Comparison of Cloud and Rain Chemistry Observations at Whiteface Mountain

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Abstract

High terrain or mountain locations are often affected by deposition arising from both non-precipitating and precipitating clouds. One such station is the summit of Whiteface Mountain, NY (elevation 1497 m) where sampling of non-precipitating cloud water in summer season has been on-going along with the precipitation measurements at a nearby lower elevation (599 m). In this study we examined the trends and relationships based on a decade long (1996 to 2006) record of ion chemistry at these two locations, and evaluated the potential linkage in estimated deposition between them.

We find that both rain and cloud water have four dominant ions: sulfate (SO_4^{-2}), nitrate (NO_3^-), hydrogen (H^+) and ammonium (NH_4^+). On the seasonal level, major ions have the same relative contributions in both rain and cloudwater. However, concentrations are considerably higher in the cloud samples than in rain. Because of this, and the large frequency of cloud occurrence at the summit during the summer season, deposition from non-precipitating clouds is much higher than that occurring from precipitation. This observation appears to be in concert with the preliminary result that high elevation lakes in the Adirondack region, those which occur above 600 m, exhibit higher sulfate and nitrate levels than those at lower elevations.

An assessment of linear trends in the deposition ions generally indicates downward trends. However, inter-annual oscillations are sizable and application of Sen's trend test did not demonstrate significance of these downward trends.

Further analysis of these data is on-going to understand effects of ion concentration deposition on high terrain landscapes between non-precipitating and precipitating clouds.

Objectives

1. Continue the work started in 1994 by MADPro
2. Analyze cloud water chemistry and compare to rain chemistry
3. Estimate cloud water deposition and compare to rain deposition
4. Analyze trends in concentrations and depositions
5. Link results to observed acidity of lakes

Sampling Methods

Cloud water

Cloud water is collected from the collector shown to the right. The apparatus sits atop the roof of the summit observatory building. Clouds that pass through the sensors are sampled when the following criteria are established:

1. A heated grid rain sensor confirms no rain is present;
2. A Gerber Continuous Particle Volume Monitor (PVM) detects cloud with a liquid water content (LWC) value greater or equal than 0.05 g m⁻³
3. The temperature is 2 degrees Celsius or greater
4. The wind speed is 2 meters per second or greater

All non-precipitating cloud events are sampled by a passive Mohnen collector.

Rain water sampling

Weekly rain chemistry data are obtained from the National Atmospheric Deposition Program/National Trends Network (NADP/NTN) (see http://nadp.sws.uiuc.edu)

