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Project Summary

Mountain Cloud Chemistry Project—Wet, Dry and Cloud Water Deposition

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The spruce-fir forests in the higher elevations of the Appalachian mountains from North Carolina to Maine are showing visible symptoms of injury and increased mortality. Concern has been raised that exposure to and deposition of atmospheric pollutants might play a role in this decline. The Mountain Cloud Chemistry Project (MCCP) sponsored by the U.S. Environmental Protection Agency (EPA) and the National Acid Precipitation Assessment Program (NAPAP) is studying the exposure and deposition of atmospheric constituents to these forests.

Atmospheric pollution is deposited to the forest a number of forms, cloud water interception represents a major deposition patterning and may exceed deposition by precipitation and gases. The full report provides estimates of cloud, precipitation and dry deposition to the spruce-fir forests at six MCCP sites. Equally important is an understanding of the elevational gradients that exist in the deposition of airborne consistents. Comparisons are made at MCCP sites at different elevations and between MCCP sites at different latitudes and longitudes.

This Project Summary was developed by EPA's Atmospheric Research and Exposure Assessment Laboratory, Research Triangle Park, NC, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

The full report is the second in a series of annual summaries of research on the deposition of airborne chemicals to forest canopies and the forest floor in eastern North America. The report is based on observations and model estimates of atmospheric deposition at six high elevation sites in the eastern United States. The report is produced by the scientists in the Mountain Cloud Chemistry Program, a multi-year study of atmospheric chemistry and physics sponsored by the EPA.

One of the major objectives of this research is the characterize geographical and elevational variability in the amounts of airborne chemicals transferred from the atmosphere into the spruce-fir and other forest ecosystems that cover high elevation sites in the Appalachian Mountains of the eastern part of the North America. The reports in this series constitute the principal linkage between the Mountain Cloud Chemistry Program (MCCP) and the Eastern Spruce-fir Research Cooperative (ESFC). Both MCCP and ESFC are important parts of the Forest Response Program (FRP) which is sponsored jointly by the U.S. Forest Service, the U.S. Environmental Protection Agency, and the National Council of the Paper Industry for Air and Stream Improvement (NCASI). Both MCCP and ESFC are contributors to the National

Acid precipitation Assessment program (NAPAP).

The MCCP has three primary objectives: (1) Determine the elevational gradients in wet and dry deposition of pollutants and climate variables; (2) determine the relative significance of various deposition mechanisms to the fluxes of chemical species into and through forest canopies; (3) determine the frequency distributions of chemical, physical and climatic exposure.

The first two objectives are addressed in the full report, the third is addressed in a complimentary report.

The full report provides estimations of deposition to the forests from precipitation, wind blown clouds and by dry deposition mechanisms. Measurement methodology used to provide data for these estimations, data sets and models used for deposition estimates are discussed in detail in the full report. Comparisons of deposition are made between southern and northern MCCP sites. Elevation gradients in deposition are also discussed.

Two models are used to estimate cloud water and chemical deposition flux. One model was developed by Lovett and modified by Mueller. This model is designed for use with spruce-fir forest canopies. The other model also based on Lovett's original model was developed by Krovetz for use with the deciduous canopy at the Shenandoah MCCP site.

The model used to estimate dry deposition in the inferential or "big Leaf" model. Since this model was originally developed for flat terrain and the model has not been fully characterized for mountainous regions, deposition estimates reported here reflect these uncertainties.

Technical Approach

Resource and logistical considerations dictate that measurements of inputs to high elevation forests in eastern North America can be performed at only a limited number of sites where proper access and facilities are available. In order to meet the needs of the project, five high elevation sites have been selected from 45N to 35N to be representative of the geographic and meteorological variability in this large region. This coverage has been augmented by the addition of a low level site (Howland, ME) to allow evaluation of the impact of elevational gradient forest types and enhance geographical coverage.

The research/monitoring sites associated with MCCP are Howland Forest, ME., Mt. Moosilauke, NH, Whiteface Mtn , NY, Shenandoah, VA, Whitetop, VA. and Mt. Mitchell, NC.

Site specific measurements of cloud and rain water, of gaseous sulfur and nitrogen compounds, and of ozone and hydrogen peroxide are sampled hourly or are directly converted into hourly concentration values. In the case of filterpack measurements, samples are integrated over a week's time. These concentration values then represent the primary exposure parameters. The concentration of pollutants and the associated meteorological conditions are needed to provide estimates of deposition by precipitation, clouds, and gases.

Results

Deposition of Pollutant Ions in Precipitation

Wet deposition of pollutants was estimated for the 1987 warm season at the MCCP sites using standard NADP/NTN measurements of rainfall amounts and chemistry. The NADP sites selected to represent MCCP sites are Greenville,ME09, Whiteface,NY98, Hubbard Brook,NH02, Big Meadows,VA29, Whitetop,VA28 and Clingsmans Peak,NC45.

Deposition is reported only for the warm season. This period is the longest at Shenandoah and Howland sites, extending from early April at both site locations to mid-November and early October, respectively. Mt. Moosilauke and Whiteface have the shortest. For comparison of wet deposition among the northern and southern sites, the wet deposition for the southern sites was adjusted to correspond to the concurrent warm season wet deposition for the northern sites. This comparison is shown in Table 1

Deposition of Pollutants in Cloud Water

Wind driven cloud droplets together with water-borne pollutants are deposited on the leaves of mountain trees. This mechanism produces a flux of pollutants at mountain tops over and above that available in nearby low elevation sites. To estimate deposition by this mechanism, MCCP uses a combination of measured pollutant concentrations in droplets and with cloud deposition rates.

