

**Desert Research Institute (DRI) Final Report
(October 12, 2009)**

TASK AGREEMENT:	COOPERATIVE AGREEMENT:	EFFECTIVE DATES:
J8R07060005	H8R07010001	05/10/2006 – 06/31/09

COOPERATOR: Desert Research Institute (DRI)

PROJECT TITLE: Development of Improved Methods for Characterizing Wildland Fire Particulate Matter Emissions and Their Air Quality/Visibility Impacts

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PROJECT ABSTRACT: This three-year project has characterized wildland fire particulate matter (PM) emissions from laboratory fires during years 1 and 2 and from wildland fires during the third year of the study. Desert Research Institute has participated in all aspects of the project including planning, laboratory and field experiments, data analysis, and dissemination of results. This project has linked to other components of a multi-phase project administered by two CESU's and a federal agency.

1. Background and Objectives

1.1. Background

Carbonaceous aerosols, which include contributions from industrial and mobile source emissions and biomass combustion, exert a significant impact on regional air quality. Some preliminary semi-quantitative analyses suggest that smoke from fire-related activity may contribute significantly to observed organic mass concentrations. Further, these emissions have resulted in increased conflicts with the need to attain air quality standards, especially for particulate matter (PM) and visibility, as mandated by the Clean Air Act. However, federal land managers and policy makers currently lack several important tools needed for air quality assessments: composition profiles and analytical techniques necessary to differentiate carbonaceous aerosols originating from industrial and mobile source activity and those from fire emissions; measurement-based PM mass emissions rates for relevant fuels and combustion conditions; and reasonable optical properties and optical property emission rates to attach to fire emissions.

1.2. DRI Products

This three-year project has characterized wildland fire particulate matter (PM) emissions from laboratory fires during years 1 and 2 and from wildland fires during the third year of the study. DRI has participated in all aspects of the project including planning, laboratory and field experiments, data analysis, and dissemination of results working jointly with scientists from Colorado State University (CSU), the U.S. Forest Service Fire Science Laboratory (USFS-FSL), and the NPS. DRI scientists have taken the lead for delivering the following products for laboratory and wildland fires as function of fuels, combustion parameters, and combustion phase:

- PM mass emission factors,
- Scattering, absorption, and extinction cross section emission factors,
- PM scattering, absorption, and extinction efficiencies (m²/g),
- PM albedo, and
- PM morphology.

These products have been delivered as documented in section 2 “DRI Deliverables”

1.3. DRI Instruments and Sample Analysis

To obtain these products, the following DRI instruments and sample analysis have been used during laboratory and field experiments:

- Tapered Element Oscillating Microbalance (TEOM) for PM mass concentration measurements with high time resolution,
- DRI Cavity Ring Down/Cavity Enhanced Detection (CRD/CRD) measurement of PM extinction coefficients with high time resolution,
- DRI Photoacoustic Spectrometer (PAS) measurement of PM absorption coefficients with high time resolution,
- Filter sampling followed by Scanning Electron Microscopy (SEM) and image analysis for the determination of PM morphology and shape descriptors.

Analysis of data collected by these DRI field instruments has occurred in conjunction with additional data collected by CSU and USFS-FSL leading to the development of the products

previously described. Results have been and will be disseminated through project reports, conference presentations, and peer-reviewed publications.

2. Desert Research Institute (DRI) Deliverables

2.1. *Education and real-world research for graduate students*

Four graduate students have participated in this project for their education and graduate degree research. So far three graduate degrees (2 Ph.D. and 1 M.S. degree) have been awarded to these students with an additional two Ph.D. degrees in progress. While DRI is not a degree granting institution, it is heavily involved in multiple science departments at the University of Nevada, Reno, with both PI (H. Moosmüller) and Co-PI (W.P. Arnott) serving as graduate advisers. Graduate students and degrees are summarized in table 1 below.