The NADP/NTN wet/dry bucket at the Whiteface Mountain is approximately 750 m lower from the location of the cloud water sampler.
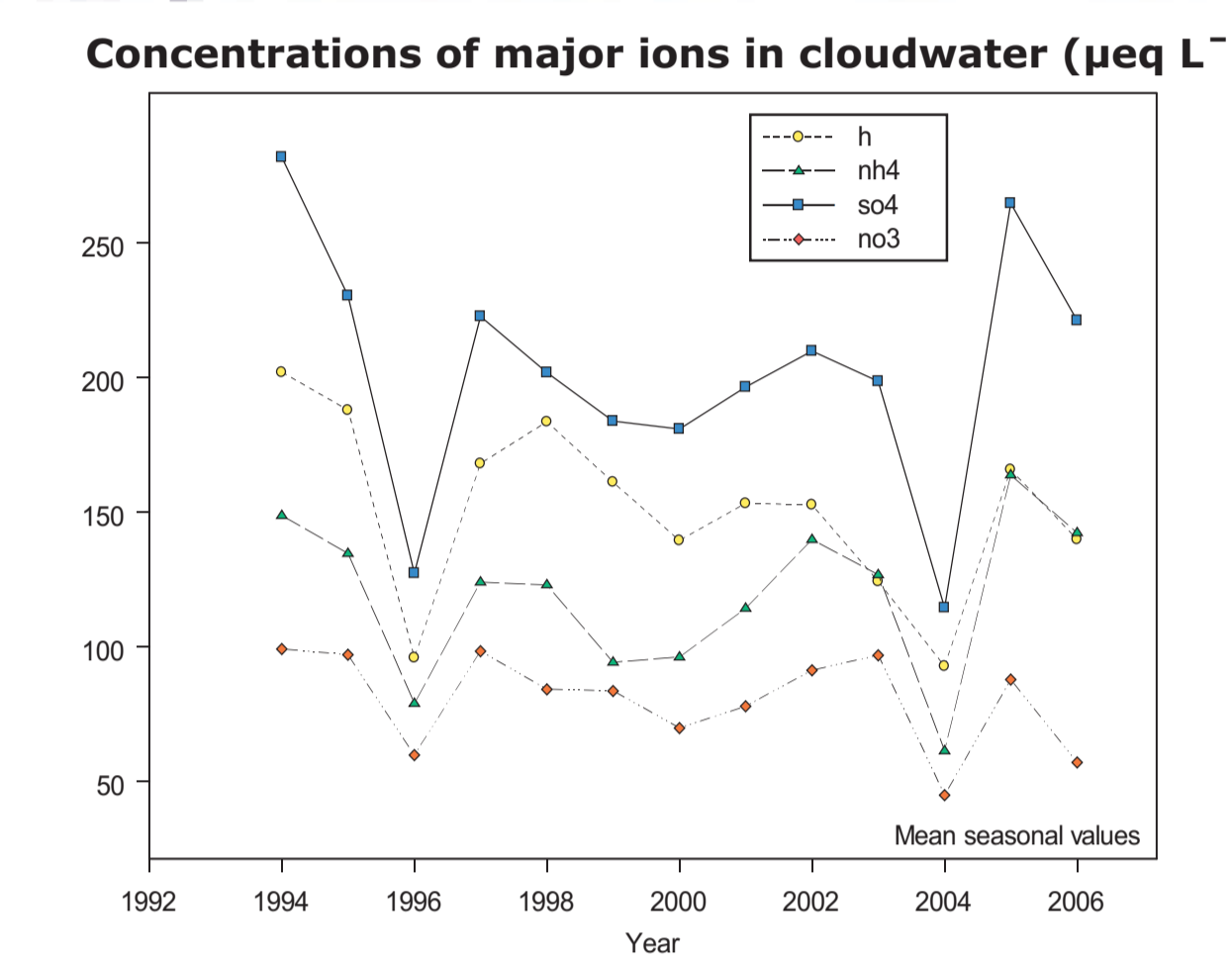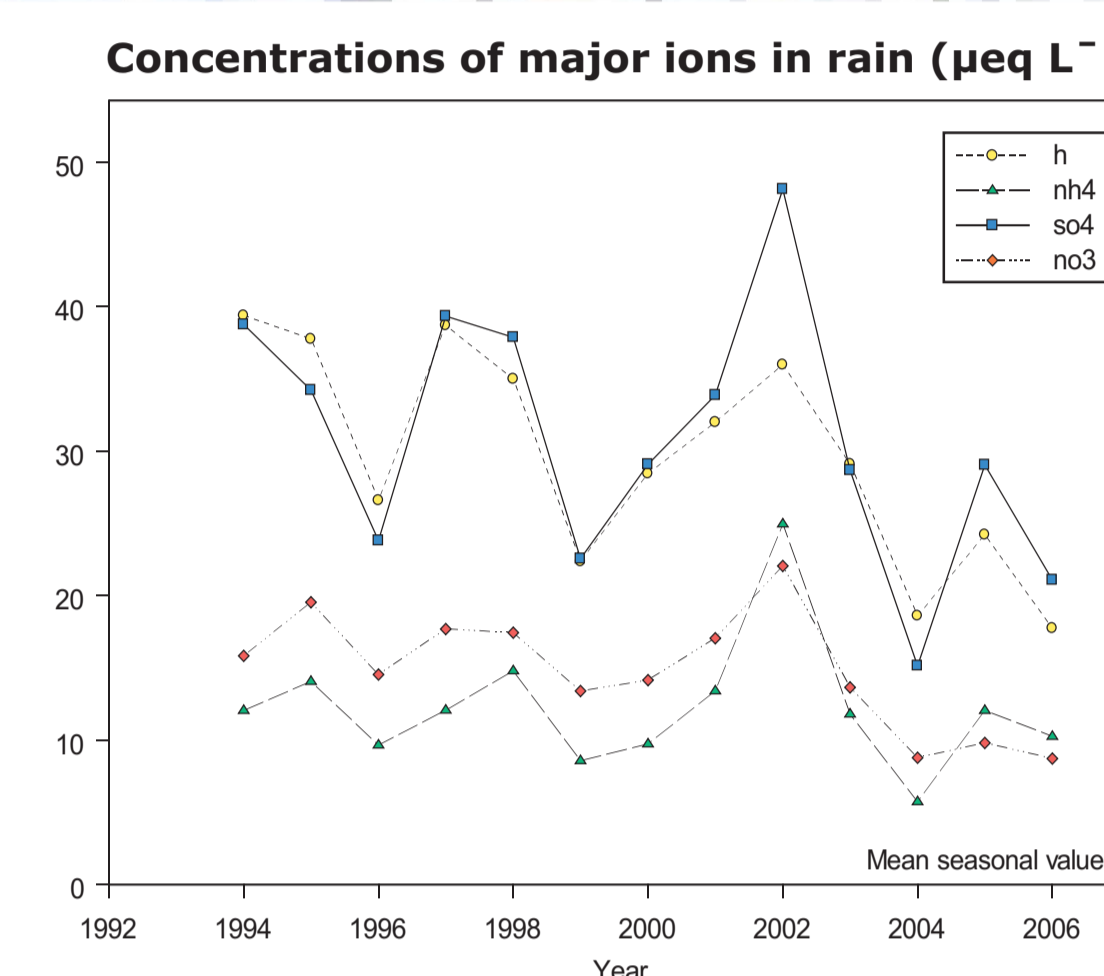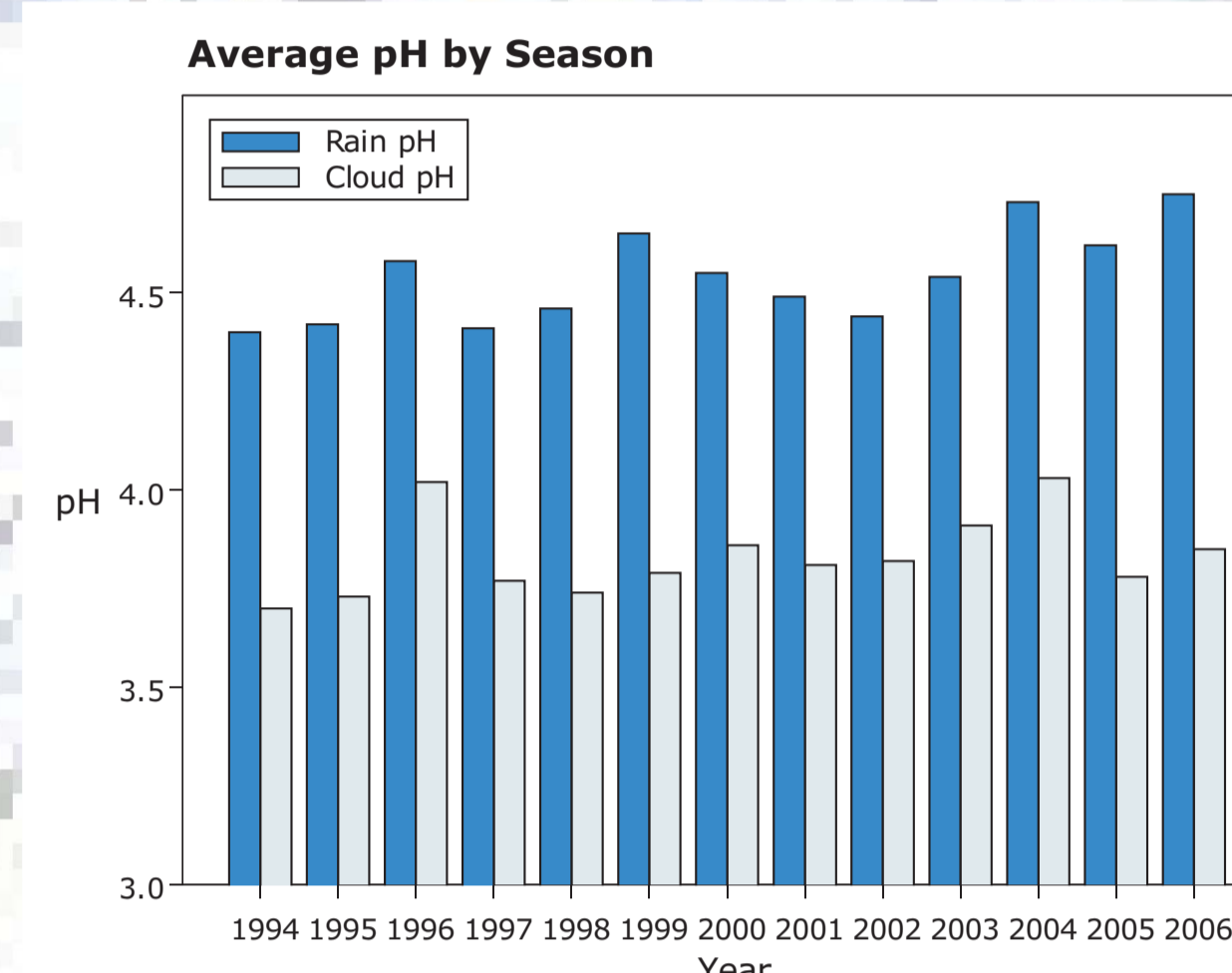
Lake water sampling

