Rainwater Composition Analysis

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Introduction[IL1]

In a study conducted in 2004 by E. Root, W. Jones, B. Schwarz, and J. Gibbons, rainwater samples were collected from Carleton College Geology Alumni across the country. 51 samples were collected from every major geographic region of the United States, containing water from a variety of weather systems. Samples were also collected by Root, et al., on the Carleton College campus. Samples were stored in a refrigerator to prevent evaporation.

26 of the collected water samples were analyzed at the University of Utah for δ^{18}O analysis. All of the samples were analyzed for anion content using the Ion Chromatograph at Carleton College. Seven anions were tested for: chloride, flouride, bromide, sulfate, nitrate, phosphate, and nitrite. Of these, only fluoride and bromide were not present in any of the water samples. (*See Figure 4, Root, et al.*) Chloride was found in all of the water samples, with the highest concentrations found in samples taken from the coastal regions of the U.S. Sulfate was found in 49 of the 51 samples. Nitrate was found in 43 of the 51 samples. Phosphate was found in only 7 samples. Nitrite was found in just 5 of the samples.

The 26 water samples analyzed for oxygen isotope 18 were tested based on the standard of ocean water, which is rich in the oxygen 18 isotope, and has an oxygen isotopic 18 value of 0. The samples ranged in value from –1.92 (Kurtistown, HI) to –18.66 (Great Falls, MT) (*See Figure 11, Root, et al.*). The lower negative numbers indicate heavier water, with less oxygen isotope 18. The heaviest water in the study was found along the west coast of the U.S.

In summary, Root, et al., 2004, discovered that the anion content of rainwater tends to include chloride, nitrate, and sulfate anions. Phosphate and nitrite anions are generally less prevalent. The concentration of chloride anions corresponds strongly to the geographic region in which the rainwater is collected, with the highest concentrations found on the coasts (near the salt water of the oceans). Oxygen isotope 18 levels also were found to be dependent on geographic location, as well as altitude, amount of rainfall, and distance from the source water in the storm (usually oceans).

Our aim in this study is to further examine the data collected for the study *Rainwater Chemistry across the United States (Root et al, 2004).* We analyzed the data for trends including patterns in ion concentration based on: population density, latitude and longitude, geographic features (Rocky Mountains, Appalachian Mountains, and the Great Lakes), and weather patterns and storms. Also in this paper will be suggestions on improvements of the past study for future research.

In this paper, we will first discuss the quality of results of the study *Rainwater Chemistry across the United States (Root et al, 2004),* then analyze the data to find trends in ion concentrations across the nation. We will point out possible reasons and/or factors for these trends. We will then discuss potential extensions of this study to further test the factors we believe contribute to the trends.

Overview of Resources

Literature

Stable Isotope Ratios of Rain and Vapor in 1995 hurricanes, written by J.R. Lawrence, S.D. Gedzelman, X. Zhang, and R. Arnold is a study that looks at the isotope ratios of water vapor and rain samples collected at the surface of four cyclones during the 1995 hurricane season. Lawrence, et al., found that the inward decrease of the isotope ratios is due to the "diffusive isotopic exchange between falling rain and converging vapor in the atmospheric boundary layer." They also found that the larger the hurricane was, the lower the isotope ratios became and vice versa. All of the hurricanes that they studied followed this pattern except for some samples that they took from both Hurricane Luis in Puerto Rico and Hurricane Opal. These differences were attributed to the storms' rain bands and Hurricane Opal's asymmetric structure. This study is useful in that it will shed more light on the results of isotope analysis done on samples collected on the edges of hurricanes.

Hurricanes Pauline and Nora Rainwater Chemical Composition, written by H.G. Padilla, R. Belmont, M.B. Torres, and A.P. Báez in 2000, discusses the chemical composition of rainwater from two hurricanes sampled at the pacific coast of Mexico. They found an excess amount of sulfate near the center of hurricane Pauline in addition to excess amounts of sodium and chloride that were found in samples from both hurricanes. However, many of these excesses were very small and close to being undetectable. The study also looked at the effect that a power plant in Manzanillo had on the chemical composition of rains sampled from Hurricane Nora. This study is important as it gives us insight into the effect that one man-made factor, in this case as power plant, can have on rain samples, like the ones that Root, et al., analyzed last year. Not only should we be looking at the location and geographical features of the towns and cities that samples were being taken from, we should also be looking at the man-made structures that could be influencing the chemical compositions of the samples.

Inside Rain is a report produced by the National Atmospheric Deposition Program whose program's object is to "characterize the chemical climate of the United States" (Lear, et al., 3). The programs monitors 220 locations across the United States where they test for acidity, sulfate, nitrate, ammonium, chloride, and base cations. The research conducted has provided average annual concentrations of the above ions and the locations where concentrations of those ions are high and low. The report also speaks to the sources of excess ions and the impact on these concentrations due to human activity.

In a study conducted by Matt Haugland ?? entitled *The Rain Shadow Effect*, rain gauges were set up in the San Jose valley at incremental distances from the Sierra Azul Mountains, which, 800m high, served as the mountain that would create the rain shadow effect. The amount of rainfall at each location was gathered during three different storms. In conclusion, Haugland found that, at first, the amount of rainfall declined sharply as elevation dropped and then leveled out further from the mountain (12-17km). Plotting the points he was able to correlate the amount of rainfall with the distance from the mountain. With this information, he separated out two effects wind had on the storms: the wind pushed the storm clouds up and over the mountains and after clearing the mountain, because there is no force on them, they continue moving and dropping less and less precipitation. Both cloud height and wind speed effect the slope of the line of the rainfall amount vs. km from mountains. A less steep slope can be caused by either faster winds or higher winds, as both spread the precipitation over a greater area, where as, a steeper slope is the result of slower or lower clouds for exactly the opposite reason.

In 2001, in *Ionic Composition of precipitation at the Central Anatolia (Turkey)*, B. Tuncer, B. Bayar, C. Yeilyurt, and G. Tuncel sought to discover the reasons and sources for the concentrations of major ions in rainfall at one collection site in Turkey. In their study they were searching for concentrations of SO_4^{2-}, NO_3^-, Cl^-, H^+, Ca^{2+}, K^+, and Mg^{2+}. Previous work in this area led Tuncer et al. to know that chemical composition of rainwater in the Mediterranean can be caused by two major factors: dust transported from North Africa (Kubilay and Saydam, 1995) and pollution aerosol from Europe (Bergametti et al., 1989). One source suggests that local anthropogenic emissions could affect rainwater composition as well (Gullu et al., 1998). By the end of their study, Tuncer et al. were able to conclude that "unusually high concentrations of SO_4^{2-} and NO_3^- suggest that the Anatolia plateau is under strong influence of pollution transport from high emission areas".

Images and Maps

The National Atmospheric Deposition Program has generated isopleth maps of Sulfate (SO_4^-), Nitrate? (NO_3), Calcium (Ca^{2+}), Magnesium (Mg^{2+}), Potassium (K^+), Sodium (Na^+), and Chloride (Cl^-) ion concentrations. Although the data collected extends to 1994, the images generated from the 2004 data will be used, as it is most pertinent to our study.

The National Atlas (nationalatlas.gov) has used information from the U.S. Geological Survey, U.S. Environmental Protection Agency, and the Natural Resources Conservation Service to generate maps that show trends of population density, average annual rainfall, and air release of pollutants.

Methods

In the fall of 2004, Root, et al., sent 150mL collection vials to family, friends, and alumni for collection of rainwater. Information about ------- was returned with each sample. In total, 51 samples were returned from varying locations around the United States. The samples were filtered through a .25 μm filter before being passed through the Ion Chromatograph. The students used standard Ion Chromatograph methods to test for the following anions: Fluoride, Chloride, Bromide, Nitrite, Nitrate, Phosphate, Sulfate and cations: Magnesium, Potassium, Ammonium, Calcium, and Sodium.

The Ion Chromatograph is a helpful tool that analyzes concentrations of anions and cations in solutions. It works by separating ions by their relative affinities for an ionic standard. ------

Discussion:

Old Data Analysis

When looking at the data collected by Root, et al. compared to the data compiled by the National Atmospheric Deposition Program (NADP) several trends emerge. The first trend that we can see is that the ion concentrations in the study done by Root, et al. are, for the most part, noticeably higher than the 2004 fall national averages compiled by the NADP. However, the concentrations of the two studies were closer in sulfate, chloride, and nitrate than they were in calcium, magnesium, ammonium, potassium, and sodium.

