Annual and Seasonal Fine Particle Composition in the Northeast: Second Year Results from the NESCAUM Monitoring Network

Richard L. Poirot
VT Dept. of Environmental Conservation
Air Pollution Control Division
Waterbury, VT 05676

Philip J. Galvin
NY Dept. of Environmental Conservation
Division of Air
Albany, NY 12233

Norma Gordon
Maine Dept. of Environmental Protection
Bureau of Air Quality
Augusta, ME 04333

Steve Quan
New Jersey Dept. of Environmental Protection
Division of Environmental Quality
Trenton, NJ 08625

Alan Van Arsdale
Northeast States for Coordinated Air Use Management
Boston, MA 02114

Robert G. Flocchini
Land, Air and Water Resources
Crocker Nuclear Laboratory
University of California
Davis, CA 95616

Introduction

The past "acid rain" decade has witnessed the development and extensive deployment of standard methods for the routine monitoring of non-urban precipitation chemistry. Although non-urban aerosol chemistry is also of obvious importance to understanding the acid rain phenomenon, and to the related issues of acid aerosols, air toxics and visibility impairment, aerosol measurements have been relatively neglected during this time period. Methods have not become standardized, and measurements have generally been conducted over short time periods at a spatially limited number of sites.

A major exception to this rule has been the (1987) deployment of the (20 site) Interagency Monitoring of Protected Visual Environments (IMPROVE) network and an equivalent (20 site) National Park Service Network (NPS).[1,2] IMPROVE and NPS networks routinely monitor scenes (automatic cameras), atmospheric optics (transmissometer or nephelometer), and aerosols (four-module aerosol samplers which together quantify fine fraction mass, light absorption, sulfates, nitrates, chloride, organic carbon, elemental carbon, trace elements and coarse mass). The sites are located in Class I Federal Areas which are generally remote and regionally representative. However, the spatial distribution of IMPROVE/NPS sites is not nationally uniform, and coverage is notably lacking in the eastern US where aerosol concentrations are highest and gradients are most complex.

In September, 1988, the Northeast States for Coordinated Air Use Management (NESCAUM), in cooperation with the University of California at Davis (UCD), added a network of seven rural and regionally representative aerosol monitoring sites, located in and operated by the States of NY, NJ, CT, MA, ME, NH and VT (see Figure 1). Each of the NESCAUM sites operates an IMPROVE Module A sampler, which collects fine-fraction (<2.5 um) particles on teflon filters. Filters are analyzed for mass, optical absorption, and elemental composition by UCD (IMPROVE analytical contractor). All NESCAUM sites also operate PM-10 samplers, while two sites (NY and MA) operate IMPROVE Module C (carbon) samplers, which collect fine particles on quartz filters, analyzed for elemental and organic carbon at Desert Research Institute (IMPROVE carbon analytical contractor). The NESCAUM Module A and Module C results are directly compatible with IMPROVE and NPS results, thereby expanding the spatial coverage of these national networks. This paper will summarize the currently available NESCAUM results for the two year period ending August 1990. Emphasis will be placed on spatial patterns and seasonal variations, with particular focus on aspects of aerosol composition most relevant to visibility effects.

Methods

Sampling and Analytical procedures for the IMPROVE[1,2] and NESCAUM[3,4] networks have been previously described in detail. NESCAUM Module A and C samplers are run 24 hours, midnight to midnight, on Wednesdays and Saturdays (IMPROVE schedule), and also every 6th day (NESCAUM PM-10 schedule). NESCAUM filter handling, analysis and data processing are identical to IMPROVE.

Module A teflon filters are analyzed by UCD for gravimetric mass; optical absorption, by Laser Integrating Plate (LIPM); hydrogen, by Proton Elastic Scattering Analysis (PESA); and multiple elements, sodium and heavier by Proton Induced X-ray Emission (PIXE). LIPM results, expressed as "laser reflectance" (LR), are reported in units of 10^{-8} m^{-1}. This is analogous to the "coefficient of absorption" or b_{abs}. All other Module A results are concentrations, reported in ng/m^3.

Module C quartz filters are analyzed by DRI for elemental and organic carbon by Thermal Optical Reflectance Combustion (TOR). The TOR analysis is conducted under 4 discrete ranges of combustion temperature: >700°C, 550 to 700°C, 120 to 550°C, and 25 to 120°C. Initial carbon results are reported according to these thermal ranges as high and low temperature elemental carbon (ECHT and ECLT) and high and low temperature organic carbon (OCHT and OCLT) respectively. These variables (and their uncertainties) also include "artifact" adjustments, based on average results from secondary (tandem) quartz filters employed in the IMPROVE network, and intended to compensate for field blank and vapor adsorption artifacts and variations.

For reasons not presently clear, these adjustments appear to over-compensate for actual blank and adsorption artifacts. Over 20% of the artifact adjusted carbon values for the first two years of IMPROVE operations were negative, and those carbon results exhibit a negative intercept when compared with other measured variables. Based on such statistical comparisons, UCD has calculated the following "statistical" adjustments to the carbon data: + 6 ng/m^3 for ECHT, + 27 ng/m^3 for ECLT, + 260 ng/m^3 for OCHT, and + 27 ng/m^3 for OCLT.

The sum of ECHT and ECLT, with artifact and statistical adjustments, is defined by current UCD convention as "light absorbing carbon" (LAC).[5] This is analogous to the "elemental carbon" commonly reported in the literature, although "elemental carbon" is frequently measured by techniques which are predominantly high temperature only.[5] The sum of OCHT and OCLT, with adjustments, represents "organic carbon" (OC). By current UCD convention, total organic matter (organic mass by carbon, or OMC) is calculated as 1.4*OC, based on the assumption that organic matter is composed of 71% carbon.

UCD determines the precision and minimum detection limit (MDL) for each measured concentration, and subjects the resulting data to several levels of QA screening[6], before conveying the results to NESCAUM on a quarterly basis in ASCII format. NESCAUM has the resulting concentration, precision and MDL data converted to Voyager format by Lantern Corp., and conducts an additional screening review using the Voyager Data Viewing software.[7] The data is then available for distribution to any interested party in either ASCII or Voyager format.

Module A Results (9/88-8/90)

Sampling was initiated at five of the NESCAUM sites in mid-September, 1988. The MA and NH sites came on-line two and one half months later. Module A results are currently available through August, 1990 - representing nearly 2 years of samples at roughly 3X weekly sampling frequency. Network sample capture efficiency (% of sampling days on which valid filters were collected) has increased from 85% in the first year of operation to 91% in the second year.

Figure 2 indicates the frequency with which individual measured variables were "detectable" on all valid NESCAUM filters during the 9/88-8/90 time period. Values are considered "non-detectable" in Figure 2 if they are below the MDL, or otherwise fail one of the QA screening reviews. S, Fe, K, Zn, H, Pb, Ca, Mass, LR, Si and Br are detectable in excess of 95% of the time.

The annual (2 year) mean concentrations of these readily detectable Module A variables are displayed in Table I. These averages are based on sample sizes

ranging from 210 to 260 days per site. Mean concentrations of most variables are generally highest at the southeasterly sites (closest to East Coast population centers), and lowest at the more remote NH and NY sites (which are also at highest elevation). The mean ratios of highest to lowest site concentrations range from 1.6 to 2.1.

The monthly mean values of Sulfur and LR (b_{abs}) are displayed in Figure 3. Sulfur concentrations are relatively uniform across all sites and exhibit distinct summer maxima. By comparison, the LR values exhibit less spatial uniformity, and are distinctly higher at the more southerly sites, particularly during the winter.

Module C Results (9/88-8/89)

Roughly 1 year of Module C carbon measurements are currently available from the NY site (9/88-9/89) and the MA site (12/88-9/89). As indicated previously, high and low temperature elemental carbon (with artifact and statistical adjustments) are summed to form "light absorbing carbon" (LAC). High and low temperature organic carbon (with adjustments) are summed and multiplied by 1.4 to form OMC. Current UCD recommended formulae[5] for LAC, OMC and other "composite variables" are listed in Table III. Annual mean (9/88-8/89) concentrations of these composite variables are summarized in Table II. By current convention, the initial carbon variables (ECHT, ECLT, OCHT, and OCLT) are reported in the NESCAUM database without inclusion of the UCD-recommended statistical adjustments. These statistical adjustments are included, however, in the calculation of the NESCAUM composite variables: LAC and OMC, and in subsequent calculations which utilize these variables.

By comparison to many of the readily detectable Module A variables, the uncertainties associated with the Module C carbon results are relatively high. Figure 4a displays the relative uncertainties associated with Module A S, H and LR at the NY site. Figure 4b displays similar uncertainties for Module C LAC and OMC for the same site and time period (note difference in scales). In these plots, the measurement uncertainty (precision) is expressed as a percentage of the measurement value, such that a relative uncertainty of 100% would indicate that the uncertainty of the measurement is as large as the measurement itself. The high relative uncertainties for the module C carbon results (which occasionally exceed 100%) may be somewhat misleading, as the highest relative uncertainties are generally for very low concentrations. Average uncertainties were 15% and 20% of average OMC and LAC respectively at the NY site. These moderately high Module C uncertainties are nonetheless disconcerting, given the relative importance of carbonaceous compounds to mass composition and visibility impairment, and the interpretive errors which can result when measurements with poor precision are utilized in statistical techniques like multiple regression and factor analysis.

Fortunately, however, there are several ways to estimate elemental and organic carbon from the more precisely determined Module A results. To the extent that these Module A estimates concur with the Module C measurements, they add a measure of confidence to the carbon measurements, and provide reasonable carbon estimates at NESCAUM sites which lack Module C samplers.

Composite Variables

Several previous reports, based on IMPROVE[1,2,8] or NESCAUM[3,4] data, have described methods for estimating major aerosol components (Sulfates, Organics,

Soot, Soil) from Module A measurements. Soil can be estimated from the "typically crustal" elements (Si, Fe, etc.) and assumptions regarding soil composition. Soot can be estimated from LR (itself a more direct measure of the visibility effect of LAC carbon). Sulfates can be estimated from S and assumptions regarding sulfur speciation (typically assumed to be ammonium sulfate at western sites). Organics can be estimated by the "Organic Matter by Hydrogen" (OMH) method, from S, H and assumptions regarding sulfate and organic speciation. Organics can also be estimated by the "remaining mass" (OMRM) method, by assuming that organics compose a relatively constant fraction of the fine mass remaining after sulfates, soot and soil, sea salt and non-soil K have been subtracted.

The one year (9/88-9/89) mean concentrations of these composite variables are summarized in Table II along with the measured OMC and LAC concentrations from the NY and MA sites. The equations employed to derive the composite estimates are listed in Table III. It should be noted that several of these equations differ from those employed in an earlier assessment of NESCAUM Winter Season results[4]. The current estimates are considered improvements upon (and are not directly comparable to) the previous ones.

Figure 5 compares monthly mean estimates of soot (by LR) and organic matter (by OMH and OMRM) with measured values of LAC and OMC at the MA site. The soot and LAC values agree reasonably well on a monthly basis, but exhibit no discernable seasonal trend at this site. The monthly organic estimates (by OMH, OMRM and OMC) all exhibit a distinct seasonal pattern, with July concentrations approximately 3 times higher than those in January. The strong agreement between the monthly concentrations derived by different approaches adds a measure of confidence to both the estimates and the measurements (themselves subject to considerable uncertainty on a day to day basis).

Figure 6 displays the mean monthly estimated fine mass composition at the relatively clean NY site and the higher concentration NJ site, with organics estimated by the OMH method and soot estimated from LR. Figure 7 displays the estimated 2 year mean compositions at all sites. It is likely that much of the "unknown" filter mass is composed of water and ammonium nitrate, both of which are lost under the vacuum conditions employed in the PIXE and PESA analysis (would consequently not contribute to the measured H concentrations). On a long-term average basis, sulfates appear to contribute about half the fine mass, with organics contributing about one fourth. Sulfates exhibit a distinct increase in the summer months, but the relative summer increase in organics is even greater, such that the average sulfate to mass ratio appears to decrease slightly from winter to summer, while the organic fraction increases.

Discussion

Although the Module A S and H measurements (used to estimate OMH) are characterized by very high precision, and although the annual and monthly OMH averages agree quite well with the average OMC measurements, the daily OMH estimates remain highly uncertain. This uncertainty is caused by the (currently unquantifiable) daily variations in the sulfur speciation on the exposed teflon filters.

Previous interpretations of IMPROVE results have indicated that fully neutralized ammonium sulfate is a reasonable assumption for most Western sites.[1] In the Northeast, however, we can anticipate a variable range of sulfate compounds in the ambient air - from fully neutralized ammonium sulfate to pure

sulfuric acid.[9-11] No precautions are currently taken in the NESCAUM and IMPROVE networks to prevent neutralization by ammonium nitrate or gaseous ammonia during sampling or prior to analysis. However, based on experience with past eastern measurement programs[9], it is probable that episodes of strong acidity may be captured on the (non-reactive, fine fraction) teflon filters and persist relatively un-neutralized up through the time of analysis. Under these conditions, our estimates of total sulfates will be inflated slightly, but our estimates of OHM will be seriously flawed. When this occurs, however, the effects are occasionally quite obvious from the Module A filters alone - providing a rough low-bound estimate of aerosol acidity. At sites where (Module C) organics are measured independently, we gain an ability to derive quantitative estimates of aerosol acidity (again lower bound) at multiple sites at minimal costs. (See Malm et al.,[12] paper 91-89.3 at this conference, for a more detailed discussion).

Figure 8 compares the measured mass at all sites with the "Reconstructed Mass" based on the estimated components (Sulfates, Organics, etc.) derived from the Module A teflon filter results. Most points fall on or within about 20% below the 1 to 1 line - which is logical given the likely contributions of water and ammonium nitrate to gravimetric mass (and subsequent loss of these compounds under vacuum). Note, however, that for a number of points, the reconstructed mass is as much as 50% lower than the measured mass. Several of these "outlier" points all occurred on the same day (8/16/89) at the NJ, CT, MA and ME sites. On this same date, however, reconstructed mass agrees closely with measured mass at the more inland NY, VT and NH sites.

The Organic fraction of reconstructed mass in Figure 8 is based on OMH estimates from the S and H concentrations. Figure 9 compares the daily OMH estimates with the OMC measurements at the NY and MA sites. The estimates and measurements (themselves characterized by significant uncertainties) agree reasonably well, with the exception of several extreme outliers where the OMH estimate is unreasonably low (negative). Each of these extreme OHM underestimates occurs during the summer season, with the 8/16/89 MA sample again representing the most extreme departure from the measured value. (The NY OMH value agreed well with the measured OMC on this date). For comparison, the NY and MA points representing 7/15/89 are also indicated in Figure 9, and show excellent agreement between OMC measurements and OMH estimates on this high organic summer day.

The occasional extreme OMH underestimates result from a flawed assumption that the sulfate is fully neutralized. Organic hydrogen is calculated by subtracting S/4 from total H. On occasions like 8/16/89 at certain sites, there is insufficient hydrogen on the filter to constitute ammonium sulfate, even if there were no organic matter or other hydrogen containing compound on the filter. This results in an estimate of negative OMH (obviously impossible), and provides a clear indication of an acidic aerosol event. This is illustrated by the Figure 10 comparison of S vs. H on a seasonal basis. Note the strong correspondence between S and H concentrations during the cold season (10/88-5/89). This suggests the possibility of common sources for sulfates and organics during the winter. The scatter is much greater in Figure 10b, suggesting more independent origins of sulfates and organics in the summer.

The lines in Figures 10a and b represent the mass ratio of H to S for ammonium sulfate. Points above the line are obviously acidic (see Malm et al.[12]). Without knowing organic hydrogen, we can't quantify this acidity; although several points exhibit H to S ratios approximating pure sulfuric acid.

Points falling below the line might also represent acidic sulfates, but without knowing organic hydrogen, these points cannot be distinguished using only the Module A results. Note that the 8/16/89 event at several sites again stands out as extreme (high S to H ratio). The 7/15/89 event (at all sites) represents the opposite extreme (low S to H ratio), and is the result of a large organic episode with very low sulfate.

The Module C measurements of organic carbon at the NY and MA sites permit a quantitative estimate of organic hydrogen (by assuming H=9% of organic matter). This reverse application of the OMH calculation permits an estimate of sulfate hydrogen, and consequently the relative acidity of the sulfate aerosol.[12] In Figure 11, such calculations are applied to the available MA and NY data. The results are expressed, by convention, as if all acidity were in the form of sulfuric acid. Except for the extremes of pure sulfuric acid or pure ammonium sulfate, there is no way of knowing - in these estimates, or most other measures of aerosol acidity - the actual mix of sulfate species on the filter (or in the ambient air). It should also be emphasized that without precautions to prevent filter exposure to ambient ammonia, these estimates represent a lower bound to ambient acidity levels. There are, nevertheless, several occasions where pure sulfuric acid is implicated, and where questions of mixed composition and artifact neutralization are simplified.

Figure 11 suggests that most filters exhibit a relatively high degree of neutralization, but that some acidity is present in nearly half the samples. The highest total acid concentrations at both sites occurred during the warm season, but frequent acidic events are also indicated during the winter. The spring is notably free of acidic events at both sites. A high sulfuric acid concentration obviously requires high total sulfate, but some of the highest sulfate events are fully neutralized, while some of the lower sulfate days are pure sulfuric acid. The highest total acidity concentration (about 9 ug/m^3 as H_2SO_4) occurred at the MA site on 8/16/89, while a similar 8/16/89 sulfate concentration at the NY site appears to have been fully neutralized. By comparison, sulfates were very low and fully neutralized on the 7/15/89 organic episode day.

Comparison of 8/16/89 and 7/15/89

Figure 12 provides a side by side comparison of selected variables across the network on 7/15 and 8/16/89. Recall from Figures 9 and 10 that 7/15/89 was characterized by the highest measured OMC concentration at NY and MA, and the highest H to S ratio (OMH) at all sites. 8/16/89 was characterized by high sulfate at all sites, which appears to have been fully neutralized at the NY, VT and NH sites and highly acidic at the other (more easterly) sites.

The two dates exhibit similar mass and hydrogen concentrations, and the reconstructed mass (sum of NHSO, OMH, Soot, Soil...) agrees very well with the measured mass at all sites on 7/15 and at the NY, VT and NH sites on 8/16. However, there are large values of unexplained mass (RSMA) on 8/16 at the more easterly sites. The reason for this is an over-estimate of sulfate hydrogen and consequent large (negative) under-estimate of OMH. Regional sulfur was roughly a factor of 10 higher on 8/16, while regional potassium was higher by a similar ratio on 7/15. The 7/15 combination of relatively high mass, high organics, and very high potassium in a mid summer episode at all sites suggests a regional scale forest fire influence. Backward air trajectory calculations (NOAA Hy-Split model[13]), displayed in Figure 13, indicate that all NESCAUM sites were influenced by strong Northwesterly flows on 7/15/89. It has subsequently been learned that

a number of large, uncontrolled fires, encompassing some 645,000 acres were burning during this time period in Northern Quebec.[14]

The trajectories for 8/16 indicate a distinctly East coast transport regime for the ME, MA, CT and NJ sites where the aerosol was strongly acidic. The equally high, but neutralized sulfate at the NY, VT and NH sites appears to have originated from more interior (and distant) sources. Conceivably, the high acidity at the coastal sites is the result of relatively nearby sources - with insufficient time for neutralization; or possibly the transport occurred predominantly over water, where ammonia availability is limited.

Conclusions

- Regional-scale fine particle mass concentrations in the NESCAUM region average about 10 ug/m^3, and are composed of roughly 50% sulfates and 25% organics. Mean concentrations of most fine mass components increase by about 50% to 100% as one moves from northwest to southeast in the region.

- Regional-scale sulfates and organics both exhibit distinct summer maxima, with the seasonal trend for organics more pronounced. Sulfates and organics appear to co-vary strongly in winter and poorly in summer, suggesting common (winter) and independent (summer) source influence on these predominant aerosol components.

- Non-sulfate hydrogen calculations of organic matter (OMH), derived from IMPROVE Module A samples, provide sound estimates of organics for annual and monthly averages, and for a majority of daily events. Daily OMH estimates are occasionally highly unrealistic on days when acidic sulfate compounds are implicated on Module A filters. For such events the Module A results can provide a rough approximation of aerosol acidity.

- Module C sampling is largely redundant for carbon, but adds considerably to the confidence of Module A estimates, and permits a more refined approximation of aerosol acidity. These (unconfirmed) acidity estimates suggest: relatively poor correspondence between total acidity and total sulfate; highest absolute acidity during summer, but frequent events of high relative acidity during the winter; possibility of relatively larger near source influence on acidity than for sulfate.

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Table I. Average NESCAUM Module A Concentrations (9/88-8/90)

	NH[a]	NY	VT	ME	MA[a]	CT	NJ	Hi/Lo[c]
Mass	7673	8147	8643	8694	10643	10243	11898	1.6
LR[b]	839	941	1010	1031	1389	1267	1800	2.1
S	872	985	972	985	1193	1168	1414	1.6
H	379	400	422	412	527	470	590	1.6
Si	60	67	69	61	78	83	99	1.7
K	29	28	37	50	37	33	41	1.8
Fe	20	21	23	20	30	30	41	2.0
Ca	16	19	21	19	23	22	26	1.6
Zn	6.8	6.6	8.0	7.5	10.6	9.4	13.1	2.0
Pb	3.8	3.6	4.1	4.0	5.0	5.0	6.7	1.8
Br	1.7	1.6	1.8	1.7	2.2	2.1	2.5	1.6

a. NH and MA missing Fall, 1988.
b. LR in 10^{-8} m^{-1}. All other values in ng m^{-3}.
c. Highest site mean/lowest site mean.

Table II. Average NESCAUM Module C and Composite Variables (in ng/m^3, 9/88-8/89)

	NH[a]	NY	VT	ME	MA[a]	CT	NJ	Hi/Lo
NHSO[b]	3649	4107	3966	4193	4902	4679	5796	1.6
OMH[c]	2135	1875	2089	1921	2719	1565	2850	1.8
OMRM	2145	1869	2412	2335	2898	2648	2755	1.5
OMC	--	1789	--	--	2767	--	--	1.5
LAC	--	346	--	--	604	--	--	1.7
SOOT	414	452	495	504	652	596	824	2.0
SOIL	286	309	298	285	383	391	457	1.6
RCMA	6645	6945	7119	7212	8836	7444	10202	1.5

a. NH and MA missing Fall, 1988.
b. See Table III for Composite Variable Definitions
c. OMH Means assume negative values = 0

Table III. Equations and Assumptions for Composite Variables

1. **NHSO** (Ammonium Sulfate) = 4.125S.

   a. All sulfur on filter is ammonium sulfate.

2. **OMH** (Organic Matter by Hydrogen) = 13.75 (H-0.25S).

   a. All Hydrogen (under vacuum) is from NHSO or organics.
   b. Organic Matter is 9% Hydrogen.
   c. 25% of organic matter is lost (from teflon) under vacuum.

3. **Soot** = LR/2.

   a. LR (b_{abs}) is caused by soot.
   b. Soot absorption efficiency is 20 m^2/g.

4. **Soil** = 2.20 Al + 2.49 Si + 1.63 Ca + 2.42 Fe + 1.94 Ti.

   a. Above elements soil derived and present in common oxide forms.
   b. Soil K (non-smoke) = 0.6 Fe.
   c. Above elements as oxides compose 86% of soil.

5. **REM** (Remaining Mass) = Mass-NHSO-Soot-Soil-1.4(K-0.6 Fe)-2.5 Na.

   a. Estimates Mass minus Sulfates, Soot, Soil, Smoke K and Salt.
   b. Comprises upper bound for organic matter.

6. **OMRM** (Organic Matter by Remaining Mass) = 0.65 REM.

   a. Organics (on average) comprise 65% of remaining mass.

7. **RCMA** (Reconstructed Mass from Module A Estimates) = OMH + Mass - REM.

   a. Sum of Module A estimates.

8. **RSMA** (Residual Mass from Module A Estimates) = Mass-REM-OMH.

   a. Difference between measured mass and sum of estimates.

9. **OMC** (Organic Matter by Carbon) = 1.4 (OCLT + OCHT) + 400.

   a. Statistical adjustments: 27 ng/m^3 for OCLT; 260 ng/m^3 for OCHT.
   b. Organic Matter is 71% organic carbon.

10. **LAC** (Light Absorbing Carbon) = ECLT + ECHT + 33.

    a. Statistical adjustments: 27 ng/m^3 for ECLT; 6 ng/m^3 for ECHT.

Figure 1. NESCAUM Site Locations and Elevations

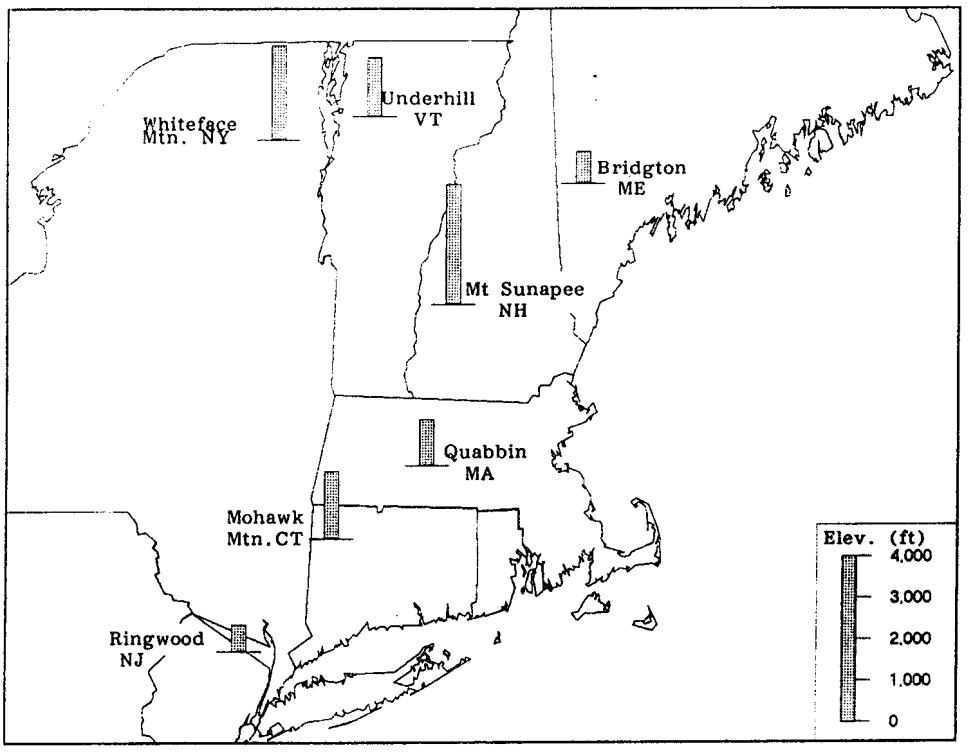

Figure 2. NESCAUM Module A Percent Detectability (9/88 - 8/90)

