Final Report for Task J2350117300, Contract H2370094000
(January 1, 2011 - March 31, 2012)

ASSISTANCE FOR VISIBILITY DATA ANALYSIS AND IMAGE DISPLAY TECHNIQUES

PRINCIPAL INVESTIGATOR: Jenny Hand

Cooperative Institute for Research in the Atmosphere, Colorado State University, Fort Collins, CO, 80523-1375

Contact: jlhand@colostate.edu, 970-491-3699

1. Public Purpose

This project funds ongoing research at the Cooperative Institute for Research in the Atmosphere (CIRA) at Colorado State University (CSU) to enhance the scientific understanding of the causes of visibility degradation and atmospheric loading to ecosystems. It is designed to assist the National Park Service (NPS), other land managers, and air pollution control agencies understand and advance the protection of scenic vistas and ecosystem resources. The results of this research will be made available through the scientific literature and through the dissemination of information to the public through the web. A key element of the project is to interpret and display this scientific information for the general public, enhancing their understanding of issues that can affect their enjoyment of publicly owned lands. Part of the effort of disseminating results includes participation in outreach efforts in elementary schools and interactions with young students on science projects. NPS scientists also respond to inquiries from the general public regarding issues related to air quality.

Peer-reviewed publications are the primary measure of success in the university system. The project will result in various peer-reviewed publications by the university research staff, coauthored with National Park Service (NPS) scientists, and will also further the university's position as a leader in disseminating scientific information to the public.

NPS scientists involved in this project are leaders in the field of aerosol and visibility research, monitoring in remote environments, and assessing which sources of air pollution lead to degradation of air quality. By working with these scientists, the research staff at the state-funded public university will directly benefit from their expertise. The university research staff will also be developing some of this expertise by working with the NPS. In addition to working with university research staff, the NPS scientists interact with university students on dissertation and thesis projects and further enhance their educational experience through collaborative projects. NPS scientists and university research staff also communicate research results to other university scientists and students through departmental seminars. This provides a unique opportunity to communicate with students and young scientists on the important of applying their research results to policy relevant issues.

Air quality regulatory activities in the United States are founded on a sound understanding of the effects of air pollutants on health and welfare and on identifying the sources of air pollutants that cause the identified effects. The regulatory agencies rely on NPS-sponsored research to inform their decisions on air pollution effects in natural areas. This project adds to this knowledge. As an example, the State of Colorado has developed a plan to reduce nitrogen deposition in Rocky Mountain National Park. The development of such plans depends on the results of ongoing analyses in this project to implement certain aspects of that plan.

2. Overview

The public visits national parks and wilderness areas to enjoy nature in an unblemished setting. Air pollutants can adversely affect that visitor experience by degrading the vistas they come to see and by affecting the natural ecosystems of these areas. The NPS and CSU scientists are working together to better understand the scientific basis of these issues, make that information available to regulatory agencies, and interpret it for the public.

Particles and gases in the atmosphere scatter and absorb light, affecting the clarity of scenic views associated with national parks and wilderness areas. This project analyzes particle data collected through the Interagency Monitoring of Protected Visual Environments (IMPROVE) program to determine their origins and radiative properties and to better understand their chemical makeup. These analyses will be published in the scientific literature, presented at scientific meetings, and made available with the data through the web. The optical properties of aerosols affect how the particles impair visibility. However, it is difficult for the public to visually interpret the meaning of changes in optical variables used to quantify changes in scene appearance under different atmospheric-particulate-loading conditions.

The most effective ways to present the effects of pollutants on scenic vistas are by photographic imaging techniques that accurately depict how the scene will appear under various illuminations and meteorological and pollutant conditions, through video productions that demonstrate pollutant effects on a scene over time, and by regional air quality simulation modeling. An image-based depiction of visibility reduction due to pollutants is dependent on a firm understanding of the optical characteristics of pollutants, on state-of-the-art measuring techniques, on a valid understanding of how chemicals are transformed as they travel through the atmosphere, on the ability to simulate accumulated effects, and on professional quality image and video production techniques. The aforementioned analyses and techniques are the key elements of successfully carrying out this cooperative project.

