2	48	178	5
4	82	2	49	165	5
5	105	3	50	307	9
6	82	2	51	152	4
7	82	2	52	184	5
8	117	3	53	BDL	BDL
9	78	2	54	62	2
10	93	3	55	106	3
11	69	2	56	122	4
12	115	3	57	90	3
14	117	3	58	214	6
16	103	3			
17	96	3	Exposure time: 49 minutes		
18	60	2	59	158	5
19	BDL	BDL	60	95	3
20	89	3	61	59	2
21	79	2	62	120	4
22	89	3	63	107	3
23	231	7	64	86	3
24	99	3	65	97	3
25	233	7	66	129	4
26	234	7	67	BDL	BDL
27	64	2			
28	134	4			
29	57	2			
30	135	4			
31	121	4			
32	85	3			
33	90	3			
34	BDL	BDL			
35	83	2			
36	86	3			
37	BDL	BDL			
38	152	4			
39	93	3			
40	776	22			
41	115	3			
42	65	2			
43	BDL	BDL			
44	104	3			
45	64	2			
47	414	12			

BDL= Below TPH detection limit of 50 µg/mL.

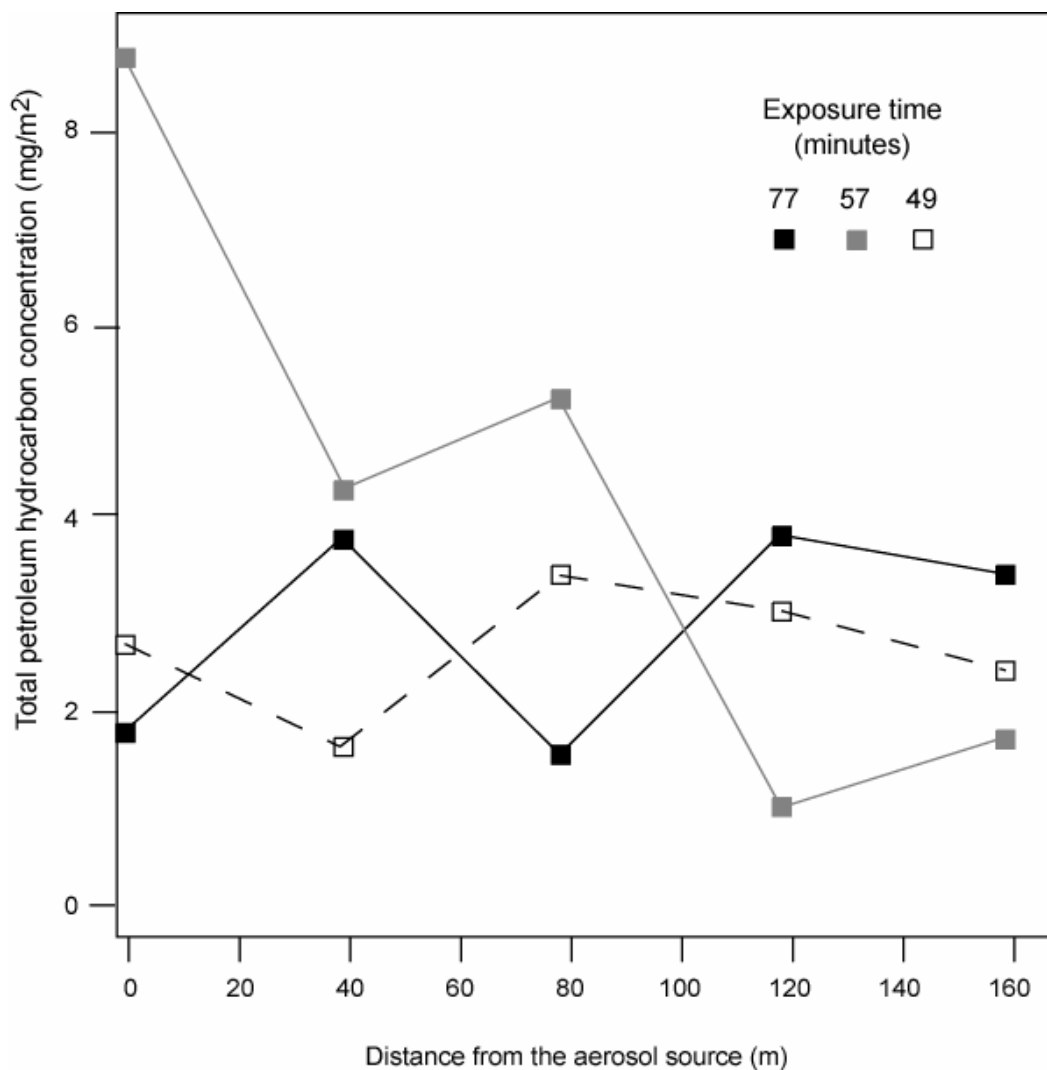


Figure 9. Event #2 (3 July 2001) total petroleum hydrocarbon deposition as a function of distance from the center of the drive track, near the fogging source, for filters with exposure times of 77, 57, and 49 min.

Results from an analysis of variance (ANOVA) suggest that there was no statistical relationship between exposure time and TPH concentration. This is contrary to our expectation that fog oil aerosol deposition to the filters would increase with exposure time. It is possible that the different loadings over time were within the error of the areal TPH concentrations we calculated from our measurements. Perhaps a wider range of exposure times would yield a more robust trend. In addition, the inhomogeneity associated with TPH deposition during an outdoor test may be large enough to prevent the quantification of subtle differences in deposition.

Relationship to Natural Vegetation

Initial attempts to measure TPH deposition to natural vegetation were unsuccessful because techniques to differentiate between the chemical signal for the very low TPH concentrations present on the vegetation and the natural chemical signal of the vegetation were not adequate. As a result, we decided to use synthetic stalks of silk flowers and polypropylene leaves as a passive sampling device selected to represent the size and morphology of vegetation. The synthetic plants are ideal because they can be placed at varied orientations and distances from the fogging sources and their silk (flowers) and polypropylene (leaves) composition does not interfere with measurement of TPH concentrations by gas chromatography.

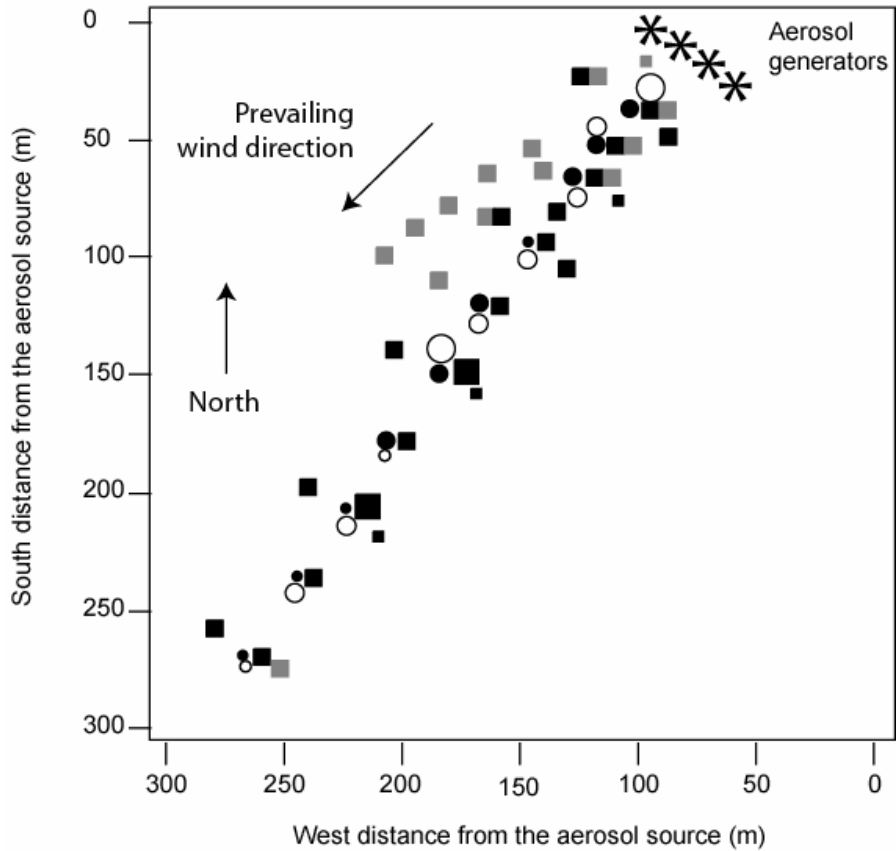
7 Fog Oil Event #3 (31 January 2002)

The 31 January 2002 winter fog oil exercise was also undertaken at the Firebird Landing Zone in the Yukon Maneuver Area, Fort Wainwright. The exercise started at 1342 at a temperature of -15°C and wind speeds of 0–3.5 m/s. The predominant wind direction was from the north-northeast. A snow pack roughly 1 m deep covered the sample site. Sampling media for this study included filter arrays on cardboard backing and synthetic silk flowers with polypropylene leaves. Ten sets of filter arrays and flowers were placed at 50-m intervals along a 300-m line downslope and downwind from four stationary fog oil generators. The generators were mounted on three HMMWVs separated 5 m apart from one another in the middle of the airstrip along a line trending northeast-southwest (Fig. 10). Additional glass fiber filters without flowers were placed before fogging commenced and 25 minutes after fogging began to increase the spatial coverage of samples. The filter boards were placed on top of the snowpack, while the synthetic plant stalks were planted 25 cm into the snow so that the leaves were even with the top of the snowpack.