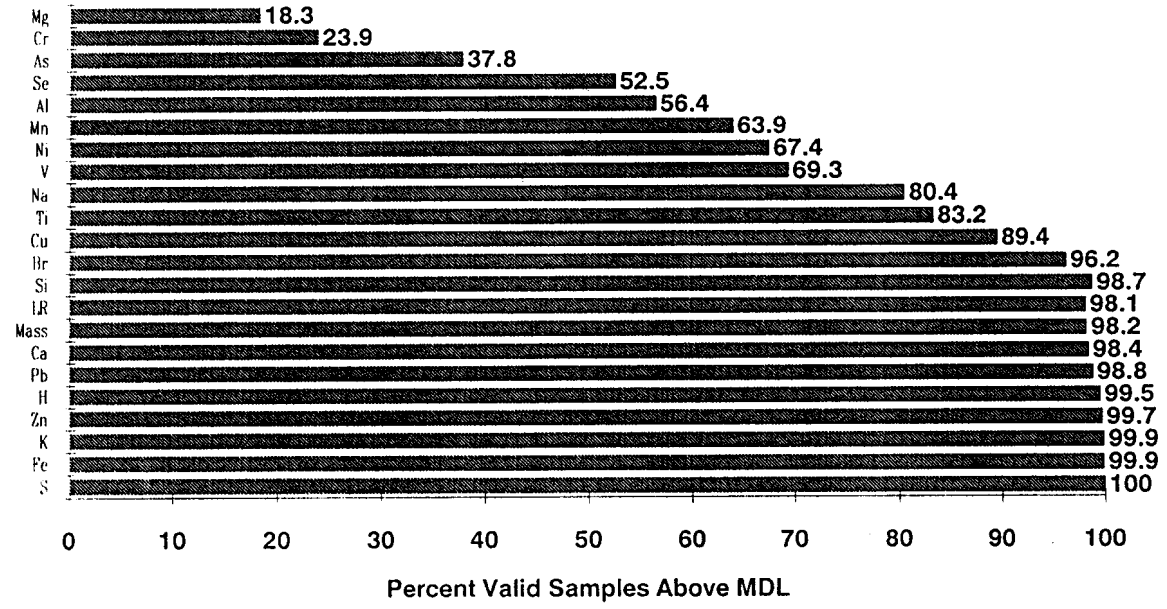

Figure 3a. Average Monthly Fine Sulfur (9/88 – 9/90)

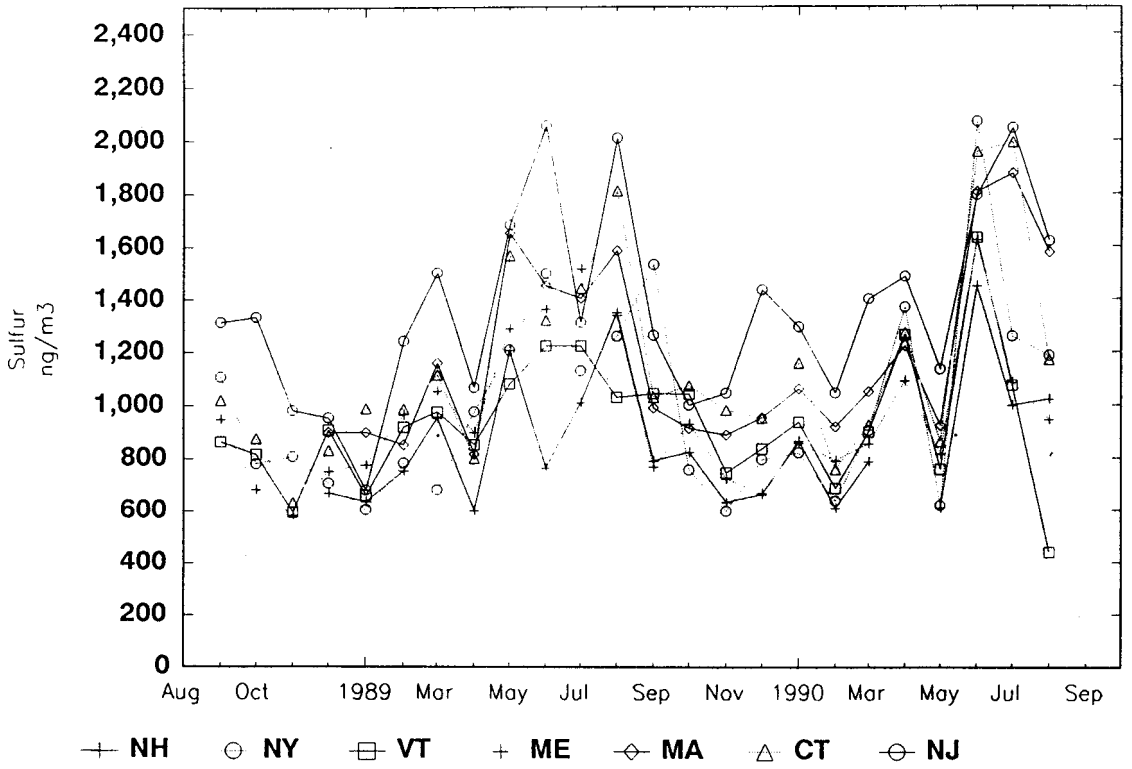

Figure 3b. Average Monthly Light Absorption (9/88 – 9/90)