Healthy ecosystems are critical to having a natural, unblemished visitor experience. Ecosystem changes due to atmospheric deposition of nitrogen compounds have been documented at Rocky Mountain National Park. The origins, chemical makeup, and temporal scales of changes in the deposition are not well understood. Field measurements were made during 2009 to provide data to enhance our understanding. Similar measurements also were performed at Grand Teton National Park during the spring and summer of 2011. This project analyzes some of these data and runs 4-dimensional chemical transport models to assess atmospheric nitrogen deposition at the parks.

The specifics identified below describe a cooperative effort between the NPS and CIRA at CSU to analyze, interpret, and make available air quality, deposition, and visibility data and analyses of these data. These data, interpretations, and analyses will be available to the scientific community, regulatory agencies, and the public.

3. Major Activities Completed by CIRA/NPS

Aerosol Research

We continued work on the apportionment of light extinction among chemical species using statistical and deterministic methods. We investigated the roles of particle composition, size distribution, and relative humidity on the optical effects of aerosols. When appropriate, we applied new models derived from special studies that reflect the latest state of the science in air pollution and visibility. We also continued to identify reasons for differences between reconstructed and measured fine particle mass and between reconstructed and measured light extinction. Understanding these differences is necessary for the accurate prediction of visibility degradation. We also continued research on organic carbon aerosols, including their measurement, characterization, and source attribution. Accomplishments this task period include the following:

- We continued research into aerosol source apportionment techniques, which include trajectory mass balance, source contribution functions, conditional probabilities, and empirical orthogonal functions to assess the appropriateness of using these techniques for pollutants such as ozone and organic and elemental carbon. We also continue to develop and use receptor models to determine transport pathways and estimate the proportion of a measured pollutant that can be attributed to each of several sources. [Gebhart et al., 2011; Schichtel et al., 2012]
- We continued research into understanding biases in fine particle speciation measurements using statistical methods resulting in peer-reviewed papers [Malm et al., 2011; Simon et al., 2011].
- We collaborated in the calibration and development of visibility monitoring equipment (e.g., transmissometers and nephelometers) at the CSU optical monitor test facility.
- We collaborated in the testing, deployment, and evaluation of new night sky brightness monitors for the purpose of analyzing the relationship between air quality and night sky brightness. Nighttime visibility is affected by aerosols and is far less studied than day time visibility.
- We continued to be actively involved with the scientific community and responded to publications using inappropriate data analysis methods and/or making misleading interpretations of analysis results affecting park resources [Schichtel et al., 2011; White et al., 2012].

IMPROVE Program

We continued the QA/QC and data management activities for the Interagency Monitoring of Protected Visual Environments (IMPROVE) program, and its vast data resources

continue to be a significant effort. Accomplishments this task period include the following:

- Data through December 2010 data received and ingested into the VIEWS (Visibility Information Exchange Web System)/IMPROVE database.

- A presentation was made at the IMPROVE steering committee meeting at Frostburg, Maryland (October 2011) [Hand et al., 2011].

- Continued work on the integration of IMPROVE and CSN (Chemical Speciation Network) network-wide data resulting in a peer-reviewed publication [Hand et al, 2012a].

- Computed short- and long-term trends of IMPROVE and CSN speciated aerosol concentration data, resulting in submission of peer-reviewed publications and manuscripts in preparation [Murphy et al., 2011; Schichtel et al., 2011; Hand et al., 2012b].

- Finalized the IMPROVE report (IMPROVE Report V) [Hand et al., 2011] that includes analyses of spatial and seasonal patterns in speciated aerosol composition from 2005 to 2008 from IMPROVE and the CSN. Excerpts from the IMPROVE report are being included in the EPA's Report to Congress on Black Carbon and the upcoming Intergovernmental Panel on Climate Change (IPCC) report.