48 lakes studied under the Adirondack long-term monitoring program, data from 1992-2006. Lake samples collected monthly at or near the outlets. We have used only annual mean values in the analysis.
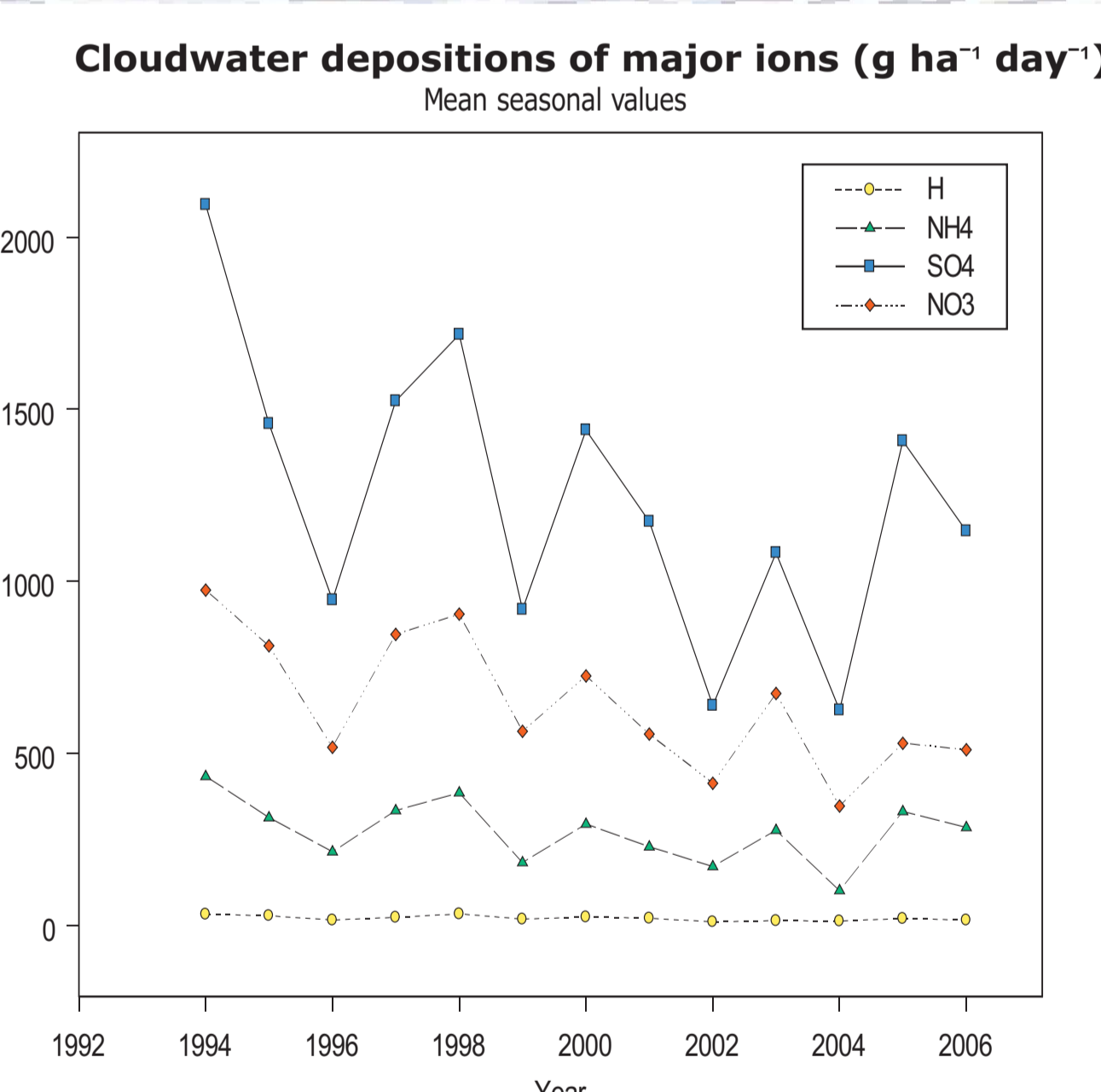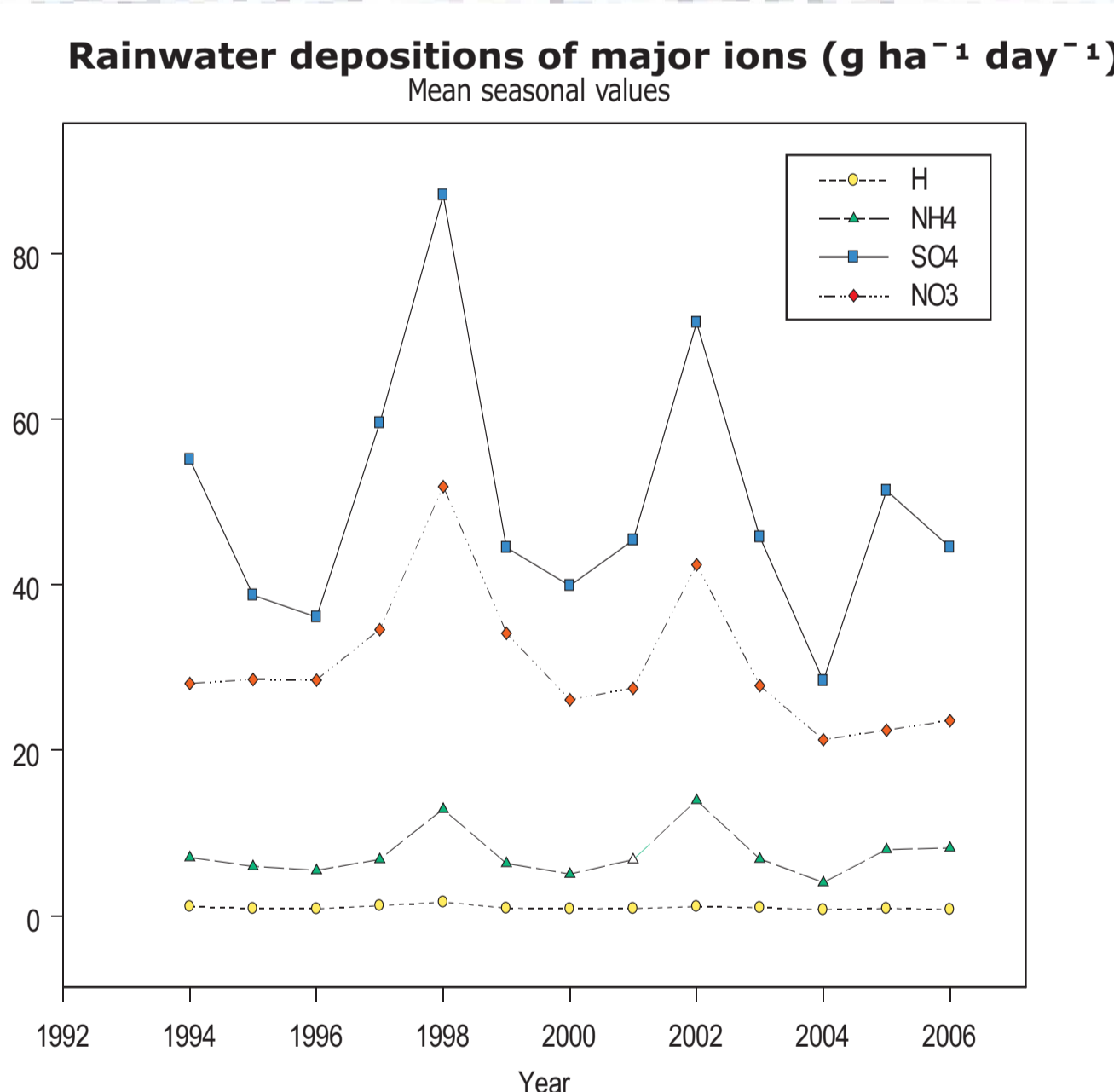
Concentration Series

