Proceedings

NADP Fall Meeting and Scientific Symposium

Expanding the Boundaries of NADP

November 4 - 8, 2019
Boulder, Colorado

National Atmospheric Deposition Program

NADP Proceedings 2019-2020
Fall Meeting and Scientific Symposium

NADP 2019

November 4 – 8, 2019
Boulder, Colorado

Scientific Symposium Chair
David Schmeltz
U.S. Environmental Protection Agency

PROCEEDINGS*

*Full Proceedings with Abstracts can be found on the NADP website at http://nadp.slh.wisc.edu/nadp2019/

Conference Schedule

Monday, November 4, 2019 (Embassy Suites Hotel)

Registration	7:30 AM – 5:40 PM
TDEP Workshop	8:00 AM – 5:35 PM
MELD	1:00 PM – 3:00 PM

Breaks will be at 9:45 AM, 11:15 AM and 3:25 PM – Lunch on Your own

Tuesday, November 5, 2019 (Embassy Suites Hotel)

Registration	7:30 AM – 6:00 PM
Joint Subcommittee Meeting	8:30 AM – 10:00 AM
Coffee and Snacks available to take to your Subcommittee Meetings	10:00 AM
NOS/CLAD/AMSC Subcommittee Meetings	10:00 AM – 12:00 PM
Lunch (on your own)	12:00 PM – 1:30 PM
Joint Subcommittee Meeting	1:30 PM – 2:30 PM
EOS	2:30 PM – 3:30 PM
Break	3:30 PM – 3:50 PM
Executive Committee Meeting	3:50 PM - 6:30 PM

Wednesday, November 6, 2019 (Williams Village Conference Center, University of Colorado-Boulder)

Registration	7:30 AM – 5:15 PM
Welcome, Introductions and Overview	8:00 AM – 8:30 AM
Annual State of the NADP Report	8:30 AM – 9:00 AM
Keynote Plenary Panel	9:00 AM – 10:00 AM
Break	10:00 AM – 10:20 AM
Session #1 (6 speakers) **Atmospheric Deposition Patterns and Trends**	10:20 AM – 12:20 PM
Lunch provided – Williams Village Dining Center	12:20 PM – 1:35 PM
Session #2 (5 speakers) **Mercury Emissions and Atmospheric Deposition**	1:35 PM – 3:15 PM
Break	3:15 PM – 3:35 PM
Session #3 (5 speakers) **Ecological Effects and Critical Loads I**	3:35 PM – 5:15 PM

Wednesday, November 6, 2019 (Embassy Suites Hotel, Settlers Park Room)

Poster Reception	6:30 PM – 8:30 PM

Thursday, November 7, 2019 (Williams Village Conference Center, University of Colorado-Boulder)

Registration	7:30 AM – 5:00 PM
Opening Remarks, Announcements and Overview	8:00 AM – 8:10 AM
Session #4 (5 speakers) **Ecological Effects and Critical Loads II**	8:10 AM – 9:50 AM
Break	9:50 AM – 10:10 AM
Session #5 – (4 speakers) **Improving Understanding of the Reactive Nitrogen Budget**	10:10 AM – 11:30 AM
Session #6 – Part 1 (2 speakers) **Modeling to Understand Emissions and Source Apportionment of Reactive Nitrogen**	11:30 AM – 12:10 PM
Lunch provided – Williams Village Dining Center	12:10 PM – 1:30 PM
Session #6 – Part 2 (2 speakers) **Modeling to Understand Emissions and Source Apportionment of Reactive Nitrogen**	1:30 PM – 2:10 PM
Session #7 – Part 1 (3 speakers) **Measurement of Atmospheric Mercury and Emerging Pollutants**	2:10 PM – 3:10 PM
Break	3:10 PM – 3:30 PM
Session #7 – Part 2 (4 speakers) **Measurement of Atmospheric Mercury and Emerging Pollutants**	3:30 PM – 4:50 PM
Closing Remarks and Meeting Adjourn	4:50 PM

Friday, November 8, 2019

Optional Field Trip – Boulder Creek Critical Zone Observatory	8:30 AM – 12:30 PM

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MEETING INFORMATION

LOCATIONS

November 4-5, 2019 - **Technical Meetings** will be held at the **Embassy Suites Hotel**, 2601 Canyon Blvd, Boulder

November 6-7, 2019 - Scientific Symposium will be held at the **Williams Village Conference Center** on the campus of the University of Colorado-Boulder, 500 – 30th Street, Boulder.

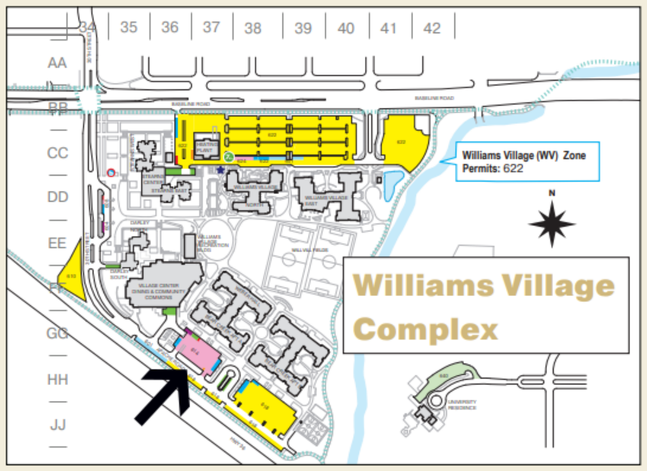
November 6, 2019 – Poster Session will be from 6:30 – 8:30 PM at the **Embassy Suites Hotel** in the Settlers Park Room.

SHUTTLE and PARKING

Shuttle – On November 6th and 7th, there will be shuttle buses running between the hotel and Williams Village in the morning before the Symposium (7:15 – 8:00 AM) and in the afternoon after the Symposium (5:00/5:15 – 5:45 PM).

Parking - **Parking at Embassy Suites** is $10.00 per day in their parking garage. The hotel address for cabs or Lyft/Uber is 2601 Canyon Blvd, Boulder 80302.

Parking at Williams Village, participants should park at the 614 pay to park lot, shown with arrow on the map at right.



Acknowledgements

The NADP Program Office would like to thank the following people for their support of and contributions to the 2019 Fall Meeting and Scientific Symposium:

- David Schmeltz, Symposium Chair
- NADP Executive Committee
- TDEP Committee
- Dr. Michael Hannigan, University of Colorado-Boulder Department of Mechanical Engineering

In addition, we thank everyone who submitted abstracts for sharing their research. The use of NADP data by researchers and policymakers is what has made NADP successful for the past 40+ years and will continue to do so for many years to come.

Agenda

NADP Fall Meeting and Scientific Symposium
Embassy Suites Hotel and Williams Village Conference Center – University of Colorado-Boulder
November 4 – 8, 2019

Monday, November 4, 2019

		Room Location
7:30 AM – 5:40 PM	Registration	Embassy Suites, Foyer
8:00 AM – 12:45 PM	TDEP Workshop	Embassy Suites, East End/West End Room
12:45 PM – 1:45 PM	Lunch on Your Own	
1:00 PM – 3:00 PM	MELD	Embassy Suites, Settlers Park Room
2:00 PM – 5:35 PM	TDEP Workshop	Embassy Suites, East End/West End Room
Breaks will be at 9:45 AM, 11:15 AM and 3:25 PM		Embassy Suites, Foyer

Tuesday, November 5, 2019

7:30 AM – 6:00 PM	Registration	Embassy Suites, Foyer
8:30 AM – 10:00 AM	Joint Subcommittee Meeting	Embassy Suites, East End/West End Room
10:00 AM	Coffee and snacks	Embassy Suites, Foyer
10:00 AM – 12:00 PM	Subcommittee Meetings	Embassy Suites
	Network Operations (NOS)	East End/West End Room
	Critical Loads (CLAD)	The Mall Room
	Aeroallergen Monitoring Science (AMSC)	Settlers Park Room
12:00 PM – 1:30 PM	Lunch on your own	
1:30 PM – 2:30 PM	Joint Subcommittee Meeting	Embassy Suites, East End/West End Room
2:30 PM – 3:30 PM	Education and Outreach (EOS)	Embassy Suites, East End/West End Room
3:30 PM – 3:50 PM	Break	Embassy Suites, Foyer
3:50 PM – 6:30 PM	Executive Committee Meeting	The Mall Room

Wednesday, November 6, 2019
Williams Village Conference Center, University of Colorado-Boulder

7:30 AM – 5:15 PM	Registration
8:00 AM – 8:30 AM	**Welcome, Introductions, Overview of Meeting Agenda** David Schmeltz – NADP Vice Chair, Symposium Chair U.S. Environmental Protection Agency Doug Burns – NADP Chair U.S. Geological Survey
8:30 AM – 9:00 AM	**Welcome and Annual State of the NADP Report** Jamie Schauer – WSLH Director and NADP Principal Investigator Michael Olson – NADP Program Coordinator
9:00 AM – 10:00 AM	**Keynote Plenary Panel:** **Expanding the Boundaries of Long-term Atmospheric Monitoring** Dr. Jeff Collett, Colorado State University Dr. Elizabeth Nichols, U.S. Department of State Dr. Elsie Sunderland, Harvard University Moderator: Dr. James Schauer, Wisconsin State Laboratory of Hygiene
10:00 AM – 10:20 AM	Break
Technical Session 1:	**Atmospheric Deposition Patterns and Trends** Session Chair: Doug Burns, U.S. Geological Survey
10:20 AM – 10:40 AM	**National Trends in acid deposition 1985-2017** Michael McHale, U.S. Geological Survey
10:40 AM – 11:00 AM	**The patterns of emissions and depositions of selected air pollutants in China during 2005-2018** Xi Mengxiao, Nanjing University
11:00 AM – 11:20 AM	**Comparison of Wet Atmospheric Deposition Measured in Mexico City, Mexico and Denver, Colorado, USA** Rodolfo Sosa Echeverría, Universidad Nacional Autonoma de México
11:20 AM – 11:40 AM	**Trends in Wet Deposition of Organic Nitrogen in the Rocky Mountains** Katherine Benedict, Colorado State University
11:40 AM – 12:00 PM	**Dry Deposition Delivers Nutrients and Heavy Metals to the Colorado Front Range** Ruth Heindel, INSTAAR, University of Colorado at Boulder

Wednesday, November 6, 2019
Williams Village Conference Center, University of Colorado-Boulder

12:00 PM – 12:20 PM	**Mapping atmospheric deposition of polycyclic aromatic compounds and trace elements in the Canadian oil sands region** Irene Cheng, Environment and Climate Change Canada
12:20 PM – 1:35 PM	Lunch Provided – Williams Village Dining Center
Technical Session 2:	**Mercury Emissions and Atmospheric Deposition** Session Chair: Colleen Flanagan Pritz, National Park Service
1:35 PM – 1:55 PM	**Trends in Mercury Emissions and Control Technologies at Power Plants in the US** Justine Huetteman, U.S. Environmental Protection Agency
1:55 PM – 2:15 PM	**Patterns of atmospheric and soil mercury in the conterminous U.S.** Charles Driscoll, Syracuse University
2:15 PM – 2:35 PM	**Implications of Updated Atmospheric Redox Chemistry and Terrestrial-Atmospheric Exchange for the Global Mercury Budget** Elsie Sunderland, Harvard University
2:35 PM – 2:55 PM	**Development of a Mercury Dry and Wet Deposition Product for NADP using AMNet and MDN Data** Muge Kafadar Yasar, University of Wisconsin-Madison
2:55 PM – 3:15 PM	**Wet Mercury Deposition Monitoring Network of Taiwan and the Asia Pacific Mercury Monitoring Network (APMMN)** Guey-Rong Sheu, National Central University
3:15 PM – 3:35 PM	Break
Technical Session 3:	**Ecological Effects and Critical Loads I** Session Chair: Mike Bell, National Park Service
3:35 PM – 3:55 PM	**Preparing critical loads information for diverse management applications** Linda Geiser, U.S. Forest Service
3:55 PM – 4:15 PM	**Change in Critical Load Exceedances for Lichen Communities in National Parks from 2000-2017** Kelly McCoy, National Park Service
4:15 PM – 4:35 PM	**Projected response of 94 tree species to changes in N and S deposition from 2005 to 2100 and the associated ecosystem services at risk** Chris Clark, U.S. Environmental Protection Agency

Wednesday, November 6, 2019
Williams Village Conference Center, University of Colorado-Boulder

4:35 PM – 4:55 PM	**Atmospheric nitrogen deposition measurement and its influence on estuarine productivity: Sundarban, India** Natasha Majumder, University of Calcutta
4:55 PM - 5:15 PM	**Overview of the Main Conclusions from the Integrated Science Assessment for Oxides of Nitrogen, Oxides of Sulfur and Particulate Matter-Ecological Criteria (2nd External Review Draft)** Tara Greaver, U.S. Environmental Protection Agency

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Wednesday, November 6, 2019 *Embassy Suites Hotel – Settlers Park Room*

6:30 PM – 8:30 PM	**Poster Session and Reception**

#1 - Experimentally derived nitrogen critical loads for northern Great Plains vegetation
Amy Symstad, Anine T. Smith, Wesley E. Newton and Alan K. Knapp

#2 - Development of a national indicator for ecosystem health in Canada using critical load exceedances
Amanda Cole, Andrea Darlington and Anne Marie Macdonald

#3 - A Decline in Exceedance of Critical Loads of Nitrogen for Alpine Areas in US National Parks from 2000 – 2016
Jeremy McClung, Michael D. Bell and Emmi Felker-Quinn

#4 - Critical Loads of Atmospheric Nitrogen Deposition for Aquatic Ecosystems in the Sierra Nevada, California
Leora Nanus, David W. Clow and James O Sickman

#5 - Cloud and Fog Deposition: Monitoring in High Elevation and Coastal Ecosystems. The Past, Present and Future
Selma Isil, Jeffrey L. Collett, Jr., Peter Weiss-Penzias, Christopher Rogers and Jason Lynch

#6 - Determining adequate levels of nitrogen and sulfur deposition to prevent harmful tree species level decreases
Justin Coughlin, Christopher M. Clark, Robert Sabo, Jeremy Ash, Jennifer James, Travis J. Smith and Linda Pardo

#7 - Incorporating uncertainty into critical loads-based risk assessments for forest ecosystems across the continental US
Linda Pardo , Christopher M. Clark, Kevin J. Horn and R. Quinn Thomas

#8 - Geospatial analysis of tree species at risk from nitrogen deposition in the northeastern U.S.
Molly Robin-Abbott , Linda H. Pardo, Jason A. Coombs, Jennifer H. Pontius and Anthony W. D’Amato

#9 - Quantifying Lichen Community Composition, Nitrogen Content, and Nitrogen Stable Isotope Composition to Assess Nitrogen Critical Loads at North Cascades National Park Service Complex
Meaghan Petix, R. Dave Evans and Michael D. Bell

#10 - Climate-driven weathering leads to enhanced cation and sulfate export in high alpine environments
John Crawford, Eve-Lyn Hinckley, Jason Neff, Janice Brahney and Iggy Litaor

#11 - Effects of simulated nitrogen deposition on soil biogeochemistry in three Chihuahuan desert semi-arid grasslands
Jennifer Holguin and Dr. Jennie R. McLaren

#12 - Evaluating the impact of species diversity on resilience of forest growth and survival to acidic deposition
Robert Daniel Sabo, Christopher M. Clark, Kevin J. Horn, Justin Coughlin, Jeremy Ash, Linda Pardo, Travis J. Smith and Quinn Thomas

#13 - The impacts of acid rain on the water quality
Chunling Tang and Jason Lynch

#14 - The Effect of Seasonal and Spatial Variability in Atmospheric Nitrogen Deposition on Biological N Cycling in Soils Along an Elevational Gradient in the Colorado Front Range
Deborah Repert, Sheila F. Murphy, Ruth C. Heindel, Toby A Halamka, Richard L. Smith, David Clow, Gregory Wetherbee, Ariel P. Reed and Mahalie Hill

#15 - Nitrogen deposition sources and patterns in the Greater Yellowstone Ecosystem determined from ion exchange resin collectors, lichens, and isotopes
Abigail Hoffman, Jill McMurray, Shannon Albeke, Dave Evans and David Williams

#16 - Establishment of a reactive nitrogen monitoring network in Mexico City
Rodolfo Sosa Echeverría, John Walker, David Gay, Ana Luisa Alarcon Jimenez, Maria del Carmen Torres Barrera, Monica Jaimes Palomera, Pablo Sanchez Alvarez and Elizabeth Vega Rangel

#17 - Seasonal and Elevational Trends of Wet and Dry Atmospheric Nitrogen Deposition Along the Front Range of Colorado, USA
Toby Ann Halamka, Mahalie Hill, Deborah A Repert, Sheila F. Murphy, Ruth C. Heindel, David Clow and Gregory Wetherbee

#18 - What controls gas phase acid exchange over forests? Investigating fluxes of HNCO and other organic acids over a pine forest
Ryan Fulgham and Dr. Delphine K. Farmer

#19 - Sensitive and Selective Organic Nitrogen Measurements: Applications of Ethanol Chemical Ionization Mass Spectrometry
Jennifer Berry and Eleanor Browne

#20 - An investigation into the importance of amine compounds to organic nitrogen in aerosol
Evelyn Bangs , Katherine B. Benedict, Amy P. Sullivan and Jeffrey L. Collett Jr.

#21 - Development and Assessment of a Method for Determination of Total Nitrogen in National Atmospheric Deposition Program (NADP) Precipitation Samples
Marie Assem, Chris Worley and Martin Shafer

#22 - Agricultural Ammonia Monitoring
Sung-Chang Hong, Sae-Nun Song, Kyeong-Sik Kim, Sun-Young Yu and Gyu-Hyeon Lee

#23 - Ammonia and amine contributions to the atmosphere from animal production
Philip Silva

#24 - An Integrated N Cycling Approach with Agriculture, Atmosphere, and Hydrology Models
Limei Ran, Yongping Yuan, Jonathan Pleim, Rohit Mathur, Ruoyu Wang, Dongmei Yang, Wenlong Liu, Verel Benson, Ellen Cooter and Jimmy Williams

#26 - Estimating Sources, Sinks, and Fluxes of Reactive Nitrogen and Sulfur within a Mixed Forest Canopy Using Eulerian and Lagrangian Inverse Models
Zhiyong Wu, John T. Walker, Xi Chen, A. Christopher Oishi, Tomer Duman and Donna Schwede

#28 - Simulation of Atmospheric Mercury using the Model for Prediction Across Scales
Orren Russell Bullock, Jr and David Schmeltz

#29 - Use of ecosystem-level flux measurements to improve atmosphere-surface exchange parameterization of elemental mercury in chemical transport models
Tanvir Khan, Daniel Obrist, Yannick Agnan, Noelle E. Selin and Judith A. Perlinger

#31 - Long-term monitoring of precipitation chemistry. Insights into environmental changes from Hubbard Brook and the MAP3S/AIRMoN network
Tom Butler, Gene E. Likens, Francoise Vermeylen, Roger Claybrooke and Robert Larson

#32 - Comparison of Wet Deposition Collectors at a High-Elevation Site, Central Rocky Mountains
Banning Starr, Timothy Fegel, Charles Rhoades and Kelly Elder

#33 - Modernization of the Quality Control Software used by the Canadian Air and Precipitation Monitoring Network (CAPMoN)
Kulbir Banwait and Bill Sukloff

#34 - Network to Network Synergies: The National Atmospheric Deposition Program and National Ecological Observatory Network
Michael SanClements, Robert Lee and Rommel Zulueta

#35 - NADP Archive Process and Program for NTN, AMoN, and AIRMoN Samples
Nichole Davis, Richard Tanabe and Amy Mager

#37 - Reactive Nitrogen and Phosphorus Comparisons Between Co-located NTN and AIRMoN Sites
Camille Danielson, Sisi Xu, Martin Shafer and Chris Worley

#38 - Evaluation of Filtering Methods for Low Volume Precipitation Samples
Camille Danielson and Katie Blaydes

#39** - **It is Raining Tires

Gregory Wetherbee, Heather Lowers and RoseAnn Martin

#40 - Canada-wide Critical Loads of Acidity (Sulphur and Nitrogen) for Terrestrial Ecosystems

Julian Aherne and Hazel Cathcart

#41 - Setting Biodiversity-Based Critical Loads of Nutrient Nitrogen in the Athabasca Oil Sands Region using Gradient Forest Analysis

Julian Aherne and Nicole Vandinther

#42 - Spatial patterns of mercury contamination of recreationally-caught fish in the south central United States: Interrelationships between mercury deposition, fish trophic position and fish size

Matthew M. Chumchal, Ray W. Drenner and Kimberly J. Adams

Thursday, November 7, 2019

Williams Village Conference Center, University of Colorado-Boulder

7:30 AM – 5:00 PM	Registration
8:00 AM – 8:10 AM	**Opening Remarks, Announcements and Overview of Day 2** David Schmeltz – NADP Vice Chair, Symposium Chair U.S. Environmental Protection Agency
Technical Session 4:	**Ecological Effects and Critical Loads II** Session Chair: Jeff Herrick and Jason Lynch, U.S. Environmental Protection Agency
8:10 AM – 8:30 AM	**Chronic and Episodic Acidification of Streams along the Appalachian Trail Corridor, eastern United States** Doug Burns, U.S. Geological Survey
8:30 AM – 8:50 AM	**Linking recovery from acidification and changing climate to shifting zooplankton communities in northeastern lakes** Stephanie Dykema, University of Maine, Orno
8:50 AM – 9:10 AM	**The Key to Park Protection—Cooperative Conservation: monitoring, management, and research in Shenandoah National Park** Jalyn Cummings, Shenandoah National Park
9:10 AM – 9:30 AM	**Dragonfly Larvae as Biosentinels of Mercury Availability and Ecological Impairment in Aquatic Food Webs of National Parks throughout the United States** Collin Eagles-Smith, U.S. Geological Survey
9:30 AM – 9:50 AM	**A Transition in Human Manipulation of the Sulfur Cycle** Eve-Lyn Hinckley, University of Colorado-Boulder
9:50 AM – 10:10 AM	Break
Technical Session 5:	**Improving Understanding of the Reactive Nitrogen Budget** Session Chair: Kristi Morris, National Park Service
10:10 AM – 10:30 AM	**Nitrogen deposition budget for a southern Appalachian deciduous forest** John Walker, U.S. Environmental Protection Agency
10:30 AM – 10:50 AM	**Ammonia monitoring within the Canadian Air and Precipitation Network and an evaluation of the relative contribution to nitrogen dry deposition** Jason O'Brien, Environment and Climate Change Canada
10:50 AM – 11:10 AM	**Speciated Inorganic Reactive Nitrogen Measurements in the Clean Air Status and Trends Network** Melissa Puchalski, U.S. Environmental Protection Agency

Thursday, November 7, 2019
Williams Village Conference Center, University of Colorado-Boulder

11:10 AM – 11:30 AM	**A 40 Site Network for Passive Ammonia Measurements along northern Utah's Wasatch Front: Winter and Summer 2019** Randy Martin, Utah State University
Technical Session 6:	**Modeling to Understand Emissions and Source Apportionment of Reactive Nitrogen** Session Chair: Greg Beachley, U.S. Environmental Protection Agency
11:30 AM – 11:50 AM	**Characterization of the Global Sources of Atmospheric Ammonia from Agricultural Soils and its Deposition** Viney Aneja, North Carolina State University
11:50 AM – 12:10 PM	**Inverse modeling constraints on sources of NH3 using CrIS remote sensing measurements** Hansen Cao, University of Colorado-Boulder
12:10 PM – 1:30 PM	Lunch Provided – Williams Village Dining Center
1:30 PM – 1:50 PM	**Source apportionment of sulfur and nitrogen deposition to Rocky Mountain National Park using CMAQ** Donna Schwede, U.S. Environmental Protection Agency
1:50 PM – 2:10 PM	**Observation-based, spatial-resolved surface concentrations and their implications for emission and deposition estimation** Kang Sun, University at Buffalo
Technical Session 7:	**Measurement of Atmospheric Mercury and Emerging Pollutants** Session Chair: Mark Olson, NADP
2:10 PM – 2:30 PM	**Passive air sampling for mercury on a global scale to fill the gaps – a Canadian led pilot study** Alexandra Steffen, Environment and Climate Change Canada
2:30 PM – 2:50 PM	**Network Implementation of a Mercury Passive Air Sampler (MerPAS) Method: Overcoming Technical and Quality Assurance Challenges** Eric Prestbo, Tekran Research
2:50 PM – 3:10 PM	**Evaluation of the Efficacy of the National Atmospheric Deposition Program (NADP) National Trends Network (NTN) for Assessment of PFAS Deposition in Precipitation** Martin Shafer, University of Wisconsin, State Laboratory of Hygiene
3:10 PM – 3:30 PM	Break

Thursday, November 7, 2019
Williams Village Conference Center, University of Colorado-Boulder

3:30 PM – 3:50 PM	**A new system that provides accurate, precise, hourly measurements of oxidized mercury can improve dry deposition estimates** Seth Lyman, Utah State University
3:50 PM – 4:10 PM	**Applying New Technologies to Arctic Mercury Monitoring** Sarrah Dunham-Cheatham, University of Nevada, Reno
4:10 PM – 4:30 PM	**Wildfire Tracer Molecules Used for Source Appropriation of Atmospheric Deposition Constituents from Combustion Emissions** Jeramy Jasmann, U.S. Geological Survey
4:30 PM – 4:50 PM	**Potential for Determining Black Carbon Wet Deposition Fluxes from the NADP Network** Ross Edwards, Wisconsin State Laboratory of Hygiene
4:50 PM – 5:00 PM	**Closing Remarks** David Schmeltz – NADP Vice Chair, Symposium Chair U.S. Environmental Protection Agency

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Friday, November 8, 2019

8:30 AM – 12:30 PM	**Optional Field Trip** - **Critical Zone Connections: From Sky to Soil to Streams in the Boulder Creek Watershed** *(Bus departs from hotel at 8:30 AM and returns to hotel at 12:30 PM)* We will visit the lower montane site of the Boulder Creek Critical Zone Observatory (BcCZO) with experts from the U.S. Geological Survey and the University of Colorado-Boulder. Part of the National Science Foundation-funded CZO Network, BcCZO investigates architecture and function of Earth’s near-surface environment, and assesses interactions among air, water, biology, and soil. The site (elevation 2000 m) is located within Betasso Preserve, an open space park managed by Boulder County, and offers a unique perspective on the urban-montane transition and the steep elevation gradient that characterizes the Colorado Front Range. The field trip will tour the BcCZO monitoring infrastructure at Betasso, discussing past and current efforts to characterize connections among atmospheric deposition, wildfire, soil development, water quality and flood generation, groundwater, and critical zone architecture. We will visit the Betasso meteorological station and National Atmospheric Deposition Program (NADP) site, and will learn about BcCZO research quantifying atmospheric dust and reactive nitrogen deposition along the Colorado Front Range elevation gradient.

2019 NADP Site Operator Awards

35 Year Award

Site Code	Operator Name	Site Name	Funding Agency	Networks	Start
MS10	Eddie Morris	Clinton	U.S. Geological Survey	NTN	1984

30 Year Awards

Site Code	Operator Name	Site Name	Funding Agency	Networks	Start
TX02	Glenda Copley	Muleshoe National Wildlife Refuge	U.S. Geological Survey	NTN	1989

25 Year Awards

Site Code	Operator Name	Site Name	Funding Agency	Networks	Start
AR03	Harrell Beckwith	Caddo Valley	U.S. Geological Survey	NTN, AMoN	1994
ME98	Bill Gawley	Acadia National Park-McFarland Hill	National Park Service-Air Resources Division	NTN, MDN	1993

20 Year Awards

Site Code	Operator Name	Site Name	Funding Agency	Networks	Start
FL23	Jimmy Bishop	Sumatra	U.S. Environmental Protection Agency - Clean Air Markets	NTN, AMoN	1999
GA99	Charles Welsh	Chula	U.S. Geological Survey	NTN	1998
NC06	Nathan Hall	Beaufort	U.S. Environmental Protection Agency - Clean Air Markets	NTN, AMoN	1999
OH54	Sally Hammond	Deer Creek State Park	U.S. Environmental Protection Agency - Clean Air Markets	NTN, AMoN	1999
OR97	Lynn Conley	Hyslop Farm	U.S. Environmental Protection Agency - Clean Air Markets	NTN	1999
PA00	Sharon Scamack	Arendtsville	U.S. Environmental Protection Agency - Clean Air Markets	NTN	1999
PR20	John Bithorn	El Verde	U.S. Forest Service U.S. Geological Survey	NTN, MDN, AMoN	1998
VA24	Gene Brooks	Prince Edward	U.S. Environmental Protection Agency - Clean Air Markets	NTN, AMoN	1999

15 Year Awards

Site Code	Operator Name	Site Name	Funding Agency	Networks	Start
AL99	Mack Smith	Sand Mountain Research & Extension Center	U.S. Environmental Protection Agency - Clean Air Markets	NTN, AMoN	2004
AR02	Stacy Wilson	Warren 2WSW	U.S. Geological Survey	NTN	2004
MD15	F. Hoss Parks	Smith Island	National Oceanic and Atmospheric Administration - Air Resources Laboratory	NTN	2004
ME04	Bill Thompson	Carrabassett Valley	U.S. Environmental Protection Agency - Clean Air Markets	NTN, MDN	2004
VA28	Liz Garcia	Shenandoah National Park-Big Meadows	National Park Service-Air Resources Division	MDN, NTN	2004

10 Year Awards

Site Code	Operator Name	Site Name	Funding Agency	Networks	Start
BC16	Geri Crooks	Saturna Island	Environment and Climate Change Canada	MDN	2009
CA67	Stacy Manson	Joshua Tree National Park-Black Rock	National Park Service-Air Resources Division	NTN, AMoN	2009
IA08	Gary Sigworth	Big Springs Fish Hatchery	U.S. Geological Survey	NTN	2009
ME09	Fred Currie	Greenville Station	Maine Department of Environmental Protection	MDN, NTN	2009
NY16	Vicky Kelly	Cary Institute	Cary Institute	AMoN	2009
PA72	Rebecca Philpot	Milford	U.S. Forest Service	NTN	2009
WI35	Fred Emstrom	Perkinstown	U.S. Environmental Protection Agency - Clean Air Markets	NTN, AMoN	2009

5 Year Awards

Site Code	Operator Name	Site Name	Funding Agency	Networks	Start
BC24	Adam Simons	Port Edward	Prince Rupert Port Authority	NTN	2014
CO19	Michelle Gibbons	Rocky Mountain National Park-Beaver Meadows	National Park Service-Air Resources Division	NTN	2014
KY19	Doug Zettwoch	Cannons Lane	U.S. Geological Survey	NTN	2014
MA14	Emily MacKinnon	Nantucket	Nantucket Land Council, Inc.	NTN	2014

5 Year Awards

Site Code	Operator Name	Site Name	Funding Agency	Networks	Start
NC41	Amanda Roth	Finley Farm	North Carolina State University	NTN	2014
NC45	Robin Dryer	Mt. Mitchell	U.S. Geological Survey	NTN	2014
NF19	Roseann Russell	Stephenville	Environment and Climate Change Canada	MDN	2014
NF19	Germaine Lavallee	Stephenville	Environment and Climate Change Canada	MDN	2014
NJ39	Bryan Hankins	Cattus Island County Park	U.S. Environmental Protection Agency - Clean Air Markets	NTN	2014
NJ99	Andrew Rdesinski	Washington Crossing	U.S. Environmental Protection Agency - Clean Air Markets	NTN	2014
OH17	Timothy Fox	Delaware	U.S. Forest Service	NTN	2014
OH52	Justin Chaffin	South Bass Island	Ohio Environmental Protection Agency	MDN, AMNet	2014
OK29	Skeate Beck	Goodwell Research Station	U.S. Geological Survey	NTN	2014
PA56	Mark A. Schroth	M. K. Goddard	U.S. Environmental Protection Agency - Clean Air Markets	AMoN	2014
SD99	Jessie Rigge	Huron Well Field	U.S. Geological Survey	NTN	2014
SK20	Gerry Scheck	Cactus Lake	Saskatchewan Ministry of Environment	NTN	2014
TN11	Ethan McClure	Great Smoky Mountains National Park-Elkmont	National Park Service-Air Resources Division	NTN, MDN	2014
WI37	Phil Holman	Spooner	U.S. Forest Service	NTN	2014

ABSTRACTS

Technical Session 1: Atmospheric Deposition, Patterns and Trends

Session Chair: Doug Burns, U.S. Geological Survey

National Trends in acid deposition 1985-2017

Michael McHale[1], Amy Ludtke[2], Gregory Wetherbee[3], Douglas Burns[4] and Mark Nilles[5]

Since at least the 1970s, acid rain has been recognized as an important pollutant that harms ecosystems and human health across a wide region of the United States and around the world. Congress enacted Title IV of the Clean Air Act Amendments in 1990 to reduce sulfur and nitrogen emissions from fossil fuel burning power plants. The Environmental Protection Agency has documented a 92% decrease in sulfur dioxide emissions from 15.73 million tons in 1990 to 1.26 million tons in 2018. Nitrogen oxide emissions decreased 84% from 6.40 million tons in 1990 to 1.02 million tons in 2018.

This study used National Atmospheric Deposition Program data from 167 stations across the United States to examine trends in acid deposition from 1985 to 2017, which show how these emission reductions are reflected in atmospheric wet-deposition chemistry in 9 regions across the conterminous US. Seasonal and regional Kendall trend analyses indicate that there were significant decreasing trends in mean sulfate deposition concentrations in all 9 regions during the study period. The largest trends in monthly mean sulfate concentrations were measured in the Mid-Atlantic (-1.29 µeq l^{-1} yr^{-1}), Midwest (-1.15 µeq l^{-1} yr^{-1}), and Northeast regions (-1.10 µeq l^{-1} yr^{-1}). The trends in monthly mean nitrate concentrations were not as strong as those for sulfate, but all of the regions had significant decreasing trends in nitrate and again the Mid-Atlantic (-0.53 µeq l^{-1} yr^{-1}), Midwest (-0.44 µeq l^{-1} yr^{-1}), and Northeast regions (-0.50 µeq l^{-1} yr^{-1}) had the strongest trends. In those regions the stations with the highest concentrations of sulfate and nitrate had the strongest decreasing trends and the relations were stronger during phase II of the regulations (2000 to 2009) than during the initial phase of the legislation (1995 to1999). As the concentrations of sulfate and nitrate decreased, the variability in concentrations across the 3 regions with the highest concentrations also decreased and there was also less annual variability at individual stations. In recent years there appears to be a flattening of the trends in sulfate and nitrate in the most impacted regions that may indicate the current status of emissions controls have reached the limit of their effectiveness. As a result, total nitrogen deposition has begun to be dominated by ammonium which has been increasing during the study period in all regions except the Mid-Atlantic and Northeast.

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The patterns of emissions and depositions of selected air pollutants in China during 2005-2018

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The paper presents the pattern of long-term SO_4^{2-}, NH_4^+ and NO_3^- bulk deposition along with the SO_2, NH_3 and NO_X emission in China from 2005 to 2018. The Generalized Additive models (GAMs) were constructed to predict the decadal bulk deposition of sulfate, ammonia and nitrogen, through the integration of satellite columns, $PM_{2.5}$ concentration, land-use information and meteorology variables. The R^2 values for established SO_4^{2-}, NH_4^+, NO_3^- deposition models were 0.71, 0.62 and 0.53, respectively. The RMSE values ranging from 0.611 to 0.881, indicating the good predictive ability of three models. During 2005-2018, sulfur wet deposition decreased significantly in China due to the sharp reduction of SO_2emissions. In four regions such as Jingjingji region (JJJ), Yangtze River Delta (YRD), Sichuan Basin (SCB) and Pearl River Delta (PRD), SO_2 emissions decreased from 183.8, 107.6, 111.2, 55.2 kgS ha^{-1} yr^{-1} to 48.7, 21.8, 31.9, 23.0 kgS ha^{-1} yr^{-1} respectively, while SO_4^{2-} bulk deposition decreased from 16.54, 25.46, 24.35, 19.14 kgS ha^{-1} yr^{-1} to 10.16, 20.88, 15.20, 15.16 kgS ha^{-1} yr^{-1} respectively. Although emissions of NO_X have been effectively controlled in recent years, due to the slight increase in rainfall, there was no significant downward trend in bulk deposition of nitrate. The average bulk deposition of nitrate in the four regions were 8.21±0.50, 13.15±1.12, 10.02±0.28, 12.47±0.96 kgN ha^{-1} yr^{-1}, respectively. It indicated that the intensity of NO_X emission reduction was not enough to offset the influence of rainfall change on the wet deposition of NO_3^-. There was a little variation in NH_3 emissions from 2008 to 2017, and NH_4^+deposition showed no trend, average values for the four regions were 12.07±0.77, 14.85±1.88, 10.02±0.88, 7.51±0.86 kgN ha^{-1} yr^{-1} respectively. In order to find the leading factors impacting deposition, the factors that influence bulk deposition were quantified. The most important factor affecting SO_4^{2-}, NH_4^+ and NO_3^- wet deposition is rainfall, accounting for 20.1%, 20.4%, and 24.2% respectively, and then the precursor concentration, accounting for 19.47%, 18.32%, and 8.28% respectively.

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Comparison of Wet Atmospheric Deposition Measured in Mexico City, Mexico and Denver, Colorado, USA

Rodolfo Sosa Echeverría[1], Gregory Wetherbee[2], Ana Luisa Alarcon Jimenez[3], Maria del Carmen Torres Barrera[4], Monica Jaimes Palomera[5] and Pablo Sanchez Alvarez[6]

Air quality and associated atmospheric deposition in the high-elevation urban centers of Mexico City and Denver were compared. The Mexico City Metropolitan Zone (MCMZ) is located in a closed basin of the Sierra Madre Mountains at 2,240 meters (m) elevation with more than 20 million inhabitants, 15 electrical generating units (EGUs, 1,416 MW), and 5 million vehicles. The Denver-Boulder, Metropolitan Area (DBMA) is also located in a basin, on the eastern slope of the Front Range of the Rocky Mountains at 1,700 m elevation with approximately 3.2 million residents, 11 EGUs (4,600 MW), and 2 million vehicles.

In the MCMZ, particulates and sulfur dioxide (SO_2) were identified as the main atmospheric pollutants three decades ago. Replacement of fuel oil with natural gas inside the MCMZ resulted in reduction of both particulates and SO_2 in ambient air. Although SO_2 no longer exceeds its ambient air quality standard, acid rain remains significant in the MCMZ with median pH<5.6 and sulfate (SO_4^{2-}) and nitrate (NO_3^-) concentrations of approximately 60 (µEq/L) and 40 µEq/L, respectively in wet deposition. The SO_4^{2-} : NO_3^- wet-deposition concentration ratio was homogeneous (1.5) at MCMZ sampling sites. A fuel oil power plant (1600 MW) is located in the northern outskirts of the MCMZ, and samples were consistently more acidic in the southern versus the northern stations with prevailing northerly winds that transport acid-rain precursor emissions from north to south. Annually, MCMZ precipitation had a median ammonium (NH_4^+) concentration of 100 µEq/L. Inorganic reactive nitrogen (Nr) was contributed predominantly by NH_4^+ (71%) compared to NO_3^- (29%).

Continuous urban wet-deposition monitoring, which began in Denver in 2017, indicated that Nr deposition loads (4.0 kilograms N per hectare (kg/ha)) exceeded SO_4^{-2} loads (1.6 – 2.6 kg/ha) across the DBMA. Nr was contributed predominantly by NH_4^+ (74%) compared to NO_3^- (26%). Annually, DBMA precipitation had median pH>6.3, and concentrations of SO_4^{2-} (2 – 5 µEq/L), NO_3^- (24 – 28 µEq/L), and NH_4^+ (60 – 78 µEq/L). The SO_4^{2-} : NO_3^- ratio was homogeneous across the DBMA at 0.1 – 0.2. Easterly winds transport urban and agricultural Nr pollution upslope into the mountainous terrain located west of the DBMA.

Sulfate concentrations in MCMZ wet atmospheric deposition are 10 times higher than in the DBMA. The NH_4^+: NO_3^- concentration ratio in MCMZ and DBMA is similar: 2.5 and 2.8, respectively.

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Trends in Wet Deposition of Organic Nitrogen in the Rocky Mountains

Katherine Benedict[1], Bret A. Schichtel[2] and Jeffrey L. Collett Jr[3]

The ionic composition of wet deposition is regularly characterized at sites across the world. However, the importance of other species, in particular, organic nitrogen is often overlooked. Organic nitrogen compounds are of interest particularly in areas where excess nitrogen deposition is occurring. While an increasing number of studies are including measurements of organic nitrogen, techniques for measurement of total organic nitrogen vary and are not always interchangeable. For this reason characterization of the spatial and temporal variability of organic nitrogen is limited. In this work we look at seasonal and annual variations of organic nitrogen at Rocky Mountain National Park from measurements made between March to October from 2008 to 2019. This record of data using the sample measurement and collection techniques provides a unique look at wet organic nitrogen deposition.

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Dry Deposition Delivers Nutrients and Heavy Metals to the Colorado Front Range

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Dry deposition is a significant input of nutrients and pollutants to ecosystems, especially in arid and semi-arid regions like the Colorado Front Range. As dust activity increases across the southwestern United States due to land use change and increasing aridity, the contribution of dry deposition to total atmospheric deposition will likely increase as well. Although the importance of dry deposition has been well established for the Rocky Mountains, the spatial and temporal variability in dry deposition fluxes is poorly understood, especially at lower elevations more proximal to anthropogenic dust sources. We collected monthly bulk deposition samples from nine sites across an elevation gradient in the Colorado Front Range from November 2017 to November 2018. We analyzed the particulate and liquid fractions for a suite of 27 elements and major ions, respectively. To relate the chemistry results to dust source locations, we calculated air parcel back trajectories for each of our collection intervals using the Stochastic Time-Inverted Lagrangian Transport (STILT) model and High Resolution Rapid Refresh reanalysis data (HRRR). Every 3 hours during the duration of the collection period, 200 air parcels were initiated from 2 m above the ground surface and tracked back for 24 hours. We assessed locations where air parcels passed within a half meter of the ground surface, assuming that those could be dust source locations.

Our results reveal that lower elevations received more particulate deposition than higher elevations, with all elevations experiencing a springtime peak. Across the elevation transect, particulate deposition was enriched in P, S, Cu, Zn, Pb, Li, Mo, and Cd relative to the composition of the upper continental crust. All of the major ions measured in the liquid fraction were higher than National Atmospheric Deposition Program (NADP) averages for the same sites, pointing toward the importance of soluble dry deposition. For K, Mg, and P, the particulate fractions accounted for more than half of the total elemental fluxes, suggesting that dry deposition is important for these elements, but that it falls in a relatively insoluble form. Seasonal and elevational differences in the composition of the particulate fraction corresponded to different back-trajectory footprints, with potential spring and summer dust source locations more localized than during fall and winter. Our results point toward the importance of dry deposition in contributing to total atmospheric deposition and highlight the need for monitoring over multiple spatial and temporal scales.

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Mapping atmospheric deposition of polycyclic aromatic compounds and trace elements in the Canadian oil sands region

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Elements are ubiquitous in the environment. Some elements are essential nutrients, while others are toxic to humans and biota. Hence, it is important to study the sources, atmospheric transport and deposition of particulate elements. We provide an overview of research on characterizing atmospheric particulate elements and approaches to mapping their deposition fluxes in the Athabasca Oil Sands Region (AOSR) in Alberta, Canada. The first study reviewed size distributions, concentrations and dry deposition fluxes of particulate elements measured worldwide from literature. Toxic priority elements, including Sb, As, Ni, Se, Ag, Tl and Zn, are predominantly emitted from anthropogenic sources and are dominant in $PM_{2.5}$. Some toxic elements including Cd, Cr, Cu and Pb are present in fine and coarse particles. Major elements comprising Al, Ca, Fe and Si are naturally abundant in the Earth's crust and are dominant in coarse particles. In terms of dry deposition velocities, crustal elements are scavenge more rapidly than anthropogenic elements. The second study is a development of an emissions database for particulate elements in the AOSR for subsequent air dispersion modeling. This is necessary to supplement the limited number of monitoring sites in the heavily industrialized AOSR. Using $PM_{2.5}$ and $PM_{2.5\text{-}10}$ emissions from the 2014 Joint Oil Sands Monitoring inventory and USEPA SPECIATE database, we determined that crustal elements make up the largest emissions of particulate elements in the AOSR and originate from mine construction and fugitive dust from unpaved roads. The third study is an ongoing analysis of monitored elemental concentrations in $PM_{2.5}$ and $PM_{2.5\text{-}10}$ at four AOSR sites. Data from the above studies will inform and serve as inputs in air dispersion and dry deposition modeling. The emissions database will be used in the CALPUFF dispersion model to produce gridded concentrations for 29 elements. Modeled concentrations will be compared with monitored concentrations to evaluate the accuracy of the emissions database and identify unmonitored areas where modeled concentrations are elevated. The inferential method will first be applied to estimate dry deposition fluxes at grid points using the knowledge of particulate element size distributions, and future work will incorporate wet deposition modeling. This will enable us to generate atmospheric deposition maps of elements across the AOSR and assess the impacts of oil sands production to surrounding ecosystems.

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Technical Session 2: Mercury Emissions and Atmospheric Deposition

Session Chair: Colleen Flanagan Pritz, National Park Service

Trends in Mercury Emissions and Control Technologies at Power Plants in the US

Justine Huetteman[1] and Taylor Macy[2]

EPA announced the Mercury and Air Toxics Standard (MATS) in December 2011, which established performance standards to reduce emissions of mercury, acid gases, and non-mercury metallic toxic pollutants from coal- and oil-fired power plants. Between 2010 and 2017, emissions of mercury from power plants dropped 86 percent. A combination of factors contributed to this decline, such as the shutdown and reduced utilization of coal-fired power plants, the conversion of coal-fired power plants to natural gas, and the installation of pollution control technology to reduce mercury. Control technologies include selective catalytic reductions (SCR) with flue-gas desulfurization (FGD), activated carbon injection (ACI), ACI with fabric filter (FF), or electrostatic precipitators (ESP). In 2010, coal-fired electric generating units (EGUs) with post-combustion control devices accounted for half of all electricity generation; in 2017, that share increased to over 90 percent. This analysis will delve into mercury emissions monitoring from power plants as well as the trends that led to the significant decrease in mercury emissions from the power sector over the last decade. Data from all MATS-affected emission sources are available at ftp://newftp.epa.gov/DMDnLoad/emissions/mats/.

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Patterns of atmospheric and soil mercury in the conterminous U.S.

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Inputs of mercury to many ecosystems are largely derived from atmospheric deposition associated with a combination of direct atmospheric emissions and secondary re-emission from historical releases. Inputs of mercury can be methylated and subsequently bioaccumulate and biomagnify along terrestrial and aquatic food chains, resulting in elevated exposure to humans and animals. Despite concerns over health effects of mercury exposure, we have a limited understanding of large-scale temporal and spatial patterns of the interrelations of mercury emissions, transport, and fate. In this presentation we summarize: (i) temporal trends and spatial patterns of mercury emissions, (ii) atmospheric concentrations of mercury species and wet mercury deposition, and (iii) spatial patterns of soil mercury in the conterminous U.S. Observations of atmospheric chemistry were obtained from the Atmospheric Mercury Network (AMNet) and wet deposition data were obtained from the Mercury Deposition Network (MDN) of the National Atmospheric Deposition Program. Soil data from the upper 5 cm and A and C horizons were obtained from a USGS survey of 4,814 sites. Consistent with recent decreases in mercury emissions, this analysis shows significant decreases in concentrations of gaseous elemental mercury and gaseous oxidized mercury at a majority of AMNet sites, which are largely located in the eastern U.S. The majority of MDN sites with significant trends in the eastern U.S. exhibited decreases in annual volume-weighted concentrations of mercury, while few significant trends were evident in the West. There were far fewer significant changes in wet mercury deposition due to variability in precipitation quantity, though many eastern sites exhibited a decreasing pattern. Soil mercury concentrations were generally similar between the surface and A horizons, but much lower in the C horizons. Concentrations of surface soil mercury were generally highest in the East, coinciding with higher concentrations of soil organic matter and an abundance of forest cover, and generally lower in the West except for elevated concentrations in lands adjacent to the Pacific coast. Forested lands generally exhibited the highest mercury concentrations in surface soils, followed by developed lands, planted/cultivated lands, herbaceous uplands, shrublands, and barren lands. Although elevated surface soil mercury in the eastern U.S. was coincident with major mercury emission sources, concentrations were only weakly correlated with estimates of wet plus dry mercury deposition.

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Implications of Updated Atmospheric Redox Chemistry and Terrestrial-Atmospheric Exchange for the Global Mercury Budget

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New insights into the atmospheric redox chemistry of mercury (Hg) and terrestrial atmospheric exchange processes have been enabled over the past several years by field and laboratory studies. Recent work has suggested that atmospheric Hg uptake by terrestrial ecosystems may be larger than previously realized and may exert a large influence on seasonality in atmospheric mercury concentrations in some regions and interhemispheric differences in concentration measurements. We explore this hypothesis using new lab measurements and theoretical rates of elemental Hg (Hg^0) oxidation in the atmosphere via bromine, chlorine, and hydroxyl radical-initiated mechanisms and theoretical calculations of the species-specific spectra of photolysis cross-sections for atmospherically-relevant Hg(II).We will present implications of these data for modeled concentrations of atmospheric Hg(II) and associated deposition patterns using the GEOS-Chem global CTM, which we compare to global atmospheric measurements. The atmospheric simulation is coupled to an updated version of the Global Terrestrial Mercury Model (GTMM) and used to investigate the significance of different atmospheric-terrestrial exchange processes. Through representation of the internal cycling and retention dynamics of terrestrial Hg, this model provides spatially-resolved insights into ecosystem factors controlling the balance between Hg deposition and re-emission across a range of timescales. We present implications for modeled spatial concentrations of atmospheric and soil mercury across the contiguous United States and compare to available measurements. Implications of improved mechanistic understanding of Hg cycling in the atmospheric and terrestrial ecosystems for the global Hg budget and timescales for cycling of anthropogenic Hg through ecosystems will be discussed.

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Development of a Mercury Dry and Wet Deposition Product for NADP using AMNet and MDN data

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Assessing emission, transport, atmospheric chemistry, and deposition processes of mercury (Hg) is vital to understanding the impact of mercury pollution on the environment and human health. Factors such as emission uncertainties, transport mechanisms, a chemical fate, including accumulation and toxicity to living organisms complicate the problem of mercury in the environment. (Clarkson 1993) Over the last decades, significant advances in the determination of speciation, deposition, and transport of atmospheric mercury have been made with the increasing number of studies on the estimation of mercury dry and wet deposition. Yet, there is still a significant gap in knowledge of mercury dry and wet deposition and identification of geographical patterns. This research builds on previous studies conducted by Risch and Kenski (2018), L. Zhang et al. (2016), L. Zhang et al. (2012), X. Zhang et al. (2012) showing that Hg dry deposition was a significant contributor to the overall Hg load at North American sites.

In order to advance the state of the science, this study aims to presents a new product for NADP that includes an estimate of total mercury wet deposition data obtained from Mercury Deposition Network (MDN) and estimated dry deposition for the Atmospheric Mercury Network (AMNet) sites. Atmospheric mercury dry deposition in different land cover around 12 sites in North America was estimated using AMNet data for the year 2017. Sites were selected based on data quality and data record completeness for MDN and AMNet network locations. The main contribution of this study is the establishment of variability assessment and geographical patterns of Hg dry and wet deposition over the dominant land cover, along with the relative importance of dry and wet deposition. The results will demonstrate the application of using ambient Hg measurements to develop an annual dry deposition estimate for AMNet network sites.

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Wet Mercury Deposition Monitoring Network of Taiwan and the Asia Pacific Mercury Monitoring Network (APMMN)

Guey-Rong Sheu[1], Neng-Huei Lin[2], Da-Wei Lin[3], David Gay[4] and David Schmeltz[5]

East, Southeast, and South Asia are the major anthropogenic mercury (Hg) emission source regions, contributing close to 50% of the global anthropogenic Hg emissions. While atmospheric and rainwater Hg monitoring activities have been steady in East Asia (China, Korea, Japan and Taiwan), such activities are limited in Southeast and South Asia due to the lack of monitoring capacity. A wet Hg deposition monitoring network, consisting of 11 sampling sites in Taiwan and a remote island site in subtropical Northwest Pacific Ocean, was established to collect weekly rainwater samples for total Hg analysis since 2009. The purpose of this network is to develop information on spatial and seasonal trends in wet Hg deposition and to evaluate the contribution of regional/long-range transport. Range of annual volume-weighted mean (VWM) Hg concentrations of this network is close to the range of values reported by NADP/MDN. However, annual wet Hg deposition fluxes in Taiwan are usually higher than in North America, mainly due to the higher annual rainfall in Taiwan.

Since 2012, the Environmental Protection Administration Taiwan (EPAT), National Central University (NCU), U.S. Environmental Protection Agency (USEPA) and National Atmospheric Deposition Program (NADP) worked together to assist Southeast and South Asian countries in capacity building of atmospheric Hg monitoring and to systematically monitor wet deposition and atmospheric concentrations of Hg in a network of stations throughout the Asia-Pacific region, resulting in the establishment of the Asia-Pacific Mercury Monitoring Network (APMMN). Currently, eight network sites measure Hg in precipitation following standardized procedures adapted from NADP. The network also has a common regional analytical laboratory at NCU, and quality assurance procedures which ensure the network makes scientifically valid and consistent measurements. Results from our ongoing analytical and field quality assurance measurements show minimal contamination in the network and accurate analytical analyses. We are continuing to monitor a potential concentration and precipitation volume bias between various types of wet deposition sampler.

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Technical Session 3: Ecological Effects and Critical Loads I

Session Chair: Mike Bell, National Park Service

Preparing critical loads information for diverse management applications

Linda Geiser[1] , Sarah Anderson[2], Jim Edmunds[3], Julie King[4], Ann Mebane[5], Ryan McCammon[6], Jill McMurray[7], Linda Pardo[8] and Charles Sams[9]

Critical loads (CLs) are thresholds of atmospheric deposition (typically in kg S or N ha-1 y-1) below which harm to specific elements of ecosystems do not occur. Recent improvements in our understanding of community, functional group and species level (71, 348 and 362 trees, herbs, and epiphytic lichens, respectively) responses to deposition have promising implications for federal land managers. Potential applications of CL information include air quality assessments for long term national forest-level planning and for project level planning for activities like oil and gas development; monitoring and assessing air quality in protected areas such as Wilderness; use as an air quality indicator within multi-indication national scale assessments of terrestrial and watershed condition; and understanding potential impacts to air pollution sensitive natural resources of proposed emissions sources outside federal lands. We present sample output for each of the above applications using available lichen CLs. Our results should contribute to the larger discussion of how to present and synthesize CL information to optimize their utility for particular management applications.

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Change in Critical Load Exceedances for Lichen Communities in National Parks from 2000-2017

Kelly McCoy[1], Michael D. Bell[2] and Emmi Felker-Quinn[3]

Anthropogenic nitrogen and sulfur deposition can have negative impacts on forested ecosystems. Negative responses begin to occur when deposition exceeds a threshold referred to as a critical load. Lichen are generally more sensitive to increased levels of nitrogen and sulfur deposition than other communities within the forest which makes them effective bioindicators of forest health. This study uses critical loads associated with a decrease in lichen species richness to determine the effects of sulfur and nitrogen deposition on ecosystems within national parks. The goal of this study was to identify how many national parks are in exceedance of lichen critical loads and how this varies spatially within a park's boundary. Additionally, the change in the risk to lichen species richness was compared between 2000 and 2017 to identify areas of improvement, degradation, and continued high risk. We evaluated the critical load exceedances using Total N and Total S estimates from the NADP Total Deposition Model (2000-2002 and 2015-2017). Forested national park units were characterized using the National Land Cover Database.

Our analysis determined that 229 National Park Service units had forested ecosystems, of which 209 were identified as having exceeded the lichen species richness critical load for nitrogen and 8 for sulfur deposition. For nitrogen, we determined that between 2000 and 2017, 158 National Park Service sites exhibited an improvement in conditions for lichen communities, while 29 sites degraded based on current deposition levels. For sulfur, 213 sites exhibited an improvement in conditions for lichen communities, while 11 sites degraded. For example, between 2000 and 2017 the area in exceedance in Acadia National Park decreased from 12,757 acres to 22 acres and the maximum decrease in richness due to N deposition went from 44% to 27%. Our research will be influential for researchers determining high risk areas within National Park Service forested communities as well as identifying areas of improvement that can be used to conduct targeted recovery surveys. Results identifying degraded areas will be useful for specific parks to locate regions of decreased forest health.

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Projected response of 94 tree species to changes in N and S deposition from 2005 to 2100 and the associated ecosystem services at risk

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Tree species provide a range of important societal values, including timber for harvesting, carbon sequestration, and recreational enjoyment for hikers, backpackers, and hunters. A recent analysis on critical loads of tree species across the U.S. indicates that tree species respond differentially to atmospheric deposition of N and S, with uncertain implications on the future forest composition and the ecosystem services that these forests provide. Here we provide a first-ever estimate for the coterminous US (CONUS) on species level changes in relative abundance of the current forest cohort from 2005 to 2100 across 16 future climate and deposition scenarios. We then estimate how two final ecosystem service (FEGS) may be affected (i.e. timber production, carbon sequestration) and one intermediate ecosystem service which underpins many FEGS (i.e. forest biodiversity). We also explore individual services that are more difficult to quantify and estimate the directional effects for U.S. forests.

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Atmospheric nitrogen deposition measurement and its influence on estuarine productivity: Sundarban, India

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Atmospheric deposition is an important source of nutrients to many ecosystems. Among the major ecosystems of the biosphere mangrove forests covers about 60 to 75% of tropical coasts. Mangrove productivity is influenced by numerous processes ranging from phytoplankton community succession to global biogeochemical cycles. Atmospheric deposition of nitrogen (AD-N) is a significant source of nitrogen enrichment to estuarine and coastal waters downwind of anthropogenic emissions. Atmospheric deposition, which includes both precipitation (wet deposition and dry deposition) of aerosols and gases, can stimulate productivity by providing macronutrients as well as trace metals. In the North Pacific, it has been noted that 40%–70% of nitrate is derived from terrestrial aerosol sources. Monsoonal variability, from complete failure, to greater than average rainfall, over seasonal and inter-annual timescales, can have profound impacts on primary productivity in waters surrounding mangroves. The deposition flux during Asian dry season and reverine supply and rain deposition during wet season both could be important factors for enhancing phytoplankton production in the land-ocean boundary of Sundarban, This present study focused on simple and cost effective approaches to collect and measurement of atmospheric deposition (dry and wet) in adverse and difficult field condition in Sundarban. In this present study atmospheric deposition was collected seasonally as aerosol and rain deposition in monsoon. Nitrogen content in both samples was estimated by Ion chromatography. Physiochemical parameter, nutrient concentration and primary productivity of the estuarine water also estimated to observe the correlation with atmospheric deposition to explain the contribution of atmospheric deposition in the nitrogen budget in ecosystem.

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Overview of the Main Conclusions from the Integrated Science Assessment for Oxides of Nitrogen, Oxides of Sulfur and Particulate Matter-Ecological Criteria (2nd External Review Draft)

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The Clean Air Act requires EPA to review the science every five years, and if necessary, revise the National Ambient Air Quality Standards (NAAQS) for six major air pollutants – carbon monoxide, lead, oxides of nitrogen, ozone, particulate matter, and oxides of sulfur. These NAAQS reviews, including the development of the Integrated Science Assessments (ISAs), play a significant role in EPA's commitment to ensuring a clean and healthy environment for the public.

Here we present updates from the 2nd draft ISA for oxides of nitrogen, oxides of sulfur, and particulate matter- ecological criteria (NOxSOxPM ISA- ECO). The NOxSOxPM ISA represents the Agency's latest evaluation of the scientific literature on potential ecological effects associated with these pollutants individually and in combination. The assessment includes over 3000 publications, of which approximately half were published since the last review (2008) and our literature cut-off date (May 2017).

The main findings of the ISA characterize the state of the science on atmospheric chemistry, deposition and ecological effects. The ISA finds that although Current NO_2 and SO_2 Secondary Standards are based on foliar injury, there is no new evidence that foliar injury occurs at current concentrations in U.S.

Nitrogen (N) enrichment from atmospheric deposition of NOy and particulate ammonium currently alters many ecosystems in the U.S. National N deposition rates have been broadly constant; decreasing NO_Y deposition offset by increased reduced nitrogen (NH_x= NH_3+NH_4^+) deposition. New quantitative evidence shows current rates of N deposition cause: decreases in lichen biodiversity and herbaceous plant biodiversity, positive and negative effects on tree growth and mortality and increases in algal growth, loss of sensitive aquatic species. Since 2008 many new thresholds of deposition (critical loads) are available for biological effects. Wetlands, estuaries, and surface waters are less sensitive to N deposition because they also receive N inputs from agricultural and urban sources. Acidification from N and sulfur (S) deposition continues to affect ecosystems across the US. Negative effects on fish, plants, plankton are well-documented. S deposition has greatly declined over the past 25 years; driving decreases in total acidifying deposition observed in the East. Some geochemical recovery has been documented in Northeast. Lastly, S enrichment from deposition alters aquatic and wetland ecosystems with new evidence that S deposition causes increases in sulfide toxicity and mercury methylation.

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Technical Session 4: Ecological Effects and Critical Loads II

Session Chair: Jeff Herrick and Jason Lynch, U.S. Environmental Protection Agency

Chronic and Episodic Acidification of Streams along the Appalachian Trail Corridor, eastern United States

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Acidic atmospheric deposition has adversely affected aquatic ecosystems globally. As emissions and deposition of sulfur (S) and nitrogen (N) have declined in recent decades across North America and Europe, ecosystem recovery has become evident in many surface waters. However, persistent chronic and episodic acidification remain important concerns in the most vulnerable regions. We evaluated stream acidification in 269 headwaters along the Appalachian Trail (AT) across the eastern U.S. The AT is an ideal study region because it transits several ecoregions, is located downwind of high levels of S and N emission sources and includes heterogeneous soils and geology. Chronic acidification at low flow was substantial as 16% of streams had a mean acid-neutralizing capacity (ANC) <0 meq/L. By applying two new approaches to calculate the extent of episodic acidification, we estimated that streams with ANC <0 meq/L doubled to 32% as discharge increased from the 15th to 85th flow percentile. The proportion of chronically and episodically acidic streams decreased from north to south along the AT. Dilution of base cation concentrations explained the greatest amount of episodic acidification among AT streams and variation in sulfate (SO_4^{2-}) concentrations was a secondary explanatory variable. However, episodic SO_4^{2-} patterns varied geographically with dilution dominant in northern streams underlain by soils developed in glacial sediment, and increased SO_4^{2-} concentrations dominant further south in streams with older, more highly weathered soils. Episodic acidification as determined by ANC decline with flow increased as low-flow ANC increased, exceeding 90 meq/L in 25% of the streams. At streams with low-flow ANC values <30 meq/L, episodic increases rather than decreases in ANC was the dominant pattern. Chronic and episodic acidification remain an ecological concern among streams along the AT. The approach developed here could be widely applied to provide estimates of the magnitude of acidification in other regions recovering from decreasing levels of atmospheric S and N deposition.

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Linking recovery from acidification and changing climate to shifting zooplankton communities in northeastern lakes

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Significant chemical shifts have been detected in northeastern lakes since the 1980s, when surface water acidification was widely reported and subsequently, programs were established by the US Environmental Protection Agency (EPA) to monitor environmental responses to emissions regulations. Since the Clean Air Act Amendments of 1990 intensified regulations to limit emissions of sulfur and nitrogen, lakes in Maine and much of the Northeast have recovered from acidification, just as other chemical and physical changes have been detected as a result of a changing climate. The organisms that inhabit lakes are susceptible to these shifts, but our understanding about how different biological communities react to simultaneous changes in geochemistry and climate is incomplete. This research investigates how zooplankton communities respond to these changes, on both long-term and seasonal scales. Due to their short life cycles, these small organisms are sensitive to changes in physical lake conditions, and variation within zooplankton communities could indicate larger ecosystem shifts. We are evaluating how zooplankton size and community composition has changed across decades, using data from US EPA's Eastern Lakes Survey (ELS-II), 145 lakes throughout the Northeast that were sampled in 1986 and resampled in 2004, a decade after implementation of the Clean Air Act Amendments. Additionally, we are assessing how zooplankton respond to annual lake phenology in seasonally ice-covered lakes across a range of elevation and climate zones in Maine. Beginning in winter 2019, we are collecting zooplankton, chlorophyll-a, water chemistry samples, and water temperature in eight remote Maine lakes from the extremes of elevations (94m – 955m above sea level) and climate divisions (mean annual T=2˚C–12˚C), in order to capture variation in climate and seasonal duration. The lakes are US EPA Long-Term Monitoring (LTM) study sites with a record of geochemistry data beginning in the 1980s. Samples were collected under ice in the winter, at 10-day intervals over the course of spring warming and will be collected during summer stratification and fall mixing. A chain of thermistors measure temperature in the epilimnion and hypolimnion throughout the year, including under ice. Zooplankton phenology and community structure will be compared among seasons and among lakes to understand how variation in climate and water chemistry influence community structure. Disentangling the drivers of zooplankton populations will help provide a mechanistic understanding of longer-term shifts observed in northeastern lake ecosystems and can provide a basis for understanding consequences of environmental change.

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The Key to Park Protection—Cooperative Conservation: monitoring, management, and research in Shenandoah National Park

Jalyn Cummings[1] and Ami Riscassi[2]

Shenandoah National Park is one of only 48 "Class I" air areas managed by the National Park Service under the Clean Air Act (CAA). "Class I" areas provide special protection for air quality, sensitive ecosystems and clean, clear views. Additional authority to consider and protect air quality related values (AQRVs) in Class I parks is provided by the NPS Organic Act and the Wilderness Act. NPS Management policies state that the "Service will acquire the information needed to effectively participate in decision-making that affects park air quality." Toward this goal, SHEN and its research partners are actively engaged in air-quality monitoring and research about air pollution's effects on human health, streams, aquatic life, vegetation, and wildlife. The park operates an air quality station that has made measurements of precipitation chemistry (National Atmospheric Deposition Program—NADP, NTN, MDN) since 1981, of fine particles and visibility (Interagency Monitoring of Protected Visual Environments—IMPROVE) since 1982, and of ground-level ozone since 1983. Meteorological measurements at the same Big Meadows location began as early as 1935.

The Shenandoah Watershed Study (SWAS), a cooperative agreement between the University of Virginia and Shenandoah National Park (SHEN), was established in 1979 to provide increased understanding of hydrologic and biogeochemical changes that occur in response to acidic deposition and other ecosystem stressors. The underlying scientific objective of the SWAS program is to improve understanding of hydro-biogeochemical processes that govern ecosystem conditions in the mountain watersheds of SHEN, but the partnership is a tool that has provided decades of positive feedback loops between air and water quality monitoring, research, and land management.

We will present a snapshot of projects that have used the long term connections built between monitoring, research, and management in this positive feedback loop. Examples include: consideration of a liming project to mitigate the effects of acid rain, determination of the impact of wild fire on stream mercury and carbon concentrations, evaluation of the impact of watershed defoliation on stream nitrate concentrations, assessment of the long-term trends in episodic acidification to inform fish monitoring trends, and looking forward, predicting the impacts of a more extreme climate. The Organic Act of 1916, created the National Park Service to "conserve the scenery and natural and historic objects and the wild life therein", and cooperative conservation is the key to park protection.

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Dragonfly Larvae as Biosentinels of Mercury Availability and Ecological Impairment in Aquatic Food Webs of National Parks throughout the United States

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Using a national-scale citizen science framework we examined variation in mercury (Hg) concentrations of dragonfly larvae across 92 National Park Service units throughout the continental US and Alaska to facilitate their development and implementation as bioindicators of Hg availability in aquatic ecosystems at a range of spatial scales. Total Hg (THg) was an effective proxy for methylmercury (MeHg) concentrations ($r^2 = 0.96$) across sampling locations and dragonfly families. Across more than 400 unique sample sites, THg concentrations averaged 112 ng/g dry weight (dw) but ranged 135-fold, between 10.4 to 1,411 ng/g dw. Variation in THg concentrations was influenced by habitat type; concentrations were highest in riverine habitats, and lowest in ponds. Additionally, rivers, streams, lakes, and ponds with substantial peripheral wetlands had substantially higher THg concentrations than comparable habitats without adjacent wetlands. Total Hg concentrations differed among dragonfly families, but strong correlations between families facilitated robust conversion equations to normalize concentrations by family. We developed the Aeshnid-equivalent dragonfly Hg concentration to facilitate unbiased spatial and temporal comparisons of Hg concentrations in consistent units. Aeshnid-equivalent THg concentrations were positively correlated with THg concentrations of four fish guilds (piscivores, sunfish, trout, and forage fish), and two amphibian taxa (salamanders and frogs) indicating that dragonfly larvae are effective indicators of Hg availability in aquatic food webs. Using the relationships between dragonfly and fish Hg concentrations we developed a series of integrated impairment benchmarks that inform potential risk of Hg exposure to fish, wildlife, and human health. Across 402 sites in 92 National Park Service units, dragonfly THg concentrations indicated that 11% of sites did not exceed any impairment benchmarks, whereas 49%, 28%, 11%, and 1% of sites exceeded low, moderate, high, and severe categories for potential health impairment. These findings highlight the efficacy of carefully designed citizen science efforts to facilitate inquiry on issues of conservation significance that would be otherwise difficult to conduct because of their resource requirements. Additionally, it demonstrates the utility of applying dragonfly larvae as robust bioindicators across a broad landscape and diverse habitats in order to measure responses to changes in environmental Hg availability and estimate potential health risks across a range of relevant endpoints.

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A Transition in Human Manipulation of the Sulfur Cycle

Eve-Lyn Hinckley[1], John T. Crawford[2] and Charles T. Driscoll[3]

Human manipulation of the sulfur (S) biogeochemical cycle has shifted dramatically in recent decades. Once dominated by fossil fuel emissions that caused inadvertent inputs of reactive S as acid deposition to forested ecosystems, our major pathway of S manipulation is now the multiple forms used in agriculture. While many decades of research have documented the consequences of atmospheric S deposition to acid-sensitive forest and aquatic ecosystems, comparatively little is known about the unintended consequences of its use in large-scale agricultural systems. This synthesis examines the inputs, transport, and ecological effects of S applications in agriculture. We describe case studies of three regional crops that use S in the United States: wine grapes in California, corn and soy in the Ohio River Valley, and sugarcane in Florida. Data from these areas demonstrate that as atmospheric S deposition has declined over time in response to federal regulation of emissions, agricultural S inputs have increased with expansion and intensification of crop systems, or in response to a decline in "free" atmospheric S deposition. Surface water sulfate export has declined about 2-5% per year over the past 30 years in areas of the northeastern U.S. historically impacted by acid rain and where crop systems are dispersed. Conversely, stream water sulfate concentrations have increased or remained elevated in the large agricultural areas represented by our case studies. In addition, we present highlights from detailed research in California wine grape systems that explores the utility of S stable isotopes for tracking agricultural S through complex watersheds, quantifying the forms and transformations of S, and determining their ultimate fates in downgradient aquatic ecosystems. Ultimately, there is a need to understand the implications of widespread agricultural S use and to develop science-stakeholder partnerships aimed at creating sustainable S management that reduces negative effects on local and adjacent ecosystems.

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Technical Session 5: Improving Understanding of the Reactive Nitrogen Budget

Session Chair: Kristi Morris, National Park Service

Nitrogen deposition budget for a southern Appalachian deciduous forest

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Assessment of critical load exceedances for nutrients requires complete and accurate atmospheric deposition budgets for reactive nitrogen (Nr). The exceedance is the total amount of Nr deposited to the ecosystem in excess of the critical load, which is the amount of Nr input below which harmful effects do not occur. Total deposition includes all forms of Nr (i.e., organic and inorganic) deposited to the ecosystem by wet and dry pathways. Total deposition budgets, which may be developed from measurements, models, or a combination of the two, are often incomplete due to lack of consideration of organic forms of Nr. Reliance on models for estimating the dry deposited fraction is another important source of uncertainty. Here we present results from the Southern Appalachian Nitrogen Deposition Study (SANDS) in which a combination of measurements and field-scale modeling is used to develop a complete annual (2015) Nr deposition budget for a mixed deciduous forest at the Coweeta Hydrologic Laboratory in southern Appalachia. Wet deposition of ammonium, nitrate, nitrite, and bulk organic N were measured directly. The dry deposited Nr fraction was estimated using a bidirectional resistance-based model driven with speciated measurements of Nr air concentrations (e.g., ammonia, ammonium aerosol, nitric acid, nitrate aerosol, bulk organic N in aerosol, total alkyl nitrates, and total peroxy nitrates), micrometeorology, canopy structure, and biogeochemistry. Wet deposition dominated the annual budget, contributing 66% of total deposition. Approximately 50% of the total (wet + dry) budget was contributed by reduced forms of Nr (NHx = ammonia + ammonium), with oxidized and organic forms of Nr contributing ~ 40% and 10%, respectively. The dry deposited fraction comprised ~ 59% NHx, with oxidized and organic Nr contributing ~ 32% and 9%, respectively. Total annual deposition was ~ 7.0 kg N ha^{-1} yr^{-1}, which is on the upper end of Nr critical load estimates recently developed for similar ecosystems in nearby Great Smoky Mountains National Park. Our results indicate that reductions in NHx deposition would be needed to achieve the lowest estimates (~ 3.0 kg N ha^{-1} yr^{-1}) of Nr critical loads in southern Appalachian forests.

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Ammonia monitoring within the Canadian Air and Precipitation Network and an evaluation of the relative contribution to nitrogen dry deposition.

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The Canadian Air and Precipitation Monitoring Network (CAPMoN) was established in 1988 to determine temporal trends and spatial distribution for wet deposition and provide estimates of dry deposition at regional representative sites in Canada. Over the last decade ammonia, the primary alkaline gas in the atmosphere has been added to the suite of nitrogen species measured during a few select studies in part to estimate the contribution of ammonia to the total nitrogen dry deposition flux. Continuous measurements of ammonia have been conducted using both a Picarro cavity ring down analyzer and a modified Thermo 42i trace level instrument (by difference)

with detection limits of approx. 100 pptv or better. In addition, two week integrated samples were collected using Radiello ammonia passive samplers in conjunction with NADP's Ammonia Monitoring Network (AMoN). Measurements of ammonia have been typically determined to be on the order of a few ppbv and have ranged from being near or below detection limit during the winter to significantly elevated levels associated with agricultural activities and forest fires. During some of these studies, the ammonia monitoring has been accompanied with continuous measurements of NO, NO_2, and NO_y and daily integrated values of HNO_3, particle nitrate and particle ammonium from CAPMoN's filter packs. The comparability of the various ammonia monitoring methods, seasonal and diurnal variations of the ambient ammonia mixing ratios, and the relative contribution of ammonia to the total nitrogen dry deposition will be presented.

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Speciated Inorganic Reactive Nitrogen Measurements in the Clean Air Status and Trends Network

Melissa Puchalski[1], Kevin Mishoe[2], John T. Walker[3], Anthony Ward[4], Gregory Beachley[5], Christopher Rogers[6] and Doris Chen[7]

Total reactive oxidized nitrogen (NOy) is measured at more than 80 sites across the U.S. to better understand ozone formation and atmospheric chemistry processes. The analyzer uses a heated molybdemum converter upon a 10m tower to convert all oxidized nitrogen species to NO while a second sample train draws ambient air. A chemiluminescence detector measures NO from both sample trains providing hourly concentrations of NO and NOy. Routine ambient monitoring networks such as the Clean Air Status and Trends Network (CASTNET), Chemical Speciation Network (CSN), and Interagency Monitoring of Protected Visual Environments (IMPROVE) network measure nitrogen-containing gases and particles contributing to the total reactive nitrogen budget, but without key components such as total reduced nitrogen (NH_x) and nitric acid (HNO_3). The routine networks also lack the temporal resolution needed to relate atmospheric chemistry to other processes with important diurnal variability (e.g., air-surface exchange, emissions, solar radiation, boundary-layer height). In this study, Wood E&IS, Inc. designed an enhanced chemiluminescence system to measure total reactive nitrogen (TNr), NOy, NO_2, NO and NH_x, HNO_3 and NO_z by difference. The system uses one NO detector to eliminate the need to bias correct between different analyzers. Chemical transport and deposition models would benefit from hourly measurements of HNO_3, NO_2, and NH_x at a large number of sites located in rural and urban areas as these are significant contributors to the total and dry nitrogen deposition budget.

The enhanced chemiluminescence systems were deployed in Beltsville, MD, a suburban/agricultural location, and above a hardwood canopy at the Duke Forest, NC flux tower. Overall performance of the systems was assessed using co-located measurements from the CASTNET filter pack, AMoN and the Monitor for AeRsols and GAses (MARGA). EPA supports NO/NOy systems at 4 sites and could upgrade the existing systems to provide more valuable data to the air quality and deposition research community.

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A 40 Site Network for Passive Ammonia Measurements along northern Utah's Wasatch Front: Winter and Summer 2019

Randy Martin[1] , Kerry Kelly[2], Jaron Hansen[3], Nancy Daher[4] and Christopher Pennell[5]

From previous measurements, including an AMON site (97), ambient levels of ammonia (NH_3) along northern Utah's Wasatch Front are known to consistently be among the highest in the nation. The overarching concern with NH_3 in the region is the formation of wintertime $PM_{2.5}$, which is locally-dominated by ammonium nitrate (NH_4NO_3). The Wasatch Front is considered a series non-attainment area for $PM_{2.5}$. Several studies, most recently the 2017 Utah Winter Fine Particulate Study (UWFPS), have pointed out that although the local airsheds appear to be slightly ammonia-rich in regards to NH_4NO_3 formation. There are times, especially during extended persistent cold-pool, capping events (inversions) in which the atmosphere switches to a more ammonia-limited regime. As such it is critical to understand NH_3 abundance and availability. Regional emission inventories are unable to account for previously observed ambient concentrations. Modeling attempts by local regulatory agencies have had to artificially enhance NH_3 emissions by factors as high as 4x to simulate the observed values. Additionally, very little information is known about the location or contributions of the potential NH_3 source emissions. Limited studies, 10 total sites, in 2016 and 2017 found ammonia wintertime concentrations ranging from 5-30 ppb with varying spatial distributions. A study was initiated for the winter and summer of 2019 in which a dense network (40 sites) of Ogawa passive NH3 samplers were deployed from Brigham City to Mona, UT, approximately 140 miles, which include the population centers of Ogden, Salt Lake City and Provo. The winter study took place from mid-January to mid-February and the summer study extended from mid-July to mid-August. At present the data are still being analyzed and will be presented. However, preliminary analysis show the average winter NH_3 concentrations (≈5-10 ppb) were lower than the average summer values (20-30 ppb), with notable difference between the Salt Lake and Utah county airshed. During both seasons, locations near suspected "hotspots" were significantly (≈5x) higher than most of the other locations.

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Technical Session 6: Modeling to Understand Emissions and Source Apportionment of Reactive Nitrogen

Session Chair: Greg Beachley, U.S. Environmental Protection Agency

Characterization of the Global Sources of Atmospheric Ammonia from Agricultural Soils and its Deposition

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Global ammonia (NH_3) emissions into the atmosphere are projected to increase in the coming years with the increased use of synthetic nitrogen fertilizers and cultivation of nitrogen-fixing crops. Here, a statistical model (NH_3_STAT) is developed for characterizing atmospheric NH_3 emissions from agricultural soil sources, and compared to the performance of other global and regional NH_3 models (e.g., EDGAR, MASAGE, MIX and U.S. EPA). The statistical model was developed by expressing a multiple linear regression equation between NH_3 emission and the physicochemical variables. The model was evaluated for 2012 NH_3 emissions. The results indicate that, in comparison to other data sets, the model provides a lower global NH_3 estimate by 57%, (NH_3_STAT: 14.2 Tg N yr^{-1}; EDGAR: 33.0 Tg N yr^{-1}). We also performed a region-based analysis (U.S., India, and China) using the NH_3_STAT model. For the U.S., our model produces an estimate that is 143% higher in comparison to EPA. Meanwhile, the NH_3_STAT model estimate for India shows NH_3 emissions between -141% and -77% when compared to other data sets. A lower estimate is also seen for China, where the model estimates NH_3 emissions 36-482% lower than other data sets. The difference in the global estimates is attributed to the lower estimates in major agricultural countries like China and India. The statistical model captures the spatial distribution of global NH_3 emissions by utilizing a more simplified approach than those used by other readily available data sets. Moreover, the NH_3_STAT model provides an opportunity to predict future NH_3 emissions in a changing world. We also determine how much ammonia/nitrogen is being deposited globally.

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Inverse modeling constraints on sources of NH3 using CrIS remote sensing measurements

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Atmospheric $NH_3$is an important precursor to particulate matter, and it has effects on ecosystem stability, soil acidification, aerosol acidity, and climate change. Previous estimates of NH_3emissions in the US are quite uncertain both in terms of magnitude and seasonal variability. The most recent remote sensing measurements of $NH_3$from CrIS can provide constraints on NH_3sources at fine resolution, and with great spatial coverage and small noises. We conducted 4D-Var inversion experiments using high-resolution CrIS observations of NH_3profiles, GEOS-Chem, and its adjoint model to estimate NH_3emissions in the contiguous US for each month in 2014. Increases are found in CrIS-derived anthropogenic NH_3emissions across most of contiguous US on an annual scale, while slight decreases are found over Northern Iowa and Southern California from March to July. CrIS-derived anthropogenic NH_3emission estimates for the contiguous US is 4.27 Tg N a^{-1}, ~45% higher than the HTAP v2 emission inventory (2.95 Tg N a^{-1}). We evaluate our CrIS-derived NH_3emissions using monthly mean AMoN surface NH_3measurements in 2014. CrIS-derived monthly NH_3emissions increased the correlation coefficient between national monthly average of GEOS-Chem surface $NH_3$and AMoN surface NH_3 measuremnents from 0.33 to 0.82, and decreased the normalized mean bias (NMB) from -0.34 to 0.10 on an annual and national scale. We will further evaluate our CrIS-derived NH_3 emissions using NADP measurements of wet deposition of NH_4^+in 2014.

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Source apportionment of sulfur and nitrogen deposition to Rocky Mountain National Park using CMAQ

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Excess deposition of sulfur and nitrogen can cause harmful effects to ecosystems. Rocky Mountain National Park (RMNP) has historically been at risk to damage due to high nitrogen deposition. In order to develop strategies to reduce deposition levels, information on geographical sources and emission sectors that contribute to the deposition levels is needed. Using the Integrated Source Apportionment Method (ISAM) in CMAQv5.3, we analyze the contribution to deposition in RMNP for 2016 from multiple emission source sectors including agricultural fertilizer, agricultural animal operations, mobile sources, electric generating units, and wildfires. Additionally, we assess the contribution from individual states and regions to the deposition in the park.

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Observation-based, spatial-resolved surface concentrations and their implications for emission and deposition estimation

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Satellite observations provide excellent spatial and temporal coverage for the abundances of atmospheric trace constituents and have tremendously advanced our understanding of the processes governing atmospheric composition, emissions, and deposition. However, the satellite products usually only retrieve the total vertical columns of the species, whereas the concentrations near the surface are more important for human and ecosystem health, land-atmosphere exchange, and air quality. Most existing studies rely on vertical profiles from chemical transport models (e.g., the GEOS-Chem model) to infer surface concentrations from satellite total columns. Recent field aircraft campaigns (DISCOVER-AQ, KORUS-AQ, SENEX, and SEAC4RS) provide a wealth of information on the vertical distributions of critical trace species, such as NOx, HCHO, and NH3. Based on first principles in fluid mechanics, we have derived dimensionless vertical profiles for a range of reactive trace gases from aircraft measurements. Combining with spatiotemporally resolved PBL height field, these observation-based vertical profiles are then applied to scale satellite total columns, yielding surface concentrations. By oversampling these observation-based surface concentrations to a regular spatial grid, we present a spatially and temporally resolved continuous concentration dataset over the contiguous US to study reactive nitrogen deposition, the ozone-NOx-VOC sensitivity, and the evolution of surface air quality.

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Technical Session 7: Measurement of Atmospheric Mercury and Emerging Pollutants

Session Chair: Mark Olson, NADP

Passive air sampling for mercury on a global scale to fill the gaps – a Canadian led pilot study

Alexandra Steffen[1], Geoff Stupple[2], Tom Harner[3], Anita Eng[4] and Frank Wania[5]

Mercury (Hg) easily travels significant distances in the air making it a global pollutant. Monitoring Hg is critical to assess changes occurring in Hg concentration in response to the implementation of regulatory measures or climatic perturbations. The aim of the 2017 Minamata Convention on Mercury (MCM) is to protect human health and the environment from anthropogenic releases of Hg. The atmosphere is one of the key pathways for the dispersion of anthropogenically emitted Hg; thus, monitoring the spatial and temporal variation of Hg is key to evaluating the success of regulatory measures. While there are several regional and multi-regional measurement programs investigating atmospheric Hg, there is currently no ongoing program on a truly global scale. The goal of this project is to collaborate with currently operating air monitoring networks to initiate or continue Hg monitoring using passive sampling technology to fill in geographic gaps. The University of Toronto Scarborough developed a passive air sampler for gaseous Hg. This sampling system has been fully characterized and is commercially produced as the MerPAS. The MerPAS passive air sampler uses sulfur-impregnated activated carbon as the sorbent for Hg which undergoes diffusive uptake and accumulation on the sorbent. This method has been shown to have accuracy on par with currently acceptable methodologies for measuring Hg in the atmosphere and demonstrates excellent precision.

ECCC has initiated a pilot study to investigate applying passive sampling of atmospheric Hg on a global scale by combining and coupling with currently existing networks into one (a “network of networks) to reduce areas with no coverage. In Canada, we have initiated the Canadian Arctic Hg passive sampling network in order to complement active air monitoring activities conducted across the country. We are collaborating with the Global Atmospheric Passive Sampling (GAPS) network that monitors persistent organic pollutants (POPs) in support of the Stockholm Convention. In this first step, the Hg passive sampler has been deployed at 23 selected sites by GAPS partners. While a good start, we have incomplete global coverage; thus, we are seeking other networks and countries to collaborate. Such networks as the APMMN, LAPAN, NADP, EMEP, AMAP and GMOS were contacted for their interest in participation in this “network of networks”. This study will not be limited to the MERPas but welcomes the use of other currently validated passive Hg technology with the ultimate goal to have comparable and accurate atmospheric Hg concentration information across the world.

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Network Implementation of a Mercury Passive Air Sampler (MerPAS) Method: Overcoming Technical and Quality Assurance Challenges

Eric Prestbo[1], Diana Babi[2], Lucas Hawkins[3], Carl Mitchell[4], Frank Wania[5], Alexandra Steffen[6], Geoff Stupple[7] and David McLagan[8]

Researchers at the University of Toronto have developed and published multiple peer-reviewed papers on the use of a mercury passive air sampler (MerPAS) method for highly accurate and precise low-resolution measurements at the ppqv level (150 ppqv = 1.3 ng/m^3). A highly accurate mercury passive air sampler has many potential applications (e.g. contaminated site monitoring). In the context of NADP, the potential for using MerPAS would likely focus on three general uses: 1) Supplementing AMNet sites to improve spatial representation, 2) Monitoring at remote, sensitive ecosystem sites, such as national parks or at high elevation and 3) Low-cost, spatially dense short term studies to map agricultural, industrial or urban landscapes. All the above MerPAS applications would help improve mercury deposition model development and verification. For routine use, a low-tech, low-cost mercury passive air sampling method must be applied with an understanding of the trade-offs in sensitivity and resolution. Furthermore, there can be technical challenges when transforming a research-based method into a routine method with a wide range of applications and multitude of end-user types. Questions answered by this presentation include: 1) What packaging and preventative measures work for use and storage of samplers to prevent contamination, 2) How critical is the surface area of the media insert and the reproducibility of the carbon preparation, 3) Is the analysis of the sample straightforward and transferable to a routine laboratory and 4) What are the quantifiable trade-offs for time resolution, accuracy and quality assurance relative to short term studies or long-term trend determination.

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Evaluation of the Efficacy of the National Atmospheric Deposition Program (NADP) National Trends Network (NTN) for Assessment of PFAS Deposition in Precipitation

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In this pilot study we address the efficacy of the National Atmospheric Deposition Program (NADP) precipitation samples for PFAS deposition determination and provide new data on levels of PFAS in precipitation across the US. We performed PFAS measurements on geographically diverse precipitation samples from the NADP National Trends Network (NTN) and in parallel conducted laboratory and field experiments designed to examine whether the NTN as currently configured would support using the large network of 255 sites as a national PFAS sampling network. The importance of precipitation as a vector of a wide range of environmental contaminants to aquatic and terrestrial ecosystems is well documented. Precipitation is also a valuable sentinel of atmospheric contaminant pools and processing. An increasing body of evidence documents measurable levels of a broad range of PFAS species in precipitation, but key gaps in our understanding of atmospheric sources and processing of PFAS remain. Information on short-chain (C3-C7) PFAS species, which may preferentially enter atmospheric cycles, is particularly sparse. Precipitation samples were obtained from the NADP central laboratory at the UW-Madison Wisconsin State Laboratory of Hygiene (WSLH) immediately upon receipt of the samples at the laboratory. Processing and analysis of the samples for 36 PFAS species at the WSLH followed ISO method 21675. Thirty-five samples, representing both urban and rural sites across the US were selected for analysis. NTN sites near probably PFAS sources were also chosen. Dedicated experiments with the diverse suite of 36 PFAS compounds addressed stability and losses of the PFAS species in the NTN precipitation collectors, with outcomes showing acceptable stability/preservation over the 7-day NTN collection period. Outcomes of system blank studies demonstrated that both "bag" and "bucket" NTN collectors were exceptionally clean with respect to PFAS contamination. Concentrations of the detectable PFAS species were low, generally less than 1 ng/L, though the sum of the quantified species exceeded 4 ng/L at many sites. The carboxylic acid species were by far the most frequently detected, with PFHxA, PFHpA, PFOA and PFNA each present in nearly 70% of all samples. Shorter-chain PFAS compounds dominated, with no PFAS compounds with carbon numbers greater than nine detected. Sites from the mid-Atlantic states generally had the greatest number of detectable PFAS species and highest concentrations. The presentation will focus on outcomes of the monitoring network evaluation and present a synoptic overview of levels and speciation of PFAS in precipitation across the US.

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A new system that provides accurate, precise, hourly measurements of oxidized mercury can improve dry deposition estimates

Seth Lyman[1]

Accurate estimates of oxidized mercury dry deposition can only be obtained if measurements of ambient oxidized mercury concentrations are accurate. KCl-coated denuders have been used to measure oxidized mercury in the past, but these systems are biased low, and the amount of bias is dependent on location and atmospheric conditions. New technology is critically needed to replace KCl denuder-based measurement systems.

We developed a dual channel atmospheric mercury measurement system that fills this gap. The system consists of a Tekran 2537 analyzer that alternately samples air that passes through a pyrolyzer and air that passes through a series of cation-exchange membranes. The pyrolyzer reduces all mercury compounds to elemental mercury, providing a measure of total mercury in the atmosphere. The cation exchange membrane channel measures elemental mercury, and we calculate oxidized mercury as the difference between these two. We developed software to reprocess the 2537 analyzer's raw detector output in real time, allowing us to achieve much more stable measurements than the analyzer outputs natively. With this system, we have been able to routinely achieve detection limits for oxidized mercury of 10-15 pg/m^3 (hourly averages).

We used a permeation tube-based automated calibration system to verify the performance of the dual channel measurement system in ambient air. We found that the system recovers 100% of the oxidized mercury compounds ($HgCl_2$ and $HgBr_2$) injected into it as oxidized mercury. In similar tests, KCl denuder-based systems have recovered only 30-50% of injected oxidized mercury compounds as oxidized mercury. In KCl denuder-based systems, the remainder is recovered as elemental mercury, since much of the oxidized mercury captured by KCl denuders is reduced to elemental mercury and lost from the denuder.

In deployments in Colorado and Utah, the new dual channel system has measured oxidized mercury concentrations that are higher than those reported using KCl denuder-based measurement systems. Even during a cold Utah winter characterized by persistent, multi-day inversion conditions, 24-hr average oxidized mercury concentrations were in the range of 20 pg/m^3. Daytime values during summer routinely exceeded 100 pg/m^3. These higher oxidized mercury values show that the impact of oxidized mercury to the environment via dry deposition is higher than has previously been assumed.

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Applying New Technologies to Arctic Mercury Monitoring

Sarrah Dunham-Cheatham[1], Stefan Osterwalder[2], Olivier Magand[3], Aurélien Dommergue[4], Jeroen Sonke[5] and Mae Sexauer Gustin[6]

Despite large-scale mercury (Hg) pollution in the Arctic having negative effects on marine and terrestrial ecosystems, the sources and cycling of Hg within this region are not well understood. Through an international collaborative effort, new technologies were deployed at a high Arctic station, the Zeppelin Observatory located close to Ny-Ålesund, Svalbard, to better understand atmospheric Hg behavior and chemical speciation. The sampling campaign spanned from April to July 2019, capturing two distinct Arctic Mercury Depletion Events (AMDE) and the annually observed peak of gaseous elemental Hg in summer. The technologies included a University of Nevada, Reno-Reactive Mercury Active System 2.0 (UNR-RMAS 2.0), passive Aerohead samplers to measure dry deposition of gaseous oxidized Hg (GOM) to membrane surfaces, and carbon sorbents for isotope analyses to identify possible sources of Hg. New to the Arctic Hg monitoring network, the UNR-RMAS 2.0 is an active sampling technique that collects reactive Hg (RM = GOM + particulate-bound Hg (PBM)) on cation exchange and nylon membranes that are then analyzed for total RM and RM chemistry, respectively. The UNR-RMAS 2.0 has been upgraded to allow for measurement of RM, GOM, and PBM concentrations and chemistry, and can be coupled with additional chemical (e.g., ion chromatography) and statistical (e.g., peak deconvolution) analyses. Results from the membrane-based techniques in the Arctic indicated that the active and passive sampling technologies yield similar trends in RM concentrations and that RM speciation changes from predominantly halide- ($-Br_x$, $-Cl_x$) or nitrogen-based compounds prior to the AMDE to mixtures of halide- and nitrogen-based compounds after the events. This work has important implications for local, regional, and global policies, as well as for refinement of Hg modeling efforts.

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Wildfire Tracer Molecules Used for Source Appropriation of Atmospheric Deposition Constituents from Combustion Emissions

Jeramy Jasmann[1], Natalie M. Kehrwald[2], Gregory A. Wetherbee[3] and Larry B. Barber[4]

Dramatic shifts in the current hydrologic cycle of the western U.S., evidenced by higher average annual temperatures, earlier snowpack melting, and greater severity of droughts, has created conditions conducive to longer wildfire seasons with higher intensity burns. Every state in the western U.S. has experienced an increase in the average number of large wildfires per year during this decade when compared to the annual averages of the previous two decades. Wildfire events impact downwind air and water quality even across distances thousands of kilometers from the source and long time periods after the fire has stopped, sometimes exacerbating pollution from gas and aerosol emissions from fossil fuel combustion.

We developed a robust high-throughput analytical method for the detection of three monosaccharide anhydrides (MAs) - levoglucosan, mannosan, and galactosan - in low-volume snow, water, and aerosol deposit samples at part per trillion concentrations. This method uses evaporative concentration, derivatization, and gas chromatography tandem mass spectrometry (GC/MS/MS) analysis with isotopic dilution quantification. The three MAs are thermal degradation products of cellulose and hemicellulose generated via combustion of biomass and are widely used as molecular tracers of wildfire and agricultural burning events. These molecules can be transported for thousands of kilometers in the atmosphere (along with other combustion constituents) before dry or wet deposition processes return them to the terrestrial environment. Since these MAs are not generated from fossil fuel combustion, they allow for the specific detection of air masses containing wildfire constituents and appropriate sources of other fire-related atmospheric deposition constituents, such as organic acids, nutrients, and mercury, that affect terrestrial and aquatic ecosystems.

This analytical tool can be used to measure MA concentrations in precipitation and dry deposition samples monitored by the NADP network to help recognize and characterize biomass burning sources of organic acids, nutrients, base cations, and mercury also determined in NADP samples. This expanded analysis approach can be applied to the NADP network to connect atmospheric transport and deposition of key combustion-derived constituents to landscape.

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Potential for monitoring black carbon wet deposition in the NADP network

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Refractory black carbon (BC) nanoparticles are emitted from incomplete fossil fuel/biomass combustion and are omnipresent in the atmosphere. These particles have far-reaching effects on the atmosphere's physical and chemical properties and have manifold impacts on human health. BC particles absorb solar radiation heating the surrounding atmosphere while dimming light at the surface (cooling). Carried aloft BC can have a significant impact on atmospheric stability and as a result precipitation patterns. Even though BC aerosols are ubiquitous, they are still poorly constrained for wet deposition – the primary removal mechanism. A coordinated analysis of BC in wet deposition over a large spatial area is needed to advance our understanding of BC aerosols and their atmospheric distribution. The National Atmospheric Deposition Program has the necessary infrastructure to rapidly capture samples of BC in wet-deposition on a national scale at time-scales close to the mean atmospheric residence time (< 6 days). As an exploratory study, we have been analyzing BC in wet deposition using an NCON bucket sampler located in Madison, Wisconsin. The initial results suggest that it may be possible to rapidly determine BC in wet deposition on a national scale. The presentation will discuss the potential for such a study.

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POSTERS

#1 - Experimentally derived nitrogen critical loads for northern Great Plains vegetation

Amy Symstad[1], Anine T. Smith[2], Wesley E. Newton[3] and Alan K. Knapp[4]

The critical load concept facilitates communication between scientists and policy makers and land managers by translating the complex effects of air pollution on ecosystems into unambiguous numbers that can be used to inform air quality targets. Anthropogenic atmospheric nitrogen (N) deposition adversely affects a variety of ecosystems, but the information used to derive critical loads for North American ecosystems is sparse and often based on experiments investigating N loads substantially higher than current or expected atmospheric deposition. In a four-year field experiment in the northern Great Plains (NGP), where current N deposition levels range from ~3 to 9 kg N ha^{-1} y^{-1}, we added 12 levels of N, from 2.5 to 100 kg N ha^{-1} y^{-1}, to three sites spanning a range of soil fertility and productivity. Our results suggest a conservative critical load of 4 to 6 kg N ha^{-1} y^{-1} for the most sensitive vegetation type we investigated – Badlands sparse vegetation, a community that supports plant species adapted to low fertility conditions – for which N addition at this rate increased productivity and litter load. In contrast, for the two more productive vegetation types characteristic of most NGP grasslands, a critical load of 6 to 10 kg N ha^{-1} y^{-1} was identified. For these vegetation types, N addition at this level altered plant tissue chemistry and increased non-native species. These critical loads are below the currently suggested range of 10 to 25 kg N ha^{-1} y^{-1} for NGP vegetation and within the range of current or near-future deposition, suggesting that N deposition may already be inducing fundamental changes in NGP ecosystems.

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#2 - Development of a national indicator for ecosystem health in Canada using critical load exceedances

Amanda Cole[1], Andrea Darlington[2] and Anne Marie Macdonald[3]

Canada's Addressing Air Pollution Horizontal Initiative will contribute to the shared ultimate outcomes of "Canadians have clean air" and "adverse impacts on human health and ecosystems are reduced." To track the success of the activities under this Initiative, performance indicators are needed. A performance indicator to track human health risks has already been developed (the percent of the Canadian population living in areas where air quality standards are achieved), but a quantitative indicator to track long-term changes in ecosystem health is not yet established. Environment and Climate Change Canada scientists are currently developing possible ecosystem health indicators based on exceedances of critical loads of acidity. These indicators draw on the following available inputs: (1) ~10 km gridded deposition of nitrogen and sulfur based on ADAGIO (Atmospheric Deposition Analysis Generated by optimal Interpolation from Observations), a combination of measurement data and chemical model output; (2) surface water critical loads of acidity based on the steady-state water chemistry model applied to sampled lakes within a ~45 km grid cell; and (3) critical loads for terrestrial ecosystems calculated using soil data at a resolution of 250 m from SoilGrids (soilgrids.org) and scaled up to the ADAGIO grid. We discuss the options as well as how they address the challenges of developing an indicator that is representative of the state of ecosystem health, robust with respect to interannual variability and future changes in model development and measurement coverage, and that can be communicated clearly to the public and the policy community.

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#3 - A Decline in Exceedance of Critical Loads of Nitrogen for Alpine Areas in US National Parks from 2000 - 2016

Jeremy McClung[1], Michael D. Bell[2] and Emmi Felker-Quinn[3]

Anthropogenic emissions of nitrogen can travel long distances to be deposited in remote, pristine ecosystems. Thin soils, short growing seasons, and steep terrain make alpine ecosystems especially sensitive to the effects of even moderate amounts nitrogen deposition. Critical Loads of N for alpine areas for changes in vegetation communities (3.0 kg N ha-1 yr-1) and soil leaching (10.0 kg N ha-1 yr-1) have been established in Colorado. Even though the research was done outside of National Park boundaries, alpine provide a multitude of ecosystem services and natural resources that are important to protect. Thus, we extrapolated the critical loads to alpine areas within parks to inform current risk to alpine systems and how that has evolved over the past several decades. We used the USGS GAP dataset to identify alpine areas within national park units and compared the alpine critical loads to the NADP Total Deposition Model received from 2000-2002 and from 2014-2016 to determine how exceedances have changed over time.

We found that 24 of the 28 park units that had alpine area received total deposition greater than the alpine vegetation critical load of 3.0 kg N ha-1 yr-1. Of these park units, 22 of them exceeded the critical load in 75% or more of their alpine area. However, only Sequoia Kings Canyon National Park received deposition greater than the unvegetated critical load of 10.0 kg N ha-1 yr-1. The maximum total deposition the park units are receiving is on an overall decline, where 20 of the parks experienced lower maximum deposition in 2016 than they did in 2002. Most of the parks didn't show a large change in percent exceedance from the 2000 – 2002 average to the 2014 – 2016 average, but Olympic National Park and Mount Rainier National Park showed a 57% and 19% decrease in area exceeded, respectively. Crater Lake National Park showed the only noticeable increase in percent exceedance (13%) over the time period. These results can help park managers identify which alpine areas potentially at risk of change due to deposition and help guide restoration and policy actions in exceeded areas

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#4 - Critical Loads of Atmospheric Nitrogen Deposition for Aquatic Ecosystems in the Sierra Nevada, California

Leora Nanus[1], David W. Clow[2] and James O Sickman[3]

High-elevation aquatic ecosystems in Sierra Nevada wilderness areas are impacted by atmospheric nitrogen (N) deposition associated with local and regional air pollution. Documented effects include elevated surface water nitrate concentrations, increased algal productivity, and changes in diatom species assemblages. Critical loads of N deposition for nutrient enrichment of aquatic ecosystems were quantified and mapped using a geostatistical approach, with N deposition, topography, vegetation, geology, and climate as potential explanatory variables. Rather than relying on a single predictive model, multiple predictive models were developed using various combinations of explanatory variables; this approach allowed for better quantification of uncertainty and more accurate identification of the aquatic ecosystems most sensitive to high atmospheric N deposition (> 3 kg N ha^{-1} yr^{-1}). The lowest critical loads estimates (< 1.0 ± 1 kg N ha^{-1} yr^{-1}) and highest exceedances identified within the Sierra Nevada occurred in high-elevation basins with steep slopes, sparse vegetation, and areas of neoglacial till and talus. Estimated critical load exceedances correspond with areas of high N deposition and vary spatially. Broad areas of the Sierra Nevada, including areas within Yosemite and Sequoia & Kings Canyon National Parks may be impacted by excess N deposition, with greatest impact at high elevations. These results are consistent with previous analyses in the Rocky Mountains, and highlight the sensitivity of high-elevation aquatic ecosystems to atmospheric N deposition in the western United States.

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#5 - Cloud and Fog Deposition: Monitoring in High Elevation and Coastal Ecosystems. The Past, Present and Future

Selma Isil[1], Jeffrey L. Collett, Jr.[2], Peter Weiss-Penzias[3], Christopher Rogers[4] and Jason Lynch[5]

Deposition of pollutants by cloud water exceeds deposition by precipitation and dry deposition in high elevation settings. The large loading of pollutants in such environments is due to a combination of factors such as high frequency of cloud immersion, high wind speeds, orographic enhancement of precipitation, and large leaf area of tree species typical in these environments. Fog impacted coastal ecosystems also experience higher pollutant loadings similar to cloud impacted high elevation sites. Therefore, development of meaningful critical load values and total nitrogen budgets for high elevation and fog impacted sites requires reliable cloud and fog water deposition estimates. However, the cost and labor intensity of cloud water sample collection have made it difficult to conduct long-term studies that would provide the data needed to develop accurate estimates. Current understanding of fog formation, transport, and the role of fog in hydrogeological and biogeochemical cycles is incomplete due, in part, to lack of a concerted interdisciplinary approach to the problem. Historically, these obstacles have limited collection of cloud and fog water samples.

Summary results from a small cloud water monitoring network that operated in the Appalachian range from the mid-nineties through 2011, as well as a qualitative review of other cloud and fog water studies conducted in the United States, Europe, South America/Pacific, and Asia will be presented. Current research findings and collection methods will also be reviewed. Recent scientific efforts by the National Atmospheric Deposition Program's (NADP) Total Deposition Science Committee and NADP's Critical Loads of Atmospheric Deposition Science Committee have identified occult deposition as a "need" in developing critical loads for ecosystems that experience significant cloud and fog impaction. To this end, remaining knowledge gaps and suggestions for future research to investigate these gaps will be explored.

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#6 - Determining adequate levels of nitrogen and sulfur deposition to prevent harmful tree species level decreases

Justin Coughlin[1], Christopher M. Clark[2], Robert Sabo[3], Jeremy Ash[4], Jennifer James[5], Travis J. Smith[6] and Linda Pardo[7]

Ecosystems in the United States have experienced extensive nitrogen and sulfur deposition decreases over the last thirty years resulting in lower levels of acidic rain, lessening eutrophication, and declining soil acidification. As nitrogen and sulfur deposition continue to decrease, policy frameworks can be established to determine adequate levels of deposition to protect species diversity and abundance. Recent advances in quantifiable deposition effects on individual tree species in the contiguous United States (CONUS) have presented novel data on the growth and survival rates of 94 different tree species including new critical load information. Using the most current NADP total nitrogen and sulfur deposition (dry + wet) surfaces, the United States Forest Service's live tree basal area surfaces, and the newly available tree species response curves, we have generated forest-level rasters showing the net (negative and positive) effects on tree species across the CONUS from 2014-2016 averaged total nitrogen and sulfur deposition. In addition, deposition magnitude CONUS rasters have been modeled to determine levels that would ensure forest growth and survival rates do not exceed 5 and 1%, respectively. This pertinent information can be used in policy decisions to ascertain appropriate ambient level concentrations of NO_x and SO_x ensuring forests are not adversely harmed.

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#7 - Incorporating uncertainty into critical loads-based risk assessments for forest ecosystems across the continental US

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Resource managers and policy makers require information about the risk to forest ecosystems from nitrogen and sulfur deposition which continue to affect the growth and survival of trees in forest ecosystems across the US. In this assessment we compare different ways of aggregating the critical loads (CL) for multiple species in the same plot and include, for the first time, an assessment of the uncertainty associated with the critical loads. Based on a prior analysis of US Forest Service Forest Inventory and Analysis (FIA) data for more than 1.4 million individual trees measured between 2000 and 2016 and US-EPA CMAQ model deposition estimates, we found that the majority of the 94 tree species we evaluated had detrimental responses to N and or S deposition. Here we evaluate how the way the critical loads are aggregated in each plot (using an area-weighted average for the CL or selecting the most protective CL) affects the confidence in the CL across the country. This information is critical for resource managers and policy makers in decision making and represents an important enhancement in critical loads risk assessments.

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#8 - Geospatial analysis of tree species at risk from nitrogen deposition in the northeastern U.S.

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Forest health is affected by multiple stress agents (e.g. pests and pathogens, climate extremes and deposition) further influenced by site and stand characteristics. The critical load - the level of deposition below which no harmful ecological effects are expected to occur – can be used to quantify risk to forest health. In this study, Nitrogen Critical Loads Assessment by Site (N-CLAS), an online GIS analysis and visualization tool, was used to examine spatial patterns of critical loads and exceedance of N deposition for 23 tree species of management concern across 12 level III ecoregions in the northeastern United States.

This novel, high resolution (30m) landscape-scale assessment maps critical loads, target loads, and exceedances for each species present through a series of calculations that incorporate the influence of climate, topographic and soil factors that modify tree response to N deposition. For every pixel across the landscape, N-CLAS calculates an adjusted critical load for individual species and an aggregate critical load for all species present.

Our analysis indicates that most forests in the northeastern United States are at risk of detrimental effects from N deposition, although the extent and magnitude of the risk varies spatially Eighty-six percent of the forested area in the region (98M acres) is in exceedance of the critical load. The magnitude of this exceedance is highest (6-8 kg N ha^{-1} yr^{-1}) in the southwestern part of the study region where N deposition is highest (e.g. North Central Hardwood Forests, Erie Drift Plain, Driftless Area, and Southern Michigan/Northern Indiana Drift Plains ecoregions). The magnitude of exceedance is lowest (1-2 kg N ha^{-1} yr^{-1}) in the northeastern and northwestern part of the study area where N deposition is lowest (e.g. Acadian Plains and Hills and the Northern Minnesota Wetland ecoregions). White pine (*Pinus strobus*), quaking aspen (*Populus tremuloides*), yellow birch (*Betula alleghaniensis*), northern red oak (*Quercus rubra*) and bigtooth aspen (*Populus grandidentata*) are in exceedance of the critical load across large portions of the study area–between 31 to 56 million acres are in exceedance for each species. Red pine (*Pinus resinosa*), pitch pine (*Pinus rigida*), and chestnut oak (*Quercus prinus*), which occur over a small geographic extent, are in exceedance of the critical load over 89 to 100 percent of their range.

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#9 - Quantifying Lichen Community Composition, Nitrogen Content, and Nitrogen Stable Isotope Composition to Assess Nitrogen Critical Loads at North Cascades National Park Service Complex

Meaghan Petix[1], R. Dave Evans[2] and Michael D. Bell[3]

Anthropogenic nitrogen (N) deposition has contributed to ecosystem changes across western North America including disruptions in nutrient cycling and ecosystem functioning, as well as shifts in community composition of certain organisms[1]. Lands managed by the National Park Service (NPS) in the Pacific Northwest (PNW), including North Cascades National Park Service Complex (NOCA), contain ecosystems that are potentially sensitive to nutrient enrichment effects from anthropogenic N deposition[2]. This study aims to determine the extent to which ecosystems in NOCA are being affected by N deposition and to identify predominant sources of N emissions affecting the park. Our methods involve conducting lichen community surveys and collecting lichen samples for elemental analyses including N content and N stable isotope composition. Lichens can be used as indicator organisms since the relationship between N deposition and lichen N content can be determined for a region. Lichen air quality plots were established throughout NOCA in the summer of 2018 and 2019. Data from these plots will be used to develop deposition estimates and determine the spatial extent of lichen sensitivity in the park. Since lichens are one of the most sensitive communities to N pollution within an ecosystem, assessing critical loads (CLs) based on lichens helps define maximum N deposition levels that may prevent negative impacts to the broader forest ecosystem[3].

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#10 - Climate-driven weathering leads to enhanced cation and sulfate export in high alpine environments

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High elevation alpine ecosystems—the "water towers of the world"—are warming at rates that far exceed those of lower elevations. Active geomorphic features, such as glaciers and permafrost, leave alpine ecosystems susceptible to climate-induced alteration. We examined recent changes in high-elevation stream chemistry in an alpine catchment of Colorado, USA and found strong evidence of increasing sulfate and base cation fluxes. To better understand these recent changes and to examine the potential causes of increased sulfur and base cation fluxes in surface waters, we present a high resolution 33-year record of atmospheric deposition (NADP site: CO02) to evaluate what factors may be driving this shift in stream chemistry. Our mass balance analysis and other supporting data suggests that recent warming is stimulating changes to hydrology and/or geomorphic processes, which in turn lead to accelerated weathering of bedrock. There is no evidence to suggest that atmospheric deposition is responsible for elevated stream export. This trend is also represented globally including in the Rocky Mountains of the United States, western Canada, the European Alps, the Icelandic Shield, and the Himalayas in Asia. All of these locations have experienced rapid increases in temperature during recent years, suggesting a climate-controlled change in sulfur and base cation export from mountainous regions via mineral weathering.

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#11 - Effects of simulated nitrogen deposition on soil biogeochemistry in three Chihuahuan desert semi-arid grasslands

Jennifer Holguin[1] and Dr. Jennie R. McLaren[2]

In the second half of the 20th century, humans have drastically increased the global quantities of “fixed” reactive nitrogen. This increase in reactive nitrogen is primarily due to the use of inorganic N fertilizers and activities associated with the production of energy. In the atmosphere, anthropogenic reactive N can be deposited to terrestrial ecosystems via wet or dry deposition. Increasing available soil N through anthropogenic deposition can alter soil biogeochemical processes involved in nutrient cycling and the breakdown of soil organic matter. In this study we examine soil biogeochemical response to N enrichment. The Carlsbad Caverns National Park (CAVE) in New Mexico USA is currently experiencing augmented levels of N deposition possibly due to rise in oil and gas activity immediately adjacent to the park. In the summer of 2018, we established a short term (2.5 year) manipulative nutrient addition experiment in three CAVE Chihuahuan desert semi-arid grasslands. All three grasslands contain four nutrient addition treatments applied once before the monsoon season rainfall (July): Control (C) ambient N deposition ca. 4 kg N ha^{-1} yr^{-1}, 1.5x N background (1.5 N) ambient + 2 kg N ha^{-1} yr^{-1}, 2x N background (2N) ambient + 4 kg N ha^{-1} yr^{-1} and one carbon (sucrose) addition treatment (S) included to stimulate uptake and immobilization of N by microbes in attempt to reduce N in soils. Soil samples are taken three times per year during the monsoon (August), winter (February) and pre-monsoon (June) season. In the first year of sampling, treatment effects were dependent on sampling date and site. During the monsoon sampling there were no differences in soil nutrients between treatments that were consistent across sites, but during the winter sampling available soil nitrate (NO_3^-) accumulated under our highest N (N2) treatment. There were no treatment effects on Ammonium or Phosphate. Despite the effects on available soil nutrients, soil microbial functioning has yet to respond: Soil microbial extracellular enzyme activity and soil microbial biomass carbon, N and did not differ between treatments. With limited N addition studies conducted in dryland ecosystems, this study will provide insight on how N enrichment can impact dryland ecosystem function. This research will also provide useful information that will help manage and conserve ecosystems within national parks.

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#12 - Evaluating the impact of species diversity on resilience of forest growth and survival to acidic deposition

Robert Daniel Sabo[1], Christopher M. Clark[2], Kevin J. Horn[3], Justin Coughlin[4], Jeremy Ash[5], Linda Pardo[6], Travis J. Smith[7] and Quinn Thomas[8]

Temperate forest ecosystems throughout the globe are a major sink for carbon and provide other essential ecosystem services, but these services have been partly compromised by chronic exposure to acidic deposition, stemming historically from NO_X and SO_X emissions from fossil fuel combustion, for over a century. While increased rates of atmospheric N deposition, also stemming from agricultural NH_3 emissions, have also been found to contribute to selective greater growth rates in trees; it is unclear if net primary production is enhanced since these studies do not account for survival. Oftentimes, the negative impacts of S deposition on growth and survival have also not been explicitly incorporated into modeled responses to atmospheric deposition. Proper accounting of species sensitivities to atmospheric S and N deposition are imperative for evaluating the impacts of NH_3-N + NO_x-N and SO_x emissions on forest growth and survival responses. We are currently applying recently published empirical, species specific growth and survival models (n=94 species) to predict the response of 1.4 million trees observed in forest inventory analysis plots (FIA) across the contiguous United States for the year 2012. We expect forest growth and survival to be enhanced by atmospheric N deposition, but this fertilization effect is substantially offset by atmospheric S deposition and other negative effects of N deposition. In addition, we will quantify species diversity in 121,000 FIA plots and compared it to survival and growth responses across regional and national scales. We expect more diverse forests to be more resilient to higher rates of atmospheric N and S deposition. This analysis will provide pertinent information to decision makers developing management strategies to make forests more resilient to future environmental change.

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#13 - The impacts of acid rain on the water quality

Chunling Tang[1] and Jason Lynch[2]

To help manage excess nitrogen in the environment includes streams and avoid unintended consequences, it is important to better understand how land-use, water use, climate and emission changes may modulate the system's exposures to pollutants and influence management targets. The biogeochemical processing of nitrogen and associated pollutants is driven by meteorological and hydrological processes in conjunction with pollutant loading. There are feedbacks between meteorology and hydrology that will be affected by land-use change and climate change. Changes in meteorology will affect pollutant deposition. It is important to account for those feedbacks and produce internally consistent simulations of meteorology, hydrology, and pollutant loading to drive the (watershed/water quality) biogeochemical models. In this study, the ecological response to emission reductions in streams in the Potomac watershed were modeled using the linked one comprehensive/environment model, namely the linkage of Community Multiscale Air Quality (CAMQ) model, Weather Research & Forecasting (WRF) model, Variable Infiltration Capacity (VIC) model and Model of Acidification of Groundwater In Catchment (MAGIC) model from 2002 to 2010.The simulated results (such as NO3, SO4, and SBC) fit well to the observed values. The linkage provides a generally accurate, well-tested tool for evaluating sensitivities to varying meteorology and environmental changes on acidification and other biogeochemical processes, with capability to comprehensively explore strategic policy and management design.

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#14 - The Effect of Seasonal and Spatial Variability in Atmospheric Nitrogen Deposition on Biological N Cycling in Soils Along an Elevational Gradient in the Colorado Front Range

Deborah Repert[1], Sheila F. Murphy[2], Ruth C. Heindel[3], Toby A Halamka[4], Richard L. Smith[5], David Clow[6], Gregory Wetherbee[7], Ariel P. Reed[8] and Mahalie Hill[9]

Atmospheric deposition of reactive nitrogen (Nr) due to human activities can have measurable effects on ecosystem processing and export of nutrients, groundwater and surface-water quality, and soil microbial community structure and function. Rates of Nr deposition to lower-elevation forests immediately adjacent to the Denver/Boulder urban area, however, have only recently been measured. In conjunction with the Network for Urban Atmospheric Nitrogen Chemistry (NUANC) and the National Atmospheric Deposition Program (NADP), we are measuring wet-plus-dry Nr deposition and evaluating how spatial and seasonal variations in N deposition affect the ability of soil microbial communities to process N along an elevational gradient (1650 to 3000 meters) from plains to subalpine ecosystems west of Boulder, Colorado. Ecosystem response to atmospheric inputs of nitrogen depends on several factors, including elevational climate conditions (freeze/thaw cycles, precipitation), geology, soil and vegetation type, N speciation and microbial community structure. Ion-exchange-resin columns were deployed at 5 locations along the elevational gradient during spring, summer and fall seasons to measure bulk (wet-plus-dry) N deposition. Soil samples were collected seasonally at 3 of the locations and measured for nitrification potential and net N mineralization rates to assess the role that the microbial community plays in processing nitrogen. Results indicated that nitrification potential rates were up to 2 times greater at the lowest elevation site, where nitrogen loads and percent soil carbon and nitrogen were higher. Net N mineralization rates were 3 times greater at the highest elevation site in the fall despite lower nitrogen loads from precipitation. This research facilitates a greater understanding of the role of the microbial community in processing atmospheric nitrogen deposition in the urban-foothills transition of the Colorado Front Range.

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#15 - Nitrogen deposition sources and patterns in the Greater Yellowstone Ecosystem determined from ion exchange resin collectors, lichens, and isotopes

Abigail Hoffman[1], Jill McMurray[2], Shannon Albeke[3], Dave Evans[4] and David Williams[5]

Regional patterns of atmospheric nitrogen deposition (N_{dep}) are often estimated using direct measurements from large-scale monitoring networks and atmospheric chemistry models. However, in the western U.S., complex topography and weather patterns lead to heterogeneous deposition patterns that are difficult to predict. Additionally, $\delta^{15}N$ values of deposition may inform sources of N. This study aimed to understand N_{dep} patterns in mountainous ecosystems and how isotope values, lichens and throughfall deposition can be used to determine N_{dep} sources and patterns in the Greater Yellowstone Ecosystem (GYE). In addition, we measured C:N ratios in lichens as an indicator of lichen physiological condition and ecosystem response to N_{dep}. We established ion exchange resin collectors and collected two lichen species (*Letharia vulpina* and *Usnea lapponica*) at 15 sites at four transects across the GYE. Mean summer N_{dep} measured by bulk collectors at each site ranged from 0.26 kg ha^{-1} to 1.66 kg ha^{-1}. In remote areas, N_{dep} was higher than expected based on other studies in the area. The $\delta^{15}N$ values of lichens were typically -15.3 to -10‰ suggesting agriculture as a primary emission source of deposition. C:N ratios for *L. vulpina* in this study ranged from 29.4 to 48.7, while for *U. lapponica*, C:N ratios ranged from 22.7 to 39.2 where lower C:N ratios indicate more N_{dep}. Overall, this study suggested that while regional patterns of N_{dep} can be estimated with modeling and large monitoring networks, N_{dep} also varies on small spatial scales that are more difficult to measure and lichen %N, $\delta^{15}N$ and C:N ratios can provide information about N_{dep} sources and patterns in complex terrain.

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#16 - Establishment of a reactive nitrogen monitoring network in Mexico City

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With more than 20 million inhabitants, as well as being located in a closed basin at an altitude of 2240 meters above sea level, the Mexico City Metropolitan Zone (MCMZ) represents a great challenge in terms of air pollution.

One of the issues that has been gaining great importance in recent years is reactive nitrogen, which includes oxidized (NOx and NOy), reduced (NH_3 and NH_4^+) and organic forms of nitrogen in gases and aerosol. To develop effective strategies for controlling secondary particulate matter (i.e., ammonium sulfate and ammonium nitrate), it is necessary to characterize both oxidized and reduced forms of nitrogen in the atmosphere of the MCMZ.

Since 1990, the air quality of criteria pollutants in the MCMZ has been evaluated through the Automatic Atmospheric Monitoring Network (RAMA), consisting of 34 air quality monitoring stations, and since 2002 wet atmospheric deposition has been monitored through the Atmospheric Deposition Network (REDDA) consisting of 16 sampling stations. Among the parameters that are determined in ambient air are nitrogen compounds in their oxidized form, such as nitrogen oxides (NOx). In wet atmospheric deposition, oxidized nitrogen is determined as nitrates (NO_3^-) and in its reduced form as ammonium (NH_4^+). The foregoing indicates the need to determine the reduced nitrogen in ambient air through the establishment of an ammonia (NH_3) measurement network. The trends of nitrogen compounds are presented in this study, and the establishment of an NH_3 network, considering some of the stations of the RAMA and the REDDA, is discussed.

The stations proposed for the NH_3 network consist of six sites, two of them in the North MCMZ located in areas of industrial activity, one in the central zone with high population density and commercial activity, another in the eastern zone with industrial activity and two in the South zone with residential land use.

In order to identify the possible contribution of mobile sources to NH_3 emissions, mainly due to the reduction of NOx to NH_3 by three-way catalytic converters, NH_3 measurements will be co-located with carbon monoxide analyzers to determine the correlation between both pollutants.

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#17 - Seasonal and Elevational Trends of Wet and Dry Atmospheric Nitrogen Deposition Along the Front Range of Colorado, USA

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Atmospheric reactive nitrogen deposition plays a key role in nutrient cycling in montane and alpine ecosystems. Anthropogenic sources of nitrogen deposition can have adverse and poorly constrained effects. Current models that predict atmospheric nitrogen deposition in Colorado are based on high elevation, alpine monitoring sites. We hypothesize that rates of reactive nitrogen deposition in the foothills ecozone are higher than models suggest due to proximity to the urbanized Denver/Boulder area. In collaboration with the Network for Urban Atmospheric Nitrogen Chemistry and the National Atmospheric Deposition Program, this study seeks to bridge the gap between urban and alpine monitoring by studying wet plus dry nitrogen deposition in the montane and foothill regions near Boulder, Colorado. Low-cost ion-exchange resin columns were deployed for multiple two-month collection periods across an elevational transect starting in the urban center of Boulder and extending up to the University of Colorado's Mountain Research Station at approximately 9,500 feet elevation. Preliminary results indicate that ammonium and nitrate concentrations are greater than previously measured in the foothills region and that dry deposition contributes as much as twice the amount of reactive nitrogen than wet deposition alone. Our data also find that atmospheric nitrogen deposition rates for the foothills are underestimated by current models. We need this type of study to understand the spatial extent of the urban signal of reactive N deposition.

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#18 - What controls gas phase acid exchange over forests? Investigating fluxes of HNCO and other organic acids over a pine forest

Ryan Fulgham[1] and Dr. Delphine K. Farmer[2]

Isocyanic acid (HNCO) is a water-soluble organic acid of interest to the atmospheric chemistry community due to its potential toxicity and its production mechanisms from oxidation of reduced organic nitrogen molecules. One key uncertainty in the isocyanic acid literature has been its dry deposition rate. We measured isocyanic acid fluxes using an acetate chemical ionization mass spectrometer coupled to the eddy covariance technique over a rural Colorado pine forest during multiple seasons. HNCO mixing ratios ranged from 0 – 130 ppt, consistent with other clean continental sites in the United States. However, while HNCO deposited from the atmosphere to the surface most evenings and during daytime during some seasons, many observed daytime HNCO flux periods showed upward fluxes. Quality-filtered HNCO fluxes ranged from -69 – 71 nmol m^{-2} h^{-1} with observed seasonal medians that are upward in winter (0.63 nmol m^{-2} h^{-1}) and fall (2.5 nmol m^{-2} h^{-1}), but downward in spring (-0.29 nmol m^{-2} h^{-1}) and summer (-5.3 nmol m^{-2} h^{-1}). Of course, an observed flux is the sum of all ecosystem sources and sinks. Here, we explore these initially puzzling results by exploring ecosystem interactions with gas phase acids, with particular emphasis on the role of water films in controlling exchange velocities of isocyanic acids. We extend the analysis to observed fluxes of other volatile organic acids to investigate persistent ecosystem sources over this forest site.

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#19 - Sensitive and Selective Organic Nitrogen Measurements: Applications of Ethanol Chemical Ionization Mass Spectrometry

Jennifer Berry[1] and Eleanor Browne[2]

Organic nitrogen (ON) is ubiquitous in our environment, accounting for ~30% of atmospheric reactive nitrogen and found in gaseous, particulate, and aqueous phases. ON remains relatively unstudied compared to inorganic nitrogen because of the analytical difficulties that arise from ON's chemical complexity. Ethanol chemical ionization mass spectrometry (CIMS) is a developing technique that is sensitive and selective towards ON. The CIMS used by our group couples chemical ionization with high-resolution time-of-flight mass spectrometry so multiple compounds can be identified at the same unit mass, leading to clear identification of important amines, amides, and urea. Additionally, our CIMS has high temporal resolution with *in-situ* measurements of ~1 second. Together this means that CIMS can identify and track the temporal trends of key ON compounds simultaneously, providing more in-depth information than the traditional total/inorganic nitrogen difference method. New developments in CIMS instrumentation opens up the possibility for eddy covariance flux measurements for a wide range of ON compounds. Eddy covariance measurements require fast *in-situ* techniques that are accurate and precise. The crossflow CIMS has new inlet that reduces wall-interactions without decreasing signal or reaction times, essential for accurate real-time covariance measurements. Flux measurements with CIMS would lead to a greater understanding of ON deposition, emission, and sinks. While CIMS can be used in the field to directly measure gas-phase compounds, it can also be used with remote, inexpensive measurement techniques like passive gaseous samplers that can be deployed in isolated, challenging locations. The applicability and versatility of CIMS will help determine the role of ON in air quality and atmospheric deposition across many ecosystems.

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#20 - An investigation into the importance of amine compounds to organic nitrogen in aerosol

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Organic nitrogen has been studied sparsely in wet deposition measurements and to better understand the sources and importance of organic nitrogen in deposition, we need to understand the forms of organic nitrogen in ambient atmosphere. In Northeastern Colorado agriculture is an importance source of atmospheric nitrogen compounds, specifically and most commonly studied is ammonia. However, amines are also emitted from a variety of agricultural activities but few studies have focused on these organic nitrogen compounds and the processes that these compounds will undergo to form particulate matter.

A set of samples from the spring of 2019 (April) were collected using URG denuder/filter-pack sampling in the following Colorado locations: Greeley, Fort Collins, and in Rocky Mountain National Park (RMNP). These samples were analyzed for a suite of amine compounds, inorganic ions, and total nitrogen (TN). Additionally a Micro-Office Uniform Impactor Depositor (MOUDI) was operated at the Fort Collins site to collect highly resolved size distribution data was collected for the summer and winter seasons. The MOUDI samples were analyzed for inorganic ions, amines, and organic acids to assess the processes that were forming amine particulate. While 16 different amines were analyzed, there were several that were observed below the detection limit. The amines that were observed in higher concentrations included methylamine, dimethylamine, trimethylamine, tert-butylamine, sec-butylamine, iso-butylamine, and amylamine.

In this study we will examine the contribution of amines to total organic nitrogen and the inorganic nitrogen species measured. We will also investigate the size distribution of the various measured species to better understand aerosol formation processes in the region. Amines were generally greatest in concentration at the Greeley site and smallest in concentration at the RMNP site, as we expected due to proximity of sources. Overall, the combined analysis of spatial and size resolved data gives a first insight into the quantification of amines for this area.

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#21 - Development and Assessment of a Method for Determination of Total Nitrogen in National Atmospheric Deposition Program (NADP) Precipitation Samples

Marie Assem[1], Chris Worley[2] and Martin Shafer[3]

NADP currently monitors the two major inorganic nitrogen species (ammonium (NH4) and nitrate (NO3)) in the National Trends Network (NTN) wet deposition samples. However, nitrogen-containing organic species such as proteins and urea can also be present in precipitation – the levels of which are poorly characterized. A few studies have shown that the contribution of organic species of nitrogen to total nitrogen (TN: org-N + inorg-N) in precipitation is very significant (20-40%), but much uncertainty remains about the regional contribution of organic nitrogen species to total nitrogen deposition. In part, the paucity of TN data reflects the limited availability of routine and robust methods for organic nitrogen quantification.

In this study we investigated the application of a total nitrogen method that uses a potassium persulfate digestion (EPA method 353.2 and Wisconsin State Laboratory of Hygiene (WSLH) Method ESS INO Method 240.0) to recover organic nitrogen species. The digestion is designed to convert (oxidize) all forms of nitrogen to nitrate which is then quantified by the robust NADP Flow Injection Analyzer (FIA) method. In the FIA method nitrate is reduced to nitrite (NO2) using a copperized cadmium column and the nitrite is then determined by diazoting with sulfanilamide and coupling with N-(1-naphthyl) ethylenediamine dihydrochloride, forming a colored azo dye which is measured by colorimetric detection at 520nm. Organic nitrogen is calculated as the difference between this TN measurement and the sum of the routinely measured inorganic species (nitrate and ammonium).

To evaluate the efficacy of this approach we assessed the recovery of specific representative and relevant organic and inorganic nitrogen species (nitrate, ammonium, dimethylacetamide, glycine, L-Methionine and urea) from spiked samples using the above method. Method detection limits (MDL) were also determined. A 2 cm flow cell (twice the path-length of the standard analytical protocols) was employed to further improve quantification limits. Our efforts will be framed in the context of determining the feasibility of integrating TN measurements into the CAL/NADP processing of NTN samples.

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#22 - Agricultural Ammonia Monitoring

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Recently, due to the frequent occurrence of high concentration of fine dust, concerns about the impact of particulate matter on the health of the citizens have increased. Consequently, interest in air quality management policy has also risen. In Korea, it is now an everyday routine to check the concentration of particulate matter before going out, just like checking weather information before leaving home. Citizens are deeply aware that high concentrations of fine particulate matter threaten the health of children and the elderly. Particulate matter is emitted from various air pollutant emission sources and, particularly, fine particulate matter is known to be generated secondarily in the atmosphere. Ammonia (NH_3) generated from the agricultural sector is known as a precursor to fine particulate matter. Fine particulate matter ($PM_{2.5}$) which is secondarily generated is more dangerous to human bodies than particulate matter (PM_{10}) and it is generated in the air by chemical reaction with various substances such as nitrogen oxides (NOx) and sulfur oxides (SOx). Agriculture is a complex system with a wide field and includes a biological system. Reducing ammonia rather than nitrogen oxides and sulfur oxides is effective in reducing the occurrence of fine particulate matter, and 50% reduction of ammonia emissions in northern Europe could reduce fine particulate matter in winter by up to 25%. There are various research results which say that the most effective method to reduce fine particulate matter is to control ammonia. Therefore, it is necessary to monitor the amount of ammonia generated in the agricultural sector. Accordingly, we are planning to establish a long-term monitoring system for ammonia and air pollutants in agricultural areas. The ammonia and air pollutant observatory site is planning to select and install monitoring systems focusing on large-scale agricultural areas in the paddy area, upland crop area, cultivation under structure area, and fruit tree growing area. The samples are to be collected from atmospheric dry samples, wet samples, PM_{10}, and $PM_{2.5}$. The major analytical items are ammonium ion (dry and wet) and gaseous ammonia (passive atmospheric sampling). From this year on, we are conducting research projects which are developing of the emission inventory of ammonia for paddy rice, upland crops and plastic house cultivation crops. Crop land sector needs to enhance, to newly develop emission factors by crop, cultivation method, nutrient input material (urea fertilizer, cow manure compost, pig manure compost and poultry manure compost), application time, and cultivation environments in Korea. The status and characteristics of ammonia emission by major crop cultivation areas in the agricultural sector will be analyzed and the characteristics of ammonia and air pollutant emissions in the agricultural area with the national atmospheric ammonia concentration, urban air pollution observation network, and emission characteristics of atmospheric pollutants will be compared. This is expected to secure these agricultural ammonia monitoring systems in the agricultural sector which provide long-term monitoring data on the ammonia and air pollutant concentration and emission characteristics of agricultural areas. Such systems are anticipated to provide scientific data for establishing a management policy for the agricultural sector, national particulate matter, and air quality.

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#23 - Ammonia and amine contributions to the atmosphere from animal production

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In recent years, a greater focus in the atmospheric community has been placed on reduced nitrogen contributions to the atmosphere. There is greater uncertainty in reduced nitrogen budgets due to the dominance of agricultural and area source emissions. However, data suggest that ammonia is one of the air emissions that has been increasing in recent decades, and it is unclear the full extent of the contributions. Agriculture is a source where available emissions information from different source categories is lacking. In this presentation we will discuss gaps in agricultural emissions inventories and their impact on understanding of atmospheric chemistry and modeling of air quality. We will also discuss experiments conducted to measure concentrations of ammonia and organic nitrogen (amines) at animal feeding operations. Experiments have been conducted from swine, dairy, poultry, and mink operations. Ammonia concentrations near animal facilities are measured at part-per-million levels near source. Organic nitrogen compounds such as amines are typically present several orders of magnitude lower than the ammonia. While indications are that ammonia is elevated at all of them, the organic-nitrogen contributions appear different from the limited studies we have conducted. It will take more work to verify whether this is generally true, but this could potentially provide a method for distinguishing nitrogen emissions between different agricultural sub-sectors. In addition, there is an indication that some amines are enriched in particulate matter near source compared to ammonia or other amines.

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#24 - An Integrated N Cycling Approach with Agriculture, Atmosphere, and Hydrology Models

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Human activities such as agricultural fertilization and fossil fuel combustion have introduced a massive amount of anthropogenic nitrogen (N) in reactive forms to the environment. As agricultural fertilization is the single largest anthropogenic N source, an integrated approach to understand the interactions among agriculture, atmosphere, and hydrology is essential in examining human-altered N cycling. Here we present an integrated modeling system (IMS) with agriculture (EPIC - Environmental Policy Integrated Climate), atmosphere (WRF/CMAQ - Weather Research and Forecast model and Community Multiscale Air Quality), and hydrology (SWAT - Soil and Water Assessment Tool) models to assess the interactions among land-air-water processes. The centerpiece of the IMS is the Fertilizer Emission Scenario Tool for CMAQ (FEST-C) which includes a Java-based interface and EPIC adapted to regional applications along with built-in database and tools. The Linux-based interface guides users through EPIC simulations for any CMAQ grid domain over the conterminous United States (CONUS) and integration among the multimedia models.

This presentation focuses on the description of the currently released FEST-C and the impact assessment of agricultural fertilization on air quality through an improved CMAQ bi-directional ammonia approach. As N deposition is also an important source altering N cycling, the influence of nitrogen deposition along with weather variability on cultivated soil N budget will also be examined for CONUS. The system is applied over CONUS with a 12km resolution for 2010, 2011, and 2012. EPIC simulations are conducted using WRF/CMAQ weather and N deposition for these years and cases adjusted to represent conditions in the early 1990s for assessing the impacts of N deposition reduction since 1990 due to tightened NO_X emission standards under the Clean Air Act (CAA). SWAT integrated with EPIC and WRF/CMAQ are then applied to the Mississippi River Basin (MRB) to simulate watershed hydrology and water quality for these years under different N deposition conditions. Preliminary results demonstrate that air quality linked with simulated agriculture improves NH_3 flux estimation and results in better performance for N cycling in the atmosphere. The N budget in agricultural production is sensitive to weather variability and atmospheric N deposition with increased N fertilization and decreased N loss in areas with N deposition reduction. In addition, the impact of N deposition reduction on N losses from MRB to the Gulf of Mexico will be analyzed and presented to show the effect of CAA policies on water quality for the biggest drainage basin in North America.

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#26 - Estimating Sources, Sinks, and Fluxes of Reactive Nitrogen and Sulfur within a Mixed Forest Canopy Using Eulerian and Lagrangian Inverse Models

Zhiyong Wu[1], John T. Walker[2], Xi Chen[3], A. Christopher Oishi[4], Tomer Duman[5] and Donna Schwede[6]

The behavior of reactive compounds in the atmosphere and their interaction with ecosystems could vary due to differences in the processes of physical transport, deposition on surfaces, biological uptake or release, and chemical transformations. Vegetation and soils can act as a source or a sink for such pollutants, and this behavior can differ near the ground, at the canopy top, or above it. Therefore, estimating the source/sink vertical distribution of air pollutants within and above forested canopies is critical for understanding the fate of these compounds and their effect on vegetation functioning. Since direct measurements of these sources or sinks are difficult to conduct, measured concentration profiles can be used to inversely infer the effective source-sink distribution. In this work, the vertical source-sink profiles of reactive nitrogen and sulfur were examined using multiple inverse modeling methods in a mixed hardwood forest in the southern Appalachian Mountains, which is a region sensitive to deposition of nutrients and acidity. Measurements of the vertical concentration profiles of ammonia (NH_3), nitric acid (HNO_3), sulfur dioxide (SO_2), and ammonium (NH_4^+), nitrate (NO_3^-), and sulfate (SO_4^{2-}) in $PM_{2.5}$ were measured at the Coweeta Hydrologic Laboratory during five intensive sampling campaigns between May 2015 and August 2016. The mean concentration of NH_3 decreased with height in the upper canopy and increased below the understory toward the forest floor. All other species exhibited patterns of monotonically decreasing concentration from above the canopy to the forest floor.

Using the measured concentration profiles and within-canopy flow fields, we estimated the vertical source-sink flux profiles using three inverse approaches: a Eulerian high-order closure model (EUL), a Lagrangian localized near-field (LNF) model, and a new full Lagrangian stochastic model (LSM). Models predicted positive (upward) NH_3 fluxes near the forest floor, indicating emissions from the litter or soil. The modeled above-canopy flux of NH_3 tended to be negative (downward), indicating that the forest was a net sink of NH_3. The modeled flux profiles of HNO_3 and SO_2 presented a monotonically decreasing trend with most uptake occurring in the upper canopy. Significant differences in the estimated flux profiles can be found between different models and for different timescale inputs. The vertical distributions of fluxes from the inverse models were compared with net canopy-scale, stomatal, cuticular, and soil fluxes estimated from resistance-based big-leaf models. This study provides new insight into atmosphere-biosphere exchange of reactive compounds in forest ecosystems and advances the development of soil-vegetation-atmosphere models capable of partitioning canopy-scale deposition of nitrogen and sulfur to specific ecosystem compartments.

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#28 - Simulation of Atmospheric Mercury using the Model for Prediction Across Scales

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Mercury (Hg) in the atmosphere is distributed globally, but global-scale modeling of atmospheric Hg, as with any other reactive constituent, presents challenges. Coarse spatial discretization is often used to achieve global coverage without incurring excessive computational cost. However, certain forms of mercury deposit rapidly from the atmosphere and fine-scale modeling is required to address this. Regional models covering a limited area have been applied within global models, but getting them to work together requires interpolation and/or averaging in time and space. The use of different treatments between the global and regional models for physicochemical processes affecting Hg has been shown to induce unrealistic artifacts. Another shortcoming is that feedback from the regional scale to the global scale (upscaling) is often neglected.

The U.S. Environmental Protection Agency (EPA) recently began development of a new generation of air quality model based on the Model for Prediction Across Scales (MPAS). This new modeling system is intended to provide a global complement to the Community Multiscale Air Quality (CMAQ) model. MPAS is comprised of separate interoperable programming components with each designed to simulate atmospheric, oceanic and other earth-system media in concert and on a global scale. MPAS uses an irregular horizontal grid based on Spherical Centroidal Voronoi Tesselations (SCVTs) producing a mesh of polygonal elements covering the globe without the polar singularities intrinsic to orthogonal grids. The mesh elements can vary in size to provide fine resolution only where needed. Gradual mesh refinement can be used to avoid the abrupt changes in resolution that have been difficult to treat with traditional grid nesting approaches. In addition, the same chemical and physical treatments can be used in all grid elements and upscale effects are intrinsically simulated. Initially, this next-generation model will simulate the pollutants currently treated in the CMAQ model, including Hg. CMAQ also treats the effect of bromine (Br) emission on tropospheric ozone chemistry. Future work to add Hg-Br chemistry could provide additional benefit to mercury simulations. Besides atmospheric Hg modeling, MPAS could eventually provide a consistent and seamless approach to including the oceans and other earth systems in simulations of the entire mercury cycle.

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#29 - Use of ecosystem-level flux measurements to improve atmosphere-surface exchange parameterization of elemental mercury in chemical transport models

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To simulate global mercury (Hg) dynamics in chemical transport models (CTMs), surface-atmosphere exchange of gaseous elemental mercury, Hg^0, is often parameterized based on a resistance-based dry deposition scheme coupled with a re-emission function from soils. Despite extensive use of this approach, direct evaluations of this implementation against field observations of net Hg^0 exchange flux are lacking. In this study, we evaluate an existing net exchange parameterization (referred to here as the base model) by comparing modeled fluxes of Hg^0 to fluxes measured in the field using micrometeorological techniques. Comparisons were performed in two terrestrial ecosystems: a grassland site in Switzerland and an Arctic tundra site in Alaska, U.S. in summer and winter. The base model included the dry deposition and soil re-emission parameterizations from Zhang et al. (2003) and the global CTM GEOS-Chem, respectively. Comparisons of modeled and measured Hg^0 fluxes showed large discrepancies, particularly in the summer months when the base model overestimated daytime net deposition by approximately 9 and 2 ng m^{-2} h^{-1} at the grassland and tundra sites, respectively. In addition, the base model was unable to capture a measured nighttime net Hg^0 deposition and wintertime deposition. We conducted a series of sensitivity analyses and recommend that Hg simulations using CTMs: (i) reduce stomatal uptake of Hg^0 over grassland and tundra in models by a factor from 5-7; (ii) increase nighttime net Hg^0 deposition, e.g., by increasing ground and cuticular uptake by reducing the respective resistance terms by factors of 3-4 and 2-4, respectively; and (iii) implement a new soil re-emission parameterization to produce larger daytime emissions and lower nighttime emissions. We conclude that the resistance-based model combined with the new soil re-emission flux parameterization is able to reproduce observed diel and seasonal patterns of Hg^0 exchange in these ecosystems. This approach can be used to improve model parameterizations for other ecosystems in which flux measurements are available.

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#31 - Long-term monitoring of precipitation chemistry. Insights into environmental changes from Hubbard Brook and the MAP3S/AIRMoN network

Tom Butler[1], Gene E. Likens[2], Francoise Vermeylen[3], Roger Claybrooke[4] and Robert Larson[5]

The NADP/NTN network began operations in 1978, but a longer record of precipitation chemistry is available from the Hubbard Brook Experimental Forest in NH (started in 1963), some independent monitoring in New York State (1970 and 1971), and the MAP3S network which began in 1976 and evolved into the NADP/AIRMoN network. We use annual data from these long-term records, and other published data, to enhance the precipitation chemistry record previous to the establishment of NADP. We also examine the importance of the entire record from all of these stations and/or networks to show how they resulted in a better understanding of precipitation chemistry, and the implications of this record for promoting policy to improve air quality and reduce atmospheric pollutant loading such as acid rain. Combining the Hubbard Brook record, and the 5 longest operating MAP3S/AIRMoN sites (IL11, NY67, DE02, PA15 and TN00) a mixed model statistical analysis show overall declines in concentrations of H^+, SO_4^{2-} and NO_3^- from 1981 to 2017 of 85%, 80% and 66%, respectively. Calcium concentration shows a 13% decline and NH_4^+ shows no change.

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#32 - Comparison of Wet Deposition Collectors at a High-Elevation Site, Central Rocky Mountains

Banning Starr[1], Timothy Fegel[2], Charles Rhoades[3] and Kelly Elder[4]

Wet deposition (wetfall) measurements are a key component of long-term biogeochemical research and monitoring at the Fraser Experimental Forest, central, Colorado. Measurements have been ongoing since 1984 at the 2745 m, snow-dominated, lodge pole pine forest site. During the majority of this time the Aerochem Metrics (ACM) model 301 collector has been used. The ACM model has been used for decades nationwide, and has been the primary sampler used within the NADP program. In 2011 a sampler of different design, the N-CON Systems Company model 00-120, was installed at the site, and the instruments operated in tandem and the number of opening/closing events were recorded. Design differences in precipitation detection between the two samplers resulted in N-CON sampler opening approximately 10 times more frequently than the Aerochem. Based on this difference in collection sensitivity, frequency and duration, we hypothesized differences in wetfall collection amounts and chemistry between the two sampler types.

We compared collection weights and chemistry between the two collocated samplers over the course of almost two years (January 2017-November 2018). Weekly samples (n=132 per collector), were analyzed for total collection weight, EC, ANC, pH, sodium, calcium, chloride, nitrate and sulfate. Summer and shoulder season comparisons between the samplers show no weight differences between the samplers (summer $p = 0.67$; shoulder $p = 0.37$). However, winter collection weights were, on average, marginally higher in the N-CON (0.64 kg), than in the ACM (0.49 kg) ($p = 0.1$). This is in line with our field observations noting the N-CON collector reacting to the onset of storms well before the ACM. Wetfall concentrations were strongly correlated ($R^2 = 0.85$) between collectors with slopes near 1 for EC, calcium, nitrate and sulfate. Nitrate ($p=0.1$) and sulfate ($p=0.05$) concentrations were higher in the N-CON collector, but other constituents did not differ between the collectors.

Though we document differences in constituent concentrations for a few constituents, the distinct collection duration of the two samplers had little overall effect on weekly chemical inputs. The lack of disparity may be due to dilution effects of smaller event differences by the larger volume of bulk collection at a weekly timescale. Although this study reports few differences in chemical input between the two collector types, further investigation may highlight event-based differences in precipitation volume and chemistry.

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#33 - Modernization of the Quality Control Software used by the Canadian Air and Precipitation Monitoring Network (CAPMoN)

Kulbir Banwait[1] and Bill Sukloff[2]

The Canadian Air and Precipitation Monitoring Network (CAPMoN) is funded and operated by Environment and Climate Change Canada (ECCC). It is an air-quality monitoring network consisting of twenty-eight sampling stations (one in the U.S.) at rural and remote locations. Its measurements support the Canada-U.S. Agreement on Air Quality, the Canadian Ambient Air Quality Standards for sulphur dioxide, ozone and fine particulate matter, and the Canada-Wide Acid Rain Strategy for Post-2000. CAPMoN monitoring of the major ions in precipitation follows the guidelines of the World Meteorological Organization's (WMO) Global Atmosphere Watch (GAW) Precipitation Chemistry Programme and have been included in global assessments and model intercomparison studies. Since 1993, data from continuous monitors and post-laboratory analysis results have been quality controlled by an in-house developed software package called the Research Data Management and Quality Control (RDMQ) System. This software is based on the Statistical Analysis System (SAS ©). The RDMQ System loads data, applies customized quality-control checks and assigns data quality and validity flags. The system includes an interface to view, plot, and assign manual flags to data. After 27 years in operation, CAPMoN is modernizing the software and approach used to quality control the data. This poster describes the approach, expected benefits, and output of the new design.

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#34 - Network to Network Synergies: The National Atmospheric Deposition Program and National Ecological Observatory Network

Michael SanClements[1], Robert Lee[2] and Rommel Zulueta[3]

Ecological research is increasingly embracing the concept of the 'macrosystem': a collection of ecological systems interacting over large temporal and spatial scales. Macrosystem research requires comprehensive datasets covering broad geographic areas and preferably long timescales. The National Ecological Observatory Network (NEON) represents a concerted effort to collect a robust and diverse suite of ecological data from 81 sites across the United States over 30 years. Included in the NEON design is the collection and dissemination of wet deposition chemistry from 41 NEON sites (37 terrestrial and 7 aquatic). Thirteen NEON wet deposition collects are co-located (five less than 0.5 km) with existing NADP sites. NEON analyzes for a nearly identical suite of chemistry as NADP (major ion concentrations, pH, and conductivity), but there is some potentially important variation in collection methods with respect to sampling frequency and the collector used. Here we present plans for a preliminary study using co-located NEON and NADP sites to assess the interoperability of wet deposition data from the two networks.

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#35 - NADP Archive Process and Program for NTN, AMoN, and AIRMoN Samples

Nichole Davis[1], Richard Tanabe[2] and Amy Mager[3]

After samples from sites are received, processed, and analyzed by the Central Analytical Lab (CAL), they are archived for future use. The National Trends Network (NTN) weekly rainwater samples are filtered into a 60 mL bottle, and placed in a freezer. The Atmospheric Integrated Research Monitoring Network (AIRMoN) samples are received in a 250 mL bottle and placed in a cooler. Once the analytical data is published, the sample is poured into a 60 mL bottle and kept in the cooler. The Ammonia Monitoring Network (AMoN) samplers are processed and placed in a sealed test tube. Theses samples are kept in the freezer, as well. All samples are logged into our FreezerPro software to organize their location in their respective cooler or freezer. Archive samples are available upon request by researchers for special projects. After six years, NTN archived samples are disposed. There are a set of regionally spaced sites , fixed and forever sites, for which the archived samples are not disposed. AIRMoN and AMoN archive samples are disposed of after two years.

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#37 - Reactive Nitrogen and Phosphorus Comparisons Between Co-located NTN and AIRMoN Sites

Camille Danielson[1], Sisi Xu[2], Martin Shafer[3] and Chris Worley[4]

In this study we compared ammonium, nitrate, chloride, and phosphate concentrations in samples from co-located NADP AIRMoN and NTN samplers. AIRMoN collections are event-based, stored at 4°C (after collection) and not filtered, while the weekly NTN samples are at ambient temperature (until received at the lab where they are stored a 4°C) and filtered in the laboratory. Our primary goals were to characterize the contribution of particulate phosphorus (comparing AIRMoN – NTN) to total phosphorus and to evaluate whether significant losses or interconversion of reactive nitrogen species is observed in the NTN collections.

NADP data from four sites (IL11, PA15, TN00 and VT99) with co-located collectors covering the period from 2011 to 2017 were used in this study. Only samples with phosphate^{-}concentrations equal to or greater than the mean method detection limit for that time period (0.005 mg/L) were included. Sixty-two samples from 2011 to 2017 met this criterion. Volume-weighted average weekly concentrations from the AIRMoN events were determined and compared with the measured NTN concentrations for the same time period.

Precipitation volumes and chloride concentrations (chosen as a conservative element with only minimal expected particulate contribution) between collectors were nearly identical (r^2 and slope = 0.954 and 0.955 and 0.961 and 0.977 for precipitation and chloride respectively), therefore direct comparisons can be made between collectors for the primary study species. The reactive nitrogen species was determined using the sum of the volume weighted ammonium and nitrate from each sample. Reactive nitrogen was highly correlated (r^2 = 0.938) with a slope of 1.02 indicating that losses and interconversion of these nitrogen species are small in NTN collection. However, phosphate levels were dramatically lower in NTN collections compared with AIRMoN samples and were poorly correlated (r^2 of 0.0011). AIRMoN samples were 67.7% higher in phosphate. This difference may be attributed to a large particulate bound phosphorus component that is not captured in the NTN collections due to sample filtration. Thus, total phosphorus wet deposition cannot be estimated from current NTN protocols and would require analysis of an unfiltered sub-sample or separately quantifying the phosphorus on the filter. In planned future studies we will examine the efficacy of MDN collections for phosphorus total wet deposition measurements.

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#38 - Evaluation of Filtering Methods for Low Volume Precipitation Samples

Camille Danielson[1] and Katie Blaydes[2]

Upon arrival at the National Atmospheric Deposition Program (NADP) central analytical lab (CAL) the National Trends Network (NTN) precipitation samples are assessed for volume and fall into one of three categories. The three categories are:

1. Wet Incomplete (WI) volume 1 -11 mL. Volume-permitting, samples are analyzed for as many chemical species as possible. Samples are not filtered or diluted (unless analytically necessary) and aliquots for pH and conductivity are not poured-off. Analysis priority starts with ammonium and continues in the priority order of NH_4^+ first, then acid anions Cl^-, NO_3^-, SO_4^{2-} and then base cations Na^+, K^+, Ca^{2+}, Mg^{2+}.

2. Wet Dilute (WD) volume 12 to 30 mL. Aliquots are poured-off for pH and conductivity (this removes ~8 mL) and the remaining volume is filtered using PALL® 47 mm 0.45 um polyethersulfone filter and then diluted (by weight) to 25.0 mL to enable analyses for the full suite of analytes.

3. Wet (W) volume > 30 mL. Aliquots are poured off for pH/conductivity, sample is filtered using a PALL® 47 mm 0.45 um polyethersulfone filter but not diluted (unless analytically necessary) and will be analyzed for the full suite of analytes.

There are several major potential disadvantages to the treatment of the WI samples. They are prepared differently than the W and WD samples due to lack of filtering and they often cannot be analyzed for all the analytes. The lack of filtering may be biasing the results for some analytes in comparison to a filtered samples. In addition, introducing samples with significant amounts of particulate matter directly into the instruments (Ion Chromatographs, Inductively Coupled Plasma and Flow Injection Analysis) can cause damage to instrument components and affect sample analysis.

Therefore, this study was undertaken to determine the comparability of PALL Acrodisc® 13mm (0.45 µM) Supor® syringe filters to the PALL® 47 mm (0.45 µM) filters currently used for the WD and W samples. The filter components have the same pore size and are made from the same kind of polyethersulfone material but the syringe components and process could have an effect on the sample. If the filtrates from both methods are comparable then a proposal to change the treatment of WI samples (and possibly WD samples) to incorporate syringe filtration and dilution will be made. The study utilized 12 NTN samples; most of which contained visible debris or pollen. Each sample had a variety of treatments analyzed for all NADP analytes (NH_4^+, PO_4^{3-}, Cl^-, NO_3^-, SO_4^{2-}, Na^+, K^+, Ca^{2+}, and Mg^{2+}). The treatments included: unfiltered, filtered with 47mm PALL® "large" filters and analyzed at 100% as well as a variety of dilutions, filtered using PALL® 13mm Acrodisc® filters and analyzed at 100% as well as a variety of dilutions. In addition, 25 blanks were prepared including syringe blanks, Acrodisc® filter blanks, PALL® "large" filter blanks and "Type I" water blanks. The results of these comparisons and an outline of the proposed changes (if recommended) to the sample preparation regime for the three sample types (W, WD, WI) will be presented.

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#39 - It is Raining Tires

Gregory Wetherbee[1], Heather Lowers[2] and RoseAnn Martin[3]

Weekly, composite wet deposition samples were collected from National Atmospheric Deposition Program (NADP) National Trends Network Sites in the Denver-Boulder metropolitan area, Front Range foothills near Boulder, and Rocky Mountain National Park (ROMO), Colorado in 2017 and 2018. Samples were filtered (0.45 micron [mm] polyethersulfone and glass fiber) to obtain solid-phase components assumed to be washed from the atmosphere. A wide variety of different types and sizes of washout particles were observed under magnification on these filters, including soil, minerals, fragments of plants and insects, pollen, microplastics, various forms of carbonaceous materials, and others. Some of the wet-deposited particles have physical appearances and characteristics of tiny fragments of tires, which have been described in previous studies as black, elongated, cylindrical or crescent shaped particles with rough surface textures resembling aggregated pieces of different materials.

Suspected tire particles were analyzed with a FEI Quanta 450 field emission gun Scanning Electron Microscope (SEM) equipped with an Oxford Instruments X-Max 50 Energy Dispersive Spectrometer (EDS). Analysis conditions were varied to optimize imaging and qualitative chemical analysis. EDS spectra obtained from these particles, which are comprised mostly of carbon, indicated the presence of metallic components found in tire rubber, such as zinc, copper, and iron. Morphology and EDS spectra of particles obtained from actual worn tire rubber were similar to the atmospherically deposited particles. Equipment rinse blanks were collected and were free of the suspected tire particles. More work with these particles is needed to confirm that the wet-deposited particles are indeed tire fragments, such as Fourier-transform infrared spectroscopy (FTIR) analysis of the rubber components of the particles.

While it is not surprising to find the suspected tire particles in atmospheric washout obtained from urban NADP sites, the presence of these particles at the remote, high-elevation, Loch Vale site (NADP ID CO98) in ROMO is alarming and poses new questions about particulate transport. The CO98 site is located in wilderness at approximately 3,159 m above MSL. This suggests that tire particles may be a pervasive contaminant from atmospheric transport as the closest road to CO98 is 3 km to the northeast, and the closest town is 14 km away on the opposite side of the Continental Divide.

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#40 - Canada-wide Critical Loads of Acidity (Sulphur and Nitrogen) for Terrestrial Ecosystems

Julian Aherne[1] and Hazel Cathcart[2]

It is well established that chronic nitrogen (N) deposition can negatively impact plant-species biodiversity; as such, there is concern that anthropogenic N emissions from the Athabasca Oil Sands Region (AOSR) are impacting surrounding habitats. The objectives of this study were to determine the relative importance of N as a driver of plant species community composition and to identify biodiversity-based thresholds for atmospheric deposition. This assessment was performed on 46 Jack pine dominant forest sites surrounding the AOSR spanning and 35 environmental gradient variables. Soil chemical variables accounted for > 26% of the total explainable variation in the dataset, followed by climate (19%) and deposition variables (5%); the joint-effects between variables also explained a significant portion of the total variation ($p < 0.001$; redundancy analysis). Total deposited nitrogen (TDN) and sulphur were identified as important variables in gradient forest analysis. A single, definitive threshold across TDN was identified at approximately 5.6 kg N $ha^{-1}yr^{-1}$ (while a TDS threshold was found at 14.4 kg S $ha^{-1}yr^{-1}$). The TDN threshold range was associated primarily with changepoints for several vascular species (P*yrola asarifolia, Pyrola chlorantha, Cornus canadensis, Arctostaphylos uva-ursi*), in addition to some bryophyte and lichen species (*Pleurozium schreberi, Vulpicida pinastri and Dicranum polysetum*), several of which are known indicators for N deposition. These results suggest that across N-sensitive Jack pine forests surrounding the AOSR, the biodiversity-based empirical critical load of nutrient N is 5.6 kg N $ha^{-1}yr^{-1}$.

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#41 - Setting Biodiversity-Based Critical Loads of Nutrient Nitrogen in the Athabasca Oil Sands Region using Gradient Forest Analysis

Julian Aherne[1] and Nicole Vandinther[2]

Critical loads of acidity (sulphur and nitrogen) for terrestrial (natural) ecosystems were determined for all provinces and territories of Canada. The approach used the Steady-State Mass Balance model with newly available high-resolution raster maps of soils and forest cover to estimate critical loads. The new high-resolution maps were used to estimate base cation weathering rate, define spatially-explicit base cation/aluminum ratios to protect selected plant species, and to estimate nutrient removal by forest harvesting. Critical loads were estimated under two ‘protection level’ scenarios: a 5% and 20% growth reduction to plant roots (specified through the base cation/aluminum ratio). In general, the lowest critical loads (<200 eq ha^{-1} yr^{-1}) across both scenarios are found in northern Ontario, northern Manitoba, Labrador, mainland Nunavut and some regions of the arctic. The 20% growth reduction scenario results in higher critical loads for much of the arctic, but the 5% growth reduction scenario reduces Nunavut to critical loads below 300 eq ha^{-1} yr^{-1}.

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#42 - Spatial patterns of mercury contamination of recreationally-caught fish in the south central United States: Interrelationships between mercury deposition, fish trophic position and fish size

Matthew M. Chumchal[1], Ray W. Drenner[2] and Kimberly J. Adams[3]

Nationwide monitoring of atmospheric mercury (Hg) deposition and Hg concentrations in fish has created the opportunity to analyze the causes and consequences of Hg contamination of fish across large regions of the United States. Here we present a case study of the south central United States where we have used datasets on Hg deposition (NADP), land cover (NLCD), and Hg concentrations in fish (USGS NDMMF) to analyze spatial patterns of methyl mercury (MeHg) contamination in fish and risk to human health. In our case study, we estimated the MeHg concentrations of five sizes of a low trophic position fish (Bluegill, *Lepomis macrochirus*) and a high trophic position fish (Largemouth Bass, *Micropterus salmoides*) in 14 ecoregions of the south central United States. Within ecoregions, the average concentrations of MeHg in fish increased with Hg deposition adjusted for the presence of coniferous forest coverage, fish trophic position and fish size. Most sizes of Largemouth Bass, but not Bluegill, had average MeHg concentrations that would pose a risk to human health. These results have implications for the use of fish consumption advisories to inform the public about MeHg in recreationally-caught fish. Due to widespread atmospheric Hg deposition, all recreationally-caught fish are contaminated with MeHg and in cases where MeHg concentrations are elevated, their consumption poses a potential threat to human health. In the United States, informing the public about the potential health hazard of consuming recreationally-caught fish that are contaminated with MeHg is primarily the responsibility of the states, territories and tribes. These agencies monitor concentrations of MeHg in fish and issue consumption advisories if the concentrations are deemed to be hazardous to humans. However, the majority of water bodies are not monitored, which could create the false impression that fish from these un-monitored water bodies are safe even though there is no information about their MeHg contamination. The USGS has compiled data on MeHg concentrations in fish collected from fish monitoring programs across the United States and we suggest that this database be used to develop an ecoregion-based monitoring system of MeHg contamination in recreationally-caught fish. The ecoregion-based monitoring system could be used to provide the public and regulators with estimates of MeHg concentrations in different species and sizes of recreationally-caught fish. This ecoregion-based monitoring approach could also be used to develop a new federally-managed fish consumption advisory system that would be complementary to current state fish consumption advisory systems.

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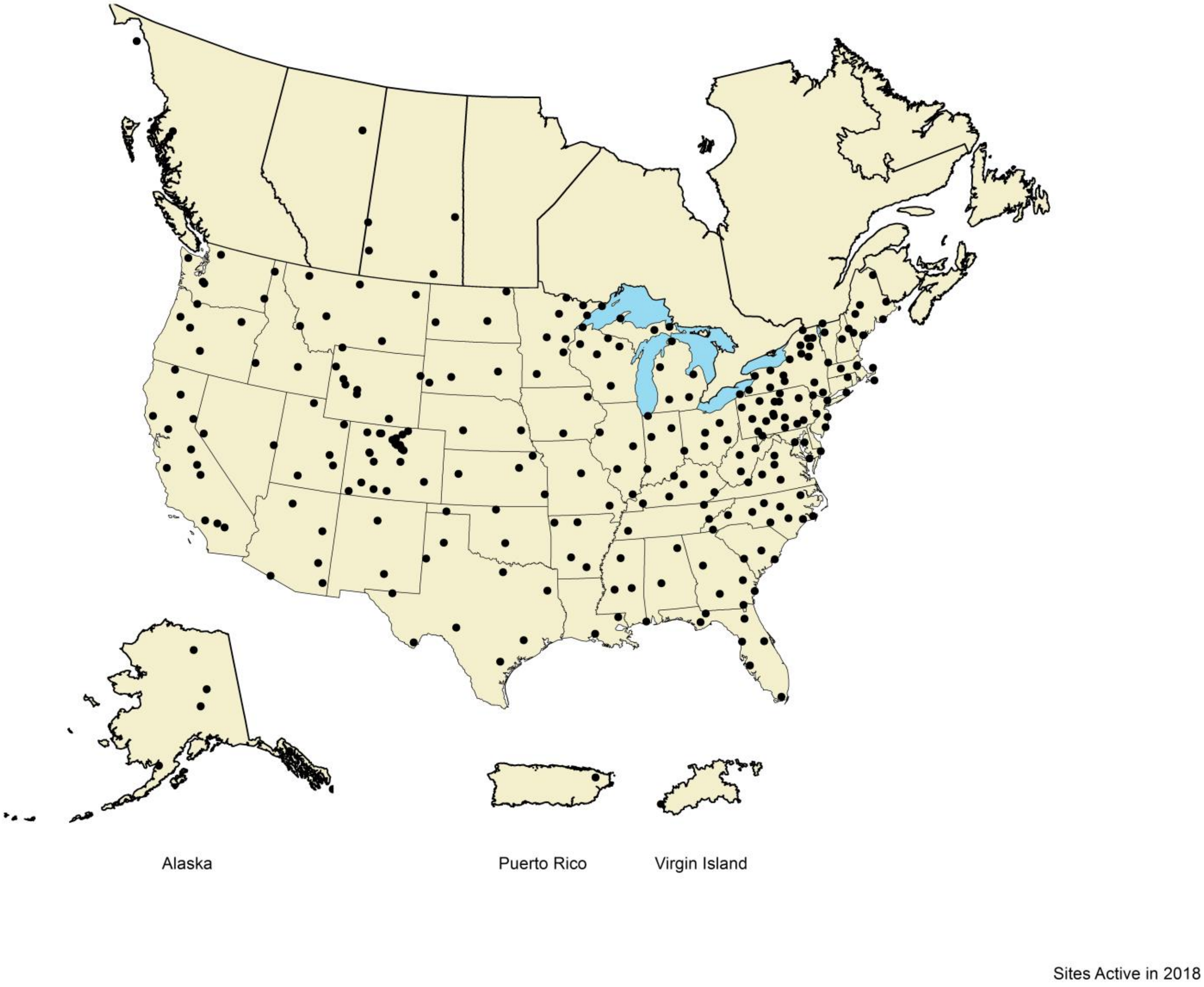
National Atmospheric Deposition Program

National Trends Network (NTN)



NTN

Site ID	Site Name	Site Sponsor	Start Date
AB32	Fort Mackay	Wood Buffalo Environmental Association	9/13/2016
AK01	Poker Creek	USDA - Forest Service	12/29/1992
AK02	Juneau	USDA - Forest Service	6/22/2004
AK03	Denali National Park-Mt. McKinley	National Park Service - Air Resources Division	6/17/1980
AK96	Toolik Field Station	University of Alaska-Fairbanks	10/12/2017
AK97	Katmai National Park - King Salmon	National Park Service - Air Resources Division	11/2/2009
AL10	Black Belt Research & Extension Center	U.S. Geological Survey	8/31/1983
AL99	Sand Mountain Research & Extension Center	U.S. Environmental Protection Agency - Clean Air Markets	10/2/1984
AR02	Warren 2WSW	U.S. Geological Survey	5/25/1982
AR03	Caddo Valley	U.S. Geological Survey	12/30/1983
AR16	Buffalo National River-Buffalo Point	National Park Service - Air Resources Division	7/13/1982
AR27	Fayetteville	U.S. Geological Survey	5/13/1980
AZ03	Grand Canyon National Park-Hopi Point	National Park Service - Air Resources Division	8/11/1981
AZ06	Organ Pipe Cactus National Monument	National Park Service - Air Resources Division	4/15/1980
AZ97	Petrified Forest National Park-Rainbow Forest	National Park Service - Air Resources Division	12/3/2002
AZ98	Chiricahua	U.S. Environmental Protection Agency - Clean Air Markets	2/23/1999
AZ99	Oliver Knoll	U.S. Geological Survey	8/25/1981
BC22	Haul Road Station	Rio Tinto	9/19/2012
BC23	Lakelse Lake	Rio Tinto	3/20/2013
BC24	Port Edward	Prince Rupert Port Authority	1/15/2014
CA28	Kings River Experimental Watershed	USDA - Forest Service	4/24/2007
CA42	Tanbark Flat	USDA - Forest Service	1/12/1982
CA45	Hopland	U.S. Geological Survey	10/3/1979
CA50	Sagehen Creek	U.S. Geological Survey	11/6/2001
CA66	Pinnacles National Monument-Bear Valley	National Park Service - Air Resources Division	11/2/1999
CA67	Joshua Tree National Park-Black Rock	National Park Service - Air Resources Division	9/19/2000
CA75	Sequoia National Park-Giant Forest	National Park Service - Air Resources Division	7/8/1980
CA76	Montague	U.S. Geological Survey	6/25/1985
CA88	Davis	U.S. Geological Survey	9/4/1978
CA94	Converse Flats	USDA - Forest Service	5/9/2006
CA96	Lassen Volcanic National Park-Manzanita Lake	National Park Service - Air Resources Division	6/13/2000
CA99	Yosemite National Park-Hodgdon Meadow	National Park Service - Air Resources Division	12/8/1981

NTN

Site ID	Site Name	Site Sponsor	Start Date
CAN5	Frelighsburg	U.S. Geological Survey	10/2/2001
CO00	Alamosa	U.S. Geological Survey	4/22/1980
CO01	Las Animas Fish Hatchery	U.S. Geological Survey	10/4/1983
CO02	Niwot Saddle	INSTAAR - University of Colorado	6/5/1984
CO06	CAMP	City of Denver	1/10/2017
CO08	Four Mile Park	U.S. Environmental Protection Agency - Clean Air Markets	12/29/1987
CO09	Kawuneechee Meadow	U.S. Bureau of Land Management / National Park Service - Air Resources Division	7/10/2012
CO10	Gothic	U.S. Environmental Protection Agency - Clean Air Markets	2/2/1999
CO11	Arvada Gardens	U.S. Geological Survey	12/5/2016
CO13	Fort Collins	U.S. Geological Survey	12/4/2018
CO15	Sand Spring	U.S. Bureau of Land Management	3/20/1979
CO19	Rocky Mountain National Park-Beaver Meadows	National Park Service - Air Resources Division	5/29/1980
CO21	Manitou	USDA - Forest Service	10/17/1978
CO22	Pawnee	Colorado Department of Public Health and Environment	5/22/1979
CO84	Betasso	U.S. Geological Survey	5/2/2017
CO85	Boulder	Colorado Department of Public Health and Environment	1/3/2017
CO86	Rocky Flats NWR	U.S. Fish and Wildlife Service	1/3/2017
CO87	National Jewish Hospital	Colorado Department of Public Health and Environment	1/10/2017
CO90	Niwot Ridge-Southeast	INSTAAR - University of Colorado	1/24/2006
CO91	Wolf Creek Pass	USDA - Forest Service	5/26/1992
CO92	Sunlight Peak	U.S. Environmental Protection Agency - Clean Air Markets	1/13/1988
CO93	Buffalo Pass - Dry Lake	USDA - Forest Service	10/14/1986
CO94	Sugarloaf	U.S. Environmental Protection Agency - Clean Air Markets	11/4/1986
CO96	Molas Pass	USDA - Forest Service	7/29/1986
CO97	Buffalo Pass - Summit Lake	USDA - Forest Service	2/7/1984
CO98	Rocky Mountain National Park-Loch Vale	U.S. Geological Survey-Biological Resources Division / Colorado State University	8/16/1983
CO99	Mesa Verde National Park-Chapin Mesa	U.S. Geological Survey	4/28/1981
CT15	Abington	U.S. Environmental Protection Agency - Clean Air Markets	1/26/1999
FL03	Bradford Forest	U.S. Environmental Protection Agency - Clean Air Markets	10/10/1978
FL05	Chassahowitzka National Wildlife Refuge	U.S. Fish and Wildlife Service	8/27/1996

NTN

Site ID	Site Name	Site Sponsor	Start Date
FL11	Everglades National Park-Research Center	National Park Service - Air Resources Division	6/17/1980
FL14	Quincy	U.S. Geological Survey	3/13/1984
FL23	Sumatra	U.S. Environmental Protection Agency - Clean Air Markets	1/26/1999
FL41	Verna Well Field	U.S. Geological Survey	8/25/1983
GA09	Okefenokee National Wildlife Refuge	U.S. Fish and Wildlife Service	6/3/1997
GA20	Bellville	U.S. Environmental Protection Agency - Clean Air Markets	4/26/1983
GA41	Georgia Station	University of Georgia - State Agricultural Experiment Station	10/3/1978
GA99	Chula	U.S. Geological Survey	2/10/1994
IA08	Big Springs Fish Hatchery	U.S. Geological Survey	8/14/1984
IA23	McNay Research Center	U.S. Geological Survey	9/11/1984
ID02	Priest River Experimental Forest	USDA - Forest Service	12/31/2002
ID03	Craters of the Moon National Monument	National Park Service - Air Resources Division	8/22/1980
ID11	Reynolds Creek	U.S. Geological Survey	11/22/1983
IL11	Bondville	U.S. Environmental Protection Agency - Clean Air Markets	2/27/1979
IL46	Alhambra	U.S. Environmental Protection Agency - Clean Air Markets	1/26/1999
IL78	Monmouth	U.S. Geological Survey	1/8/1985
IN20	Roush Lake	U.S. Geological Survey	8/22/1983
IN22	Southwest Purdue Agriculture Center	U.S. Geological Survey	9/25/1984
IN34	Indiana Dunes National Lakeshore	National Park Service - Air Resources Division	7/15/1980
IN41	Agronomy Center for Research and Extension	Purdue University - State Agricultural Experiment Station	7/13/1982
KS07	Farlington Fish Hatchery	U.S. Geological Survey	3/27/1984
KS31	Konza Prairie	Kansas State University - State Agricultural Experiment Station	8/17/1982
KS32	Lake Scott State Park	U.S. Geological Survey	3/27/1984
KS97	Kickapoo Tribe - Powhattan	Kickapoo Tribe	10/13/2015
KY03	Mackville	U.S. Geological Survey	11/29/1983
KY10	Mammoth Cave National Park-Houchin Meadow	National Park Service - Air Resources Division	8/27/2002
KY19	Cannons Lane	U.S. Geological Survey	10/7/2003
KY22	Lilley Cornett Woods	U.S. Geological Survey	9/6/1983
KY35	Clark State Fish Hatchery	U.S. Geological Survey	8/30/1983
KY99	Mulberry Flat	Murray State University	12/27/1994
LA12	Iberia Research Station	U.S. Geological Survey	11/16/1982

NTN

Site ID	Site Name	Site Sponsor	Start Date
LA30	Southeast Research Station	U.S. Geological Survey	1/18/1983
MA01	North Atlantic Coastal Lab	National Park Service - Air Resources Division	12/15/1981
MA08	Quabbin Reservoir	Northeast States for Coordinated Air Use Management	3/5/1982
MA14	Nantucket	Nantucket Land Council, Inc.	3/4/2014
MA22	Boston University	Boston University	6/16/2015
MA98	Arnold Arboretum	Harvard University	2/9/2016
MD08	Piney Reservoir	Maryland Department of Natural Resources	6/29/2004
MD13	Wye	University of Maryland - State Agricultural Experiment Station	3/8/1983
MD15	Smith Island	National Oceanic and Atmospheric Administration - Air Resources Laboratory	6/1/2004
MD18	Assateague Island National Seashore-Woodcock	Maryland Department of Natural Resources	9/5/2000
MD99	Beltsville	Maryland Department of Natural Resources	6/1/2004
ME00	Caribou	Maine Department of Environmental Protection	4/14/1980
ME02	Bridgton	Maine Department of Environmental Protection	9/30/1980
ME04	Carrabassett Valley	U.S. Environmental Protection Agency - Clean Air Markets	3/12/2002
ME08	Gilead	U.S. Geological Survey	9/28/1999
ME09	Greenville Station	Maine Department of Environmental Protection	11/20/1979
ME94	Indian Township	Passamaquoady Tribe	10/3/2013
ME96	Casco Bay-Wolfe’s Neck Farm	Maine Department of Environmental Protection	1/6/1998
ME98	Acadia National Park-McFarland Hill	National Park Service - Air Resources Division	11/10/1981
MI09	Douglas Lake	Michigan State University - State Agricultural Experiment Station	7/3/1979
MI26	Kellogg Biological Station	Michigan State University - State Agricultural Experiment Station	6/26/1979
MI48	Seney National Wildlife Refuge-Headquarters	U.S. Fish and Wildlife Service	11/28/2000
MI51	Unionville	U.S. Environmental Protection Agency - Clean Air Markets	1/26/1999
MI52	Ann Arbor	U.S. Environmental Protection Agency - Clean Air Markets	1/26/1999
MI53	Wellston	USDA - Forest Service	10/10/1978
MI99	Chassell	USDA - Forest Service	2/15/1983
MN01	Cedar Creek	Minnesota Pollution Control Agency	12/31/1996
MN08	Hovland	Minnesota Pollution Control Agency	12/31/1996

NTN

Site ID	Site Name	Site Sponsor	Start Date
MN16	Marcell Experimental Forest	USDA - Forest Service	7/6/1978
MN18	Fernberg	U.S. Environmental Protection Agency - Clean Air Markets	11/18/1980
MN23	Camp Ripley	U.S. Geological Survey	10/18/1983
MN27	Lamberton	Minnesota Pollution Control Agency	1/2/1979
MN28	Grindstone Lake	Minnesota Pollution Control Agency	12/31/1996
MN32	Voyageurs National Park-Sullivan Bay	National Park Service - Air Resources Division	5/30/2000
MN99	Wolf Ridge	Minnesota Pollution Control Agency	12/31/1996
MO03	Ashland Wildlife Area	U.S. Geological Survey	10/20/1981
MO05	University Forest	U.S. Geological Survey	10/27/1981
MS10	Clinton	U.S. Geological Survey	7/10/1984
MS12	Grand Bay NERR	National Oceanic and Atmospheric Administration - Air Resources Laboratory	3/9/2010
MS19	Newton	National Oceanic and Atmospheric Administration - Air Resources Laboratory	11/11/1986
MS30	Coffeeville	USDA - Forest Service	7/17/1984
MT00	Little Bighorn Battlefield National Monument	U.S. Geological Survey	7/13/1984
MT05	Glacier National Park-Fire Weather Station	National Park Service - Air Resources Division	6/3/1980
MT07	Clancy	U.S. Geological Survey	1/24/1984
MT96	Poplar River	Fort Peck Assiniboine & Sioux Tribes	12/21/1999
MT97	Lost Trail Pass	USDA - Forest Service	9/25/1990
MT98	Havre - Northern Agricultural Research Center	U.S. Geological Survey	7/30/1985
NC03	Lewiston	North Carolina State University	10/31/1978
NC06	Beaufort	U.S. Environmental Protection Agency - Clean Air Markets	1/26/1999
NC17	University Research Farm	North Carolina A&T State University	1/30/2015
NC25	Coweeta	USDA - Forest Service	7/5/1978
NC29	Hofmann Forest	U.S. Geological Survey	7/2/2002
NC34	Piedmont Research Station	North Carolina State University	10/17/1978
NC35	Clinton Crops Research Station	North Carolina State University	10/24/1978
NC36	Jordan Creek	U.S. Geological Survey	10/18/1983
NC41	Finley Farm	North Carolina State University	10/3/1978
NC45	Mt. Mitchell	U.S. Geological Survey	11/26/1985
ND00	Theodore Roosevelt National Park-Painted Canyon	National Park Service - Air Resources Division	1/30/2001
ND08	Icelandic State Park	U.S. Geological Survey	10/25/1983
ND11	Woodworth	U.S. Geological Survey	11/29/1983

NTN

Site ID	Site Name	Site Sponsor	Start Date
NE15	Mead	University of Nebraska–Lincoln - State Agricultural Experiment Station	7/25/1978
NE99	North Platte Agricultural Experiment Station	U.S. Geological Survey	9/24/1985
NH02	Hubbard Brook	USDA - Forest Service	7/25/1978
NJ00	Edwin B. Forsythe National Wildlife Refuge	U.S. Fish and Wildlife Service	10/13/1998
NJ39	Cattus Island County Park	U.S. Environmental Protection Agency - Clean Air Markets	12/4/2012
NJ99	Washington Crossing	U.S. Environmental Protection Agency - Clean Air Markets	8/4/1981
NM07	Bandelier National Monument	National Park Service - Air Resources Division	6/22/1982
NM08	Mayhill	U.S. Geological Survey	1/24/1984
NV03	Smith Valley	U.S. Geological Survey	8/7/1985
NV05	Great Basin National Park-Lehman Caves	National Park Service - Air Resources Division	1/15/1985
NY01	Alfred	U.S. Geological Survey	8/17/2004
NY06	Bronx	New York State Energy Research and Development Authority	1/22/2013
NY08	Aurora Research Farm	Cornell University	4/17/1979
NY10	Chautauqua	U.S. Geological Survey	6/10/1980
NY20	Huntington Wildlife	New York State Energy Research and Development Authority	10/31/1978
NY22	Akwesasne Mohawk-Fort Covington	U.S. Environmental Protection Agency - Clean Air Markets	8/18/1999
NY28	Piseco Lake	New York State Energy Research and Development Authority	12/31/2012
NY43	Rochester	New York State Energy Research and Development Authority	4/30/2013
NY52	Bennett Bridge	U.S. Environmental Protection Agency - Clean Air Markets	6/10/1980
NY59	Wanakena	New York State Energy Research and Development Authority	1/2/2013
NY67	Ithaca	National Oceanic and Atmospheric Administration - Air Resources Laboratory	1/2/2018
NY68	Biscuit Brook	U.S. Geological Survey	10/11/1983
NY92	Amherst	New York State Energy Research and Development Authority	10/29/2013
NY93	Paul Smith's	New York State Energy Research and Development Authority	1/1/2013
NY94	Nick's Lake	New York State Energy Research and Development Authority	11/3/2015
NY96	Cedar Beach-Southold	Suffolk County (New York)	11/25/2003
NY98	Whiteface Mountain	U.S. Geological Survey	7/3/1984
NY99	West Point	U.S. Geological Survey	9/13/1983

NTN

Site ID	Site Name	Site Sponsor	Start Date
OH09	Oxford	U.S. Geological Survey	8/14/1984
OH17	Delaware	USDA - Forest Service	10/3/1978
OH49	Caldwell	U.S. Geological Survey	9/26/1978
OH54	Deer Creek State Park	U.S. Environmental Protection Agency - Clean Air Markets	1/26/1999
OH71	Wooster	U.S. Geological Survey	9/26/1978
OK00	Salt Plains National Wildlife Refuge	U.S. Geological Survey	12/13/1983
OK17	Kessler Atmospheric and Ecological Field Station	National Oceanic and Atmospheric Administration - Air Resources Laboratory	3/29/1983
OK29	Goodwell Research Station	U.S. Geological Survey	1/8/1985
OR09	Silver Lake Ranger Station	U.S. Geological Survey	8/23/1983
OR10	H. J. Andrews Experimental Forest	USDA - Forest Service	5/13/1980
OR18	Starkey Experimental Forest	U.S. Geological Survey	3/6/1984
OR97	Hyslop Farm	U.S. Environmental Protection Agency - Clean Air Markets	4/26/1983
PA00	Arendtsville	U.S. Environmental Protection Agency - Clean Air Markets	1/26/1999
PA13	Allegheny Portage Railroad National Historic Site	The Pennsylvania State University	7/26/2011
PA15	Penn State	National Oceanic and Atmospheric Administration - Air Resources Laboratory	6/7/1983
PA18	Young Woman's Creek	U.S. Geological Survey	4/20/1999
PA29	Kane Experimental Forest	USDA - Forest Service	7/18/1978
PA30	Erie	The Pennsylvania State University	7/27/2011
PA42	Leading Ridge	The Pennsylvania State University	4/25/1979
PA72	Milford	USDA - Forest Service	12/27/1983
PA90	Hills Creek State Park	Pennsylvania Department of Environmental Protection	7/26/2011
PR20	El Verde	USDA - Forest Service	2/12/1985
SC05	Cape Romain National Wildlife Refuge	U.S. Fish and Wildlife Service	11/21/2000
SC06	Santee National Wildlife Refuge	U.S. Geological Survey	7/19/1984
SD04	Wind Cave National Park-Elk Mountain	National Park Service - Air Resources Division	11/5/2002
SD08	Cottonwood	U.S. Geological Survey	10/11/1983
SD99	Huron Well Field	U.S. Geological Survey	11/29/1983
SK20	Cactus Lake	Saskatchewan Ministry of Environment	2/14/2012
SK21	Hudson Bay	Saskatchewan Ministry of Environment	4/30/2012

NTN

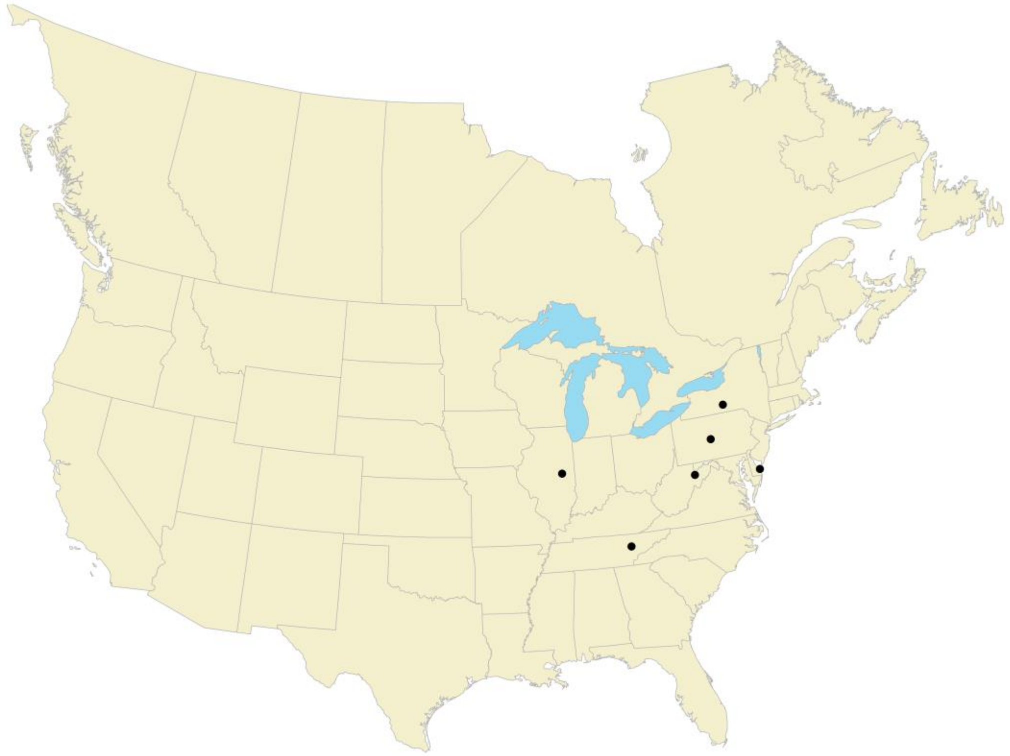
Site ID	Site Name	Site Sponsor	Start Date
SK30	Weyburn	Saskatchewan Ministry of Environment	6/7/2016
SK31	Fox Valley	Saskatchewan Ministry of Environment	6/14/2016
TN04	Speedwell	U.S. Environmental Protection Agency - Clean Air Markets	1/26/1999
TN11	Great Smoky Mountains National Park-Elkmont	National Park Service - Air Resources Division	8/12/1980
TN14	Hatchie National Wildlife Refuge	U.S. Geological Survey	10/2/1984
TX02	Muleshoe National Wildlife Refuge	U.S. Geological Survey	6/18/1985
TX03	Beeville	U.S. Geological Survey	2/7/1984
TX04	Big Bend National Park - K-Bar	National Park Service - Air Resources Division	4/10/1980
TX10	Attwater Prairie Chicken National Wildlife Refuge	U.S. Geological Survey	7/3/1984
TX16	Sonora	U.S. Geological Survey	6/26/1984
TX22	Guadalupe Mountains National Park Frijole Ranger Station	U.S. Geological Survey	6/5/1984
TX43	Cañónceta	Texas A&M University	7/24/2007
TX56	L.B.J. National Grasslands	U.S. Geological Survey	9/20/1983
UT01	Logan	U.S. Geological Survey	12/6/1983
UT09	Canyonlands National Park-Island in the Sky	National Park Service - Air Resources Division	11/11/1997
UT95	East McKee	USDA - Forest Service	12/5/2017
UT98	Green River	U.S. Geological Survey	4/25/1985
UT99	Bryce Canyon National Park-Repeater Hill	National Park Service - Air Resources Division	1/29/1985
VA00	Charlottesville	U.S. Geological Survey	10/2/1984
VA13	Horton's Station	U.S. Environmental Protection Agency - Clean Air Markets	7/25/1978
VA24	Prince Edward	U.S. Environmental Protection Agency - Clean Air Markets	1/26/1999
VA28	Shenandoah National Park-Big Meadows	National Park Service - Air Resources Division	5/12/1981
VA99	Natural Bridge Station	USDA - Forest Service	7/2/2002
VI01	Virgin Islands National Park-Lind Point	National Park Service - Air Resources Division	4/14/1998
VT01	Bennington	U.S. Geological Survey	4/28/1981
VT99	Underhill	U.S. Geological Survey	6/12/1984
WA14	Olympic National Park-Hoh Ranger Station	National Park Service - Air Resources Division	5/20/1980
WA19	North Cascades National Park-Marblemount Ranger Station	U.S. Geological Survey	2/7/1984

NTN

Site ID	Site Name	Site Sponsor	Start Date
WA21	La Grande	U.S. Environmental Protection Agency - Clean Air Markets	4/24/1984
WA24	Palouse Conservation Farm	U.S. Geological Survey	8/20/1985
WA98	Columbia River Gorge	USDA - Forest Service	5/7/2002
WA99	Mount Rainier National Park-Tahoma Woods	National Park Service - Air Resources Division	10/26/1999
WI08	Brule River	Wisconsin Department of Natural Resources	4/22/2014
WI10	Potawatomi	Forest County Potawatomi Community	6/7/2005
WI31	Devil's Lake	Wisconsin Department of Natural Resources	1/7/2014
WI35	Perkinstown	U.S. Environmental Protection Agency - Clean Air Markets	1/26/1999
WI36	Trout Lake	Wisconsin Department of Natural Resources	1/22/1980
WI37	Spooner	USDA - Forest Service	6/3/1980
WV04	Babcock State Park	U.S. Geological Survey	9/6/1983
WV05	Cedar Creek State Park	U.S. Environmental Protection Agency - Clean Air Markets	1/26/1999
WV18	Parsons	USDA - Forest Service	7/5/1978
WY00	Snowy Range	USDA - Forest Service	4/22/1986
WY02	Sinks Canyon	U.S. Bureau of Land Management	8/21/1984
WY06	Pinedale	U.S. Bureau of Land Management	1/26/1982
WY08	Yellowstone National Park-Tower Falls	National Park Service - Air Resources Division	6/5/1980
WY94	Grand Tetons National Park	Wyoming Department of Environmental Quality	9/27/2011
WY95	Brooklyn Lake	USDA - Forest Service	9/22/1992
WY97	South Pass City	USDA - Forest Service-Shoshone National Forest	4/30/1985
WY98	Gypsum Creek	USDA - Forest Service-Bridger-Teton National Forest	12/26/1984
WY99	Newcastle	U.S. Bureau of Land Management	8/11/1981

National Atmospheric Deposition Program

Atmospheric Integrated Research Monitoring Network (AIRMoN)



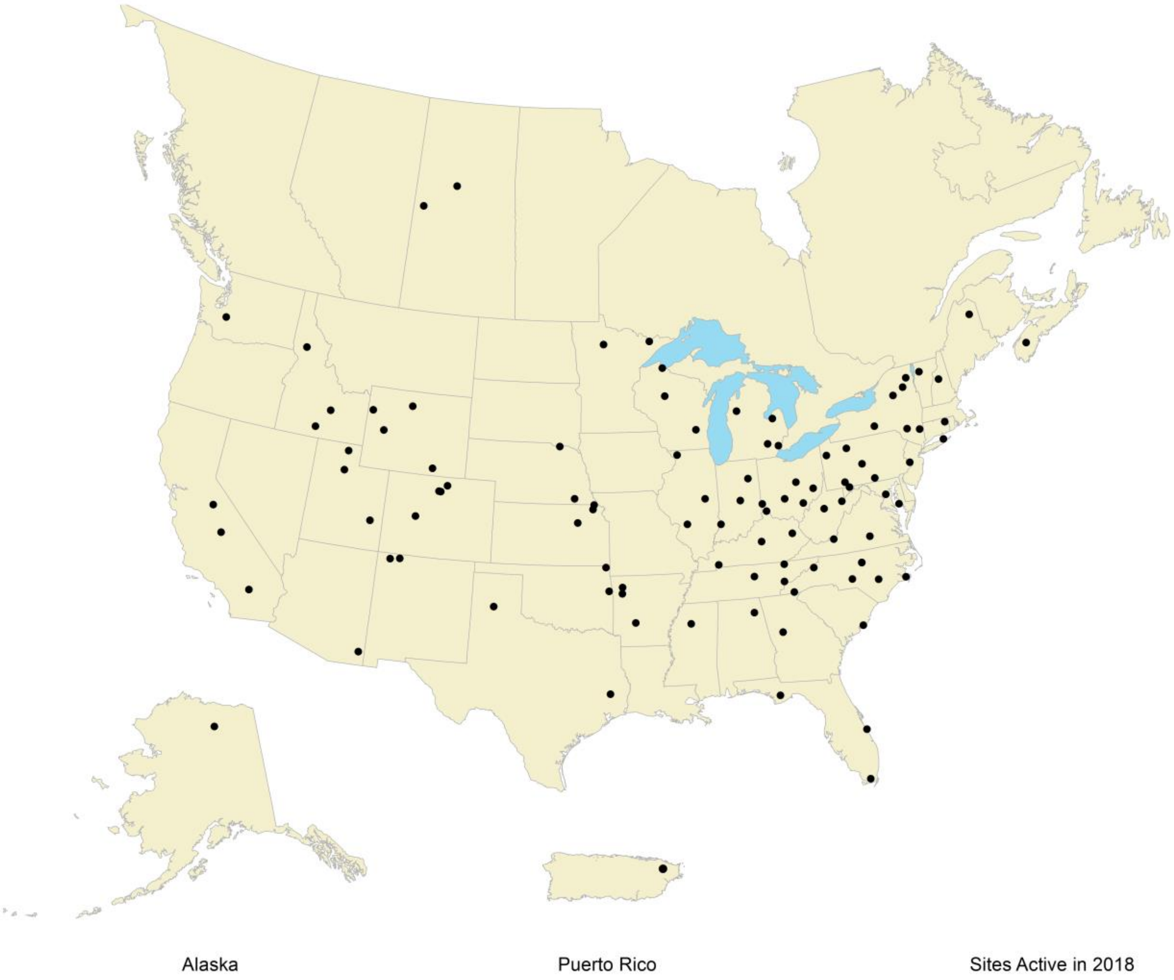
Sites Active in 2018

AIRMoN

Site ID	Site Name	Site Sponsor	Start Date
NY67	Ithaca	National Oceanic and Atmospheric Administration - Air Resources Laboratory	9/30/1992
PA15	Penn State	National Oceanic and Atmospheric Administration - Air Resources Laboratory	10/6/1992
TN00	Walker Branch Watershed	National Oceanic and Atmospheric Administration - Air Resources Laboratory	9/23/1992
WV99	Canaan Valley Institute	National Oceanic and Atmospheric Administration - Air Resources Laboratory	6/1/2000

National Atmospheric Deposition Program

Ammonia Monitoring Network (AMoN)



AMoN

Site ID	Site Name	Site Sponsor	Start Date
AK96	Toolik Field Station	U.S. Bureau of Land Management	9/4/2018
AL99	Sand Mountain Research & Extension Center	U.S. Environmental Protection Agency - Clean Air Markets	3/29/2011
AR03	Caddo Valley	U.S. Environmental Protection Agency - Clean Air Markets	3/1/2011
AR09	Rambo Hill	U.S. Department of Agriculture - Agricultural Research Service	10/6/2015
AR15	LC Farms	U.S. Department of Agriculture - Agricultural Research Service	10/6/2015
AZ98	Chiricahua	National Park Service - Air Resources Division	3/22/2011
CA44	Yosemite NP - Turtleback Dome	National Park Service - Air Resources Division	3/15/2011
CA67	Joshua Tree National Park-Black Rock	National Park Service - Air Resources Division	3/1/2011
CA83	Sequoia NP - Ash Mountain	National Park Service - Air Resources Division	3/22/2011
CO10	Gothic	U.S. Environmental Protection Agency - Clean Air Markets	9/11/2012
CO13	Fort Collins	U.S. Environmental Protection Agency - Clean Air Markets	11/27/2007
CO88	Rocky Mountain National Park - Longs Peak	National Park Service - Air Resources Division	5/10/2011
CO98	Rocky Mountain National Park-Loch Vale	National Park Service - Air Resources Division	5/10/2011
CT15	Abington	U.S. Environmental Protection Agency - Clean Air Markets	3/29/2011
FL11	Everglades National Park-Research Center	National Park Service - Air Resources Division	3/15/2011
FL19	Indian River	U.S. Environmental Protection Agency - Clean Air Markets	4/26/2011
FL23	Sumatra	U.S. Environmental Protection Agency - Clean Air Markets	1/13/2015
GA41	Georgia Station	U.S. Environmental Protection Agency - Clean Air Markets	6/7/2011
ID03	Craters of the Moon National Monument	National Park Service - Air Resources Division	6/7/2010
ID07	Nez Perce	U.S. Environmental Protection Agency - Clean Air Markets	12/15/2015
ID14	Kimberly	USDA-Agricultural Research Service	6/13/2017
IL11	Bondville	U.S. Environmental Protection Agency - Clean Air Markets	10/30/2007
IL37	Stockton	U.S. Environmental Protection Agency - Clean Air Markets	4/26/2011
IL46	Alhambra	U.S. Environmental Protection Agency - Clean Air Markets	3/3/2011
IN20	Roush Lake	U.S. Environmental Protection Agency - Clean Air Markets	1/13/2015

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Site ID	Site Name	Site Sponsor	Start Date
IN22	Southwest Purdue Agriculture Center	U.S. Environmental Protection Agency - Clean Air Markets	1/13/2015
IN99	Indianapolis	U.S. Environmental Protection Agency - Clean Air Markets	10/30/2007
KS03	Reserve	Kansas Department of Health and Environment	10/11/2011
KS31	Konza Prairie	U.S. Environmental Protection Agency - Clean Air Markets	3/1/2011
KS97	Kickapoo Tribe - Powhattan	U.S. Environmental Protection Agency - Clean Air Markets	1/13/2015
KY03	Mackville	U.S. Environmental Protection Agency - Clean Air Markets	3/1/2011
KY29	Crockett	U.S. Environmental Protection Agency - Clean Air Markets	1/13/2015
KY98	Cadiz	U.S. Environmental Protection Agency - Clean Air Markets	3/15/2011
MD06	Blackwater NWR	U.S. Environmental Protection Agency - Clean Air Markets	1/20/2015
MD08	Piney Reservoir	Maryland Department of Natural Resources	8/3/2010
MD99	Beltsville	Maryland Department of Natural Resources	8/3/2010
ME93	Ashland	U.S. Environmental Protection Agency - Clean Air Markets	1/13/2015
MI51	Unionville	U.S. Environmental Protection Agency - Clean Air Markets	1/18/2015
MI52	Ann Arbor	U.S. Environmental Protection Agency - Clean Air Markets	2/3/2015
MI95	Hoxeyville	U.S. Environmental Protection Agency - Clean Air Markets	1/13/2015
MI96	Detroit	U.S. Environmental Protection Agency - Clean Air Markets	10/29/2007
MN02	Red Lake	U.S. Environmental Protection Agency - Clean Air Markets	1/13/2015
MN18	Fernberg	U.S. Environmental Protection Agency - Clean Air Markets	10/30/2007
MS30	Coffeeville	U.S. Environmental Protection Agency - Clean Air Markets	1/6/2015
NC02	Cranberry	U.S. Environmental Protection Agency - Clean Air Markets	1/13/2015
NC06	Beaufort	U.S. Environmental Protection Agency - Clean Air Markets	4/27/2010
NC25	Coweeta	U.S. Environmental Protection Agency - Clean Air Markets	5/24/2011
NC26	Candor	U.S. Environmental Protection Agency - Clean Air Markets	4/26/2011
NC30	Duke Forest	U.S. Environmental Protection Agency - Clean Air Markets	6/24/2008

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Site ID	Site Name	Site Sponsor	Start Date
NC35	Clinton Crops Research Station	U.S. Environmental Protection Agency - Clean Air Markets	8/5/2008
NC98	Duke Forest Flux Tower	U.S. Environmental Protection Agency - Clean Air Markets	8/22/2018
NE09	Homestead	National Park Service - Air Resources Division	7/26/2016
NE98	Santee	U.S. Environmental Protection Agency - Clean Air Markets	4/26/2011
NH02	Hubbard Brook	U.S. Environmental Protection Agency - Clean Air Markets	6/5/2012
NJ98	Washington Crossing CASTNET	U.S. Environmental Protection Agency - Clean Air Markets	3/1/2011
NM98	Navajo Lake	U.S. Environmental Protection Agency - Clean Air Markets	1/11/2008
NM99	Farmington	U.S. Environmental Protection Agency - Clean Air Markets	1/9/2008
NS01	Kejimkujik National Park	Environment and Climate Change Canada	10/8/2013
NY16	Cary Institute	Cary Institute	10/13/2009
NY20	Huntington Wildlife	U.S. Environmental Protection Agency - Clean Air Markets	6/5/2012
NY67	Ithaca	U.S. Environmental Protection Agency - Clean Air Markets	10/30/2007
NY91	Claryville	U.S. Environmental Protection Agency - Clean Air Markets	1/13/2015
NY94	Nick's Lake	U.S. Environmental Protection Agency - Clean Air Markets	11/20/2012
NY96	Cedar Beach-Southold	U.S. Environmental Protection Agency/ County of Suffolk-Department of Health Services-Peconic Estuary Program	8/5/2014
NY98	Whiteface Mountain	U.S. Environmental Protection Agency - Clean Air Markets	11/20/2012
OH02	Athens Super Site	U.S. Environmental Protection Agency - Clean Air Markets	10/30/2007
OH09	Oxford	U.S. Environmental Protection Agency - Clean Air Markets	1/13/2015
OH27	Cincinnati	U.S. Environmental Protection Agency - Clean Air Markets	10/30/2007
OH32	Kenyon College	Kenyon College	8/22/2017
OH54	Deer Creek State Park	U.S. Environmental Protection Agency - Clean Air Markets	3/1/2011
OH99	Quaker City	U.S. Environmental Protection Agency - Clean Air Markets	1/13/2015
OK98	Quapaw	U.S. Environmental Protection Agency	10/6/2015
OK99	Stilwell	U.S. Environmental Protection Agency - Clean Air Markets	10/30/2007
PA00	Arendtsville	U.S. Environmental Protection Agency - Clean Air Markets	10/13/2009

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Site ID	Site Name	Site Sponsor	Start Date
PA29	Kane Experimental Forest	U.S. Environmental Protection Agency - Clean Air Markets	3/8/2011
PA56	M. K. Goddard	U.S. Environmental Protection Agency - Clean Air Markets	12/30/2014
PA96	Penn State - Fairbrook Park	U.S. Environmental Protection Agency - Clean Air Markets	1/13/2015
PA97	Laurel Hill	U.S. Environmental Protection Agency - Clean Air Markets	7/17/2015
PR20	El Verde	USDA - Forest Service	3/4/2014
SC05	Cape Romain National Wildlife Refuge	U.S. Environmental Protection Agency - Clean Air Markets	10/30/2007
SK27	Pinehouse	Environment and Climate Change Canada	3/24/2017
SK28	Flat Valley	Environment and Climate Change Canada	3/22/2017
TN01	Great Smoky Mountains NP - Look Rock	National Park Service - Air Resources Division	3/15/2011
TN04	Speedwell	U.S. Environmental Protection Agency - Clean Air Markets	1/13/2015
TN07	Edgar Evins	U.S. Environmental Protection Agency - Clean Air Markets	1/13/2015
TX41	Alabama-Coushatta	U.S. Environmental Protection Agency - Clean Air Markets	1/13/2015
TX43	Cañónceta	U.S. Environmental Protection Agency - Clean Air Markets	10/30/2007
UT01	Logan	Utah Department of Environmental Quality	11/8/2011
UT09	Canyonlands National Park-Island in the Sky	National Park Service - Air Resources Division	5/6/2014
UT97	Salt Lake City	Utah Department of Environmental Quality	11/8/2011
VA13	Horton's Station	U.S. Environmental Protection Agency - Clean Air Markets	1/13/2015
VA24	Prince Edward	U.S. Environmental Protection Agency - Clean Air Markets	3/1/2011
VT99	Underhill	U.S. Environmental Protection Agency - Clean Air Markets	11/20/2012
WA99	Mount Rainier National Park-Tahoma Woods	National Park Service - Air Resources Division	3/16/2011
WI01	Odanah	Bad River Band of Lake Superior Chippewa	10/2/2018
WI07	Horicon Marsh	U.S. Environmental Protection Agency - Clean Air Markets	10/30/2007
WI35	Perkinstown	U.S. Environmental Protection Agency - Clean Air Markets	3/29/2011
WV05	Cedar Creek State Park	U.S. Environmental Protection Agency - Clean Air Markets	1/13/2015
WV18	Parsons	U.S. Environmental Protection Agency - Clean Air Markets	6/7/2011
WY06	Pinedale	U.S. Environmental Protection Agency - Clean Air Markets	1/14/2015

AMoN

Site ID	Site Name	Site Sponsor	Start Date
WY93	Basin - Big Horn	U.S. Bureau of Land Management	6/2/2015
WY94	Grand Tetons National Park	National Park Service - Air Resources Division	9/22/2011
WY95	Brooklyn Lake	U.S. Environmental Protection Agency - Clean Air Markets	6/19/2012

National Atmospheric Deposition Program

Mercury Deposition Network (MDN)

Sites active in 2018

MDN

Site ID	Site Name	Site Sponsor	Start Date
AB14	Genesee	Intrinsik Corp	7/18/2006
AK96	Toolik Field Station	University of Alaska Fairbanks	10/10/2017
AK98	Kodiak	State of Alaska Department of Environmental Conservation	9/18/2007
BC16	Saturna Island	Environment and Climate Change Canada	9/1/2009
CA75	Sequoia National Park-Giant Forest	National Park Service - Air Resources Division	7/22/2003
CA94	Converse Flats	USDA - Forest Service	4/20/2006
CO96	Molas Pass	U.S. Bureau of Land Management	6/30/2009
CO97	Buffalo Pass - Summit Lake	USDA - Forest Service	9/29/1998
CO99	Mesa Verde National Park-Chapin Mesa	National Park Service - Air Resources Division	12/26/2001
FL05	Chassahowitzka National Wildlife Refuge	U.S. Fish and Wildlife Service	7/1/1997
FL11	Everglades National Park-Research Center	South Florida Water Management District	3/5/1996
FL95	Everglades - South Palm Beach County	South Florida Water Management District	4/7/2015
FL97	Everglades-Western Broward County	South Florida Water Management District	11/8/2006
GA09	Okefenokee National Wildlife Refuge	U.S. Fish and Wildlife Service	7/29/1997
IL11	Bondville	University of Illinois - ISWS	1/6/1999
IN21	Clifty Falls State Park	Lake Michigan Air Directors Consortium	1/12/2001
IN22	Southwest Purdue Agriculture Center	Lake Michigan Air Directors Consortium	12/31/2013
IN34	Indiana Dunes National Lakeshore	Lake Michigan Air Directors Consortium	10/27/2000
KS03	Reserve	Kansas Department of Health and Environment	1/2/2008
KS05	Coffey County Lake	Kansas Department of Health and Environment	12/30/2008
KS24	Glen Elder State Park	Kansas Department of Health and Environment	5/27/2008
KS32	Lake Scott State Park	Kansas Department of Health and Environment	6/10/2008
KY10	Mammoth Cave National Park-Houchin Meadow	National Park Service - Air Resources Division	8/27/2002
MA01	North Atlantic Coastal Lab	National Park Service - Air Resources Division	7/29/2003
MD00	Smithsonian Environmental Research Center	Maryland Department of Natural Resources	12/7/2006
MD08	Piney Reservoir	Maryland Department of Natural Resources	6/29/2004
MD99	Beltsville	Maryland Department of Natural Resources	6/1/2004

MDN

Site ID	Site Name	Site Sponsor	Start Date
ME00	Caribou	Maine Department of Environmental Protection	5/9/2007
ME02	Bridgton	Maine Department of Environmental Protection	6/3/1997
ME04	Carrabassett Valley	Penobscot Indian Nation	2/17/2009
ME09	Greenville Station	Maine Department of Environmental Protection	9/3/1996
ME96	Casco Bay-Wolfe’s Neck Farm	Maine Department of Environmental Protection	1/6/1998
ME98	Acadia National Park-McFarland Hill	USDA - Forest Service-Acadia National Park / Maine Department of Environmental Protection	3/5/1996
MI09	Douglas Lake	Lake Michigan Air Directors Consortium	12/31/2013
MI48	Seney National Wildlife Refuge-Headquarters	U.S. Fish and Wildlife Service	11/11/2003
MI52	Ann Arbor	Lake Michigan Air Directors Consortium	12/31/2013
MN06	Leech Lake	Leech Lake Band of Ojibwe	6/23/2014
MN16	Marcell Experimental Forest	USDA - Forest Service-Northern Research Station	2/27/1996
MN18	Fernberg	Minnesota Pollution Control Agency	3/5/1996
MN23	Camp Ripley	Minnesota Pollution Control Agency	7/2/1996
MN27	Lamberton	Minnesota Pollution Control Agency	7/2/1996
MO46	Mingo National Wildlife Refuge	U.S. Fish and Wildlife Service	3/26/2002
MS12	Grand Bay NERR	National Oceanic and Atmospheric Administration - Air Resources Laboratory	3/9/2010
MT05	Glacier National Park-Fire Weather Station	National Park Service - Air Resources Division	10/28/2003
MT95	Badger Peak	Northern Cheyenne Tribe	11/2/2010
NC08	Waccamaw State Park	North Carolina Department of Environmental Quality	2/27/1996
NC17	University Research Farm	North Carolina A&T State University	1/30/2015
NC26	Candor	North Carolina Department of Environmental Quality	11/8/2005
ND01	Lostwood National Wildlife Refuge	U.S. Fish and Wildlife Service	11/25/2003
NE15	Mead	Nebraska Department of Environmental Quality	6/26/2007
NE98	Santee	Santee Sioux Nation of Nebraska	10/1/2013
NF19	Stephenville	Environment and Climate Change Canada	2/23/2010
NJ30	New Brunswick	New Jersey Department of Environmental Protection	1/17/2006
NS01	Kejimkujik National Park	Environment and Climate Change Canada	7/2/1996
NY06	Bronx	New York State Department of Environmental Conservation	1/9/2008

MDN

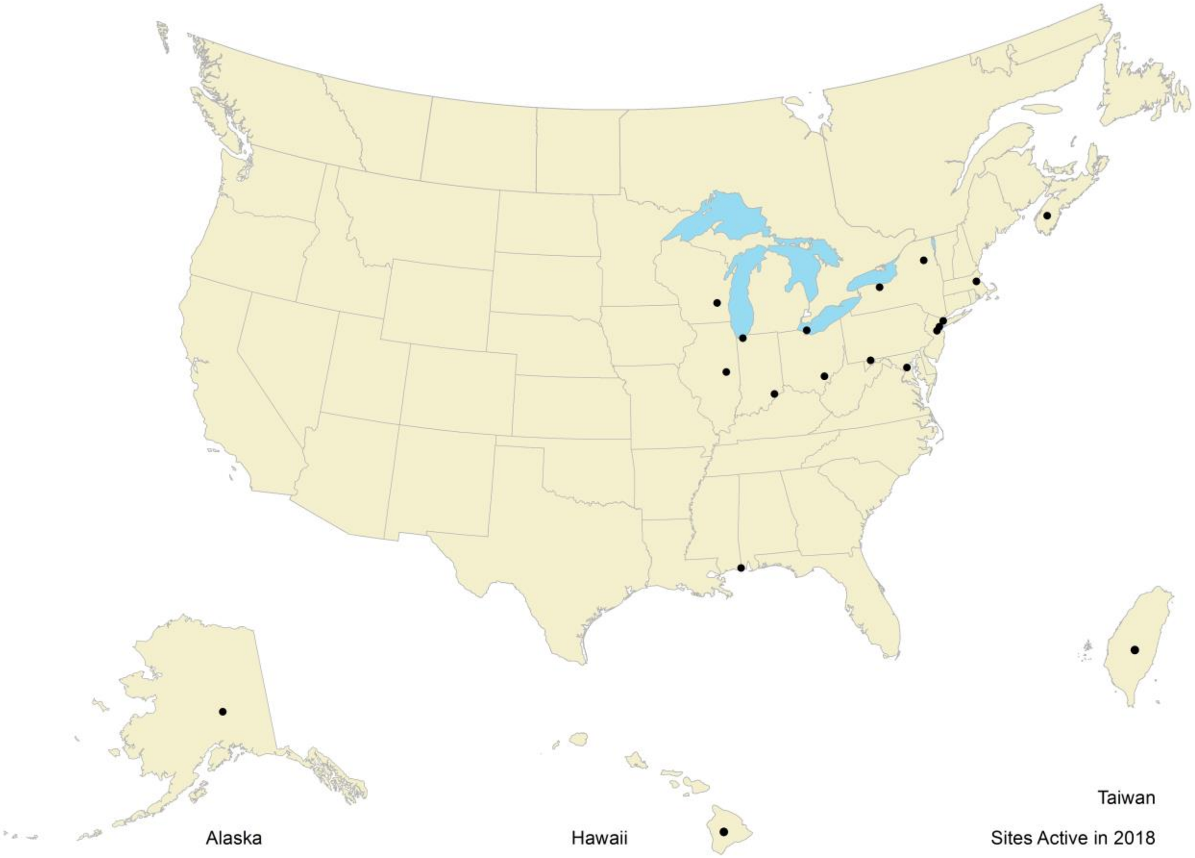
Site ID	Site Name	Site Sponsor	Start Date
NY20	Huntington Wildlife	New York State Energy Research & Development Authority	12/10/1999
NY43	Rochester	New York State Department of Environmental Conservation	1/8/2008
NY68	Biscuit Brook	New York State Energy Research & Development Authority	3/9/2004
NY96	Cedar Beach-Southold	New York State Energy Research & Development Authority	9/24/2013
OH02	Athens Super Site	Ohio Environmental Protection Agency	12/28/2004
OH16	Northeast Ohio Regional Sewer District (NEORSD)	Northeast Ohio Regional Sewer District (NEORSD)	11/29/2017
OH52	South Bass Island	Ohio Environmental Protection Agency	5/8/2014
OK01	McGee Creek	Oklahoma Department of Environmental Quality	10/31/2006
OK04	Lake Murray	Oklahoma Department of Environmental Quality	10/30/2007
OK05	Hugo	Choctaw Nation of Oklahoma	12/19/2017
OK06	Wichita Mountains NWR	Oklahoma Department of Environmental Quality	11/20/2007
OK31	Copan	Oklahoma Department of Environmental Quality	10/24/2006
OK97	Tuskahoma	Choctaw Nation of Oklahoma	12/27/2017
OK99	Stilwell	Cherokee Nation Environmental Programs	4/29/2003
ON07	Egbert	Environment and Climate Change Canada	3/7/2000
PA00	Arendtsville	The Pennsylvania State University	11/14/2000
PA13	Allegheny Portage Railroad National Historic Site	The Pennsylvania State University	1/7/1997
PA30	Erie	The Pennsylvania State University	6/20/2000
PA42	Leading Ridge	The Pennsylvania State University	3/2/2010
PA90	Hills Creek State Park	The Pennsylvania State University	1/7/1997
PR20	El Verde	U.S. Geological Survey	8/6/2014
SC05	Cape Romain National Wildlife Refuge	U.S. Fish and Wildlife Service	3/2/2004
SC19	Congaree Swamp	South Carolina Department of Health and Environmental Control	3/5/1996
SD18	Eagle Butte	Cheyenne River Sioux Tribe	3/21/2007
SK27	Pinehouse	Environment and Climate Change Canada	5/14/2015
TN11	Great Smoky Mountains National Park-Elkmont	National Park Service - Air Resources Division	1/30/2002
TN12	Great Smoky Mountains National Park-Clingmans Dome	National Park Service - Air Resources Division	4/28/2015
VA28	Shenandoah National Park-Big Meadows	National Park Service - Air Resources Division	10/22/2002
VT99	Underhill	The University of Vermont	7/27/2004

MDN

Site ID	Site Name	Site Sponsor	Start Date
WA03	Makah National Fish Hatchery	Wisconsin State Laboratory of Hygiene	3/2/2007
WA18	Seattle/NOAA	Eurofins Frontier Global Sciences	3/19/1996
WI08	Brule River	Wisconsin Department of Natural Resources	3/5/1996
WI10	Potawatomi	Forest County Potawatomi Community	6/7/2005
WI31	Devil's Lake	Wisconsin Department of Natural Resources	1/11/2001
WI36	Trout Lake	Wisconsin Department of Natural Resources	3/5/1996
WY08	Yellowstone National Park-Tower Falls	Wyoming Department of Environmental Quality	10/21/2004
WY26	Roundtop Mountain	Wyoming Department of Environmental Quality	12/20/2011

National Atmospheric Deposition Program

Atmospheric Mercury Network (AMNet)



AMNet

Site ID	Site Name	Site Sponsor	Start Date
AK03	Denali National Park-Mt. McKinley	National Park Service - Air Resources Division	3/10/2014
HI00	Mauna Loa	National Oceanic and Atmospheric Administration - Air Resources Laboratory	12/30/2010
IL11	Bondville	University of Illinois - ISWS	1/1/2017
IN21	Clifty Falls State Park	Lake Michigan Air Directors Consortium	4/29/2016
IN34	Indiana Dunes National Lakeshore	Lake Michigan Air Directors Consortium	10/3/2018
MA22	Boston University	Boston University	7/21/2017
MD08	Piney Reservoir	Maryland Department of Natural Resources	1/1/2008
MD98	Beltsville Second Instrument	National Oceanic and Atmospheric Administration - Air Resources Laboratory	1/26/2007
MN06	Leech Lake	Leech Lake Band of Ojibwe	5/1/2018
MS12	Grand Bay NERR	National Oceanic and Atmospheric Administration - Air Resources Laboratory	9/29/2006
NJ30	New Brunswick	U.S. Environmental Protection Agency - Clean Air Markets	10/1/2015
NJ54	Elizabeth Lab	U.S. Environmental Protection Agency - Clean Air Markets	10/1/2015
NY06	Bronx	New York State Department of Environmental Conservation	8/27/2008
NY20	Huntington Wildlife	New York State Energy Research and Development Authority	11/21/2007
NY43	Rochester	New York State Department of Environmental Conservation	9/26/2008
OH02	Athens Super Site	Ohio Environmental Protection Agency	1/1/2007
OH52	South Bass Island	Ohio Environmental Protection Agency	1/2/2011
TW01	Mt. Lulin	Taiwan EPA-National Central University	1/1/2010
WI07	Horicon Marsh	Lake Michigan Air Directors Consortium	12/31/2011

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National Atmospheric Deposition Program