- Continued work on urban excess estimates using IMPROVE and CSN data. A manuscript describing results in is preparation.

- Completed back trajectory analyses for all IMPROVE sites going back to 2000 for use with trends analyses.

IMPROVE Ammonia Study

- Continued sampling NH_x species using the modified IMPROVE sampler at nine IMPROVE sites. A manuscript describing the method and data is in preparation.

Investigations of Smoke Aerosols

We continued work to fingerprint smoke from forest wildfire and prescribed fire on aerosol filters, developing better emissions information about these types of fire. In addition, hybrid receptor models are being developed and used to investigate the impacts of smoke on regional haze levels [Hennigan et al., 2011, Holden et al., 2011; Munchak et al., 2011; Schichtel et al., 2012].

Regional Ozone Simulations for the Western United States

To investigate regional ozone at western national parks and Class I areas, the CAMx chemical transport model was used to extend the analyses developed for the Four Corners Air Quality Task Force ("4CAQTF") study. The emission inventory developed for the

4CAQTF represents the most current and detailed inventory available for the western U.S., includes updates to important source sectors such as wildfires and oil and gas development, and provides an excellent opportunity to simulate regional ozone at relatively fine scale (i.e., 12 km). These simulations are being evaluated with regard to proposed changes to the primary and secondary ozone standards.

Evaluation of Proposed Nitrogen Oxide Controls at Colorado's Craig Power station

The Craig power station in northwestern Colorado is the largest single source of nitrogen oxide (NO_x) emissions within the state. This study examined the impact of applying selective catalytic reduction (SCR) controls to the power station, and predicting the downwind impact at Rocky Mountain National Park and other Class I areas in terms of nitrogen deposition and ozone and particulate nitrate concentration.

Review of Air Quality Environmental Impact Statements for Oil and Gas Development

Reviewed air quality modeling results for several proposed oil and gas development leases in Colorado, Wyoming and Utah.

Fate of Atmospheric Nitrogen

Rocky Mountain Atmospheric Nitrogen and Sulfur Study (ROMANS)

The objective of the 2009 (RoMANS II) study is to determine the fate and origin of nitrogen and sulfur species in Rocky Mountain National Park, specifically, to develop and refine emission estimates of ammonia, nitrogen oxides, and sulfur oxides and determine the relative contribution of long-range transport versus local emissions to ambient and deposited ammonium, nitrates, and sulfates levels in Rocky Mountain National Park. This is planned to be accomplished by apportioning the relative contributions of these species between mobile and stationary sources such as power plants, other industrial activity, feedlots, and fertilizer applications.

Continued data and model analyses from the 2009 field campaign included

- Completed analysis of real-time gas and particle data collected during the RoMANS II study [Benedict et al., 2012].

- Completed model evaluation of the CAMx regional air quality model, resulting in a peer-reviewed publication [Rodriguez et al., 2011].

- Completed ammonia measurement study around the Front Range and eastern plains of northern Colorado, resulting in a peer-reviewed manuscript [Day et al., 2012].

- Completed several simulations using CAMx model runs for the entire 2009 year to further understand nitrogen deposition in the Rocky Mountain National Park region. The simulations included tracer and full chemistry runs.

- Continued analyses using Particulate Source Apportionment Technology (PSAT) to assess the apportionment of ambient concentrations of nitrogen species.

- Performed several tests of the mesoscale meteorological models using the MM5 model and Weather Research and Forecasting (WRF) model with different observational nudging.

- Refined several statistical techniques for analyzing back trajectories. Because they have different assumptions and use different input data, these methods are valuable as independent methods for determining source-receptor relationships.

GrandTreNDs: The Grand Tetons Reactive Nitrogen Deposition Study

- Deployed and monitored instruments during the Grand Trends study at the Grand Tetons National Park (spring–summer 2011).

- Participated in laboratory evaluations of gaseous ammonia measurements.

Data and Display Dissemination

The program activities pertaining to the media center and web development included the following:

- Maintained and improved access to resources, including the CIRA/NPS/IMPROVE web site and an FTP server for dissemination of data and summary reports, for the general public.

- Continued implementation and development of the IMPROVE website, including developing an interactive database, allowing users to download data and selected analyses of these data, including appropriate quality assurance information, directly from the web, a display of current IMPROVE graphics, up-to-date information about the visibility regulations, and a growing bibliographic reference site for visibility and IMPROVE scientific information (http://vista.cira.colostate.edu/improve).

- Contributed to the development of the Federal Land Manager Environmental Database (FED). The project includes the development of data delivery and visualization tools to facilitate creation of environmental data assessments and reports needed by the NPS and Forest Service (http://views.cira.colostate.edu/fed/).

- Continued to develop and implement the interactive multimedia program "Introduction to Visibility". Completed the "Impacts of Haze" section. This web document will introduce basic visibility science and monitoring concepts as well as the regional haze regulations to the regulatory community and the general public.

- Continued to provide graphics support, graphs, posters, etc., to the NPS researchers in the Air Resources Division and CIRA.

- Developed custom graphic materials for presentation and distribution to the general public and K-12 education outreach activities, such as the dual-image bookmark that demonstrated visibility extremes for the Grand Canyon Visitor Center, photos, pH scales and stickers.

- Produced the 2012 IMPROVE calendar.

- Continued the development of multimedia outreach materials for understanding and communicating climate change in national parks to the general public, including an interactive interpretative display for the Edwin B. Forsythe National Wildlife Refuge Visitor Center.

- Provided high quality graphics for CIRA/NPS scientists for peer-reviewed publications.

4.0 Project Deliverables

Deliverables for this project include conference presentations and publications (see reference list).

PUBLICATIONS

Benedict, K. B., D. E. Day, F. M. Schwandner, S. M. Kreidenweis, B. A. Schichtel, W. C. Malm and J. L. Collett, Jr., Observations of atmospheric reactive nitrogen species in Rocky Mountain National Park and across Colorado, submitted to Atmospheric Environment, 2012.

Chen, L.-W. A., J. C. Chow, J. G. Watson and B. A. Schichtel, Recent Elemental Carbon Trends from Multiple Tests of the IMPROVE Network Data (2000 – 2009), submitted to Geophysical Research Letters, 2011.

Day, D. E., X. Chen, K. A. Gebhart, C. M. Carrico, F. Schwandner, K. B. Benedict, B. A. Schichtel and J. L. Collett, Jr., Spatial and temporal variability of ammonia and other inorganic aerosol species on the Front Range and eastern plains of northern Colorado, USA, submitted to Atmospheric Environment, 2012.

Gebhart, K. A., B. A. Schichtel, W. C. Malm, M. G. Barna, M. A. Rodriguez and J. L. Collett, Jr., Back-trajectory-based source apportionment of airborne sulfur and nitrogen concentrations at Rocky Mountain National Park, Colorado, USA, Atmospheric Environment, 45, 621-633, 2011.

Hand, J. L., K. Gebhart, B. A. Schichtel and W. C. Malm, Increasing trends in wintertime particulate sulfate and nitrate ion concentrations in the Great Plains of the United Stated (2000-2010), Atmospheric Environment, accepted, 2012a.

Hand, J. L., B. A. Schichtel, M. L. Pitchford, W. C. Malm and N. H. Frank, Seasonal composition of remote and urban fine particulate matter in the United States, Journal of Geophysical Research, 117, D05209, doi:10.1029/2011JD017122, 2012b.

Hennigan, C. J., M. A. Miracolo, G. J. Engelhart, A. A. May, A. A. Presto, T. Lee, A. P. Sullivan, G. R. McMeeking, H. Coe, C. E. Wold, W. M. Hao, J. B. Gilman, W. C. Kuster, J. de Gouw, B. A. Schichtel, J. L. Collett, Jr., S. M. Kreidenweis and A. L. Robinson, Chemical and physical transformations of organic aerosol from the photo-oxidation of open biomass burning emissions in an environmental chamber, Atmospheric Chemistry and Physics, 11(15), 7669-7686, doi:10.5194/acp-11-7669-2011, 2011.

Holden, A. S., A. P. Sullivan, L. A. Munchak, S. M. Kreidenweis, B. A. Schichtel, W. C. Malm and J. L. Collett, Determining contributions of biomass burning and other sources to fine particle contemporary carbon in the western United States, Atmospheric Environment, 45(11), 1986-1993, 2011.

Hyslop, N. P. and W. H. White, Identifying sources of uncertainty from the inter-species covariance of measurement errors, Environmental Sceince & Technology, 45, 4030-4037, 2011.

Malm, W. C., B. A. Schichtel and M. L. Pitchford, Uncertainties in PM2.5 gravimetric and speciation measurements and what we can learn from them, Journal of the Air & Waste Management Association, special Xi'an issue, 61, 1131-1149, DOI:10.1080/10473289.2001.603998, 2011.

Munchak, L. A., B. A. Schichtel, A. P. Sullivan, A. S. Holden, S. M. Kreidenweis, W. C. Malm and J. L. Collett, Jr., Development of wildland fire particulate smoke marker to organic carbon emission ratios for the conterminous United States, Atmospheric Environment, 45, 395-403, 2011.

Murphy, D. M., J. C. Chow, E. M. Leibensperger, W. C. Malm, M. Pitchford, B. A. Schichtel, J. G. Watson and W. H. White, Decreases in elemental carbon and fine particle mass in the United States, Atmospheric Chemistry and Physics, 11(10), 4679-4686, 2011.

Rodriguez, M. A., M. G. Barna, K. A. Gebhart, J. L. Hand, Z. E. Adelman, B. A. Schichtel, J. L. Collett and W. C. Malm, Modeling the fate of atmospheric reduced nitrogen during the Rocky Mountain Atmospheric Nitrogen and Sulfur Study (RoMANS): Performance evaluation and diagnosis using integrated processes rate analysis, Atmospheric Environment, 45(1), 223-234, 2011.

Schichtel, B. A., M. L. Pitchford and W. H. White, Comments on "Impact of California's Air Pollution Laws on Black Carbon and their Implications for Direct Radiative Forcing" by R. Bahadur et al., Atmospheric Environment, 45(24), 4116-4118, 2011.

Schichtel, B. A., M. A. Rodriguez, M. G. Barna, K. A. Gebhart, M. L. Pitchford and W. C. Malm, A semi-empirical, receptor-oriented Lagrangian model for simulating fine particulate carbon at rural sites, submitted to Atmospheric Environment, 2012.

Simon, H., P. V. Bhave, J. L. Swall, N. H. Frank and W. C. Malm, Determining the spatial and seasonal variability in OM/OC ratios across the U.S. using multiple regression, Atmospheric Chemistry and Physics, 11, 2933-2949, 2011.

Sorooshian, A., A. Wonaschutz, E. G. Jarjour, B. I. Hashimoto, B. A. Schichtel and E. A. Betterton, An aerosol climatology for a rapidly growing arid region (southern Arizona): Major aerosol species and remotely sensed properties, Journal of Geophysical Research-Atmospheres, 116D19205, doi:10.1029/2011D016197, 2011.

White, W. H., R. J. Farber, W. C. Malm, M. Nuttal, M. L. Pitchford and B. A. Schichtel, Comments on "Effect of coal-fired power generation on visibility at a nearby national park" by J. Terhorst and M. Berkman, Atmospheric Environment, in press, 2012.

PRESENTATIONS

Barna, M. G., Oil and gas source contribution at rural/national park sites using CAMx/OSAT, presented at the Western Meteorological, Emissions, and Air Quality Modeling Workshop, Boulder, June 2011.

Barna, M. G., M. A. Rodriguez, K. A. Gebhart, B. A. Schichtel, T. Moore, J. Vimont and W. C. Malm, Simulating nitrogen deposition and ozone in western national parks, presented at the Community Modeling and Analysis System (CMAS) 10th annual conference, Chapel Hill, October 23-27, 2011.

Barna, M. G., M. A. Rodriguez, K. A. Gebhart, B. A. Schichtel and J. Vimont, Simulating how EPA's new primary and secondary ozone standards will affect western national parks, presented at the 92nd American Meteorological Society Annual Meeting, New Orleans, January 22-26, 2012.

Carrico, C. M., J. L. Collett, Jr., S. M. Kreidenweis, E. J. T. Levin, A. J. Prenni, M. Schurman, D. E. Day, K. B. Benedict, J. Ray, B. A. Schichtel and W. C. Malm, Continuous measurements of reactive nitrogen species: Observations from the laboratory and an alpine site, presented at the Air & Waste Management 104th Annual Conference, Orlando, June 21-24, 2011.

Collett, J. L., Jr., K. B. Benedict, C. M. Carrico, S. Raja, F. Schwandner, M. Schurman, D. E. Day, E. J. T. Levin, A. P. Sullivan, T. Lee, A. J. Prenni, S. M. Kreidenweis, W. C. Malm and B. A. Schichtel, Transport and deposition of reactive nitrogen species in Rocky Mountain National Park, presented at the American Meteorological Society Annual Conference, New Orleans, January 2012.

Connell, B. and K. A. Gebhart, Golden words from elementary kids: Can I show you my observation!, presented at the American Meteorological Society Annual Conference, New Orleans, January 2012.

Gebhart, K. A., B. A. Schichtel, W. C. Malm, C. M. Carrico and J. L. Collett, Jr., A year-long back trajectory analysis of sources of reactive nitrogen measured continuously in the Rocky Mountains, presented at the Air & Waste Management 104th Annual Conference, Orlando, June 21-24, 2011.

Gebhart, K. A., B. A. Schichtel, M. G. Barna, M. A. Rodriguez, W. C. Malm, J. L. Collett, Jr., K. B. Benedict and C. M. Carrico, Back trajectory analysis of reactive

nitrogen measured continuously at Rocky Mountain National Park, Colorado, presented at the National Atmospheric Deposition Program Annual Meeting, Providence, October 2011.

Gebhart, K. A., B. A. Schichtel, M. G. Barna, M. A. Rodriguez, W. C. Malm, J. L. Collett, Jr., C. M. Carrico and K. B. Benedict, A year-long back trajectory analysis of reactive nitrogen measure continuously at Rocky Mountain National Park, Colorado, presented at the American Meteorological Society Annual Conference, New Orleans, January 2012.

Hand, J. L., B. A. Schichtel, W. C. Malm, M. L. Pitchford, N. P. Hyslop and W. H. White, Temporal trends in remote and rural speciated aerosol concentrations from the IMPROVE network from 1989 to 2008, presented at the American Association for Aerosol Research 30th Annual Conference, Orlando, October 2011.

Hand, J. L., B. A. Schichtel, W. C. Malm, M. L. Pitchford and K. A. Gebhart, Recent IMPROVE data analyses, presented at the IMPROVE annual steering committee meeting, Frostburg, Maryland, October 25-27, 2011.

Malm, W. C., J. V. Molenar, M. L. Pitchford and L. B. Deck, Which visibility indicators best represent a population's preference for a level of air quality?, presented at the Air & Waste Management 104th Annual Conference, Orlando, June 21-24, 2011.

McClure, S., Three-state air quality study and data warehouse project, presented at the Federal Leadership Forum meeting, Denver, January 19, 2011.

