

## **Final report for Task # J2350093004 (September 2009 – December 2010)**

Characterizing reactive nitrogen in Rocky Mountain National Park and the Rocky Mountain region

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### 1. Overview of Project

The National Parks are immensely popular public resources. Protection of these national treasures requires understanding of various threats to park resources. Included are threats to visibility and to sensitive ecosystems. The research in this project relates directly to diagnosing and remedying air quality problems in our national parks. It provides the basis for informed decision-making about steps to protect park resources by improving and managing air quality.

The long-term goals of this project are to improve understanding of visibility degradation in national parks, to improve understanding of deposition of pollutant species to sensitive park ecosystems, to diagnose contributors to air quality problems in specific parks, and to generate fundamental new knowledge about specific pollutant species contributing to air quality problems in national parks. Attainment of these goals involves the planning, execution, and analysis of field measurements of air quality at select national parks.

### 2. Major National Park Service Research Activities Completed by CSU

- ***Characterizing reactive nitrogen in Rocky Mountain National Park and the Rocky Mountain region***

Rocky Mountain National Park is experiencing a number of deleterious effects due to atmospheric nitrogen and sulfur compounds. These effects include visibility degradation and changes in ecosystem function and surface water chemistry from atmospheric deposition. The nitrogen compounds include both oxidized and reduced nitrogen. Emissions of both nitrogen and sulfur compounds will need to be reduced to alleviate these deleterious effects.

Ongoing work at Rocky Mountain National Park (RMNP) has provided important new insights into the importance of various nitrogen deposition pathways as well as the sources of the deposited nitrogen. New measurements in the park, developed and led by CSU, have revealed

the importance of previously undocumented deposition pathways, including dry deposition of gaseous ammonia and wet and dry deposition of organic nitrogen. Figure 1 illustrates the spring and summer reactive nitrogen deposition budgets measured by CSU during the 2006 Rocky Mountain Airborne Nitrogen and Sulfur (RoMANS) study. These observations were published in 2010 (Beem et al., 2010) as part of ongoing data analysis and publication efforts in the current project. Wet deposition of organic nitrogen and dry deposition of gaseous ammonia, although previously unmeasured, were found to be major contributors to reactive nitrogen deposition fluxes in the park.

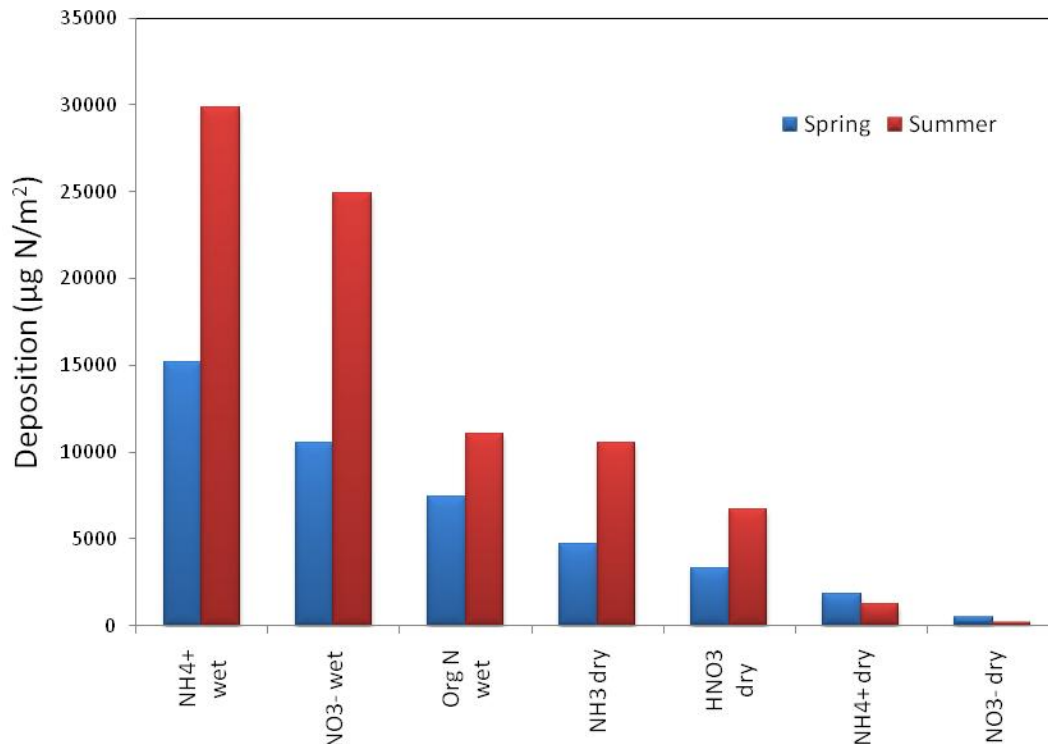


Figure 1. Reactive nitrogen deposition budget for spring and summer 2006, determined from the RoMANS study (Beem et al., 2010).

Since the 2006 RoMANS study, ongoing measurements of reactive nitrogen species concentrations and deposition fluxes have increased our understanding of reactive nitrogen sources and deposition in RMNP. Figure 2 illustrates timelines of key inorganic nitrogen species measured in RMNP during the period Nov. 2008-Nov. 2009. This full-year data set (wet deposition of reactive nitrogen species was also measured at daily time resolution) provides a much more complete look at atmospheric reactive nitrogen concentrations in the park than was previously available. Considerable day-to-day variability in nitrogen species concentrations is evident. Much of this is tied to local-to-regional scale transport patterns, as discussed below. Concentrations of reactive nitrogen species tend to be lowest in winter, when emissions of some

sources (e.g., agricultural ammonia sources) are low and shallow mixing layers tend to leave the park isolated from pollutant emissions at lower altitudes.