When comparing the data collected by Root, et al. 2004, to the data collected by the NADP, a nationwide network of precipitation monitoring sites, there are some overwhelming discrepancies. However, while the differences in ion concentrations between the study conducted by Root, et al. and the 2004 fall national averages are significant, there are also several reasons for the disparities.

Firstly, the conditions under which the samples were collected for ion concentration analysis, by the sites that participate in the NADP, are put much more emphasis on issues of both quality assurance (QA) and quality control (QC). Collection sites follow strict guidelines enforced by the NADP and if there data is not up to the standards of the NADP, the sample is either not included in averages or the fact that the sample did not meet NADP standards is disclosed. While the study conducted by Root, et al. eliminated samples that were obviously fit to be included in the study (one participant collected rainwater by filling his sample bottle with run-off from a drain), Future studies should either follow a stricter set of guidelines or write a more in depth disclosure of the quality of their samples.

Number	Location	Ca National	Ca	K National	K
28	Northfield, MN	0.32	0.09	0.018	1.08
29	Northfield, MN	0.32	0.18	0.018	1.55
30	Northfield, MN	0.32	0.81	0.018	1.95
31	Northfield, MN	0.32	0.43	0.018	2.16

One of the reasons the NADP collects a multitude of samples before issuing their annual and seasonal averages is because there are many things such as hurricanes, other weather systems, and the amount of precipitation in a specific area that can influence the ion concentrations of samples. Because the study by Root, et al. in most cases only had one sample, differences between their results and the NADP results should be looked at with that factor in mind.

However, while some of the differences between the results can be explained by the factors listed above, there were also legitimate problems with the study conducted by

Root, et al. in 2004. The most important issue to look at is the quality of the samples that Root, et al. received and included in their study. Because the majority of the people who collected samples were parents and friends and not trained professionals there were a multitude of problems that could have negatively impacted the quality of the samples and in turn the quality of the results.

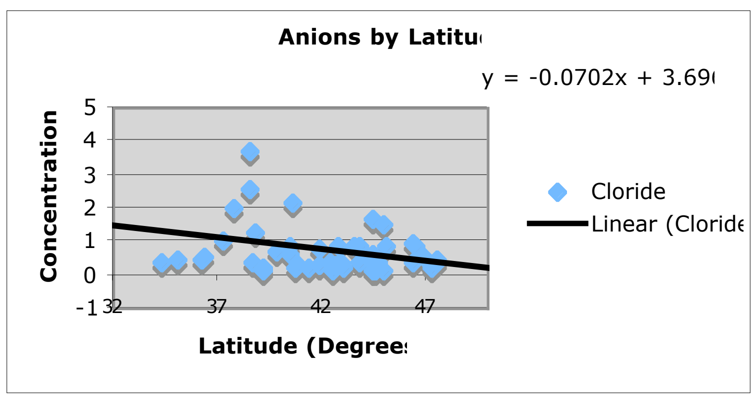
The issue that seems to have been the most destructive to the quality of the results is the fact that many of the participants, whose samples were used in the study, did not collect the rainwater in the container that was sent to them by Root, et al.. Instead of using the sterile glass bottles that were intended for their use, participants, fearing that the bottle was not big enough to collect ample samples used larger containers, which included Pyrex cups, stainless steel bowls, a ceramic bowl usually used for soup, and a 7" saucepan. It is possible that the containers themselves because, they were not properly cleaned, contaminated the samples. Another problem with contamination that stemmed for using larger containers was that it the samples were much more likely to be contaminated by debris. The collectors of samples 3,26,36, 43, 44, and 47 disclosed some level of contamination on the forms that they returned to Root, et al.. These contaminations ranged from a small amount of dust getting into the sample (#43) to significant amounts of leaves and pine needles in the sample (# 36 and #47 respectively).

To avoid contamination in future studies, we would first suggest being more explicit in the instructions sent to participants, specifically stating that rainwater should be collected in the sterile containers that were sent for them to use. Another issue that should be explored is the way that participants can prevent debris for getting into the samples. Future researchers should explore placing the container in a location where debris cannot easily get in or explore including a sterile straining device with the kit that they send to participants that might help limit the amount of debris that could contaminate the sample. Lastly and possibly most importantly, in the letter sent to participants, future researchers must emphasize that if participants do get debris in their samples, they must disclose it, noting not only that there is debris in the sample, but what the possible sources of the contamination are.

Latitude

With the hypothesis in mind that the average temperature of a location would affect the concentrations of ions deposited in rainwater, graphs were constructed using the degrees latitude of each location. Once plotted, the graphs showed no distinct trends.

The average slope trends of the data ranged from increasing .0521 mg/kg every degree latitude north one heads to decreasing .0702 mg/kg for every degree latitude north one heads. The average of all of the slope trends turned out to be decreasing by .0037mg/kg per degree latitude heading north. Keeping in mind that the samples spanned a total of 35.75 degrees latitude, this trend would predict a change in concentration due to latitude of only .13 mg/kg across all samples. In conclusion, no general trends can be pointed



Graph of chloride concentration vs. degrees latitude. The chloride ion produced the most noticeable trend, with a general slope downward of .0702 mg/kg for each degree of Latitude north one goes.

out at this time, as the error involved in the experiment would likely be greater than the .13mg/kg variance observed.

According to research, ion concentrations are much more dependent on other factors than latitude (if latitude is a factor). Population, agriculture, proximity to oceans and other factors are known to have a greater effect on ion concentration than any possible effects of latitude. Upon looking at the data used, none of the variables were separated out when looking at latitude: there were locations that had different population densities, elevations, weather patterns, and external sources of ions.

In order to separate the variables in order to test to see if there are any true effects of latitude, one would need to choose locations along a certain longitude and areas of similar population density and similar environments. It would also be important to pick locations that are usually influenced by the same weather patterns. Developing uniform sampling methods and taking multiple samples will also set up an experiment likely to lead to more reliable results.

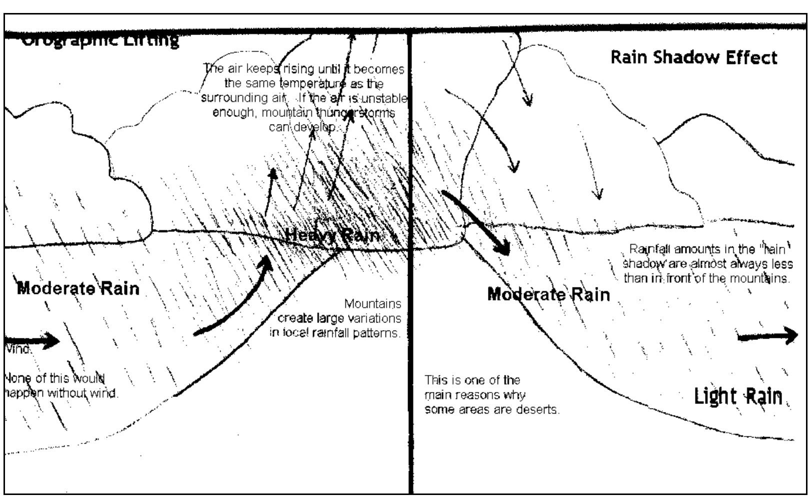
Longitude

We thought that the longitude at which the rain samples were collected might have some bearing on the concentrations of various ions that we could test for. Perhaps some longitudes will reflect certain concentrations of ions that other longitudes will not have. After looking at the data provided in terms of the longitude of each city, from which the samples were collected, it appears as if the longitude does not have an effect on the concentrations of ions. In looking at the nitrate as an example you can see that at any given longitudinal degree, the concentration of nitrate varies from nearly no nitrate to the most nitrate for this given data set. Hence, based on these data no real conclusions can be drawn. It may not be that longitude never has any effect on the concentrations of ions for the United States, but rather that this data set is merely limited in its scope.

Geographic features

Mountains

One factor that was thought worthy of analyzing was the effect mountains have on ion concentrations. Aware of the rain shadow effect, we hypothesized that not only would the amount of rainfall be less as the storm comes down the leeward side of the mountain and continues into the valley (rain shadow effect), but also that the concentration of ions would be reduced. We thought this because as the clouds rose in elevation to pass over the mountain range, the temperature would cool off because there is less air pressure and heat. This cooling of the air temperature would cause the moisture in the air to condense and the heavier, condensed water would then fall out of the cloud because of its mass, raining down on the earth below:



A diagram showing the process of orographic lifting, also referred to as the rain shadow effect. This effect predicts a change in the amount of rainfall in reference to a location's distance from a mountain range or, more specifically, the mountaintop.
Source: Haugland, M.
(Figure 2)

When analyzing the data, both the Rocky Mountains in the western part of the United States and the Appalachian Mountains in the eastern part of the U.S. were used as possible obstructions to the normal distribution of ions. The large area covered by the Rocky Mountains prompted the use of two separate study areas: one over the northern part of the mountains and one over the southern.