Rodriguez, M. A., M. G. Barna, K. A. Gebhart, B. A. Schichtel, J. L. Hand and W. C. Malm, Modeling the fate of atmospheric reduced nitrogen during the RoMANS 2009 field campaign, presented at the Western Meteorological, Emissions, and Air Quality Modeling Workshop, Boulder, June 2011.

Rodriguez, M. A., M. G. Barna, K. A. Gebhart, J. L. Hand, B. A. Schichtel, J. L. Collett, Jr. and W. C. Malm, The challenges to model the fate of atmospheric reduced nitrogen in the western U.S.: Using CAMx during the Rocky Mountain Atmospheric Nitrogen and Sulfur Study (RoMANS II), presented at the Community Modeling and Analysis System (CMAS) 10th annual conference, Chapel Hill, October 23-27, 2011.

Rodriguez, M. A., M. G. Barna, K. A. Gebhart, J. L. Hand, B. A. Schichtel, K. B. Benedict, J. L. Collett, Jr. and W. C. Malm, Modeling the fate of atmospheric reduced nitrogen in the western U.S. during the Rocky Mountain Atmospheric Nitrogen and Sulfur Study (RoMANS II), presented at the American Meteorological Society Annual Conference, New Orleans, January 2012.

Schichtel, B. A., M. A. Rodriguez, M. G. Barna, K. A. Gebhart, T. E. Pierce, L. A. Patterson, J. L. Collett, Jr. and W. C. Malm, Contributions of biomass burning and other sources to fine particulate carbon at rural locations throughout the United States, presented at the Air & Waste Management 104th Annual Conference, Orlando, June 21-24, 2011.

Schichtel, B. A., Long-term trends in carbonaceous aerosols at U.S. Urban and rural sites , presented at the Air & Waste Management 104th Annual Conference, Orlando, June 21-24, 2011.

Schichtel, B. A., Reactive nitrogen composition and origin in the Rocky Mountains, presented at the National Oceanic and Atmospheric Administration (NOAA) Earth System Research Laboratory (ESRL) Chemical Sciences Division Seminar, Boulder, November 9, 2011.

Schichtel, B. A., K. B. Benedict, C. M. Carrico, E. J. T. Levin, D. E. Day, W. C. Malm, J. L. Collett, Jr. and S. M. Kreidenweis, Seasonal nitrogen deposition budgets at Rocky Mountain National Park, presented at the Air & Waste Management 104th Annual Conference, Orlando, June 21-24, 2011.

Schichtel, B. A., M. A. Rodriguez, M. G. Barna, K. A. Gebhart, T. E. Pierce, L. A. Patterson, J. L. Collett, Jr. and W. C. Malm, Contributions of biomass burning and other sources to fine particulate carbon at rural locations throughout the United States, presented at the American Meteorological Society Annual Conference, New Orleans, January2012.

Schichtel, B. A., Rocky Mountain Atmospheric Nitrogen and Sulfur (RoMANS) study, presented at the 2012 Agriculture Air Quality Symposium, Lamar, Colorado, February 17, 2012.

Sullivan, A. P., S. M. Kreidenweis, B. A. Schichtel and J. L. Collett, Jr., Smoke marker ratios from controlled laboratory burns versus prescribed burns and wildfires, presented at the American Meteorological Society Annual Conference, New Orleans, January 2012.

REPORT

Hand, J. L., S. A. Copeland, D. E. Day, A. M. Dillner, H. Indresand, W. C. Malm, C. E. McDade, C. T. Moore, Jr., M. L. Pitchford, B. A. Schichtel and J. G. Watson, Spatial and Seasonal Patterns and Temporal Variability of Haze and its Constituents in the United States, IMPROVE Report V, Cooperative Institute for Research in the Atmosphere, Colorado State University, Fort Collins, Colorado. ISSN 0737-5352-97, 2011.