TRENDS IN SNOWPACK CHEMISTRY AND COMPARISON TO NATIONAL ATMOSPHERIC DEPOSITION PROGRAM RESULTS FOR THE ROCKY MOUNTAINS, USA, 1993-2004

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ABSTRACT

Seasonal snowpack chemistry data from the Rocky Mountain region for 1993-2004 was examined to identify long-term trends in concentration and chemical deposition in snow, and in snow-water equivalent. Comparisons of trends were made between snowpack data and National Atmospheric Deposition Program wetfall data from nearby sites in the region. We used an innovative, non-parametric correlation method known as the Regional Kendall Test. This technique expressed the slope, direction, and probability of trend for several sites at once in each of the Northern, Central, and Southern Rockies subregions. Seasonal Kendall tests were used to evaluate trends at individual sites. Sulfate deposition decreased with moderate to high significance in all three subregions in both wetfall and snowpack. Precipitation trends consistently were downward for wetfall-, snowpack-, and SNOTEL data for the Central and Southern Rockies subregions ($p<0.02$), while no trends were noted for the Northern Rockies subregion.

INTRODUCTION

Because snowmelt dominates the annual water budget in mountain lakes, streams, and wetlands in much of the Rocky Mountain region, monitoring the water quality of snow is important for quantifying atmospheric deposition. Concerns about adverse effects associated with atmospheric deposition of nitrogen or sulfur in North America historically have focused on eastern areas of the continent. However, recent work indicates watersheds in the Rocky Mountains of the western USA, particularly in Colorado and parts of Wyoming are receiving elevated concentrations of nitrogen in atmospheric deposition.

To identify long-term spatial and temporal trends in chemical concentrations to the Rocky Mountain snowpack, the USGS in cooperation with the National Park Service, USDA Forest Service, and other organizations have collected snowpack samples at a large network of snowpack-sampling sites in the region. The Rocky Mountain Snowpack (RMS) network sampling sites were selected to complement the existing National Atmospheric Deposition Program (NADP) sites in the region. This report combines snow-chemistry results from 1993-2004 with wetfall-chemistry from nearby NADP sites to illustrate trends in precipitation chemistry.

METHODS

Samples representing the seasonal snowpack were collected at 54 sites in the region for each year of this study. Snowpack sites were collocated in many cases with 16 NADP sites for comparison of 12-year trends (Figure 1). National Resources Conservation Service snow-telemetry (SNOTEL) data from 43 selected sites in the region were compared to snowpack- and wetfall-precipitation data for verification of precipitation trends (Figure 2).

Poster presented Western Snow Conference 2007
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Figure 1: Snow pit co-located near NADP wetfall collection station.

The non-parametric Regional Kendall Test was used to compute the slope, direction, and probability of trend for grouped sites in each of the Northern, Central, and Southern Rockies subregions. Seasonal Kendall tests also were used to evaluate trends at individual sites.

RESULTS AND CONCLUSIONS

Chemical-concentration data for 54 RMS snowpack sites and 16 NADP wetfall sites for the 12-year period indicate significant subregional trends in many cases ($p<0.15$) (Figure 3). For trends at specific sites, higher significance ($p<0.05$) also is shown. Comparisons of trends for nitrogen (NH_4^+ and NO_3^-) and sulfur (SO_4^{2-}) concentrations were limited by the small number of NADP sites in the Northern and Central Rockies subregions. However, in the Southern Rockies increasing trends in ammonium and nitrate concentrations were significant for both NADP and RMS networks. Greater population density and development in the Southern Rockies likely contributed to the increasing nitrogen trend. In contrast, sulfur concentrations have significantly decreased in wetfall in the Central and Southern Rockies subregions at NADP sites, and in snowpack in all three subregions. This is consistent with national and regional reductions in sulfur emissions.