The flowers and the first filter sets were exposed to fogging for 93 minutes, while a second filter set was exposed for 68 minutes. The middle HMMWV ran both of its generators continuously throughout the test, while the other two HMMWVs used only one of their generators at a time. The four generators, which ran nonstop throughout the exercise, used a total of 200 gallons (760 L) of fuel. Because of low air temperatures, the fuel mix in the winter test was 70:30 SGF2:diesel fuel to decrease viscosity.

Deposition on Filters and Synthetic Leaves and Flowers

Filter samples yielded TPH values ranging from 4.8 to 32.3 mg/m², with an average TPH deposition for all 35 filters of 10.4 mg/m² (Table 4). Leaf sample TPH concentrations ranged from 4.3 to 35.7 mg/m², with an average value of 14.1 mg/m². Flower samples yielded TPH values ranging from 0.6 to 15.8 mg/m², with an average TPH deposition of 7.3 mg/m². Results from an analysis of variance for the two sample exposure times for filter samples show no statistical difference between TPH deposition on filters exposed for the two time intervals.



Total petroleum hydrocarbon concentration in mg/m ²						
Filters		Flowers	Leaves			
Exposure time (minutes)		Exposure time (minutes)		TPH (mg/m ²)		
93	68	93	93	•	○	<6
■	■	●	○	●	○	6-25
■	■	●	○	●	○	26-50
■	■	●	○	●	○	51-100
■	■	●	○	●	○	101-500

Figure 10. Filter distribution and total petroleum hydrocarbon concentration measured on filters, flowers, and leaves by sample location for winter fogging event #3 (31 January 2002).

Table 4. Fog oil residues measured on sample media during event #3 (30 January 2001).

Sample	Exposure time (min)	Filter total TPH (mg/m ²)	Leaf total TPH (mg/m ²)	Flower total TPH (mg/m ²)
1	93	8		
2	68	9		
3	68	7		
4	93	6		
5	93	5		
6	93	7		
7	93	6		
8	93	5		
9	93	6		
10	93	10		
11	93	12		
12	93	10		
13	93	9		
14	68	12		
15	68	13		
16	68	10		
17	68	10		
18	68	10		
19	68	10		
21	68	5		
53	68	9		
54	93	10	12	7
55	93	9	6	4
56	93	9		
57	93	14	10	6
58	93	11	9	11
59	93	16	28	16
60	68	8		
61	68	12		
62	68	10		
63	93	12	5	1
64	93	13	16	2
65	93	25	14	BDL
66	93	16	4	13
67	93	32	36	NS

BDL= Below TPH detection limit of 50 µg/mL

NS= no sample

The coefficient of determination (r^2) between filter and leaf TPH concentrations was 0.49, suggesting little linear relationship between filter and leaf TPH concentrations. The coefficient of determination between filter and flower sample TPH concentrations was 0.06, while the coefficient of determination between flower and leaf TPH concentrations was 0.11. Taken in total, these results suggest that during our winter field test there was almost no correlation between TPH concentrations on the filter and leaf sample media and no correlation between these media and the flowers. Some of this lack of correlation could be related to the unique meteorological conditions occurring at the site during the winter field test. This is discussed in more detail below.

Deposition Versus Distance from the Fog Oil Source

During the fogging event, we observed the fog oil plumes leaving the generators and traveling down the airstrip, with the base of the plume remaining 1–2 m above the snow surface for roughly 150–200 m downwind of the fogging source. There, the bottom of the plume dropped in elevation to the top of the snowpack. The fog oil plume then rose slightly off the snow surface and traveled downwind another 50 m, again with the base of the plume remaining 1–2 m above the surface of the snowpack. Then the base of the plume dropped back to contact the snow surface again.

This “bouncing” evolution of the fog oil plume and its relationship to fog oil deposition rates on the snow surface are supported by results from the filter, flower, and leaf samples. Plots of the filter, flower, and leaf TPH deposition by sample location (Fig. 10, 11, and 12) show the highest TPH values in samples located approximately 120 m downwind of the fogging source. Furthermore, the results from filter samples indicate that the second highest TPH values are located 150–175 m downwind of the fogging source. These results support the visual observations of the movement of the fog oil plume over the snow surface.

Meteorological conditions present during this test (Fig. 13) probably included a cold-air boundary layer above the snow surface, which is common during cold winter days in interior Alaska. This prevented the warmer, lower-density fog oil air mass from contacting the top of the snow surface. Such boundary layers are common over snow as cold, dense air settles to the snow surface and radiational cooling under clear sky conditions further cools the snow surface. Future fogging events during inver-

sion conditions could be designed to further investigate this phenomenon and to assess the efficacy of using fog oil as an obscurant during temperature inversions. Since the bouncing process raised the lower boundary of the fog oil plume up to 2 m above the ground surface, this limits the ability of fog oil to provide obscurance when metrorological conditions favor the development of an inversion.

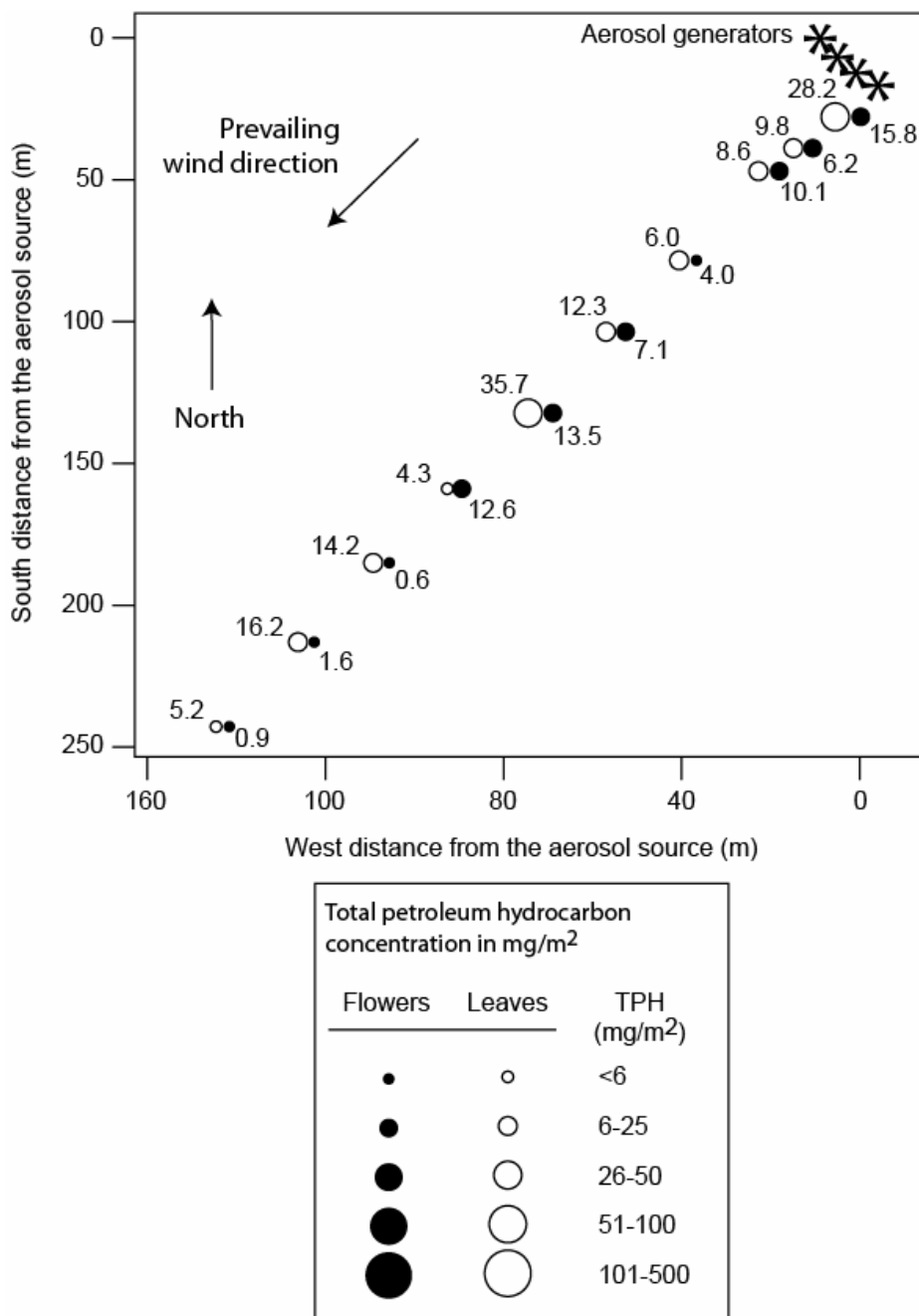


Figure 11. Silk flower and polypropylene leaf distribution and total petroleum hydrocarbon concentration measured on flowers and leaves for event #3 (31 January 2002).

