Regional Haze Trans-Boundary Monitoring Study Report
June 29, 2012

Air Quality Division

Air Monitoring
&
Quality Assurance
Program

619 E. Ship Creek Ave. #249
Anchorage, AK 99501

Phone: (907) 269-7577
Fax: (907) 269-7508

www.state.ak.us/dec/

This page intentionally left blank

Table of Contents

1 Regional Haze Rule ____ *10*

1.1 Class I Areas in Alaska ____ **10**

1.1.1 Denali National Park and Preserve ____ 11

1.1.2 Tuxedni Wilderness Area ____ 11

1.1.3 Simeonof Wilderness Area ____ 11

1.1.4 Bering Sea Wilderness Area ____ 11

1.2 The IMPROVE program ____ **11**

1.3 Contributing Sources ____ **11**

1.3.1 Arctic Haze ____ 12

1.3.2 Asian Dust ____ 12

1.3.3 Seasonality in Alaska ____ 13

2 Study Design ____ *13*

2.1 Pilot Study ____ **14**

2.2 Main Study ____ **15**

2.2.1 Study Objectives ____ 15

2.2.2 Site Selection ____ 15

2.2.3 Data Quality Assurance/Quality Control ____ 16

2.2.4 Monitoring Instruments ____ 17

3 Results ____ *19*

3.1 Quality Assurance/Quality Control ____ **19**

3.1.1 Data capture ____ 19

3.1.2 Timing Record ____ 20

3.1.3 Data quality ____ 21

3.2 $PM_{2.5}$ Mass Concentrations ____ **22**

3.2.1 Problems with Determining DRUM Mass Concentration ____ 23

3.2.2 Comparison Among Sampling Technologies ____ 24

3.2.3 Selected Data Subset for Analysis and Interpretation ____ 25

3.3 HYSPLIT Summary Analysis ____ **27**

3.4 Analysis of Periods of Interest: April 2008 ____ **32**

3.4.1 Sources of aerosols ____ 33

3.4.2 Supporting evidence for April 2008 events: Models and Satellite Images ____ 34

3.4.3 Event Designation ____ 37

3.4.4 Mass data: April 2008 Events ____ 38

3.4.5 Element data: April 2008 Events ____ 40

4 Conclusions ____ *49*

4.1 Use of DRUM samplers as substitution for IMPROVE ____ **49**

4.2 IMPROVE Site _____ 50

4.3 Source apportionment _____ 50

4.4 Future sampling/interpretation _____ 51

5 References Cited _____ 58

6 Appendices _____ 57

List of Appendices

6.1 Appendix A: Site Locations, Characteristics and Photographs

A-1 Satellite image of the DNPP area including site locations and Park boundary 60

A-2 Summary of site characteristics 61

A-3 Instrument configurations and analysis methods for the final four sites 62

A-4 Site descriptions and photographs 56

6.2 Appendix B Quality Assurance/Quality Control documents

B-1 Example Field log sheet: DRUM sampler (Lake Minchumina site) 67

B-2 DRI Standard Operating Procedure #2-209.6 B-3 68

B-3 DEC Regional Haze monitoring MQOS 74

B-4 Quality Assurance Summary and Size Resolved Mass Data Archive, Alaska DEC 3 DRUM Network 78

6.3 Appendix C HYSPLIT Models: April 3-26, 2008

C-1 Denali Headquarters- Low Level, 310 hours 96

C-2 Lake Minchumina – Low Level, 310 hours 117

C-3 McGrath – Low Level, 310 hours 141

C-4 Denali Headquarters- Low Level, 24 hours- April 3-14, 2008 165

6.4 Appendix D Supporting Evidence for April 2008 Events

D-1 Jet lab cruises Alaska skies as scientist study bit of floating pollution 179

D-2 Asian Haze Colors Palmer Skies 180

D-3 Satellite Images of Fires in East Russia 181

D-4 Russian Wildfires Reach Mongolia 183

List of Tables

Table 1. Sampling schedule and start and end dates for each site 18

Table 2. Monthly and overall 15-month study average capture rates 19

Table 3. DRUM, IMPROVE and Partsiol particulate matter summary statistics 22

Table 4. Paired regression statistics for the sites 25

Table 5. Summary statistics for selected element concentrations 26

Table 6. HYSPLIT model settings 27

Table 7. Example of partial HYSPLIT chart for Denali Headquarters site, May 1-10, 2009 30

Table 8. Thresholds used to determine event episodes 37

Table 9. Comparison of $PM_{2.5}$ averages during the two April events as compared to the overall study average 40

Table 10. Daily DRUM concentration averages for selected elements 44

Table 11. Wildfire History of Alaska 1990 – 2009 50

List of Figures

Figure 1. Alaska's four Class I areas 10

Figure 2 IMPROVE visibility data at DNPP headquarters (1988-2000 data) 13

Figure 3. $PM_{2.5}$ mass DRUM comparison 24

Figure 4. Denali Headquarters total $PM_{2.5}$ mass regression 24

Figure 5. Map showing Gobi and Taklamakan Deserts 28

Figure 6. Map showing location of Norilsk, Russia circled in red 28

Figure 7. Example HYSPLIT back trajectory 29

Figure 8. Percentage of time that trajectories crossed certain source regions during transport to the sites 31

Figure 9. Percentage of time that trajectories crossed at least one of the source regions before reaching each site vs the time they did not cross a source region 32

Figure 10. MODIS satellite image centered over the Sea Okhotsk on April 17, 2008 35

Figure 11. Satellite image of smoke over the Kamchatka Peninsula and Northern Pacific on April 21, 2008 36

Figure 12. Total $PM_{2.5}$ mass data: March – April 2008 38

Figure 13. Total $PM_{2.5}$ mass data: April 2008 39

Figure 14. Elemental concentrations charts: Br, Cl and Na, April 2008 42

Figure 15. Example of 24 hour back trajectory HYSPLIT model run for Denali Headquarters 44

Figure 16. Elemental concentrations charts: Al, Ca, K, Mg and Si, April 2008 47

Figure 17. Elemental concentrations charts: Cu, Ni, V and Zn, April 2008 48

Abbreviations and Acronyms

AFS Air Force Station

Al	aluminum
AMQA	Air Monitoring and Quality Assurance
ANILCA	Alaska National Interest Lands Conservation Act
Avg	average
Br	bromine
^{o}C	degrees Celsius
Ca	calcium
CARB	California Air Resources Board
Cl	chlorine
cm	centimeters
Cu	copper
DEC	Department of Environmental Conservation
DELTA	Detection and Evaluation of the Long-Range Transport of Aerosols (UC Davis)
DENA	Denali Headquarters monitoring site
DNPP	Denali National Park and Preserve
DRI	Desert Research Institute
DRUM	Davis Rotating-drum Unit for Monitoring
^{o}F	degrees Fahrenheit
ED XRF	Energy Dispersive X-ray Fluorescence
EPA	U.S. Environmental Protection Agency
Fe	iron
FWS	U.S. Fish and Wildlife Service
GDAS1	Global Data Assimilation System (1° latitude-longitude grid)
HYSPLIT	HYbrid Single-Particle Lagrangian Integrated Trajectory
IMPROVE	Interagency Monitoring of Protected Visual Environments
in Hg	inches of mercury
K	potassium

km	kilometers
LAMI	Lake Minchumina monitoring site
L/min	liters per minute
$\mu g/m^3$	micrograms per cubic meter
μm	micrometers
Max	maximum
Med	median
MET	meteorological
MCGR	McGrath monitoring site
MODIS	Moderate-resolution Imaging Spectrometer
mi	miles
ng/m^3	nanograms per cubic meter
n	number of samples or paired samples
N	north
NAAQS	National Ambient Air Quality Standards
Ni	nickel
NOAA	National Oceanic and Atmospheric Administration
NPS	U. S. National Park Service
NW	northwest
NWS	U. S. National Weather Service
PIXE	Particle Induced X-Ray Emission
PM	particulate matter
$PM_{2.5}$	particulate matter (aerodynamic diameter less than 2.5 μm)
PM_{10}	particulate matter (aerodynamic diameter less than 10 μm)
QA	quality assurance
QAPP	quality assurance project plan
QC	quality control

S	sulfur
Se	selenium
SE	southeast
Si	silicon
SIP	State Implementation Paln
SOA	State of Alaska
SOIL	2.20 * Al + 2.49 * Si + 1.63 * Ca + 2.42 * Fe + 1.94 * Ti (Eldred, 2003)
stdev	standard deviation
Ti	titanuim
TRCR	Trapper Creek monitoring site
TSM	Trajectory Statistical Methods
W	west
WINS	Well Impactor Ninety Six
UAF	University of Alaska Fairbanks
UC Davis	University of California Davis
XRF	x-ray fluorescence
Zn	zinc

1 Regional Haze Rule

In 1999, the U.S. Environmental Protection Agency (EPA) announced a nationwide effort to improve air quality in national parks and wilderness areas. The Regional Haze Rule calls for state and federal agencies to work together to improve visibility in 156 national parks and wilderness areas. The rule requires the states, in coordination with the EPA, the National Park Service (NPS), the U.S. Fish and Wildlife Service (FWS), the U.S. Forest Service, and other interested parties to develop and implement air quality protection plans to reduce the pollution that impairs visibility. Some haze-causing pollutants, mostly fine particles, are directly emitted to the atmosphere by activities such as electric power generation, truck and auto emissions, burning related to forestry and agriculture, construction activities, etc. Others are formed when gases emitted to the air form particles as they are carried downwind. Emissions can span broad geographic areas and can be transported great distances - sometimes hundreds or thousands of miles.

In the 1977 Clean Air Act, the U.S. Congress established a national visibility goal as ‘‘prevention of any future, and the remedying of any existing, impairment of visibility in mandatory Class I federal areas which impairment results from man-made air pollution.’’ The amendments required the EPA to issue regulations to assure “reasonable progress” toward meeting this national goal. Each state must develop coordinated strategies and implement programs to make reasonable progress toward the goal of no “man-made impairment” in Class I areas by reducing emissions that contribute to haze. To aid the implementation of the Regional Haze rule, the Interagency Monitoring of Protected Visual Environments (IMPROVE) program was initiated in 1985. This program implemented an extensive, long-term monitoring program to document current visibility conditions, track changes in visibility, and determine causal mechanisms for the visibility impairment in the National Parks and Wilderness Areas.

Alaska’s State Implementation Plan (SIP) must include a monitoring strategy to measure, characterize, and report regional haze visibility impairment that is representative of all Class I areas within the State. Compliance with this requirement may be met through participation in the IMPROVE network. The State of Alaska (SOA) is working with EPA and federal land managers to ensure that monitoring networks provide data that are representative of visibility conditions in each affected Class I area within the State. Along with monitoring strategies for the Class I areas, the SIP will also need to include a determination of whether additional monitoring sites or equipment are needed to verify if progress goals are being achieved.

Figure 1. Alaska’s four Class I areas

1.1 Class I Areas in Alaska

Alaska has four Class I areas that are impacted by the Regional Haze Rule: Denali National Park and Preserve (DNPP), Tuxedni Wilderness Area, Simeonof Wilderness Area, and Bering Sea Wilderness Area. Figure 1 shows the general locations of Alaska’s Class I areas.

1.1.1 Denali National Park and Preserve

Denali National Park and Preserve lies 240 miles north of Anchorage in the center of the Alaska Range. The park area totals more than 6 million acres. Denali, the highest mountain in North America at 20,320-feet, is a prominent feature in the park and interior Alaska. DNPP is the only Class I site in Alaska that is easily accessible, connected to the road system and accommodates a wide variety of visitor uses.

1.1.2 Tuxedni Wilderness Area

Tuxedni Wilderness Area is located in southcentral Alaska, in western lower Cook Inlet at the mouth of Tuxedni Bay. Tuxedni comprises two Islands, Chisik and Duck, totaling 6,402 acres. Most of the wilderness area lies on Chisik. Duck is a small rocky island, only 6 acres, with little or no vegetation. Tuxedni Wilderness Area is only accessible by small boats and planes, weather permitting.

1.1.3 Simeonof Wilderness Area

Simeonof Wilderness Area consists of 25,141 acres located in the Alaska Peninsula 58 miles from the mainland. It is one of 30 islands that make up the Shumagin Group on the western edge of the Gulf of Alaska. Access to Simeonof is difficult due to its remoteness and unpredictable weather.

1.1.4 Bering Sea Wilderness Area

The Bering Sea Wilderness Area is located off the western coast of Alaska approximately 275 miles southwest of Nome. The Class I area comprises 41,113 acres and is made up of the St. Matthew Island group (which totals approximately 81,340 acres). The Bering Sea Wilderness Area is one of the most isolated landmasses in America with few, if any, visitors. Due to the extremely remote location of this area, little or no visibility monitoring is planned.

1.2 The IMPROVE program

The IMPROVE program is a cooperative measurement effort governed by a steering committee of federal, regional, and state organization representatives. The IMPROVE monitoring program was established in 1985 to aid the creation of federal and state implementation plans for the protection of visibility in Class I areas. The objectives of IMPROVE are to document current visibility and aerosol conditions in mandatory Class I areas, to identify chemical species and emission sources responsible for existing man-made visibility impairment, to document long-term trends for assessing progress towards the national visibility goal, and to provided regional haze monitoring representing all visibility-protected federal Class I areas where practical. Currently in Alaska there are four IMPROVE monitoring sites that represent the Class I areas: one at Trapper Creek, one at the DNPP headquarters air monitoring site, one at Tuxedni Wilderness Area, and one in Sand Point representing the Simeonof Wilderness Area. No site was selected for the Bering Sea Wilderness area due to the remoteness of this Class I area.

1.3 Contributing Sources

The international transport of air pollutants into the State is a primary issue. Unlike the states in the contiguous United States, Alaska borders no other U.S. state. Instead of intra-state transport of air pollutants, Alaska is directly impacted by air pollutants from Russia, China, other parts of Asia, Europe, and Canada. Alaska is particularly affected by transport from Asia and Russia/Eastern Europe. Due to the winter conditions at high latitudes, namely a lack of sunlight and liquid water, expected atmospheric chemical reactions do not occur. This can cause

emissions which have been transported hundreds or thousands of miles to appear in analyses as though from a local source. International transport of pollutants into Alaska has been documented through a variety of research studies. In particular, the research has focused on Arctic haze and Asian dust events.

1.3.1 Arctic Haze

Arctic haze can be defined as diffuse bands of tropospheric aerosol that occur north of about 70° latitude and at altitudes of up to 9,000 meters (Rahn and Shaw, 1982). These layers are hundreds to thousands of kilometers (km) wide and 1 to 3 km thick. Arctic haze specifically refers to the presence of anthropogenic aerosol from mid-latitudinal sources (Polissar et al., 1999).

Scientific observations of Arctic haze were first made in the 1950's; however, extensive research did not begin until the early 1970's. Arctic haze is most visible during the spring. Aerosol pollution reaches its maximum in March/April due to increased airflow from central Eurasia and increased gas to particle conversion (Wilcox, 2001). Haze particles are no larger than 2 µm in diameter. Aerosols between 0.1 µm and 1 µm are capable of remaining suspended in the atmosphere for weeks and therefore able to travel into the Arctic, which has few locally generated aerosols (Seinfield and Pandis, 1998). The size of Arctic haze aerosols is roughly the same as the wavelength of visible light (0.39-0.76 µm) allowing the aerosol to scatter light and therefore diminish visibility very effectively. Coal burning and metal smelting appear to be the primary contributors to arctic haze, based on both its composition and the source regions (Wilcox, 2001).

Evidence from meteorological studies indicates that the pollution comprising Arctic haze originates in industrial regions of the world, mainly Europe and Russia. The presence of strong source regions in Eurasia; the occurrence of the Arctic air mass over much of this source; the occurrence of a poleward circulation over the source area; and the lack of precipitation, clouds, and vertical mixing along the transport trajectory indicate that Eurasia is a major source region for the Arctic (Polissar et al., 1999).

DNPP is in the sub-Arctic and not as severely impacted as the Arctic; sulfate aerosol mixing ratios in Denali are 30-50% of those in the Arctic. Nevertheless, Arctic haze appears to have a substantial impact on visibility in DNPP. For seven months out of the year (November-May), sulfates are the dominant aerosol species in DNPP, of which Arctic haze aerosol appears to make up a sizeable portion (Wilcox, 2001).

1.3.2 Asian Dust

In 1976, a study of Arctic haze found a large amount of Asian dust in Arctic haze air samples collected in May of that year (Rahn et al., 1977). The Taklamakan and Gobi deserts and China loess plateu in Asia are some of sources of Asian dust aerosols that make up a portion of Actic haze. Like the glacial dust events in Alaska, soils and mineral particles are entrained in the air column by wind events especially prevalent in the spring. Smaller size-fraction particles are often be transported between continents and oceans. Since that study, several others have addressed the transport of Asian dust across the Pacific Ocean including Shaw, 1980; Duce et al., 1980; Parrington et al., 1983; Uematsu et al., 1983; Merrill et al., 1989; Bodhaine, 1995; Husar et al., 1997, Perry et al., 1999; McKendry et al, 2001; and DeBell et al , 2004.

1.3.3 Seasonality in Alaska

There are strong seasonal trends to the visibility degradation in the State of Alaska. From March to May, dust and anthropogenic emissions originating in Asia blow across the Pacific Ocean as described above. This long–range transport of particulates and pollutants comes at the tail end of the Arctic haze time period, which runs from October to March. Regional wild fires typically start when the snow melts, usually in April, and continue until mid-August and impact visibility in interior Alaska.

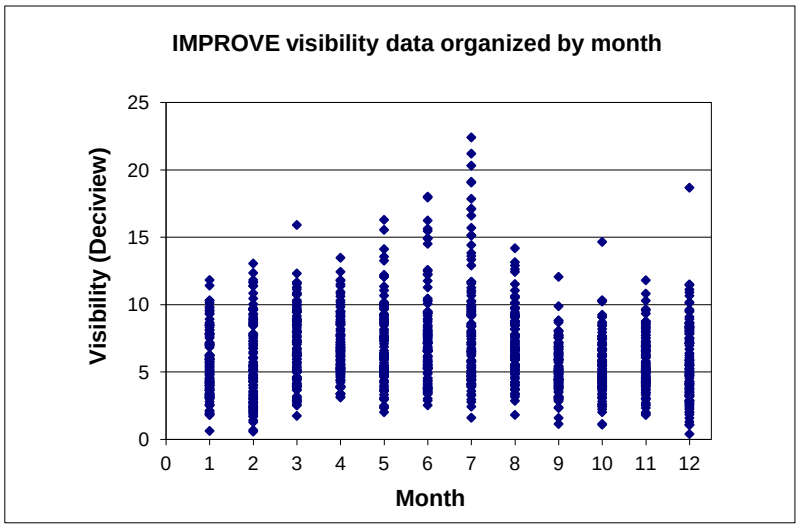


Figure 11 IMPROVE visibility data at DNPP headquarters (1988-2000 data)

The seasonal nature of long-range transport and regional pollution lead to a bimodal trend of low visibility which peaks once in summer and once in winter as can be seen in Figure 2. The graph displays the IMPROVE visibility data collected at the DNPP Headquarters from March 1988 to February 2000.

2 Study Design

IMPROVE data from the DNPP Class I area indicate that the visibility conditions in the park are close to natural. Because the concentrations of pollutants are generally low, internationally transported pollution becomes a more important component to consider in determining what controls will be effective for improving visibility and the rate of improvement that can be expected at each area.

Since foreign emissions are out of Alaska's control, the effect of these emissions must be isolated and considered separately from controllable emissions within the State regional haze SIP. The two primary ways to evaluate these pollutants are through sample data analyses or through the use of emissions information and modeling. At this time, it is unlikely that Alaska will obtain emission inventory information from other countries to use in regional haze analyses. However, Alaska could isolate and address international pollution transport by monitoring for visibility impairing pollutants being transported across international boundaries into Alaska's Class I areas.

Alaska's four Class I areas are separated by hundreds of miles and represent different ecosystems. Because of these vast distances and the complicated logistics for such remote areas, simultaneous monitoring of all four regions would present a significant strain on State personnel and funds. The State of Alaska therefore proposed a phased approach where the initial focus was

to test equipment/ monitoring strategy and assess the DNPP Class I area. Additionally, DEC proposed to compare the DNPP headquarters and Trapper Creek sites in terms of their representativeness of the air quality for the entire DNPP Class I area.

The logistical difficulty of monitoring at remote locations within the State presents significant challenges to the Alaska Department of Environmental Conservation (DEC) air quality monitoring program. Remote location challenges include providing reliable power for instrumentation and the high cost of travel to sites for maintenance and operations. Monitors that are located at the nearest power source, such as a town, are also near local sources of emissions and, therefore, less likely to be representative of the Alaska's remote and largely pristine Class I areas. Because regulatory action is based on the monitoring data, the State needs to assure that the IMPROVE sites accurately represent the majority of any Class I area.