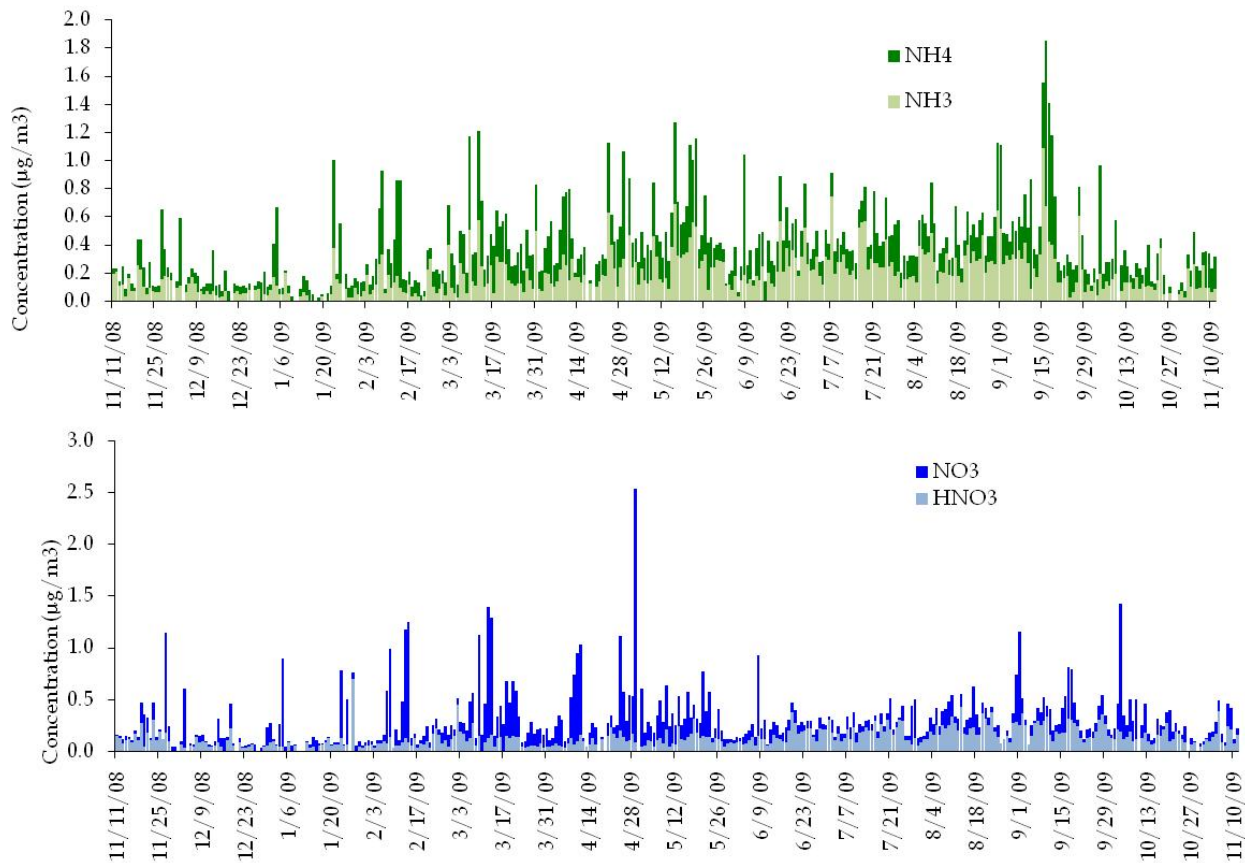


Figure 2. Concentrations of key airborne reactive nitrogen species concentrations measured in daily, 24 hr samples collected at RMNP. Included are gaseous ammonia and nitric acid and fine particle (PM<sub>2.5</sub>) ammonium and nitrate.

Using observations of atmospheric reactive nitrogen species concentrations (gas and particle phase) and measurements of wet deposition fluxes of nitrate, ammonium, and organic nitrogen, we constructed a full-year reactive nitrogen deposition budget for the park. This budget is depicted in Figure 3. Peak deposition months during the study period (Dec. 2008 – Nov. 2009) were April, July, and October. The smallest deposition amounts are observed in winter (November through February). During the 2006 RoMANS campaign, upslope snow storms, which transport pollutants from NE Colorado urban and agricultural sources into RMNP, were found to be important contributors to springtime deposition budgets. The more recent data included in Fig. 3 point to the potential importance of similar scenarios in autumn as well. The data in Fig. 3 represent the first look at the RMNP annual dry deposition budget for gaseous

ammonia and the annual wet deposition budget for organic nitrogen. Both deposition pathways are relatively important throughout the year. Neither deposition pathway has been previously included in national deposition network measurements in the park.