1. Rain and cloud water data analysis was performed on actual measurements.
2. Only valid observations that satisfy ion balance were used.
3. At Whiteface, cloud chemistry observations have 1 hour resolution, with the ideal sampling season from June 1 to September 30.
4. Collection begins late each spring, as soon as the local weather conditions allow.
5. Rain chemistry measurements, on the other hand, are weekly and around the year. In order to match these observations, we have first calculated corresponding weekly means of valid cloud ion concentrations weighted by mass (sampled volumes). The cloud and rain data were then matched by the calendar and pooled into one table to calculate seasonal means of concentrations.

Average pH by Season

Concentrations of major ions in rain (µeq L⁻¹)

Concentrations of major ions in cloudwater (µeq L⁻¹)

Observation Seasons

| Year	Season start	Season end	Days
1994	12-Jul-94	04-Oct-94	84
1995	23-May-95	10-Oct-95	140
1996	04-Jun-96	01-Oct-96	119
1997	10-Jun-97	07-Oct-97	119
1998	02-Jun-98	06-Oct-98	126
1999	08-Jun-99	05-Oct-99	119
2000	20-Jun-00	26-Sep-00	98
2001	12-Jun-01	02-Oct-01	112
2002	04-Jun-02	24-Sep-02	112
2003	22-Jul-03	16-Sep-03	56
2004	13-Jul-04	03-Aug-04	21
2005	21-Jun-05	27-Sep-05	98
2006	30-May-06	19-Sep-06	112

Deposition Series

1. Cloud water deposition was calculated by Lovett model.
2. Model was run for all cloud events which had valid chemical observations and matched meteorological observations.
3. Calculated chemical fluxes were averaged for the season, after weighting for duration.
4. Deposition totals for each season were calculated by multiplying the mean chemical fluxes times the cloud-hours for the season.
5. Seasonal totals are divided by the number of days in the season to obtain mean daily deposition for the season [(kg ha⁻¹ day⁻¹)].
6. Rainwater depositions are calculated from observed concentrations and rainfall.