Table 1: DRI/UNR Graduate Students and Degrees

Name	Degree (Date)	Program	Thesis Title
Rajan Chakrabarty	Ph.D. (12/2008)	Chemical Physics (UNR)	On the Morphology and Optics of Carbonaceous Aerosols
Rajan Chakrabarty	M.S. (8/2006)	Atmospheric Sciences (UNR)	Characterization of Size, Morphology, and Fractal Properties of Aerosols Emitted from Spark Ignition Engines and from the Combustion of Wildland Fuels
Kristin Lewis	Ph.D. (12/2008)	Atmospheric Sciences (UNR)	Development of a Dual-Wavelength Photoacoustic Instrument for Measurement of Light Absorption and Scattering by Aerosol and Gases
Madhu Gyawali	Ph.D. (TBD)	Physics (UNR)	TBD
Guoxun Tian	Ph.D. (TBD)	Physics (UNR)	TBD

2.2. *Obtaining emission factors for combustion of wildland fuels that can be used in future research*

Emission factors have been obtained and have been documented and disseminated for use in future research in 6 peer-reviewed publications (i.e., #15, #14, #10, #5, #4, and #3) as listed in section 2.3 below.

2.3. *Peer reviewed publication of scientific findings*

Scientific findings of this project have been summarized in the following 17 publications (9 published, 2 in press, 1 accepted, 2 submitted, and 3 in preparation) in peer-reviewed journals.

- 17) Moosmüller, H., C. E. Wold, S. M. Kreidenweis, J. L. Collett, Jr., W. M. Hao, and W. C. Malm (2009). A Near Homogeneous Ignition System for the Laboratory Combustion of Biomass. In preparation.

- 16) Moosmüller, H., L.-W. A. Chen, W. P. Arnott, and S. M. Kreidenweis (2009). Laboratory Combustion of Wildland Fuels: Repeatability of Emission Measurements. In preparation.
- 15) Levin, E. J. T., G. R. McMeeking, C. M. Carrico, L. Mack, S. M. Kreidenweis, C. E. Wold, H. Moosmüller, W. P. Arnott, W. M. Hao, J. L. Collett, Jr., and W. C. Malm (2009). Biomass Burning Smoke Aerosol Properties Measured during FLAME 2. *J. Geophys. Res.*, in preparation.
- 14) Chakrabarty, R. K., H. Moosmüller, L.-W. A. Chen, K. Lewis, W. P. Arnott, C. Mazzoleni, M. Dubey, C. E. Wold, W. M. Hao, and S. M. Kreidenweis (2009). Brown Carbon in Tar Balls from Smoldering Biomass Combustion. *PNAS*, submitted.
- 13) Lewis, K. A., W. P. Arnott, H. Moosmüller, R. K. Chakrabarty, C. M. Carrico, S. M. Kreidenweis, D. E. Day, W. C. Malm, A. Laskin, J.-L. Jimenez, J. A. Huffman, I. M. Ulbrich, T. B. Onasch, A. Trimborn, L. Lui, and M. I. Mishchenko (2009). Reduction in Biomass Burning Aerosol Light Absorption upon Humidification: Roles of Inorganically-Induced Hygroscopicity, Particle Collapse, and Photoacoustic Heat and Mass Transfer. *Atm. Chem. Phys. Discuss.*, **9**, 15247-15294, *Atm. Chem. Phys.*, in review.
- 12) Gyawali, M., W. P. Arnott, K. Lewis, and H. Moosmüller (2009). In Situ Aerosol Optics in Reno, NV, USA during and after the Summer 2008 California Wildfires and the Influence of Aerosol Coatings. *Atm. Chem. Phys. Discuss.*, **9**, 14059-14079, *Atm. Chem. Phys.*, accepted for publication.
- 11) Petters, M. D., C. M. Carrico, S. M. Kreidenweis, A. J. Prenni, P. J. DeMott, J. L. Collett, Jr., and H. Moosmüller (2009). Cloud Condensation Nuclei Activity of Biomass Burning Aerosol. *J. Geophys. Res.*, **114**, doi:10.1029/2009JD012353, in press.
- 10) McMeeking, G. R., S. M. Kreidenweis, S. Baker, C. M. Carrico, J. C. Chow, J. L. Collett Jr., W. M. Hao, A. S. Holden, T. W. Kirchstetter, W. C. Malm H. Moosmüller, A. P. Sullivan, and C. E. Wold (2009). Emissions of Trace Gases and Aerosols during the Open Combustion of Biomass in the Laboratory. *J. Geophys. Res.*, **114**, doi:10.1029/2009JD011836, in press.
- 9) DeMott, P. J., M. D. Petters, A. J. Prenni, C. M. Carrico, S. M. Kreidenweis, J. L. Collett, Jr., and H. Moosmüller (2009). Ice Nucleation Behavior of Biomass Combustion Particles at Cirrus Temperatures. *J. Geophys. Res.*, **114**, D16205, doi:10.1029/2009JD012036 (13 pages).
- 8) Moosmüller, H., R. K. Chakrabarty, and W. P. Arnott (2009). Aerosol Light Absorption and its Measurement: A Review. *J. Quant. Spectrosc. Radiat. Transfer*, **110**, 844-878.
- 7) Petters, M. D., M. T. Parsons, A. J. Prenni, P. J. DeMott, S. M. Kreidenweis, C. M. Carrico, A. P. Sullivan, G. R. McMeeking, E. Levin, C. E. Wold, J. L. Collett, Jr., and H. Moosmüller (2009). Ice Nuclei Emissions from Biomass Burning. *J. Geophys. Res.*, **114**, doi:10.1029/2008JD011532, (10 pages).
- 6) Lewis, K., W. P. Arnott, H. Moosmüller, and C. E. Wold (2008). Strong Spectral Variation of Biomass Smoke Light Absorption and Single Scattering Albedo Observed with a Novel Dual-Wavelength Photoacoustic Instruments. *J. Geophys. Res.*, **113**, doi:10.1029/2007JD009699 (14 pages).
- 5) Obrist, D., H. Moosmüller, R. Schürmann, L.-W. A. Chen, and S. M. Kreidenweis (2008). Particulate-Phase and Gaseous Elemental Mercury Speciation During Biomass Combustion: Controlling Factors and Correlation with Particulate Matter Emissions. *Environ. Sci. Technol.*, **42**, 721-727.
- 4) Chen, L.-W. A., H. Moosmüller, W. P. Arnott, J. C. Chow, J. G. Watson, R. A. Susott, R. E. Babbitt, C. E. Wold, E. N. Lincoln, and W. M. Hao (2007). Emissions from Laboratory Combustion of Wildland Fuels: Emission Factors and Source Profiles. *Environ. Sci. Technol.*, **41**, 4317-4325.