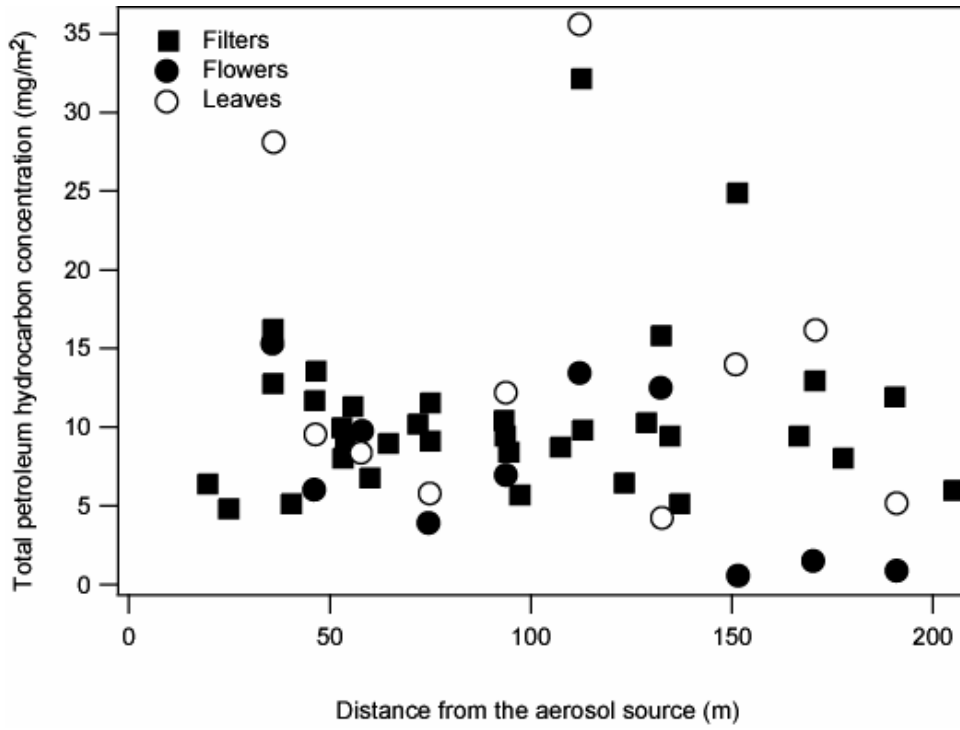


Figure 12. Total petroleum hydrocarbon concentration versus distance from the fog oil aerosol source for filters, flowers, and leaves after event #3 (31 January 2002).

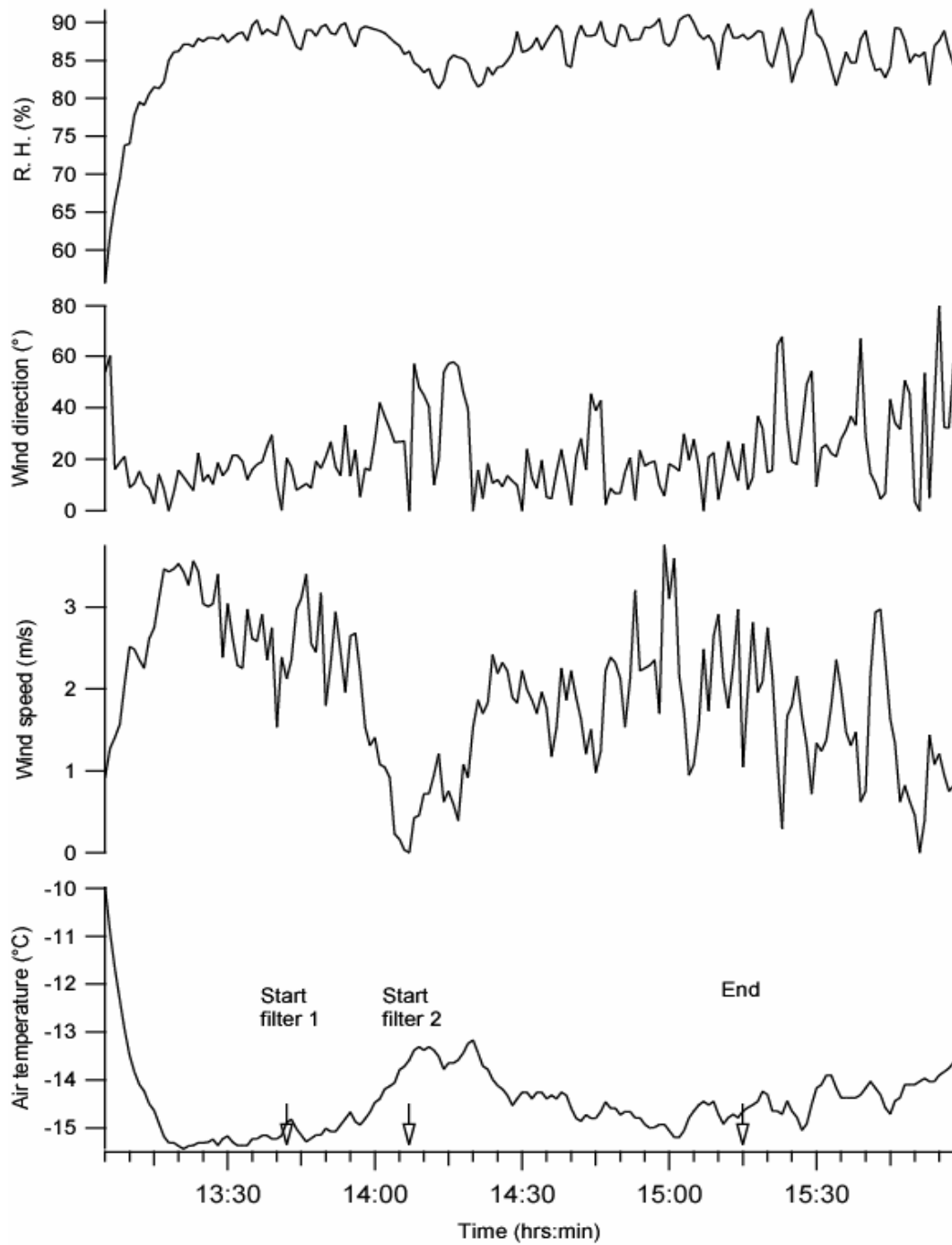


Figure 13. Meteorological data for event #3 (31 January 2002). The arrows on the plot indicate when the exercise started, when filters were deployed, and when the exercise ended.

8 Fog Oil Event #4 (12 September 2002)

On 12 September 2002 we monitored fog oil emission and deposition at the Firebird Landing Zone from two stationary HMMWVs spaced 5 m apart (Fig. 14). Both HMMWVs were oriented to send fog oil aerosol in a southeasterly direction from two fog oil generators that were run on static mode for 110 minutes between 1232 and 1342. A total of 111 gallons (420 L) of SGF2 was used. This summer field test was undertaken during mild temperatures ranging from 10 to 15°C, gusting winds (up to 8.6 m/s, predominantly in a northwest to southeast direction heading sideways across the Firebird Landing Zone), and cloudy sky conditions.

Synthetic plants were placed in the ground adjacent to glass microfiber filter arrays at each of 20 sample locations in a grid roughly 60 m on a side (Fig. 15). A portable drill was used to excavate a small hole (0.5 cm diameter, 25 cm deep) in which the flower stems were placed. The samples ran perpendicularly to the long axis of the gravel pad, allowing 70 m of distance between the generators and the edge of the airstrip.

Deposition to Filters and Synthetic Leaves and Flowers

Total petroleum hydrocarbon deposition to filters during this test ranged from 2.4 to 330.5 mg/m², with an average value of 48.4 mg/m². Leaf TPH concentrations ranged from 0.9 to 437.0 mg/m², with an average value of 77.1 mg/m², while flower TPH concentrations ranged from 21.8 to 281.6 mg/m², with an average value of 85.8 mg/m² (Table 5).

The coefficient of determination (r^2) between filter and leaf TPH concentrations was 0.95, suggesting an extremely strong linear relationship between filter and leaf TPH concentrations. The coefficient of determination between filter and flower sample TPH concentrations was 0.57, while the coefficient of determination between flower and leaf TPH concentrations was 0.73. These results suggest that TPH concentrations measured on the three sample media are correlated, especially between the filters and polypropylene leaves.