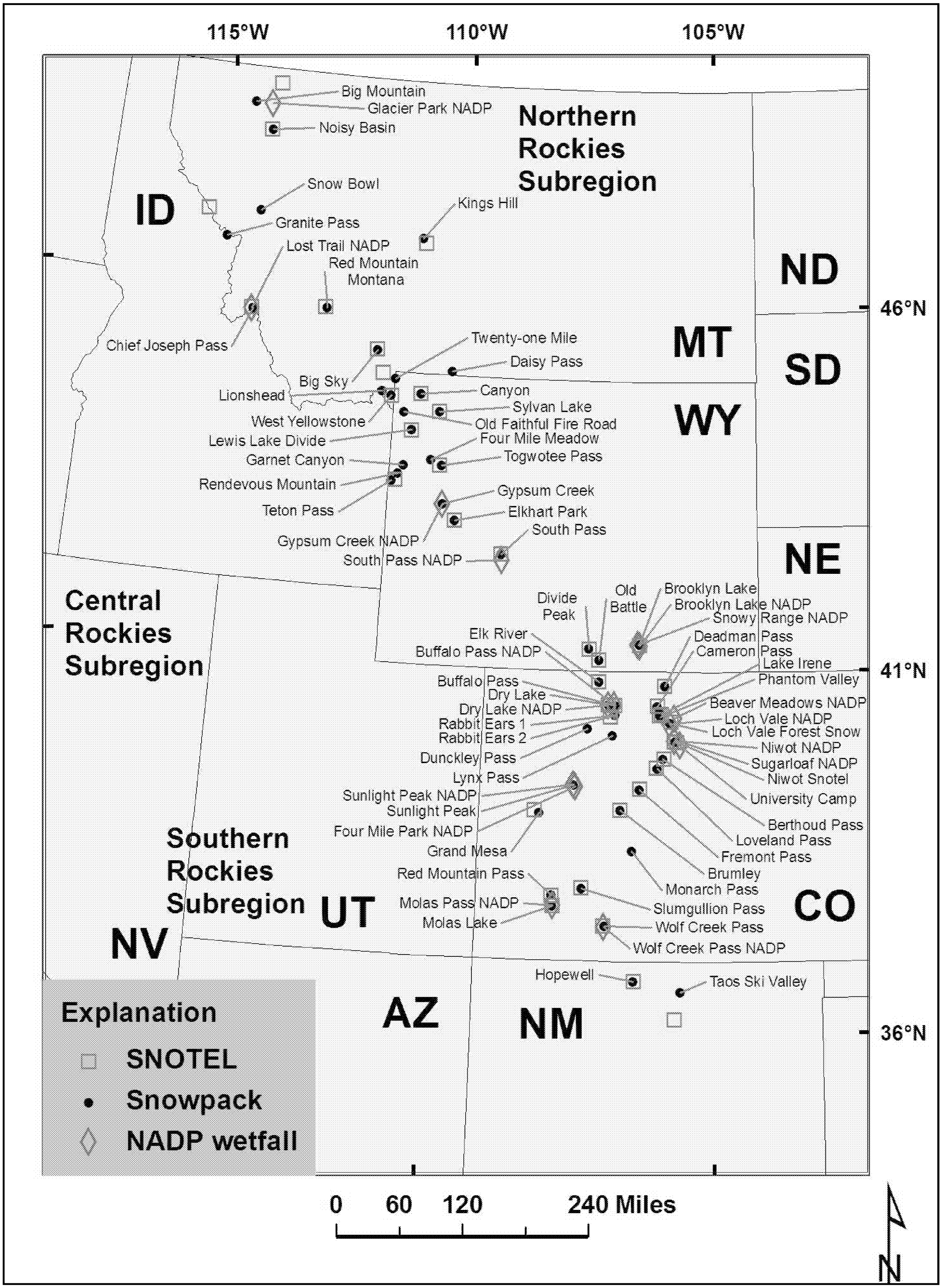

Figure 2: SNOTEL stations, RMS-snowpack sites, and NADP-wetfall sites in subregions of the Rocky Mountain Region.

Trends in precipitation consistently were downward and significant for wetfall-, snowpack-, and SNOTEL data for the Central and Southern Rockies subregions ($p<0.03$), while no trends in precipitation were noted for the Northern Rockies subregion (Figure 4). These precipitation declines reflect the substantial drought that occurred in the latter part of the study period.