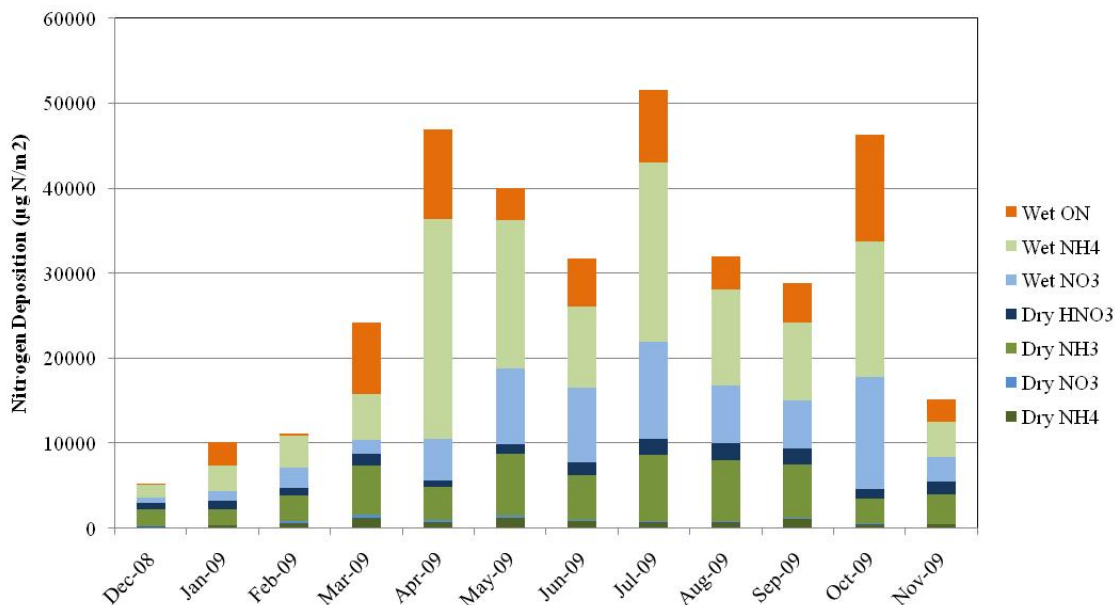


Figure 3. Monthly dry and wet RMNP deposition fluxes for key reactive nitrogen species.

Reactive nitrogen species concentration measurements conducted in RMNP since 2008 have increasingly focused on high time resolution characterization of gas and particle phase species. These data permit a more direct look at transport conditions that give rise to elevated pollutant concentrations. Figure 4 examines the relationship between local wind direction at the RMNP core measurement site and reactive nitrogen species concentrations. Panel (a) illustrates the overall frequency of wind direction observations at the site. Panels (b) and (c) illustrate the wind directions associated with elevated (highest 10%) ammonia, ammonium, and nitrate concentrations. These comparisons clearly illustrate that high concentrations of ammonia, ammonium and nitrate are most commonly observed during upslope transport conditions (local SE wind), suggesting that elevated concentrations are associated with transport of air from source regions located east of the park. Additional source attribution efforts are planned, in collaboration with NPS scientists, using these and similar data to identify regional emissions that are associated with elevated concentrations and deposition fluxes in RMNP. An assessment of this type for the 2006 RoMANS study periods was recently published by Gebhart et al. (2011).

Field measurements during this project included measurements at the RMNP RoMANS core site in Fall 2009 and spring/summer 2010. Core site measurements made use of the NPS/CSU Mobile Air Sampling Laboratory and included daily, 24 hr measurements of key nitrogen and sulfur species in the gas and particle phases, 15-min measurements of fine particle composition using a Particle Into Liquid Sampler, and continuous trace gas measurements (including NO, NO<sub>2</sub>, NO<sub>y</sub>, and NH<sub>3</sub>). High volume aerosol samples were also collected for analysis of organic and elemental carbon (OC and EC), smoke marker concentrations, and organic nitrogen concentrations. During several weeks in 2010 we also deployed a high resolution Aerodyne Aerosol Mass Spectrometer (AMS) at the site to characterize aerosol composition, including organic matter, at high time resolution. In addition to measurements at the core site, this project included several months of gas phase NH<sub>3</sub> measurements at a new site established just outside the western boundary of RMNP as well as measurements east of RMNP in Loveland and Brush, Colorado. Measurements in Loveland included a study of gaseous NH<sub>3</sub> at a golf course site, a potentially important source of ammonia due to high fertilizer use. These measurements were complemented by USDA-sponsored ammonia measurements conducted by CSU at a network of sites in northeast Colorado. Fig. 5 illustrates the variability in average ammonia concentrations observed in this network. The highest concentrations were observed at a site in Kersey, close to a cattle feedlot.

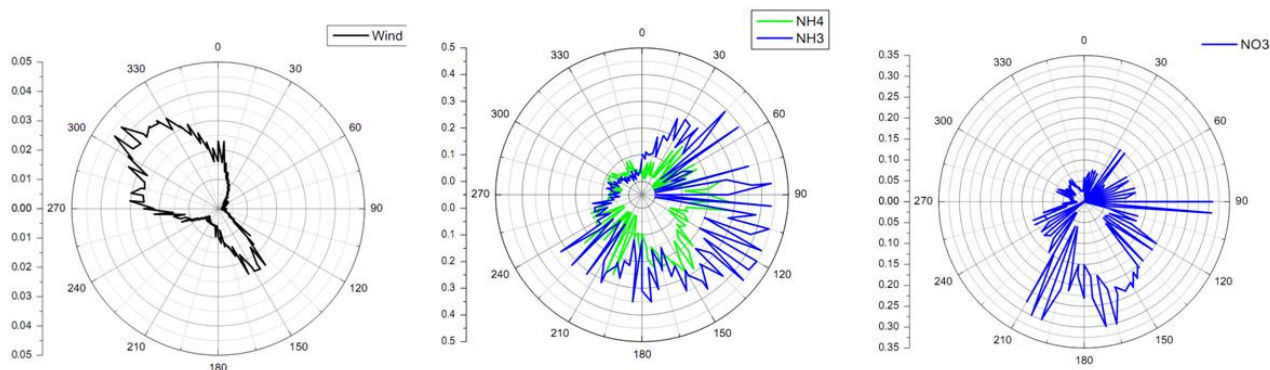


Figure 4. Frequency distributions of (a) wind direction, (b) wind direction associated with the highest 10% of gaseous ammonia and fine particle ammonium concentrations, and (c) highest 10% of fine particle nitrate concentrations at the RMNP core measurement site.

The other main field project conducted as part of this project was the design and implementation of a pilot network for routine measurement of reduced nitrogen: fine particle ammonium and gaseous ammonia. Measurement methods were tested at CSU and implemented in spring 2010 at 9 pilot IMPROVE network monitoring sites. Careful assessment of field data revealed possible artifact formation of methylamine in collected filter samples. A series of laboratory and field tests revealed this artifact resulted from acid degradation of the Delrin plastic used in IMPROVE filter sampling modules and simultaneous reaction with collected ammonia.

Alternative cartridge materials were tested and new cartridges manufactured for 2011 deployment.

In addition to the field efforts outlined above, CSU continued to conduct laboratory analyses of collected samples and to work up and analyze field measurement data from RoMANS and post-RoMANS studies. We also continued analysis of earlier studies, sponsored or co-sponsored by NPS, of smoke aerosol produced by biomass burning. As part of this effort we made numerous presentations at national and international meetings, interacted with regional stakeholder groups, and prepared manuscripts for publication in peer-reviewed journals. Chief accomplishments from our efforts are outlined below.

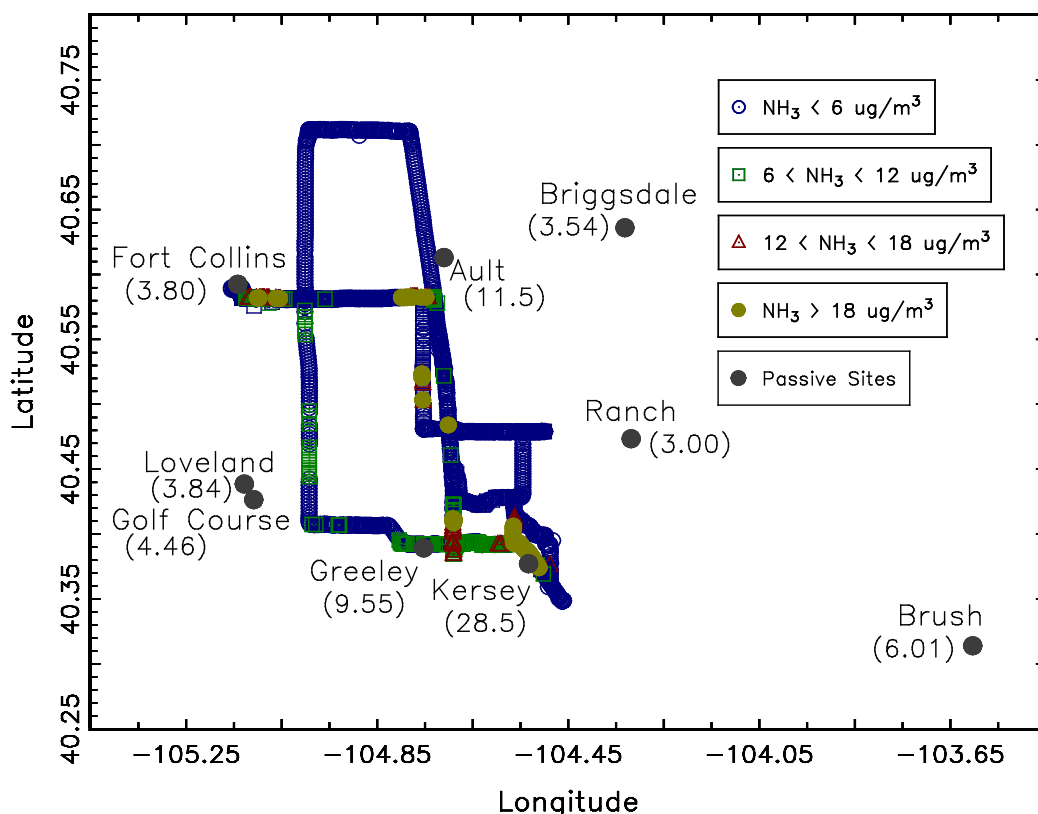


Figure 5. Spatial variability in gaseous ammonia concentrations measured in NE Colorado in partnership with a separate CSU project funded by USDA. Data from Radiello passive ammonia samplers are included (black symbols) as well as (colored symbol) concentration observations made with a mobile Picarro continuous ammonia analyzer. Understanding variability in ammonia concentrations in this key source region is important for determining impacts of transport from this region on reactive nitrogen deposition in RMNP.

- ***Chief Project Accomplishments***
- Analysis of denuder and filter-pack samples collected at RMNP and other field study sites
- Analysis of precipitation samples collected at RMNP field sites
- Measurements of organic nitrogen in RoMANS precipitation and aerosol sample
- Collection and analysis of Hi-Vol filter samples for OC, EC, and smoke marker concentrations
- Testing of mist chamber techniques for sampling atmospheric ammonia, nitric acid, and organic nitrogen
- Preparation and submission to NPS personnel of RMNP reactive nitrogen species data sets
- Comparison of monthly 2008-09 wet and dry nitrogen and sulfur deposition fluxes at the Rocky Mountain NP RoMANS core study site
- Measurement of ammonia concentration gradients between the western and eastern sides of RMNP and from RMNP eastward to Loveland and Brush, CO.
- Characterized soil emission fluxes of gaseous ammonia in RMNP.
- Establishment of a pilot network, in collaboration with IMPROVE, for quantifying reduced nitrogen ( $\text{NH}_x$  = particulate ammonium + gaseous ammonia) concentrations.
- Intercomparison and laboratory evaluations of the performance of 3 continuous ammonia analyzers (API chemiluminescence, PMS ion mobility, and Picarro Cavity Ringdown units).
- Presentations of project findings at several national and international meetings, including the annual meetings of the American Association for Aerosol Research, the American Geophysical Union, and the Air and Waste Management Association (AWMA), the AWMA International Air Pollution Specialty Conference in Xian, China, and the International Nitrogen Conference in Delhi, India. See full presentation list below.
- February 2010 presentations of RMNP nitrogen study findings to stakeholder communities at Agriculture Air Quality Symposia held in Fort Collins and Sterling, CO.
- Publication of several peer-reviewed journal articles reporting findings from the RoMANS study and for smoke characterization studies partly sponsored by NPS (see full publication list below).
- ***Maintenance and operation of the NPS Mobile Air Sampling Laboratory***

During this project CSU researchers continued to maintain, improve, and operate the NPS Mobile Air Sampling Laboratory (MASL). The MASL was deployed during this time period in RMNP in support of measurements in Fall 2009 and summer 2010.

## **Project Deliverables**

Deliverables for this project include submission of project data sets for the RoMANS II field campaign (Nov. 2008 – Nov. 2009), establishment of standard operating procedures for the IMPROVE reduced nitrogen (NH<sub>x</sub>) pilot study, publication of reactive nitrogen deposition budgets in a peer reviewed journal article (Beem et al., 2010), and submission of this final report. In addition, several other journal manuscripts describing findings from the RoMANS study or earlier studies of biomass burning aerosols partially funded by NPS were published (Malm et al., 2009, Levin et al., 2009, McMeeking et al., 2009, Carrico et al., 2010, Levin et al., 2010, Mack et al., 2010) or accepted for publication (Rodriguez et al., 2011, Gebhart et al., 2011, Holden et al., 2011, Munchak et al., 2011, Sullivan et al., 2011a, b).

## **Project peer-reviewed journal publications**

1. Beem, K. B., Raja, S., Schwandner, F. M., Taylor, C., Lee, T., Sullivan, A. P., Carrico, C. M., McMeeking, G. R., Day, D., Levin, E., Hand, J., Kreidenweis, S. M., Schichtel, B., Malm, W. C., and Collett, Jr., J. L. (2010) Deposition of reactive nitrogen during the Rocky Mountain Airborne Nitrogen and Sulfur (RoMANS) study, *Environ. Poll.*, 158, 862-872, doi:10.1016/j.envpol.2009.09.023.
2. Carrico, C. M., Petters, M.D., Kreidenweis, S. M., Sullivan, A.P., McMeeking, G. R., Levin, E. J. T., Engling, G., Malm, W. C., and Collett, Jr., J. L. (2010) Water uptake and chemical composition of fresh aerosols generated in open burning of biomass, *Atmos. Chem. Phys.*, 10, doi:10.5194/acp-10-5165-2010.
3. Gebhart, K. A., Schichtel, B. A., Malm, W. C., Barna, M. G., Rodriguez, M. A., and Collett, Jr., J. L. (2011) Back-trajectory-based source apportionment of airborne sulfur and nitrogen concentrations at Rocky Mountain National Park, Colorado, USA. *Atmos. Environ.*, 45, 621-633, doi:10.1016/j.atmosenv.2010.10.035.
4. Holden, A. S., Sullivan, A. P., Munchak, L. A., Kreidenweis, S. M., Schichtel, B. A., Malm, W. C., and Collett, Jr. J. L. (2011) Determining contributions of biomass burning and other sources to fine particle contemporary carbon in the western United States. *Atmos. Environ.*, 45, 1986-1993, doi:10.1016/j.atmosenv.2011.01.021
5. Lee, T., Sullivan, A. P., Mack, L., Jimenez, J. L., Kreidenweis, S. M., Onasch, T. B., Worsnop, D. B., Malm, W., Wold, C. E., Hao, W. M., and Collett, Jr., J. L. (2010) Chemical smoke marker emissions during flaming and smoldering phases of laboratory open burning of wildland fuels, *Aerosol Sci. Tech.*, 44, 9, i-v; doi: 10.1080/02786826.2010.499884.
6. Levin, E.J.T., Kreidenweis, S.M., McMeeking, G.R., Carrico, C.M., and J.L. Collett, Jr. (2009) Aerosol physical, chemical and optical properties during the Rocky Mountain



Airborne Nitrogen and Sulfur study. *Atmos. Environ.* 43,1932-1939,  
doi:10.1016/j.atmosenv.2008.12.042.