The analyzed data led to many interesting observations. First, there was a noticeable difference between the ion concentration variance over the Rocky Mountains as opposed to the Appalachian Mountains. The cross-section of the Appalachians showed trends for individual ions, but was fairly constant in overall ion concentrations (see figure ------). One hypothesis to explain this is the effect of a mountain range's elevation on the intensity of the rain shadow effect; perhaps the Rocky Mountains, being higher in elevation, were able to better stop storms. Both sample areas over the Rocky Mountains, however, had two definite trends that happen to oppose one another. In the southern sample area, the sites on the western side of the mountains had an average of twice the concentration of the specific ions than did the eastern side. In the northern samples, exactly the opposite was true, but to an even greater extent (the eastern side containing over three times the concentration).

These opposing results led us to further examine our methods and data used. One potential problem that was identified was the varied distances the locations were from the

				Ion Concentration in mg/kg					
	Cloride	*Nitrate*	*Sulfate*	**Sodium**	**Ammonium**	**Magnesium**	**Potassium**	**Calcium**	
Place									
South, West									
Oakland, CA	2.02976	0	1.295	3.35	0	3.5	1.11	1.37	
Fair Oaks, CA	3.696	2.5827	2.333	6.14	22.2	4.12	0.87	4.1	
Sandy, UT	0.8546	1.5821	1.841	3.07	6.27	0.51	0.49	3.38	
Moab, UT	2.5376	0	2.5744	3.32	8.88	2.83	2.3	16.08	**Average Conc**
Average Concentration (mg/kg)	*2.27949*	*1.0412*	*2.01085*	*3.97*	*9.3375*	*2.74*	*1.1925*	*6.2325*	***3.600505***
South, East									
Co. Springs, CO	1.2382	3.0644	2.1222	5.17	8.06	1.56	0.41	3.5	
Manhattan, KS	0.2218	0.2181	0.2546	1.57	0.42	0.14	0.12	0.95	**Average Conc**
Average Concentration									

charts for the northern cross-section and Appalachian Mountain cross-section can be found in the appendix of this paper (Figures -----and----)

mountain ranges. According to Haugland's previous study, as the distance from the mountain increases the amount of rainfall decreases. Perhaps the distance from the mountains would also affect the ion concentrations. Also, the small number of sights leads to more error with the analysis; if there are only four samples on each side of the mountain range and one is an outlier, then the data will be greatly skewed. Another consideration is the assumption that all of the weather that crossed the Rocky and Appalachian Mountains crossed it at about a right angle. Further investigation into the storms patterns of the area would help confirm whether this is a factor in the opposing results. Lastly, the sampling methods could have contributed to the error of this analysis. Many of the samples were taken during different storms and, therefore, their concentrations cannot be relatively compared.

If one wanted to further investigate the prevalence of a rain shadow-type effect on ion concentration, it is suggested that sample sites closer to the mountain range and more similar to one another are chosen. Samples should also be collected during the same storm so that direct comparison of the ion concentrations is possible. Adding additional cross-sections of the mountain ranges would also increase the reliability of the results.

The Great Lakes

Just as one could imagine how mountain ranges might impact the ion concentrations of rainwater, we hypothesized that the large bodies of water in the northern United States, the Great Lakes, would also have an effect on the ion concentration of the rainwater. If storms have a chance to cycle the water of the Great

Lakes through the water cycle, we hypothesize that the Great Lakes will add a purifying factor to the rainwater.

The data was analyzed by selecting points on both sides of the Great Lakes and then comparing the ion concentrations of the selected cations and anions. While no universal trend resulted, there were trends present for individual ions. Overall, the average difference between the western side and eastern side of the Great Lakes for all ions was -.30 mg/kg. The data for nitrate, ammonium, magnesium, and sulfate ions all followed the hypothesized trend of decreasing concentration on the eastern side of the Great Lakes. However, chloride, calcium, potassium, and sodium all showed the opposite trend of increasing concentration on the eastern side. While chloride and potassium increased only slightly, both calcium and sodium averages increased by 1.594 mg/kg and 2.433 mg/kg respectively.

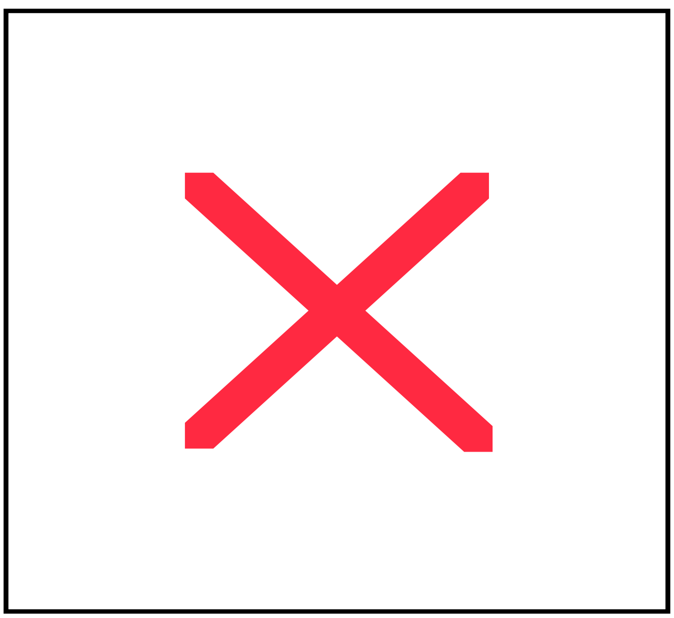


Figure ----. This graph shows the sodium ion concentrations. The end points of the trend line represent the average concentrations on both sides of the Great Lakes.

When looking at the results of this study, the sources of the tested ions should be taken into consideration. For example, the high sodium concentrations can be explained by national trends and also its main source: sea salt. Because many of the sample sites were located relatively close to the ocean, they may have been influenced by this source, creating the abnormally high concentrations (see figure----). Also, chloride ions are heavily present in sea spray from the oceans, but this source failed to show up in our analysis of the data.

Overall, the analysis of this data is inconclusive. The two above examples show why it will be important for future studies to eliminate these variables as much as possible. Another variable that was overlooked was the weather patterns of the area. Without knowing the patterns of the storms, it is not known whether the rain clouds crossed the Great Lakes in the pattern that we assumed (directly from west to east). Also, there could be possible outliers because of the collection methods used or the varying storms water was sampled from.

Sources of Ions

As many predicted trends did not show up in our data analysis, we thought it was important to examine the sources of the various ions. Knowing and understanding the sources of these ions helps to separate out various factors in ion concentration that may have been overlooked.

Sulfate

Common natural sources of sulfate in rainwater include: oceans, microorganisms, vegetation and crops, and volcanic and geothermic activity. Humans have also increased the sulfate concentration in rainwater by the burning of fossil fuels.

Data collected by the NADP showed that the sulfate concentration in rainwater was lowest in northern California and highest in the Ohio Valley. (Lear et al., 1999)

Nitrate

Lightning, oceans, and soil microorganisms are some of the biggest natural sources of nitrate in rainwater. Exhaust emissions and industrial emissions are two of the largest sources of nitrate due to human activity. Many urban areas have high nitrate concentrations in their rainwater due to the large amount of exhaust present. Also, the Great Plains tend to have a higher concentration of nitrate in its rainwater because of the high amount of agricultural activity that takes place there. (Lear et al., 1999)

Ammonium

Another ion that is highly impacted by the amount of farming is ammonium. Sources for this ion include livestock waste and the use of fertilizer. With this fact in mind, it is not surprising to find that the lowest concentrations of this ion are found in the Pacific Northwest, while the highest concentrations are found in the Great Plains. (Lear et al., 1999)