- 3) Mazzoleni, L. R., B. Zielinska, and H. Moosmüller (2007). Emissions of Levoglucosan, Methoxy Phenols, and Organic Acids from Prescribed Burns, Wildland Fuels, and Residential Wood Combustion, *Environ. Sci. Technol.*, **41**, 2115-2122.
- 2) Chakrabarty, R. K., H. Moosmüller, M. A. Garro, W. P. Arnott, J. W. Walker, R. A. Susott, R. E. Babbitt, C. E. Wold, E. N. Lincoln, and W. M. Hao (2006). Particle Emissions from Laboratory Combustion of Wildland Fuels: Particle Morphology and Size. *J. Geophys. Res.*, **111**, doi:10.1029/2005JD006659 (16 pages).
- 1) Chen, L.-W. A., H. Moosmüller, W. P. Arnott, J. C. Chow, J. G. Watson, R. A. Susott, R. E. Babbitt, C. E. Wold, E. N. Lincoln, and W. M. Hao (2006). Particle Emissions from Laboratory Combustion of Wildland Fuels: *In-Situ* Optical and Mass Measurements. *Geophys. Res. Lett.*, **33**, doi:10.1029/2005GL024838 (4 pages).

2.4. Special Journal Issue

The DRI PI (Moosmüller) is currently serving as the lead editor of a special journal issue relevant to the project.

- 1) Special Issue of "Atmospheric Chemistry and Physics" in 2010 entitled "Measurement and Modeling of Aerosol Emissions from Biomass Burning"

2.5. Other publications

Findings of this project have also been highlighted in two other publications.

- 2) Moosmüller, H., S. M. Kreidenweis, J. L. Collett Jr., W. M. Hao, and W. C. Malm (2009). Characterization of Particle Emissions from Laboratory Combustion of Wildland Fuels. Interagency Monitoring of Protected Visual Environments (IMPROVE) 2009 Calendar.
- 1) Moosmüller, H., S. M. Kreidenweis, J. L. Collett Jr., W. M. Hao, and W. C. Malm (2007). Characterization of Particle Emissions from Laboratory Combustion of Wildland Fuels. Newsletter of the Integrated Land Ecosystem – Atmosphere Processes Study (iLEAPS), **4**, 22-23.

2.6. Conference presentations of scientific findings

Scientific findings of this project have been (or will be) disseminated in the following 44 conference presentations (37 presented, 7 to be presented).

- 44) Kreidenweis, S. M., P. J. DeMott, M. D. Petters, A. J. Prenni, C. M. Carrico, C. E. Wold, J. L. Collett, Jr., H. Moosmüller, W. C. Malm, and W. M. Hao (2010). Ice nucleation Behavior of Particles Generated in Open Burning of Biomass. *90th American Meteorological Society Annual Meeting*, Atlanta, GA, January 17-21, 2010.
- 43) Kreidenweis, S. M., G. R. McMeeking, W. P. Arnott, S. Baker, C. M. Carrico, J. C. Chow, J. L. Collett, Jr., W. M. Hao, A. S. Holden, T. W. Kirchstetter, E. J. T. Levin, K. A. Lewis, L. Mack, W. C. Malm, H. Moosmüller, A. P. Sullivan, and C. E. Wold (2009). The Fire Lab at Missoula Experiment (FLAME): Measurements of Trace Gases and Aerosols during the Open Combustion of Biomass in the Laboratory. *4th International Fire Ecology and Management Congress: Fire as a Global Process*, Savannah, GA, November 30 - December 4, 2009.
- 42) Malm, W. C., J. L. Collett, Jr., S. M. Kreidenweis, B. A. Schichtel, H. Moosmüller, W. M. Hao, and C. M. Carrico (2009, **invited**). Measurements Needed to Understand the

Role of Biomass Burning within the Regulatory Framework of the Environmental Protection Agency and the Federal Land Managing Community. *28th Annual Conference of the American Association for Aerosol Research*, Minneapolis, MN, October 26-30, 2009.

- 41) Gyawali, M., W. P. Arnott, and H. Moosmüller (2009). Wavelength Dependence of Aerosol Light Absorption: Diurnal and Seasonal Variation in Reno, NV. *28th Annual Conference of the American Association for Aerosol Research*, Minneapolis, MN, October 26-30, 2009.
- 40) Chakrabarty, R. K., H. Moosmüller, L.-W. A. Chen, W. P. Arnott, K. A. Lewis, C. Mazzoleni, M. Dubey, C. E. Wold, W. M. Hao, and S. M. Kreidenweis (2009). Brown Carbon in Smoldering Biomass Aerosols. *28th Annual Conference of the American Association for Aerosol Research*, Minneapolis, MN, October 26-30, 2009.
- 39) Mack, L., T. Lee, J.-L. Jimenez, S. M. Kreidenweis, J. L. Collett, Jr., H. Moosmüller, C. E. Wold, J. R. Kimmel, T. B. Onasch, W. M. Hao, and W. C. Malm (2009). Elemental Analysis of Aerosol Mass Spectrometer Measurements Of Laboratory Biomass Burning Aerosols. *28th Annual Conference of the American Association for Aerosol Research*, Minneapolis, MN, October 26-30, 2009.
- 38) Levin, E. J. T., L. Mack, C. M. Carrico, G. R. McMeeking, S. M. Kreidenweis, C. E. Wold, H. Moosmüller, W. P. Arnott, W. M. Hao, J. L. Collett, Jr., and W. C. Malm (2009). Optical Properties of Biomass Burning Smoke Aerosols. *28th Annual Conference of the American Association for Aerosol Research*, Minneapolis, MN, October 26-30, 2009.
- 37) Arnott, W. P. and H. Moosmüller (2009). Multispectral Photoacoustic Analysis of Atmospheric Aerosol. *15th International Conference on Photoacoustic and Photothermal Phenomena*, Leuven, Belgium, July 19-23, 2009.
- 36) Gyawali, M., W. P. Arnott, I. Arnold, K. A. Lewis, G. Parades-Miranda, H. Moosmüller, R. K. Chakrabarty, G. Kok, J. W. Walker, and D. Baumgardner (2009). Wavelength Dependence of Aerosol Light Absorption. *Annual Science Team Meeting of the Department of Energy Atmospheric Science Program (DOE ASP)*, Santa Fe, NM, February 25–27, 2009.
- 35) Moosmüller, H. (2009, **invited**). Measurement of Aerosol Optical Properties: Principles and Applications. *Seminar, National Space Science and Technology Center, University of Alabama in Huntsville*, Huntsville, AL, February 18, 2009.
- 34) Mack, L., D. Obrist, H. Moosmüller, K. A. Lewis, W. P. Arnott, G. R. McMeeking, E. J. T. Levin, S. M. Kreidenweis, C. E. Wold, W. M. Hao, J. L. Collett, Jr., and W. C. Malm (2008). Optical Closure Experiments for Biomass Smokes Aerosols. *27th Annual Conference of the American Association for Aerosol Research*, Orlando, FL, October 20-24, 2008.
- 33) Chakrabarty, R. K., H. Moosmüller, H., L.-W. A. Chen, C. Mazzoleni, P. Chylek, M. Dubey, W. P. Arnott, K. Lewis, and W. M. Hao (2008). Morphology and Effective Refractive Indices of Aerosols Emitted from High-Moisture-Content Biomass Combustion. *9th International Conference on Carbonaceous Particles in the Atmosphere (ICCPA)*, Berkeley, CA, August 12-14, 2008.