2.1 Pilot Study

In 2003, DEC, in partnership with the University of California at Davis (UC Davis) and the University of Alaska at Fairbanks (UAF), began a pilot study to investigate the usability of the **D**avis **R**otating-drum **U**nit for **M**onitoring (DRUM) in the remote Alaskan field setting. The initial scope of the study was to develop a sampling system which could be deployed around the boundary of DNPP. The park's six million acres were represented by two monitoring sites at its eastern and southeastern, most populated border. The park is influenced by long-range transport which might have a greater impact on the northern, western or southwestern borders.

An IMPROVE monitoring site had been established at the DNPP headquarters in 1988. However, this site is in the most populous part of DNPP, especially during summer tourist season; is in a valley; is near a road that is heavily travelled in summer; and is in the northeast part of this very large park. For these reasons, DEC and the National Park Service (NPS) decided to establish another monitoring site at Trapper Creek, a site that has lower population and less traffic than the headquarters site, has power, has easy road access, and is on the south side of the park.

In July 2003 DEC purchased three DRUM samplers, which the manufacturer delivered directly to the UC Davis for low flow adaptation. The goal was to operate the samplers off the grid using alternative power to reduce local source impacts. A Phase I comparison to the Trapper Creek IMPROVE sampler was planned for September that same year. Phase II was to involve sampling in locations along a latitudinal transect to test the sensitivity of the equipment to plumes traveling across the State and through the park.

The pilot study was delayed due to complications at the UC Davis Delta Lab while modifying the DRUM samplers for the low power requirements. UC Davis completed modification and testing of two low flow DRUM samplers and shipped them to DEC on December 29, 2004. In addition to low flow modifications which impacted the slit width and therefore impactor performance, UC Davis decided to replace the synchrotrous motor which rotates the drum impactors to a stepping motor. This change would allow a programmable rotation speed instead of a fixed, six-week rotation. UC Davis modified the three-stage DRUM samplers for eight rotation speeds between 5 days and 1.8 years. The additional speed control added to the small sampler caused numerous problems which had to be worked out over the next year and a half. Field tests performed from March 2005 through July 2006 failed for many reasons, amongst them operator errors, instrumentation problems, and combinations of both. During the testing it became clear that the low flow set-up still drew too much power for a viable, remote off-the-grid

deployment. DEC, in cooperation with UC Davis and UAF, decided to reconfigure the Alaska DRUMs to the initial slit sizes and pump set-up.

Planning and formal agreement efforts for the main study continued in parallel with working out instrumentation issues. In the summer of 2006 funding for the main study was approved. DEC modified the monitoring plan according to the funding level and prepared a Quality Assurance Project Plan (QAPP) for EPA approval. The main study required a minimum of six DRUM samplers. DEC tried to purchase three additional samplers, but the initial manufacturer had gone bankrupt and production at a new company was at least a year out. DEC, with the help of Dr. Cathy Cahill of UAF, was able to put together enough samplers to start the monitoring in early 2008.

2.2 Main Study

2.2.1 Study Objectives

DEC set four goals for the 12 month-long DNPP Regional Haze monitoring study. They were to:

1) Determine if either of the two existing IMPROVE sites adequately represent the entire park and, if so, determine which one is best,
2) Determine the impact of local sources on regional haze in the park,
3) Determine the contribution of long range transport to regional haze in the park,
4) Assess the DRUM sampler as a future monitoring instrument for other Class I areas in Alaska.

During the spring of 2008 DEC changed the study length to 15 months because of start-up problems during the extreme cold of winter months. This would allow DEC to capture Arctic Haze and Asian dust events in both 2008 and 2009.

2.2.2 Site Selection

Long-range transport patterns into interior Alaska exhibit strong seasonal patterns. Southwesterly flow is most common from late summer through the winter. The corresponding low pressure center is situated southwest of the Kamchatka Peninsula, supporting long-range transport from the Northwest Pacific, including Asian dust and other pollutants. A strong low pressure center over the Arctic Ocean, north of Canada's Northwest Territories, is typically found in the fall and winter and brings pollution from Europe and Russia into interior Alaska. A weather pattern with southerly currents, originating from a low pressure center over the Aleutian Chain can transport air from lower latitudes into the interior of the State. This weather pattern occurs year round, but is most common and strongest during fall and winter, producing sudden rises in temperature and high winds along the North side of the Alaska Range and in mountain passes. Therefore, the strongest international transport signatures should be found on the north to northwest and south to southwest Park boundaries [Raatz and Shaw, 1984]. Monitoring stations located to the north and northwest (2 sites), to the west (1 site), and to the south and southwest (2 sites) would best characterize the air transport across the park boundary.

Although Denali NPP is accessible by road along its eastern border, most of the park's area spreads over pristine wilderness far removed from roads and airports. In addition, the population of interior Alaska is spread thin, leaving small communities to supply their own electrical power water and to manage their solid waste. Many of these communities are not tied into the road network and are only accessible by small aircraft or by boat. Travel to these villages and small towns can be time intensive, logistically challenging, and weather dependent. Thus major

consideratations in monitoring site selection were that the sites not only make sense from a geographical and meteorological standpoint, but also financially and logistically. Operator and maintenance personnel safety was also a key component.

The logistics of remote monitoring made this project expensive and challenging. To strike a balance between optimal coverage of the air flow regimes in the region and financial feasibility, DEC selected the monitoring site locations according to the criteria below in the order of listing:

1) Flow regimes that bring long range transport to the interior of Alaska,
2) Geographic and topographic locations in reference to the park boundary,
3) Accessibility by plane or boat or road,
4) Population centers,
5) National Weather Service meteorological information and potential power sources for the instrumentation,
6) Availability of field operators.

To cover the north and northwestern boundary of DNPP, DEC selected three potential monitor locations: DNPP headquarters, Lake Minchumina, and Clear Air Force Station (Clear AFS). To the west of the park there were two potential favorable locations for setting up monitors: McGrath and Nikolai; McGrath was chosen because of its National Weather Station staff and the accessibility of McGrath which is a hub community for Kuskokwim Valley area west of DNPP. South of DNPP, Trapper Creek IMPROVE network site was an obvious choice because of its road system accessibility and the presence of the IMPROVE samplers and local operators (see Appendix A-1 for satellite image of DNPP boundary and site locations). The Clear AFS site was not installed as stated in the QAPP because one of the DRUM samplers was nonfunctional and DEC decided that the precision from collocated DRUM samplers at Trapper Creek were more important to the study design than a fifth site.

DEC chose the following four sites to collect data for the study: DNPP headquarters (DENA), Lake Minchumina (LAMI), McGrath (MCGR), and Trapper Creek (TRCR). Site descriptions, locations, and photos of each site are contained in Appendix A.

2.2.3 Data Quality Assurance/Quality Control

DEC proposed to tie the DRUM sampler network into the existing IMPROVE network and to use the IMPROVE network data for comparability and quality control. DEC selected the NPS headquarters site at DNPP; this site is close to the eastern boundary of the park and could act as a representative site for eastern air flow entering the Class I area. As a second comparison site, the IMPROVE site at Trapper Creek was selected for collocation of two DRUM samplers. This location can act as one of the two sites necessary to characterize southern air flow into the park. To compare air composition outside the park to air composition found inside the park we proposed to position one DRUM sampler and a meteorological tower in the heart of the park, close to Wonder Lake. This station would have also helped to verify that the surrounding stations were located correctly to characterize air transport into the Class I area. However, logistical and funding considerations caused DEC to omit the Wonder Lake site before the QAPP was finished in 2008. Instead, a site at Lake Minchumina was chosen because of the small population and remoteness of the village and its proximity to the northwest boundary of DNPP.

DEC determined that the following data and quality assurance data would be necessary to meet the project goals:

- ‘Raw’ (but adjusted) DRUM sampler data ($PM_{2.5}$ and elemental concentrations) at all sites,
- IMPROVE data at the Trapper Creek and DNPP headquarters sites,
- Filter-based back-up data to the DRUM samplers data at the Lake Minchumina and McGrath sites
- Meteorological data at all four sites,
- HYSPLIT modeling with a discussion of caveats to the model’s relevance and utility,
- Analysis of sampling uncertainties including flow verifications, error associated with time alignment, analytical error, and field and lab precision to adequately assess comparability of the sampling methods, as well as an estimate of the total error through error propagation calculations.

Each sampling site was supposed to have meteorological (met) data associated with it. The sites at Trapper Creek and DNPP Headquarters already had sophisticated met information as did McGrath with the monitoring site located near the NWS field office. A collocated DRUM sampler at Trapper Creek was supposed to provide precision information. Locating the DRUM samplers next to the two IMPROVE sites was intended to tie the DRUM sampler network into the existing IMPROVE visibility monitoring network for quality assurance purposes. Thermo Electron Inc. Partisol 2000® filter-based samplers were used as back-ups for the DRUM samplers at McGrath and Lake Minchumina.

As laid out in the study’s Quality Assurance Project Plan (QAPP), every DRUM sampler was to be calibrated by UAF prior to each field deployment. Samplers were supposed to be deployed in the field for two six-week sample collection periods, i.e. three months. Upon return of DRUM sampler from the field to UAF, each sampler was to be flow calibrated again. A rotation of the DRUM samplers thus included pre and post deployment calibration or flow verifications at UAF to bracket the samples. The samples and meteorological data were to be validated according to DEC’s ambient air Monitoring Quality Objectives (MQOs) using $PM_{2.5}$ mass validation criteria tables for the Partisol and DRUM that are inAppendix B (Regional Haze Monitoring Study QAPP, SOA DEC AMQA, 2008).

The three drums in the DRUM sampler were replaced with newly mounted drums sent to the operator by Dr. Cahill or delivered by DEC staff once the six week sampling was finished. The drums with exposed Mylar™ strips still attached were placed into labeled plastic containers and shipped back to UAF along with the field data sheet including start and stop times and records of the weekly or every three or six days checks that the local operators had done on the DRUM sampler. At UAF, Dr. Cahill or her students removed the mylar strips and mounted them for beta gauge and XRF analyses and mounted new mylar strips on the drums for the next field exposure. The mounted, exposed mylar strips along with one shipping blank per approximately 18 strips were then shipped via Fed Ex to UC Davis for analysis. The QAPP’s MQOs for the DRUM sampler included flow rate calibrations and verifications within ±10%. In addition to flow calibrations, each DRUM sampler was to be evaluated for correct sample timing (see Appendix B for QA/QC documentation). The sampling period acceptance criterion was ±2 weeks for each six-week sampling period.

2.2.4 Monitoring Instruments

The DRUM sampler collects three size fractions (0.1 to 0.34 μm, 0.34 to 1.15 μm, and 1.15 to 2.5 μm) by pumping ambient air through a series of sequentially smaller slits that act as cut

points. The aerosols are caught on Mylar™ strips coated with a thin layer of Apiezon™ grease. Each DRUM sampler has three drums that rotate synchronously and continuously for approximately six weeks. Each of the drums has a Mylar strip associated with one of the cut points. The Mylar tapes are analyzed for mass by beta gage and for elemental composition by a synchrotron XRF (Delta Group, 2012). The tapes from this study were analyzed at UC Davis. Due to a shortage of functioning DRUM samplers for this study, Dr. Cahill lent DEC two samplers. The DEC samplers operated at approximately 10 L/min while Dr Cahill's samplers operated at 23 L/min. This chage affected the inlet head. There were no toher functional changes between the two types of DRUM samplers.

Denali headquarters and Trapper Creek sites had pre-existing IMPROVE sites run by the NPS. Module A of the four modules at IMPROVE stations collects $PM_{2.5}$ aerosols by filtering ambient air through a Teflon® filter (3 μm pore size) at a rate of 22.9 L/min beginning and ending at midnight (24-hours) every three days. (IMPROVE, March 2001). Mass is obtained gravimetrically then subsequent PIXE and XRF analyses gives the filter's elemental concentrations (IMPROVE SOP 301 and 326, 1997).

Because the Lake Minchumina and McGrath sites did not have IMPROVE stations, DEC chose to back up the DRUM samplers with Thermo Electron, Inc. Partisol 2000 monitors. These are commonly used to do long term ambient air quality monitoring for compliance with the federal National Ambient Air Quality Standards (NAAQS) at state and local monitoring sites across the country. The Partisol collected aerosols on a Teflon filter from ambient air flow (16.7 L/min) drawn through a PM_{10} head and then through Well Impactor Ninety Six (WINS) which cut the particle size down to less than 2.5 micrometers (aerodynamic diameter) (SOA DEC AMQA, 2009b). The samples were weighed in DEC's Juneau lab (SOA DEC AMQAa, 2009) and a subset of the filters were analyzed for elemental composition by Energy Dispersive X-ray Fluorescence (ED XRF) at Desert Research Institute (DRI, 2010). Filter choices for the elemental analyses were chosen on the basis of having high gravimetric concentrations, occurring in the missing periods from the DRUM sampler data set, and periods of potential interest based on the initial DRUM results. Elevated concentrations of one or more of calcium (Ca), chlorine (Cl), potassium (K), nickel (Ni), sulfur (S), silicon (Si), and zinc (Zn) from the un-validated preliminary DRUM data were used to determine the periods of interest for the Partisol filter analyses.

Local site operators at McGrath and Lake Minchumina were to follow EPA's 2008 and 2009 sampling schedules for filter-based Partisol sampling. DRUM samplers were intended to sample continuously throughout the 15 month study period. Table 1 summarizes the sampling periods at each of the four sites.

Table 1. Sampling schedule and start and end dates for each site

Sampling periods			
Site Names	Monitor Type	Start Date	End Date
DENA	DRUM	2/20/2008	6/11/2009
	IMPROVE		
LAMI	DRUM	2/24/2008	6/1/2009
	Partisol		
MCGR	DRUM	2/6/2008	6/1/2009
	Partisol		
TRCR	DRUM	2/20/2008	6/3/2009
	IMPROVE		

3 Results

3.1 Quality Assurance/Quality Control

3.1.1 Data capture

Monthly data capture rate is defined for this study as the number of valid samples divided by the number of possible samples for one month. A sample, as used to calculate data capture rates, is a 24-hour daily average. The IMPROVE and Partisol samples are collected from midnight to midnight and encompass a single 24-hour period. The DRUM samplers sample in three hour increments. DEC used the 24-hour value because it is the coarser of the two time period resolutions. The monthly rates were averaged to calculate an overall capture rate for the 15 month study. Table 2 summarizes the data capture for the three different monitor types used in the study. Trapper Creek and Denali headquarters IMPROVE samplers had the most complete datasets with overall capture rates of 100% and 99% respectively. The DRUM sampler capture rate at Denali headquarters site was 95%, with Lake Minchumina at 63%, McGrath at 33%, and Trapper Creek at16%. Partisols used as back up to the DRUM samplers for the sites lacking IMPROVE samplers had overall study capture rates of 35% for Lake Minchumina and 53% for McGrath.

Since the two collocated Trapper Creek DRUM samplers only had two complete verifiable runs that did not overlap in time, no precision calculations were possible for the DRUM samplers. The Trapper Creek DRUM data were treated as a single sampler for calculating capture rate and were deemed too incomplete to include in the results and interpretation for this the study.

Table 9. Monthly and overall 15-month study average capture rates

Data Capture Rates																			
Site[1]	Sampler	Month-Year																	Overall Study
		F-08	M-08	A-08	M-08	J-08	J-08	A-08	S-08	O-08	N-08	D-08	J-09	F-09	M-09	A-09	M-09	J-09	
DENA	DRUM	100%	100%	100%	100%	77%[2]	100%[2]	100%[2]	97%[2]	94%	47%[2]	100%[2]	100%	100%	100%	100%	100%	100%	95%
	IMPROVE	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	90%	100%	100%	100%	100%	99%
LAMI	DRUM	33%	50%	50%	50%	40%	30%	64%	20%	50%	20%	0%	0%	67%	60%	60%	0%	0%	35%
	Partisol	23%	100%	100%	100%	100%	71%	81%	100%	100%	37%	100%	10%	100%	48%	0%	0%	0%	63%
MCGR	DRUM	54%	0%	0%	13%	100%	6%	100%	43%	100%	23%	0%	0%	82%	39%	0%	0%	0%	53%
	Partisol	0%	30%	100%	30%	70%	70%	91%	50%	50%	90%	36%	36%	56%	70%	70%	55%	0%	33%
TRCR	DRUM[3]	0%	0%	0%	0%	0%	0%	32%	63%	0%	0%	0%	0%	0%	0%	0%	84%	100%	16%
	IMPROVE	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%

[1]Site abbreviations: DENA -Denali Headquarters; LAMI - Lake Minchumina; MCGR - McGrath; TRCR - Trapper Creek

[2]Denali particulate data capture only. (Dr. Cahill requested reruns of synchrotron analyses for the DENA June to August and November to

[3]Trapper Creek collocated samples were treated as a single monitor in this table.

Color codes for capture rates:	90-100%	70-89%	50-69%	0-49%

DEC found that the elemental analyses for two 6-week DRUM sample periods were missing from the data set. Dr. Cahill requested the strips be reanalyzed at the UC Davis synchrotron XRF in spring 2012. The DRUM elemental data from these two time periods (Denali headquarters June-August 2008 and November-December 2008) are not available as of finalization of this report but may be analyzed and interpreted at a later date.

The issues leading to low capture rate for the DRUM samplers and Partisols included problems with the instruments themselves, the remoteness of the sites, extreme weather, and local operator

error. Flights to Lake Minchumina were limited to once per week on the mail plane. These flights were contingent on both having enough mail packages to justify the flight and having acceptable weather conditions in the Alaska Range. In winters 2008 and 2009, the contractors often canceled the flight if there was not enough mail to make the run worthwhile in comparison to more lucrative freight and/or people traveling to a larger village or multiple villages on a single flight. DEC often had to charter a plane from Fairbanks to Lake Minchumina because local operator availability and DEC staff schedules had to be coordinated each time a problem with samplers occurred. Even delivery of the replacement drums for the DRUM sampler and Partisol filters were delayed because of the intermittent mail delivery. Responding to issues in a timely way was almost impossible given the remoteness of the four sites, even though Trapper Creek and Denali site were located on the road system. The DRUM samplers were far more "finicky" than DEC was led to believe and required close surveillance and constant maintenance with problems such as the stepping motor not turning the drums reliably. DEC also had issues with the pumps in the extreme winter cold. Additionally, resupplying the DRUM strips through UAF to the site operators in a timely fashion, often using the mail system, contributed to missed sampling days. The operators at McGrath and Trapper Creek did not always inform DEC in a timely manner of issues with the DRUM samplers or Partisol, leading to more missed samples.

3.1.2 Timing Record

Timing of samples has a large impact on the comparability of the data sets from different types of monitors. Ideally, all equipment would have run synchronously to maintain maximum data overlap of the various collection frequencies. The DRUM sampler records are of critical importance because the instruments themselves are not capable of tracking date and time. The DRUM sampler timing is dependent on both detailed and accurate operator records and assumption of regularity and reliability of the synchronous motors in turning the three drums at a continuous and steady rate throughout the six weeks of a run. Local operators and DEC staff were not consistent on recording timing data for the DRUMS as discussed in the next paragraph. The sampling frequency of the IMPROVE and Partisol samplers was a much coarser scale than the continuous DRUM samplers. IMPROVE and Partisols sampled over a full day which averaged out any elemental or $PM_{2.5}$ fluctuations that were captured by the three hour resolution of the DRUM sampler data.

Issues with recording of the timing for the DRUM samplers were much more common than DEC anticipated. Timing problems with the DRUM sampler runs included instrument or pump malfunctions that resulted in unanticipated stop times, poor and inconsistent records of start and end dates by operators, and extremely low particulate matter loadings of the DRUM strips that made it nearly impossible to detect the start and end of the strips. Dr. Cahill informed us that clean air at DNPP meant that almost no visible sample was observable on the strips at times. Not having a visible sample made determining the sample start on the strip and where to begin the x-ray analysis difficult. The UC Davis Delta Group uses the deposit to determine approximately where to start the analysis so that they do not spend a lot of time on blank Mylar. The light particulate matter loading also made it difficult to determine exactly where the sample ended (almost blank-level X-ray counts) so the Delta Group made their best estimate of where to stop the analysis. The light particulate matter loading was a problem especially for the Lake Minchumina strips and all of the strips collected during summer 2008. Some of the strips appeared not as long as they should have been probably due to light particulate matter loading at the beginning or end of the sampling period. Dr. Cahill and the UC Davis Delta Lab staff

matched peaks and aligned the strips as best as they could. Because the three sample strips corresponding to the sampling run were mounted separately and have different levels of loading, they may have been analyzed for different lengths based on the determinations of start and stop times as described above. Appendix B-4 contains UAF's QA summary for the DRUM samplers. Thus, even though the DRUM sampler was set up to have a three-hour resolution, comparing the data to Partisol or IMPROVE data is problematic.