Rainwater depositions of major ions (g ha⁻¹ day⁻¹)
Mean seasonal values

Cloudwater depositions of major ions (g ha⁻¹ day⁻¹)
Mean seasonal values

Average seasonal percent contribution to the total sum of the ions

	H	NH4	SO4	NO3	Other ions
NADP	26	20	34	14	6
Cloud	26	20	34	14	6
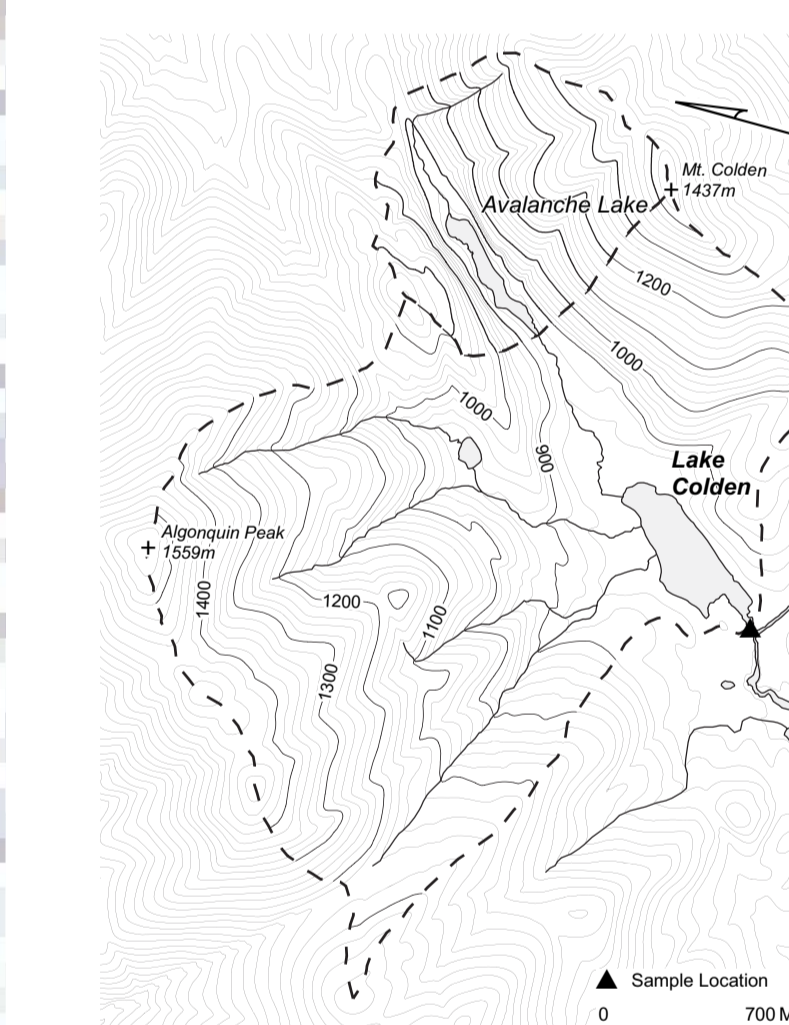
Avalanche Lake and Lake Colden are the two highest ALTM lakes with watersheds extending above 1400 m msl.

Mean annual concentrations of major ions in Adirondack LTM lakes 1992-2006

	16 high elevation lakes	32 other lakes
SO4 [ueq L⁻¹]	89.1	89.7
NO3 [ueq L⁻¹]	17.1	11
NH4 [ueq L⁻¹]	2.2	2.8
H [ueq L⁻¹]	9.62	6.17

Conclusions

1. Both rain and cloud water has four dominant ions: SO_4^{-2}, NO_3^{-}, H^+ and NH_4^+.
2. On the seasonal level, major ions have the same relative contributions in both rain and cloud water, but
3. Ion concentrations are considerably higher in the cloud samples than in rain.
4. At high elevations acid deposition from cloud water, when it happens, greatly exceeds rain deposition
5. High elevation Adirondack lakes appear to have higher nitrate and hydrogen ion levels than other Adirondack lakes.
6. Linear trends in the cloud and rain deposition ions are generally downward, but
7. Inter-annual oscillations are sizable and application of Sen's trend test did not demonstrate trends significance.

Assistance provided by: