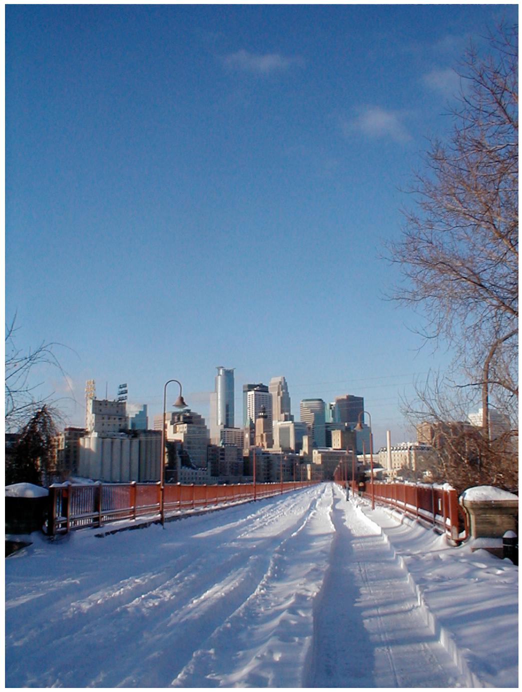
The Effects of Urban Sprawl on Snow Composition: Rural to Urban, Northfield to Minneapolis, Winter 2006



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ABSTRACT

Over the past 50 years, the United States' Midwest has seen a surge in urban and suburban growth in the areas of Chicago/Milwaukee, Kansas City, Cincinnati, Indianapolis, and Minneapolis/St. Paul [the Twin Cities]. Compositional changes in these cities' precipitation have accompanied this growth, which, in other areas of the country, contribute to such phenomena as acid rain and smog. Midwestern cities are interesting contrasts to other American cities because they possess predictable winter temperatures and weather systems, including frequent snow precipitation, from November through March. This study sought to investigate the effect of urban sprawl on snow composition by analyzing the variances in the chemical composition of snow collected throughout the winter from six fixed locations along US Interstate 35 between Northfield, MN, a rural suburb 40 miles south of the Twin Cities, and Minneapolis, MN. The chemical composition of the snow for the cations sodium, ammonium, lithium, potassium, magnesium, and calcium was determined using an Atomic Absorption Spectrometer and an Ion Chromatograph. The data collected was compared to previous data from 1980-1981 and 2004 of the snow composition for the area. The data evidenced a general trend of gradual increase for the cation concentration as the proximity of the collection site became closer to the urban center, which supports several conclusions.

INTRODUCTION

The 1990 U.S. Census determined that over 60% of the U.S. population lived either in suburbia or on the urban fringes of metropolitan areas, a major change from the first half of the century. As these metropolitan areas have expanded, the use of vehicles which emit chemical pollutants into the atmosphere has also risen (Meloski, *Automobile in American Life and Society*), as has the presence of polluting coal power plants, oil refineries, and factories. These factors can substantially affect the composition of precipitation, and the changes in the precipitation are indicative of their environmental impact. By collecting snow samples along the major thoroughfare (US Interstate 35 and 35W) between the Twin Cities and their southern suburbs, this study seeks to ascertain the affect of this pollution on precipitation, determine the differences in concentration in relation to distance, and establish the changes in composition since last measured in 1981 by the U.S. Geologic Survey (Peters 1982).

This USGS study measured the sodium, potassium, chloride, calcium, fluoride, sulfate, nitrate, lead, ammonium, iron, and arsenic levels in 179 sites across the northeastern and north-central United States. This study also gives us comparative data, though the closest collection sites were at 444205,933927 in Carver County, Minnesota. The results for these sites are show in Table 1. The differences in numbers will demonstrate how drastically the chemical composition of snow has changed in areas around Minneapolis over the past 25 years.

Table 1: Chemical concentrations in Carver County snowfall for 1980-1981 (Peters 1982)

	Ca (mg/L)	Cl (mg/L)	F (mg/L)	K (mg/L)	Li (µg/L)
Site 1	3.4	0.65	0.08	0.1	19
Site 2	2.9	0.77	0.07	0.01	<4
	Mg (mg/L)	NH4 (mg/L)	NO3 (mg/L)	Na (mg/L)	SO4 (mg/L)
Site 1	0.6	0.84	1	0.3	5.9
Site 2	0.6	0.8	0.9	0.3	4.4