7. Levin, E. J. T., McMeeking, G. R., Carrico, C., Mack, L., Kreidenweis, S.M., Wold, C. E., Moosmüller, H., Arnott, W. P., Hao, W. M., Collett, Jr., J. L., and Malm, W. C. (2010) Biomass burning smoke aerosol properties measured during FLAME 2, *J. Geophys. Res.*, 115, D18210, doi:10.1029/2009JD013601.
8. Mack, L. A., Levin, E. J. T., Kreidenweis, S. M., Obrist, D., Moosmueller, H., Lewis, K. A., Arnott, W. P., McMeeking, G. M., Sullivan, A. P., Wold, C. E., Hao, W.-M., Collett, Jr., J. L., and Malm, W. C. (2010) Optical closure experiments for biomass smoke aerosols, *Atmos. Chem. Phys.*, 10, 9017–9026.
9. Malm, W.C., McMeeking, G.R., Kreidenweis, S.M., Levin, E., Carrico, C.M., Day, D.E., Collett, Jr., J. L., Lee, T., Sullivan, A.P., and Raja, S. (2009) Using high time resolution aerosol and number size distribution measurements to estimate atmospheric extinction. *J. Air and Waste Management Assoc.* 59, 1049-1060, doi:10.3155/1047-3289.59.9.1049.
10. McMeeking, G. R., Kreidenweis, S.M., Baker, S., Carrico, C.M., Chow, J.C., Collett, Jr., J. L., Hao, W.M., Holden, A. S., Kirchstetter, T. W., Malm, W.C., Moosmueller, H., Sullivan, A.P., and Wold, C.E. (2009) Emissions of trace gases and aerosols during the open combustion of biomass in the laboratory. *J. Geophys. Res.*, 114, D19210, doi:10.1029/2009JD011836. Munchak, L. A., Schichtel, B. A., Sullivan, A. P., Holden, A. S., Kreidenweis, S. M., Malm, W. C., and Collett, Jr., J. L. (2011) Development of wildland fire particulate smoke marker to organic carbon emission ratios for the conterminous United States, *Atmos. Environ.*, 45, 395-403, doi:10.1016/j.atmosenv.2010.10.006.
11. Munchak, L. A., Schichtel, B. A., Sullivan, A. P., Holden, A. S., Kreidenweis, S. M., Malm, W. C., and Collett, Jr., J. L. (2011) Development of wildland fire particulate smoke marker to organic carbon emission ratios for the conterminous United States, *Atmos. Environ.*, 45, 395-403, doi:10.1016/j.atmosenv.2010.10.006.
12. Rodriguez, M. A., Barna, M. G., Gebhart, K. A., Hand, J. L., Adelman, Z. E., Schichtel, B. A., Collett, Jr., J. L., and Malm, W. C. (2011) 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. *Atmos. Environ.*, 45, 223-234, doi:10.1016/j.atmosenv.2010.09.011.
13. Sullivan, A. P., Frank, N., Onstad, G., Simson, C. D., and Collett, Jr., J. L. (2011a) Application of high-performance anion-exchange chromatography - pulsed amperometric detection for measuring carbohydrates in routine daily filter samples collected by a national network: 1. Determination of the impact of biomass burning in the upper midwest, *J. Geophys. Res.*, in press.

14. Sullivan, A. P., Frank, N., Kenski, D. M., and Collett, Jr., J. L. (2011b) Application of high-performance anion-exchange chromatography - pulsed amperometric detection for measuring carbohydrates in routine daily filter samples collected by a national network: 2. Examination of sugar alcohols/polyols, sugars, and anhydrosugars in the upper midwest, *J. Geophys. Res.*, in press.

### **Project presentations**

Beem, K.B., Collett, Jr., J.L., Carrico, C.M., Schwandner, F.S., Mack, L., Lee, T., Sullivan, A.P., Raja, S., Kreidenweis, S.M., and Malm, W.C., The influences of averaging timescales on dry deposition calculations, Poster for presentation at AAAR, 28th Annual Conference, October 26 - 30, 2009, Minneapolis, MN.

Beem, K.B., Y. Desyaterik, M.Z. Ozel, J.F. Hamilton, and J.L. Collett (2010) Identifying organic nitrogen compounds in Rocky Mountain National Park aerosols. Presented at the American Geophysical Union Fall Meeting, San Francisco, California, Dec. 13-17, 2010.

Carrico, C. M., J. L. Collett, S. M. Kreidenweis, E. J. T. Levin, M. Schurman, K. Beem, J. Ray, D. Day, B. A. Schichtel, and W. C. Malm (2010) Annual cycle in atmospheric nitrogen species at Rocky Mountain National Park, presented at the A&WMA Annual Meeting, Calgary, Canada, June 21-25, 2010.

Christian M. Carrico, Jeffrey L. Collett, Sonia M. Kreidenweis, Ezra Levin, Misha Schurman, Derek Day, Katherine Beem, John Ray, Bret Schichtel, and William Malm. Annual Cycle in Atmospheric Nitrogen Species at Rocky Mountain National Park, presented at the 2010 Rocky Mountain National Park Research Conference, Estes Park, CO, March 30-31, 2010.

Chen, X., D. Day, B. Schichtel, W. Malm, J. Mojica, C. McDade, S.M. Kreidenweis, and J. Collett, Jr. (2010) Atmospheric NH<sub>x</sub> monitoring: a pilot study at selected IMPROVE sites. Presented at the American Assn. for Aerosol Research 29th Annual Conference, Portland, Oregon, October 25-29, 2010.

Collett, Jr., J. L., Beem, K., Raja, S., Schwandner, F., Lee, T., Sullivan, A., Taylor, C., Carrico, C., McMeeking, G., Kreidenweis, S., Day, D., Barna, M., Gebhart, K., Hand, J., Schichtel, B., and Malm, W., Transport and deposition of airborne nitrogen in Rocky Mountain National Park, invited seminar at Hong Kong Polytechnic University, Hong Kong, China, September, 2009.

Collett, Jr., J. L., Kreidenweis, S.M., Lee, T., Raja, S., Beem, K., Yu, X., Schwandner, F., Carrico, C., Malm, B., and Schichtel, B., Reactive nitrogen: contributions to visibility degradation and deposition. Invited seminar to the Electric Power Research Institute, Broomfield, CO, October 7 2009.

Collett, Jr., J.L., Sullivan, A.P., Holden, A.S., Patterson, L., Schichtel, B., Kreidenweis, S., Malm, W.C., Wold, C., and Hao, W.M., Identifying chemical markers for quantifying smoke impacts on particulate matter concentrations and regional haze, Platform presentation at the 4th International Congress, Fire, Ecology and Management, November 30 -- December 4, 2009, Savannah, GA.

Collett, Jr., J. L. (2010) Rocky Mountain Atmospheric Nitrogen and Sulfur (RoMANS) Study Overview and Results. Presented at the Agricultural Air Quality Symposium, Fort Collins, CO, Feb. 24, 2010.

Collett, Jr., J. L. (2010) Rocky Mountain Atmospheric Nitrogen and Sulfur (RoMANS) Study Overview and Results. Presented at the Agricultural Air Quality Symposium, Sterling, CO, Feb. 25, 2010.

Collett, J. L., Jr., et al. (2010) Reactive nitrogen: contributions to visibility degradation and deposition, presented at the EPRI Nitrogen Meeting, Palo Alto, California, July 7-8, 2010.

Collett, J. Jr. et al.(2010) Temporal and spatial variability in concentrations of atmospheric ammonia in the western United States, presented at the AWMA International Specialty Conference: Leapfrogging Opportunities for Air Quality Improvement, Xian, China, May 10-14, 2010.

Collett, Jr., J. L., Y. Desyaterik, A. Sullivan, C. Hennigan, A.L. Robinson, A.S. Holden, S.M. Kreidenweis and B. Schichtel (2010) Organic Nitrogen in Fresh and Aged Aerosols Produced by Biomass Burning. Presented at the American Assn. for Aerosol Research 29th Annual Conference, Portland, Oregon, October 25-29, 2010.

Collett, Jr., J.L., T. Lee, K.B. Beem, C.M. Carrico, S. Raja, F.M. Schwandner, Y. Li, S.M. Kreidenweis, D. Chen, D. Day, W.C. Malm, B.A. Schichtel, J. Ray, M. Tigges, C. Archuleta, L. Sherman, J. Molenaar, H.J. Sewell, J. Mojica, and C. McDade (2010) Temporal and spatial variability in atmospheric ammonia concentrations in the western United States. Presented at the 5th International Nitrogen Conference, New Delhi, India, Dec. 3-7, 2010.

Collett, Jr., J.L., K.B. Beem, C.M. Carrico, S. Raja, F.M. Schwandner, M. Schurman, E. Levin, S.M. Kreidenweis, W.C. Malm, and B.A. Schichtel (2010) Transport and deposition of reactive nitrogen species in Rocky Mountain National Park, USA. Presented at the 5th International Nitrogen Conference, New Delhi, India, Dec. 3-7, 2010.

Day, D., W. Malm, B. Schichtel, X. Chen, F. Schwandner, and J. Collett, Jr. (2010) Observations of the Spatial and Temporal Variability of Ammonia at Several different sites in Colorado. Presented at the American Assn. for Aerosol Research 29th Annual Conference, Portland, Oregon, October 25-29, 2010.

Desyaterik, Y., L. Mack, T. Lee, S.M. Kreidenweis, J.L. Collett, J.L. Jimenez, and D.R. Worsnop (2010) Elemental Composition of Primary Aerosols Emitted from Burning of 21 Biomass Fuels Measured by Aerosol Mass Spectrometer. Presented at the American Geophysical Union Fall Meeting, San Francisco, California, Dec. 13-17, 2010.

Gebhart, K. A., B. A. Schichtel, W. C. Malm, M. G. Barna, M. A. Rodriguez and J. Collett, Jr. (2010) An Ensemble Method for Trajectory-Based Source Apportionment of Airborne Concentrations at Rocky Mountain National Park, Colorado, presented at the A&WMA Annual Meeting, Calgary, Canada, June 21-25, 2010.

Holden, A.S., Desyaterik, Y., Collett, J.L., Kreidenweis, S.M., and Malm, W., Analysis of fresh and aged aerosols produced by biomass combustion, Abstract for presentation at AAAR, 28th Annual Conference, October 26 -- 30, 2009, Minneapolis, MN

Holden, A.S., Chiavetta, D.A., Sullivan, A.P., and Collett, Jr., J.L., Analyzing biomass smoke marker emissions from the combustion of paper products, Poster for presentation at AAAR, 28th Annual Conference, October 26 -- 30, 2009, Minneapolis, MN

Holden, A.S., Y. Desyaterik, A. Laskin, J. Laskin, B.A. Schichtel, W.C. Malm, S.M. Kreidenweis, and J.L. Collett (2010) Analysis of Fresh and Aged Aerosols Produced by Biomass Combustion. Presented at the American Geophysical Union Fall Meeting, San Francisco, California, Dec. 13-17, 2010.