For this assessment of the DRUM dataset 24-hour averages were computed starting with the first complete three-hour period after midnight and including the subsequent seven three-hour periods. The Trapper Creek collocated site had such poor results that DEC could not use the data from the two samplers as one, much less as a collocated (precision) site for the study. DEC removed the site from the study since the results were so questionable.

3.1.3 Data quality

Long term monitoring networks are set up with stringent QA/QC requirements. These requirements are well documented in DEC and IMPROVE Quality Assurance Project and Plans (SOA DEC AMQA, 1998; SOA DEC AMQA, 2008; SOA DEC AMQA, 2010; IMPROVE 2001). Quality control checks for the IMPROVE samplers include 1) flow rate history for each transducer using monthly checks, 2) quarterly comparison of the flow rates of the different modules, and 3) flow rate calibrations every six months or more often if potential problems are indicated by the monthly or quarterly check (IMPROVE, 2001). Desert Research Institute (DRI) was contracte to analyze a subset of the Partisol filters using ED-XRF (see SOP in Appendix B-2). For the back-up samplers, DEC adopted a revised QA/QC regime to save on costs and time. Rather than the usual monthly leak checks and flow and time verifications, flow checks for the McGrath and Lake Minchumina Partisols were scheduled to coincide with the every six-week or every twelve-week site visits by DEC staff. However, DEC staff shortages during 2008 and 2009 greatly reduced the frequency of the site visits.

DRUM samplers were supposed to be calibrated initially and upon return from 12 week field deployments. Persistent malfunctions of the DRUM samplers before and at the beginning of 2008 left DEC with no working spares to rotate between the sites and UAF. Dr. Cahill conducted flow verification checks on the DRUM samplers at UAF after the study was concluded in summer 2009 however, DEC have not received the final flow verifications. As a best field substitution to regular QC checks, the operators were instructed to record the value of the DRUM pressure gauge weekly or as often as every three days. DEC decided to accept any DRUM data that had reasonable start and stop times and that did not have wildly varying pressure gauge readings on the field log sheets. This allowed more of the McGrath and Lake Minchumina DRUM data to be counted as valid but still invalidated most of the Trapper Creek DRUM data.

The recorded pressure gauge readings showed large changes (e.g.,-19 to -4 in Hg) of the flow over the six week period of a DRUM run. See Appendix B-1 for an example of a field log sheet that records the changes observed during a six week run. This unquantifiable flow instability leads DEC to question the use of DRUM sampler data for any quantitative analyses and regulatory compliance purposes.

Finally, DEC has not received confirmation from UAF that the blanks shipped with the exposed Mylar tapes to UC Davis were clean. When DEC receives blank and flow verifications from UAF, DRUM data may be able to better quantify errors associated with sampling which may allow DRUM data to be validated or invalidated according the MQOs listed in Appendix B-3.

3.2 $PM_{2.5}$ Mass Concentrations

DEC calculated a 24-hour average concentration for the DRUM sampler by summing the averages of the eight three-hour concentrations for each day for each fraction and then adding the three fractions together. DEC compared this calculated 24-hour average from the DRUM sampler to the 24-hour average sampled by the IMPROVE monitor. Summary statistics for the particulate concentrations from the Partisol and IMPROVE samplers at the three sites are contained in Table 3.

Overall, the average particulate loading was highest at McGrath with a $PM_{2.5}$ mean value of 6.1 $\mu g/m^3$ and a median value of 5.5 $\mu g/m^3$. DEC expected that the Denali headquarters average readings would be highest because of the summer tourist population and associated high traffic volume. The McGrath result could be due to a combinationof local particulates such as fugitive road dust and emission from the local power plant and home heating in the town. It could also be due to a combination of local and long range transport sources. However, Denali headquarters recorded the maximum daily value (16.9 $\mu g/m^{3)}$ for all three sites for $PM_{2.5}$ on April 7, 2008 and McGrath had slightly lower daily maximum value of 13.3$\mu g/m^3$ on February 13, 2008. The Lake Minchumina site is the most pristine site. It has a small population of about a dozen, two dirt roads, and very slow, intermittent vehicle traffic. Predictably, Lake Minchumina had the lightest particle loading of the three sites with an average of 3.8 $\mu g/m^3$ and median of 4.0 $\mu g/m^3$, less than 10% of the NAAQS standard of 35 $\mu g/m^3$. Lake Minchumina had a daily maximum of 6.4 $\mu g/m^3$ on February 25, 2008 which is just 18% of the EPA standard for $PM_{2.5}$. Lake Minchumina and Denali headquarters had mass distributions among the three particulate fractions that were fairly even but McGrath had significantly more of the largest fraction (2.5-1.15 μm) on average 3.3 $\mu g/m^3$ as opposed to 1.8 $\mu g/m^3$ and 1.0 $\mu g/m^3$ for the smaller two fractions respectively.

Table 3. DRUM, IMPROVE and Partsiol particulate matter summary statistics

Site DRUM Fractions[1] and DRUM, IMPROVE and Partisol $PM_{2.5}$ Summary Statistics					
Denali Headquarters (DENA)					
Monitor:	DRUM				IMPROVE
	Large	Medium	Small	$PM_{2.5}$	$PM_{2.5}$
N	453	450	449	453	170
Avg	1.6	1.9	1.4	4.9	1.7
Stdev	1	1.1	1	2.8	1.4
Median	1.4	1.6	1.1	4.1	1.2
Max	6.3	6.9	4.8	16.9	9.3
Min	0	0	0	0.7	-0.1
Avg+2*stdev	3.6	4.1	3.4	10.5	4.6
Lake Minchumina (LAMI)					
Monitor:	DRUM				Partisol
	Large	Medium	Small	$PM_{2.5}$	$PM_{2.5}$
N	325	325	325	325	63
Avg	1.4	1.3	1.3	3.8	3.5
Stdev	0.5	0.6	0.5	1.1	2.6
Median	1.3	1.3	1.4	4	3.1
Max	3.5	3.3	2.3	6.4	18.2
Min	0.6	0.1	0	1.1	-0.2
Avg+2*stdev	2.4	2.6	2.4	6	8.8
McGrath (MCGR)					
Monitor:	DRUM				Partisol
	Large	Medium	Small	$PM_{2.5}$	$PM_{2.5}$
N	166	166	166	166	92
Avg	3.3	1.8	1	6.1	3.5
Stdev	2.1	0.6	0.6	1.8	2.2
Median	2.3	1.6	1.2	5.5	3.2
Max	8.2	6.3	3.2	13.3	16.6
Min	0	1	0	1.8	0.6
Avg+2*stdev	7.5	3.1	2.3	9.7	7.8

[1]Mass fractionation: Large = 1.15 -2.5 μm, Medium =0.6-1.15 μm and small = 0.1 - 0.6 μm

3.2.1 Problems with Determining DRUM Mass Concentration

The Mylar strips are mounted separately on three different drum impactors and thus the sampling strips can have different levels of loading. To synchronize the three drum strips, elevated mass was used to determine the start and stop time for each individual strip at the lab, so it is possible that light loading at either end of a strip could be missed and lead to misalignment of the drums or missing days.

The three strips from each six-week run sometimes had disparities in end times due to the two completely different analysis techniques used: beta gauge for mass concentration and synchrontron XRF for elemental concentrations. During synchrotron XRF analysis, X-rays excite electrons in the lower shells of an element which emit a characteristic wavelength (fluoresce) as outer shell electrons fall back into the vacancies. Beta gauge analyses are based on the principle that a radioactive source produces beta particles at a consistent rate. The stream of beta particles, or radiation, is then measured by a detector. The radiation is attenuated proportional to the density of aerosols on the sample strip.

Usually the beta gauge was run across the whole strip so the periods with elevated mass were used to determine the start and stop times for the sample. The X-ray data were then aligned with the beta gauge data to match up the elemental composition data with the mass data (Dr. Cahill email communication, 2012, March 14). However, due to differences in analysis length, the sample end point sometimes varied across the different stages. This resulted in the sample time ending earlier for some strips because it looked clean to the analysis technician. For example, the technician might have stopped the run before the actual end of the sampling period. The starts were determined from the beta gauge data and alignment, so they should be more regular. Thus, if the strip is missing a point at the beginning of a sample period, it means that the X-ray analysis missed the first points due to the sample being hard to detect. These issues explain the differences in the length of time that were recorded in the final Denali headquarters DRUM particulate matter fraction and elemental contentration data.

It is difficult to determine the statistical distribution of the sample population for particulate and chemistry concentrations at the three sites because the detection limit cuts off a differing percentage of the concentrations depending on the parameter in question. For example, the Denali headquarters IMPROVE elemental concentrations above the detection limit ranged from 0 to 100%: the percentages for molybdenum (Mo), nickel (Ni), and calcium (Ca) were 0%, 30% and 100% respectively. Because of the ambiguity of the population distributions, both means and medians were calculated for this project.

3.2.2 Comparison Among Sampling Technology

There are significant and seemingly systematic differences between the DRUM and IMPROVE or DRUM and Partisol data. Even when the light loading is taken into account, there seems to be a consistent bias. The DRUM $PM_{2.5}$ concentrations are systematically higher than the Partisol or IMPROVE concentrations. For example, the McGrath DRUM daily $PM_{2.5}$ concentrations were approximately double the Partisol filter $PM_{2.5}$ concentrations collected on the same day (Figure 3). Another more detailed example of the bias is evident in March and April 2008, the DRUM sampler seems to be offset from the IMPROVE particulate by about 6 ug/m^3 at Denali headquarters (Figure 3). The offset is not nearly as clear with the Lake Minchumina data perhaps because the concentrations are lower and much nearer the Partisol detection limit than the Denali headquarters site. With the exception of the two highest concentrations, the Partisol concentrations are generally lower than the DRUM by about 1 to 3 µg/m^3.

DEC anticipated much higher correlation between the DRUM samplers and Partisol masses than were actually obtained. The Delta

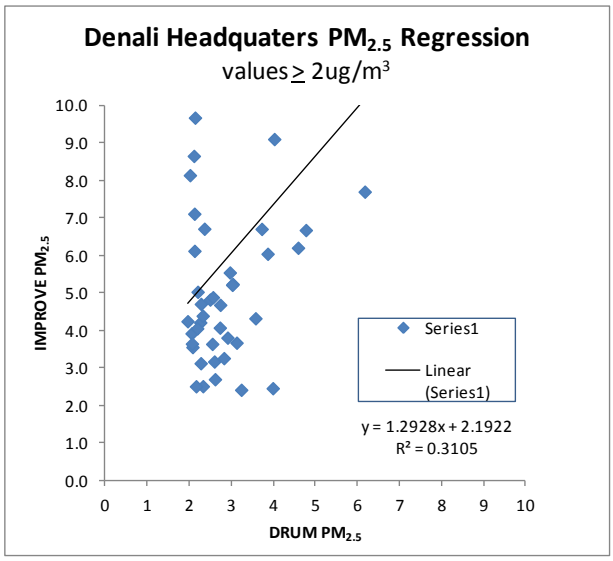


Figure 4. Denali Headquarters total $PM_{2.5}$ mass regression

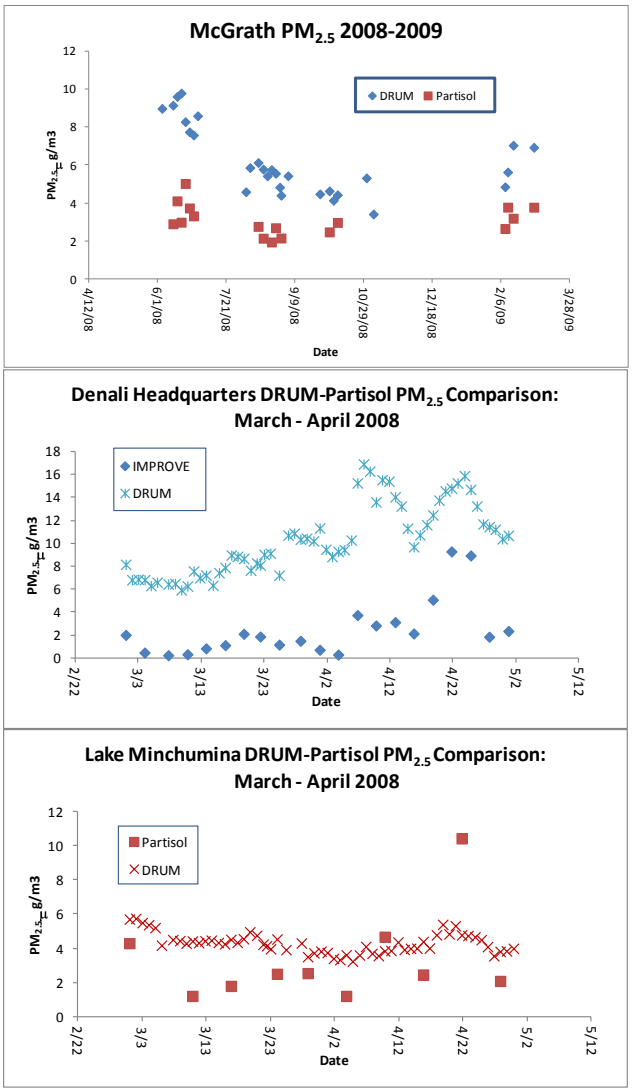


Figure 12. $PM_{2.5}$ mass DRUM comparison; McGrath (2008-2009), Denali headquarters (March and April 2008), and Lake Minchumina (March and April 2008)

Lab made a comparison between California Air Resources Board (CARB) Partisols $PM_{2.5}$ 24-hour filters and DELTA Group 8 DRUM in 2007 that resulted in a correlation $r^2 = 0.85$ and a slope within 5% of unity (Delta Group, 2012, Jan. 20). At the Denali headquarters site, 47 paired IMPROVE concentrations predicted DRUM sampler measurements with a correlation coefficient of 0.31 (Figure 4). The McGrath Partisol over-predicted DRUM $PM_{2.5}$ concentrations however, the regression had a very low correlation coefficient of 0.11 (Table 4). The Trapper Creek and Lake Minchumina

sites showed minimal to no correlation between the IMPROVE Partisol and DRUM strip $PM_{2.5}$ mass concentrations. Table 4 summarizes site regression equations and correlation coefficients. For $PM_{2.5}$ mass concentration measurements, the Partisol samplers at Lake Minchumina and McGrath were assumed to be equivalent to the IMPROVE samplers at Denali headquarters and Trapper Creek sites because of DEC's previous 2000 through 2003 study at DNPP headquarters. In that study, 68 paired IMPROVE and Partisol data points resulted in a linear regression with correlation r^2=0.98, slope m=0.96, and intercept b=-0.297 (SOA DEC AMQA, 2012).

Table 10. Paired regression statistics for the sites

Paired $PM_{2.5}$ Regressions			
Site	**n**	**Equation**	**r^2**
TRCR[1]	5	0.24x + 2.08	0.16
TRCR(2)[2]	5	0.21x + 2.17	0.13
DENA	47	1.29x + 2.19	0.31
LAMI	28	0.08x + 3.94	0.05
MCGR	19	0.70x + 4.37	0.11

[1]TRCR – primary DRUM sampler;
[2]TRCR(2) – collocated DRUM sampler

DEC has concluded from this initial analysis that the beta gauge mass data from the DRUM samplers are useful in only a qualitative sense. Because of the flow and timing issues with the DRUM samplers discussed above and the poor correlation between Partisols and the DRUM samplers, DEC decided not to use the data for any quantitative analysis. It is possible that mistake(s) were made in the multiplicative factors used to correct the beta gauge data and that could account for the differences between the Partisol and DRUM or IMPROVE and DRUM data. Dr. Cahill is investigating whether a correction factor is causing a systematic calculation error in the DRUM data and, if so, if it needs to be changed.

3.2.3 Selected Data Subset for Analysis and Interpretation

DRUM, IMPROVE and XRF elemental concentrations sampled over the 15 month period of this monitoring project produced a wealth of data even with all the missed sampling periods. For example, a six week DRUM sample comprising three size-fractionated strips that are analyzed for 28 parameters at a frequency of three hours results in 27,216 concentrations. A single day of IMPROVE data consists of 28 parameters and a single Partsiol filter produces 54 concentrations when XRF analysis on the filter is included. Even with the limited capture rates from three of the sites, there are much more data than DEC could do justice to in the short time that the almost complete data sets were available for analysis in this project. To reduce the data set to a more manageable size, DEC limited the analysis to elements of significance for long range transport.

Table 5 contains summary statistics of daily elemental concentrations. The elements listed are most commonly associated with storms, soils, and anthropogenic events from Asia (personal comm., Dr. Cahill; 2012, April 10). DEC calculated daily concentrations of each element exactly the same way as for the beta gage particulate data. Median and average concentrations were included for each element along with the number of samples and maximum value because the daily elemental sample distribution is unknown. A significant number of sample concentrations fall below or very near the analyses detection limits. The distributions are not complete due to an unknown number and distribution of the lower portion of the concentrations below the detection levels of the analytical instrumentation. DEC calculated criteria for validity equal to the ratio of the average of all the concentrations to the lab reported uncertainty. Ratios greater than unity were deemed useable.

Table 5. Summary statistics for selected element concentrations

Summary Statistics

Storm Elements	Cl				Br				Na			
	N	mean	med.	max	N	mean	med.	max	N	mean	med.	max
DENA DRUM	330	30	1	733	330	2	2	23	251	3	3	25
DENA IMPROVE	170	52	14	940	170	1	1	12	98	86	53	580
LAMI DRUM	332	29	3	1795	332	1	1	7	289	5	2	41
LAMI FRM	36	17	1	198	36	3	2	8	36	175	110	579
MCGR DRUM	163	60	3	689	163	2	1	54	135	2	2	7
MCGR FRM	44	24	3	331	59	3	2	20	63	222	229	581

SOIL Elements	Al				Ca				Fe				K				Mg				Si			
	N	mean	med.	max	N	mean	med.	max	N	mean	med.	max	N	mean	med.	max	N	mean	med.	max	N	mean	med.	max
DENA DRUM	330	36	30	216	330	13	8	125	330	17	10	133	330	10	6	51	330	76	42	768	330	45	27	355
DENA IMPROVE	113	22	14	154	172	14	9	117	172	14	9	124	172	13	9	113	64	16	11	185	167	52	35	409
LAMI DRUM	332	14	7	109	332	5	3	50	332	4	2	29	332	5	3	49	223	51	17	1289	332	15	7	109
LAMI FRM	36	4	0	23	36	9	8	22	36	10	9	48	36	15	12	112	36	2	0	28	26	20	15	108
MCGR DRUM	163	26	14	178	163	21	9	164	163	10	5	70	163	10	6	80	163	62	29	599	163	33	18	220
MCGR FRM	36	12	9	41	62	23	17	143	63	14	12	53	62	17	12	156	25	8	0	51	63	28	24	144

Anthropogenic Elements	Cu				Ni				S				Se				V				Zn			
	N	mean	med.	max	N	mean	med.	max	N	mean	med.	max	N	mean	med.	max	N	mean	med.	max	N	mean	med.	max
DENA DRUM	330	0.5	0.3	3.3	330	0.3	0.2	1.8	330	191	101	1651	330	0.35	0.24	1.08	330	0.6	0.2	14.4	330	2.0	1.4	17.0
DENA IMPROVE	116	0.2	0.2	0.8	30	0.1	0	0.3	172	193	132	897	79	0.07	0.07	0.17	112	0.1	0.1	0.3	171	1.9	1.2	14
LAMI DRUM	332	0.4	0.2	13.6	332	0.4	0.2	31.1	332	100	44	827	332	0.24	0.16	1.37	332	0.24	0.07	17.6	332	1.0	0.8	19.3
LAMI FRM	36	0.5	0	3.7	36	0.2	0.1	1.9	36	262	196	958	4	0.96	0.62	2.5	36	0	0	0.6	36	1.4	0.8	9.3
MCGR DRUM	163	0.3	0.2	2.5	163	0.2	0.1	1.5	163	144	73	1881	163	0.28	0.18	0.82	163	1.9	0.8	19	163	1.9	0.8	19.0
MCGR FRM	44	0.8	0.6	5.6	35	0.3	0.2	0.9	63	244	155	1166	4	1.06	0.75	2.45	9	0.3	0.2	5.0	57	3	1.4	15.7

Grayed out numbers are elements that were deemed too low for use (the ratio of average value divided by the analytical uncertainty was less then one)

3.3 HYSPLIT Summary Analysis

Dr. Cahill at UAF computed HYbrid Single-Particle Lagrangian Integrated Trajectory (HYSPLIT) models for every day that the DRUM samplers ran at the four monitoring sites for the entire study period. The settings for the HYSPLIT model runs are in Table 6.**Error! eference source not found.** They used meteorological data from the GDAS1 database because it is the only one that extends westward from Alaska into Asia and Europe. Dr. Cahill modeled the trajectories back for 310 hours or about 12 days in order to create statistics regarding possible Asian sources of haze and dust. UAF's results are discussed in the next section. The 24-hour and 310-hour HYSPLIT model runs for the four sites for every day that the DRUM sampler ran can be requested from DEC. However, a subset of April 2008 low level trajectories is included in Appendix C.