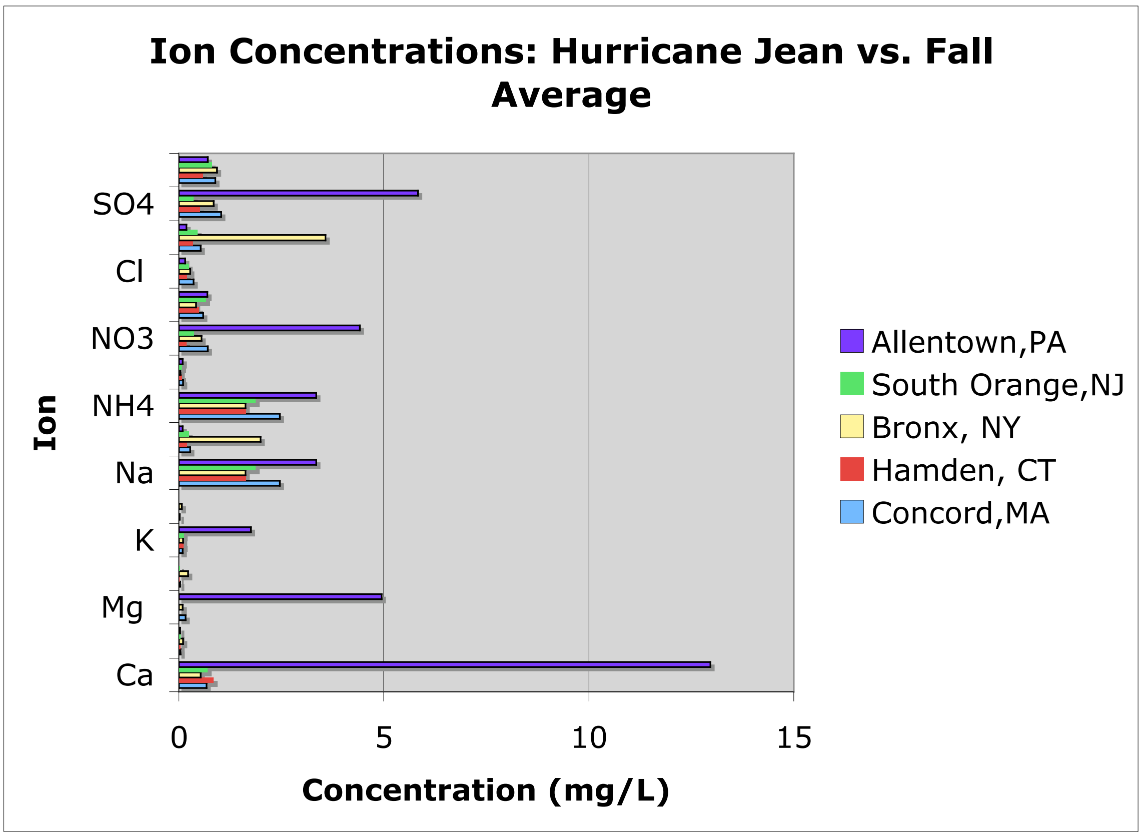
Chloride

One major determining factor of the chloride concentration of rainwater is the proximity of the sample site to an ocean. Sea salt (containing chloride) in sea spray is carried to nearby land by way of storm clouds. Figure----- shows the national trends of chloride concentration.

Cations: Calcium, Magnesium, Potassium, and Sodium

Dust from soil, sea spray, unpaved roads, agriculture, and industrial emissions are all sources for calcium, magnesium, potassium and sodium ions in rainwater. High concentrations of these cations are usually found in locations where farming is prevalent and/or there is an abundance of unpaved roads or exposed soil. Wind erosion is the way in which a majority of the ions make their way into rainwater. The Midwest and Southwest, because of their drier climate and a higher presence of farming, are the locations in the United States in which cations in rainwater are most highly concentrated.

Hurricanes



Because of the time period that the study was conducted during, five of the samples were collected in locations that were being affected by Hurricane Jean. Research done on Hurricanes Pauline and Nora by Padilla, et al. found that in samples taken in areas affected by hurricanes, there is often a excess amount of sulfate in addition to smaller, but still noticeable, excess amounts of sodium and chloride in samples. Were the concentrations found by Root, et al. higher than the national averages it would not be surprising considering that both the literature we encountered would lead us to believe that the concentrations of sulfate, sodium, and chloride, from the samples collected by Root, et al. would be higher than the NADP national fall averages. In addition to the fact that throughout the entire study the ion concentrations in the 2004 Carleton College study were higher than the national averages. However, in the ion concentration analysis done by Root, et al. and expressed in the figure (below????) and in figure 4?????, there are many instances where the national fall average concentration is higher than the concentrations found by Root, et al. The literature that we read stated that the increase in ion concentrations in samples taken from hurricane areas was often undetectable or close to being undetectable. Therefore it is not surprising that there is not a huge difference between the samples collected by Root et al. and the national averages. However, it is surprising that the concentrations in these five specific samples do not follow the greater trend.

This discrepancy could be a result of the problems with the quality of the samples as described in the old data analysis section. However, to verify the finding of the literature above and to gain more insight into the data collect by Root, et al., we would suggest that in future studies dealing with rainwater, and specifically dealing with hurricanes, researchers collect as many samples as possible from various places within the area affected by the hurricane. Specific attention should be paid to each sample's distance away from the center of the hurricane as well as to where the hurricane started, and the strength of the hurricane. In addition, the quality of the samples should be monitored to ensure that the rainwater has not been contaminated, which would most likely affected the results.

Population Density

We hoped that population density would reveal trends in sulfate and nitrate concentrations. Studies have revealed that higher population densities correlate directly to higher concentrations of nitrate and sulfate, largely because higher population densities usually correspond to increased industrialization. Industrialization pollutes the air and is thus usually marked by higher levels of nitrate and sulfate. In looking at Figure ?, the highest population density (250+ people/sq. mile) reveals some higher concentrations of sulfate, as expected. The highest concentration of sulfate for high population density is 5.83 mg/L. Unfortunately there are also a couple samples that revealed high concentration of sulfate at low population density too. In fact, the highest concentration of sulfate overall was from a population density of 10-24 people/sq. mile with a concentration of 7.33 mg/L. For the most part the data does not match the expected result. A possible reason for this could be that the areas of higher industrialization put higher levels of nitrate and sulfate into the air, but do not come down as rainwater in the same location.

Weather Patterns and Other Influences

It is important when studying rainwater content to understand the factors that contribute to the composition of the rainwater. These factors include everything from the passing of storm systems over large metropolitan areas, to forest fires and other natural occurrences (Middleton, ????). One of the key difficulties in reanalyzing the data from the study by Root, et al., was that their study was not designed to specifically study the effects of these factors. Their rainwater samples were not collected from the same storm systems, making it hard to compare data in relation to such factors as geographic location, population density, etc. Though there are likely patterns in the rainwater content of storm systems that follow the same general path through the atmosphere, it is impossible to make any conclusions without a more comprehensive, specific study.

An ideal study would sample water from a single storm system at various points across the continental United States. This would provide a wealth of data about changes in the rainwater content as the storm encounters different factors that can effect the chemical composition of the rainwater (urban areas, etc.). Data could then be analyzed in relation to topographic features (mountain ranges, etc.), population density and human influences, and natural disasters (forest fires, hurricanes, dust storms, etc.) (*See Figures ??, ??, and ??*). Other factors that should be studied in greater depth include studies across specific latitudes and longitudes, the influence of atmospheric dust storms (primarily from east Asia and northern Africa), and the rainwater content of hurricanes that strike the eastern portion of the United States.

Conclusion:

Acknowledgements

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Distribution of Sampling Sites across the US

State	City
1 Maine	Yarmouth
2 Maine	Phippsburg
3 Vermont	Burlington
4 Vermont	Shrewsbury
5 Massachusettes	Concord
6 New York	Troy
7 Conneticut	Hamden
8 New York	Bronx
9 New Jersey	South Orange
10 Pennsylvania	Allentown
11 Pennsylvania	Huntingdon
12 Florida	Miami
13 Mississippi	Oxford
14 Tennessee	Oak Ridge
15 Missouri	Cape Girardeau
16 Missouri	St. Louis
17 Indiana	Bloomington
18 Illinois	Springfield
19 Illinois	Chicago
20 Illinois	Chicago
21 Wisconsin	Kenosha
22 Wisconsin	Milwaukee
23 Michigan	Northport
24 Michigan	Marquette
25 Wisconsin	Hurley
26 Minnesota	Renville
27 Minnesota	Cohasset
28 Minnesota	Northfield
29 Minnesota	Northfield
30 Minnesota	Northfield
31 Minnesota	Northfield
32 Minnesota	Minneapolis
33 Minnesota	Moose Lake
34 North Dakota	Dickinson
35 South Dakota	Lake Norden
36 South Dakota	Vermillion
37 Kansas	Manhattan
38 Colorado	Colorado Springs
39 Wyoming	Greybull
40 Montana	Great Falls
41 Idaho	Pocatello
42 Utah	Sandy
43 Utah	Moab
44 New Mexico	Albuquerque
45 Nevada	Las Vegas
46 California	Fair Oaks
47 California	Oakland
48 Oregon	Salem
49 Washington	Seattle
50 Hawaii	Kurtistown
51 Alaska	Kenai

Fig. 1. Map of the United States and sampling sites.