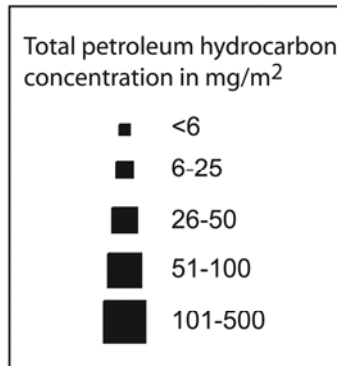
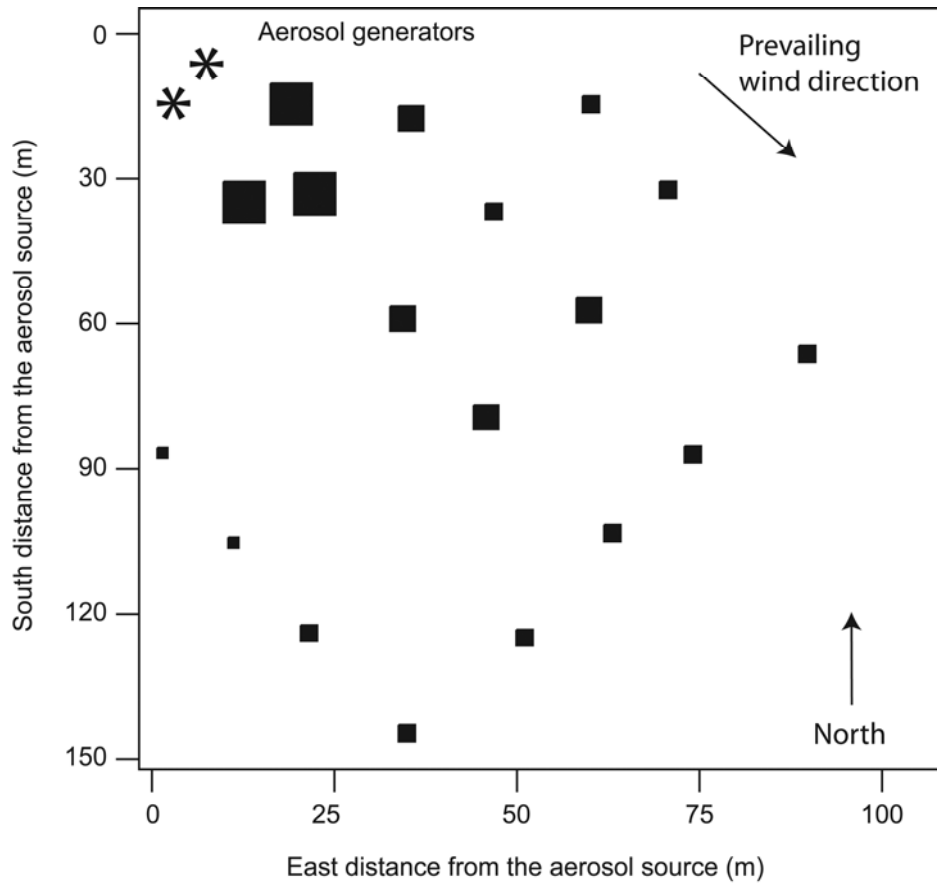
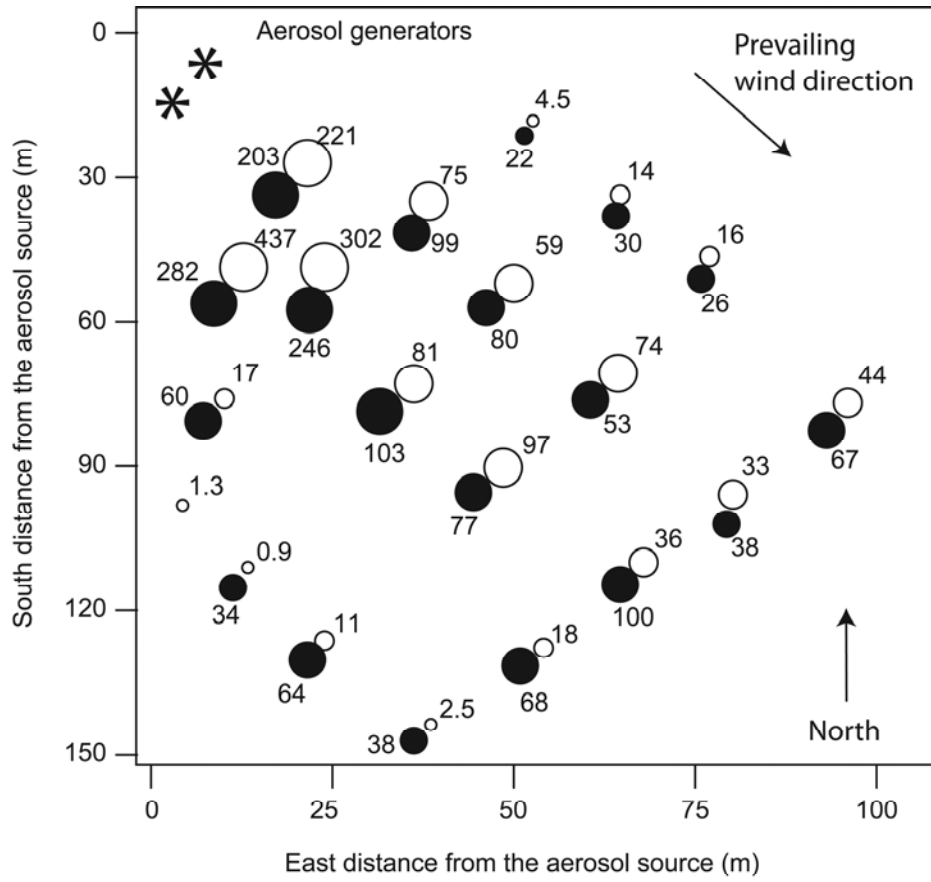


Figure 14. Filter distribution and total petroleum hydrocarbon concentration measured on filters for event #4 (12 September 2002).



Total petroleum hydrocarbon concentration in mg/m ²		
Flowers	Leaves	TPH (mg/m ²)
●	○	<6
●	○	6-25
●	○	26-50
●	○	51-100
●	○	101-500

Figure 15. Silk flower and polypropylene leaf distribution and total petroleum hydrocarbon concentration measured on flowers and leaves for event #4 (12 September 2002).

Table 5. Fog oil residues measured on sample media during event #4 (12 September 2002). The exposure time for all samples was 110 minutes.

Sample	Distance to the aerosol source (m)	Filter total TPH (mg/m ²)	Flower total TPH (mg/m ²)	Leaf total TPH (mg/m ²)
1	36	8	22	5
2	45	15	30	14
3	54	21	26	16
4	73	22	67	44
5	65	18	38	33
6	48	32	53	74
7	34	23	80	59
8	21	34	99	75
9	10	160	203	221
10	14	153	246	302
11	30	46	103	81
12	43	35	77	97
13	61	28	100	36
14	60	12	68	18
15	61	9	38	3
16	49	7	64	11
17	40	5	34	BDL
18	32	2	NS	BDL
19	21	8	60	17
20	9	331	282	437

BDL= Below TPH detection limit of 50 µg/mL.

NS= no sample

Deposition Versus Distance from the Fog Oil Source

Contour plots of the filter, flower, and leaf samples (Fig. 14 and 15) and a plot of TPH concentration versus distance from the aerosol source (Fig. 16) show a distinct trend of high values within 20 m of the fog oil generators decreasing rapidly to consistently low values more than 20 m away from the generators. TPH concentrations in all three sample media were below 100 mg/m² for all samples greater than 20 m from the aerosol source. These differences are most likely attributable to the proximity of the sample media to the generators and the fact that gusty winds precluded uniform deposition of fog oil as the plume moved farther away from the fogging source.

Throughout most of the test, the fog oil aerosol plume emanated from the source generators as a bulbous mass that thinned horizontally after traveling roughly 20 m from the source. Beyond 20 m from the aerosol source,

the plume traveled consistently along the gravel pad, with the bottom of the plume maintaining contact with the top of the gravel surface. Occasional wind gusts drove boundary layer turbulence that stirred the plume, generally in a vertical direction. During a gusting event, the aerosol plume would rise off the ground, swirling skyward, and the aerosol plume had minimal contact with the ground surface, generally traveling off the sampling area within seconds. As a consequence, these gusting events can be best described as periods of up to five seconds when there was minimal aerosol deposition to the sample array. Within seconds of cessation of a wind gust, the fog oil plume resumed its stable plume morphology.

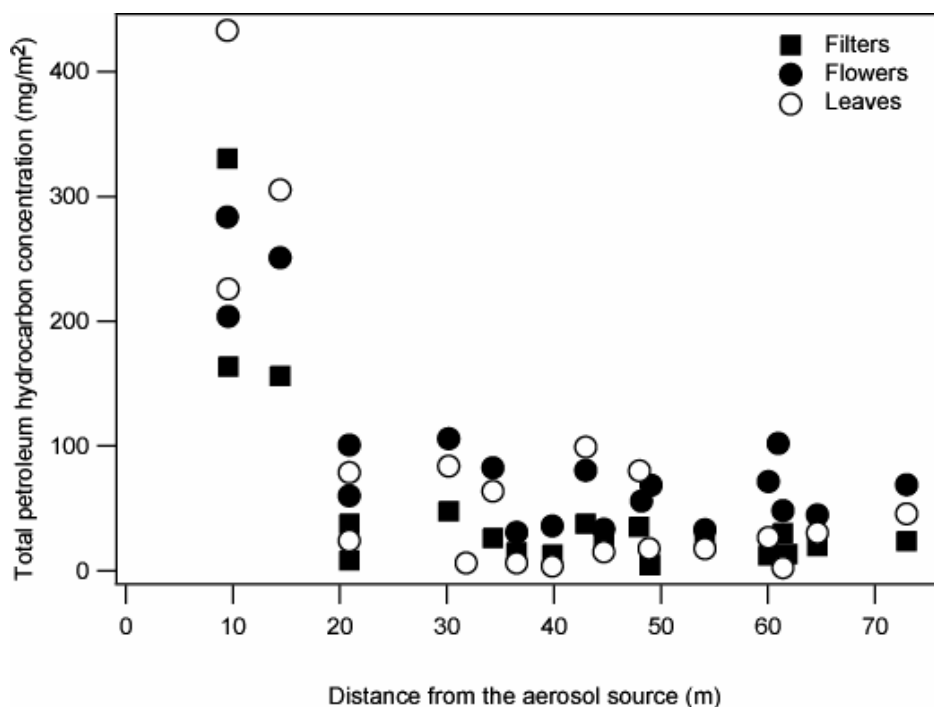


Figure 16. Total petroleum hydrocarbon concentration measured on filters, silk flowers, and polypropylene leaves versus distance from the fog oil aerosol generators for event #4 (12 September 2002).

9 Evaporation Experiment

Indoor and outdoor experiments were performed to determine the relationship between air temperature and evaporation of fog oil and a fog oil-diesel fuel mixture. Two 300-mL high-density polyethylene pans of fog oil and two pans containing a 50:50 mixture of fog oil:diesel fuel were prepared for the evaporation tests. A pan of 100% fog oil and a pan of fog oil-diesel mix were placed in an exhaust hood at 20°C for 2016 hours (84 days). Laminar flow through the hood was held constant at 0.5 m/s. The second set of fog oil and fog oil-diesel mix was placed outdoors protected from the wind at air temperatures that remained below -35°C for 264 hours (11 days). The mass of each pan of oil was measured repeatedly during the evaporation test.

The results (Fig. 17) indicate that evaporation rates of fog oil are highly temperature and wind dependent. After four days, the pure fog oil held at temperatures below -35°C with no air flow had lost 0.2% of its original mass, while the fog oil kept at 20°C with a steady air flow had lost 0.5 % of its original mass. After 11 days, the fog oil-diesel mix kept at temperatures below -35°C with no air flow had lost 1% of its original mass, while the fog oil-diesel mix kept at 20°C with air flow had lost 20% of its original mass.

The fog oil evaporation tests yield three important results. First, the fog oil-diesel mix undergoes more rapid evaporation than the pure fog oil. This is likely attributable to the higher vapor pressure for diesel fuel (0.44 mm of mercury at 20°C) than for SGF2 (<0.007 mm of mercury at 20°C). Second, at 20°C the pure fog oil evaporates at twice the rate that it evaporates at -35°C. Third, pure fog oil does not evaporate readily regardless of the temperature or air flow (wind) conditions. It is important to note that these tests were performed on a pool of stationary oil. Natural conditions, including soil and vegetation morphology, increased surface-area-to-volume ratios in fog oil aerosols deposited to natural surfaces, and constantly changing meteorological events should lead to a far greater evaporation rate of fog oil aerosols deposited on leaf and soil surfaces.

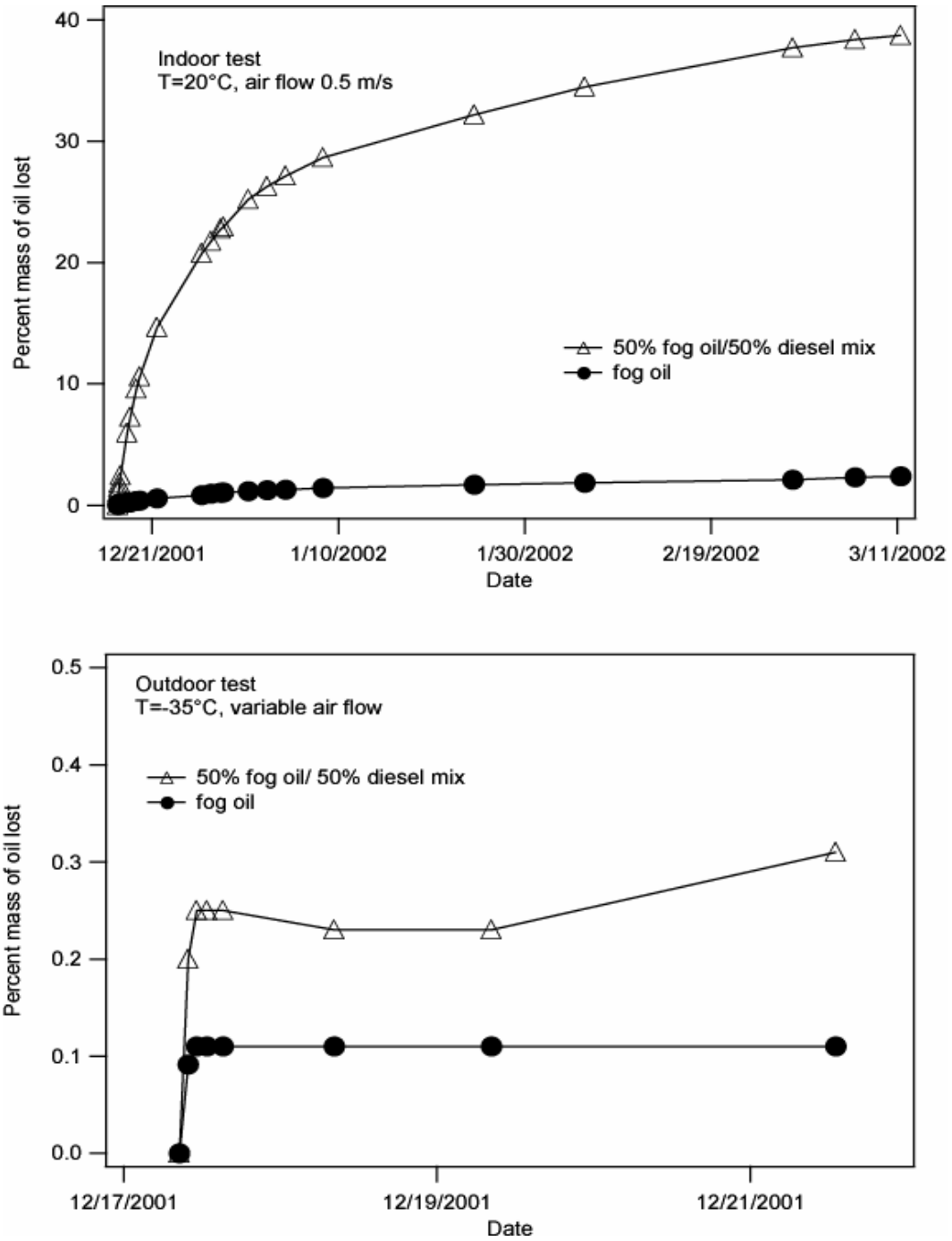


Figure 17. Results from the indoor (top) and outdoor (bottom) Standard Grade Fuel #2 (fog oil) evaporation tests.

10 Fog Oil Deposition to Urban Snow

To assess the deposition of petroleum hydrocarbons by human activities in a populated area, eight snow core samples were taken from four locations along roadways in Fairbanks, Alaska, on 3 March 2002. The snow was collected to provide a reference for the TPH concentrations we measured during fog oil training. Snow samples consisted of cores of the entire snowpack collected in a SIPRE snow sampling tube (5.7 cm diameter). The surface area of snow represented by the core samples was 25.5 cm² (2.6×10^{-3} m²). Samples were selected from regions of undisturbed snow 5 m away from the road surface. All eight samples were gray to brown and contained layers of darker colored snow. These snow samples contained no vegetation.

The results from the snow samples are included as Table 6. The total mass of the measured oil in the snow was used to calculate the oil per unit area to be consistent with the filter and synthetic flower results reported as milligrams per square meter. TPH deposition in the nine samples taken at these sites ranged from 47.9 to 116.6 g/m², while the average TPH deposition value from these samples was 74.7 g/m². These values are over 450 times greater than the maximum TPC concentration measured in snow exposed to fog oil training and are 250 times greater than the values from filter samples taken during winter tests. As another reference, the lowest value of these nine urban snow samples is over 100 times greater than the highest concentration of any sample media measured during a fog oil exercise (polypropylene leaf sample #20 from event #4 had a TPH concentration of 0.4 g/m²).

Table 6. Fairbanks snow samples collected on 26 March 2002.

Sample	Type	Volume (mL)	TPH (μg)	Surface area (m^2)	TPH (g/m^2)
1	Snow	96	1,980	0.00255	75
2	Snow	124	1,870	0.00255	91
3	Snow	128	1,860	0.00255	93
4	Snow	110	1,550	0.00255	67
5	Snow	120	1,250	0.00255	59
7	Snow	130	2,290	0.00255	117
8	Snow	128	970	0.00255	49
9	Snow	129	950	0.00255	48
Blank1	Filter	1	BDL	0.0346	BDL
Blank2	Filter	1	BDL	0.0346	BDL

BDL= Below TPH detection limit of 50 $\mu\text{g}/\text{mL}$

11 Conclusions

Discussion

We collected fog oil aerosol on glass membrane fiber filters, polypropylene leaves, and silk flowers in an attempt to quantify aerosol deposition to these three sample media. The focused objective was to quantify total petroleum hydrocarbon (TPH) deposition to synthetic plant surfaces during a typical fog oil training exercise. Tests were conducted in winter and summer field conditions. Three important results emerged from this study: 1) there is a statistical relationship between flower, filter, and leaf TPH concentrations during the summer field test but not during the winter test, 2) meteorological conditions can greatly affect the migration of a fog oil plume, especially in the winter, and 3) the maximum total petroleum hydrocarbon concentration we measured during four fogging events is over 100 times lower than TPH concentrations present in snow along city roadways. These results are discussed in detail below.

First, our results show that glass membrane fiber filters, silk flowers, and polypropylene leaves yield similar TPH concentrations in summer field conditions (Fig. 18 bottom). In the summer test the polypropylene leaves yielded TPH concentrations 1.7 times that of filters, with good correlation ($r^2 = 0.95$, $n = 19$), while the silk flowers yielded TPH concentrations 1.6 times that of filters ($r^2 = 0.73$, $n = 18$). Polypropylene, silk, and SGF2 aerosol are all hydrophobic surfaces, while glass membrane fiber filters are not. As a consequence the elevated TPH concentrations measured on the polypropylene and silk surfaces may be due to the preferential sorbing of SGF2 aerosol to these surfaces. The lower correlation between flowers and filters may be attributable to the more intricate morphology of the flowers; the polypropylene leaves present a surface area that is more similar to the glass fiber filters than the silk flowers. However, both types of sample media appeared to collect and retain fog oil aerosol more conservatively than the fiber filters. The reason for this is unclear.

Unlike the summer test, there was little to no correlation in TPH concentrations measured on silk flowers, polypropylene leaves, and filters during winter field conditions (Fig. 18 top). In addition, the overall range of concentrations measured during the summer (0–300 mg/m²) was far

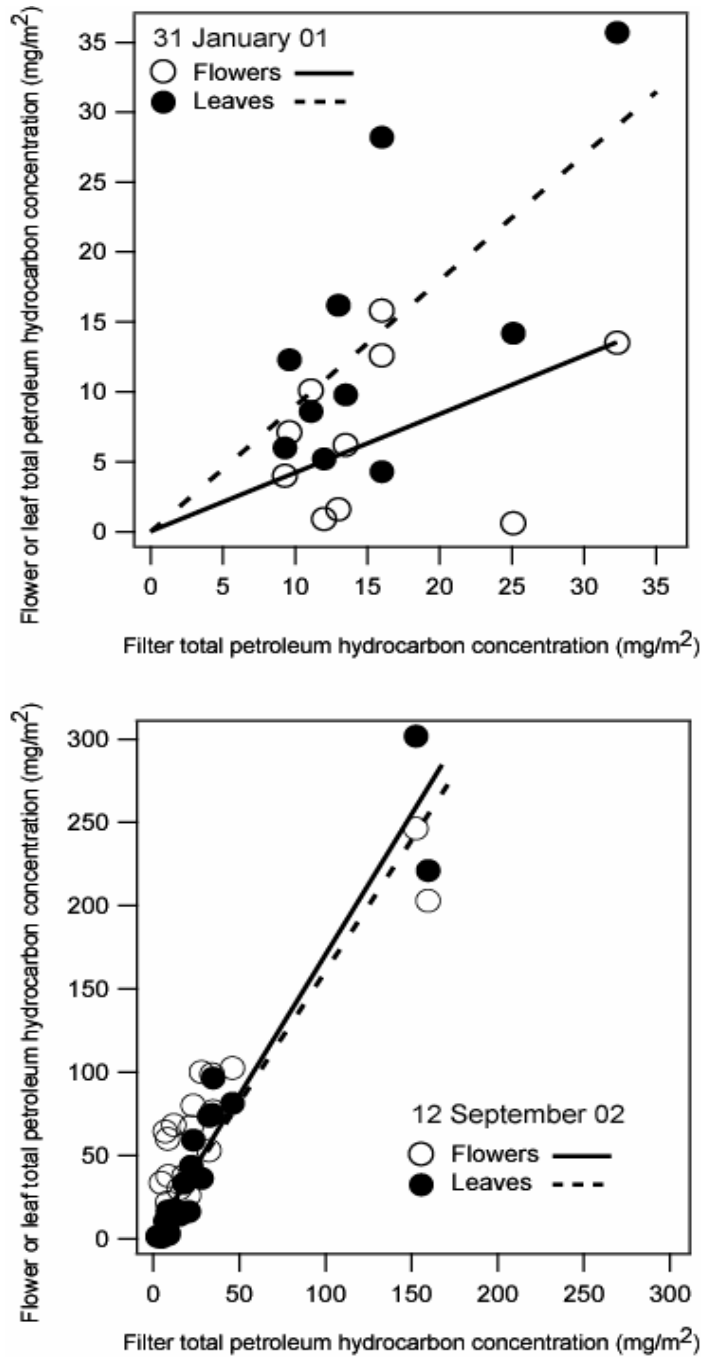


Figure 18. Silk flower and polypropylene leaf total petroleum hydrocarbon concentrations versus filter TPH concentrations for events #3 (31 January 2001) and #4 (12 September 2002). For event #3 there is minimal correlation in TPH concentrations between the filters, flowers, and leaves. For event #4 there is considerable correlation with flowers and leaves, yielding TPH concentrations that are 1.7 and 1.6 times that of the filters, respectively.

greater than that measured during the winter (8–35 mg/m²). We believe the lower TPH concentrations measured during the winter test are related to a low level inversion present during this winter test.

Meteorological conditions likely play a large role in controlling the evolution of the fog oil plume and the subsequent deposition of fog oil to environmental media. The meteorological conditions during the summer test were not remarkable. As a consequence, the fog oil aerosol plume behaved as would be expected: the warm aerosol mass rose slightly following emission from the generator source. Over a distance of tens of meters, the aerosol particles cooled in the ambient air and slowly settled to the ground surface. This process occurred consistently throughout the test. The winter field test, however, was characterized by the presence of a strong temperature inversion, which we believe caused the anomalous deposition pattern and general lack of correlation between TPH concentrations on filter, flower, and leaf surfaces. TPH concentrations measured on filters, flowers, and leaves exposed during the winter test were highest at a distance of roughly 100 m from the source. This matches the visible evolution of the unique aerosol plume we witnessed. It is possible that there is an effect of cold temperatures on the adsorption of fog oil aerosol to the three sample media; however, we have no information to support this.

Third, maximum TPH concentrations measured in a range of sample media were less than a percent of what is represented by snow along city streets in Fairbanks, Alaska. This suggests that the loading of SGF#2 at a training area, even following multiple events, is substantially lower than the loading attributable to automobile emissions. This result also places the TPH concentrations we measured from environmental media in perspective with a common environmental occurrence.

Recommendations for Designing Monitoring Programs

The results from these experiments suggest that glass microfiber filters can be used to accurately represent leaf surfaces during summer field conditions. The concentrations measured on filters are generally 60% lower than those measured on polypropylene leaves and silk flowers but the filters are a good proxy for leaf and flower surfaces. The lower deposition to filters is most likely caused by the irregular morphology (more intricate surfaces) of the synthetic plants compared to that of the filters.

The relationship between filters and synthetic plants is important in environmental monitoring investigations, especially where gas chromatographic techniques cannot discern plant oils secreted during natural processes from hydrocarbon aerosol contaminants like fog oil. This finding can be used to design sampling strategies where the deposition of fog oil aerosols (or other petroleum hydrocarbon-based aerosols) to vegetation can be accurately quantified. The TPH concentrations we measured on glass microfiber filters can be corrected (by a factor of roughly 1.6) to better estimate the commensurate deposition to leaf surfaces. Future expansion of this research could include comparing TPH deposition to bird feathers, conifer needles, or grasses to filters to assess the ability of filters to represent a wider range of environmental media. Additionally, future work could include deploying sample collectors at a range of heights above the ground surface to investigate the micrometeorological controls on SGF2 deposition.

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Appendix A. Results of Laboratory Analyses

Table A-1. Results of laboratory analysis of fog oil residues on filters from the fog oil sampling event on 26 March 2001 (Event #1).

Sample	Type	DRO1 ¹ (µg/mL)	DRO2 (µg/mL)	RRO1 ² (µg/mL)	RRO2 (µg/mL)	Mean DRO (µg/mL)	Mean RRO (µg/mL)	Fog oil on filter (µg)	Fog oil on foil (µg)	Total fog oil (µg)	Surf. area (m ²)	Total fog oil (mg/m ²)
South corner												
S1F1	filter	1032	1142	1617	1674	1087	1645	2732	BDL	2732	0.27	10
S1F2	filter	814	811	706	732	812	719	1531	BDL	1531	0.27	6
S1F3	filter	845	835	2112	2120	840	2116	2956	BDL	2956	0.27	11
S1F4	filter	669	632	502	592	651	547	1197	BDL	1197	0.27	4
S1F5	filter	578	623	485	696	601	590	1191	BDL	1191	0.27	4
S1F6	filter	568	590	713	772	579	742	1321	BDL	1321	0.27	5
S1F7	filter	530	476	740	675	503	707	1210	BDL	1210	0.27	5
S1F8	filter	242	239	577	608	240	593	833	BDL	833	0.27	3
S1F9	filter	279	189	385	411	234	398	632	BDL	632	0.27	2
S1F10	filter	447	459	746	876	453	811	1264	BDL	1264	0.27	5
S1F11	filter	437	494	707	786	466	747	1212	BDL	1212	0.27	5
S1F12	filter	596	579	1622	1872	587	1747	2334	BDL	2334	0.27	9
S1F13	filter	294	291	482	536	292	509	802	BDL	802	0.27	3
S1F14	filter	410	405	987	1056	407	1021	1428	51	1479	0.27	6
S1F15	filter	311	352	485	562	332	523	855	BDL	855	0.27	3
S1F16	filter	350	321	636	604	335	620	955	BDL	955	0.27	4
S1F17	filter	433	370	535	597	402	566	967	76	1043	0.27	4
S1F18	filter	277	323	456	629	300	543	843	BDL	843	0.27	3
S1F19	filter	1357		1523		678	762	1440	445	1884	0.27	7
North corner												
S2F1	filter	2697	2738	3182	3395	2717	3288	6006	BDL	6006	0.27	22
S2F2	filter	2163	2247	2724	2875	2205	2800	5005	301	5306	0.27	20
S2F3	filter	999	939	1393	1406	969	1399	2368	229	2597	0.27	10
S2F4	filter	51646	51606	21900	22467	51626	22183	73809	8041	81850	0.27	300
S2F5	filter	2592	2459	11894	11597	2525	11745	14270	758	15028	0.27	60
S2F6	filter	489	548	769	842	519	806	1324	BDL	1324	0.27	5
S2F7	filter	1700	1725	1420	1435	1713	1427	3140	BDL	3140	0.27	12
S2F8	filter	15250	15343	7880	7826	15296	7853	23149	635	23784	0.27	90
S2F9	filter	1275	1256	1846	1824	1266	1835	3101	BDL	3101	0.27	12
S2F10	filter	1844	1764	2269	2211	1804	2240	4044	BDL	4044	0.27	15

Table A-1 (cont.).

Sample	Type	DRO1 ¹ (µg/mL)	DRO2 (µg/mL)	RRO1 ² (µg/mL)	RRO2 (µg/mL)	Mean DRO (µg/mL)	Mean RRO (µg/mL)	Fog oil on filter (µg)	Fog oil on foil (µg)	Total fog oil (µg)	Surf. area (m ²)	Total fog oil (mg/m ²)
S2F11	filter	758	760	868	956	759	912	1671	86	1757	0.27	7
S2F12	filter	4948	4901	3425	3055	4924	3240	8164	495	8659	0.27	32
S2F13	filter	17489	17303	7380	7997	17396	7688	25084	1713	26797	0.27	99
S2F14	filter	606	627	926	981	616	954	1570	BDL	1570	0.27	6
S2F15	filter	2979	2480	2375	2038	2729	2207	4936	233	5169	0.27	19
S2F16	filter	574	557	584	631	565	607	1173	BDL	1173	0.27	4
S2F17	filter	2167	2279	2067	2281	2223	2174	4397	495	4892	0.27	18
S2F18	filter	1470	1633	1152	1432	1551	1292	2843	BDL	2843	0.27	11
S2F19	filter	25896	26165	11128	11573	26031	11351	37381	736	38117	0.27	141
S2F20	filter	117	148	440	493	133	466	599	BDL	599	0.27	2
S2F21	filter	291	246	2283	1993	268	2138	2406	1030	3436	0.27	13

¹DRO1=Diesel Range Organics concentration measurement one.

²RRO1=Residual Range Organics concentration measurement one.

BDL=Below Detection level of 50 µg.

Table A-2. Results of laboratory analysis of fog oil residues on snow from the north corner site following the fog oil sampling event on 26 March 2001 (Event #1). The first eight samples correspond to filters in the north corner; the last three samples are control samples taken upwind.

Sample	Type	DRO1 (µg/mL)	DRO2 (µg/mL)	RRO1 (µg/mL)	RRO2 (µg/mL)	Mean DRO (µg/mL)	Mean RRO (µg/mL)	TPH in snow (mg/m ²)
1	snow	69	75	85	65	72	75	147
4	snow	0	3	18	1	1.5	10	9
5	snow	2	BDL	40	42	1	41	42
9	snow	BDL	BDL	20	22	BDL	21	19
11	snow	BDL	BDL	81	58	BDL	70	67
13	snow	20	12	88	53	16	71	87
16	snow	45	19	272	260	32	266	298
19	snow	1	BDL	81	89	1	85	84
25	snow	31	4	270	190	18	230	248
28	snow	2	4	142	61	3	102	105
30	snow	1	BDL	99	55	1	77	77

BDL=Below Detection level of 50 µg/mL.

Table A-3. Results of laboratory analysis of fog oil residues from the fog oil sampling event on 3 July 2001 (Event #2).

Sample	Type	Exposure time (min)	DR01 (µg/mL)	DR02 (µg/mL)	RRO1 (µg/mL)	RRO2 (µg/mL)	Mean DRO (µg/mL)	Mean RRO (µg/mL)	TPH on filter (µg)	Surface area (m ²)	TPH by area (mg/m ²)
1	filter	77	29	45	37	25	37	31	68	0.035	2
4	filter	77	77	37	26	23	57	25	82	0.035	2
5	filter	77	75	65	33	36	70	35	105	0.035	3
6	filter	77	35	37	38	54	36	46	82	0.035	2
7	filter	77	77	54	8	24	66	16	82	0.035	2
8	filter	77	62	47	61	63	55	62	117	0.035	3
9	filter	77	39	29	43	44	34	44	78	0.035	2
10	filter	77	36	62	37	50	49	44	93	0.035	3
11	filter	77	37	24	39	38	31	39	69	0.035	2
12	filter	77	51	24	79	76	38	78	115	0.035	3
14	filter	77	80	56	11	87	68	49	117	0.035	3
16	filter	77	29	15	91	71	22	81	103	0.035	3
17	filter	77	37	34	61	59	36	60	96	0.035	3
18	filter	77	23	8	39	49	16	44	60	0.035	2
19	filter	77	33	12	8	29	23	19	BDL	0.035	BDL
20	filter	77	11	20	90	56	16	73	89	0.035	3
21	filter	77	54	64	30	9	59	20	79	0.035	2
22	filter	77	36	22	54	65	29	60	89	0.035	3
23	filter	77	61	51	194	155	56	175	231	0.035	7
24	filter	77	65	71	44	18	68	31	99	0.035	3
25	filter	77	33	26	201	205	30	203	233	0.035	7
26	filter	77	95	98	140	135	97	138	234	0.035	7
27	filter	77	27	30	40	30	29	35	64	0.035	2
28	filter	77	80	118	32	37	99	35	134	0.035	4
29	filter	77	16	23	38	36	20	37	57	0.035	2
30	filter	77	58	27	97	87	43	92	135	0.035	4
31	filter	77	9	39	100	94	24	97	121	0.035	4
32	filter	77	25	40	50	55	33	53	85	0.035	3
33	filter	77	77	67	16	20	72	18	90	0.035	3
34	filter	77	21	19	26	19	20	23	BDL	0.035	BDL
35	filter	77	6	2	72	85	4	79	83	0.035	2
36	filter	77	124	BDL	48	BDL	62	24	86	0.035	3
37	filter	77	44	27	18	4	36	11	BDL	0.035	BDL
38	filter	77	68	86	60	89	77	75	152	0.035	4

Table A-3 (cont.).

Sample	Type	Exposure time (min)	DR01 (µg/mL)	DR02 (µg/mL)	RR01 (µg/mL)	RR02 (µg/mL)	Mean DRO (µg/mL)	Mean RRO (µg/mL)	TPH on filter (µg)	Surface area (m ²)	TPH by area (mg/m ²)
39	filter	77	78	91	5	11	85	8	93	0.035	3
40	filter	77	675	640	104	132	658	118	776	0.035	22
41	filter	77	90	100	25	15	95	20	115	0.035	3
42	filter	77	105	N/A	24	N/A	53	12	65	0.035	2
43	filter	77	41	39	BDL	BDL	40	BDL	BDL	0.035	BDL
44	filter	77	49	121	17	21	85	19	104	0.035	3
45	filter	77	51	10	21	46	31	34	64	0.035	2
47	filter	77	163	117	249	298	140	274	414	0.035	12
48	filter	57	94	73	112	77	84	95	178	0.035	5
49	filter	57	57	72	83	118	65	101	165	0.035	5
50	filter	57	14	34	294	271	24	283	307	0.035	9
51	filter	57	39	28	118	119	34	119	152	0.035	4
52	filter	57	123	127	59	59	125	59	184	0.035	5
53	filter	57	16	17	25	15	17	20	BDL	0.035	BDL
54	filter	57	31	26	27	40	29	34	62	0.035	2
55	filter	57	38	30	58	85	34	72	106	0.035	3
56	filter	57	30	16	100	98	23	99	122	0.035	4
57	filter	57	33	52	34	60	43	47	90	0.035	3
58	filter	57	98	120	93	116	109	105	214	0.035	6
59	filter	49	161	123	10	22	142	16	158	0.035	5
60	filter	49	42	48	50	50	45	50	95	0.035	3
61	filter	49	37	35	31	14	36	23	59	0.035	2
62	filter	49	51	45	69	75	48	72	120	0.035	4
63	filter	49	36	48	71	59	42	65	107	0.035	3
64	filter	49	66	56	19	31	61	25	86	0.035	3
65	filter	49	66	58	39	30	62	35	97	0.035	3
66	filter	49	92	68	17	81	80	49	129	0.035	4
67	filter	49	40	20	10	7	30	9	BDL	0.035	BDL

BDL = Below detection level of 50 µg/mL.

Table A-4. Results of laboratory analysis of fog oil residues on filters from the fog oil sampling event on 31 January 2002 (Event #3).

Sample	Type	Exposure time (min)	DR01 (µg/mL)	DR02 (µg/mL)	RRO1 (µg/mL)	RRO2 (µg/mL)	Mean DRO (µg/mL)	Mean RRO (µg/mL)	TPH on filter (µg)	Surface area (m ²)	TPH by area (mg/m ²)
1	filter	93	263	233	50	15	248	33	281	0.035	8
2	filter	68	261	261	33	34	261	34	295	0.035	9
3	filter	68	198	210	20	23	204	22	226	0.035	7
4	filter	93	197	186	38	22	192	30	222	0.035	6
5	filter	93	159	155	27	11	157	19	176	0.035	5
6	filter	93	230	219	6	14	225	10	235	0.035	7
7	filter	93	178	197	32	3	188	18	205	0.035	6
8	filter	93	156	159	28	27	158	28	185	0.035	5
9	filter	93	130	168	81	51	149	66	215	0.035	6
10	filter	93	317	327	35	35	322	35	357	0.035	10
11	filter	93	375	411	41	24	393	33	426	0.035	12
12	filter	93	288	290	36	48	289	42	331	0.035	10
13	filter	93	294	271	7	57	283	32	315	0.035	9
14	filter	68	391	395	22	5	393	14	407	0.035	12
15	filter	68	411	427	31	31	419	31	450	0.035	13
16	filter	68	322	319	24	47	321	36	356	0.035	10
17	filter	68	331	321	29	36	326	33	359	0.035	10
18	filter	68	286	315	41	42	301	42	342	0.035	10
19	filter	68	303	306	24	23	305	24	328	0.035	10
21	filter	68	137	137	30	29	137	30	167	0.035	5
53	filter	68	252	283	48	32	268	40	308	0.035	9
54	filter	93	258	238	104	63	248	84	332	0.035	10
55	filter	93	255	281	58	49	268	54	322	0.035	9
56	filter	93	264	277	34	41	271	38	308	0.035	9
57	filter	93	432	416	26	62	424	44	468	0.035	14
58	filter	93	343	345	39	38	344	39	383	0.035	11
59	filter	93	480	458	89	74	469	82	551	0.035	16
60	filter	68	241	230	37	68	236	53	288	0.035	8
61	filter	68	344	362	25	68	353	47	400	0.035	12
62	filter	68	325	311	31	37	318	34	352	0.035	10
63	filter	93	357	369	58	44	363	51	414	0.035	12
64	filter	93	415	453	21	12	434	17	451	0.035	13
65	filter	93	848	823	21	43	836	32	868	0.035	25
66	filter	93	471	465	94	78	468	86	554	0.035	16
67	filter	93	1055	1099	53	28	1077	41	1118	0.035	32
TB2	filter	93	9	7	18	13	8	16	BDL	0.035	BDL
TB4	filter	93	8	6	10	17	7	14	BDL	0.035	BDL

BDL = Below detection level of 50 µg/mL.

Table A-5. Results of laboratory analysis of fog oil residues on leaves and flowers from the fog oil sampling event on 31 January 2002 (Event #3).

Sample	Type	Exposure time (min)	DRO1 ($\mu\text{g}/\text{mL}$)	DRO2 ($\mu\text{g}/\text{mL}$)	RRO1 ($\mu\text{g}/\text{mL}$)	RRO2 ($\mu\text{g}/\text{mL}$)	Mean DRO ($\mu\text{g}/\text{mL}$)	Mean RRO ($\mu\text{g}/\text{mL}$)	TPH on filter (μg)	Surface area (m^2)	TPH by area (mg/m^2)
54	leaves	93	562	551	184	243	557	214	770	0.063	12
55	leaves	93	330	344	39	42	337	41	378	0.063	6
57	leaves	93	580	534	63	53	557	58	615	0.063	10
58	leaves	93	454	489	57	77	472	67	539	0.063	9
59	leaves	93	1664	1650	99	117	1657	108	1765	0.063	28
63	leaves	93	218	300	46	90	259	68	327	0.063	5
64	leaves	93	614	606	391	411	610	401	1011	0.063	16
65	leaves	93	313	373	500	590	343	545	888	0.063	14
66	leaves	93	123	134	148	132	129	140	269	0.063	4
67	leaves	93	1443	1478	769	784	1461	777	2237	0.063	36
54	flowers	93	131	159	286	274	145	280	425	0.06	7
55	flowers	93	217	189	42	44	203	43	246	0.061	4
57	flowers	93	281	341	52	21	311	37	348	0.056	6
58	flowers	93	449	453	188	198	451	193	644	0.061	11
59	flowers	93	899	894	97	72	897	85	981	0.062	16
63	flowers	93	32	10	40	33	21	37	58	0.063	1
64	flowers	93	22	8	84	90	15	87	102	0.065	2
65	flowers	93	40	30	2	9	35	6	BDL	0.068	BDL
66	flowers	93	182	255	577	611	219	594	813	0.065	13

BDL = Below detection level of 50 $\mu\text{g}/\text{mL}$.

Table A-6. Results of laboratory analysis of fog oil residues on filters from the fog oil sampling event on 12 September 2002 (Event #4).

Sample	Type	Exposure time (min)	DR01 (µg/mL)	DR02 (µg/mL)	RRO1 (µg/mL)	RRO2 (µg/mL)	Mean DRO (µg/mL)	Mean RRO (µg/mL)	TPH on filter (µg)	Surface area (m ²)	TPH by area (mg/m ²)
1	filter	110	79	112	196	191	96	194	289	0.035	8
2	filter	110	264	169	353	141	217	247	464	0.031	15
3	filter	110	387	382	384	270	385	327	712	0.035	21
4	filter	110	528	492	246	261	510	254	764	0.035	22
5	filter	110	424	472	163	188	448	176	624	0.035	18
6	filter	110	863	785	381	212	824	297	1121	0.035	32
7	filter	110	361	462	254	528	412	391	803	0.035	23
8	filter	110	1014	974	180	206	994	193	1187	0.035	34
9	filter	110	4227	3899	1801	1130	4063	1466	5529	0.035	160
10	filter	110	4535	4571	486	964	4553	725	5278	0.035	153
11	filter	110	1366	1379	246	195	1373	221	1593	0.035	46
12	filter	110	991	966	271	180	979	226	1204	0.035	35
13	filter	110	649	549	570	167	599	369	968	0.035	28
14	filter	110	365	336	97	33	351	65	416	0.035	12
15	filter	110	157	109	231	110	133	171	304	0.035	9
16	filter	110	232	306	BDL	BDL	269	BDL	246	0.035	7
17	filter	110	98	97	51	84	98	68	165	0.035	5
18	filter	110	220	198	BDL	BDL	209	BDL	82	0.035	2
19	filter	110	134	143	73	229	139	151	290	0.035	8
20	filter	110	9532	9484	1804	2063	9508	1934	11442	0.035	331
TB1	filter	N/A	BDL	60	138	194	BDL	166	203	0.035	6

BDL = Below detection level of 50 µg/mL.

Table A-7. Results of laboratory analysis of fog oil residues on flowers from the fog oil sampling event on 12 September 2002 (Event #4).

Sample	Type	Exposure time (min)	Flower sample	DR01 (µg/mL)	DR02 (µg/mL)	RR01 (µg/mL)	RR02 (µg/mL)	Mean DRO (µg/mL)	Mean RRO (µg/mL)	TPH on flowers (µg)	Flower surface area (m ²)	TPH by area (mg/m ²)
1	flowers	110	70	294	254	991	1311	274	1151	1425	0.065	22
2	flowers	110	71	594	564	1448	1375	579	1412	1991	0.066	30
3	flowers	110	70	808	794	827	973	801	900	1701	0.065	26
4	flowers	110	62	1176	1135	2819	2662	1156	2741	3896	0.058	67
5	flowers	110	71	1376	1357	1142	1113	1367	1128	2494	0.066	38
6	flowers	110	72	2632	2700	829	955	2666	892	3558	0.067	53
7	flowers	110	72	3183	3125	2277	2188	3154	2233	5387	0.067	80
8	flowers	110	72	3508	3692	2966	3141	3600	3054	6654	0.067	99
9	flowers	110	72	10777	10705	3137	2700	10741	2919	13660	0.067	203
10	flowers	110	72	11366	10818	6166	4806	11092	5486	16578	0.067	246
11	flowers	110	72	4237	4156	2799	2603	4197	2701	6898	0.067	103
12	flowers	110	71	3770	3733	1389	1272	3752	1331	5082	0.066	77
13	flowers	110	72	2062	2048	4593	4771	2055	4682	6737	0.067	100
14	flowers	110	69	1290	1335	3029	3146	1313	3088	4400	0.065	68
15	flowers	110	73	276	385	2148	2333	331	2241	2571	0.068	38
16	flowers	110	71	497	567	3717	3764	532	3741	4273	0.066	64
17	flowers	110	54	139	140	1656	1460	140	1558	1698	0.050	34
19	flowers	110	72	782	800	3309	3186	791	3248	4039	0.067	60
20	flowers	110	72	14043	13422	5582	4865	13733	5224	18956	0.067	282
Blank1	flowers	N/A	72	108	136	1032	821	122	927	1049	0.067	16
Blank2	flowers	N/A	72	289	341	1875	1892	315	1884	2199	0.067	33

Table A-8. Results of laboratory analysis of fog oil residues on leaves from the fog oil sampling event on 12 September 2002 (Event #4).

Sample	Type	Exposure time (min)	DR01 (µg/mL)	DR02 (µg/mL)	RR01 (µg/mL)	RR02 (µg/mL)	Mean DRO (µg/mL)	Mean RRO (µg/mL)	TPH on leaves (µg)	Leaf surface area (m ²)	TPH by area (mg/m ²)
1	leaves	110	208	152	155	45	180	100	280	0.063	5
2	leaves	110	361	328	572	511	345	542	886	0.063	14
3	leaves	110	757	756	163	376	757	270	1026	0.063	16
4	leaves	110	939	881	1863	1776	910	1820	2730	0.063	44
5	leaves	110	1577	1365	842	396	1471	619	2090	0.063	33
6	leaves	110	3447	3294	1422	1036	3371	1229	4600	0.063	74
7	leaves	110	2971	2985	733	716	2978	725	3703	0.063	59
8	leaves	110	3704	3728	980	941	3716	961	4677	0.063	75
9	leaves	110	11686	11527	2231	2232	11607	2232	13838	0.063	221
10	leaves	110	14832	14817	4149	3981	14825	4065	18890	0.063	302
11	leaves	110	4120	4095	939	1024	4108	982	5089	0.063	81
12	leaves	110	4675	4736	1232	1443	4706	1338	6043	0.063	97
13	leaves	110	1672	1591	689	598	1632	644	2275	0.063	36
14	leaves	110	713	721	324	429	717	377	1094	0.063	18
15	leaves	110	78	88	100	51	83	76	159	0.063	3
16	leaves	110	89	84	570	582	87	576	663	0.063	11
17	leaves	110	BDL	BDL	BDL	BDL	BDL	BDL	56	0.063	BDL
18	leaves	110	BDL	BDL	88	BDL	BDL	44	76	0.056	1
19	leaves	110	793	727	292	266	760	279	1039	0.063	17
20	leaves	110	20843	19934	7861	6080	20389	6971	27359	0.063	437
LB1	leaves	N/A	217	177	226	193	197	210	407	0.063	7
LB2	leaves	N/A	264	281	241	285	273	263	536	0.063	9

BDL = Below detection level of 50 µg/mL.

Table A-9. Results of laboratory analysis of Fairbanks snow samples taken on 26 March 2002.

Sample	Type	Volume (mL)	TPH ($\mu\text{g/mL}$)	Surface area (m^2)	TPH (mg)	TPH (g/m^2)
1	Snow	96	1981	0.00255	190	75
2	Snow	124	1867	0.00255	231	91
3	Snow	128	1857	0.00255	238	93
4	Snow	110	1546	0.00255	170	67
5	Snow	120	1255	0.00255	151	59
7	Snow	130	2287	0.00255	297	117
8	Snow	128	972	0.00255	124	49
9	Snow	129	947	0.00255	122	48
Blank1	Filter	1	39	0.0346	BDL	BDL
Blank2	Filter	1	37	0.0346	BDL	BDL

BDL = Below detection level.