Table 6. HYSPLIT model settings

HYSPLIT Model Settings			
Source locations	DENA	63.72 N	148.97 W
	LAMI	63.88 N	152.31 W
	MCGR	62.96 N	155.60 W
	TRCR	62.31 N	150.32 W
Medium Level Elevations	4500 m AGL		
	5500 m AGL		
	6500 m AGL		
Low Level Elevations	1500 m AGL		
	2500 m AGL		
	3500 m AGL		
Durations	310 hours for medium & low levels; beginning at 21 00 UTC for each day		
	24 hours for low level; beginning at 21 00 UTC for each day		
Trajectory direction	Backward		
Meteorological data	GDAS1		
Vertical motion calculation method	Model Vertical Velocity		

UAF used the HYSPLIT model runs to determine if an air parcel crossed a specified source region on its way to one of the study sites. After all of the HYSPLIT runs were individually analyzed to observe the path of the air parcel at each height, a chart was made to record where the air parcel traveled during transport. The chart specifically identified when the air parcel traveled over possible source locations, such as the Taklimakan and Gobi deserts in China and Mongolia (Figure 5) and Norilsk, Russia (Figure 6). The Gobi and Taklamakan deserts were chosen because the are the two largest expanses of sand or dust in eastern Asia. Norilsk is the second largest city north of the artic circle and is known for its mining- metallurgic industrial complex and the severe pollution caused by the industry. Nickel copper, cobalt, platinum and palladium are mined in the Siberian Traps igneous province (Norilsk-Talnakh deposts). Coal is also mined in Norilsk. To determine if the parcel passed over a certain area a circle or oval representing the approximate size of the location was drawn around the area. The Gobi Desert is approximately 1,500 km (932 mi) long from southeast to northwest and has a north to south width of 800 km (497 mi) (Wikipedia 1, 2010) so an area of approximately 2,092 km (1300 mi) long west to east and 966 km (600 mi) wide north to south was used to represent the Gobi desert. The Taklamakan Desert is approximately 1,000 kilometers (620 mi) long and 400 kilometers (250 mi) wide (Wikipedia 2, 2010), so an area of approximately 660 miles long and 300 miles wide was used to represent the Taklamakan desert. Norilsk is approximately 45 kilometers (20 mi) in diameter, so an area with a radius of approximately 100 mi was used to represent Norilsk for creating the statistical chart of whether or not a parcel was modeled as passing over one of the chosen source areas. Figure 7 shows an example HYSPLIT run with the three source regions indicated on the map.

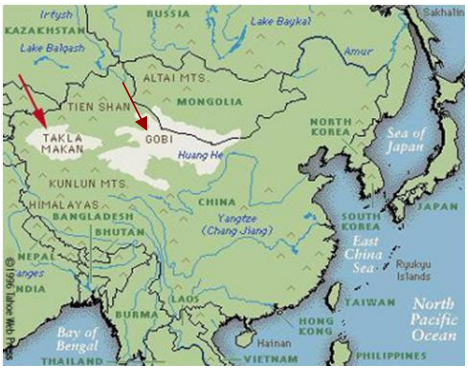


Figure 5. Map showing Gobi and Taklamakan Deserts (Dailyrepublican.com/china.jpg)

Figure 6. Map showing location of Norilsk, Russia circled in red (mapofrussia.org)

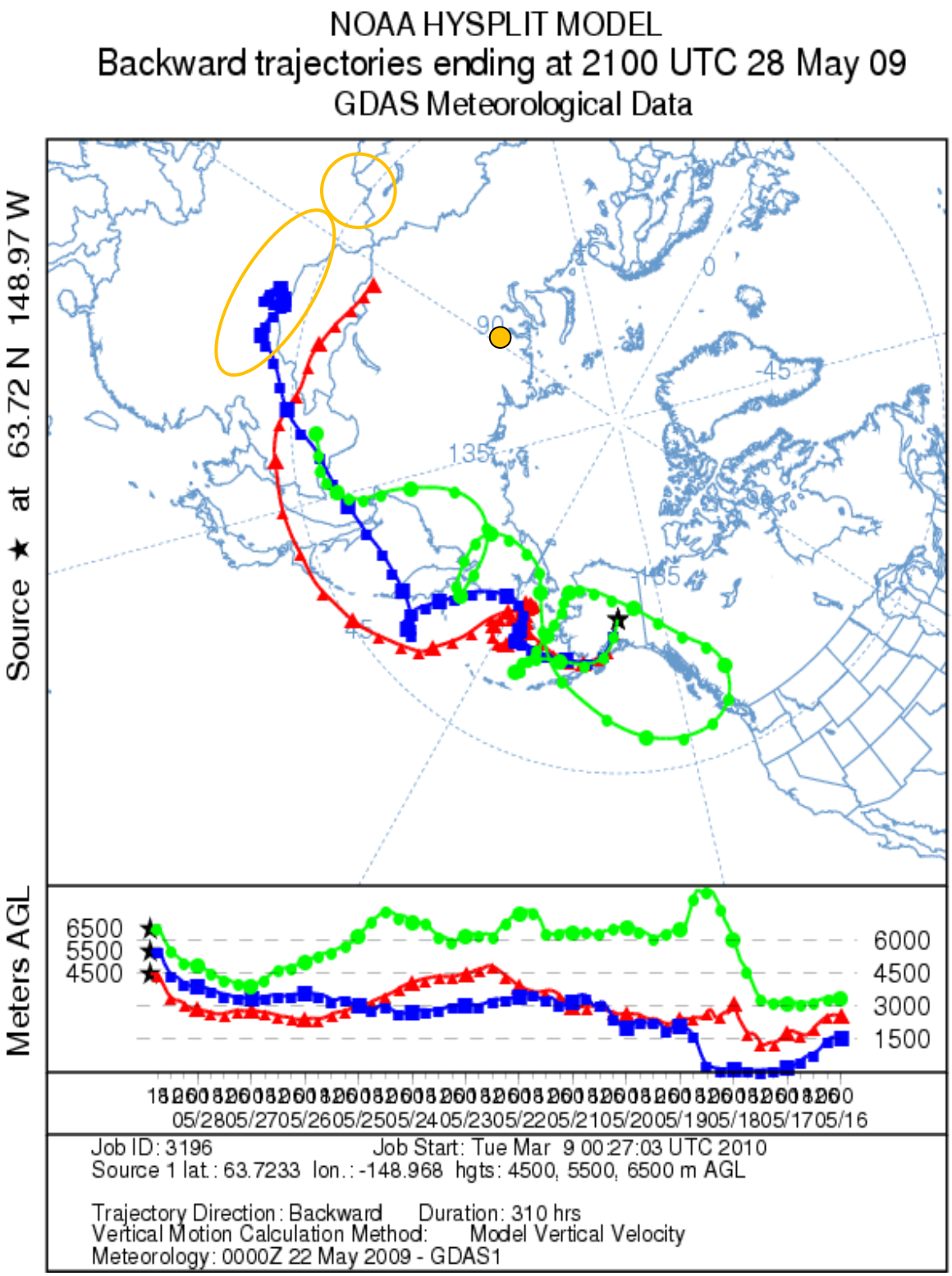


Figure 7. Example HYSPLIT back trajectory with the yellow dot for Norilsk and yellow ovals for the Gobi and Taklamakan Deserts (not to scale)

Table 7. Example of partial HYSPLIT chart for Denali Headquarters site, May 1-10, 2009

Date	Crossed Gobi	Crossed Taklamakan	Crossed Norilsk
5/1/2009	2	2	2
5/2/2009	2	2	2
5/3/2009	2	2	2
5/4/2009	1	1	2
5/5/2009	1	2	2
5/6/2009	2	2	1
5/7/2009	2	2	2
5/8/2009	2	2	2
5/9/2009	2	2	2
5/10/2009	1	1	2

An example of a partial HYSPLIT chart for the Denali headquarters site is shown in Table 7. If the air parcel crossed within the area representing a specific location for that trajectory it received a 1; if it did not it received a 2. UAF made charts for each site for the entire study period but the data have not yet released to DEC. Pie charts for the four sites were created from the HYSPLIT charts (Figure 8). The percentage of time that an air parcel crossed either the Gobi Desert, Taklamakan Desert, or Norilsk, Russia on its way to a selected site (Denali headquarters, Lake Minchumina, McGrath, Trapper Creek) is much less than the percentage of time when the trajectories did not cross the source regions on the way to the site.

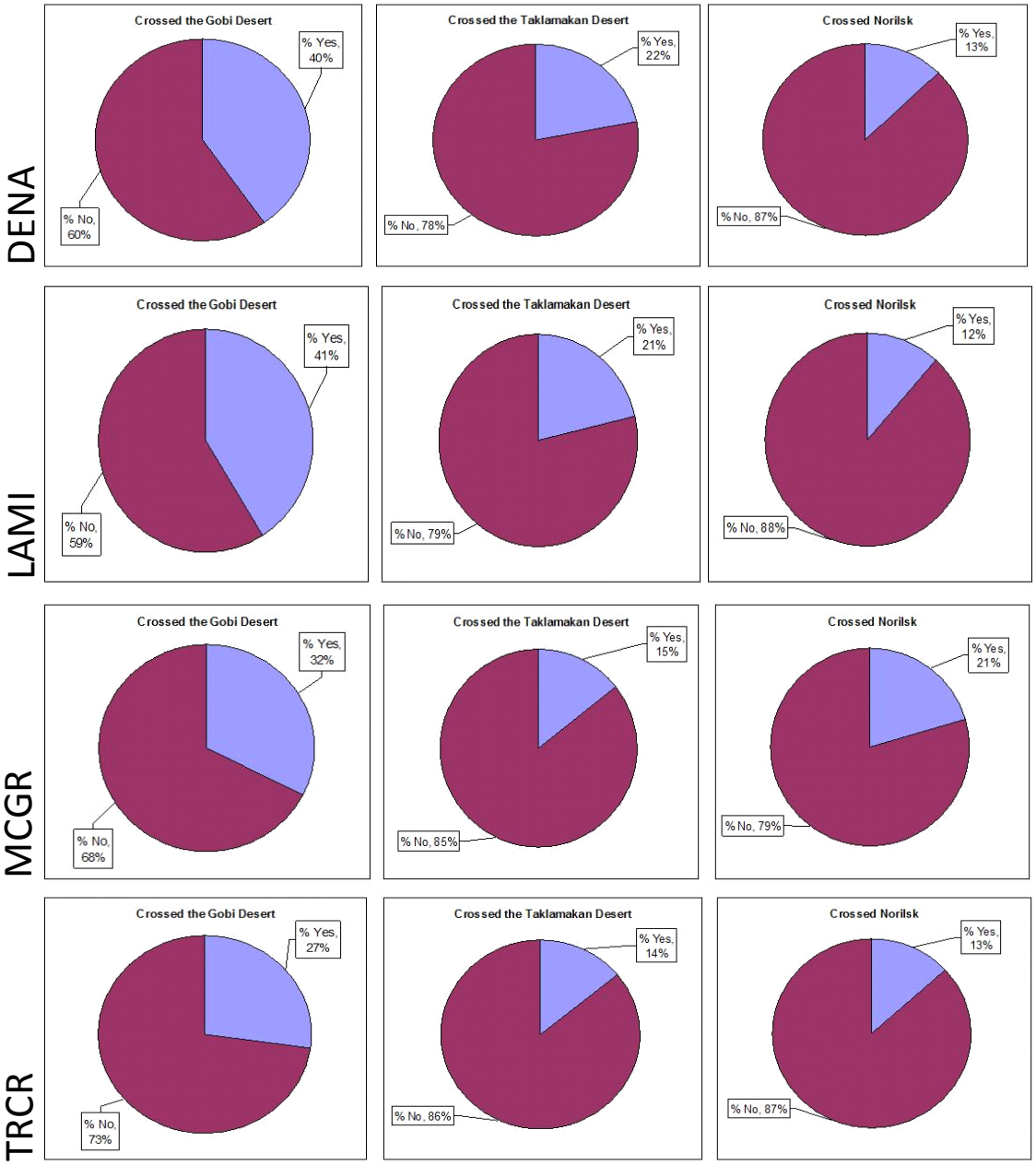


Figure 8. Percentage of time that trajectories crossed certain source regions during transport to the sites

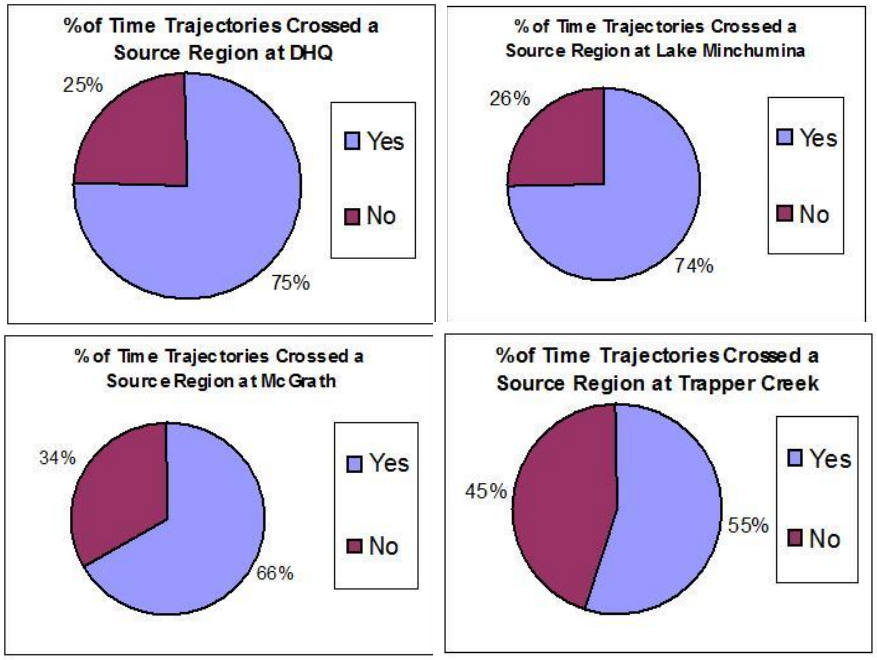


Figure 9. Percentage of time that trajectories crossed at least one of the source regions before reaching each site vs the time they did not cross a source region

Also calculated was the percentage of time trajectories did not cross a source region (Gobi Desert, Taklimakan Desert, and Norilsk, Russia) versus the percent of time it crossed at least one of the source regions at each site (Figure 9). This calculation counts the Gobi Desert and the Taklamakan as one source region because about half of the time (46% at McGrath, 63% at Lake Minchumina, 63% at Denali headquarters, and 41% at Trapper Creek) the trajectory crossed the Gobi it also crossed the Taklamakan. Interestingly, the trajectories crossing Norilsk were significantly more common for McGrath (20%) than Denali headquarters and Lake Minchumina (13% and 12% respectively). Lake Minchumina and Denali headquarters have similar percentages for trajectories crossing Norilsk and the Gobi and Taklimakan Deserts. The next step in this analysis would be to regress the charts for all the 15 months of HYSPLIT data to determine if and how the individual days correlate between Lake Minchumina and Denali headquarters. At Lake Minchumina and Denali headquarters, 25% of the daily back trajectories crossed any of the three designated sources in Asia whereas over a third of the daily back trajectories crossed designated Asian sources. This kind of analysis provides a qualitative look at the probability that aerosols from the respective source regions in Asia could be sources of haze/dus observed at DNPP. DEC views this analysis is another piece of corroborating evidence that long-range transport is possible. Seasonally recurring meteorological conditions indicate that these dust events or pollution from Norilsk and other industrial centers in Asia are likely to be transported to Alaska annually.

3.4 Analysis of Periods of Interest: April 2008

DEC received the partially complete DRUM data from UAF at the end of January 2012. Due to time constraints and the complexity of the data, DEC selected a single month in April 2008 to illustrate events that are typical of spring air quality at DNPP. In cooperation with Dr. Cahill,

DEC selected the period based on a cursory look at the data capture rates, known seasonal events in Alaska (i.e., arctic haze, Wilcox and Cahill, 2003; Wetzel et al, 2003), and an observed dust storm from the Gobi and/or Taklamakan Deserts. Arctic haze usually maximizes in early spring (March and April in the northern hemisphere) because the rapidly increasing amount of sunlight coupled with increasing temperatures and humidity in the air allows the photochemical reactions that were not possible during the darkness and cold of the arctic winter to occur all at once (Rahn et al, 1977). In March and April 2008, local site operators at Lake Minchumina and Denali headquarters, Dr. Cahill in Fairbanks, and the DEC staff in Anchorage noticed a significantly dusty/hazy period which DEC associated with prevailing easterly winds from Asia toward Alaska (see Appendixces D-1 and D-2). These observations were corroborated by media reports of the yellow snow in Northeast Asia and Asian dust transported to Alaska (Joling, 2008, April 18; Martinson, 2008, April 24). Wildfires and, possibly, agricultural burns in eastern Siberia were also contributing smoke to the atmosphere (Lindsey, 2008 April 15; April 22). Siberia had extensive forest fires in spring of 2008 with almost 89,000 acres burned as of April 23, 2008 (see Appendixces D-3 and D-4). Ideal conditions for the fires were caused by a record heat wave in summer in 2007 followed by an abnormally dry winter with little snow. The fires are believed to have been started intentionally by illegal loggers or by runaway agricultural burns (Terra Daily 2008, April 23; Daily New Bulletin 2008, April 24).

3.4.1 Sources of aerosols

Possible long range transport events could include spring or summer wildfires in eastern Russia, dust storms in the Gobi and Taklimakan Deserts, and north Pacific storms. All of these events could also transport anthropogenic haze elements (mostly from industry and power plants) from Russia, China, Korea and/or Japan, as the air parcels and their associated pollutant load move across the northern Pacific toward Alaska. Alaskan sources of anthropogenic particulates include local power plants (Healy coal, diesel power plants in McGrath and Lake Minchumina), fugitive dust from the DNPP road, and smoke from prescribed burns. Natural, local sources of particulates include sea salt from the ocean, volcanic eruptions (ie., Mount Redoubt, spring 2009), glacial dust in spring and fall, and wildfire smoke from Alaska and/or northwestern Canada.

Asian dust would be characterized by elevated soil element concentrations and could include anthropogenic tracer elements from Asian industrial pollution as well. DEC opted to use the soil elements as defined by the IMPROVE network. IMPROVE uses the Equation 1, the "SOIL" equation, to calculate a dust or mineral component by creating the oxides of aluminum (Al), silicon (Si), calcium (Ca), iron (Fe) and titanium (Ti) (Eldred, 2003).

Equation 1 $$SOIL = 2.20 * Al + 2.49 * Si + 1.63 * Ca + 2.42 * Fe + 1.94 * Ti$$

This equation uses Fe as a surrogate for K because K is a signature of both terrestrial mineral dust and wildfire or agricultural burns. However, Eldred (2003) discusses the problems with using Fe as a proxy for the soil component of K and suggests that Si is actually a better proxy for the mineral component (SOIL) as opposed to the fire component in monitored aerosols. Eldred concludes that the original equation is good enough and cites only a 3% increase in mean soil concentration if K were used at high soil concentrations. At low soil concentrations, like those DEC observed in this study, the non-soil smoke component can increase the soil artificially by a large percentage (20% for 15 % of the samples and over 100% for 1% of the samples). Long range transport (ie. Siberian fires) wildfire or prescribed burn smoke is usually indicated by

elevated K in the 1.1 to 0.2 μm size fraction as opposed to higher K in the largest size fraction (2.5-1.1 μm) usual from the more local Alaskan or Western Yukon fires due to the transport distance (personal comm., Dr. Cahill, April 10, 2012).

Local diesel power plants should show no sulfur (S) peak but more likely a selenium (Se) peak in the winter whereas long range industrial transport from Asia would show one or more sulfur peaks in the middle size (1.1-0.3 μm) fraction associated with copper (Cu), zinc (Zn) and nickel (Ni) in the smallest size range fraction (0.3-0.1μm) (personal comm., Cahill, Apri 10, 2012). It is nearly impossible to distinguish local power sources from Asian ones in the summer because of adequate sunlight and warmth to drive photochemical reactions.