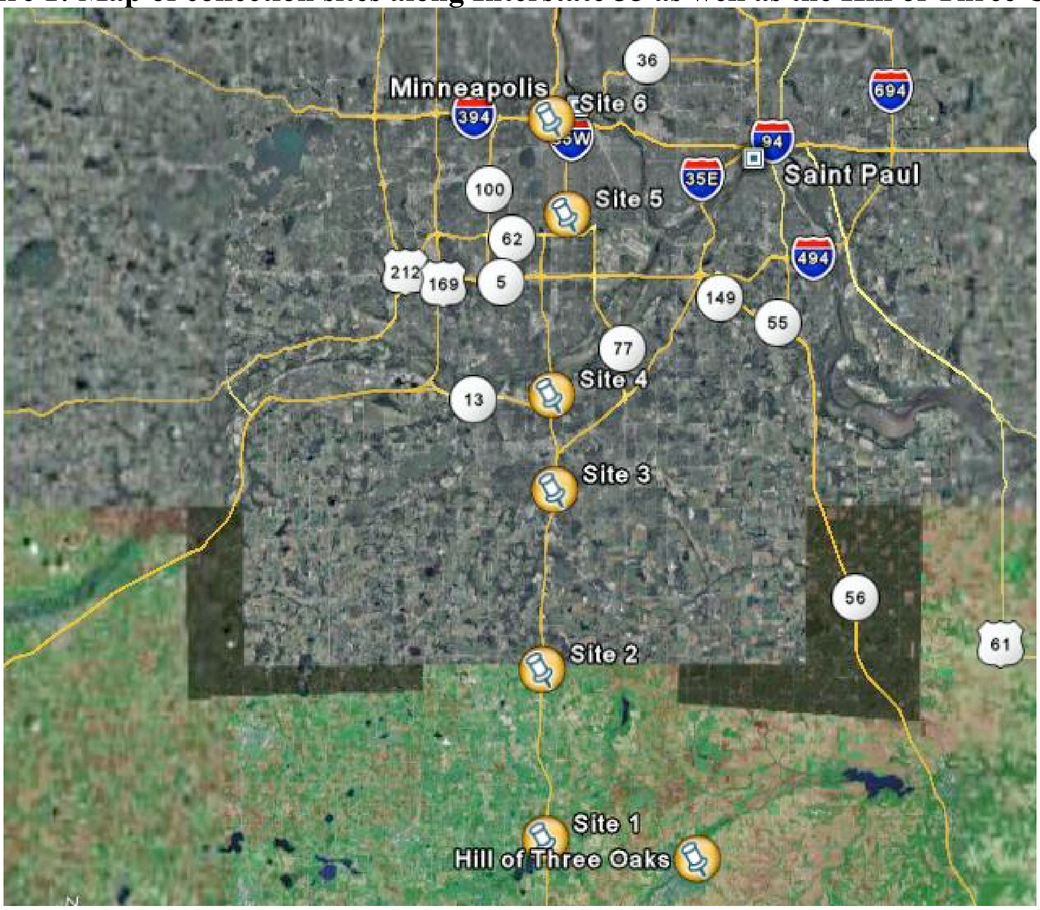
This study was modeled on the research and findings of several other scientists as well. In the study "Arctic Haze, Mercury and the Chemical Composition of Snow Across Northwestern Alaska" (2004), geologists gathered samples from three different layers of snow at sixteen different sites throughout Alaska and analyzed each sample's chemical composition, conductivity, and pH, and determine that the pollutants in the snow cause Alaska's arctic haze. Another study, "Accretion of Pollutants in Snow Exposed to Urban Traffic and Winter Storm Maintenance Activities" (2002), investigated pollutants in snow as a result of exposure to urban traffic and winter storm maintenance in urban Cincinnati. The researches discovered that because traffic levels were lower while it was snowing, fresh fallen snow had a consistent chemical composition and a pH variation of approximately one across the entire urban area, while the pH dropped and the chemical impurities of the snow increased the longer the snow was on the ground. . The conclusion of the research was that traffic and winter maintenance activities generate a great deal of pollution and that the closer the sites were to Cincinnati and the heavier the traffic was on the roads, the more pollutants, specifically heavy metals, were present. The study "Snow Quality in the city of Lulea, Sweeden" (1998) measured the amount of lead, zinc, copper, and phosphorus in the composition of the snow near the roads of Lulea, Sweden, an industrial city of approximately 70,000. The conclusions of the study include the discovery that the heavy metal concentration in the snow increased as the winter progressed because even though the snow melted as the particles remained in the snow collection and attributed the inconsistencies in the snow composition across different collection sites to the design and grade of the streets which affect runoff and the snow handling operation of Lulea. The final source we utilized were "pristine" snow data analysis from samples taken at Carleton College in the Winter of 2004 by Professor Bereket Haileab. Professor Haileab's samples provided a "pristine" sample with which to compare all of our results. This study seeks to build on all previous work addressing precipitation composition by demonstrating that a fundamental factor in the chemical concentration of snow is the increase in polluting emissions of suburban and metropolitan-based automobiles and heavy industry.

No study of this particular nature has been previously done at Carleton College. Many studies have been done concerning rainwater, lake water, and runoff; yet the composition of snow is seemingly new territory for the scope of these studies. The basis of this project has been the scale upon which it is premised: a distance long enough to compare incremental precipitation changes between the urban Minneapolis and rural Northfield. Given the increase in population, industry, energy creation, and automobile usage in suburban and urban areas, it is our claim that we will find increasing concentrations of chemicals found in urban pollutants in samples taken closer and closer to downtown Minneapolis. Analysis revealed that more factors were affecting chemical concentrations than just proximity to urban areas, so we expanded the scope of our study to consider how long the snow had been on the ground before we collected it and how far from the road the sample was collected.

METHODS

The major routes of transportation that connects the city of Minneapolis with its southern suburbs are US Interstates 35 and 35W. Therefore, the collection sites for this project were, for the most part, placed alongside this major thoroughfare. The collection sites were chosen on merits of location and practicality. A consistent range of distances was necessary between each collection site, and landmarks defined the sites within these ranges. Industrial areas, road signs, the Minneapolis Sculpture Garden, and a typical urban neighborhood were chosen for their application and recognition. Site one (1) was on mile marker 70 of Interstate 35 (N44_22.275', W93_17.508'); site two (2) was mile marker 78 (N44_35.340', W93_17.847') on the same highway; site three (3) was Exit 86 (N44_42.96', W93_17.076') on the highway, the off-ramp for the city of Lakeville, Minnesota; site four (4) was an industrial area along mile marker three (N44_46.78', W93_17.274') of Interstate 35W; site five (5) was an urban neighborhood road off exit 12B on Interstate 35W (N44_54.165', W93_16.452'), and site six (6) was the pond in the Minneapolis Sculpture Garden in downtown Minneapolis (N44_58.148', W93_17.345'). Snow was collected from these sites on January 31, February 3, and Feburary 10, 2006. Snow was also collected from the Hill of Three Oaks at Carleton College in Northfield, Minnesota (N44_46', W93_14'). The sites are shown in Figure 1. Samples were collected from this site on January 17, January 29, and Feburary 9, 2006.

Figure 1: Map of collection sites along Interstate 35 as well as the Hill of Three Oaks



The samples were obtained by scooping snow from the surface of the snow cover at selected roadside collection sites into clean, gallon-sized Nalgene beakers. The samples were loaded into a car, labeled, and covered. At the time of collection, the longitude and latitude of the sites were determined. The samples were allowed to melt in a controlled-temperature laboratory and were, once liquid, transferred into glass or plastic collection receptacles and refrigerated.