- 32) Lewis, K., W. P. Arnott, and H. Moosmüller (2008). Photoacoustic Evidence for Strong Spectral Variation of Biomass Smoke Light Absorption and Single Scattering Albedo. *9th International Conference on Carbonaceous Particles in the Atmosphere (ICCPA)*, Berkeley, CA, August 12-14, 2008.
- 31) McMeeking, G. R., A. P. Sullivan, P. J. DeMott, S. M. Kreidenweis, J. L. Collett, Jr., T. W. Kirchstetter, M. M. Lunden, H. Moosmüller, W. P. Arnott, K. Lewis, W. M. Hao, and W. C. Malm (2008). The Light Attenuation Spectral Dependence of Organic Carbon Emitted by Biomass Burning. *9th International Conference on Carbonaceous Particles in the Atmosphere (ICCPA)*, Berkeley, CA, August 12-14, 2008.
- 30) McMeeking, G. R., C. M. Carrico, M. D. Petters, M. Parsons, A. J. Prenni, A. P. Sullivan, P. J. DeMott, S. M. Kreidenweis, J. L. Collett, Jr., T. W. Kirchstetter, M. M. Lunden, H. Moosmüller, W. P. Arnott, K. Lewis, S. Baker, C. E. Wold, W. M. Hao, and W. C. Malm (2008). Characterization of Emissions from the Laboratory Combustion of Wildland Plant Species. *9th International Conference on Carbonaceous Particles in the Atmosphere (ICCPA)*, Berkeley, CA, August 12-14, 2008.
- 29) Moosmüller, H. (2008, **invited**). Light Absorption. *Conference on "Light Scattering: Mie and More – Commemorating 100 Years Mie's 1908 Publications"*, *Gesellschaft für Aerosol Forschung (GAeF) Annual Meeting*, Karlsruhe, Germany, July 3-4, 2008.
- 28) Chakrabarty, R. K., H. Moosmüller, H., L.-W. A. Chen, C. Mazzoleni, P. Chylek, M. Dubey, W. P. Arnott, K. Lewis, and W. M. Hao (2008). Determination of Effective Refractive Indices of Aerosols Emitted from High-Moisture-Content Biomass Combustion Using Mie Theory. *Conference on "Light Scattering: Mie and More – Commemorating 100 Years Mie's 1908 Publications"*, *Gesellschaft für Aerosol Forschung (GAeF) Annual Meeting*, Karlsruhe, Germany, July 3-4, 2008.
- 27) Lewis, K., W. P. Arnott, and H. Moosmüller (2008). Multiwavelength Photoacoustic Measurements of Light Absorption and Scattering by Biomass Smoke. *Conference on "Light Scattering: Mie and More – Commemorating 100 Years Mie's 1908 Publications"*, *Gesellschaft für Aerosol Forschung (GAeF) Annual Meeting*, Karlsruhe, Germany, July 3-4, 2008.
- 26) Moosmüller, H., W. P. Arnott, L.-W. A. Chen, R. K. Chakrabarty, D. Obrist, K. Lewis, C. Mazzoleni, C. E. Wold, E. N. Lincoln, and W. M. Hao (2008). Aerosol Optical Properties During Flaming and Smoldering Phases of Laboratory Combustion of Wildland Fuels. *Conference on "Light Scattering: Mie and More – Commemorating 100 Years Mie's 1908 Publications"*, *Gesellschaft für Aerosol Forschung (GAeF) Annual Meeting*, Karlsruhe, Germany, July 3-4, 2008.
- 25) Moosmüller, H., L.-W. A. Chen, W. P. Arnott, G. R. McMeeking, and S M. Kreidenweis (2008). Repeatability of PM Emissions during Laboratory Combustion of Wildland Fuels. *Aerosol and Atmospheric Optics: Visual Air Quality and Radiation Balance Conference*, Air & Waste Management Association, Moab, UT, April 28 - May 2, 2008.
- 24) Moosmüller, H., L. Mack, D. Obrist, W. P. Arnott, and S M. Kreidenweis (2008). Cavity Ring Down Measurements of Extinction from Smoke Generated through Laboratory Combustion of Wildland Fuels. *Aerosol and Atmospheric Optics: Visual Air Quality and Radiation Balance Conference*, Air & Waste Management Association, Moab, UT, April 28 - May 2, 2008.

- 23) Moosmüller, H. and D. DuBois (2008, **invited**). Aerosol Optical Properties and Visibility Impairment in the Southwestern US. *DRI's Environmental Seminar Series*, Desert Research Institute, Reno, NV, April 25, 2008.
- 22) Moosmüller, H. (2008, **invited**). Optical Properties of Aerosols. *Seminar, Department of Chemistry, University of Nevada, Reno*, Reno, NV, April 18, 2008.
- 21) Moosmüller, H., W. P. Arnott, L.-W. A. Chen, D. Obrist, R. K. Chakrabarty, C. E. Wold, W. M. Hao, and S. M. Kreidenweis (2008). Particle Emissions from Flaming and Smoldering Laboratory Combustion of Wildland Fuels. *NASA Fire Science Workshop*, Adelphi, MD, February 20-22, 2008.
- 20) Arnott, W. P., K. Lewis, G. Parades-Miranda, S. Winter, D. Day, R. K. Chakrabarty, L.-W. A. Chen, and H. Moosmüller (2007). Relative Humidity Influence on Aerosol Light Absorption and Scattering by Biomass Burning Aerosol. *26th Annual Conference of the American Association for Aerosol Research*, Reno, NV, September 24-28, 2007.
- 19) McMeeking, G. R., C. M. Carrico, E. Levin, S. M. Kreidenweis, J. L. Collett, Jr., H. Moosmüller, W. P. Arnott, C. E. Wold, W. M. Hao, and W. C. Malm (2007). Measurements of Smoke Aerosol Size Distributions and Refractive Indices During a Series of Laboratory Biomass Burning Experiments. *26th Annual Conference of the American Association for Aerosol Research*, Reno, NV, September 24-28, 2007.
- 18) McMeeking, G. R., A. P. Sullivan, S. M. Kreidenweis, J. L. Collett, Jr., T. W. Kirchstetter, M. M. Lunden, L.-W. A. Chen, D. Obrist, H. Moosmüller, J. C. Chow, C. E. Wold, W. M. Hao, D. E. Day, and W. C. Malm (2007). A Comparison of Thermal-Optical Carbon Measurement Methods for Aerosols Emitted by a Series of Controlled Biomass Burning Experiments. *26th Annual Conference of the American Association for Aerosol Research*, Reno, NV, September 24-28, 2007.
- 17) Mack, L., D. Obrist, H. Moosmüller, K. A. Lewis, W. P. Arnott, G. R. McMeeking, E. Levin, S. M. Kreidenweis, C. E. Wold, W. M. Hao, J. L. Collett, Jr., and W. C. Malm (2007). Experimental and Theoretical Closure Experiments for Biomass Smokes Using Extinction Cells, Photoacoustics, and Nephelometry. *26th Annual Conference of the American Association for Aerosol Research*, Reno, NV, September 24-28, 2007.
- 16) Chen, L.-W. A., R. K. Chakrabarty, H. Moosmüller, W. P. Arnott, J. G. Watson, and J. C. Chow (2007). Nanoparticle Emission from Biomass Burning? *Symposium on PM Formation in Fuel Combustion, 233rd American Chemical Society National Meeting*, Chicago, IL, March 25-29, 2007.
- 15) K. A. Lewis, W. P. Arnott, and H. Moosmüller (2006). Multiwavelength Photoacoustic Measurements of Light Absorption and Scattering by Wood Smoke. *2006 Fall Meeting of the American Geophysical Union*, San Francisco, CA, December 11-15, 2006.
- 14) Arnott, W. P., K. A. Lewis, G. Parades-Miranda, S. Winter, D. Day, R. K. Chakrabarty, H. Moosmüller, J.-L. Jimenez, I. Ulbrich, A. Huffman, T. B. Onasch, A. Trimborn, S. M. Kreidenweis, C. M. Carrico, C. E. Wold, E. N. Lincoln, P. Freeborn, W. M. Hao, and G. R. McMeeking (2006). Observations of Aerosol Light Scattering, Absorption and Particle Morphology as a Function of Relative Humidity. *2006 Fall Meeting of the American Geophysical Union*, San Francisco, CA, December 11-15, 2006.

- 13) Obrist, D., H. Moosmüller, C. E. Wold, E. N. Lincoln, P. Freeborn, W. M. Hao and S. M. Kreidenweis (2006). Speciated Mercury Emissions from Laboratory Combustion of Wildland Fuel. *Tahoe Research Symposium*, Incline Village, NV, October 18-20, 2006.
- 12) K. Lewis, W. P. Arnott, and H. Moosmüller (2006, **invited**). Multiwavelength Photoacoustic Measurements of Light Absorption and Scattering by Wood Smoke. *Science Talk, Division of Atmospheric Sciences, Desert Research Institute, Nevada System of Higher Education*, Reno, NV, September 27, 2006.
- 11) Arnott, W. P., K. A. Lewis, G. Parades-Miranda, S. Winter, D. E. Day, R. K. Chakrabarty, H. Moosmüller, J.-L. Jimenez, I. Ulbrich, A. Huffman, T. B. Onasch, A. Trimborn, S. M. Kreidenweis, C. M. Carrico, C. E. Wold, E. N. Lincoln, P. Freeborn, and W. M. Hao (2006, **invited**). Observations of the Reduction of Aerosol Light Absorption and Increase of Aerosol Light Scattering for Biomass Burning for Increasing Relative Humidity. *Science Talk, Division of Atmospheric Sciences, Desert Research Institute, Nevada System of Higher Education*, Reno, NV, September 27, 2006.
- 10) Huang, L., P. Tans, K. Higuchi, D. Worthy, T. Chan, A. Shashkov, H. Moosmüller, W. M. Hao, B. Chen (2006). Carbon Cycle and Environmental Changes on Regional Scales: What We Can Learn From High Precision Isotope Measurements in Atmospheric CO₂. *7th International Symposium on Environmental Geochemistry (7th ISEG)*, Beijing, China, September 24-27, 2006.
- 9) Chen, L.-W. A., H. Moosmüller, W. P. Arnott, R. A. Susott, R. E. Babbitt, C. E. Wold, E. N. Lincoln, and W. M. Hao (2006). Emission Factors for Carbon Monoxide, Elemental Carbon, and Light Absorption from Laboratory Combustion of Wildland Fuels. *International Aerosol Conference*, St. Paul, MN, September 10-15, 2006.
- 8) Chakrabarty, R. K., H. Moosmüller, M. A. Garro, and W. P. Arnott (2006). Characterization of Morphology and Structural Properties of Particles Emitted from the Laboratory Combustion of Wildland Fuels. *Conference on Visibility, Aerosol, and Atmospheric Optics*, Vienna, Austria, September 3-6, 2006.
- 7) Moosmüller, H., W. P. Arnott, L.-W. A. Chen, R. K. Chakrabarty, R. A. Susott, R. E. Babbitt, C. E. Wold, E. N. Lincoln, and W. M. Hao (2006). Particle Emissions from Laboratory Combustion of Wildland Fuels: Time Evolution of Aerosol Optical Properties and the Transition from Flaming to Smoldering Combustion. *Conference on Visibility, Aerosol, and Atmospheric Optics*, Vienna, Austria, September 3-6, 2006.
- 6) Chakrabarty, R. K., H. Moosmüller, L.-W. A. Chen, C. Mazzoleni, P. Chylek, M. Dubey, W. P. Arnott, K. Lewis, and W. M. Hao (2006). Experimental Determination of Effective Refractive Indices of Aerosols Emitted from High-Moisture-Content Biomass Combustion. *Aerosol Workshop on Climate Prediction Uncertainties, Second International Conference on Global Warming and the Next Ice Age*, Santa Fe, NM, July 17-21, 2006.
- 5) Moosmüller, H. and W. P. Arnott (2006, **invited**). *In Situ* Measurements of Shortwave Aerosol Optical Properties Relevant for Climate Change. *Aerosol Workshop on Climate Prediction Uncertainties, Second International Conference on Global Warming and the Next Ice Age*, Santa Fe, NM, July 17-21, 2006.