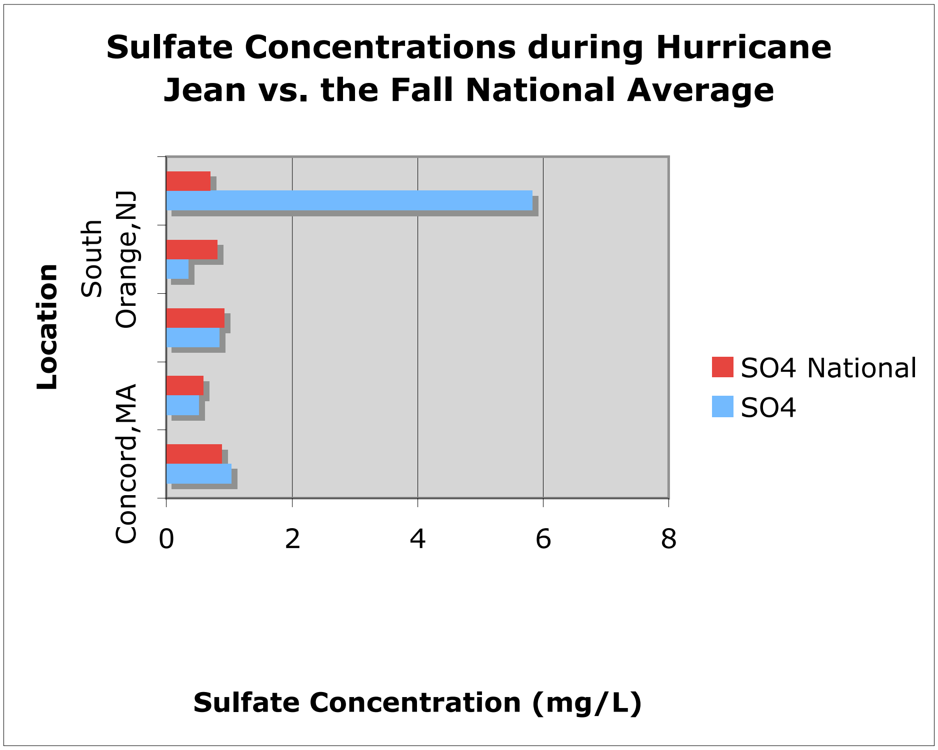


Figure 4. Graph comparing the concentrations of sulfate during Hurricane Jean vs. the fall national average

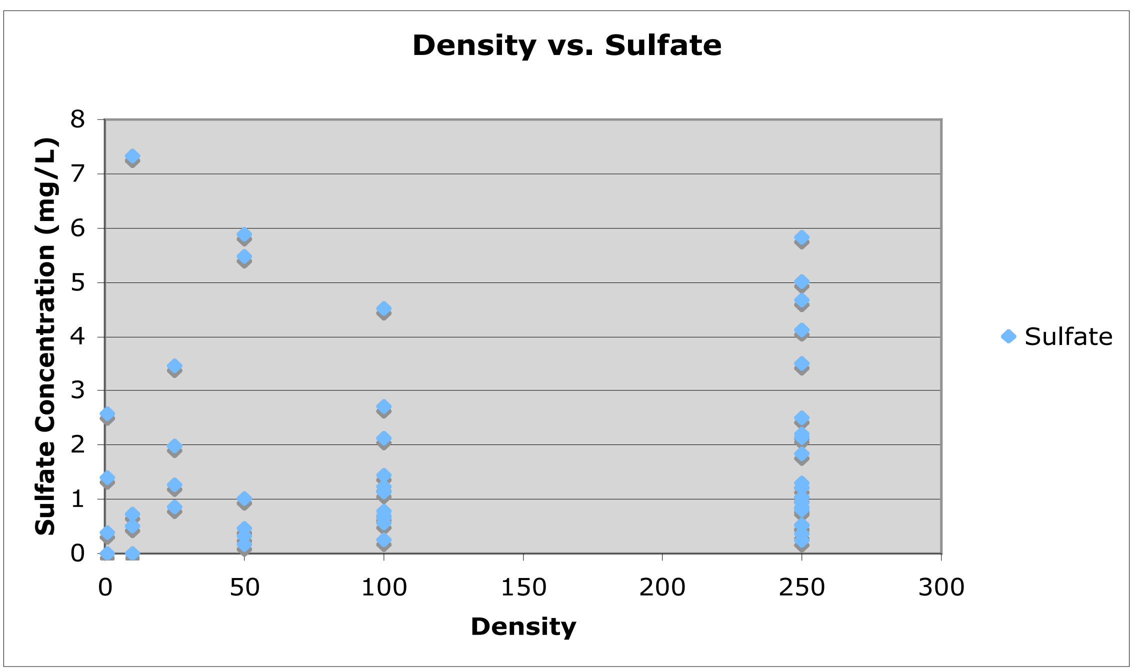


Figure ?. Graph of sulfate concentration in terms of population density.

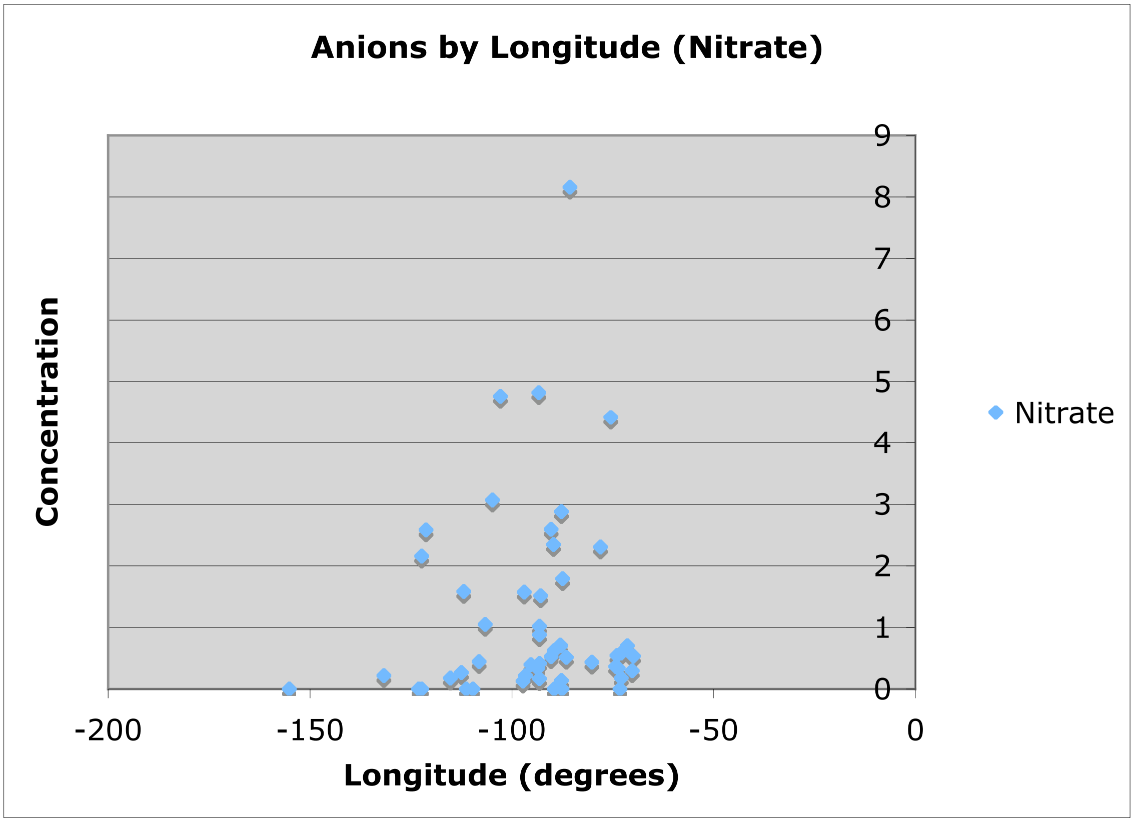


Figure ?. Graph of nitrate ions in terms of longitude.