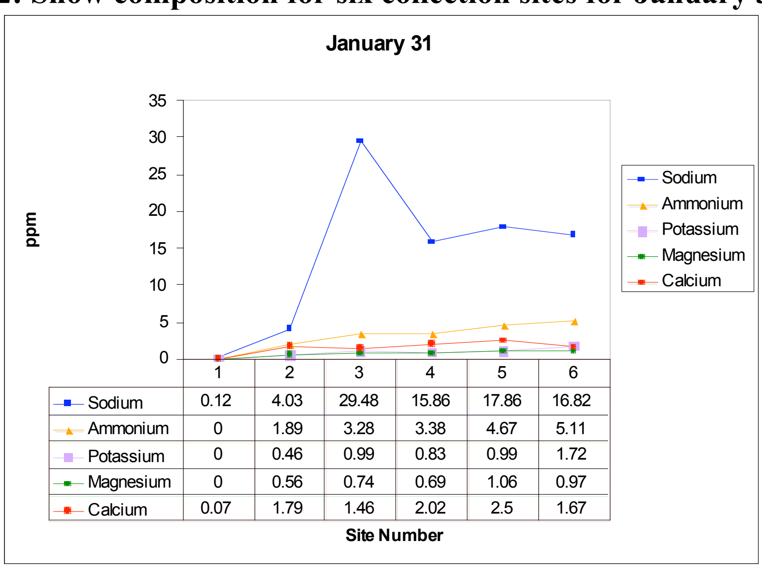
The chemical compositions of the samples were determined with the use of an atomic absorption machine and an ion chromatograph. The former determined the presence of sodium in all samples by igniting samples of the water while shining an element-enforced light bulb through the flame and analyzing the light spectrum absorbed from the combination of the two. The machine was recalibrated before every test to ensure accuracy. The latter forced the water samples through pressurized columns and determined the ionic compositions of sodium, ammonium, lithium, magnesium, potassium, and calcium. The results were entered into Microsoft Excel, which was also the medium for our graphs and tables.

RESULTS

We can gather a number of observations from the cation results from the ion chromatograph. These observations divided by collection date to acknowledge the inherent initial compositional differences between each snowfall, and further divided by element as to show the difference in chemical concentrations in relation to the sample's location. We also collected data from the Hill of Three Oaks and made observations about the individual sites and the distribution of cations. Our results conclude with observations about the weather patterns which caused these snowfalls.

January 31st, 2006

Figure 2: Snow composition for six collection sites for January 31, 2006



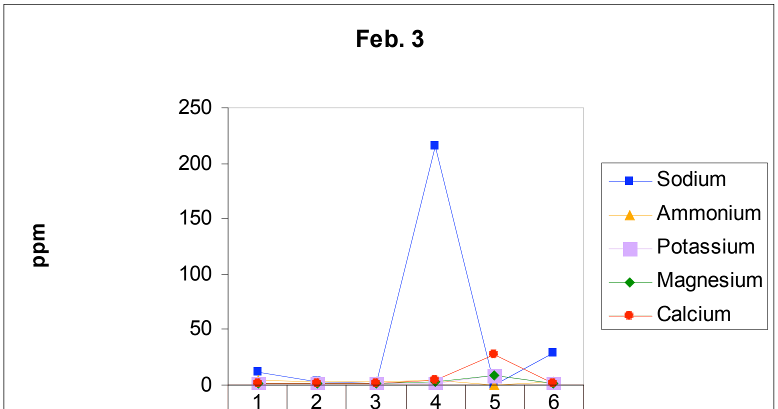
	1	2	3	4	5	6
Sodium	0.12	4.03	29.48	15.86	17.86	16.82
Ammonium	0	1.89	3.28	3.38	4.67	5.11
Potassium	0	0.46	0.99	0.83	0.99	1.72
Magnesium	0	0.56	0.74	0.69	1.06	0.97
Calcium	0.07	1.79	1.46	2.02	2.5	1.67

Out of all the collections, the snowfall from the six sites collected on January 31, 2006 has the most consistent and positive slope. Site 1 has the most "pure" sample, with the fewest results of cations, while Site 6 has overall the highest concentrations of cations. The sodium content in all samples is disproportionately more concentrated than the other samples, a trend which appeared in all collection sets. The compositional results of all the sites and of all the elements by site are in the Appendix.

February 3, 2006

At this snowfall, Site 1 had considerable changes, possessing concentrations in five elements rather than two. The sodium level at Site 4 is very concentrated, and the "0" reading at

Figure 3: Snow composition for six collection sites from February 3, 2006



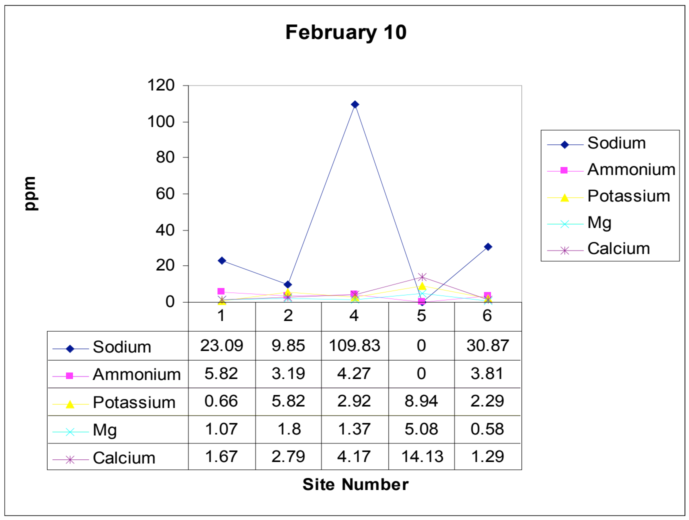
Site Number	1	2	3	4	5	6
Sodium	10.88	2.33	1.203	215.2	0	28.36
Ammonium	3.7	2.72	2.59	4.53	0	3.5
Potassium	1.3	0.87	0.73	0.98	8.28	1.41
Magnesium	0.73	1.58	1.06	2.4	8.6	1.13
Calcium	1.33	1.89	1.3	3.64	26.83	1.87

Site 5 suggests that the snow sample was saturated with an immeasurable amount of sodium, especially with the comparatively high potassium and calcium readings at the site.

February 10, 2006

Once again, Site 5 registered a “0” for sodium while possessing the highest concentrations of most other elements. The February 10 collection confirms the consistency of the other dates, as Site 4 also possesses a sodium “peak” like the February 3 collection.

Figure 4: Snow composition for five of six sites for February 10, 2006



Locations

To gauge the concentrations of our samples to determine if they possessed pollutants, our study possessed a controlled variable at the Hill of Three Oaks in Northfield, MN (N44_46’, W93_14’). Located on the northeast corner of Carleton College’s campus and far away from roads in a rural environment, this location allowed from us to have a “clean” sample from which to compare the snow gathered from each collection site. Table 2 illustrates our control values at the hill. The snow collected on January 17th is disproportionately inflated to the other two dates.