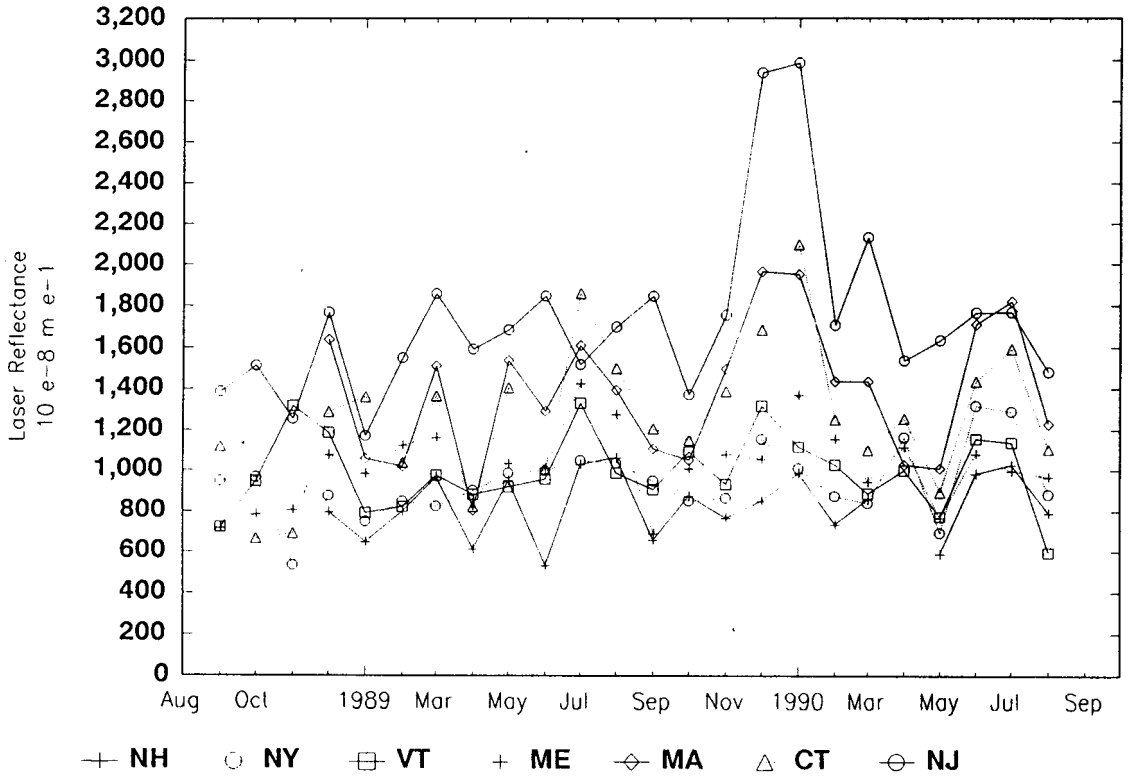

Figure 4a. Relative Uncertainty of S, H and LR at Whiteface Mtn., NY

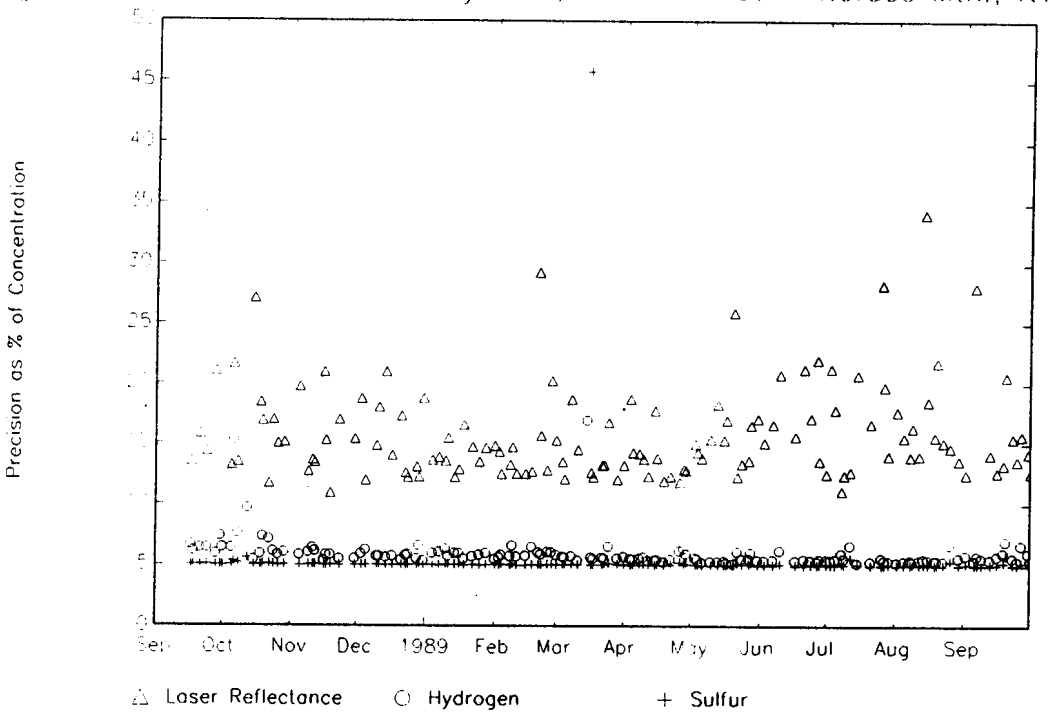

Figure 4b. Relative Uncertainty of OMC and LAC at Whiteface Mtn., NY

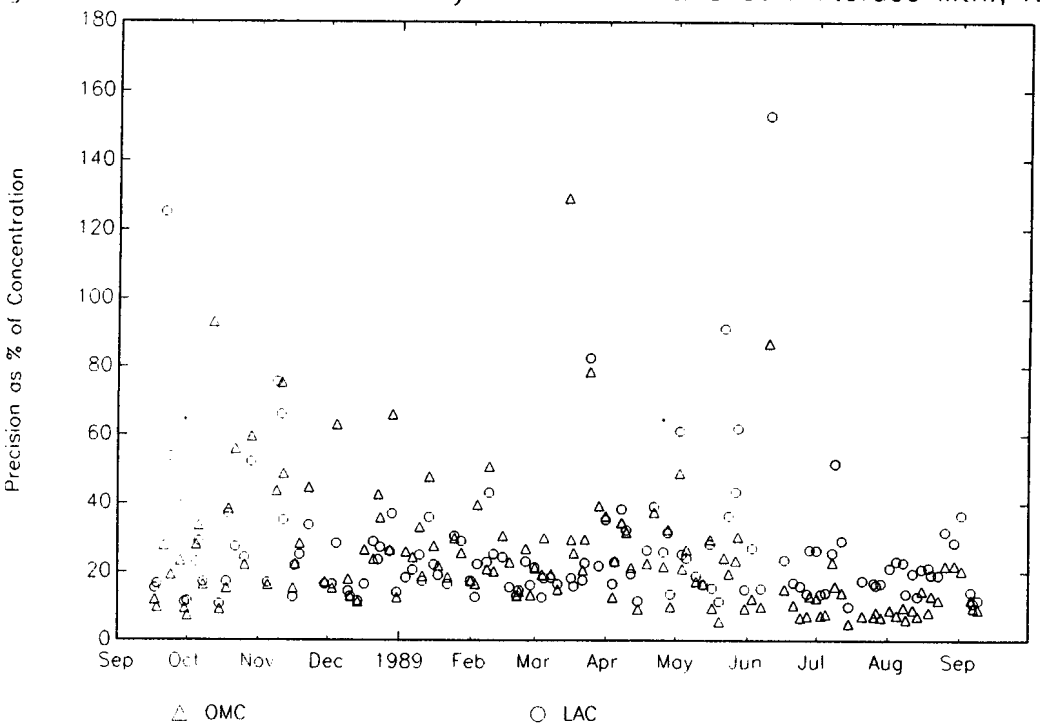

Figure 5a. Monthly Soot Carbon Estimates at Quabbin, MA

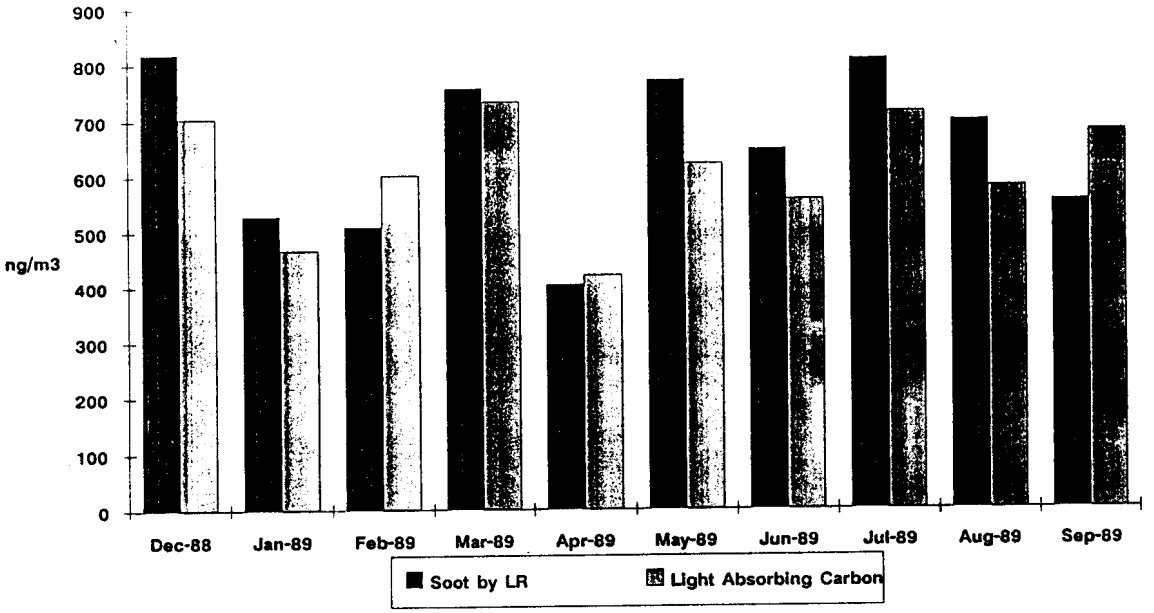

Figure 5b. Monthly Organic Carbon Estimates at Quabbin, MA

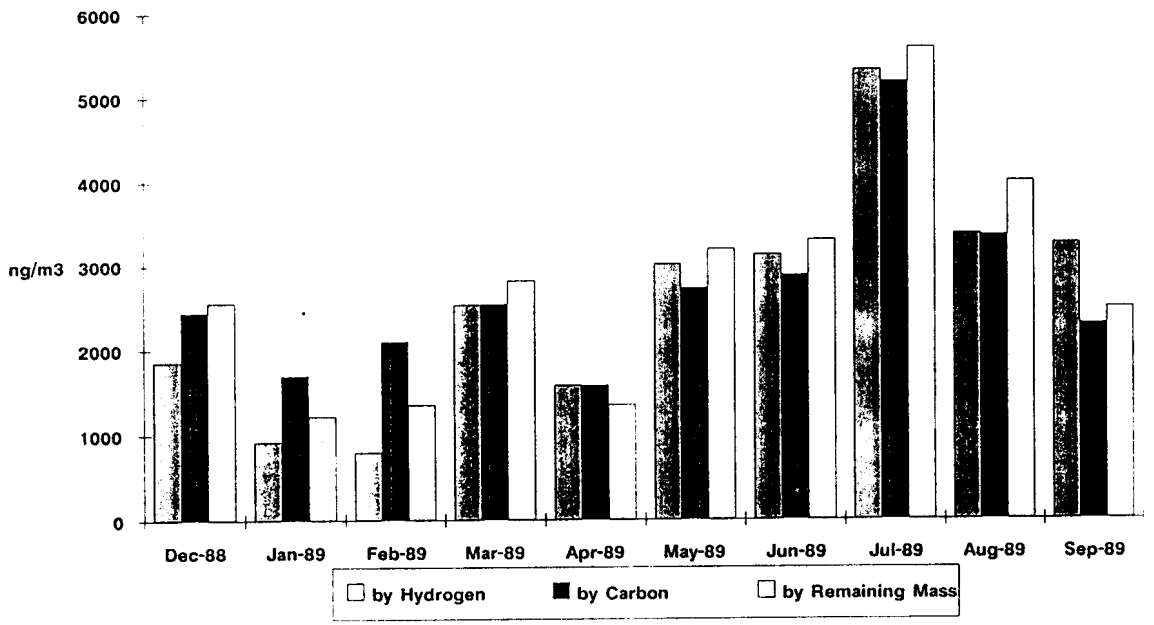

Figure 6a. Estimated Monthly Fine Mass Composition at Whiteface Mtn., NY

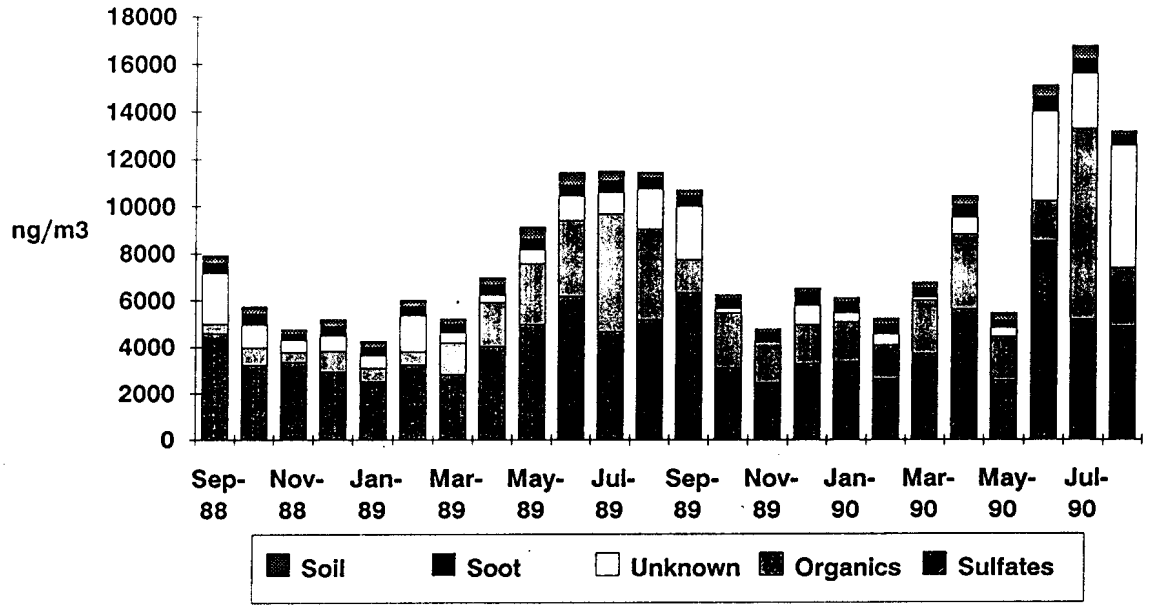

Figure 6b. Estimated Monthly Fine Mass Composition at Ringwood, NJ

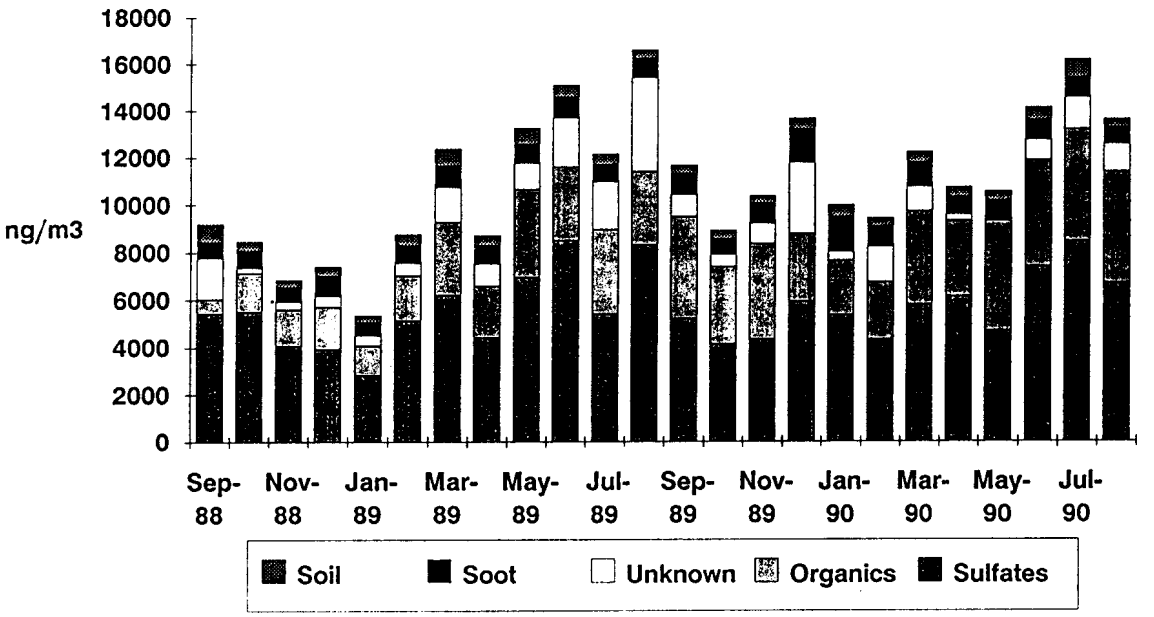

Figure 7. Average Nescaum Fine Mass Composition (9/88 - 8/90)