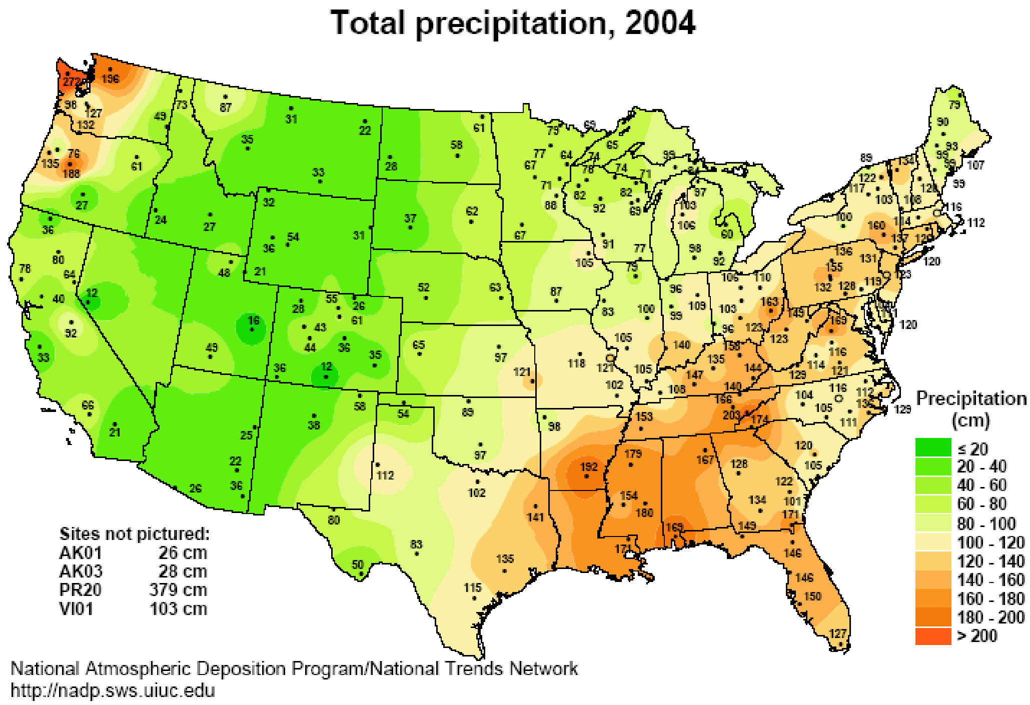
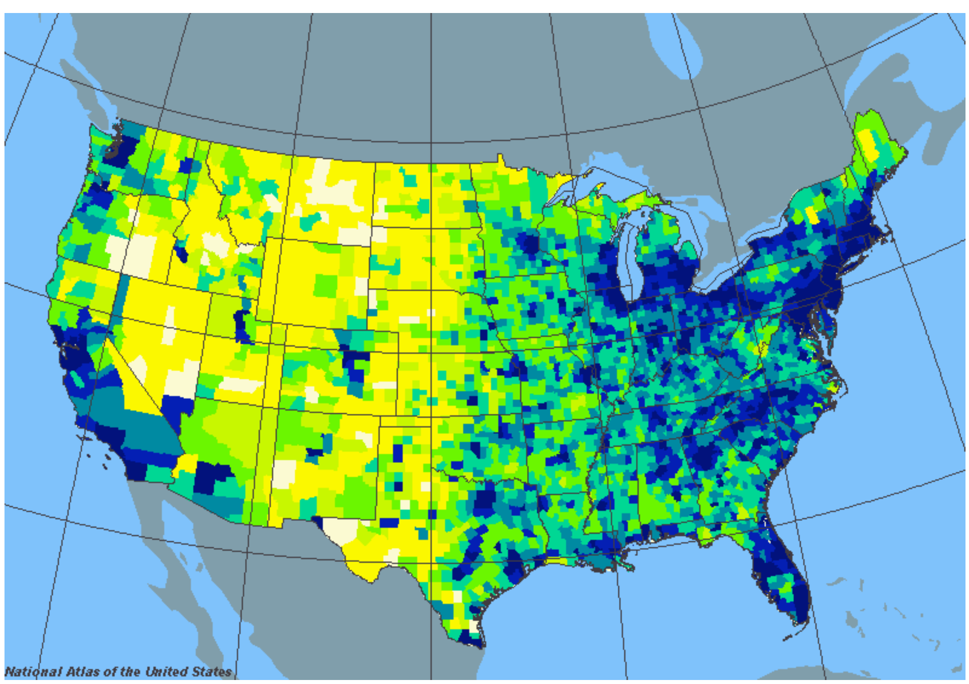


Figure 12. Map of 2004 total precipitation.
Source: United States Geological Survey



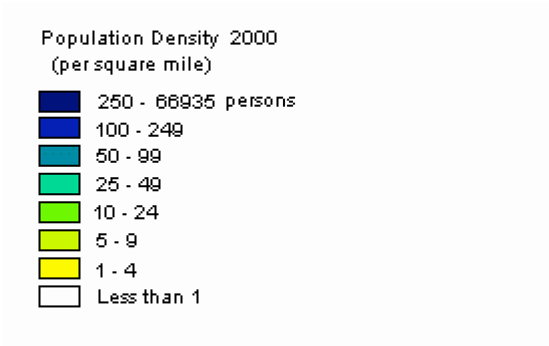


Figure 13. Map of population density for 2000.
Source: nationalatlas.gov

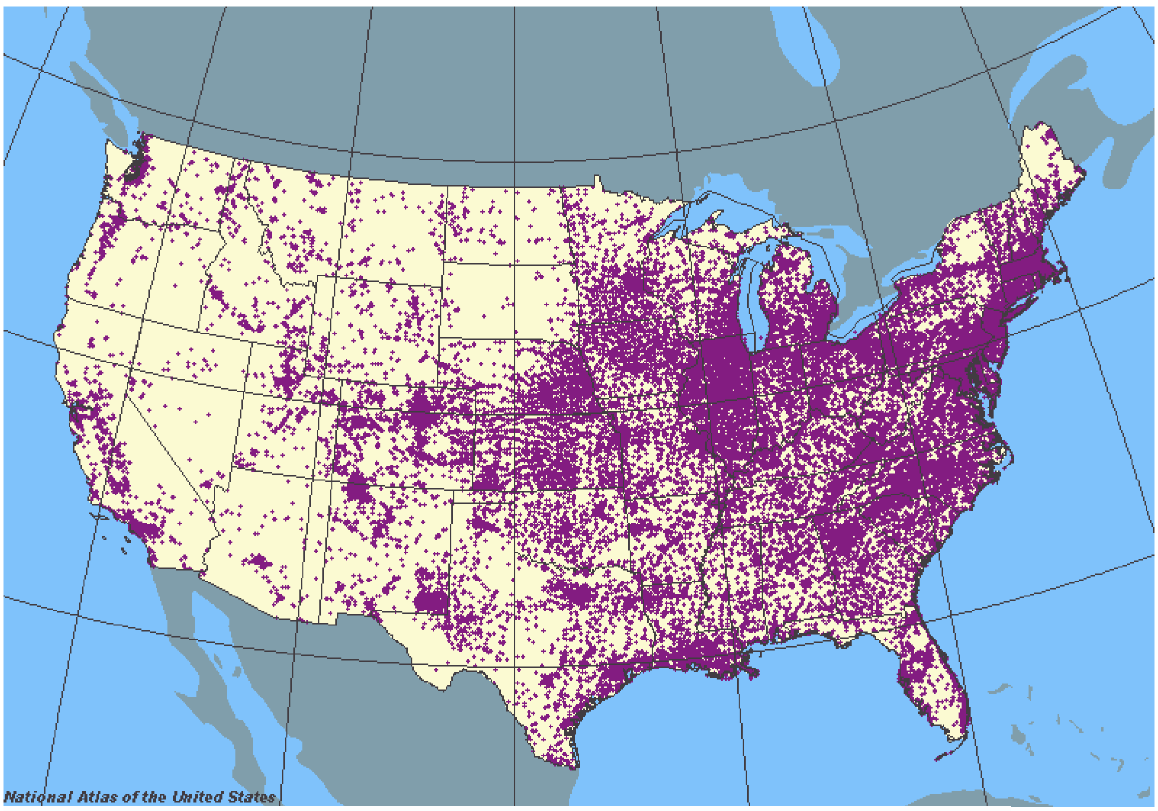


Figure 14. Map of air pollutant releases (May 2005).
Source: nationalatlas.gov

Air releases are sites where pollutants are released into the atmosphere from stationary sources, such as smokestacks and other vents at commercial or industrial facilities. This map layer was produced by the U.S. Environmental Protection Agency (EPA), which collects emissions information for six common air pollutants: carbon monoxide, lead, nitrogen dioxide, ozone, particulate matter, and sulfur dioxide. The EPA regulates these pollutants and establishes national air quality standards, as authorized by the 1970 Clean

Air Act, to protect human health and prevent environmental and property damage. EPA air release information is stored in the Aerometric Information Retrieval System (AIRS).