Table 2: Snow composition results from the Hill of Three Oaks

Collection Date	Na (ppm)	NH4 (ppm)	K (ppm)	Mg (ppm)	Ca (ppm)
1/17/2006	16.95	4.07	2.13	0.73	1.36
1/29/2006	3.03	3.63	0.58	0.43	0.93
2/9/2006	1.04	0.35	0.93	0.21	0.37

The locations of our collection sites varied from rural to urban, and undoubtedly affect the chemical composition of our data. The various and inconsistent distances from the interstate are explained by the sheer logistics of collecting on a busy thoroughfare. Site 1, a road sign at mile marker 70 along Interstate 35 (N44_22.275', W93_17.508') was approximately 15 yards from the southbound lane of the highway, surrounded by prairie grass in a rural environment. The second site was approximately 25 yards from the northbound lane of the same highway at mile marker 78 (N44_35.340', W93_17.847') and was also in a rural environment. Site 3 was the first collection area in suburbia, and was approximately five yards from the southbound exit 86 ramp (N44_42.96', W93_17.076'). The collection area had a gravel base and was close to the pavement. Site 4 was approximately 100 yards from Interstate 35W mile marker 3 (N44_46.78', W93_17.274'). The area, surrounded by prairie grass, was near an industrial runoff creek, a set of railroad tracks, and a grain elevator. Site 5 was a pavement collection site in an urban neighborhood in the city limits of Minneapolis (N44_54.165', W93_16.452'). During all of our collections, the city roads had already been plowed, though we strove to scoop the snow from untainted driveways. Finally, the snow from Site 6 was obtained by scooping the top layer off an untainted frozen pond at the center of the Walker Sculpture Garden (N44_54.165', W93_16.452'), and is therefore the only sample which was not packed around pavement, gravel, or grass.

Cation Specifics

Sodium (see Figure 6) was found most frequently among the elements at each site and tended to be at the highest concentrations at each site though it followed no linear or consistent trend. This fluctuation is discussed below. Ammonium (see Figure 7) was found at most sites in consistently low concentrations, and both ammonium and calcium concentrations followed little linear pattern as well. Though we tested for lithium, it did not prove relevant to our discussion as it was only found at one out of six collection sites and only in trace amounts. Magnesium (see

Figure 9) was present at nearly each site, and it consistently followed an ascending trend between sites 1 through 5 on all three collection days but then dropped significantly at the Walker Sculpture Garden (see Figures 2-4).

Weather Patterns

On January 31, the snow that we collected had been part of a north moving air drift which began overt the Gulf of Mexico on January 28. The front moved northward slowly eventually meeting a west moving air front from the Great lakes forcing the air to circle back over southern Minnesota and fall late on January 30. The snow that fell on February 3 came from a western air front which originated along the Pacific Coast west of Washington State. It moved across the plains, picking up speed over Wyoming and the Dakotas late on February 1. The snow that fell on February 3 was the tail end of this air front, which eventually, late on February 3 would collide with a north-moving front from the Gulf of Mexico around western Indiana and then continued to move east. Finally, the snow that fell on February 10 was part of a west moving air front which originated on February 9 in southern Alberta and Western Wyoming. It picked up speed over the Dakotas and fell mid-day on February 10.

DISCUSSION

One of the factors that influenced concentration levels of certain elements appeared to be the amount of time snow was on the ground before it was collected. Our original hypothesis, that snow samples would contain increasing concentrations of pollutant elements the closer they were to the city, was correct when applied to samples that had been on the ground for more than one week. The snow collected on January 31st had been on the ground for more than two days, and four out of the five elements increased concentrations nearly linearly as they were taken closer and closer to downtown Minneapolis. The snow was collected the same day it fell on both

February 3rd and 10th, and these samples did not follow our hypothesis clearly. Both samples had higher concentrations of some elements closer to the city, but the pattern was not linear or predictable. Therefore, snow composition changes the longer it is exposed to the pollutants in the air and on the ground in urban environments, and the longer the snow sits, the higher the levels of pollutants will be.

Our original hypothesis proved correct in that concentrations of most elements increased in samples taken closer and closer to downtown Minneapolis. Our sample from January 31st shows this pattern most clearly, but some increase in elemental concentration occurred in samples from every test date. On January 31st, the highest concentrations of Ammonium, Potassium, Magnesium, and Calcium were found at the two sites closest to the city. Because the sample from this date is most reflective of the surrounding environment, this collection is considered the most significant.

Another factor influencing element concentration is how far from the road samples were collected. Depending on the availability of snow, we took samples from between 2 and about 140 yards from the highway. At Site 3, we collected snow once 140 yards from the road and twice about 30 yards away. The sodium concentrations were significantly higher in the samples collected closer to the highway. This is logical because the highway had recently been salted before each collection, so samples taken closer to the road absorbed more sodium.

When interpreting the presence of cations in our samples, each sample must remain relative to the control, in this case the samples from the Hill of Three Oaks. However, we can still make some inferences based on the data. First, the exponentially increased amounts of sodium, potassium, and calcium compared to the controlled sample can be attributed to the winter maintenance of the roads. All three are used extensively to lower the freezing temperature of ice when in an aqueous solution with a chloride anion. This explains why the most urban sample—Site 6—does not have the highest concentrations of these cations, as the collection site was not on or near a roadside but rather on a frozen body of water. It also illuminates why Site 5 possessed an immeasurable amount of sodium and disproportionately high levels of potassium and calcium, as a neighborhood road is salted but does not receive enough traffic to quickly remove and distribute the particles. However, this practice of adding said compounds to roadways does not explain the initially high levels of sodium for the Hill of Three Oaks on January 17. However, snow is naturally sodium-enriched, as the North American weather systems which distribute the snow absorb most of their moisture from the "salty" bodies of the Pacific Ocean or Gulf of Mexico. The snow from January 17 was also the oldest snow collected at the control site, suggesting that it may be a composite of past snows rather than just representative of one snow.

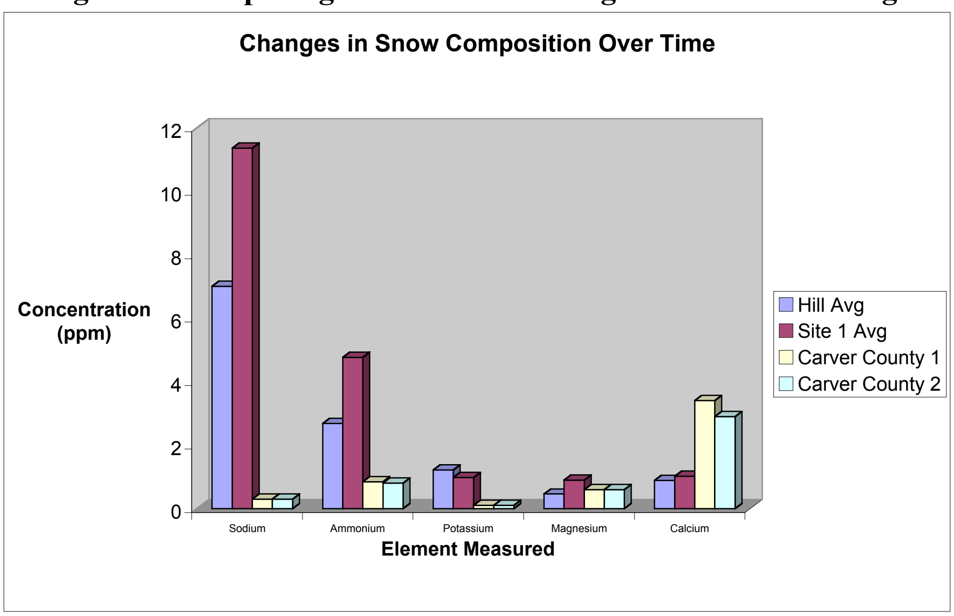
By using Professor Haileab's results from 2004, we can further compare our "control" samples from the Hill of Three Oaks and our findings with the "pristine" samples to further gauge the degree of concentration changes from their "pristine" form. An example of the change between our results and the pristine snowfall can be seen in the increased magnesium concentrations from the pristine samples compared to those of the Hill and those from Collection Site Six at the Walker Sculpture Garden as shown in Table 3. This confirms our hypothesis that the concentrations of particles increase in an urban environment.

Table 3: Differences in magnesium concentrations of snow samples contrasting time and location

Winter 2004: Mudd Hall, Carleton College		Winter 2006: Hill of Three Oaks, Carleton College		Winter 2006: Collection Site 6, Walker Sculpture Garden	
February 1	0.192	January 17	0.73	January 31	0.97
March 3	0.0535	January 29	0.43	February 3	1.13
March 10	0.2554	January 9	0.21	February 10	0.58

Though the snow samples may appear to be "polluted," they are within the acceptable range of the Environmental Protection Agency Clear Water Act's standards. Despite being politically "unpolluted," the presence of the cation calcium suggests something more that the use of calcium chloride ($CaCl2$) to melt ice-covered roads. When acidic precipitation falls to the ground, it reacts with the calcium carbonate ($CaCO3$) in the clay-rich soil, leaving calcium cations dissolved in embankments of snow. However, when the controlled data and the data from the six sites are compared with Peter's study from 1980-1981, it is clear that calcium levels have actually dropped over the past 25 years. Figure 5 compares the two Carver County sites in Peter's study with the two most similar sites in our study, the Hill of Three Oaks and Site 1.

Figure 5: Comparing Peter's 1982 findings to our 2006 findings



Yet calcium is the only element which has a significant drop—in fact, the concentrations of sodium and ammonium in the snow have sizably increased in the past 25 years. Though this study did not investigate the soil surrounding the collection sites, it is possible that the top soil surrounding roadways are overly saline, which may be detrimental to the regional water table and crop production. Additionally, the presence of ammonium in almost all of our samples hints that particles from fertilizer have permeated the snow both as dust particles in the sky and directly from the soil. However, all of these claims cannot be strongly supported or endorsed without further research and data analysis and must be dismissed as only theories.

CONCLUSION

It would be scientifically unsound to conclude that concentration increases between Northfield and Minneapolis reflect increases of pollution in urban areas. The increase in cations could be due to pollution, but could also be attributed to the salting of the roads, the origins of the snow-producing weather systems, dust particles in the air from gravel roads, the pre-snowfall condition of the collection site, the amount of time the snow has sat on the ground prior to collection, and fertilizer run-off, among others. Given more time and more research, we could develop more conclusive theories as to the causes of the changing snow concentrations. One area that would be of benefit would be to study certain key anions such as sulfate, nitrate, and phosphate, as well as the pH of the snow. Such data could lead to conclusions about the acidity and the presence of pollutants in the snow samples as well as in the air drifts which bring the snow to southern Minnesota. Though we do not have overwhelming evidence to prove our initial claim that pollutant concentrations increase as distance to downtown Minneapolis decreases (and all the environmental ills that come with it), we feel that the evidence we did gather certainly supports this claim. With the addition of further evidence, the difference in snow composition between rural and urban areas could reveal even more about the many influences and dangers the environment faces.

ACKNOWLEDGEMENTS

Our group would like to thank Professor Bereket Haileab, Ellen Root, Tim Vick, and Carleton College Geology Department. We could not have completed our project without their support.

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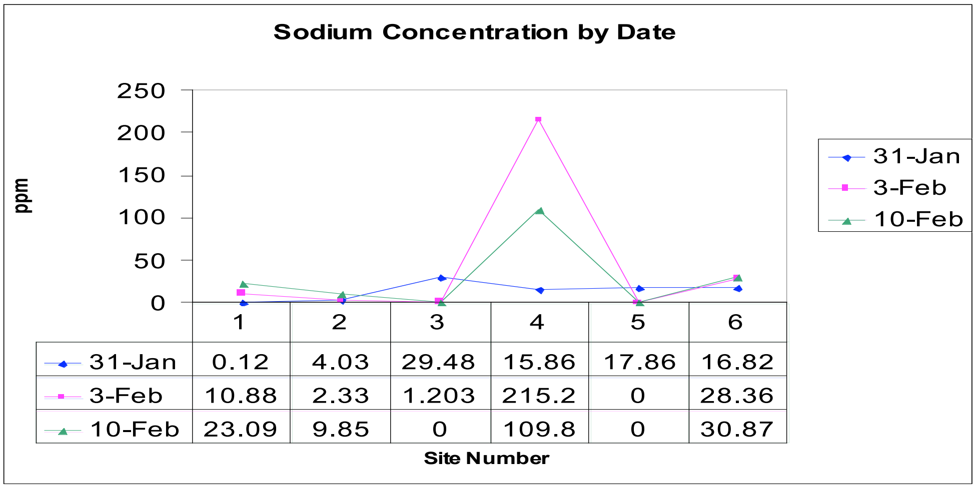
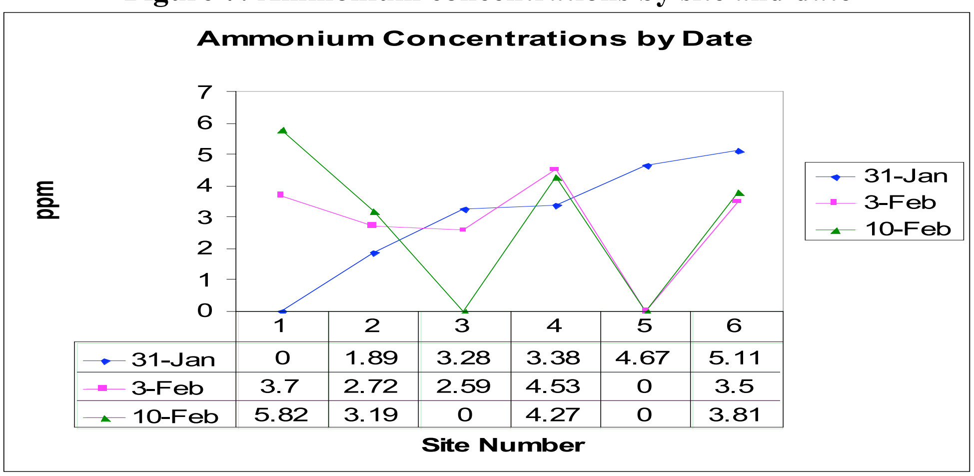
APPENDIX

Figure 6: Sodium concentrations by site and date



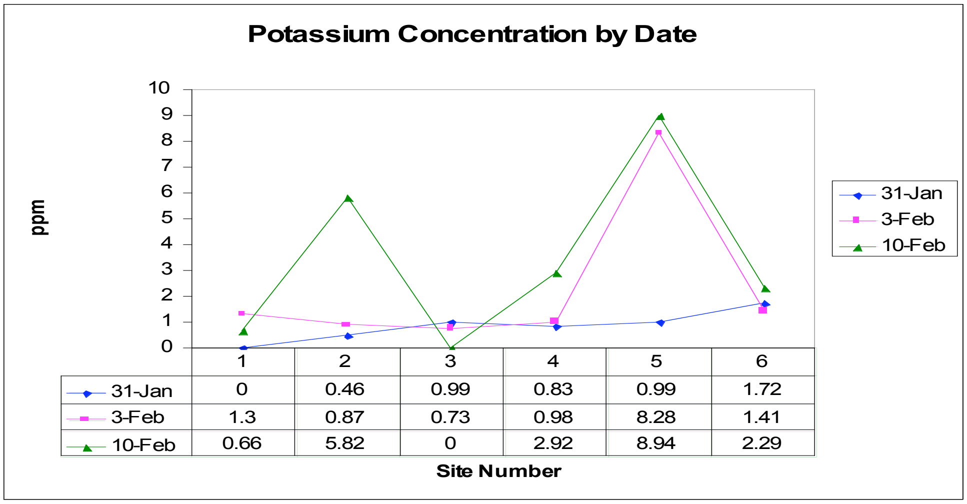
	1	2	3	4	5	6
31-Jan	0.12	4.03	29.48	15.86	17.86	16.82
3-Feb	10.88	2.33	1.203	215.2	0	28.36
10-Feb	23.09	9.85	0	109.8	0	30.87

Figure 7: Ammonium concentrations by site and date



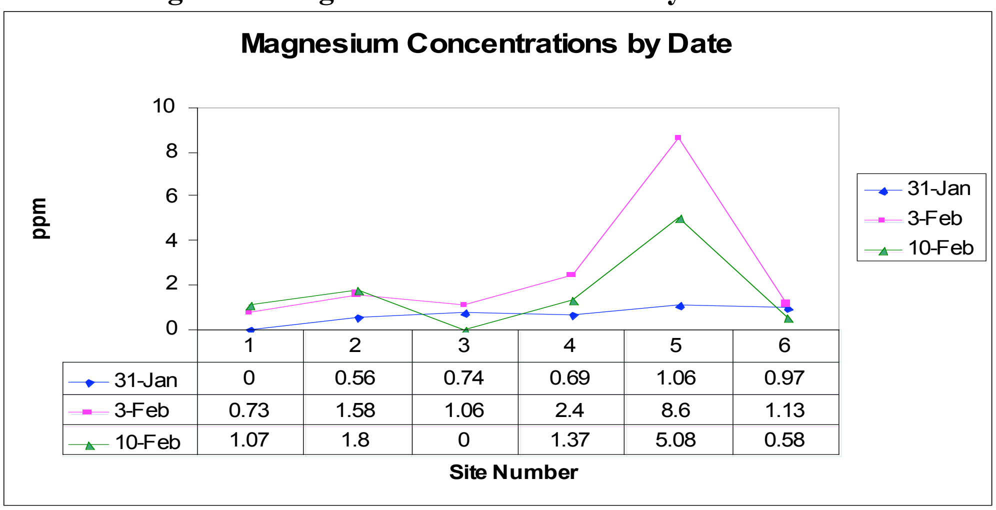
	1	2	3	4	5	6
31-Jan	0	1.89	3.28	3.38	4.67	5.11
3-Feb	3.7	2.72	2.59	4.53	0	3.5
10-Feb	5.82	3.19	0	4.27	0	3.81

Figure 8: Potassium concentrations by site and date



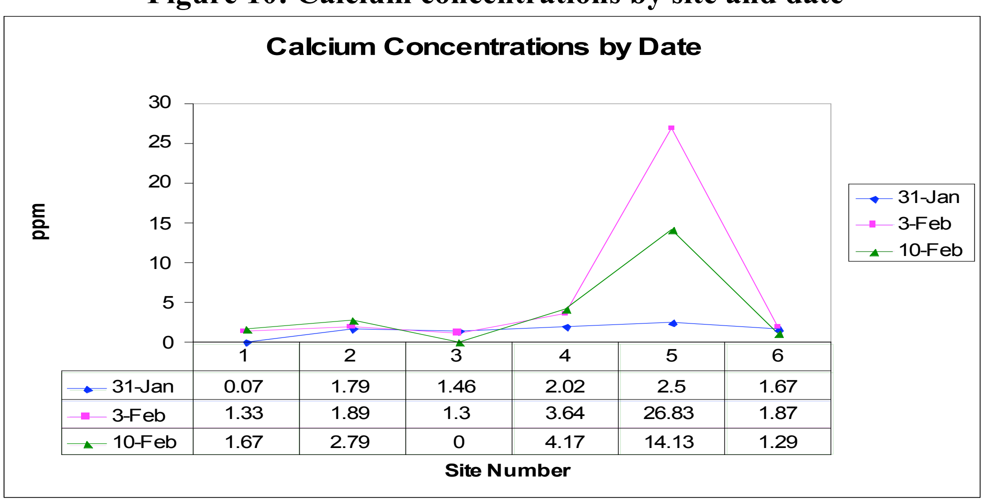
	1	2	3	4	5	6
31-Jan	0	0.46	0.99	0.83	0.99	1.72
3-Feb	1.3	0.87	0.73	0.98	8.28	1.41
10-Feb	0.66	5.82	0	2.92	8.94	2.29

Figure 9: Magnesium concentrations by site and date



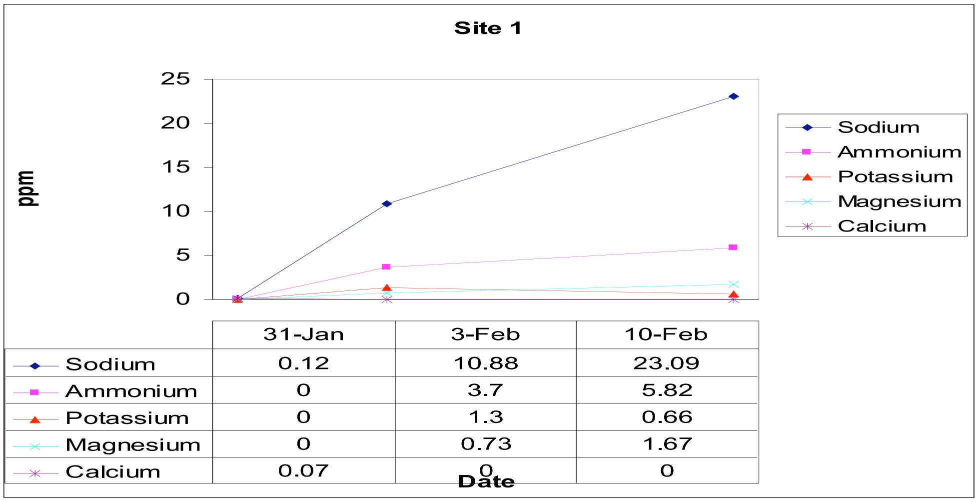
	1	2	3	4	5	6
31-Jan	0	0.56	0.74	0.69	1.06	0.97
3-Feb	0.73	1.58	1.06	2.4	8.6	1.13
10-Feb	1.07	1.8	0	1.37	5.08	0.58

Figure 10: Calcium concentrations by site and date



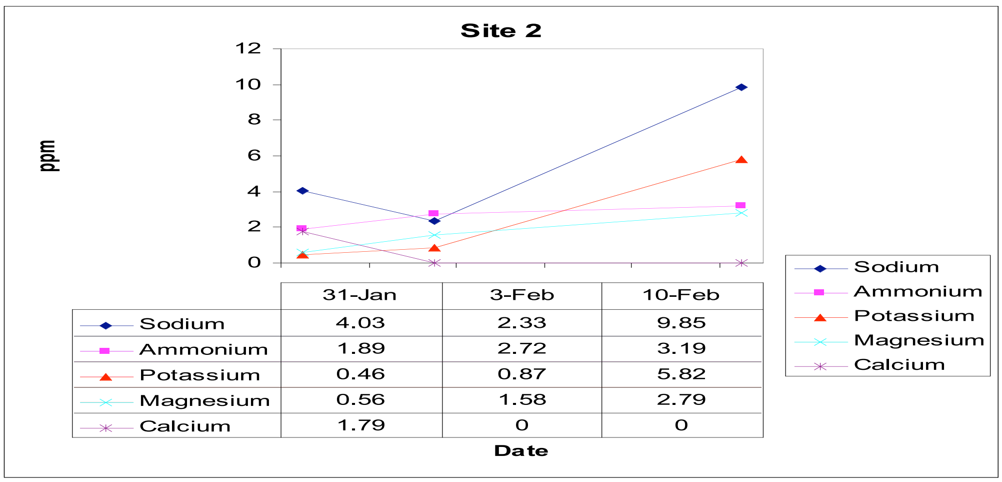
	1	2	3	4	5	6
31-Jan	0.07	1.79	1.46	2.02	2.5	1.67
3-Feb	1.33	1.89	1.3	3.64	26.83	1.87
10-Feb	1.67	2.79	0	4.17	14.13	1.29

Figure 11: Snow composition by element and date at Site 1



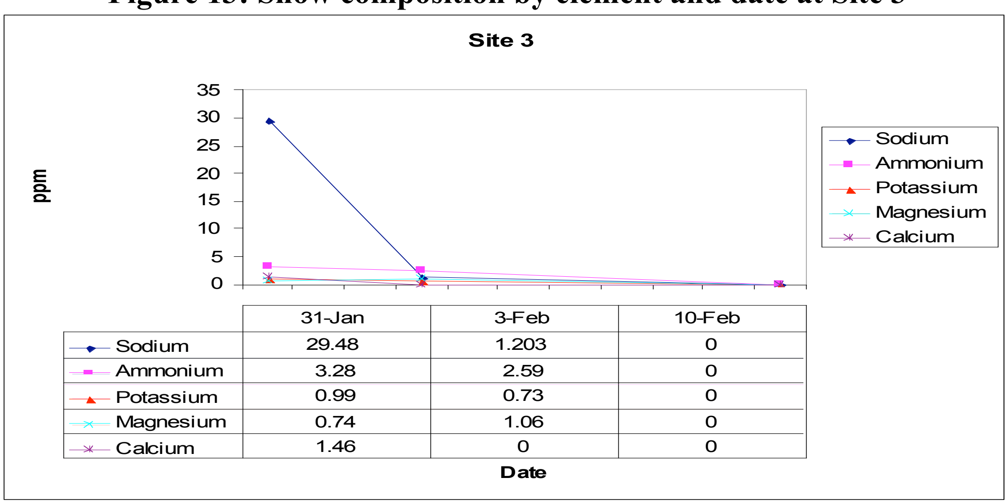
	31-Jan	3-Feb	10-Feb
Sodium	0.12	10.88	23.09
Ammonium	0	3.7	5.82
Potassium	0	1.3	0.66
Magnesium	0	0.73	1.67
Calcium	0.07	0	0

Figure 12: Snow composition by element and date at Site 2



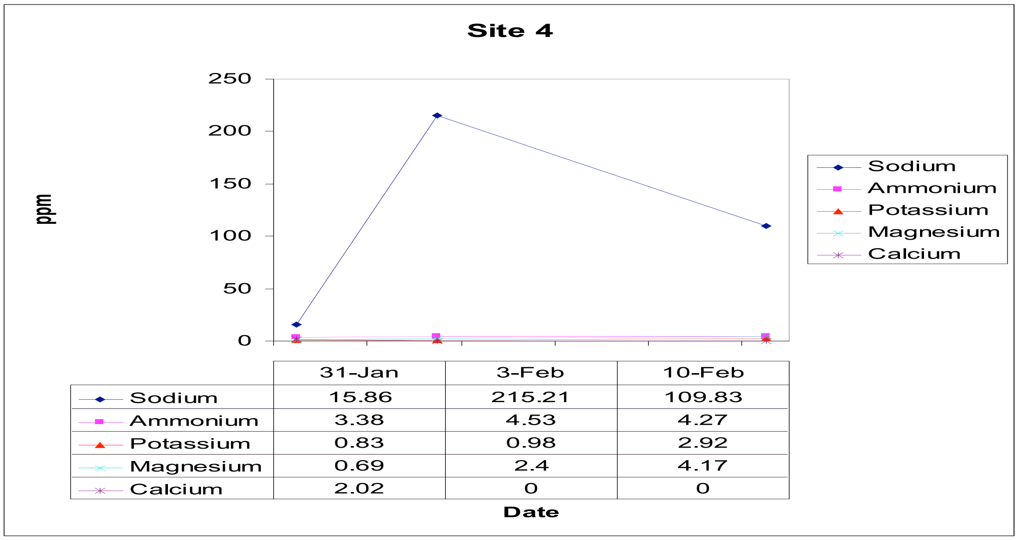
	31-Jan	3-Feb	10-Feb
Sodium	4.03	2.33	9.85
Ammonium	1.89	2.72	3.19
Potassium	0.46	0.87	5.82
Magnesium	0.56	1.58	2.79
Calcium	1.79	0	0

Figure 13: Snow composition by element and date at Site 3



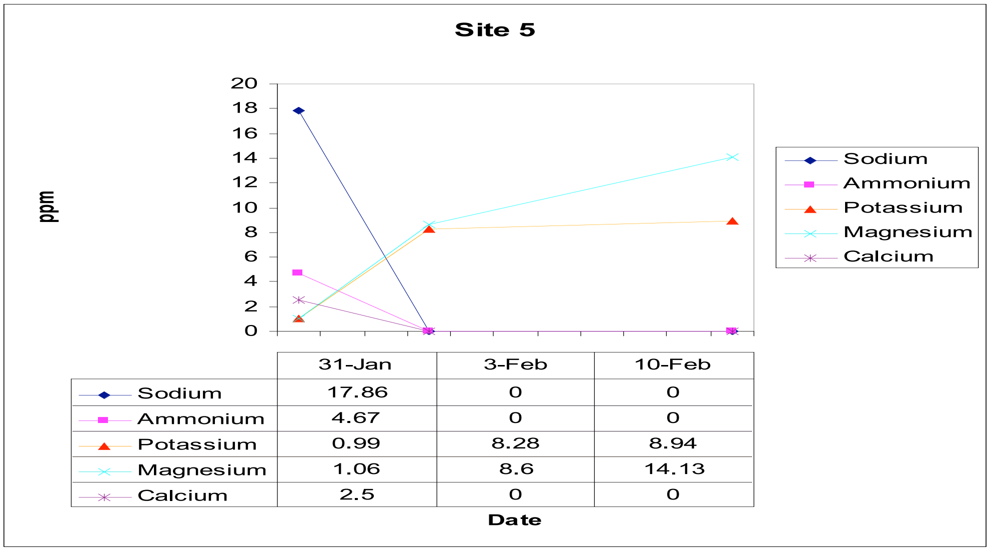
	31-Jan	3-Feb	10-Feb
Sodium	29.48	1.203	0
Ammonium	3.28	2.59	0
Potassium	0.99	0.73	0
Magnesium	0.74	1.06	0
Calcium	1.46	0	0

Figure 14: Snow composition by element and date at Site 4



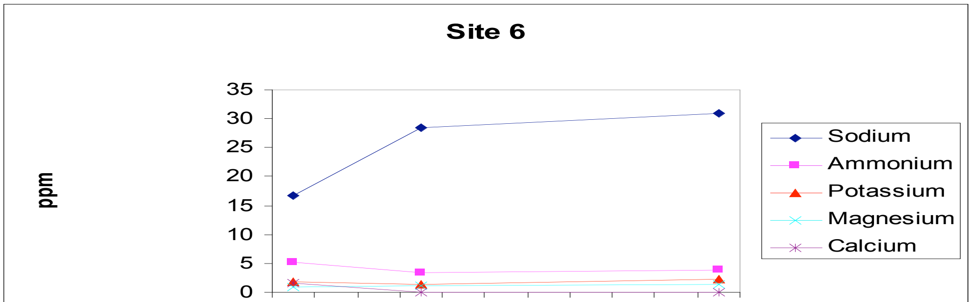
	31-Jan	3-Feb	10-Feb
Sodium	15.86	215.21	109.83
Ammonium	3.38	4.53	4.27
Potassium	0.83	0.98	2.92
Magnesium	0.69	2.4	4.17
Calcium	2.02	0	0

Figure 15: Snow composition by element and date at Site 5



	31-Jan	3-Feb	10-Feb
Sodium	17.86	0	0
Ammonium	4.67	0	0
Potassium	0.99	8.28	8.94
Magnesium	1.06	8.6	14.13
Calcium	2.5	0	0

Figure 16: Snow composition by element and date at Site 6



	31-Jan	3-Feb	10-Feb
Sodium	16.82	28.36	30.87
Ammonium	5.11	3.5	3.81
Potassium	1.72	1.41	2.29
Magnesium	0.97	1.13	1.29
Calcium	1.67	0	0

Date