Two models were used to estimate cloud water and chemical deposition flux. One model was developed by Lovett and modified by Mueller This model was designed for use with the spruce-fir forest canopies The other model, is also based on Lovett's original model and has been modified by Krovetz for use with the deciduous canopy at the Shenandoah MCCP site.

Table 1 *Concurrent Warm Season Adjusted Wet Deposition (kg/ha)*

Location	NH_4^+	$SO_4^=$	NO_4^+
Greenville, NE.	*.44*	*5.1*	*2 61*
Whiteface, NY	*1.30*	*9.10*	*3.80*
Hubbard Beach, NH.	*1.13*	*11.34*	*5.84*
Whitetop, VA.	*1 23*	*12.78*	*5.29*
Mt Mitchell, NC.	*1.83*	*20 60*	*9.04*
Big Meadows, VA	*1.75*	*9 28*	*5.71*
Shenandoah, VA	*1 39*	*12.45*	*5 01*

Table 2 presents estimates for growing season deposition of ions via the cloud water mechanism for all sites. These estimates are significant for all sites and are comparable or larger than precipitation deposition for most. The range of deposition values is wide. It is clear that there are some regional differences in deposition of ions in cloud water

Dry Deposition of Gases and Particles

MCCP uses current available methodology to estimate dry deposition flux. The model of choice to provide estimates of dry deposition velocities is the inferential model under development by the ATDL/NOAA. There is considerable uncertainty associated with the application of this type of model to mountain environments. Still, to obtain dry deposition estimates it is necessary to apply a model to estimate dry deposition velocities for use with MCCP measured concentration values.

Table 3 shows the dry deposition values for different MCCP sites during the warm season.

Conclusions

Wet deposition of pollution related ions in rain summed over the growing season (warm season) exhibited a significant west to east gradient from Whiteface/-Moosilauke to Howland, Maine. Sulfate deposition decreased from about 12 kg/ha for the Adirondacks and Green

Table 2. *Total Cloud Deposition During the 1987 Growing Season (ka/ha/growing season)*

Location	H^+	NH_4^+	NO_3^-	$SO_4^=$
Whiteface	0.7	9.2	19.3	44.9
Moosilauke	0.2	1.2	4.0	8.3
Shenandoah	0 3	1.9	9.4	9.6
Whitetop	1.2	14.3	42.5	76.0
Mt. Mitchell	0.5	5 0	14.2	30.2

Mountains down to about 6 kg/ha in central Maine. Combined nitrate and ammonium deposition decreased from about 8 kg/ha to 4 kg/ha.

Wet deposition for the southern MCCP sites also exhibited a gradient with higher values for Shenandoah and lesser values for Whitetop and Mitchell. Sulfate deposition summed over the growing season decreased from about 21 kg/ha for Shenandoah to about 8 kg/ha for Mitchell. Combined nitrate and ammonium deposition decreased from about 12 kg/ha to 4 kg/ha.

Dry deposition of sulfur and nitrogen compounds is low at all MCCP sites except Shenandoah. Typical warm season deposition fluxes are around or below 3 kg/ha for the combination of sulfur dioxide and sulfate. Nitrate deposition is less than 1.5 kg/ha at all sites except Shenandoah.

Deposition of pollution related ions in cloud water (cloud interception) represents a major input to montane forest canopies. It can exceed the flux from wet and dry deposition at mountain sites frequently exposed to cloud. Whiteface Mt. has an estimated warm season sulfate deposition flux of 45 kg/ha, about a factor of five higher than the measured wet deposition flux. Whitetop Mt. exhibits equally high cloud sulfate deposition with 76 kg/ha. Mt. Mitchell has an estimated cloud water sulfate deposition of 30 kg/ha. The combined nitrate end ammonium deposition from cloud interception are also high for the high elevation MCCP sites at Whiteface Mt. (28 kg/ha), Whitetop Mt. (57 kg/ha) and Mt. Mitchell (19 kg/ha). For the other MCCP sites, wet and dry deposition equals or exceeds cloud deposition flux for sulfate, nitrate and ammonium ions, essentially because of lower frequency of exposure to clouds. Cloud interception therefore has the potential to be the major and sometimes dominant process for the input of sulfur and nitrogen compounds into montane forests. For MCCP sites with elevations greater than 1200 m, cloud water interception contributes more sulfur and nitrogen to the forests than does wet and dry deposition. However, significant errors may be associated with the deposition estimation procedures available to, and used by, the MCCP for the estimation of both dry deposition and cloud water interception by mountain forests. A major effort will be undertaken by MCCP in the 1989 field season to define the accuracy of these estimation procedures.

Table 3. *MCCP Warm Season Dry Deposition (kg/ha/season)*

Location	Ozone	SO_2	HNO_3	NO_2	SO_4	NO_3
Howland Forest	33.8	0.85	1.76		0.67	0.015
Moosilauke	31 5					
Whiteface	26.5	1.38			0.90	
Shenandoah	105.9	22 4	6.04		5.85	0.050
Mt. Mitchell	42 1	2.13		1.07		
Whitetop	29.1	.99			1.11	0.073

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***Ralph Baumgardner** is the EPA Project Officer (see below).*
The complete report, entitled "Mountain Cloud Chemistry Project—Wet, Dry and Cloud Water Deposition," (Order No. PB 89-148 597/AS; Cost: $15.95, subject to change) will be available only from:
National Technical Information Service
5285 Port Royal Road
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