- 4) K. Lewis, W. P. Arnott, and H. Moosmüller (2006). Multi-wavelength Photoacoustic Measurements of Light Absorption and Scattering by Wood Smoke. *Aerosol Workshop on Climate Prediction Uncertainties, Second International Conference on Global Warming and the Next Ice Age*, Santa Fe, NM, July 17-21, 2006.
- 3) Moosmüller, H., W. P. Arnott, L.-W. A. Chen, R. K. Chakrabarty, D. Obrist, K. Lewis, C. Mazzoleni, C. E. Wold, E. N. Lincoln, and W. M. Hao (2006). Particle Emissions from Laboratory Combustion of Wildland Fuels: Aerosol Optical Properties During Flaming and Smoldering Combustion Phases. *Second International Conference on Global Warming and the Next Ice Age*, Santa Fe, NM, July 17-21, 2006.
- 2) Arnott, W. P., K. Lewis, G. Parades-Miranda, S. Winter, D. Day, R. K. Chakrabarty, H. Moosmüller, J.-L. Jimenez, I. Ulbrich, A. Huffman, T. B. Onasch, A. Trimborn, S. M. Kreidenweis, C. M. Carrico, C. E. Wold, E. N. Lincoln, P. Freeborn, and W. M. Hao (2006). Observations of the Reduction of Aerosol Light Absorption and Increase of Aerosol Light Scattering for Biomass Burning for Increasing Relative Humidity. *Aerosol Workshop on Climate Prediction Uncertainties, Second International Conference on Global Warming and the Next Ice Age*, Santa Fe, NM, July 17-21, 2006.
- 1) Chakrabarty, R. K., H. Moosmüller, M. A. Garro, W. P. Arnott, J. G. Slowik, E. S. Cross, J.-H. Han, and P. Davidovits (2006). Comparison of *In Situ* Measurements and Rayleigh-Debye-Gans Theory for Optical Properties of Flame Generated Monodispersive Soot Particles. *99th Annual Conference of the Air & Waste Management Association*, New Orleans, LA, June 20-23, 2006.

2.7. Organization of relevant conference sessions

The DRI PI (Moosmüller) has helped organizing 5 conference sessions relevant for the dissemination of project findings.

- 5) Co-Chair, Special Symposium on Recent Advances in Biomass Burning Emission Measurement and Modeling, *Annual Meeting of the American Association for Aerosol Research (AAAR)*, Minneapolis, MN, October 26-30, 2009.
- 4) Chair, Biomass Burning Emissions Session, *Aerosol and Atmospheric Optics: Visual Air Quality and Radiation Balance Conference*, Air & Waste Management Association, Moab, UT, April 28 - May 2, 2008.
- 3) Chair, Poster/Oral Session, *Aerosol Workshop on Climate Prediction Uncertainties, Second International Conference on Global Warming and the Next Ice Age*, Santa Fe, NM, July 17-21, 2006.
- 2) Chair, Aerosols and Climate Session, *Second International Conference on Global Warming and the Next Ice Age*, Santa Fe, NM, July 17-21, 2006.
- 1) Chair, Atmospheric Science Session, *61st Northwest Regional Meeting of the American Chemical Society*, Reno, NV, June 25-28, 2006.

2.8. Enhanced reputation in the field of emissions from wildland fires

The reputation of the DRI research group in the field of emissions from wildland fires has been greatly enhanced by participation in this project as evidenced by:

- 3 graduate degrees have been awarded, two are in progress
- 17 publications (9 published, 2 in press, 1 accepted, 2 submitted, and 3 in preparation) in peer-reviewed journals
- PI is the lead editor of a special issue of “Atmospheric Chemistry and Physics” in 2010 entitled "Measurement and Modeling of Aerosol Emissions from Biomass Burning"
- Findings of this project have been highlighted in two not peer-reviewed publications
- Scientific findings of this project have been (or will be) disseminated in 44 conference presentations (37 presented, 7 to be presented)
- PI has helped organizing 5 conference sessions relevant for the dissemination of project findings