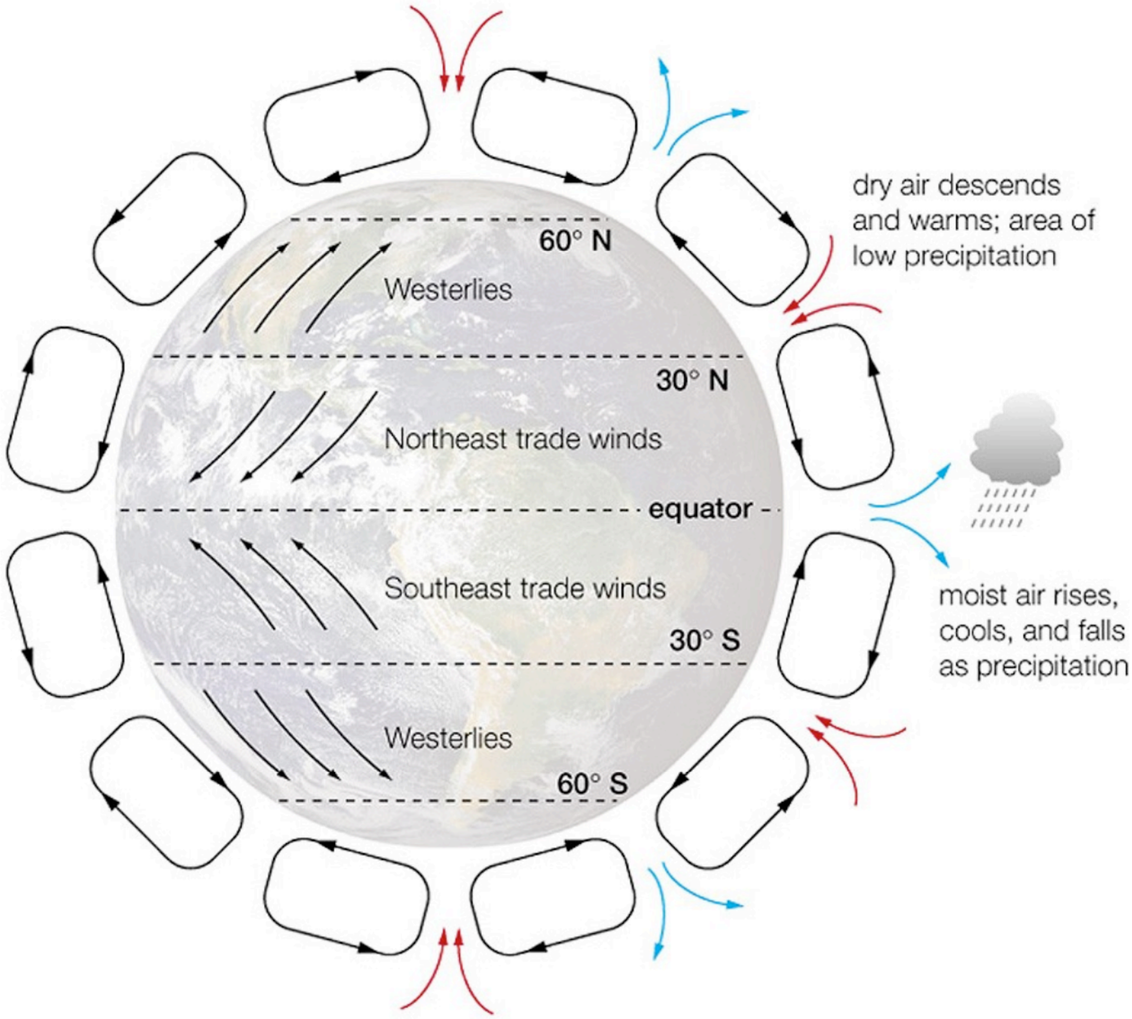
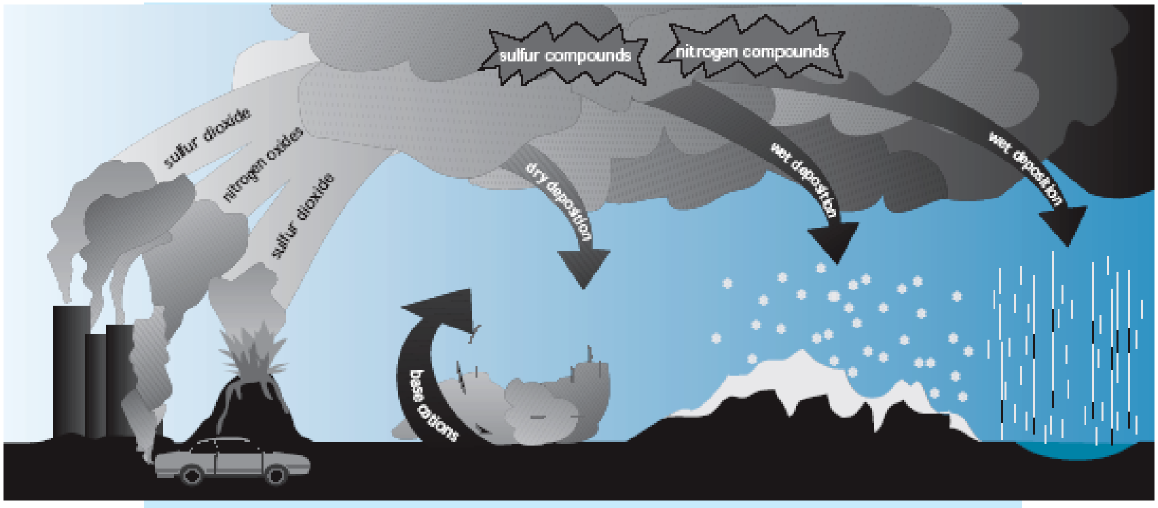


Figure ?. Diagram showing the global winds.
Source: http://plantphys.info/plant_biology/climate.html



(put in chart of mountains)

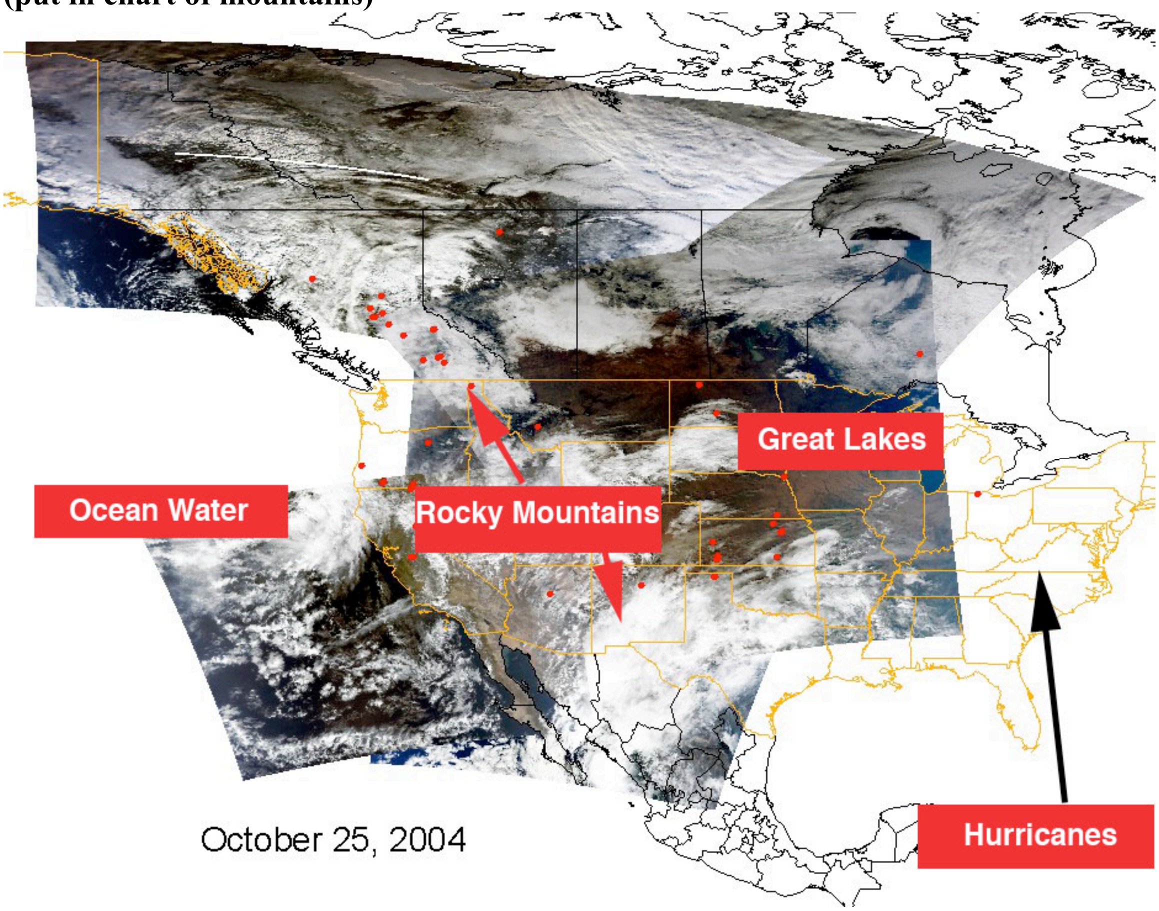


Figure ??. Mosaic showing some possible natural influences on rainwater conent.
Source: NCDC/NOAA