3.4.2 Supporting evidence for April 2008 events: Models and Satellite Images

Multiple US and international satellites in polar orbits obtain daily images of Alaska, the northern Pacific, and northeastern Asia. The images sometimes record dust and smoke events that can be used as supporting evidence for scenarios that combine the sampled aerosol data with modeling and observed regional weather systems.

A MODIS satellite photo over the Sea of Okhotsk clearly shows dust and haze being transported by a cyclonic weather pattern eastward across the northern Pacific on April 17, 2008 (Figure 10). Again on April 21, 2008 smoke is captured by a MODIS satellite image over the Kamchatka Peninsula and Sea of Okhotsk (Figure 11). The smoke was from wildfires and agricultural burning in eastern Siberia and northern China and was widely reported in Russian media (i.e., Terra Daily, 2008).

Interpreting individual HYSPLIT back trajectories for more than a few days back to identify individual sources would require significantly more research and supporting documentation to verify. DEC does not have the resources or experience to verify the full 310 hours. Therefore DEC chose to focus on the most recent 100 hours (about four days). Even having three or four trajectories from around DNPP per day is very simplistic and the rough results should be interpreted warily (Stohl, 1998). Trajectory Statistical Methods (TSM) spatial concentration fields or redistributed concentration fields and newer statistical methods including GIS land cover data seem to be more robust methods of interpreting back trajectory models with the associated uncertainties quantified, for example by a calculated confidence limit (Stohl 1996; van Pinxteren et al, 2010). The low level HYSPLIT model runs for Denali headquarters, Lake Minchumina, and McGrath sites for April 2008 are located in Appendix C.

HYSPLIT back trajectories (only the most recent 96-120 hours of the low level model runs) from Denali headquarters, Lake Minchumina, and McGrath for the dates April 17, 2008 through April 22, 2008, support the eastward and rapid cyclonic transport indicated by the satellite images. The HYSPLIT models for all three sites show a distinct change on April 23, 2008 to much decreased wind speeds and a high pressure system centered on interior Alaska. This is consistent with subsiding air that could potentially deposit particulates previously held aloft by more energetic winds as they were transported eastward from the deserts and taiga of northeastern Asia five to seven days earlier. Both the high pressure and low pressure cyclonic movements have the potential to mix the relatively heavier dust from the Asian deserts with the lighter smoke particles and aerosols from the Siberian fires making the signals from the two events difficult to distinguish from one another with a first pass through the data. However, the satellite images and HYSPLIT back trajectory model runs are consistent with and provide circumstantial

evidence that supports the trends in the DRUM, Partisol, and IMPROVE data from the three sites. The particulate and chemistry data from March and April from this monitoring study will be placed into the context of this story and will be discussed in greater detail in the next section of this report.

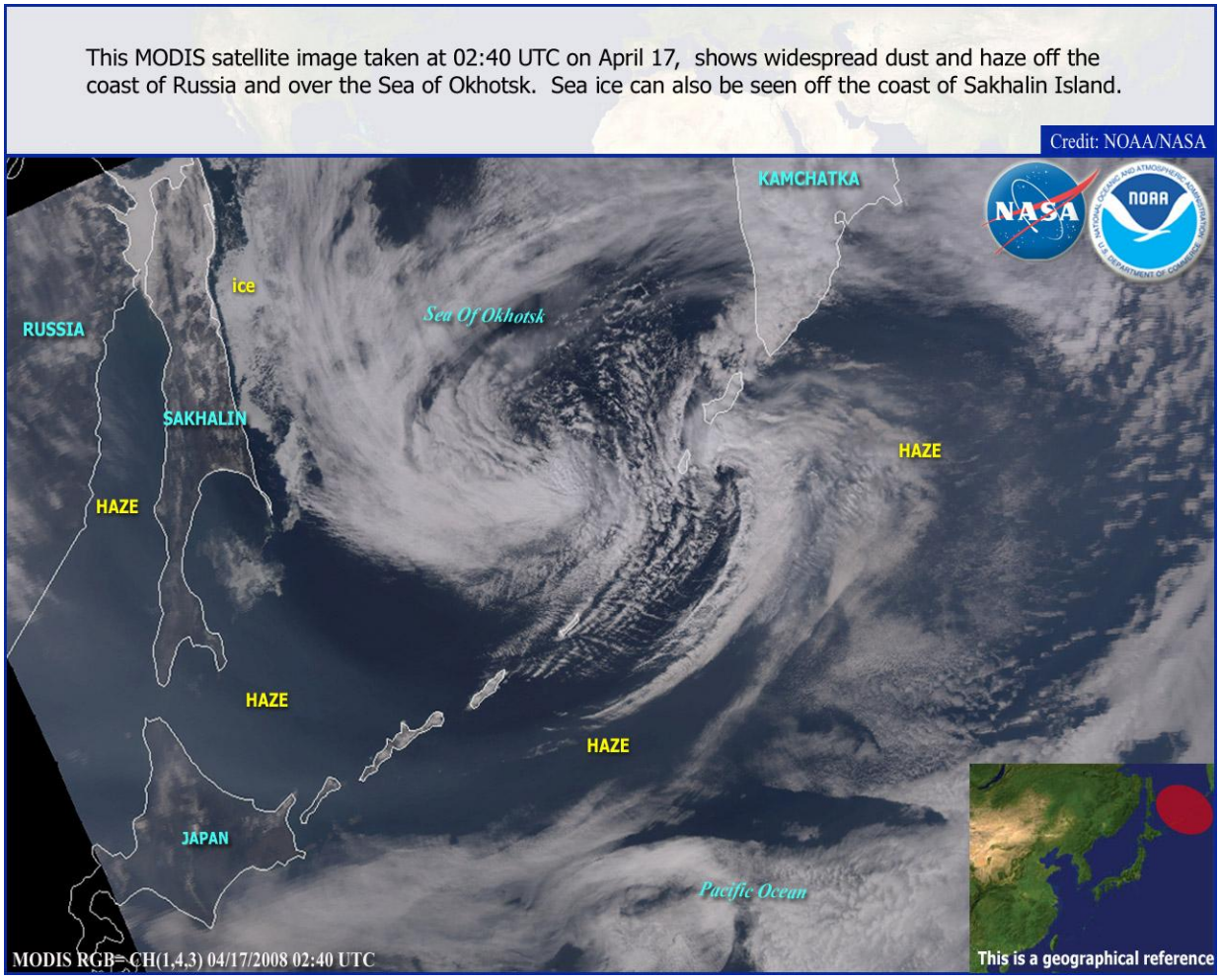


Figure 10. MODIS satellite image centered over the Sea Okhotsk on April 17, 2008

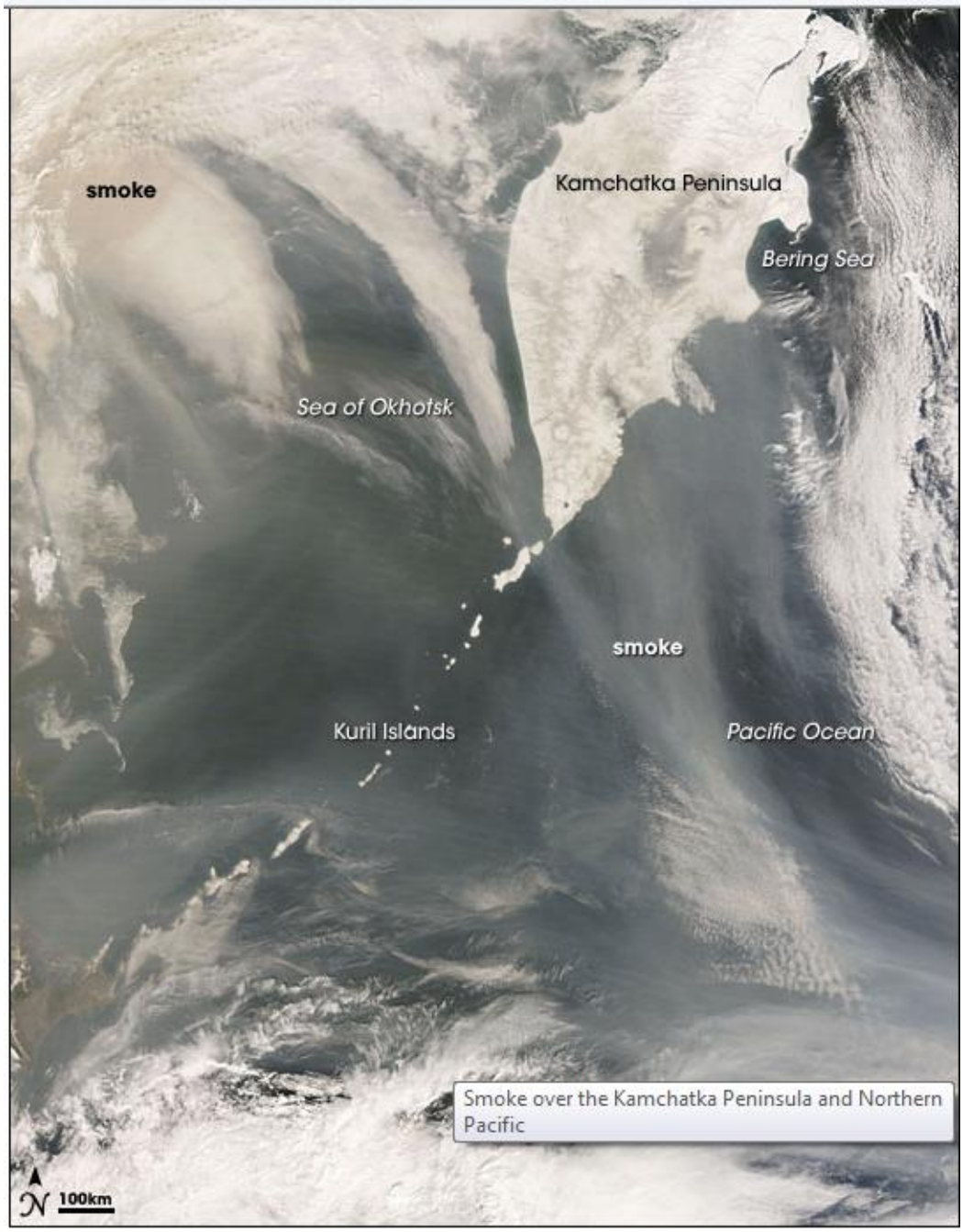


Figure 11. Satellite image of smoke over the Kamchatka Peninsula and Northern Pacific on April 21, 2008

3.4.3 Event Designation

DEC reduced the number of elements to a reasonable sized subset of data to evaluate an episode or event. In order to compare the different sampling methods, all mass and elemental data were compared using 24-hour averages because it was the coarsest sampling frequency. For the purposes of this study, an event occurs whenever $PM_{2.5}$ concentrations of one or more 'signature' element concentrations are significantly high for a given day. Signature elements for dust (or soil) events are aluminum (Al), potassium (K), calcium (Ca), magnesium (Mg) and silicon (Si). Storm events are signified by elevated bromine (Br), chlorine (Cl), and/or sodium (Na) concentrations. Anthropogenic events are signaled by high concentrations of copper (Cu), nickel (Ni), sulfur (S), vanadium (V), and/or zinc (Zn) (personal communication Dr. Cahill 2012, April 10, 2012). Wildfire smoke, another possible aerosol source, was not condsidered due of the lack of significant wildfires in Alaska during the study period. 2008 had the second lowest wildfire-burned acreage of the 20 years between 1990 and 2009 (AICC, 2009). A single event may have elevated elements from more than one of the three source categories (dust, storm, anthropogenic) but not show an elevated mass concentration. DEC defined an "event threshold" as two standard deviations above the average in order to distinguish high particulate events from normal variation. Table 8 summarizes the event thresholds for $PM_{2.5}$ and the signature element for soils, storms and anthropogenic sources. Although a subset of the McGrath Partisol data were analyzed by ED-XRF to obtain element concentrations, thresholds were not calculated for these data because the site did not have DRUM data during the period of interest.

Below is a discussion of the April 2008 events using two separate approaches: particulate mass data (two events on April 1-14, 2008 and April 21-26, 2008) and elemental data (two events on April 4-16, 2008 and April 15-24, 2008).

Table 8. Thresholds used to determine event episodes, $PM_{2.5}$ units: $\mu m/m^3$, element units: ng/m^3

Event thresholds[1]							
		DENA		LAMI		MCGR	
		DRUM	IMPROVE	DRUM	Partisol	DRUM	Partisol
Mass	$PM_{2.5}$	10.5	4.6	6.0	8.8	9.7	7.8
Storm elements	Br	5.6	3	4.6	7.4		
	Cl	219	296	273	105		
	Na	9	280	21	487		
Soil elements	Al	101	71	43	21		
	Ca	45	48	18	21		
	K	31	43	16	52		
	Mg	270	63	239	13		
	Si	149	170	52	66		
Anthropogenic elements	Cu	1.4	0.5	2.5	2		
	Ni	0.9	BDL[2]	4	1		
	S	688	567	360	677		
	V	4.1	0.2	2.3	0.3		
	Zn	6.3	6	3.6	5		

$PM_{2.5}$ concentration units: $\mu g/m^3$; element concentration units: ng/m3

[1]Event threshold = average + 2 * stdev

[2]BDL - below detection limit

3.4.4 Mass data: April 2008 Events

DEC chose to focus on two episodes in April 2008: the April 21-26 event and the April 4-14 event. A plot of $PM_{2.5}$ concentrations (Figure 16) shows that the Denali Headquarters DRUM sampler data reflect the episodes most clearly. Data sets available for March and April 2008 include $PM_{2.5}$ concentrations and elemental concentrations from DRUM, IMPROVE, and Partisol data at McGrath and Lake Minchumina as well as at Denali headquarters sites. Unfortunately, McGrath DRUM data are missing for this entire two month time period. Light brown boxes highlight the two events discussed in further detail in the remainder of this section. Days with concentrations that exceeded the event threshold are labeled with the concentration on all graphs in this section. Days having concentrations below the relevant event threshold are plotted but not labeled.

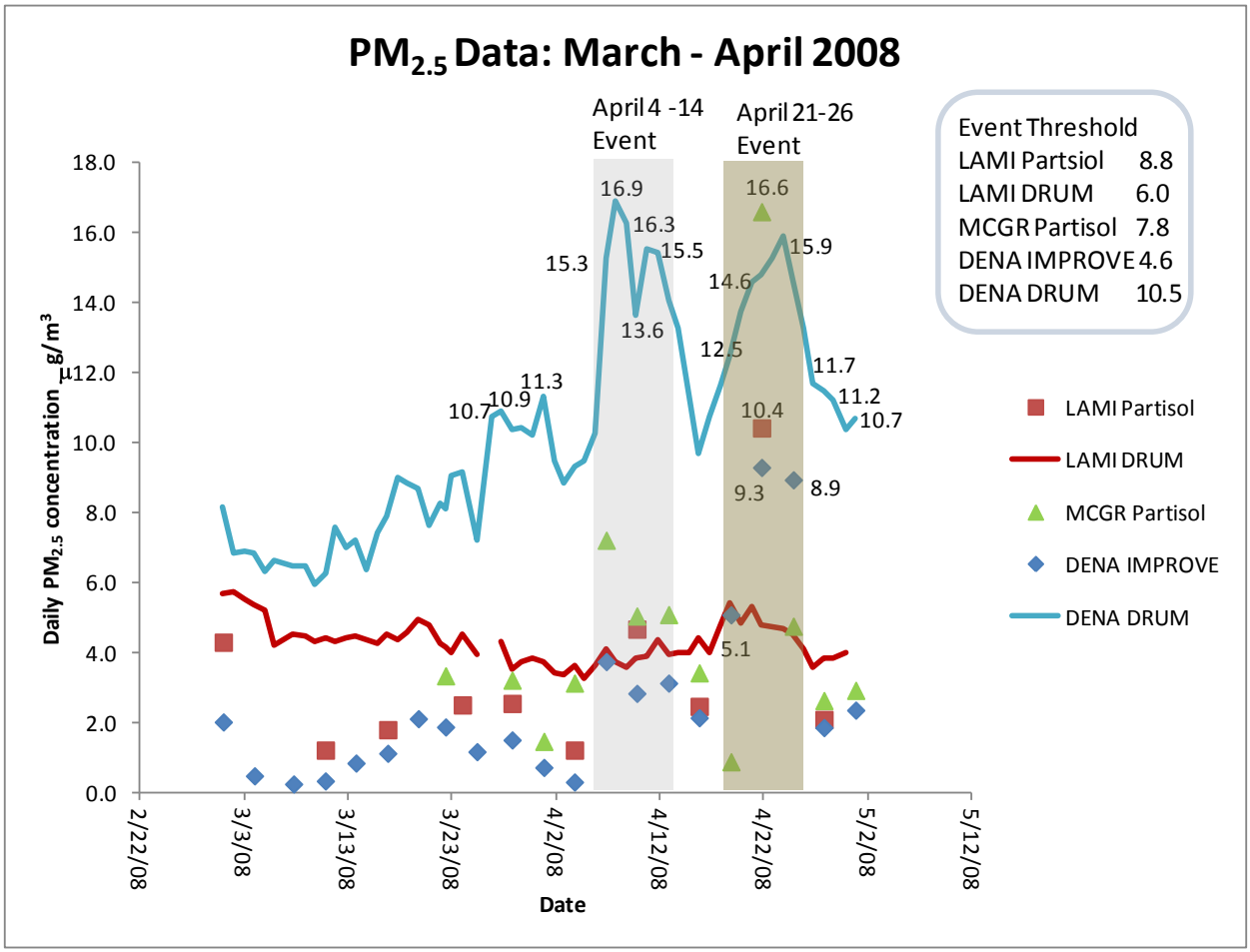


Figure 12. Total $PM_{2.5}$ mass data: March – April 2008, values above the individual sampler event threshold are labeled with the concentration

The April 21-26 event is reflected by exceedances of event thresholds for $PM_{2.5}$ at all three sites. It is clearly shown by the Denali headquarters DRUM data and has some support in Lake Minchumina Partisol, McGrath Partisol, and Denali headquarters IMPROVE data (Figure 12). Only the Lake Minchumina DRUM sampler did not reflect the episode in elevated $PM_{2.5}$ concentrations. Denali headquarters DRUM data show that the event started on April 16, 2008, peaked on April 23, 2008 (15.9 µg/m^3) and ended on April 30, 2008 (Figure 13). This period is

indicated by light brown on the graph. The event period that is seen in data at all the sites is a darker brown on the Figure 13. Three Denali headquarters IMPROVE concentrations on April 17, 21, and 24, 2008 are above the event threshold. A single Lake Minchumina Partisol sample having a concentration of 10.4 μg/m^3 on April 21, 2008 also supports the episode seen in DRUM and IMPROVE data at the Denali headquarters site. McGrath may have seen the event earlier than Lake Minchumina and DENA with a single high value of 16.6 μg/m^3 measured on April 21, 2008. However, the April 28, 2008 McGrath concentration (4.8 μg/m^3) is well below the event threshold as are Lake Minchumina Partisol and DRUM, and Denali headquarters IMPROVE concentrations leaving only the Denali headquarters DRUM data as lingering evidence of the episode. The Lake Minchumina site has the most distinct discrepancy between the DRUM sampler data and the Partisol data. DRUM data collected at Lake Minchumina do not show the same degree of elevation during the April 21-26 events as the Partisol and Denali headquarters samplers (Table 8).