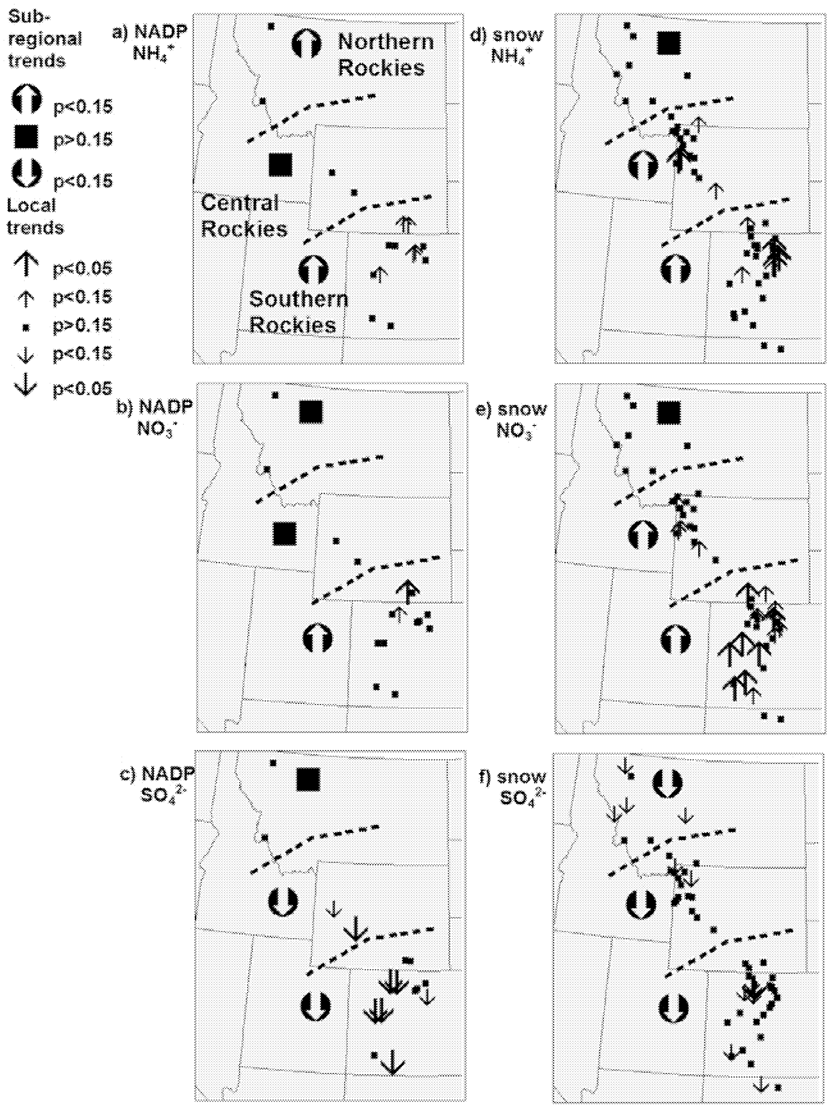

Figure 3: Trends in NADP wetfall- and snowpack concentrations.

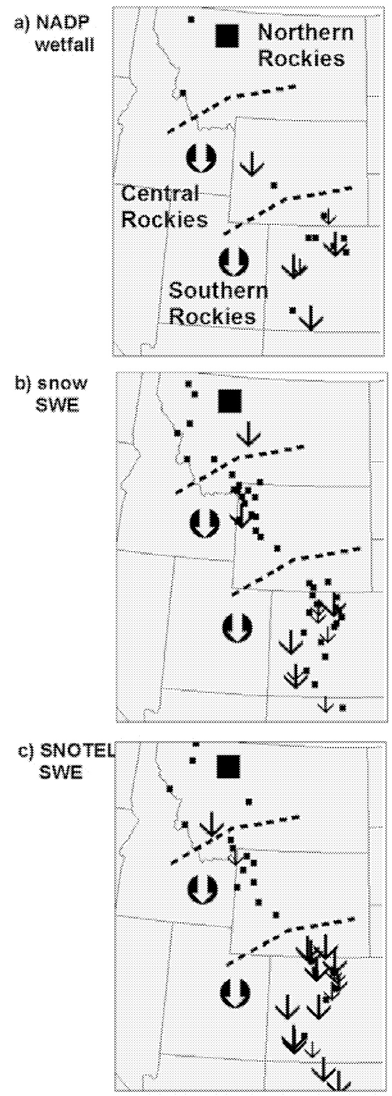

Figure 4: Trends in precipitation.

ACKNOWLEDGEMENTS

This research has been made possible by the National Park Service, USDA Forest Service, the US Geological Survey, and other organizations. The authors also wish to thank our many colleagues for their support of the Rocky Mountain Snowpack Program.