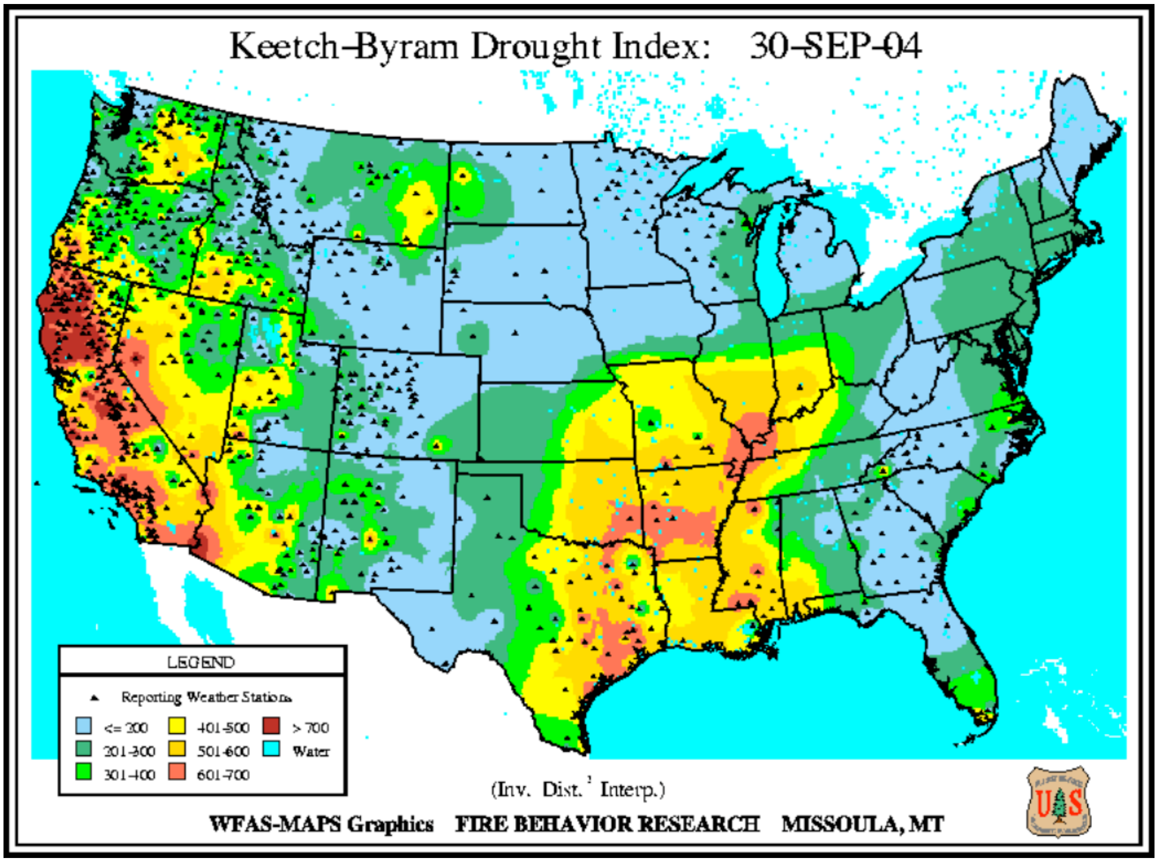


Figure ??. Map depicting the Keetch-Byram Drought Index, 30-September, 2004.
Source: NCDC/NOAA

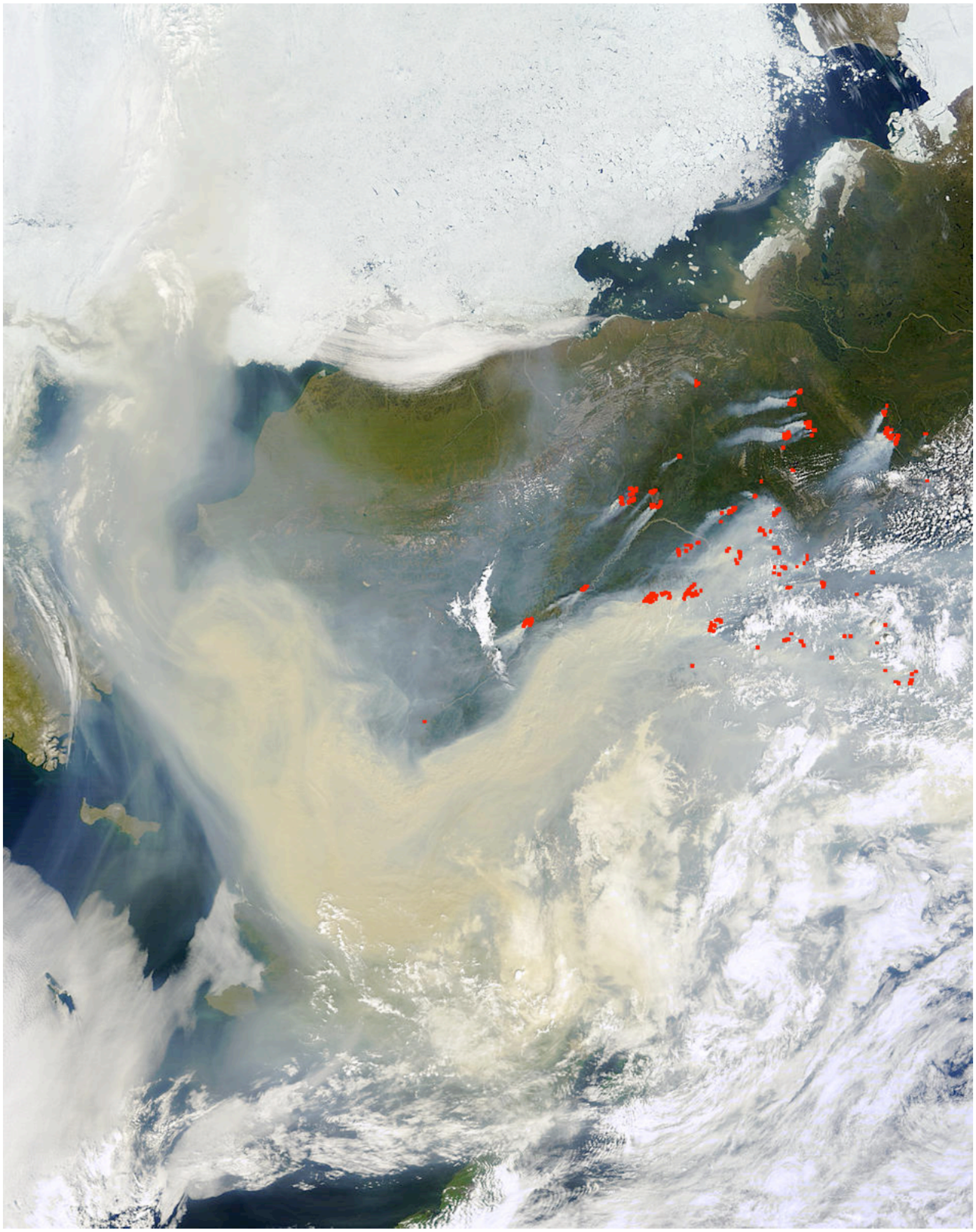


Figure ??. Satellite mosaic MODIS image depicting wildfires and smoke across Alaska, 1-July, 2004.
Source: NCDC/NOAA