Kreidenweis, S.M., McMeeking, G.R., Arnott, W.P., Baker, S., Carrico, C.M., Chow, J.C., Collett, Jr., J.L., Hao, W.M., Holden, A.S., Kirchstetter, T.W., Levin, E.J., Lewis, K., Mack, L., Malm, W.C., Moosmuller, H., Sullivan, A.P., and Wold, C.E., The Fire Lab at Missoula Experiment (FLAME): Measurements of trace gases and aerosols during the open combustion of biomass in the laboratory, poster presentation at the 4th International Congress, Fire, Ecology and Management, November 30 -- December 4, 2009, Savannah, GA.

Kreidenweis, S.M., J.L. Collett, H., Moosmuller, W.P. Arnott, W. Hao, and W.C. Malm (2010) Overview of the Fire Lab at Missoula Experiments (FLAME). Presented at the American Geophysical Union Fall Meeting, San Francisco, California, Dec. 13-17, 2010.

Lee, T., Collett, J.L., Kreidenweis, S.M., Sullivan, A., Mack, L., Jimenez, J.L., Kimmel, J., Onasch, T.B., Malm, W., Wold, C., and Hao, W-M., Aerosol mass spectrometer measurement of the evolution of chemical smoke markers during laboratory open burning of wildland fuels, platform presentation at AAAR, 28th Annual Conference, October 26 -- 30, 2009, Minneapolis, MN .

Levin, E.J.T., Carrico, C.M., Beem, K.B., Schurman, M., Day, D., Kreidenweis, S.M., Collett, Jr., J.L., Schichtel, B., and Malm, W.C., Aerosol number and volume concentrations during the

second Rocky Mountain Atmospheric Nitrogen and Sulfur study (RoMANS 2), Abstract for presentation at AAAR, 28th Annual Conference, October 26 -- 30, 2009, Minneapolis, MN

Levin, E.J.T., Mack, L., Carrico, C.M., McMeeking, G.R., Kreidenweis, S.M., Wold, C.E., Moosmuller, H., Arnott, W.P., Hao, W.M., Collett, Jr., J.L., and Malm, W.C., Optical properties of biomass burning smoke aerosols, Abstract for presentation at AAAR, 28th Annual Conference, October 26 -- 30, 2009, Minneapolis, MN

Mack, L., Lee, T., Jimenez, J-L., Kreidenweis, S., Collett, Jr., J., Moosmuller, H., Wold, C., Kimmel, J.R., Onasch, T., Hao W.M., and Malm, W., Elemental analysis of aerosol mass spectrometer measurements of laboratory open biomass burning aerosols, Poster presented at AAAR, 28th Annual Conference, October 26 -- 30, 2009, Minneapolis, MN.

Malm, W.C., Collett, Jr., J.L., Kreidenweis, S.M., Schichtel, B.A., Moosmuller, H., Hao, W.M., and Carrico, C.M., Measurements needed to understand the role of biomass burning within the regulatory framework of the Environmental Protection Agency and the Federal Land Managing Community, Abstract for presentation at AAAR, 28th Annual Conference, October 26 -- 30, 2009, Minneapolis, MN.

McCluskey, C.S., K.B. Beem, and J.L. Collett (2010) The Presence of Reactive Nitrogen in Fine and Coarse Aerosol. Presented at the American Geophysical Union Fall Meeting, San Francisco, California, Dec. 13-17, 2010.

Schichtel, B.A., Malm, W.C., Collett, Jr., J.L., Sullivan, A.P., Patterson, L.A., and Holden, A.S., Hybrid receptor modeling framework for estimating the contribution of smoke and its source regions to fine particulate matter, Platform presentation at the 4th International Congress, Fire, Ecology and Management, November 30 -- December 4, 2009, Savannah, GA.

Schichtel, B.A., Malm, W.C., Collett, J.L., Sullivan, A.P., Patterson, L.A., and Holdend, A.S., Estimating the contribution of smoke and its source regions to fine particulate matter using a hybrid-receptor model, Abstract for presentation at AAAR, 28th Annual Conference, October 26 -- 30, 2009, Minneapolis, MN.

Schichtel, B. A., W. C. Malm, J. L. Collett, Jr., et al.(2010) Estimating the Contribution of Smoke and Its Source Regions to Fine Particulate Matter using a Hybrid receptor Model, presented at the AWMA International Specialty Conference: Leapfrogging Opportunities for Air Quality Improvement, Xian, China, May 10-14, 2010.

Schurman, M.I., T. Lee, Y. Sun, B.A. Schichtel, S.M. Kreidenweis, and J.L. Collett (2010) Using Aerosol Mass Spectrometry to Investigate Types and Sources of Organic Aerosol in Rocky Mountain National Park. Presented at the American Geophysical Union Fall Meeting, San Francisco, California, Dec. 13-17, 2010.

Stratton, J.J, E.J. Levin, J.M. Ham, J.L. Collett, and T. Borch (2010) Quantifying Ammonia Emissions from High Elevation Grassland and Forest Soils. Presented at the American Geophysical Union Fall Meeting, San Francisco, California, Dec. 13-17, 2010.

Sullivan, A.P., N. Frank, and J.L. Collett, Jr. (2010) Application of an alternative method for measuring carbohydrates in routine filter samples collected by the FRM network. Presented at the CACGP/IGAC Conference, Halifax, Canada, July 11-16, 2010.

Sullivan, A.P., S.M. Kreidenweis, and J.L. Collett (2010) Examination of Smoke Marker Ratios from Controlled Laboratory Burns vs. Wildfires and Prescribed Burns. Presented at the American Geophysical Union Fall Meeting, San Francisco, California, Dec. 13-17, 2010.