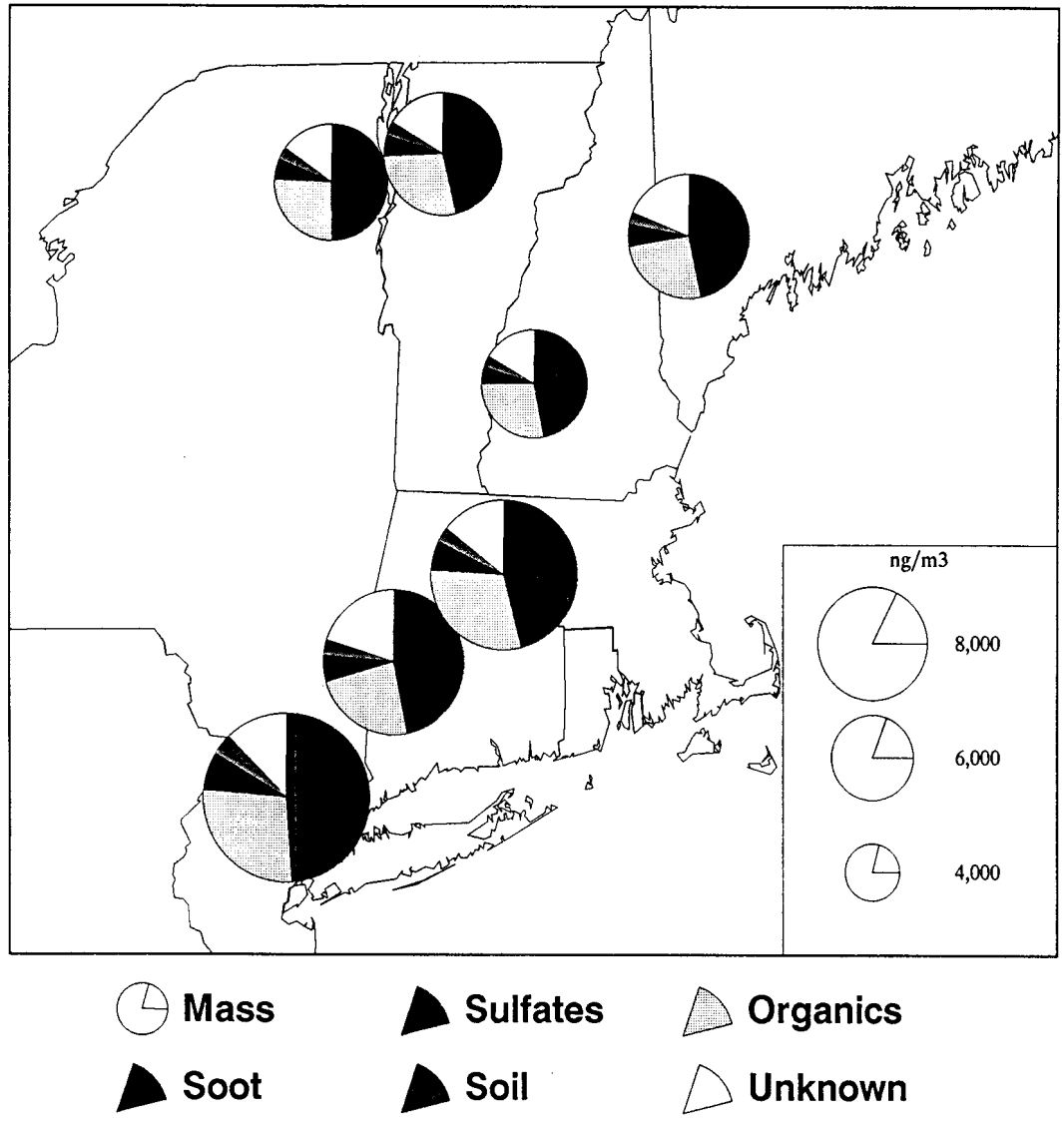

Figure 8. Measured vs. Reconstructed Mass

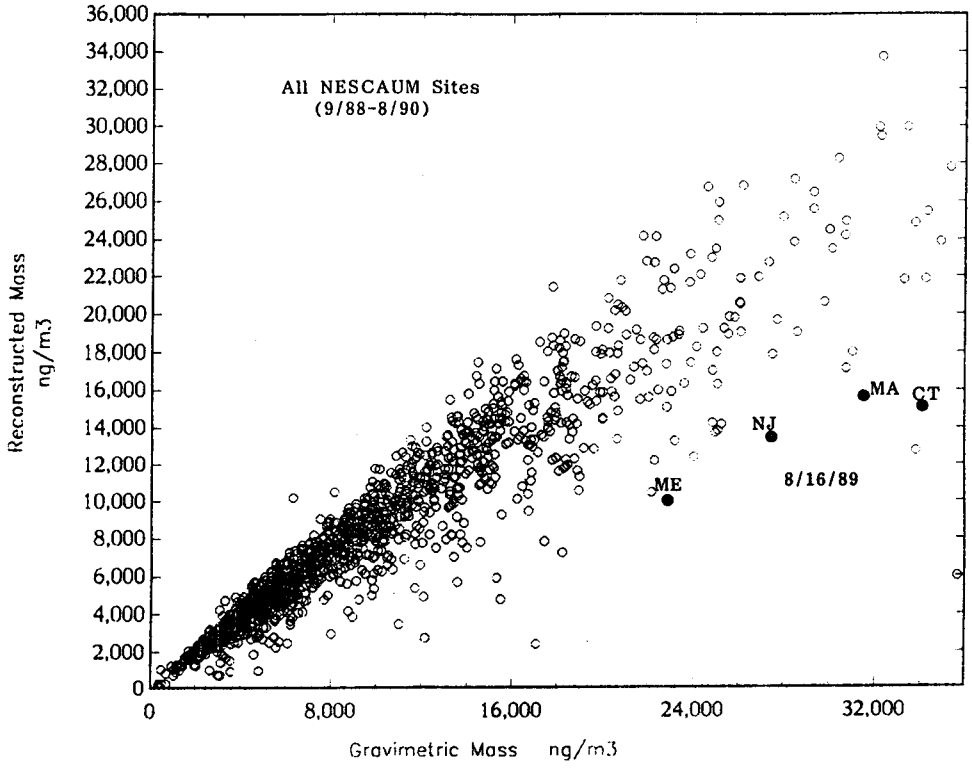

Figure 9. Organics by H vs. Organics by C

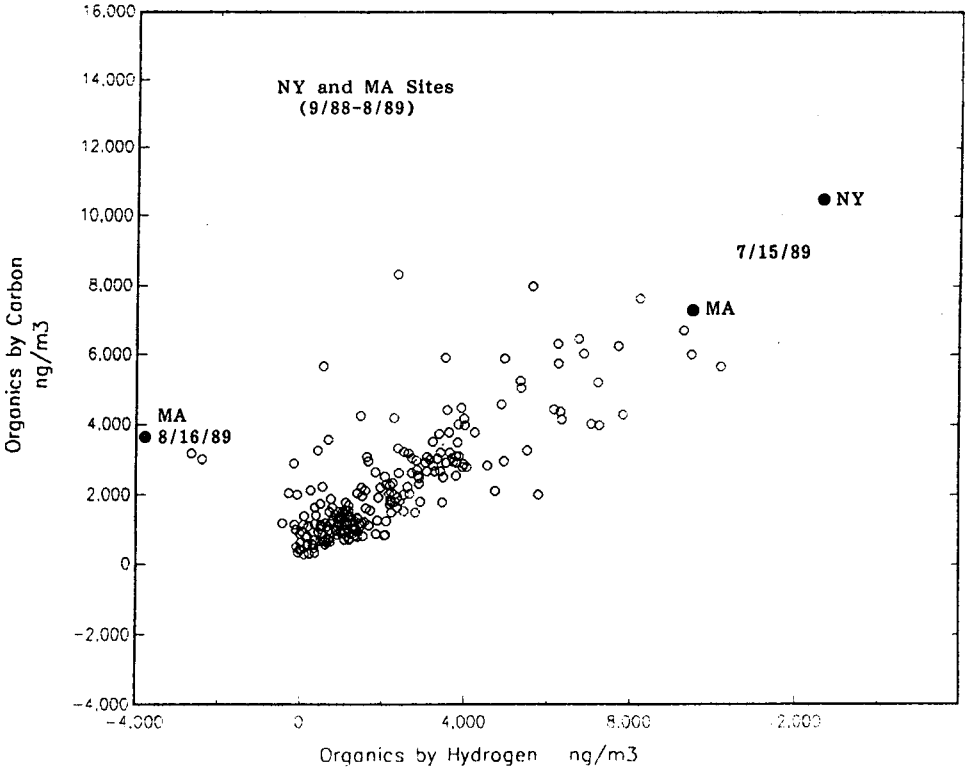

Figure 10a. Cold Season (9/88-5/89) Sulfur vs. Hydrogen (All NESCAUM Sites)

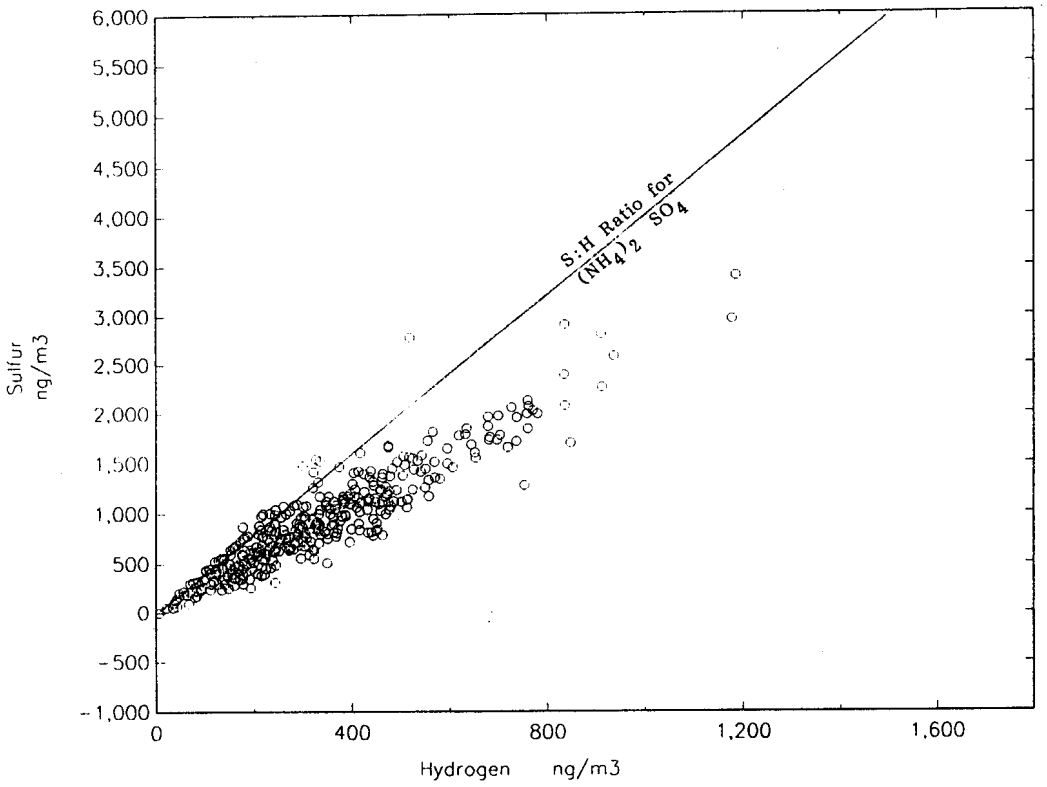

Figure 10b. Warm Season (5/89-9/89) Sulfur vs. Hydrogen (All NESCAUM Sites)

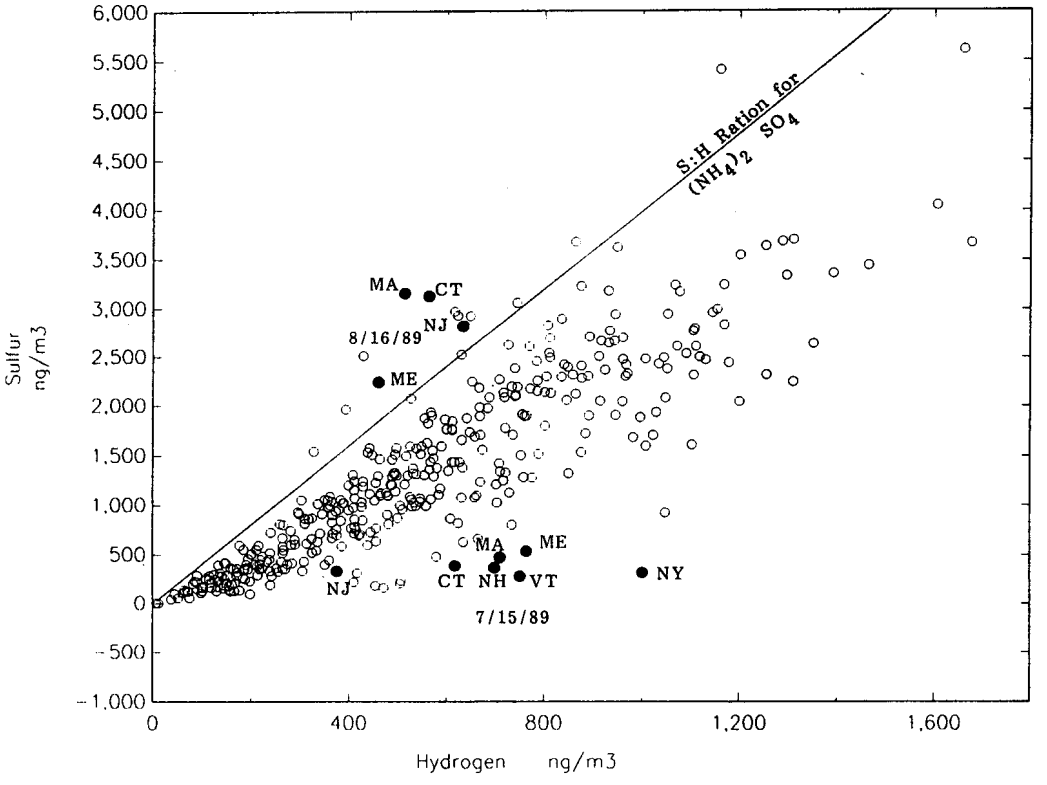

Figure 11a. Sulfates at Whiteface Mtn., NY (as Ammonium Sulfate and Sulfuric Acid)

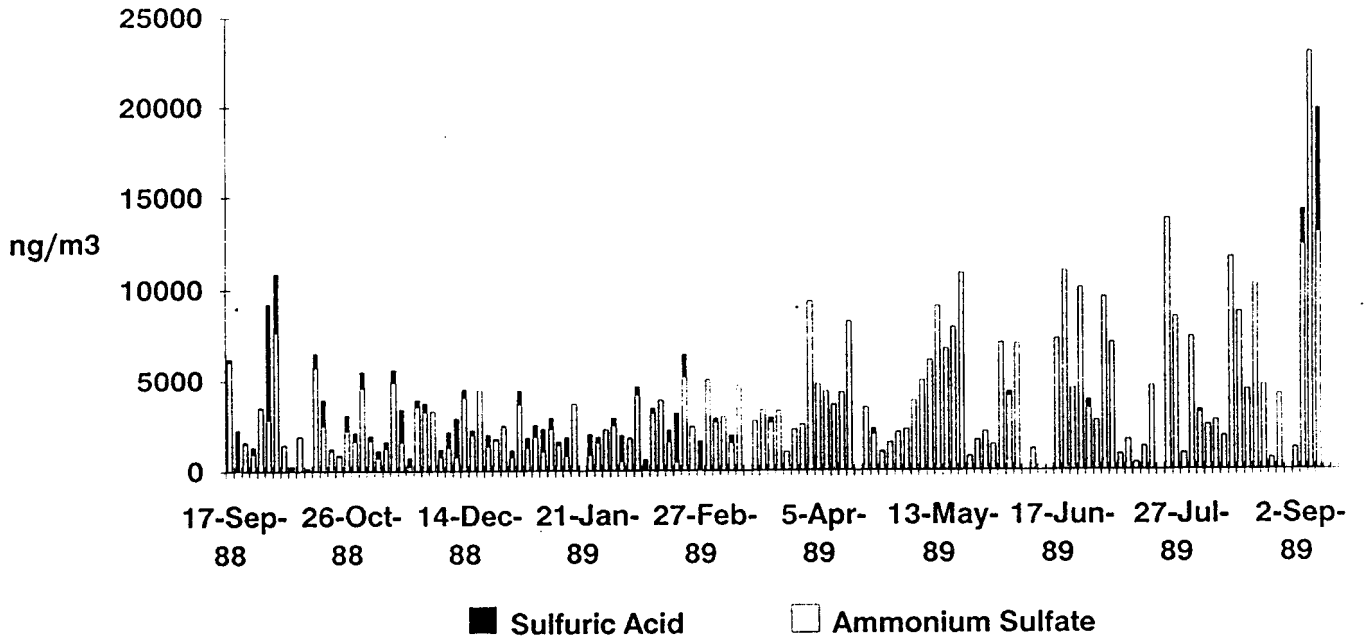

Figure 11b. Sulfates at Quabbin, MA (as Ammonium Sulfate and Sulfuric Acid)

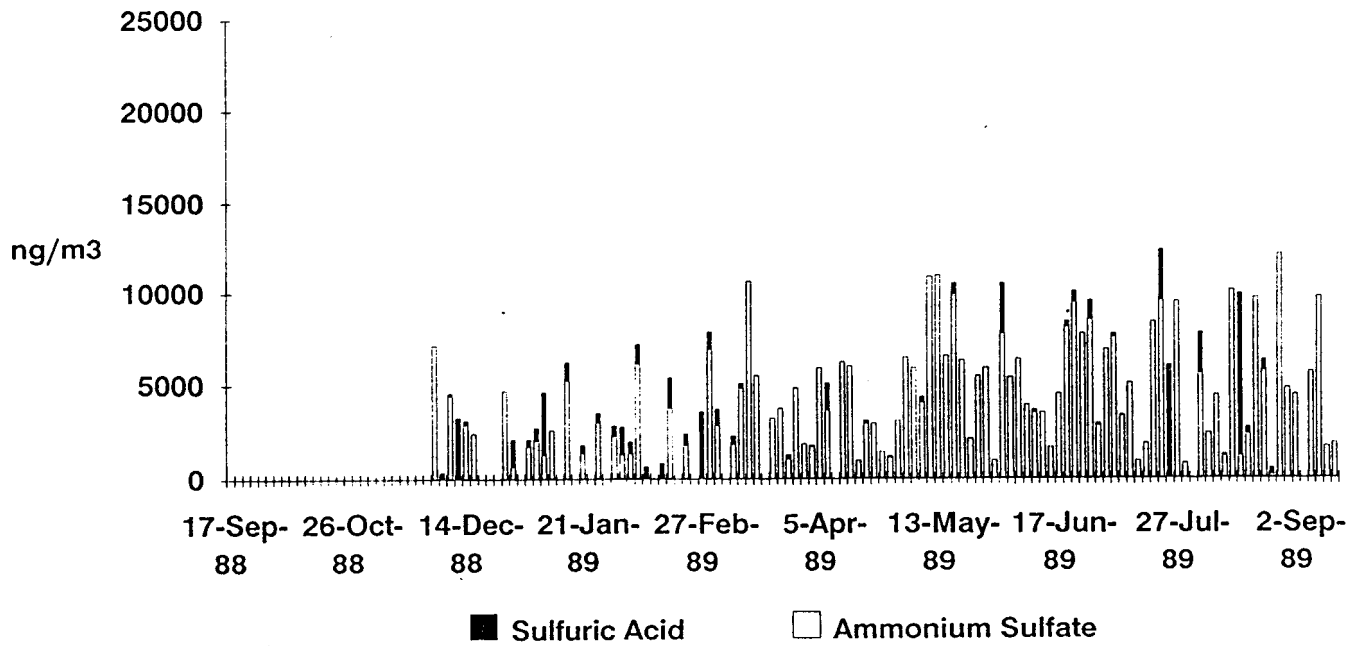

Figure 12. Comparison of Selected Variables on 7/15/89 and 8/16/89

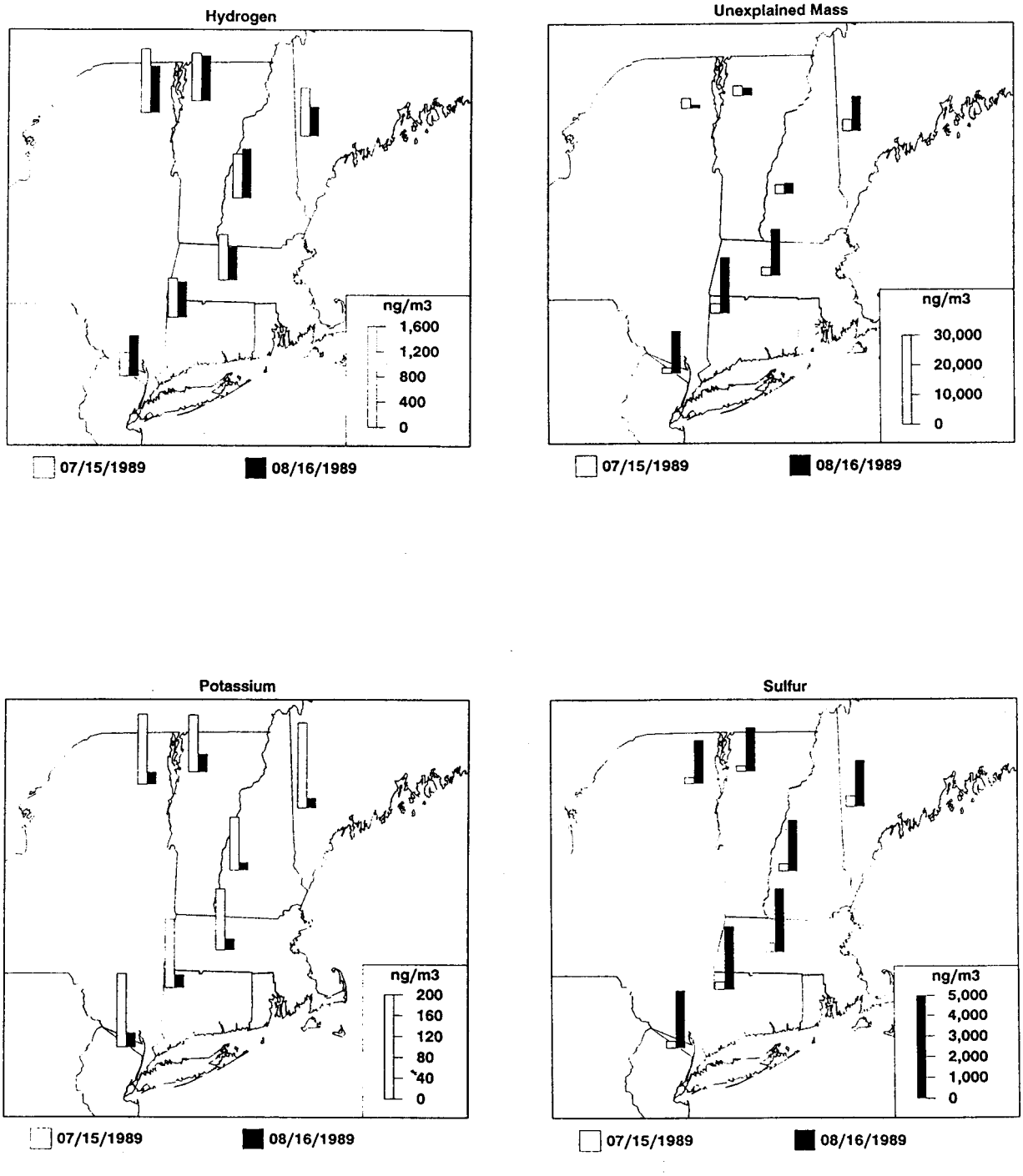

Figure 13. 3 Day Back Trajectory Calculations (NOAA HYSPLIT Model) Arriving at NESCAUM Sites on 7/15/89 and 8/16/89