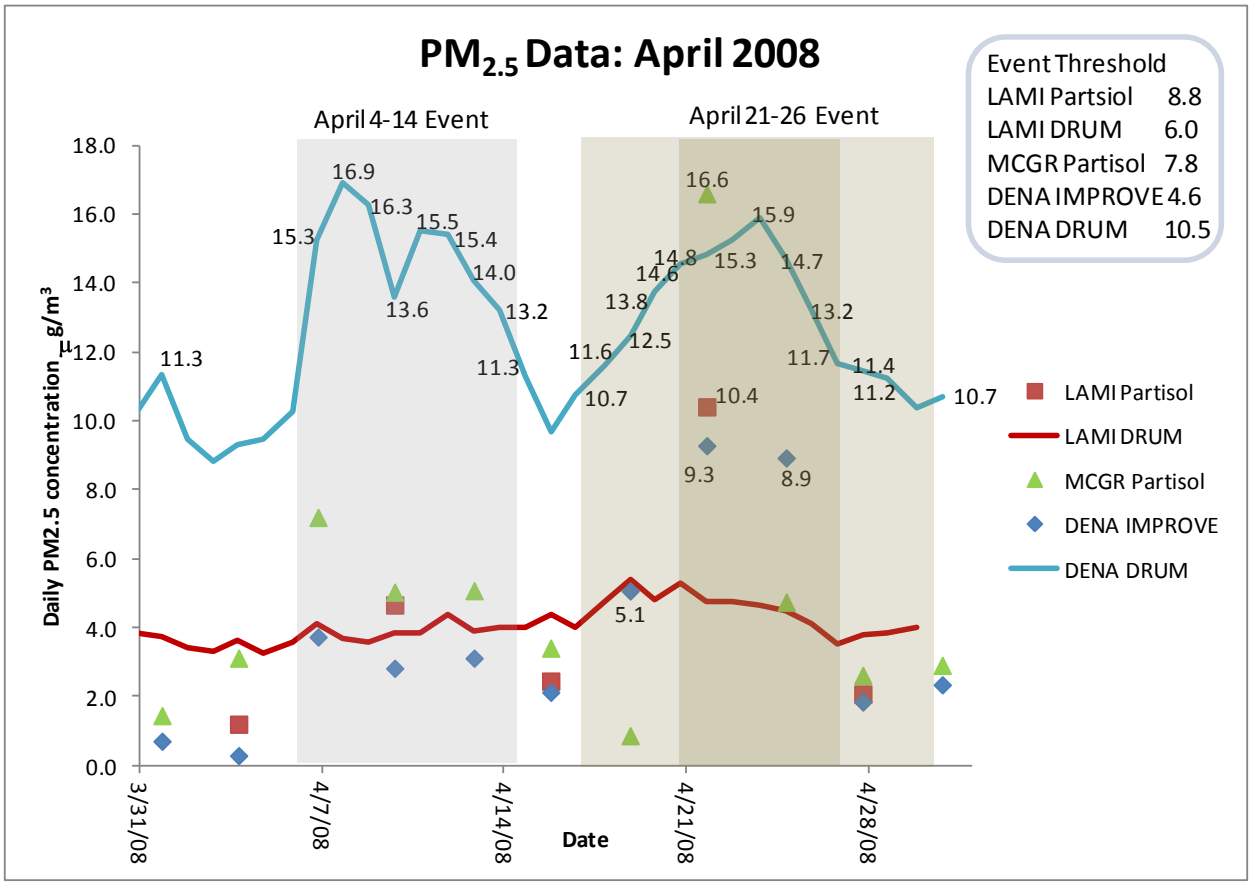


Figure 13. Total $PM_{2.5}$ mass data, April 2008, values above the individual elemental threshold are indicated with a concentration label

Table 9. Comparison of $PM_{2.5}$ averages during the two April events as compared to the overall study average (thresholds are included for reference)

Comparison of Averages: April Events and Overall Study				
Units: $\mu g/m^3$	April 21-26 Average	Study average	April 4-14 Average	Event Threshold
DENA DRUM	14.3	4.9	13.8	10.5
DENA IMPROVE	9.1	1.7	3.2	4.6
LAMI DRUM	4.4	3.8	4.7	6.0
LAMI Partisol	10.4	3.5	3.8	8.8

The April 4 – 11 event showed up clearly in the Denali headquarters DRUM data as a double peak on April 8, 2008 and on April 10, 2008. The event is highlighted by a gray band on the graph (Figure 13). Contrary to the DRUM concentrations, the Denali Headquarters IMPROVE concentrations are all half or less than half of the 4.6 $\mu g/m^3$ event threshold. Lake Minchumina DRUM and Partisol data for all of March and April 2008 are well below the threshold for an event of 6.0 $\mu g/m^3$. Only the McGrath concentration of 7.2 $\mu g/ m^3$ almost meets the event threshold of 7.8 $\mu g/m^3$. So there are no other samplers that had $PM_{2.5}$ concentrations that meet the criteria set beforehand to support the April 4 -16 event reflected in the Denali Headquarters DRUM data as demonstrated by the averages summarized in Table 9.

3.4.5 Element data: April 2008 Events

DEC has little confidence in using this study's DRUM data for quantitative analysis. DRUM sampler data were not bracketed by flow checks and due to the low particulate matter loading on the strips and analysis issues discussed in section 2.2.3. The data may not be comparable between sites much less comparable to element concentrations from IMPROVE or Partisol filters. DEC assumes that they are comparable from 6 week period to another 6 week period at the same site. For the purpose of this analysis, DEC assumed little to no error caused by the lack of flow verifications, as DEC has no documentation to assume otherwise. The next paragraphs provide a more detailed discussion of the April 2008 events as recorded by the DRUM samplers assuming that errors caused by the timing and flow verifications are negligible. DEC also made a cursory attempt to connect the DRUM data with Partisol and IMPROVE data for the Lake Minchumina and Denali headquarters sites.

Two events were evident in the elemental trends in the April 2008 DRUM data. The two sites for which DEC has valid data to compare, Denali headquarters and Lake Minchumina, show different elemental ratios in the peaks but the overall trends still show two distinct events with similar timing. According to DRUM elemental concentrations data, the first event occurred April 4 - 16, 2008 and then a second event occurred April 15 -24, 2008. Note that these are not the same set of days as discussed in the total mass analysis data section (3.4.4). This section focuses mainly on the DRUM sampler elemental concentrations and just does a cursory comparison to the few IMPROVE and Partisol elemental concentrations available. Plots of the April 2008 elemental concentrations are shown in Figures 14, 16 and 17. The plots are split into storm, soil, and anthropogenic signifier elements. Threshold event concentrations (see Table 8) were calculated for each site and type data set (IMPROVE, DRUM, Partisol) as the mean plus two

standard deviations or the 95% upper confidence interval if the data were normally distributed which is not true in this case.

Storms are usually indicated by elevated concentrations of bromine (Br), chlorine (Cl) and sodium (Na) (personal comm., Dr. Cahill 2012, April 10, 2012). The April 15-24 event is only reflected in Denali headquarters DRUM data by a Na peak on April 18 – 19, 2008 (Figure 14). There are increases in Lake Minchumina DRUM Cl, Br, and Na concentrations but the concentrations did not exceed the respective event thresholds. Unfortunately, IMPROVE and Partisol data for the most part do not have elevated values during this time period.

The April 4-14 event was marked by spikes in DRUM Na and Cl concentrations that exceeded the event thresholds at Denali headquarters but only a DRUM Na concentration spike that exceeded the event threshold at Lake Minchumina on April 10, 2008. Interestingly, for the April 4-14 event, when the Lake Minchumina DRUM Cl concentration spikes, Na concentrations decrease. This inverse relationship is unusual since Cl and Na usually increase and decrease together as seen in the other DRUM, Partisol, and IMPROVE storm data (Figure 14). DEC has no explanation for the DRUM's inverse relationship between Cl and Na concentrations for the April 4-14 event.

One caveat about the storm data is that the IMPROVE and Partisol Na concentrations are roughly two orders of magnitude greater than the Na concentrations measured by the DRUM samplers. This may be due to Na being the lightest element that is detectable by XRF on the DRUM sampler strips and that the low particulate matter loading could have provided insufficient material for a reasonable result.

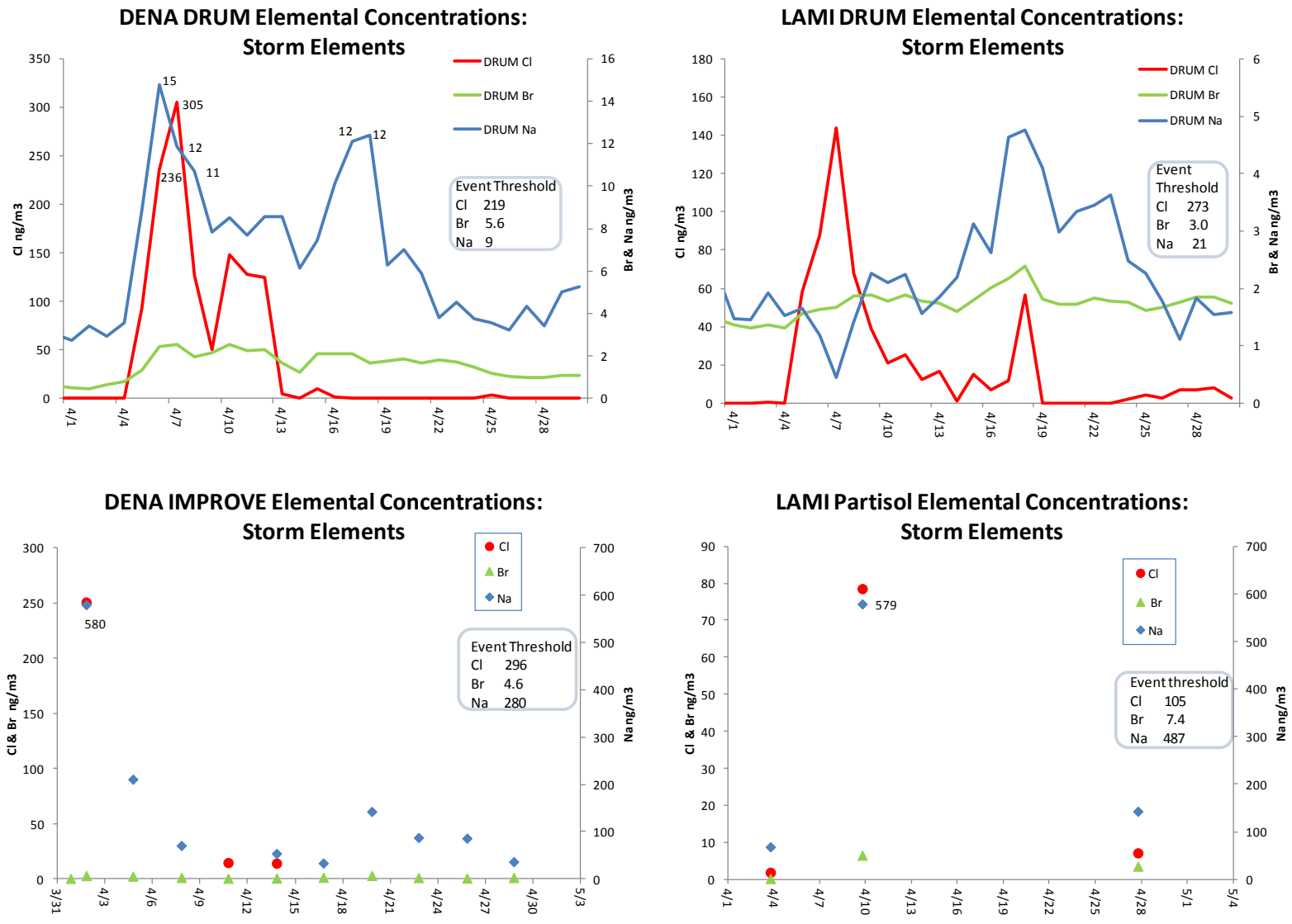


Figure 14. Elemental concentrations charts: Br, Cl and Na, April 2008, values above the individual elemental threshold are indicated with a concentration label

The April 15-24 event is very visible as peaks in all the soil elements, aluminium (Al), silicon (Si), potassium(K), calcium(Ca) and magnesium(Mg), but only K exceeds the event threshold at the Denali headquarters site (Figure 15). Interestingly, even though the Lake Minchumina DRUM data did not show any significant increase in $PM_{2.5}$ concentration (Figure 16) for the April 21-26 event, all of the soil element concentrations except for Mg exceeded their respective event thresholds. Unfortunately, the Lake Minchumina Partisol samples from April 11-27, 2008 were not collected and/or were invalidated so there are no corroborating or conflicting data to compare to the DRUM data during the bulk of the event period.

At Denali headquarters, the April 4-16 event clearly appears as peaks in the DRUM data for all of the soil components but only Mg and K exceed the event thresholds (Figure 16). The event appears to be bi-modal with the second broader peak lower which abruptly decreased on April 14, 2008. The IMPROVE soil elemental data show a marked increase in Al (49 ng/m^3) and Si (157 ng/m^3) but not greater than the event thresholds. Soil elemental concentrations averages for the two events can be compared to the overall daily value averages for the study in Table 10 below.

The Lake Minchumina April 4-16 event is barely evidenced by a single Ca value of 22 ng/m^3 in the Partisol data just above the event threshold and a single small Mg peak of about 80 ng/m^3 from the DRUM sampler. It is possible that the air mass transporting aerosols for this event did not cross over Lake Minchumina at all. HYSPLIT model runs between April 4 and 12 show the air parcels coming from the south for the previous day. See example of Denali headquarters HYSPLIT run for April 8, 2008 (Figure 15). Appendix C-4 contains Denali Headquarters 24-hour HYSPLIT model runs for April 3, 2008 through April 14, 2008. DEC can be contacted to request for the complete 24-hour HYSPLIT model runs for the four monitoring sites throughout the duration of the monitoring study

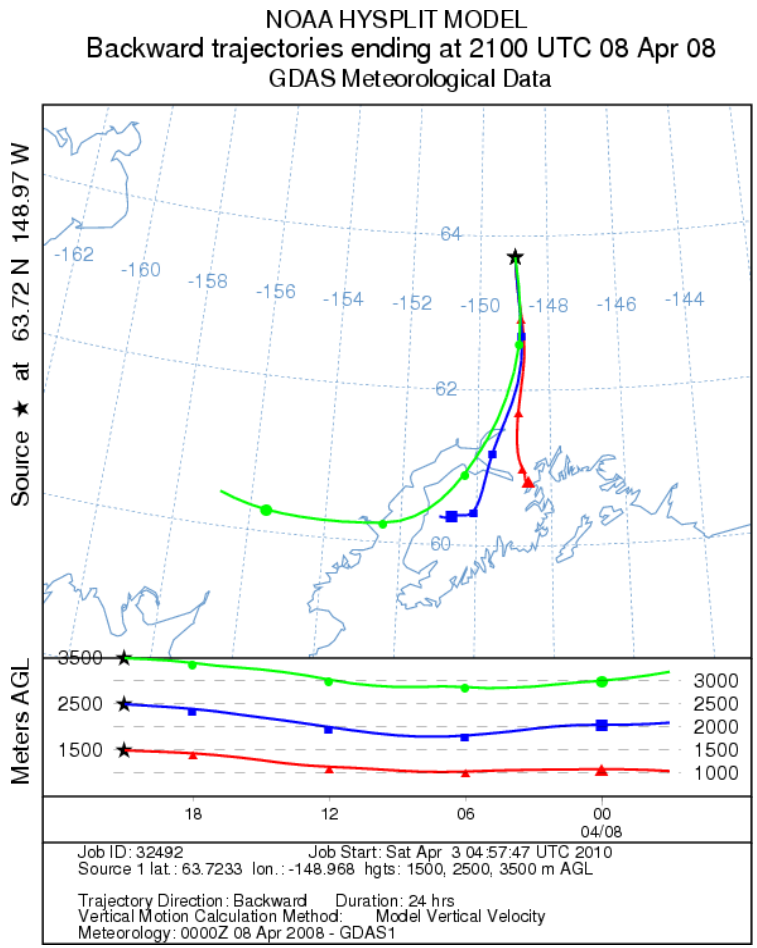


Figure 15. Example of 24 hour back trajectory HYSPLIT model run for Denali Headquarters ending at 2100 UTC on April 8, 2008

Selected Elements: Average DRUM Concentrations during April events			
Units ng/m³	Event Average & Range April 4-16	Event Average & Range April 15-24	Study Average & Range (daily concentrations 2008-09)
Al DENA DRUM	66 20 – 105	73 53 – 87	36 2 – 216
Ca DENA DRUM	22 5 – 35	22 12 – 28	13 0 – 125
K DENA DRUM	22 4 – 36	37 18 – 51	10 0 – 51
Mg DENA DRUM	188 31 – 349	133 101 – 163	84 1 – 768
Si DENA DRUM	72 26 – 99	98 54 – 125	45 1 – 355
Al DENA IMPROVE	25 10 – 50	27 18 – 35	22 2 – 154
Si DENA IMPROVE	84 35 – 157	88 64 – 113	52 3 – 408
Ca DENA IMPROVE	16 7 – 26	11.3 10 – 13	13.9 1 – 117
K DENA IMPROVE	15 7 – 20	15 12 – 17	13 1 – 113
Mg DENA IMPROVE	6 5 – 7	10 9 – 11	42 5 – 185

Table 10. Daily DRUM concentration averages for selected elements; range of concentrations for the relevant dates is listed below each average concentration

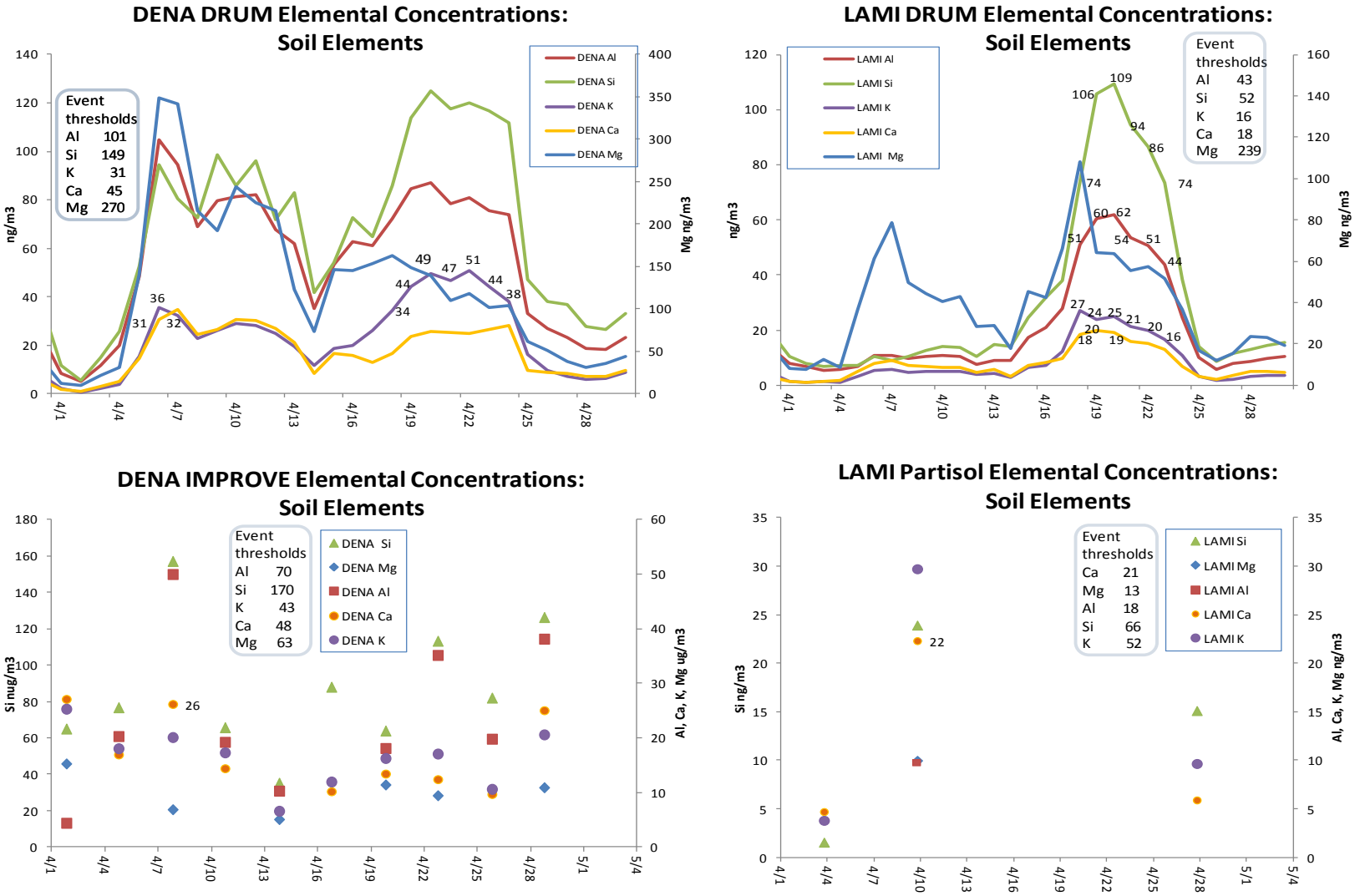


Figure 16. Elemental concentrations charts: Al, Ca, K, Mg and Si, April 2008; values above the individual elemental threshold are indicated with a concentration label

Anthropogenic pollutants are indicated by elevated concentrations of sulfur (S), zinc (Zn), nickel (Ni), vanadium (V) and copper (Cu) (personal communication Dr. Cahill 2012, April 10, 2012). Zn concentrations generally mimic S concentration fluctuations (Figure 21). Sulfur concentrations exceeding the event threshold signify the April 15 -24 event between April 15 and 20, 2008. Denali headquarters IMPROVE data exceed the event threshold on April 16 (654 ng/m^3) and again on April 25 (703 ng/m^3) but the two samples between the dates measured approximately half those concentrations. At the Lake Minchumina site neither DRUM sampler nor the single Partisol sample taken during the April 16-24 event exceeded the event thresholds for any element signifying an anthropogenic source. However S and Zn concentrations showed an abrupt increase beginning on April 14, peaking below the event threshold on April 18, 2008 followed by a more gentle decrease to a low on April 26, 2008 (Figure 17).

Denali headquarters DRUM concentrations of elements that signal an anthropogenic source mark the April 4-16 event by elevated S concentrations above the event threshold between April 6 and 12, 2008. The April 4-16 event also has a slightly delayed but distinct spike in Ni above the threshold of 0.9 ng/m^3 on April 9, 2008. In addition, the Cu concentration doubles on April 9 but still is less than half its event threshold. Lake Minchumina DRUM data have similarly trending S and Zn concentrations that are much more subdued than the high concentrations at Denali headquarters for the April 4-16 event. S concentrations increase modestly to about 110 ng/m^3 (Figure 17).

Similarly to the Denali headquarters IMPROVE data, the Lake Minchumina Partisol data exhibit no S or Zn events in the first half of April. However the April 4 -16 event does show up in Lake Minchumina Partisol Cu concentration on April 4 with a single value of 3.7 ng/m^3 which is almost double its event threshold. However, Cu is not elevated in Lake Minchumina DRUM data or at Denali Headquarters in either the DRUM or IMPROVE concentrations. There are no significant local sources of Cu in the local DNPP area or greater Alaska.

In summary, two distinct events in April 2008 were indicated by the total particulate mass and elemental concentrations data from the Denali headquarters and Lake Minchumina sites. The early April event (April 4-14 for $PM_{2.5}$ or April 4-16 for the element concentrations) observed at Denali headquarters site exceeded the event thresholds for the DRUM data: total $PM_{2.5}$ mass concentrations, storm elements Cl and Na, soil elements K and Mg, and anthropogenic elements S and Ni. Although the other soil elements Ca, K, Si, and Ca and the anthropogenic elements Cu and Zn had similar trends, they did not exceed the event threshold at Denali headquarters. These results were supported by two IMPROVE concentrations exceeding the event thresholds for Ca (soils) and Na (storms). Lake Minchumina DRUM data presented a less clear record of the event with only the following parameters exceeding event thresholds: total $PM_{2.5}$ mass, Ca and K. However Partisol XRF data showed the first event in that Na (storms), K and Ca (soils), and Cu (anthropogenic) all exceeded the event thresholds.

The second event, from April 15, 2008 to April 24, 2008 (DRUM element concentrations), showed up in Denali headquarters DRUM data in the following parameters exceeding the event thresholds: total $PM_{2.5}$ mass (April 21-26 event), Na (storms), K (soils), and S (anthropogenic). As in the first April event, Na, Cl and perhaps even Br (storms), Al, Ca, Mg and Si (soils) and Zn (anthropogenic) could be seen to increase during the event but did not exceed their respective thresholds. Lake Minchumina DRUM data showed, more clearly than Denali headquarters DRUM data, exceedances of the event thresholds for total $PM_{2.5}$ mass and soil components Al,

Ca, K, and Si. Although the elements Mg, S, and Zn were not high enough to meet the event threshold they all showed similar trends to the elements that did exceed the threshold. Except for the elevated total $PM_{2.5}$ mass concentrations, Denali headquarters IMPROVE data and Lake Minchumina Partisol data did not have chemical evidence to support the DRUM data for the second April event.

By and large the three sampling methods resulted in a somewhat cohesive story of two events occurring during April 2008. These two events were supported by MODIS satellite images and HYSPLIT model runs consistent with transport of dust and associated pollutants (and possibly wildfire smoke) from eastern Asia. However, there were significant discrepancies between the semi-continuous DRUM data and the filter-based IMPROVE and Partisol data. These discrepancies included no high DRUM total $PM_{2.5}$ mass concentrations at Lake Minchumina through all of April 2008 while a single Partisol filter did measure an elevated total $PM_{2.5}$ mass concentration. The elemental DRUM concentrations did record concentrations of elements that exceeded the respective event thresholds without an increased mass concentration. Similarly, the DRUM sampler at Denali headquarters recorded high $PM_{2.5}$, Cl, Na, Ca, S, and Ni concentrations that exceeded their various thresholds for the April 4-16 event whereas the IMPROVE sampler at Denali headquarters only exceeded thresholds for one or two element concentrations: Ca and possibly Na. Additional more detailed analysis of all data might help to clarify the inconsistencies between the data sets. The differing methods, sampling frequencies, and the different mass and element analyses might also be part of the explanation.

A qualitative analysis of long-range transport was not possible due to problems described earlier. On the other hand, DEC's qualitative analysis clearly shows that long-range transport is a frequent and regular occurrence that can be detected in the data. Additional or new sampling technology is needed for a quantitative analysis of the long-range transport phenomena.

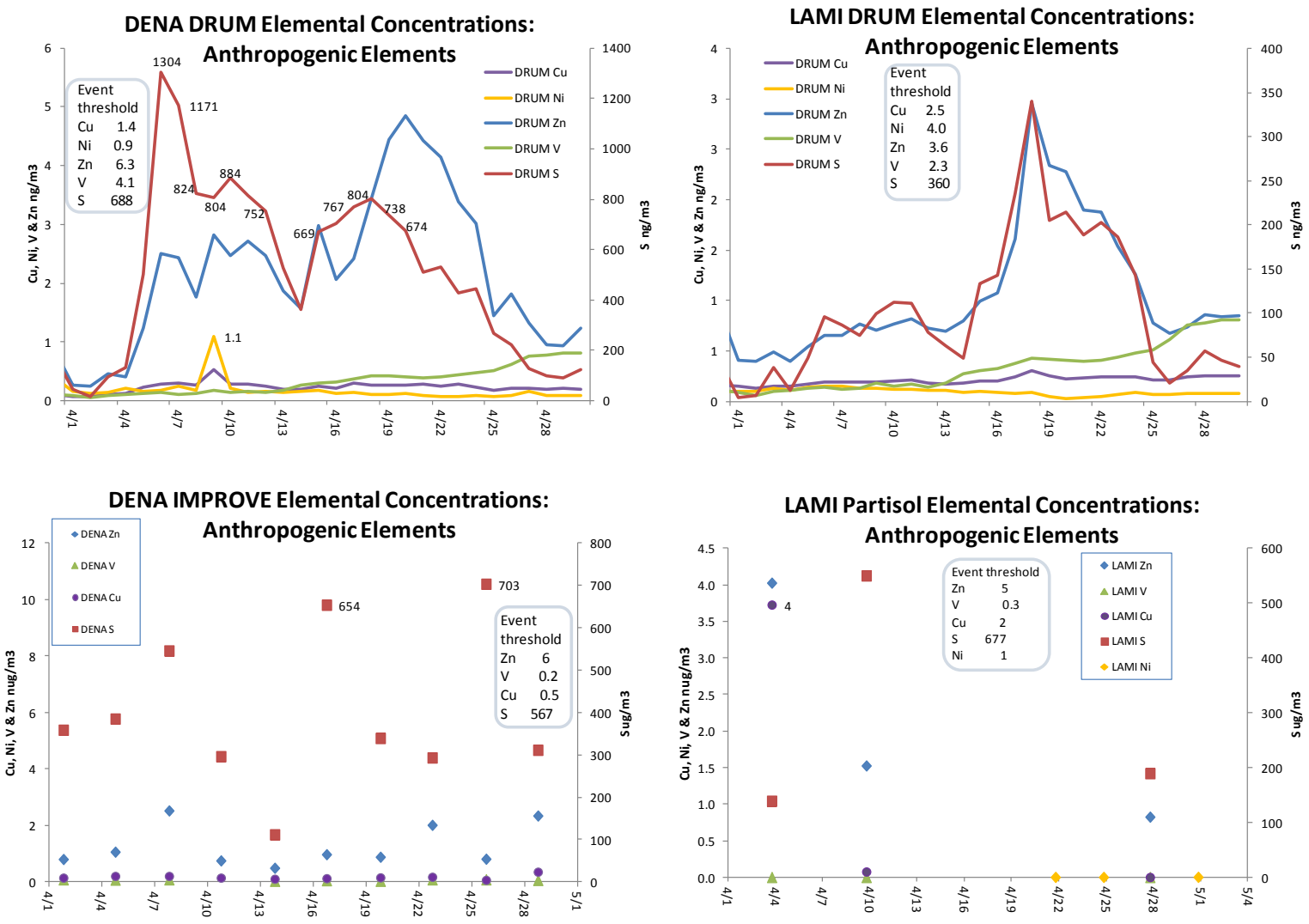


Figure 17. Elemental concentrations charts: Cu, Ni, V and Zn, April 2008; values above the individual elemental threshold are indicated with a concentration label

4 Conclusions

The main study objectives as listed in section 2.2.1 were only partially met. One of the driving factors for the study was the quantities evaluation of foreign contribution to local air quality impacts. While long-range transport of pollutants was observed and documented through various measurement techniques, DEC was unable to quantify international source contribution even as a whole. Current sampling methods do not provide enough time resolution with the IMPROVE sampling schedule missing 2/3 of the year (samplers operate every third day) to adequately document short events lasting only a few days. DRUM samplers which operate on a semi continuous basis, collecting 3 hour samples, initially seemed a viable method to collect year round data and provide a comparison to the IMPROVE chemical analysis. Low mass loading on the DRUM sampling strips and with that uncertainty for start and end hours failed a reliable quantitative comparison to the IMPROVE data set, even if all the other problems encountered with operating the DRUM samplers in a remote field setting could be overcome.

4.1 Use of DRUM samplers as substitution for IMPROVE

The study showed that DRUM sampling worked best at locations where an agency like the National Park Service provides a full time staff person and supports the reliable, knowledgeable operator with trained backup, (i.e. Denali Headquarters site). In this case the local operator, Andrea Blakesley, was available by phone and email during regular work week hours, understood the purpose and necessity of QA/QC processes, and was experienced in operating sophisticated air quality sampling equipment. However, DEC is concerned with the operations at the Trapper Creek and Lake Minchumina sites. DEC had difficult and unreliable communication with the operators during the study period. Often the only options available were phone and sometimes US Postal mail (intermittent during the winter months). The Trapper Creek operators had no answering machine, voice mail or email. Local non-scientist operators, like Penny and Tom Green at Lake Minchumina, were fully willing and capable to change filters on the Partisols. Even so, the extreme weather was hard on the pumps and instruments. Due to the unreliable flight schedule to Lake Minchumina, DEC was not able to visit the site and perform the site maintenance necessary for the delicate sampling equipment under the extreme climatic conditions encountered. Additionally, site maintenance took much more work and time than DEC or the operators anticipated. Despite more reliable flights to McGrath and more sophisticated communications systems, NWS-trained technicians at McGrath, had as many issues as Lake Minchumina operators due to the same kinds of problems with instruments caused by extreme conditions described above. DEC concludes that DRUM samplers are best suited for sites that experience higher levels of particulate matter than even the poor visibility days at DNPP. The DRUMs should be checked daily by an experienced air quality scientist, and should not be used for a long term study, rather should be placed to measure specific events like a volcanic eruption or a wildfire.

Initially DEC thought that the DRUM samplers were robust enough to be placed in remote locations and that the instruments could be supplied by alternative power sources. However after thoroughly researching the issue, DEC determined that siting DRUM samplers in remote locations was not practical or feasible. The Alaska National Interest Lands Conservation Act (ANILCA), passed by Congress in 1980, enlarged the Park and also described the new purposes which included a charge to preserve wilderness values. Alternative power sources even for the

low flow (10 L/min) DRUM sampler would require large and prohibitively expensive battery banks in addition to an unsightly wind generator or solar panels. The battery banks and pump noise would also negatively impact the management strategy of DNPP, as was determined by the NPS when DEC's request for a 3 months study at the Toklat Ranger Station concurrent with this study was denied.

4.2 IMPROVE Site

DEC still has concerns about the siting of the Denali headquarters IMPROVE station as a location representative of the entire class I area. The Denali Headquarters IMPROVE site is located within the area of most heavy use and development and, thus, may not be representative of the pristine wilderness that makes up the remainder of the park lands. Lake Minchumina was clearly the cleanest site. An argument could be made that most of the 6 million acres of DNPP best resemble Lake Minchumina with its current 13 residents compared to Denali headquarters or Trapper Creek which see nearly a half a million visitors per year. Most of the park visitors (432,301 in 2008), and DNPP staff (145 permanent, 290 summer seasonal) and Talkeetna staff (10 permanent, approximately 20 summer seasonal) are concentrated around DNPP headquarters (personal communication Blakesley 2012, June 6; DNPP, 2012). Traffic is mostly concentrated on the main highway and the single dirt road through the wilderness area (DNPP, 2012). The question that still needs to be answered is whether or not the Lake Minchumina site is more representative of the entire park than the two existing IMPROVE sites at Denali Headquarters and Trapper Creek. Before a final decision for relocation would be made, additional studies should be conducted that integrate meteorological observations with aerosols concentrations more quantitatively than was possible for this study analysis.

4.3 Source apportionment

Other than the greater Anchorage area, Fairbanks and remote interior villages that produce anthropogenic aerosols, sources like diesel and coal power plants and fugitive dust from dirt roads might contribute to the aerosols measured at Denali headquarters and McGrath. However the majority of local (Alaskan) aerosols come from volcanic eruptions, wildfires and glacial dust wind events.

Mount Redoubt erupted on March 22 and 23, 2009 and sent ash plumes 19 km above Cook Inlet near Anchorage. Skwentna, 113 km northwest of Anchorage, received 0.64 cm of ash. The Trapper Creek site was the most promising candidate to record ash from the eruptions. The DRUM sampler data from Trapper Creek did not cover the time period containing the eruptions. DEC did not find evidence of the eruptions at the three other monitoring sites.

Table 11. Wildfire History of Alaska 1990 – 2009

Alaskan Wildfires							
Year	Acres burned	Year	Acres burned	Year	Acres burned	Year	Acres burned
1990	3,189,427	1995	43,965	2000	756,296	2005	4,649,597
1991	1,750,653	1996	599,267	2001	218,113	2006	270,539
1992	135,360	1997	2,026,899	2002	2,186,682	2007	649,411
1993	713,116	1998	120,751	2003	602,146	**2008**	**103,299**
1994	265,721	1999	1,005,428	2004	6,523,816	2009	2,951,592

Summer wildland fires are a common and frequent occurrence in Alaska. Most years numerous wild fires burn though out the state, producing smoke, which can blanket large areas. This smoke impacts air quality and reduces visibility often reaching unhealthy levels. Unfortunately for our monitoring study, but not necessarily the state, the wildfire season in Alaska for 2008 was almost nonexistent with only 103,299 acres burnt. 2008 had the lowest wildfire-burned acreage of the 20 years between 1990 and 2009 (Table 10). Also, most of the 2,951,592 wildfires in Alaska in 2009 began after the study was completed in early June 2009. The monitoring study did not capture a normal wildfire year for Alaska. However, eastern Siberia and northern China did have extensive fires in 2008. One or both of the April events discussed in sections 3.4.4 and 3.4.5 may have recorded long range transport of the Asian smoke.

DEC believes that very light loadings of aerosol from long range international transport of smoke, pollution, and natural dust storms, were recorded by the DRUM samplers at multiple times during the study period. However, DEC is not able to quantify the impact of long range transport with the available data set. The data set has too many timing, sampling and quality control issues to be use to quantitatively distinguish between local and long range sources or apportion natural versus anthropogenic sources of aerosols.

4.4 Future sampling/interpretation

As time and staffing allow, DEC will continue to evaluate these data in the future, especially once the outstanding data from UAF has been delivered. The wealth of data makes any further analysis more suitable for academic research than as part of the State SIP process.

DEC will not employ DRUM samplers for any extended monitoring due to the delicacy of and the maintenance effort associated with the instrument. Research studies designed to document particular short timeframe events would be the ideal use for DRUM samplers in Alaska. The instrument has the potential to document long range transport, particularly events that have high particulate loads like volcanic eruptions or Asian dust events. Shorter timeframe intensive field studies with research grade equipment monitored by scientifically trained personnel could be implemented with some degree of success given sufficient staff and funding availability.

Future studies will use more robust sampling equipment for long term monitoring. Because of the remoteness of the wilderness sites of Alaska's Class I sites, DEC will most likely explore other sampling equipment for regulatory monitoring to demonstrate compliance with the Regional Haze Rule glide-path. As the concentrations of anthropogenic aerosols decreases toward background it will become more difficult to monitor successfully in the future without advances in monitoring instrument, pump and power technologies.

As if to underline the main message to the State, EPA, and the FLM, the complications experienced in this study were due in large part to the low particulate matter loading of DRUM samplers and further emphasize how clean the air in DNPP is. Natural sources and long range transport of pollution from overseas are important to the visibility impacts observed in Alaska's Class I areas. As DEC continues to implement its Regional Haze plan and performs required updates in future years, the experience and data gained through this study can be used to inform the development and planning for new monitoring efforts that may provide additional insight into aerosol impacts in Alaska's Class I areas. Given the vast, remote areas of Alaska, the challenge remains to develop air monitoring approaches that can be successfully operated in the State's wilderness areas

5 References Cited

Statistics were performed using SOFA Statistics version 1.1.3, Paton-Simpson & Associates Ltd, Auckland, New Zealand

40CFR 58, Appendix A, "Quality Assurance Requirements for State and Local Air Monitoring Stations (SLAMS)"

AICC (2009) Alaska Fire Season 2009 Wildland Fire Summary and Statistics Annual Report - AICC

Cahill, C., (2002) Asian aerosol transport to Alaska during ACE-Asia, J. Geophysical Research. 108(D23), 8664, doi:10.1029/2002JD003271, 1003.

Daily New Bulletin (2008, April 24) Russian Wildfires Reach Mongolia, ProQuest Information and Learning, Moscow - English, accessed from: http://www.firefightingnews.com/article.cfm?articleID=48177

DeBell, L. J., M. Vozella, R. W. Talbot and J. E. Dibb, 2004, Asian dust storm events of spring 2001 and associated pollutants observed in New England by the Atmospheric Investigation, Regional Modeling, Analysis and Prediction (AIRMAP) monitoring network, Journal of Geophysical Research, vol. 109. D1304, doi:10.1029/2003JD003733, 16 pp.

DELTA Group, January 20, 2012, Quality Assurance Summary and Size Resolved Mass Data Archive, Alaska Department of Environmental Conservation 3 DRUM Network, 16 pp.

DRI (2010, September 17) X-Ray Fluorescence (XRF) Analysis of Aerosol Filter Samples (PANalytical Epsilon 5), DRI SOP #2-209.6, Desert Research Institute, 32 pp.

Eldred, B, 2003, June 23, Internal Memo to IMPROVE Staff from Bob Eldred, Subject: Evaluation of the Equation for Soil Composite, accessed from http://vista.cira.colostate.edu/improve/Publications/GrayLit/023_SoilEquation/Soil_Eq_Evaluation.pdf, 9 pp.

Joling, D. (2008, April 20). Jet lab cruises Alaska skies as scientists study bits of floating pollution. *Anchorage Daily News.* p. A10.

Lindsey, R. (2008, April 15) Fires in Amur Oblst', Russia: Image of the Day, Caption to Earth Observatory, NASA, accessed from: http://earthobservatory.nasa.gov/IOTD/view.php?id=8668

Lindsey, R. (2008, April 22) Fires North of Amur River, Russia, Earth Observatory, Natural Hazards, NASA, accessed from: http://earthobservatory.nasa.gov/NaturalHazards/view.php?id=19657.

IMPROVE (March 2001) Quality Assurance Guidance Document Revision 0.0, IMPROVE: Interagency Monitoring of Protected Visual Environments, OAQPS Category 1 QAPP http://vista.cira.colostate.edu/improve/Publications/QA_QC/IMPROVE_QAPP_R0.pdf, 187 pp.

IMPROVE Standard Operating Protocols (SOP 101, 126, 151, 176, 201, 226, 276, 251, 301, 326 & 351) http://vista.cira.colostate.edu/improve/Publications/SOPs/ucdsop.asp, 68 pp.IMPOVE SOP 301

IMPROVE SOP 301 (February 1997) SOP 301 X-ray Fluorescence Analysis http://vista.cira.colostate.edu/improve/Publications/SOPs/ucdsop.asp, 47 pp.

IMPOVE SOP 326 (February 1997) SOP 326 PIXE and PESA Analysis http://vista.cira.colostate.edu/improve/Publications/SOPs/ucdsop.asp, 68 pp.

Malm, W. C., J. F. Sisler, D Huffman, R. A. Eldred, & T. A. Cahill(1994) Spatial and seasonal trends in particle concentration and optical extinction in the United States, *J. Geophys. Res*., 99 1347-1370.

Martinson, B. (2008, April 24). Asian Haze Colors Palmer Skies. *Anchorage Daily News.* p. A9. Reel # ANCH 6/1084, Microfilm Collection, Alaska State Library.

McKendry, I. G., J. P. Hacker, R. Stull, S. Saiyama, Mignacca and K. Reid, 2001, Long-range transport of Asian dust to the Lower Fraser Valley, British Columbia, Canada, Journal of Geophyiscal Research, vol., 106, no. D16, 18,316-18,370.

NOAA NASA (2008, April 17) MODIS satellite image of widespread dust and haze off the coast of Russian and over the Sea of Okhostk, retrieved from: http://www.osei.noaa.gov/Events/Dust/Asia_E/2008/DSTchina108_MO.jpg

Rahn, K. A., R. Borys, and G. E. Shaw, 1977, The Asian sources of Arctic Haze bands, *Nature*, 268, 713-715.

Rahn K. A. and G. E. Shaw (1982) Sources and transport of Arctic Pollution Aerosol, Navel Reseach Review, 34, p. 3-26.

Scott, M. (2008, April 21) Smoke over the Kamchatka Peninsula and Northern Pacific: Natural Hazards, MODIS image & caption, http://earthobservatory.nasa.gov/NaturalHazards/view.php?id=19820

Shaw, G. E (1980) The Arctic Haze Phenomenon, Bulletin of American Meteorological Society, 76,

Seinfield and Pandiw (1998)

SOA DEC AMQA (1998) Quality Assurance Project Plan for the State of Alaska $PM_{2.5}$ Ambient Air Quality Monitoring Program, Alaska Department of Environmental Conservation Air Quality Division Air Monitoring & Quality Assurance Program, http://dec.alaska.gov/air/doc/AK_PM2-5_QAPP.pdf, 83 pp.

SOA DEC AMQA (2008) Quality Assurance Project Plan for the Alaska Regional Haze Monitoring Study 2008/2009: Denali National Park &Preserve Class I Area, Alaska Department of Environmental Conservation Air Quality Division Air Monitoring & Quality Assurance Program, 45 pp.

SOA DEC AMQA (2010) Quality Assurance Project Plan for the State of Alaska Air Monitoring and Quality Assurance Program, Alaska Department of Environmental Conservation Air Quality Division Air Monitoring & Quality Assurance Program, http://dec.alaska.gov/air/doc/ADEC_AMQA_QAPP_23FEB10-final.pdf, 106 pp.

SOA DEC AMQA (2012, March 8) Air Quality Monitoring at Denali National Park & Preserve, Alaska: 2000-2003, Alaska Department of Environmental Conservation Air Quality Division Air Monitoring & Quality Assurance Program, http://dec.alaska.gov/air/am/Denali_rpt_8mar12.pdf, 9 pp.

SOA DEC AMQAa (2009) Standard Operating Procedure For Laboratory Gravimetric Analysis of Fine Particulate Matter ($PM_{2.5}$) Air Quality Filter Samples, Alaska Department of Environmental Conservation Air Quality Division Air Monitoring & Quality Assurance Program, http://dec.alaska.gov/air/doc/Lab%20SOP%20-%20Grametric%20Analysis%20-%20Morgan%20Rev.pdf, 17 pp.

SOA DEC AMQAb (2009) Standard Operating Procedure Thermo Electron Partisol 2000-FRM, Alaska Department of Environmental Conservation Air Quality Division Air Monitoring & Quality Assurance Program, http://dec.alaska.gov/air/doc/FRM2000SOP%209_09.pdf, 27 pp.

Stohl, A. (1996) Trajectory Statistics—A new method to establish source-receptor relationships of air pollutants and its application to the transport of particulate sulfate in Europe, Atmos. Environ., 30(4), pp. 579-587.

Stohl, A. (1998) Computation, accuracy and applications of trajectories—A review and bibliography, Atmospheric. Environ., 32(6), pp. 947-966.

Stohl, A., (2006) Characteristics of atmospheric transport into the Arctic troposphere, J. Geophys. Research-Atmos. 111, D11306, doi: 10.1029/2005JD006888.

van Pixteren, D., E. Bruggemann, T. Gnauk, K. Muller, C. Thiel, H. Herrmann, (2010), A GIS based approach to back trajectory analysis for the source apportionment of aerosol constituents and its first application, J. Atmos. Chem., 67:1-28, doi 10.1007/s10874-011-9199-9.

Uematsu et al (1983) Trasport of mineral aerosol and antrhropogenic aerosols during a Kosa event over East Asia, Journal of Geophysical Research, 88, 5343-5352.

Wetzel, M.A., G.E. Shaw, J.R. Slusser, R.A. Borys and C.F. Cahill (2003). Physical, Chemical and Ultraviolet Radiative Characteristics of Aerosol in Central Alaska. J. Geophys. Res., 108(D14), 4418, doi:10.1029/2002JD003208.

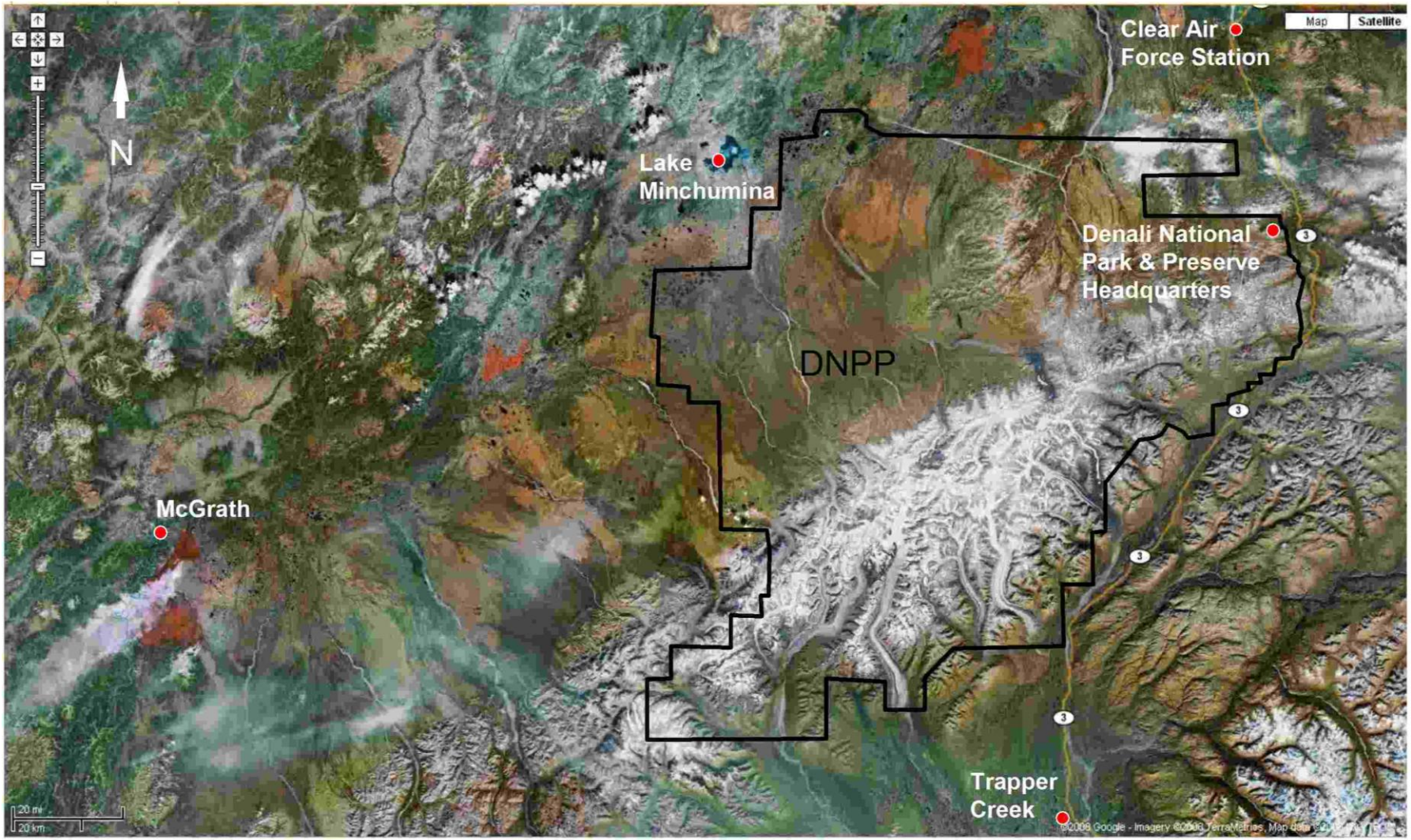
Wilcox, W. J and C. F. Cahill (2003) Regional Haze Trends in Alaska: Implications for protected Class I visibility areas, EM, Dec. 2003, p 34-39.

Fire sweeps through Siberian forests. (2008, April 23) Terra Daily: New about planet earth, Moscow (AFP). Retrieved from http://www.terradaily.com/reports/Fire_sweeps_through_Siberian_forests_999.html

U.S Census (Need 2000 & 2010) United States; Dept. of Commerce; Census Bureau; Manufacturing, Mining, and Construction Statistics; *Housing Units Authorized by Building Permits*; US Dept. of Commerce, 5 Feb. 2008; Web; 23 Dec. 2008; table 1a.

6 Appendices

6.1 Appendix A: Site Locations, Characteristics and PhotographsA-1 Satellite image of the DNPP area including site locations and Park boundary



A-2 Summary of site characteristics

Monitoring Site Characteristics				
	DENA	LAMI	MCGR	TRCR
Installed per QAPP	Yes	Yes	Yes	Yes
Location	63º 43.398’ N 148 º 58.05’ W 658 m	63º 54.69’ N 152 º 16.870’ W 7 m	62º 57.331’ N 155 36.179’ W 155 m	62º 18.917’ N 150º 18.900’ W 155 m
DRUM	Yes	Yes	Yes	Yes
Collocated DRUMS	No	No	No	Yes
Partisol 2000	No	Yes	Yes	No
IMPROVE	Yes	No	No	yes
Site Characteristics	Regional scale, semi rural, wilderness oriented	Regional scale, semi rural, wilderness oriented	Regional scale, semi rural, wilderness oriented	Regional scale, rural to wilderness site
Meteorological instrumentation	Included at IMPROVE site	Installed by DEC	National Weather Service site	Included at IMPROVE site
Monitoring data useable?	Yes	Yes, limited	Yes, limited	No

Abbreviations:
LAMI – Lake Minchumina
DENA – Denali Headquarters
MCGR – McGrath
TRCR – Trapper Creek
DEC – Department of Environmental Conservation
DRUM – Davis Rotating-drum Unit for Monitoring
IMPROVE – Interagency Monitoring of Protected Visual Environments
QAPP – Quality Assurance Project Plan

A-3 Instrument configurations and analysis methods for the final four sites.

Instrument Configurations, Analysis Methods, and QA/QC References								
Method	Sites	Schedule	Flow rate	Filter media	Particulate analysis method	Chemical analysis method	Monitoring QA/QC	Laboratory QA/QC
Partisol	LAMI MCGR	Once every three days[1] 24 hrs starting @ midnight	16.7 L/min	Teflon™	Gravimetric	ED XRF	See *Regional Haze Monitoring Study QAPP* (SOA ADEC AMQA, 2008)and Appendix B for MQO tables	See SOP Laboratory *Gravimetric Analysis of Fine Particulate Matter ($PM_{2.5}$) Air Quality Filter Samples* (SOA DEC AMQAa, 2009) and Appendix B: *X-Ray Fluorescence (XRF) Analysis of Aerosol Filter Samples* (DRI, 2010)
IMPROVE	DENA TRCR	Once every three days 24 hrs starting @ midnight	22.8 L/min	Teflon (pore size 3.0 μm)	Gravimetric	Synchrotron XRF	See IMPROVE QAPP (IMPROVE, 2001)	See IMPROVE QAPP & SOPs (IMPROVE, 2001 & 1996-2006)
DRUM	DENA LAMI MCGR TRCR	Continuous 6 week sample strip @ 3-hour resolution	23 L/min 3mm slit size; 10 L/min, 6mm slit size	Apiezon ™ coated mylar strips	Beta gage	Synchrotron XRF	Not much field QA/QC possible; See *Alaska Regional Haze Monitoring Study QAPP* (SOA ADEC AMQA, 2008)	See Appendix A: *Quality Assurance Summary and Size Resolved Mass Data Archive* (Delta Group, 2012)

[1] All reasonable attempts were made to adhere to the EPA's published year sampling schedule however, many samples did not fall on scheduled run days and thus many of the Partisol samples were not directly comparable to IMPROVE samples.

Abbreviations:

DRUM – Davis Rotating-drum Unit for Monitoring

DENA – Denali Headquarters

ED XRF – Energy Dispersive X-ray Fluorescence

IMPROVE – Interagency Monitoring of Protected Visual Environments

LAMI – Lake Minchumina

MCGR – McGrath

MQO – Measurement Quality Objective

QAPP – Quality Assurance Project Plan

TRCR – Trapper Creek

MQO – Measurement Quality Objective

A-4 Site descriptions and photographs

Denali National Park and Preserve Headquarters (DENA)

The Denali National Park and Preserve Headquarters (DENA) site is located in the Park Headquarters area just north of the offices at the IMPROVE site at latitude 63.7233º and longitude -148.9675, and 658 meters (1974 feet) above sea level.

The site is located on the edge of the park headquarter buildings and is a regional scale, semi-rural site. It is in the Jenny Creek valley which runs east-west and is bounded on the north and south by mountains reaching elevations of approximately 6000 feet. Jenny Creek drains into the Nenana River approximately 2.5 miles east of the site. The town of Healy, population 971 (2007 census), is approximately 15 miles north of the site. Healy has a coal power plant. The pollution sources outside the valley are limited to Fairbanks and long ranging particulate and gases from forest fires in Alaska, Canada and northeast Asia, and intra continental industrial pollution and dust sources. The sources of particulate matter near DNPP Headquarters include: residential wood smoke, dust from the Denali Park Road, coal plant emissions from Healy and vehicle exhaust from the Parks Highway that runs along the east side of the park

The DNPP Headquarters site was equipped with $PM_{2.5}$ IMPROVE and a DRUM sampler running on a 6 week cycle with 3 hour sampling frequency. The DRUM sampler was installed on the roof of the IMPROVE trailer, approximately 2 meters (6 feet) above the ground. The nearest IMPROVE inlet head was greater than 1 meter from the DRUM sampler inlet head. The IMPROVE samplers are installed approximately 5 meters (15feet) from the dirt parking lot for the site. There is a row of trees approximately 50 meters (160 feet), at the closest point, skirting the southern and eastern exposures of the site. The trees are approximately 3-8 meters (9-24 feet) tall. Airflow is generally uninterrupted with the exception of the trees to the north-northeast. These trees are not considered to be a barrier because of their distance from the site. The DNPP Headquarters site is approximately 2 miles north of the unpaved Denali Park Road which receives constant traffic during the summer tourist season.

North	East	South	West
Views in four cardinal directions from the Denali Headquarters Site			
Views in four cardinal directions toward the Denali Headquarters Site			

Lake Minchumina (LAMI)

Lake Minchumina is located north of Mount McKinley in Interior Alaska. It lies at 63.88278° N Latitude and -152.31222° W Longitude. (Sec. 08, T012S, R024W, Fairbanks Meridian.) Lake Minchumina is located in the Fairbanks Recording District.

Lake Minchumina is a small settlement of approximately 32 residents, roughly 10 miles outside the northwest edge of the park. This location has an airfield, a small Native Alaskan village, a lodge and store. A post office was established in 1930. The school was closed for the 1999-2000 year due to insufficient students. The Park Service, lodge and school provide the majority of employment in this small community. Due to its isolation, subsistence activities, trapping and dog mushing are also pursued. Half of all households have individual wells; the remainder haul water from untreated surface sources. No homes are fully plumbed; the majority use outhouses or honeybuckets. A private company, Lake Minchumina Power, provides electrical services. A new landfill site has been developed. A State-owned 4,200' gravel airstrip is available. The lake may be accessed by boat in the summer. There is no road connection.

Lake Minchumina and other sites in interior Alaska experience seasonal temperature extremes (lows of –40 ^{o}F to –50 ^{o}F). January temperatures range from –22°F to -2 ^{o}F; July temperatures range from 50 ^{o}F to 72 ^{o}F. Average annual precipitation is 11.3 inches. Ice fog is common during the winter. The National Weather Service (NWS) operates a weather observation site (PAMH) in town. This site will provide data for monitoring low level air flow from the north to northwest into the park.

North	East	South	West
Views in four cardinal directions from the Lake Minchumina Site			
Views in four cardinal directions toward the Lake Minchumina Site			

McGrath (MCGR)

McGrath is located 221 miles northwest of Anchorage and 269 miles southwest of Fairbanks in Interior Alaska. It is adjacent to the Kuskokwim River directly south of its confluence with the Takotna River. It lies at 62.95639° N Latitude and -155.59583° W Longitude. (Sec. 18, T033N, R033W, Seward Meridian.) McGrath is located in the Mt. McKinley Recording District. McGrath was a seasonal Upper Kuskokwim Athabascan village which was used as a meeting and trading place for Big River, Nikolai, Telida and Lake Minchumina residents. The Old Town McGrath site, was originally located across the river. In 1940, an airstrip was cleared, the FAA built a communications complex, and a school was opened. McGrath became an important refueling stop during World War II, as part of the Lend-Lease Program between the U.S. and Russia. In 1964, a new high school was built, attracting boarding students from nearby villages. The City was incorporated in 1975 and is home to 401 residents. A little less than half of the population are Native Alaskans. As a regional center, McGrath offers a variety of employment opportunities, but subsistence remains an important part of the local culture. McGrath functions as a transportation, communications, and supply center in Interior Alaska. It has a diverse cash economy, and many families rely upon subsistence. Salmon, moose, caribou, bear, and rabbits are utilized. McGrath operates a piped water system that serves nearly all 178 households; a few homes have individual wells or haul water. The FAA operates its own water system. Individual septic tanks are used by the majority of residents; a limited City sewage system serves approximately 34 homes. There are no road connections to McGrath, but local roads are used by ATVs and trucks. Winter trails are marked to Nikolai (50 mi.) and Takotna (20 mi.) Residents rely on air service and barges to deliver cargo. Air facilities include a State-owned 5,435' paved runway with a 1,700' crosswind landing strip, and a seaplane base on the Kuskokwim River.

The McGrath area has a cold, continental climate. Average summer temperatures range from 62°F to 80 ^{o}F, winter's temperatures can range from -64 ^{o}F to 0 ^{o}F. Precipitation is light, averaging 10 inches per year, including an average snowfall of 86 inches. The Kuskokwim River is generally ice-free from June through October. The NWS operates a weather observations site in McGrath.

North	East	South	West
Views in four cardinal directions from the McGrath Site			
Views in four cardinal directions toward the McGrath Site			

Trapper Creek (TRCR)

The Trapper Creek site is located near Trapper Creek Elementary School at IMPROVE site at latitude 62.3153º, longitude -150.315, and 155 meters (465 feet) above sea level. The site is located in a lightly populated residential area with a population of 423 (2000 Census). The Chulitna and Susitna Rivers and the village of Talkeetna, population 876 (2010 Census), are approximately 7 miles east of the site. The site is protected by the Alaska Range to the west and north and sits in the Susitna River valley which runs north to south. In summer it can receive flow from Cook Inlet and the southern part of the Susitna River to the mouth of the river. Trapper Creek is a regional-scale, rural to wilderness site. Trapper Creek is a small village providing minimal sources, wood smoke and road dust. Other sources outside the local area could include forest fire smoke, small particulate from winds off of nearby glaciers, industrial and dust particulates from Asia and/or Europe.

The Trapper Creek site was equipped with $PM_{2.5}$ IMPROVE monitors and two collocated Davis Rotating-drum Unit for Monitoring (DRUM) samplers running on a 6 week cycle with 3 hour sampling frequency. The DRUM sampler was installed on a 1.5 meter high stand approximately 1 meter from the IMPROVE shed. The nearest IMPROVE inlet head was on the other side of the shed from the DRUM sampler inlet head. The sampler was installed approximately 50 (150feet) from the dirt parking lot for the site. There is a row of trees approximately 50 meters (150 feet), at the closest point, skirting the southern and eastern exposures of the site. The trees are approximately 3-8 meters (9-24 feet) tall. Airflow is generally uninterrupted with the exception of the trees to the north-northeast.

The Trapper Creek Site is located approximately 0.2 miles southwest of Trapper Creek Elementary School and 2.5 miles west of the Parks Highway on Petersville Road. Traffic is light on the Petersville Road and moderate to heavy on the Parks highway during tourist season in the summer.

North	East	South	West
Views in four cardinal directions from the Trapper Creek Site			
Views in four cardinal directions toward the Trapper Creek Site			